LOS ANGELES REGIONAL WATER QUALITY CONTROL BOARD

ADMINISTRATIVE RECORD INDEX

ORDER NO. 01-182
NPDES PERMIT NO. CAS004001
WASTE DISCHARGE REQUIREMENTS FOR
MUNICIPAL STORM WATER AND URBAN RUNOFF DISCHARGES WITHIN THE COUNTY OF LOS ANGELES, AND THE INCORPORATED CITIES THEREIN, EXCEPT THE CITY OF LONG BEACH

PAGE #	CD Vol.	ITEM	DATE	DOCUMENT
R0000001	STORM001	1.	1/31/01	Transmittal Letter to Dennis A. Dickerson for the ROWD for Municipal Stormwater and Urban Runoff Discharges in the County of Los Angeles
R0000004	STORM001	2.	1/31/01	Report of Waste Discharge (ROWD) for Municipal Stormwater and Urban Runoff Discharges in the County of Los Angeles (ROWD+ 7 Plans)
R0000073	STORM001	3.	2/1/01	Watershed Management Area Plans (WMAP) prepared by the LA County Department of Public Works
R0000248	STORM001	4.	2/1/01	SQMP - Public Information and Participation Program - Industrial and Commercial Educational Program
R0000365	STORM001	5.	6/30/97	Stormwater Quality Management Plan (SQMP) - Public Information and Participation Program - Five-Year Education Plan
R0000420	STORM001	6.	2/1/01	SQMP - Development Construction Program
R0000626	STORM001	7.	2/1/01	SQMP - Illicit Connection and Illicit Discharge Elimination
R0000766	STORM001	8.	2/1/01	SQMP - Development Planning Program
R0001037	STORM001	9.	2/1/01	SQMP - Public Agency Activities Program
R0001224	STORM001	10.	2/5/01	Fax from Carolina Trevizo to Dan Radulescu regarding submittal letters for ROWDs (County-wide and Santa Clara River Watershed) Attached list of permittees by watershed
R0001231	STORM001	11.	2/14/01	EAC Meeting - Agenda with presentation on permit comparison, faxed attendance from Carolina Trevizo, and 5 articles on permit requirements
R0001275	STORM001	12.	2/15/01	E-mail from Wendy Phillips to Mustafa Ariki on Proposed Renewal Schedule for LA County MS4

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R0001277	STORM001	13.	2/22/01	E-mail from Wendy Phillips to Carolina Trevizo on IC/ID Work Group Meeting Agenda
R0001278	STORM001	14.	2/27/01	Inspection Program Issues Working Group Meeting - Agenda, notes from Dan Radulescu. and attendance
R0001282	STORM001	15.	2/28/01	IC/ID Working Group Meeting with agenda. attachment on exempted non-storm water discharges, and attendance from the meeting
R0001290	STORM001	16.	2/28/01	Transmittal Letter from Harry Stone and Rod Kubomoto to Laura Gentile about the ROWD for LA County
R0001291	STORM001	17.	3/1/01	Monitoring Working Group Meeting outline. notes. executive summary. program review. and attendance attachments
R0001332	STORM001	18.	3/2/01	Letter from Dennis Dickerson to Harry Stone regarding the Review of the ROWD. including municipal co-permittees list, summary of comments, and ROWD review and comments
R0001351	STORM001	19.	3/6/01	Email from Rufus Young (BWSLaw) to Dennis Dickerson regarding the Suggested ROWD Revisions.
R0001369	STORM001	20.	3/12/01	PIPP Working Group Meeting agenda, attendance. meeting notes, school education attachment, and public education program attachment
R0001393	STORM001	21.	3/12/01	Letter from Harry Stone and Donald Wolfe to Dennis Dickerson regarding 2001 Stormwater Pollution Prevention Media Campaign
R0001395	STORM001	22.	3/14/01	EAC Meeting - Agenda. proposed renewal schedule, workshop registration. and Cigarette recycling article
R0001399	STORM001	23.	3/14/01	Issues from the meeting with the BIA, with copy of Richard Lambros business card
R0001401	STORM001	24.	3/14/01	Construction Program Working Group Meeting - Agenda and attendance
R0001404	STORM001	25.	3/15/01	Email from Xavier Swamikannu to Mustafa Ariki with parts 1-3 of the Preliminary Draft attached
R0001442	STORM001	26.	3/19/01	Email from Xavier Swamikannu to Megan Fisher regarding monitoring with an attached report on "Comparability of Suspended-Sediment Concentration and Total Suspended Solids Data"
R0001462	STORM001	27.	3/20/01	Working Group to Address Industrial/Commercial Program Issues Agenda. attendance. key concept points
R0001467	STORM001	28.	3/20/01	Construction Program Working Group Meeting - Agenda, chart, and attendance
R0001470	STORM001	29.	3/21/01	Letter from Xavier Swamikannu to Permittees LA County regarding public workshop for the storm water permit renewal, with agenda attached

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R0001472	STORM001	30.	3/22/01	Preliminary Review Permit Draft Working Group - Agenda and attendance, with draft, GIS article, excerpts from CWC, and proposed changes to the PIPP
R0001528	STORM001	31.	3/22/01	Letter form Desi Alvarez (EAC) to Alexis Strauss regarding her 12/19/00 letter to Dickerson
R0001530	STORM001	32.	3/23/01	Letter from David Spence, La Canada Flintridge Mayor, to Christine Whitman regarding local inspection recommendations
R0001532	STORM001	33.	3/29/01	Email form Eduardo Escobar with attached recommendations for the draft NPDES permit
R0001539	STORM001	34.	3/30/01	List of City of LA gas station permits issued from 1/1/99 and 12/31/00
R0001541	STORM001	35.	4/9/01	Monitoring Work Group Meeting Attendance sheet and points of discussion
R0001549	STORM001	36.	4/9/01	Email from Shelley Luce to Megan Fisher regarding tributary monitoring sites
R0001551	STORM001	37.	4/13/01	Letter from Xavier Swamikannu to Interested Parties (Permittees) regarding the First Draft of the NPDES Permit, list of permittees, proposed agenda for the April 24th workshop, Staff Report and Draft attached
R0001684 & R0042863	STORM001 & STORM005	38.	4/13/01	Letter from Kenneth Farfsing, Coalition for Practical Regulation, to Dennis Dickerson regarding NPDES Workshop
R0001686	STORM001	39.	4/17/01	Agenda from Water Policy Task Force SCAG meeting with ROWD and comments attachment, permit and comparison presentations, watershed management article, Draft Regional/subregional Implementation program, and 2 articles from the Coalition for Practical Reform regarding the RSIP and proposed shift of to cities
R0001803	STORM001	40.	4/17/01	Email from Xavier Swamikannu regarding SCAG Committee Meeting
R0001804	STORM001	41.	4/19/01	Fax to Jorge Leon and Alex Mayer from Wendy Phillips regarding letter to Dennis Dickerson from the Coalition for Practical Reform (letter attached)
R0001807	STORM001	42.	4/19/01	Agenda from the Bay Watershed Council Meeting, with attendance, and attachments from Marianne Yamaguchi and Permit Reissuance presentation from Xavier Swamikannu
R0001828	STORM001	43.	4/20/01	Letter from Rutan & Tucker, Attorneys at Law, to Dennis Dickerson regarding the Draft NPDES permit, with attachments from 40 CFR, State Board Order WQ 2000 – 11, article on storm water discharge associated with industrial activity, 2 articles from the Coalition for Practical Regulation, and the Draft RSIP
R0001887	STORM001	44.	4/23/01	Letter from Wendy Phillips to Kenneth Farfsing regarding the Coalition for Practical Reform's comments on the April 24th Workshop, with revised agenda attached
R0001891	STORM001	45.	4/23/01	Letter from Patrick F. West, City Manager, City of Paramount, to Dennis Dickerson regarding the limited time to review the NPDES Permit before the April 24th Workshop

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R0001892	STORM001	46.	4/24/01	Public Workshop Agenda with CWA Amendment (WQA 1987). workshop presentation. and State Board Orders WQ 2000 – 11, WQ 99 - 05, WQ 98 – 01
R0001984	STORM001	47.	4/24/01	Letter from Honorable David Dreier to Christine Todd Whitman, USEPA Administrator
R0001985	STORM001	48.	4/24/01	Notes from the BIA meeting with Tim Piasky
R0001986	STORM001	49.	4/26/01	Letter from Wendy Phillips to Patrick West regarding comments to the April 24th workshop
R0001987	STORM001	50.	4/26/01	Email from Megan Fisher with agenda for April 27th Monitoring Work Group Meeting
R0001989	STORM001	51.	4/27/01	Email from Megan Fisher to Dan Radulescu and Xavier Swamikannu regarding SNA map
R0001992	STORM001	52.	4/30/01	Email from Megan Fisher regarding the May 9th Monitoring Work Group Meeting
R0001993	STORM001	53.	4/30/01	Letter from Alexis Strauss, Director Water Division, USEPA Region 9 to Congressman Horn regarding concerns from the CPR
R0001995	STORM001	54.	5/1/01	Letter from David Fike, Director of Public Work, City of Monrovia. to Dennis Dickerson regarding the limited time to review the NPDES Permit before the April 24th Workshop
R0001997	STORM001	55.	5/2/01	Email from Don Wolfe to J. Bishop regarding trash monitoring
R0001998	STORM001	56.	5/8/01	Email from Megan Fisher with agenda for the 5/09 Monitoring Work Group Meeting
R0001999	STORM001	57.	5/9/01	Monitoring Work Group Meeting Topics, attendance, notes, and data tables and maps. Also includes an email from TJ Kim to Megan Fisher regarding minimum detection limits with an attachment of Bill Number SB 72 introduced by Senator Kuehl
R0002020	STORM001	58.	5/9/01	Email from Megan Fisher regarding the 5/30 tributary Monitoring Work Group Meeting
R0002021	STORM001	59.	5/9/01	Email from Megan Fisher regarding the tributary proposal
R0002022	STORM001	60.	5/10/01	Email from TJ Kim regarding chlorpyrifos water quality data from the tributary proposal
R0002023	STORM001	61.	5/14/01	Email from Megan Fisher regarding 5/31 monitoring Work Group Meeting to discuss questions prior to the second draft permit
R0002024	STORM001	62.	5/14/01	Fax from Dan Radulescu to Edward Schroeder, City of Signal Hill. with an attached copy of Board Resolution 98-08
R0002032	STORM001	63.	5/15/01	Email from Megan Fisher regarding the cancellation notice of the May 31st Work Group Meeting
R0002033	STORM001	64.	5/16/01	Letter to James DeStefano, Interim City Manager – Diamond Bar, from Alexis Strauss. EPA Region IX Water Division Director, regarding comments on the letter concerning inspection requirements in the LA MS4 draft permit
				LEGAL GROUPS & COALITIONS
R0002035	STORM001	65.	4/18/01	Letter from William Mills, Association of Ground Water Agencies (AGWA). to Dennis

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				Dickerson regarding the possible negative impact of the SUSMP requirements in the LA MS4 permit could have on groundwater quality
R0002037	STORM001	66.	5/17/01	Building Industry Association of Southern California comments on the first draft of LA MS4 permit
R0002052	STORM001	67.	5/15/01	Letter from the law offices of Burke, Williams & Sorenson on behalf of the City of **Alhambra**, with attached comments on the first draft.
R0002065	STORM001	68.	5/16/01	Letter from Mark Smith, Charles Abbott Associates (CAA), to Dennis Dickerson, on behalf of the cities of **Bell, Hidden Hills, and Norwalk**.
R0002071	STORM001	69.	5/16/01	Coalition for Practical Regulation (CPR) comments on the first draft of LA MS4 permit
R0002092	STORM001	70.	4/26/01	Letter from Desi Alvarez, Chair Executive Advisory Committee (EAC), to David Nahai. Stating that the ROWD was a sufficient application for the NPDES Permit, and is disappointed that the Board does not want to negotiate the next permit
R0002095	STORM001	71.	5/16/01	Executive Advisory Committee (EAC) comments on the first draft of LA MS4 permit
R0002105	STORM001	72.	5/17/01	Richards, Watson & Gershon, Attorneys at Law is submitting comments on behalf of the Cities of **Agoura Hills, Carson, Artesia, Beverly Hills, Hidden Hills, Norwalk, La Mirada, Monrovia, Rancho Palos Verdes, San Marino, San Fernando, and Westlake Village**.
R0002115	STORM001	73.	4/24/01	Rutan & Tucker, LLP representing a "Coalition" of cities comments on the first draft of LA MS4 permit
R0002119	STORM001	74.	5/16/01	Rutan & Tucker, LLP representing CPR comments on the first draft of LA MS4 permit
CITIES & LA COUNTY				
R0002184	STORM001	75.	5/16/01	City of Arcadia comments to the first draft with specific comments attached.
R0002195	STORM001	76.	5/14/01	City of Baldwin Park comments to the first draft
R0002198	STORM001	77.	5/16/01	City of Bellflower comments to the first draft
R0002200	STORM001	78.	5/18/01	City of Bell Gardens comments to the first draft
R0002205	STORM001	79.	5/16/01	City of Burbank comments to the first draft
R0002209	STORM001	80.	5/16/01	City of Calabasas comments to the first draft
R0002216	STORM001	81.	5/16/01	City of Carson comments to the first draft
R0002226	STORM001	82.	5/16/01	City of Commerce comments to the first draft
R0002227	STORM001	83.	5/16/01	City of Compton comments to the first draft
R0002230	STORM001	84.	5/3/01	City of Covina comments to the first draft
R0002233	STORM001	85.	5/16/01	City of Cudahy comments to the first draft

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R0002239	STORM001	86.	5/15/01	City of Diamond Bar comments to the first draft
R0002242	STORM001	87.	5/16/01	City of Glendale comments to the first draft
R0002248	STORM001	88.	5/16/01	City of Hawaiian Gardens comments to the first draft
R0002255	STORM001	89.	5/17/01	City of Irwindale comments to the first draft
R0002259	STORM001	90.	5/16/01	City of La Canada Flintridge comments to the first draft
R0002266	STORM001	91.	5/14/01	City of Lakewood comments to the first draft
R0002267	STORM001	92.	5/14/01	City of La Mirada comments to the first draft
R0002269	STORM001	93.	5/15/01	City of Los Angeles comments to the first draft
R0002280	STORM001	94.	6/4/01	City of Los Angeles requesting modification of two technical comments on first draft
R0002282	STORM001	95.	7/2/01	City of Los Angeles additional comments on first draft
R0002319	STORM001	96.	5/16/01	City of Manhattan Beach comments to the first draft
R0002321	STORM001	97.	5/16/01	City of Maywood comments to the first draft
R0002327	STORM001	98.	5/15/01	City of Monrovia comments to the first draft
R0002341	STORM001	99.	5/16/01	City of Montebello comments to the first draft
R0002351	STORM001	100.	5/16/01	City of Monterey Park comments to the first draft
R0002353	STORM001	101.	6/11/01	City of Norwalk comments to the first draft
R0002355	STORM001	102.	5/16/01	City of Paramount comments to the first draft
R0002361	STORM001	103.	5/16/01	City of Pomona comments to the first draft
R0002366	STORM001	104.	5/16/01	City of Rancho Palos Verdes comments to the first draft
R0002370	STORM001	105.	5/10/01	City of Rosemead comments to the first draft
R0002371	STORM001	106.	5/16/01	City of Rosemead additional comments to the first draft
R0002378	STORM001	107.	5/16/01	City of San Gabriel comments to the first draft
R0002390	STORM001	108.	5/21/01	City of San Marino comments to the first draft
R0002401	STORM001	109.	5/16/01	City of Signal Hill comments to the first draft
R0002403	STORM001	110.	6/6/01	City of South Gate comments to the first draft
R0002411	STORM001	111.	5/24/01	City of Temple City comments to the first draft
R0002419	STORM001	112.	5/16/01	City of Vernon comments to the first draft
R0002422	STORM001	113.	5/16/01	City of Whittier comments to the first draft
R0002425	STORM001	114.	5/16/01	Los Angeles County Department of Public Works comments to the first draft
				ENVIRONMENTAL GROUPS
R0002528	STORM001	115.	4/3/01	Heal the Bay comments regarding Monitoring and Reporting Requirements in the first draft

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R0002536	STORM001	116.	5/16/01	Heal the Bay additional comments on the first draft
R0002543	STORM001	117.	5/16/01	NRDC comments on the first draft
R0002551	STORM001	118.	5/15/01	Santa Monica BayKeeper comments on the first draft
				OTHER GROUPS
R0002721	STORM001	119.	6/15/01	Western States Petroleum Association (WSPA), with comments regarding RGOs and first draft
R0002728	STORM001	120.	5/15/01	Ballona Creek/Santa Monica Bay Watershed cities comments on the first draft
R0002737	STORM001	121.	5/16/01	NEST Environmental Services comments on the first draft
R0002741	STORM001	122.	5/15/01	LA County Sanitation Districts comments on the first draft
				END OF COMMENT LETTERS on first draft
R0002744	STORM001	123.	5/16/01	Independent Cities Association (ICA) request for LA MS4 negotiation process
R0002747	STORM001	124.	5/17/01	Letter from James Noyes and Rod Kubomoto from LA County Department of Public Works regarding the ROWD withdrawal for the Santa Clara River Watershed
R0002748	STORM001	125.	5/18/01	Letter from Dennis Dickerson to David Fike, Monrovia Director of Public Works. responding to comments made about the 4/24 workshop and permit review schedule
R0002750	STORM001	126.	5/23/01	Email from Megan Fisher to TJ Kim regarding monitoring changes, with an attached outline of significant changes to the Monitoring Program
R0002753	STORM001	127.	5/23/01	Letter from Larry Forester, CPR to Dickerson regarding joint request for LA Storm Water Permit Facilitator
R0002757	STORM001	128.	5/24/01	Letter from Dan Radulescu to Ann Wessel, Stormwater Permit Manager, requesting information on RGOs in Washington and Seattle
R0002759	STORM001	129.	5/24/01	Letter from Dan Radulescu to Kelly Hendrix, Water Pollution Control Lab, requesting information on RGOs in Oregon and Portland
R0002763	STORM001	130.	5/24/01	Notes and attendance from Regional Board meeting with Tim Piasky, BIA.
R0002765	STORM001	131.	5/24/01	Letter from Tracy Patterson regarding Bioassessment in LA County Storm Water Permit
R0002769	STORM001	132.	5/31/01	Email from Mark Gold to Megan Fisher regarding 6/4 monitoring Work Group Meeting agenda
R0002770	STORM001	133.	6/4/01	Letter from James Noyes and Donald Wolfe, LA County Department of Public Works, to Dennis Dickerson regarding proposed addition of shoreline monitoring program to NPDES
R0002776	STORM001	134.	6/4/01	Monitoring Work Group Meeting - Agenda, attendance, presentation slides, and attached General Workplan for Wet Weather Modeling of the LA River and Santa Monica Bay

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				Watersheds
R0002811	STORM001	135.	6/4/01	Letter from Melinda Marks, Chair of California Stormwater Quality Task Force, to Dennis Dickerson regarding support for stakeholder consensus-building process
R0002813	STORM001	136.	6/5/01	Email from John Dorsey to Megan Fisher regarding shoreline monitoring
R0002814	STORM001	137.	6/7/01	NPDES presentation by Wendy Phillips at the City and County Engineers Meeting
R0002818	STORM001	138.	6/7/01	Email from Megan Fisher to Carolina Trevizo regarding Santa Clara station
R0002819	STORM001	139.	6/8/01	Email from Megan Fisher to Carolina Trevizo regarding 6/8 Monitoring Draft
R0002839	STORM001	140.	6/11/01	Letter form Larry Forester, CPR, to Dennis Dickerson regarding request for facilitative review process
R0002847	STORM001	141.	6/12/01	Email from Megan Fisher to C. Trevizo regarding 6/25 Monitoring Work Group Meeting
R0002849	STORM001	142.	6/13/01	Fax from Southern California Association of Governments to Xavier Swamikannu regarding percentage of land use in LA County
R0002855	STORM001	143.	6/15/01	Letter from Heal the Bay regarding preliminary revised draft of the monitoring and reporting requirements
R0002856	STORM001	144.	6/15/01	Letter from Dennis Dickerson to Donald Wolfe, County of LA Department of Public Works, regarding working with local agencies to address storm water issues at industrial sites
R0002863	STORM001	145.	6/18/01	Email from Ann Wessel to Dan Radulescu regarding information on BMPs for gas stations
R0002867	STORM001	146.	6/18/01	Memo from Water Pollution Control Lab, City of Portland, to Dan Radulescu regarding retail gasoline outlets
R0002879	STORM001	147.	6/19/01	Email from John Dorsey to Megan Fisher regarding shoreline comments
R0002882	STORM001	148.	6/25/01	Monitoring Work Group Meeting - Attendance, agenda, and notes 6-25-01
R0002897	STORM001	149.	6/26/01	Email from TJ Kim to Megan Fisher regarding 6/25 Work Group Meeting
R0002900	STORM001	150.	6/29/01	Announcement of Storm Water Workshop with attached copy of Second Draft Permit
R0003124	STORM001	151.	6/29/01	Letter from James Langley (for Judith Wilson) to Dennis Dickerson regarding additional review comments on first draft.
R0003161	STORM001	152.	7/3/01	Attendance from meeting with BIA
R0003162	STORM001	153.	7/9/01	Attendance from Special Executive Advisory Committee Meeting
R0003165	STORM001	154.	7/11/01	Public notice of 7/26/01 Workshop for LA MS4 permit to print in LA Times
R0003168	STORM001	155.	7/12/01	Letter from Christine Todd Whitman, USEPA Administrator, to Congressman David Dreier regarding enforcement of stormwater pollution controls at industrial and commercial sites in municipal stormwater permits

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R0003171	STORM001	156.	7/18/01	Attendance from EAC-RB staff Meeting
R0003174	STORM001	157.	7/23/01	Attendance from Environmental Groups – RB staff Meeting
R0003175	STORM001	158.	7/24/01	Letter from David Fike, City of Monrovia, to Dennis Dickerson regarding the NPDES 2nd Draft Workshop
R0003177	STORM001	159.	7/25/01	Attendance from the WSPA-RB staff Meeting
R0003178	STORM001	160.	7/26/01	Public Meeting/Workshop 444th Regular Board Meeting – agenda and attached documents (continued in volume 8)
			7/26/01	Public Meeting/Workshop 444th Regular Board Meeting – agenda and attached documents
R0004156	STORM001	161.	7/26/01	Public Meeting/Workshop 444th Regular Board Meeting – Transcript of proceedings
				CITIES & LA COUNTY
R0004377	STORM001	162.	8/3/01	City of Arcadia comments to the second draft
R0004382	STORM001	163.	8/6/01	City of Baldwin Park comments to the second draft
R0004392	STORM001	164.	8/6/01	City of Burbank comments to the second draft
R0004394	STORM001	165.	8/6/01	City of Calabasas comments to the second draft
R0004398	STORM001	166.	8/2/01	City of Carson comments to the second
R0004408	STORM001	167.	8/7/01	City of Cerritos comments to the second draft
R0004410	STORM001	168.	8/9/01	City of Claremont comments to the second draft
R0004420	STORM001	169.	8/6/01	City of Compton comments to the second draft
R0004431	STORM001	170.	7/30/01	City of Covina comments to the second draft
R0004435	STORM001	171.	8/3/01	City of Culver City comments to the second draft
R0004439	STORM001	172.	8/6/01	City of Diamond Bar comments to the second draft
R0004443	STORM001	173.	8/6/01	City of Duarte comments to the second draft
R0004454	STORM001	174.	8/3/01	City of Hawthorne comments to the second draft
R0004458	STORM001	175.	7/24/01	City of Industry comments to the second draft
R0004459	STORM001	176.	8/2/01	City of Irwindale comments to the second draft
R0004463	STORM001	177.	8/1/01	City of Lakewood comments to the second draft
R0004465	STORM001	178.	8/2/01	City of Lakewood comments to the second draft
R0004474	STORM001	179.	8/1/01	City of La Mirada comments to the second draft
R0004476	STORM001	180.	8/6/01	City of Los Angeles comments to the second draft
R0004514	STORM001	181.	8/6/01	City of Monrovia comments to the second draft
R0004520	STORM001	182.	8/2/01	City of Montebello comments to the second draft

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R0004534	STORM001	183.	8/1/01	City of Norwalk comments to the second draft
R0004538	STORM001	184.	8/6/01	City of Paramount comments to the second draft
R0004540	STORM001	185.	8/6/01	City of Pico Rivera comments to the second draft
R0004543	STORM001	186.	8/2/01	City of Santa Clarita comments to the second draft
R0004548	STORM001	187.	8/8/01	City of Santa Fe Springs comments to the second draft
R0004552	STORM001	188.	8/2/01	City of San Gabriel comments to the second draft
R0004562	STORM001	189.	8/3/01	City of San Gabriel comments to the second draft
R0004565	STORM001	190.	8/3/01	City of San Marino comments to the second draft
R0004575	STORM001	191.	8/2/01	City of South Pasadena comments to the second draft
R0004578	STORM001	192.	8/6/01	City of Temple City comments to the second draft
R0004583	STORM001	193.	8/2/01	City of Vernon comments to the second draft
R0004586	STORM001	194.	8/3/01	City of Whittier comments to the second draft
R0004596	STORM001	195.	7/25/01	County of Los Angeles Fire Department comments to the second draft
R0004597	STORM001	196.	8/6/01	County of Los Angeles Dept. of Public Works comments to the second draft with comments made in color on the draft permit.
				LEGAL GROUPS & COALITIONS
R0004699	STORM001	197.	7/19/01	Law Offices Burke, Williams & Sorensen, LLP comments to the second draft on behalf of the cities of **Alhambra, Compton, El Segundo, Lomita, Santa Clarita, and Torrance**
R0004719	STORM001	198.	8/6/01	Law Offices Burke, Williams & Sorensen, LLP additional comments to the second draft on behalf of the cities of **Alhambra, Compton, El Segundo, Lomita, Santa Clarita, and Torrance**
R0004727	STORM001	199.	8/6/01	Law Offices Burke, Williams & Sorensen, LLP comments to the second draft on behalf of the cities of **Camarillo** and **Moorpark**
R0004737	STORM001	200.	8/8/01	Law Offices Burke, Williams & Sorensen, LLP comments to the second draft on behalf of the cities of **Alhambra, Compton, El Segundo, Lomita, Santa Clarita, and Torrance** (first supplemental comment)
R0004740	STORM001	201.	8/6/01	Rutan & Tucker, Attorneys at Law comments to the second draft on behalf of CPR
R0004789	STORM001	202.	8/6/01	Richards, Watson & Gershon, Attorneys at Law comments to the second draft on behalf of the cities of **Agoura Hills, Carson, Artesia, Beverly Hills, Hidden Hills, Norwalk, La Mirada, Monrovia, Rancho Palos Verdes, San Marino, San Fernando and Westlake Village**.
R0004797	STORM001	203.	8/6/01	Charles Abbott Associates (CAA), on behalf of the cities of **Bell, Hidden Hills, and Norwalk**

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R0004804	STORM001	204.	8/6/01	Coalition for Practical Regulation comments to the second draft
R0004822	STORM001	205.	8/6/01	Construction Industry Coalition on Water Quality (CICWQ) comments to the second draft
R0004875	STORM001	206.	8/6/01	Executive Advisory Committee (EAC) - comments to the second draft
				ENVIRONMENTAL GROUPS
R0004881	STORM001	207.	8/6/01	Heal the Bay comments to the second draft
R0004893	STORM001	208.	8/6/01	NRDC comments to the second draft
R0004901	STORM001	209.	8/6/01	Santa Monica BayKeeper comments to the second draft
				OTHER GROUPS
R0004904	STORM001	210.	7/30/01	Bull Shot Systems Inc.- comments to the second draft
R0004906	STORM001	211.	7/25/01	California Coastal Commission comments to the second draft
R0004908	STORM001	212.	8/6/01	California Regional Water Quality Control Board – Raymond Jay, Nonpoint Source Unit, comments to the second draft
R0004912	STORM001	213.	7/31/01	California Water Service Company – comments to the second draft
R0004915	STORM001	214.	8/1/01	Central Basin Water Association (CBWA) – comments to the second draft
R0004917	STORM001	215.	8/6/01	County Sanitation Districts of Los Angeles County comments to the second draft
R0004922	STORM001	216.	8/2/01	National Association of Industrial and Office Properties (NAIOP) SoCal Chapter – comments to the second draft
R0004928	STORM001	217.	8/6/01	Southern California Water Company comments to the second draft
R0004930	STORM001	218.	8/6/01	South Montebello Irrigation District – comments to the second draft
R0004931	STORM001	219.	8/6/01	State of California Department of Health Services comments to the second draft
R0004934	STORM001	220.	7/27/01	Upper Los Angeles River Area Watermaster comments to the second draft
R0004936	STORM001	221.	8/6/01	Water Replenishment District of Southern California (WRD) comments to the second draft
R0004938	STORM001	222.	8/6/01	Western States Petroleum Association (WSPA) comments to the second draft
				END OF COMMENT LETTERS
R0004974	STORM001	223.	8/20/01	Letter from Xavier Swamikannu to Melinda Marks regarding BMP Guide for RGOs.
R0004978	STORM001	224.	8/22/01	Letter from EAC to Dennis Dickerson regarding stakeholder involvement in preparation of NPDES order
R0004980	STORM001	225.	8/23/01	Attendance and outline for LA County MS4 Peak Discharge Study Work Group Meeting
R0004982	STORM001	226.	9/4/01	Agenda for the Malibu Creek Watershed Advisory Council Meeting. Resource Conservation District of the Santa Monica Mountains – with attached presentation of Municipal Storm Water Permit

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R0005009	STORM001	227.	9/12/01	Agenda from EAC meeting, with notes from Dan Radulescu, and attendance
R0005014	STORM001	228.	9/13/01	Email from Xavier Swamikannu to Betsy Jennings regarding SUSMPs provisions
R0005015	STORM001	229.	9/20/01	Letter from Dennis Dickerson to David Fike regarding the municipal storm water permit
R0005016	STORM001	230.	9/20/01	Email from Stan Ciuba to Xavier Swamikannu regarding questions on gas stations
R0005018	STORM001	231.	9/21/01	Analytes and Detection Limit Issues (Agenda items 5-6). From Storm water Monitoring Work Group Meeting with Long Beach.
R0005040	STORM001	232.	9/24/01	Letter from Dennis Dickerson to Don Wolfe regarding municipal storm water permit
R0005042	STORM001	233.	9/27/01	Attendance form BIA meeting with Agenda
R0005044	STORM001	234.	9/27/01	LA County MS4 Public Education Program Work Group Meeting, with attendance, agenda, and LA County Public Education Program slides
R0005053	STORM001	235.	9/28/01	Email from Tim Piasky to Dennis Dickerson regarding concerns with LA permit
R0005055	STORM001	236.	10/3/01	Restaurant Inspection Work Group Meeting LA County DHS – Attendance, notes, handouts
R0005069	STORM001	237.	10/9/01	Letter from Judith Wilson to Dennis Dickerson requesting 10-day extension to submit comments on 3rd draft permit
R0005071	STORM001	238.	10/9/01	Announcement for MSA LA & Orange Area Chapter General Meeting
R0005072	STORM001	239.	10/11/01	Announcement of Public Hearing and Transmittal of the Tentative Draft LA MS4 permit
R0005339	STORM001	240.	10/17/01	Email from Carlos Santos to Wendy Phillips regarding reporting format
R0005344	STORM001	241.	10/30/01	Fax from Joyce Clark to Carlos Urrunaga regarding debromination, and its inapplicability to drinking water.
R0005348	STORM001	242.	11/6/01	Change of location of public hearing for tentative draft of NPDES permit to 11/29/01
R0005349	STORM001	243.	11/6/01	Email from Steve Bay to Megan Fisher regarding toxicity testing
R0005351	STORM001	244.	11/9/01	Agenda for mediated discussion of inspection/enforcement permit language with handouts
				CITIES & LA COUNTY
R0005431	STORM001	245.	11/1/01	City of Baldwin Park - comments to tentative draft
R0005438	STORM001	246.	11/13/01	City of Bellflower - comments to tentative draft
R0005441	STORM001	247.	11/13/01	City of Bell Gardens - comments to tentative draft
R0005447	STORM001	248.	11/13/01	City of Burbank - comments to tentative draft
R0005449	STORM001	249.	11/13/01	City of Carson - comments to tentative draft
R0005456	STORM001	250.	11/14/01	City of Claremont - comments to tentative draft
R0005457	STORM001	251.	11/15/01	City of Covina - comments to tentative draft
R0005462	STORM001	252.	11/13/01	City of Cudahy - comments to tentative draft

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R0005468	STORM001	253.	11/13/01	City of Culver City - comments to tentative draft
R0005474	STORM001	254.	11/13/01	City of Diamond Bar - comments to tentative draft
R0005479	STORM001	255.	11/13/01	City of Gardena - comments to tentative draft
R0005480	STORM001	256.	11/13/01	City of Hawaiian Gardens - comments to tentative draft
R0005486	STORM001	257.	11/13/01	City of La Canada Flintridge - comments to tentative draft
R0005492	STORM001	258.	11/13/01	City of Lakewood - comments to tentative draft
R0005499	STORM001	259.	11/9/01	City of Los Angeles - comments to tentative draft
R0005561	STORM001	260.	11/9/01	City of Lynwood - comments to tentative draft
R0005563	STORM001	261.	11/14/01	City of Manhattan Beach - comments to tentative draft
R0005565	STORM001	262.	11/14/01	City of Monrovia - comments to tentative draft
R0005573	STORM001	263.	11/13/01	City of Paramount - comments to tentative draft
R0005579	STORM001	264.	11/13/01	City of Pasadena - comments to tentative draft
R0005585	STORM001	265.	11/13/01	City of Pomona - comments to tentative draft
R0005587	STORM001	266.	11/13/01	City of Rosemead - comments to tentative draft
R0005593	STORM001	267.	11/15/01	City of Rancho Palos Verdes- comments to tentative draft
R0005596	STORM001	268.	11/15/01	City of Rancho Palos Verdes- additional comments to tentative draft
R0005600	STORM001	269.	11/13/01	City of Redondo Beach - comments to tentative draft
R0005603	STORM001	270.	11/13/01	City of Santa Clarita - comments to tentative draft
R0005609	STORM001	271.	11/13/01	City of Santa Fe Springs - comments to tentative draft
R0005611	STORM001	272.	11/14/01	City of San Gabriel - comments to tentative draft
R0005618	STORM001	273.	11/8/01	City of San Marino - comments to tentative draft
R0005625	STORM001	274.	11/13/01	City of Signal Hill - comments to tentative draft Included two reports: "Financial and Economic Impacts of Storm Water Treatment – Los Angeles County NPDES Permit Area" and "Assessing the TMDL Approach to Water Quality Management"
R0005752	STORM001	275.	11/14/01	City of Sierra Madre - comments to tentative draft
R0005754	STORM001	276.	11/7/01	City of South El Monte - comments to tentative draft
R0005761	STORM001	277.	11/8/01	City of South Gate - comments to tentative draft
R0005768	STORM001	278.	11/13/01	City of Vernon - comments to tentative draft
R0005775	STORM001	279.	11/9/01	City of West Hollywood - comments to tentative draft
R0005781	STORM001	280.	11/13/01	County of Los Angeles - comments to tentative draft Included summary of comments and 2 copies of comments marked on the draft

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				LEGAL GROUPS & COALITIONS
R0006065	STORM001	281.	11/6/01	Law Offices Burke, Williams & Sorensen, LLP - comments to tentative on behalf of the **LAEDC, Cities of Alhambra, Camarillo, Compton, El Segundo, Industry, Lawndale, Lomita, Moorpark, Santa Clarita, and Torrance**. Included three reports: "SCAG Staff Report: Regional Solutions for Managing Stormwater Pollution", "Financial and Economic Impacts of Storm Water Treatment – Los Angeles County NPDES Permit Area", "Cost of Storm Water Treatment for the Los Angeles County NPDES Permit Area"
R0006190	STORM001	282.	11/9/01	Law Offices Burke, Williams & Sorensen, LLP - comments to tentative draft submitted report "Cost of Storm Water Treatment for California Urbanized Areas." On behalf of the cities of **Alhambra, Camarillo, Compton, El Segundo, Industry, Lawndale, Lomita, Moorpark, Santa Clarita, and Torrance, and LAEDC**
R0006449	STORM001	283.	11/13/01	Law Offices Burke, Williams & Sorensen, LLP - comments to tentative on behalf of the **LAEDC, Cities of Alhambra, Camarillo, Compton, El Segundo, Industry, Lawndale, Lomita, Moorpark, Santa Clarita, and Torrance.**
R0006471	STORM001	284.	11/14/01	Charles Abbott Associates (CAA) comments to tentative draft on behalf of the cities of **Bell, Hidden Hills, and Norwalk**
R0006483	STORM001	285.	11/13/01	Richards, Watson & Gershon, Attorneys at Law - comments to tentative draft Submitted letter and comments on behalf of the cities of **Agoura Hills, Carson, Artesia, Beverly Hills, Hidden Hills, Norwalk, La Mirada, Monrovia, Rancho Palos Verdes, San Marino, San Fernando and Westlake Village**
R0006496	STORM001	286.	11/19/01	Richards, Watson & Gershon, Attorneys at Law – revised comments to tentative draft Submitted letter and comments on behalf of the cities of **Agoura Hills, Carson, Artesia, Beverly Hills, Hidden Hills, Norwalk, La Mirada, Monrovia, Rancho Palos Verdes, San Marino, San Fernando and Westlake Village**
R0006509	STORM001	287.	11/13/01	Rutan & Tucker, Attorneys at Law - comments to tentative draft on behalf of **Signal Hill and members of CPR.**
R0006545	STORM001	288.	11/13/01	Construction Industry Coalition on Water Quality (CICWQ) - comments to tentative draft
R0006551	STORM001	289.	11/13/01	Executive Advisory Committee (EAC) - comments to tentative draft
R0006555	STORM001	290.	11/9/01	Ballona Creek/Santa Monica Watershed - comments to tentative draft
				ENVIRONMENTAL GROUPS
R0006562	STORM001	291.	11/15/01	Heal the Bay – comments to tentative draft

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R0006571	STORM001	292.	11/14/01	NRDC - comments to tentative draft
R0006575	STORM001	293.	11/13/01	UCLA Environmental Law Clinic - comments to tentative draft submitted on behalf of the Santa Monica BayKeeper.
				OTHER GROUPS
R0006591	STORM001	294.	11/13/01	County of Los Angeles Department of Health Services Public Health - comments to tentative draft concerning restaurant inspections
R0006593	STORM001	295.	11/13/01	County Sanitation Districts of Los Angeles County - comments to tentative draft
R0006595	STORM001	296.	11/9/01	Metropolitan Water District of Southern California (MWD) - comments to tentative draft
R0006599	STORM001	297.	11/15/01	Southern California Water Company - comments to tentative draft
R0006601	STORM001	298.	11/14/01	Upper Los Angeles River Area Watermaster - comments to tentative draft Melvin L. Blevins, ULARA Watermaster.
R0006603	STORM001	299.	11/13/01	Western States Petroleum Association - comments to tentative draft
				END OF COMMENT LETTERS
R0006611	STORM001	300.	11/19/01	Monitoring Work Group Meeting – Agenda, notes
R0006614	STORM001	301.	11/20/01	Email from Steve Bay to Megan Fisher regarding LA County toxicity language, with suggested changes attached
R0006619	STORM001	302.	11/14/01	Letter from CPR Steering Committee to Dennis Dickerson regarding completion request for NPDES Permit item on 11/29/01
R0006621	STORM001	303.	11/15/01	Letter from L. Donald Duke, Assistant Professor, UCLA Environmental Science and Engineering Program. Regarding GeoMatrix document: "Review of RGOs…"
R0006624	STORM001	304.	11/20/01	Letter from Dennis Dickerson to Kenneth Farfsing regarding renewal of municipal storm water permit for LA County
R0006625	STORM001	305.	11/26/01	Letter from William Kelly, City Manager of Arcadia, to Congressman David Dreier requesting support for mediation effort
R0006627	STORM001	306.	11/26/01	Letter from William Kelly to Honorable Robert Margett requesting support for mediation effort.
R0006629	STORM001	307.	11/26/01	Letter from William Kelly to Honorable Richard Mountjoy requesting support for mediation effort
R0006631	STORM001	308.	11/27/01	Letter from Xavier Swamikannu to Sandy Matthews regarding review of BMP guide for RGOs

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R0006632	STORM001	309.	11/29/01	Supporting documents distributed at the 11/29/01 mediation session. Packet includes report from Dan Radulescu, "The Role of Municipal Operators in Controlling the Discharge of Pollutant in Storm Water Runoff from Industrial/Commercial Facilities." Packet includes NPDES permits from different regions across the nation, and City of Monterey Storm Water Ordinance
R0006709	STORM001	310.	11/29/01	Meeting notes and agenda for mediated dialogue on MS4 industrial/commercial inspections permit language
R0006727	STORM001	311.	12/3/01	Letter from Xavier Swamikannu to Steve Arita, WSPA, regarding supplemental document to 06/2001 RGO technical report "New Development Design Standards for Mitigation of Storm Water Impacts"
R0006738	STORM001	312.	12/3/01	Letter from CPR requesting continuation of mediation process
R0006740	STORM001	313.	12/3/01	Letter from Dennis Dickerson to Harry Seraydarian regarding version A/C industrial/commercial inspections permit language
R0006743	STORM001	314.	12/4/01	Fax from Dan Radulescu to Ronald Wilkniss, WSPA, containing 12/3/01 documents to Steve Arita, and report from Dan Radulescu, "Storm Water Quality Task Force BMP Guide for Retail Gasoline Outlets"
R0006750	STORM001	315.	12/5/01	Notes from WSPA Meeting regarding tentative permit, along with attendance and business card from BP's Maryann Gonzalez.
R0006752	STORM001	316.	12/5/01	Email from Dennis Dickerson regarding 12/13/01 Board meeting
R0006754	STORM001	317.	12/6/01	Fax from Ron Wilkniss to Dennis Dickerson regarding select language changes and delay of mark-up delivery
R0006756	STORM001	318.	12/6/01	Email from Shahram Kharanghani to Megan Fisher regarding suggested language from MS4
R0006758	STORM001	319.	12/7/01	Letter from Honorable Bob Margett to Chairman David Nahai regarding continuing the dialogue for the LA MS4 permit
R0006760	STORM001	320.	12/10/01	City of Signal Hill comments regarding proposed inspection program for version A/C
R0006763	STORM001	321.	12/10/01	Letter from CPR to Dennis Dickerson regarding LA MS4 permit schedule
R0006769	STORM001	322.	12/11/01	City of Baldwin Park - Alternative to Industrial/commercial pollution control program version A/C
R0006773	STORM001	323.	12/11/01	City of Walnut - Outlines major issues with the LA MS4 permit
R0006776	STORM001	324.	12/12/01	City of Irwindale - comments to tentative draft alternative to industrial/commercial pollution control program version A/C

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R0006780	STORM001	325.	12/12/01	Fax from Angela Hudnall to Dennis Dickerson regarding increase of taxes due to storm water permit proposal
R0006782	STORM001	326.	12/12/01	Letter from Los Angeles Mayor James Hahn regarding issues related to the LA MS4 permit
R0006784	STORM001	327.	12/13/01	Notice of Exemption to State Board from Regional Board
R0006786	STORM001	328.	12/13/01	Board Meeting Agenda Item #10 (continued in Volume 14)
R0007753	STORM001	328.5	12/13/01	Board Meeting - Statement from Jacqueline Lambrichts, Friends of the San Gabriel River, supports efforts for approving a strong permit
R0007754	STORM001	329.	12/13/01	Board Meeting – Letters to the Board in support of passage of LA MS4 permit – List of senders only and a sample copy attached (originals available for review)
R0007762	STORM001	330.	12/13/01	Board Meeting - Statement by Larry Forester, Mayor, City of Signal Hill, and CPR.
R0007770	STORM001	331	12/13/01	Board Meeting- Transcript of Proceedings
R0007972	STORM001	332	12/17/01	Letter from Dennis Dickerson to Donald Wolfe regarding inspection of facilities covered under general permit
R0007973	STORM001	333	12/21/01	Letter from Dennis Dickerson to James Noyes regarding requirements for baseline monitoring of trash in LA River and Ballona Creek
R0007977	STORM001	334	1/3/02	Transmittal letter and copy of the adopted LA MS4 Permit including the attachments to the permit and the fact sheet
R0008088	STORM001	335	1/7/02	Letter from Xavier Swamikannu regarding adoption of the LA County MS4 NPDES Permit
R0008090	STORM001	336	1/10/02	Letter from Howard Gest, Burhenn & Gest LLP, to Dennis Dickerson regarding petition of Order No. 01-182 and request for preparation of Administrative Record and list of interested persons
R0008092	STORM001	337	1/11/02	Letter from Dennis Dickerson to Senator Bob Margett replying to 12/7/01 letter regarding LA MS4 NPDES permit renewal

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R0008093	STORM001	339.		Federal Water Pollution Control Act – (33 U.S.C. 1251 et seq.)
R0008201	STORM001	340.		40 CFR § 122.26 et seq.
R0008238	STORM001	341.	11/90	Federal Register – Part II EPA – 40 CFR Parts 122, 123, and 124 NPDES Permit Application Regulations for Storm Water Discharges; Final Rule
R0008341	STORM001	342.	11/93	Federal Register – Part II EPA – Water Pollution Control, NPDES General Permits and Fact Sheets: Storm Water Discharges from Industrial Activity; Notice - Pages 61157-61158 The

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				Role of Municipal Operator
R0008344	STORM001	343.	8/9/96	Federal Register – Part III EPA – 40 CFR Part 122 Interpretative Policy Memorandum on Reapplication Requirements for Municipal Separate Storm Sewer Systems; Final Rule.
R0008361	STORM001	344.	6/18/90	Order No. 90-079 NPDES No. CA0061654 WDR Stormwater/Urban Runoff Discharge for LA County and Co-Permittees.
R0008378	STORM001	345.	1/9/91	Memorandum from Donald Elliott, USEPA, regarding compliance with Water Quality standards in MS4 NPDES permits
R0008383	STORM001	346.	5/24/91	Memorandum from Craig Wilson, SWRCB, to Jesse Diaz regarding enforcement of general industrial storm water permit
R0008385	STORM001	347.	7/93	NPDES Storm Water Program. Question and Answer Document, Volume 2 US EPA Office of Water EPA 833-F-93-0028 – excerpt Question 88
R0008388	STORM001	348.	12/93	Memorandum from Eugene Bromley, EPA Region 9, to Maryann Jones, Storm Water SWRCB, regarding "Role of municipalities in Implementation of State General NPDES Permits for Storm Water Associated with Industrial Activity."
R0008395	STORM001	349.	10/5/94	Memorandum from William Attwater, SWRCB, to Clayton Roche regarding Attorney General Opinion NO. 94-814
R0008399	STORM001	350.	10/3/95	Memorandum from Elizabeth Miller Jennings to Bruce Fujimoto regarding compliance with water quality objectives in MS4 permits
R0008402	STORM001	351.	2/96	Responses to Comments Received on 12/18/95 Draft NPDES Permit
R0008455	STORM001	352.	4/17/96	Memorandum from Jorge Leon, Office of the Chief Counsel, to Catherine Tyrrell, regarding Legal issues for the draft LA MS4 NPDES permit
R0008472	STORM001	353.	7/30/96	Letter from Catherine Tyrrell to Permittees regarding WDR and NPDES Permit. Includes attachments: Storm Water Information Resources, letter from Winnie Jesena, letter from Catherine Kuhlman, and copy of Order No. 96-054
R0008581	STORM001	354.	3/17/98	Letter from Alexis Strauss, USEPA Region IX, to Walt Pettit regarding receiving water limitations language in MS4 permits
R0008584	STORM001	355.	5/5/98	Letter from Winnie Jesena, LA Coastal Watershed Unit, to LA County Municipal Storm Water Permittees regarding approval of BMPs for Development Construction and Industrial/Commercial Education Programs (NPDES Permit No. CAS614001)
R0008590	STORM001	356.	7/7/99	Letter from Dennis Dickerson to Ray Holland and Edward Putz transmitting the City of Long Beach Municipal Storm Water NPDES permit CAS004003
R0008647	STORM001	357.	2/00	Announcement – NPDES-Development Planning for Stormwater Management SUSMP

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				implementation by the LA County DPW
R0008649	STORM001	358.	2/23/00	Letter from David Beckman, Senior Attorney NRDC, including the formal petition to withdraw the NPDES program from the Regional Board
R0008686	STORM001	359.	4/3/00	Email from Barry Chalofsky regarding swimming pool discharges and attachments
R0008698	STORM001	360.	4/6/00	Letter from Lloyd Pellman, LA County Counsel, to Carol Browner regarding NRDC petition for correction of legal deficiencies or withdrawal of EPA approval
R0008700	STORM001	361.	7/31/00	Letter from Harry Stone and Terri Grant, LA County Department of Public Works, to Dennis Dickerson with attached Countywide Stormwater Management Plan (CSWMP) Report of Effectiveness
R0008740	STORM001	362.	7/31/00	Five-Year Storm Water Public Education Strategic Analysis, submitted by LA County Department of Public Works
R0008821	STORM001	363.	8/3/00	Letter from Dennis Dickerson to Jeff Pratt transmitting Ventura County Municipal Storm Water NPDES Permit CAS004002 (letter of transmittal)
R0008822	STORM001	364.	10/18/00	Letter from Gary Lee Moore, City of LA, to Wendy Phillips on SUSMP Requirements as Part of CEQA Mitigation Measures
R0008828	STORM001	365.	12/11/00	Fax from Gerald P. Munoz, Health Hazardous Materials Division, with attached letters concerning 'Residual Blood Releases'
R0008830	STORM001	366.	12/19/00	Letter from Alexis Strauss, Director Water Division, US EPA Region IX to Dennis A. Dickerson in support of a municipal inspection program for industrial sites included in the renewed MS4 Permit for LA County
R0008838	STORM001	367.	12/19/00	Ordinance (1995 CCS) of City of Santa Monica City Council regarding green buildings standards
R0008840	STORM001	368.	1/10/01	Executive Advisory Committee Meeting Agenda and email from Dennis Dickerson
R0008890	STORM001	369.	04/08/99	Rouge River National Wet Weather Demonstration Project – Task Product Memorandum - Evaluation of On-Line Media Filters – Alsaigh, R; Boerma, J; Ploof, A and L. Regenmorter
R0008940	STORM001	370.	01/12/96	Storm Water Best Management Practices for Retail Gasoline Outlets – Project No. S2498 – Geomatrix Consultants Inc.
R0009086	STORM001	371.	10/94	Action Plan Demonstration Project – Demonstration of Gasoline Fueling Station Best Management Practices – Final Report-Uribe & Associates, Larry Walker Associates
R0009136	STORM001	372.	09/26/94	Results of a Retail Gasoline Outlet and Commercial Parking Lot Storm Water Runoff Study – Project No. S2498 – Geomatrix Consultants Inc.
R0008649	STORM001	373.	03/1997	Best Management Practice Guide Retail Gasoline Outlets – California Stormwater Quality

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				Task Force (SWQTF). Prepared by Retail Gasoline Outlet Work Group
R0009145	STORM001	374.	08/17/98	Petroleum Hydrocarbons in Stormwater Runoff from Retail Gasoline Stations – Pat L. Ashley. CSUF
R0009253	STORM001	375.	1995	Concentrations Of Selected Constituents In Runoff From Impervious Surfaces In Four Urban Catchments Of Different Land Use by Florence I. Rabanal et all in Proceedings of the 4th Biennial Conference on Stormwater Research, 18-20 October, 1995. Southwest Florida Water Management District, Clearwater, Florida, pp. 42-52.
R0009264	STORM001	376.	1998	A Review of Semivolatile and Volatile Organic Compounds in Highway Runoff and Urban Stormwater U.S. Department of the Interior and U.S. Geological Survey Open-File Report 98-409 http://wwwsd.cr.usgs.gov/nawqa/pubs/ofr/ofr98-409.pdf
R0009336	STORM001	377.	4-10/00	Stormwater Sampling – StormFilter™ Performance Results. Burwell/Straley's Union 76 Station Bremerton, Washington:
R0009343	STORM001	378.	1/11/01	Legislative Analysis – Committee Hearing: Economic Development. Transportation and Technology. File Number: 97-97-057 – Motor Fuel Prices. www.ci.sf.ca.us/bdsupvrs/leganalyst/97-97-057.htm
R0009354	STORM001	379.	1/23/01	Fax from the Board of Equalization Statistics Section to Dan Radulescu, with attachments regarding fuel taxes and highway gasoline use
R0009357	STORM001	380.	1/25/01	California Retail Service Stations, Fleet Fueling Facilities and Private Storage Tank Sites and Other Statistical Data by County – http://www.energy.ca.gov/statistics/gasoline_stations/
R0009361	STORM001	381.	3/7/01	Email from Dan O'Leary to Dan Radulescu regarding impact of gas stations to storm water with photographs attached
R0009369	STORM001	382.		Hydrocarbon Hotspots in the Urban landscape – Article 2: Feature article from Watershed Protection Techniques. 1(1): 3-5 (with notes from www.stormwatercetner.net)
R0009375	STORM001	383.		Cars are Leading Source of Metal Loads in California – Article 6: Technical Note #13 from Watershed Protection Techniques. 1(1): 28 – (TRS)
R0009376	STORM001	384.		Multi-Chamber Treatment Train Developed for Stormwater Hot Spots – Article 111: Technical Note from Watershed Protection Techniques 2(3): 11-13 – (TJL)
R0009381	STORM001	385.	2/01	Impact of Annual Average Daily Traffic on Highway Runoff Pollutant Concentration – ASCE Journal of Environmental Engineering
R0009410	STORM001	386.		Performance of Oil-Grit Separators in Removing Pollutants at Small Sites – Article 119: Technical Note #101 from Watershed Protection Techniques. 2(3): 539-542 – (TRS)

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R0009413	STORM001	387.		Petroleum Hydrocarbon Concentrations Observed in Runoff from Discrete, Urbanized Automotive-Intensive Land Uses – David L. Shepp, Senior Environmental Engineer, Metropolitan Washington Council of Governments, Washington, DC
R0009419	STORM001	388.	7/01	Characteristics of Parking Lot Runoff Produced by Simulated Rainfall – Southern California Coastal Water Research Project. Liesl L. Tiefenthaler, Kenneth C. Schiff, Steven M. Bay
R0009514	STORM001	389.	10/01	New York State Stormwater Management Design Manual – Chapter 4 Unified Stormwater Sizing Criteria
R0009529	STORM001	390.		State of Virginia Stormwater Management Manual – Chapter 2 Stormwater Management and Urban BMPs
R0009552	STORM001	391.		Pollutant Dynamics of Pond Muck – Watershed Protection Techniques, Summer 1994 – http://www.stormwater-resources.com/Library/124Pmuck.htm
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R0024024	STORM003	555.	7/95	Beware the Sediment Scare – Jonathan Jones – Civil Engineering.
R0024030	STORM003	556.	7-8/95	Landscape Architects and Urban Erosion Control – Libbe S. HaLevy "Where better to address urban runoff than at a project's front end, where landscape architects can control more than runoff." (2 copies)
R0024034	STORM003	557.	1995	Potential for Chemical Transport Beneath a Storm-Runoff Recharge (Retention) Basin for an Industrial Catchment in Fresno, California – Roy A. Schroeder. USGS Water-Resources Investigations Report 93-4140. In cooperation with Fresno Metropolitan Flood Control District.
R0024078	STORM003	558.	1995	Water Quality of Storm Runoff and Comparison of Procedures for Estimating Storm-Runoff Loads, Volume, Event-Mean Concentrations, and the Mean Load for a Storm for Selected Properties and Constituents for Colorado Springs, Southeastern Colorado, 1992 – Paul von Guerard and William B. Weiss. USGS Water-Resources Investigations Report 94-4194. In cooperation with Colorado Springs City Engineering Division
R0024151	STORM003	559.	1996-98 #1202	Water Quality in the Allegheny and Monongahela River Basins: Pennsylvania, West Virginia, New York, and Maryland. US Department of the Interior, US Geological Survey. Circular #1202.
R0024193	STORM003	560.	1996-98 #1203	Water Quality in the Lake Erie-Lake Saint Clair Drainages; Michigan, Ohio, Indiana, New York, and Pennsylvania. US Department of the Interior, US Geological Survey. Circular #1203.
R0024236	STORM003	561.	1996-98 #1204	Water Quality in the Kanawha-New River Basin; West Virginia, Virginia, and North Carolina. US Department of the Interior, US Geological Survey. Circular #1204.
R0024276	STORM003	562.	1994-98 #1205	Water Quality in the Upper Tennessee River Basin; Tennessee, North Carolina, Virginia, and Georgia. US Department of the Interior, US Geological Survey, Circular #1205.
R0024315	STORM003	563.	1995-98 #1206	Water Quality in the Santee River Basin and Coastal Drainages: North and South Carolina. US Department of the Interior, US Geological Survey. Circular #1206. (2 copies)
R0024357	STORM003	564.	1996-98 #1207	Water Quality in Southern Florida; Florida. US Department of the Interior, US Geological Survey. Circular #1207.
R0024398	STORM003	565.	1995-98	Water Quality in the Mississippi Embayment; Mississippi, Louisiana, Arkansas, Missouri,

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			#1208	Tennessee, and Kentucky. US Department of the Interior, US Geological Survey. Circular #1208.
R0024442	STORM003	566.	1995-98 #1209	Water Quality in the Lower Illinois River Basin; Illinois. US Department of the Interior, US Geological Survey. Circular #1209.
R0024486	STORM003	567.	1996-98 #1210	Water Quality in the Eastern Iowa Basins; Iowa and Minnesota. US Department of the Interior, US Geological Survey. Circular #1210.
R0024531	STORM003	568.	1995-98 #1211	Water Quality in the Upper Mississippi River Basin: Minnesota, Wisconsin, South Dakota, Iowa, and North Dakota. US Department of the Interior, US Geological Survey. Circular #1211.
R0024580	STORM003	569.	1995-98 #1213	Water Quality in the Central Arizona Basins; Arizona. US Department of the Interior, US Geological Survey. Circular #1213.
R0024626	STORM003	570.	1996-98 #1214	Water Quality in the Upper Colorado River Basin. US Department of the Interior, US Geological Survey. Circular #1214.
R0024667	STORM003	571.	1994-98 #1215	Water Quality in the Sacramento River Basin; California. US Department of the Interior, US Geological Survey. Circular #1215.
R0024713	STORM003	572.	1996-98 #1216	Water Quality in the Puget Sound Basin; Washington and British Columbia. US Department of the Interior, US Geological Survey. Circular #1216.
R0024752	STORM003	573.	6-7/98	Advances in Urban Wet Weather Pollution Reduction – Water Environment Federation.
R0025374	STORM003	574.	6/98	Water Quality Concerns and Regulatory Controls for Nonstorm Water Discharges to Storm Drains – L. Donald Duke and Molly M. Kihara. Journal of the American Water Resources Association. Vol. 34, no. 3, June 1998.
R0025391	STORM003	575.	1998	Pollutants in storm water runoff from metal plating facilities, Los Angeles, California – L. Donald Duke, Matthew Buffleben, Lisette A. Bauersachs. Waste Management 18 (1998) 25-38
R0025405	STORM003	576.	1998	A Framework for Assessing Time-Scale Effects of Wet Weather Discharges – Water Environment Research Foundation – Final Report.
R0025678	STORM003	577.	1998	A Research Needs Survey for Urban Areas – Wet Weather Flow Management – Water Environment Research Foundation – Project 96-IRM-1.
R0025950	STORM003	578.	1998	Residential and Commercial Source Control Programs to Meet Water Quality Goals - Water Environment Research Foundation. Project 95-IRM-1.
R0026329	STORM003	579.	Spring 1999	Controlling Oil Pollution in Surface Water – includes an attached project from Group 7: Krister Andersson, Katherine Ardizone, and Laura Hilden; School of Public and Environmental Affairs,

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				Indiana University. www.spea.indiana.edu/v625-group7.
R0026347	STORM003	580.	1999	Southern California Environmental Report Card 1999 – UCLA Institute of the Environment
R0026395	STORM003	581.	1999	Malibu Creek Watershed – Conserving Our Natural Resources – US Department of Agriculture, Natural Resources Conservation Service (NRCS).
R0026419	STORM003	582.	6/00	State of the Watershed – Report on Surface Water Quality – The San Gabriel River Watershed. California Regional Water Quality Control Board – Los Angeles Region.
R0026463	STORM003	583.	8/00	Comparability of Suspended-Sediment Concentration and Total Suspended Solids Data – John R. Gray, G. Douglas Glysson, Lisa M. Turcios, and Gregory E. Schwarz. US Department of the Interior, US Geological Survey. WRIR 00-4191.
R0026482	STORM003	584.	10/19/00	The State Water Resources Control Board Water Quality Enforcement Policy – draft revised policy
R0026525	STORM003	585.	11/27/00	Collection and Use of Total Suspended Solids Data – Office of Water Quality Technical Memorandum No. 2001.03, Office of Surface Water Technical Memorandum No. 2001.03. US Department of the Interior, USGS.
R0026528	STORM003	586.	12/00	Watershed Management Initiative Chapter – California Regional Water Quality Control Board – Los Angeles Region. (2 copies)
R0026799	STORM003	587.	2000	Clean Coastal Waters – Understanding and Reducing the Effects of Nutrient Pollution – National Research Council
R0027215	STORM003	588.	2000	Southern California Environmental Report Card 2000 – UCLA Institute of the Environment
R0027263	STORM003	589.	2000	*Water Quality in the Long Island-New Jersey Coastal Drainages-New Jersey and New York, 1996-98, USGS*
R0027311	STORM003	590.	5/4/01	Coal mining, fecal bacteria, and radon are water-quality issues for the Kanawha River basin – News Release US Department of the Interior, US Geological Survey – James Eychaner and Katherine Paybins.
R0027314	STORM003	591.	5/01	Potential Pollutant Sources Associated with Various Industrial and Commercial Activities – Staff Report – Regional Water Quality Control Board – Los Angeles.
R0027327	STORM003	592.		Pesticides in Stream Sediment and Aquatic Biota; Current Understanding of Distribution and Major Influences – USGS Fact Sheet 092-00.
R0027331	STORM003	593.		Environmental Indicator Profile Sheet – Center for Watershed Protection
R0027335	STORM003	594.	3/75	Contributions of Urban Roadway Usage to Water Pollution – Office of Research and Development US EPA
R0027688	STORM003	595.	1996	Assessing the Condition and Status of Aquatic Life Designated Uses in Urban and Suburban

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				Watersheds – Chris O. Yoder and Edward T. Rankin
R0027715	STORM003	596.	1/01	Preparing for the Storm: Preserving Water Resources with Stormwater Utilities – Barrett P. Walker, Policy Study No. 275 RPPI
R0027760	STORM003	597.	1976	Basic Data on Urban Storm-Water Quality, Portland, Oregon – USGS Open File Report 76-594. In cooperation with the US Army Corps of Engineers and the Columbia Region Association of Governments.
R0027836	STORM003	598.	1998	**Administrative Record for the City of Long Beach v. Los Angeles Regional Water Quality Control Board Case No. BC174293**

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R0027929	STORM004	600.	6/18/90	Order No. 90-079 (NPDES No. CA0061654, CI 6948) – Waste Discharge Requirements Storm Water/Urban Runoff Discharge for Los Angeles County and Co-Permittees
R0027946	STORM004	601.	6/8/93	City of Long Beach letter addressed to T.A. Tidemanson – Letter of intent to participate as co-permittee in NPDES permit CA0061654, CI 6948
R0027947	STORM004	602.	8/8/94	LARWQCB Letter to Long Beach RE: Permit Renewal Requirements.
R0027949	STORM004	603.	11/15/94	LARWQCB Letter to Long Beach RE: Submitting a Letter of Intent
R0027952	STORM004	604.	¼/95	LARWQCB – Letter to LA County Department of Public Works notifying inadequate fees
R0027954	STORM004	605.	1/13/95	LARWQCB – Acknowledgement of renewal application
R0027956	STORM004	606.	2/14/95	Letter from CRWQCB addressed to James Noyes, Deputy Director
R0027957	STORM004	607.	2/10/95	Draft of Storm water Management/Urban Runoff Discharges within the Malibu Creek an other Rural Areas Watershed -- Santa Monica Bay, Los Angeles County
R0028002	STORM004	608.	9/15/95	Memo from Catherine Tyrrell to County of LA /Municipal Permittee Transmitting Sept. 15 draft of LA Municipal Permit
R0028003	STORM004	609.	9/15/95	Draft LA County Municipal Stormwater Discharge Permit – Sept. 15, 1995
R0028046	STORM004	610.	9/26/95	City of Long Beach comments on September 15, 1995, partial draft of the LA County Municipal Storm Water Permit.
R0028048	STORM004	611.	1/8/96	LARWQCB Response to Permittee Comments on September 15, 1995, draft permit.

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R0028075	STORM004	613.	12/18/95	Dec. 18, 1995 Draft Permit
R0028176	STORM004	614.	1/29/96	City of Long Beach comments on the December 18, 1995, draft permit.
R0028184	STORM004	615.	1/29/96	Letter from Jorge Leon, Lisa Peskay Malmsten and Rufus Young
R0028196	STORM004	616.	4/17/96	Letter to Municipal/ County Counsel from Jorge Leon, Senior Staff Counsel, State Water Resource Control Board
R0028200	STORM004	617.	5/8/96	City Attorney of Long Beach, Lisa Peskay Malmsten, Letter – addressed to Catherine Tyrrell
R0028203	STORM004	618.	5/17/96	City of Long Beach comments on the May 15, 1996 in-house draft Tentative Permit
R0028207	STORM004	619.	7/3/97	City of Long Beach. Transmitting July 2, 1996 Resolution
R0028214	STORM004	620.	5/23/96	LARWQCB letter to Permittees and interested parties transmitting the May 23, 1996 draft permit
R0028218	STORM004	621.	5/23/96	LARWQCB Fact Sheet to Permittees and interested parties transmitting with the May 23, 1 996 draft permit
R0028231	STORM004	622.	5/23/96	The May 23, 1 996 Tentative Permit
R0028333	STORM004	623.	4/17/96	Memoranda from Jorge Leon (Board Counsel) to Catherine Tyrrell (Board Assistant Executive Officer) on legal issues raised by permittees.
R0028351	STORM004	624.	2/11/93	Memoranda from Elizabeth Miller Jennings, Senior Staff Counsel, State Water Resource Control Board
R0028356	STORM004	625.		LARWQCB Staff Response to Permittee Comments on December 18, 1995, draft permit.
R0028409	STORM004	626.	5/22/96	Memoranda from Jorge Leon to Catherine Tyrrell on Receiving Water Limitations.
R0028411	STORM004	627.	6/17/96	June 17, 1996 Letter/Transmitting Revisions to May 23,1996 LA County Storm Water Tentative Permit.
R0028415	STORM004	628.	6/26/96	City of Long Beach comments on the May 23, 1996, Tentative Permit.
R0028428	STORM004	629.	6/25/96	City of Long Beach Resolution
R0028445	STORM004	630.	7/5/96	LARWQCB letter to Permittees and interested parties transmitting the July 5, 1996 Revised Tentative Permit
R0028446	STORM004	631.		Fact Sheet
R0028454	STORM004	632.	7/5/96	The July 5, 1996 Revised Tentative Permit
R0028570	STORM004	633.	7/5/96	Hearing Procedure for the July 15, 1996, Regional Water Quality Control Board Meeting
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R0028610	STORM004	636.	7/15/96	Letter from the City of Long Beach transmitting an adopted City Resolution (July 2, 1996) provided to Regional Board members on July 15, 1996.
R0028621	STORM004	637.	8/94 to 7/15/96	List of LA County Storm Water Permit/Meetings and Agendas
R0028625	STORM004	638.		List of Commenters on the December 18, 1996 Draft Permit
R0028629	STORM004	639.		List of Commenters on the May 15, 1996 in-house Draft Permit
R0028630	STORM004	640.		List of Commenters on the May 23, 1996 Tentative Permit
R0028634	STORM004	641.		List of letters received by the Regional Board from Business, Industry and Concerned Citizens
R0028636	STORM004	642.		List of names of people from business and industry who sent letters to the Board concerning the Permit
R0028655	STORM004	643.		List of Government officials who sent letters to the Regional Board in regards to the Permit.
R0028656	STORM004	644.	7/30/96 7/15/96	Letter to Permittee Contacts transmitting LA County Permit for Discharges of Stormwater and Urban Runoff in the County of Los Angeles and Attached Final July 15, 1996 Permit
R0028762	STORM004	645.	7/31/96	Letter to Interested Parties plus attachments
R0028766	STORM004	646.	3/5/96	USEPA – Addressed to Dr. Robert Ghirelli
R0028768	STORM004	647.	3/5/96	USEPA - Addressed to Dr. Robert Ghirelli
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R0028776	STORM004	652.		Schedule of Events for Municipal Storm Water Permit Renewal
R0028777	STORM004	653.	1/26/94	Executive Advisory Committee Meeting
R0028779	STORM004	654.	8/29/94	Municipal Storm Water Management Plan - Development Schedule
R0028781	STORM004	655.	3/21/95	Memo regarding Storm Water Permit Renewal Meeting of March 20, 1995
R0028788	STORM004	656.	4/95	Storm Water Permit Renewal Subjects and Meeting Dates and Permit Outline
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R0028800	STORM004	663.	11/2/95	Timeline for Finalizing Permit Sections
R0028801	STORM004	664.	11/15/95	Los Angeles County Municipal Storm Water Permit Schedule
R0028802	STORM004	665.	12/12/95	Los Angeles County Municipal Storm Water Permit Schedule
R0028803	STORM004	666.	06/18/96	Agenda for Los Angeles County Municipal Storm Water NPDES Permit at Los Angeles City Hall, Board of Public Works Hearing Room.
R0028805	STORM004	667.		Sign-in Sheet
R0028817	STORM004	668.	8/1/94	LA County Storm Water Permit meeting of the Executive Advisory Committee at LA County Dept. of Public Works Headquarters
R0028818	STORM004	669.		Sign-in Sheet
R0028820	STORM004	670.	8/11/94	NPDES Permit Renewal Coordinating Committee
R0028821	STORM004	671.	10/17/94	Joint Co-Permittee Meeting Minutes
R0028824	STORM004	672.	11/23/94	Phase III - Monthly Permittee Meeting Minutes
R0028827	STORM004	673.	1/17/95	NPDES Storm Water Permit Renewal Meeting - Representatives of Santa Monica Bay Cities Agenda and Sign-in sheet, Schedule, letter of Jan. 13,1995, and Initial Assessment of Volume 2 and 3 of ROWD
R0028837	STORM004	674.	1/19/95	Monthly Malibu Creek and Other Rural Areas Watershed Permittee Meeting and Sign-in Sheet
R0028841	STORM004	675.	1/24/95	NPDES Storm Water Permit Renewal Meeting Agenda - Environmental Group Representatives
R0028842	STORM004	676.	2/2/95	Santa Monica Bay, Malibu Creek and Other Rural Areas - Agenda Permittee Meeting
R0028843	STORM004	677.	4/3/95	NPDES Storm Water Permit Renewal Meeting - Regional Water Quality Control Board, Los Angeles Region Agenda and Sign-in Sheet
R0028846	STORM004	678.	4/17/95	NPDES Storm Water Permit Renewal Meeting - Regional Water Quality Control Board, Los Angeles Region Agenda and Sign-in Sheet
R0028847	STORM004	679.	5/15/95	NPDES Storm Water Permit Renewal Meeting - Regional Water Quality Control Board, Los Angeles Region Agenda Draft
R0028854	STORM004	680.	5/15/95	NPDES Storm Water Permit Renewal Meeting - Regional Water Quality Control Board, Los Angeles Region Final Agenda and Sign-in Sheet

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R0028858	STORM004	682.	6/5/95	NPDES Storm Water Permit Renewal Meeting -Regional Water Quality Control Board, Los Angeles Region Agenda and Sign-in Sheet
R0028860	STORM004	683.	6/14/96	NPDES Storm Water Permit Renewal Meeting - Regional Water Quality Control Board, Los Angeles Region Agenda
R0028861	STORM004	684.	6/22/95	Santa Monica Bay, Malibu Creek and Other Rural Areas - Agenda Permittee Meeting and Co-Permittee Meeting w/ Sign-in Sheet
R0028864	STORM004	685.	6/29/95	LA County Storm Water Permit Renewal Meeting Sign-in Sheet
R0028865	STORM004	686.	7/24/95	Los Angeles County - Storm Water Permit Renewal Meeting Agenda and Sign-in Sheet
R0028866	STORM004	687.	7/24/95	Minutes of General NPDES Co-Permittee Meeting
R0028868	STORM004	688.	7/27/95	Santa Monica Bay, Malibu Creek and Other Rural Areas - Permittee Meeting
R0028869	STORM004	689.	8/24/95	San Gabriel River Watershed Monthly Co-Permittee Meeting and Sign-in Sheet
R0028872	STORM004	690.	8/28/95	NPDES Storm Water Permit Renewal Meeting Agenda and Program Outline - Regional Water Quality Control Board, Los Angeles Region
R0028876	STORM004	691.		Agenda Los Angeles River Watershed Permittee Meeting
R0028877	STORM004	692.	9/20/95	NPDES Storm Water Permit Renewal Meeting - Regional Water Quality Control Board, Los Angeles Region Agenda
R0028878	STORM004	693.	9/26/95	Sign-in Sheet for Negotiating Meeting - LA County Municipal Storm Water Permit
R0028879	STORM004	694.	9/27/95	Los Angeles County - Storm Water Permit Renewal Meeting Agenda and Sign-in Sheet
R0028887	STORM004	695.	9/28/95	San Gabriel River Watershed Permittee Meeting Agenda
R0028888	STORM004	696.	9/28/95	Sign-in Sheet for the Malibu Watershed NPDES Meeting
R0028889	STORM004	697.	10/05/95	Sign-in Sheet for the LA Municipal Storm Water Permit Renewal Meeting
R0028890	STORM004	698.	10/10/95	Sign-in Sheet for the LA Municipal Storm Water Permit Renewal Meeting
R0028891	STORM004	699.	10/17/95	NPDES Storm Water Permit Renewal Meeting - Regional Water Quality Control Board, Los Angeles Region Agenda and Sign-in Sheet
R0028893	STORM004	700.	10/25/95	Santa Monica Bay, Ballona Creek and Other Urban Areas Agenda -Permittee Meeting
R0028894	STORM004	701.	10/26/95	Santa Monica Bay, Malibu Creek and Other Rural Areas Agenda -Permittee Meeting
R0028895	STORM004	702.	11/06/95	NPDES Storm Water Permit Renewal Meeting Regional Water Quality Control Board, Los Angeles Region - Agenda and Sign-in Sheet
R0028898	STORM004	703.	11/13/95	Sign-in Sheet for LA Municipal Storm Water Permit Renewal Meeting

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R0028904	STORM004	706.	12/7/95	LA Municipal Storm Water Permit Renewal - California Regional Water Quality Control Board Agenda an Sign-in Sheet
R0028906	STORM004	707.	1/8/95	Draft Permit Guidance Manual Update Meeting
R0028907	STORM004	708.	1/11/96	Malibu Creek and Other Rural Areas Watershed Monthly Co-Permittee Meeting and Sign-in Sheet
R0028909	STORM004	709.	1/11/96	Los Angeles River Watershed Monthly Co-Permittee Meeting Notes and Sign-in Sheet
R0028912	STORM004	710.	1/16/96	Sign-in Sheet for Santa Clara River Watershed Monthly Permittee Meeting
R0028913	STORM004	711.	1/16/96	Ballona Creek and Urban Santa Monica Bay Watershed Management Area - Permittee Meeting Agenda
R0028914	STORM004	712.	1/25/96	Dominguez Channel/Los Angeles Harbor Drainage Watershed Management Area - Permittee Meeting and Sign-in Sheet
R0028916	STORM004	713.	1/25/96	San Gabriel River Watershed Management Area - Permittee Meeting
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R0028918	STORM004	715.	2/6/96	Los Angeles County Municipal Storm Water Permit Meeting - Sign-in Sheet
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R0028926	STORM004	717.	2/20/96	Santa Clara River Watershed Permittee Meeting Agenda
R0028927	STORM004	718.	2/22/96	Dominguez Channel/Los Angeles Harbor Drainage Watershed -Permittee Meeting Agenda and Sign-in Sheet
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R0028937	STORM004	721.	2/29/96	LA Municipal Storm Water Discharge Permit Meeting Sign-in Sheet
R0028938	STORM004	722.	3/96	SCAG Briefing Packet Materials
R0028966	STORM004	723.	3/1/96	Storm Water Permit Meeting Sign-in Sheet
R0028967	STORM004	724.	3/4/96	NPDES Storm Water Permit Renewal Meeting - Regional Water Quality Control Board, Los Angeles Region - Agenda and Sign-in Sheet
R0028969	STORM004	725.	3/05/96	LA Municipal Stormwater Discharge Permit Renewal Sign-in Sheet
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R0028973	STORM004	729.	3/28/96	Dominguez Channel/Los Angeles Harbor Drainage Watershed -Permittee Meeting
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R0028978	STORM004	733.	5/7/96	City of Los Angeles Inter-Departmental Correspondence - NPDES Co-Permittee Public Outreach Committee for May 1 996
R0028979	STORM004	734.	5/15/96	NPDES Storm Water Permit Renewal Meeting, Regional Water Quality Control Board, Los Angeles Region - Agenda Draft and Sign-in Sheet
R0028984	STORM004	735.	5/23/96	Water Resources Committee Meeting Notice - Los Angeles Area Chamber of Commerce
R0028986	STORM004	736.	6/6/96	Santa Monica Bay, Malibu Creek and Other Rural Areas - Permittee Meeting Agenda and sign in sheet
R0028988	STORM004	737.	6/11/96	Malibu Creek and Other Rural Areas Watershed Monthly Co-Permittee Meeting- Major items of Discussion and Sign-in Sheet
R0028989	STORM004	738.	6/13/96	Los Angeles River Watershed Monthly Co-Permittee Meeting - Major Points of Discussion and Sign-in Sheet
R0028992	STORM004	739.	6/14/96	LA County Renewal Meeting Sign-in Sheet
R0028993	STORM004	740.	6/27/96	Dominguez Channel/LA Harbor Drainage Watershed Monthly Permittee Meeting - Major Items of Discussion and Sign-in Sheet
R0028995	STORM004	741.	7/11/96	Santa Monica Bay, Malibu Creek and Other Rural Areas - Permittee Meeting Agenda
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R0029000	STORM004	743.	7/11/96	Malibu Creek and other Rural Areas Watershed Monthly Co-Permittee Meeting - Major Items of Discussion and Sign-in Sheet
R0029002	STORM004	744.	7/15/96	Malibu Creek Watershed Executive and Advisory Council Meeting Approving Minutes of April 8, 1996 meeting
R0029007	STORM004	745.	9/15/95	Memo from SMBRP to Bay Oversight Committee
R0029009	STORM004	746.	9/28/95	Meeting Agenda - SMBRP- Recommendation for Motion re Municipal Storm Water NPDES

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				Permit and Minutes
R0029015	STORM004	747.	11/29/95	Meeting Agenda and Minutes - SMBRP - Los Angeles County Municipal Stormwater NPDES Permit
R0029022	STORM004	748.	1/18/96	Meeting Agenda and Minutes - SMBRP - Los Angeles County Municipal Stormwater NPDES Permit
R0029030	STORM004	749.	2/21/96	Meeting Agenda and Minutes - SMBRP - Plan Implementation: Storm Water/Urban Runoff Management - Los Angeles County Municipal Stormwater NPDES Permit
R0029035	STORM004	750.	3/14/96	Meeting Agenda and Minutes - SMBRP - Management and Control of Storm Water/Urban Runoff : Los Angeles County Municipal Storm Water NPDES Permit.
R0029042	STORM004	751.	5/7/96	Meeting Agenda - SMBRP - Script for NPDES Advisory Video
R0029045	STORM004	752.	06/10/96	Meeting Agenda - SMBRP - Letter from City Council members
R0029046	STORM004	753.	06/20/96	Meeting Agenda and Minutes - SMBRP - Storm Water Permit
R0029051	STORM004	754.	6/27/96	Meeting Agenda - SMBRP
1995 MEETING AGENDA PACKAGES				
R0029054	STORM004	755.	4/3	LARWQCB Storm Water Permit Renewal Meeting Agenda Package
R0029108	STORM004	756.	4/17	LARWQCB Storm Water Permit Renewal Meeting Agenda Package
R0029160	STORM004	757.	5/1	LARWQCB Storm Water Permit Renewal Meeting Agenda Package
R0029377	STORM004	758.	5/15	LARWQCB Storm Water Permit Renewal Meeting Agenda Package
R0029466	STORM004	759.	6/5	LARWQCB Storm Water Permit Renewal Meeting Agenda Package
R0029594	STORM004	760.	7/24	LARWQCB Storm Water Permit Renewal Meeting Agenda Package
R0029764	STORM004	761.	9/27	LARWQCB Storm Water Permit Renewal Meeting Agenda Package

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GOVERNMENT OFFICIALS AND PUBLIC AGENCIES				
R0029841	STORM004	762.	1/29	State Senator Tom Harden
R0029843	STORM004	763.	1/29	State Assembly member Sheila James Kuehl, 41st District
R0029844	STORM004	764.	1/29	California Coastal Commission
R0029848	STORM004	765.	1/25	Metropolitan Water District
R0029851	STORM004	766.	1/29	Santa Monica Bay Restoration Project

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R0029854	STORM004	767.	1/22	County Sanitation Districts of Los Angeles County
R0029856	STORM004	768.	1/23	County of Los Angeles, Department of Health Services
R0029859	STORM004	769.	1/29	Ventura Countrywide Storm Water Quality Management Program
				ENVIRONMENTAL GROUPS
R0029860	STORM004	770.	1/25	Heal the Bay, NRDC, American Oceans Campaign, SM BayKeeper, Friends of LA River
R0029862	STORM004	771.	1/29	American Oceans Campaign
R0029864	STORM004	772.	1/29	Treepeople
R0029867	STORM004	773.	1/29	Heal the Bay
R0029883	STORM004	774.	2/27/96	Heal The Bay
R0029894	STORM004	775.	1/29	NRDC
R0029914	STORM004	776.	1/29	Santa Monica Baykeeper
				BUSINESS ASSOCIATIONS AND COMPANIES
R0029916	STORM004	777.	1/25	Ahmanson Land Company
R0029917	STORM004	778.	1/26	Building Industry Association
R0029928	STORM004	779.	3/17	Building Industry Association
R0029930	STORM004	780.	1/26	Southern CA Contractors' Assn.
R0029935	STORM004	781.	1/26	Southern CA Rock Products & Ready Mixed Concrete Assns.
R0029936	STORM004	782.	1/30	Valencia Company
R0029942	STORM004	783.	1/29	Western States Petroleum Assn.
				CONSULTANTS TO PERMITTEES
R0029946	STORM004	784.	1/25	John L. Hunter and Associates, Inc. – For Sierra Madre, Signal Hill, South El Monte, and South Gate
R0029963	STORM004	785.	1/30	Burke, Williams, & Sorensen – For City of Bellflower
R0029988	STORM004	786.	1/29	Richards, Watson & Gershon – For: Bradbury, Beverly Hills, Carson, Diamond Bar, Hermosa Beach, Norwalk, Rolling Hills, West Hollywood, & Westlake Village
R0030001	STORM004	787.	2/12	Richards, Watson & Gershon – Public Records Request
R0030007	STORM004	788.	2/15	Burke, Williams & Sorensen – Public Records Act Request
R0030015	STORM004	789.	4/17	Richards, Watsonl& Gershon –Municipal Storm Water Permit Transmittal of Diskette
R0030016	STORM004	790.	4/23	Richards, Watson & Gershon – Redlined copy of the revised version of NPDES permit.

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				(December 18 draft)
R0030112	STORM004	791.	4/26	Richards, Watson & Gershon – Waste Discharge Requirements For Municipal Storm Water Discharges Within The County of Los County
R0030114	STORM004	792.	5/9	Richards, Watson & Gershon – Program Evaluation and Reporting Section of Draft NPDES Permit
R0030119	STORM004	793.	5/6	Oliver, Vose, Sandifer, Murphy and Lee –Request to reschedule the May 29, 1996 workshop
				PERMITTEE
R0030122	STORM004	794.	1/24	LA County Dept. of Public Works – Transmitted Executive Advisory Committee (EAC) comments
R0030123	STORM004	795.		LA County Dept. of Public Works – Executive Advisory Committee Concerns
R0030132	STORM004	796.	1/29	LA County Dept. of Public Works – Principal Permittee
R0030172	STORM004	797.	4/23	LA County Dept. of Public Works – EAC Adoption of Alternative Countywide Program Requirements
				CITIES OF:
R0030191	STORM004	798.	1/23 & 1/29	Alhambra
R0030232	STORM004	799.	1/26	Agoura Hills
R0030239	STORM004	800.	1/24	Azusa
R0030241	STORM004	801.	1/25	Baldwin Park
R0030248	STORM004	802.	1/26	Bellflower
R0030250	STORM004	803.	1/26	Bellflower
R0030253	STORM004	804.	1/29	Bell Gardens
R0030256	STORM004	805.	1/29	Calabasas
R0030260	STORM004	806.	1/25	Carson
R0030262	STORM004	807.	2/8	Cerritos
R0030267	STORM004	808.	1/26	Claremont
R0030271	STORM004	809.	1/23	Commerce
R0030283	STORM004	810.	1/9	Covina
R0030287	STORM004	811.	1/25	Covina, addressed to Frank Kuo
R0030294	STORM004	812.	1/25	Culver City

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R0030309	STORM004	814.	1/29	Downey
R0030311	STORM004	815.	1/29	El Segundo
R0030335	STORM004	816.	1/26	El Segundo
R0030337	STORM004	817.	3/28	El Segundo
R0030371	STORM004	818.	1/25	Glendale
R0030374	STORM004	819.	5/1	Glendale
R0030375	STORM004	820.	1/29	Glendora
R0030380	STORM004	821.	1/30	Hermosa Beach
R0030385	STORM004	822.	1/29	Industry
R0030389	STORM004	823.	1/29	Inglewood
R0030391	STORM004	824.	1/30	Irwindale
R0030394	STORM004	825.	1/25	Lakewood
R0030401	STORM004	826.	1/29	La Mirada
R0030404	STORM004	827.	1/29	La Verne
R0030419	STORM004	828.	1/3	City of La Verne; Memo of General Comments
R0030430	STORM004	829.	1/24	Lomita
R0030442	STORM004	830.	1/29	Long Beach
R0030461	STORM004	831.	2/6	Los Angeles
R0030556	STORM004	832.	2/20	Malibu
R0030557	STORM004	833.	1/26	Manhattan Beach
R0030558	STORM004	834.	2/6	Monterey Park
R0030560	STORM004	835.	1/8	Paramount
R0030563	STORM004	836.	1/25	Paramount
R0030566	STORM004	837.	1/25	Palos Verdes Estates
R0030570	STORM004	838.	1/29	Pico Rivera
R0030571	STORM004	839.	1/29	Rosemead
R0030574	STORM004	840.	1/26	San Dimas
R0030575	STORM004	841.	1/29	San Marino
R0030596	STORM004	842.	1/29	Santa Clarita

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R0030604	STORM004	844.	1/29	Santa Fe Springs
R0030606	STORM004	845.	1/29	Santa Monica
R0030608	STORM004	846.	1/24	Sierra Madre
R0030612	STORM004	847.	1//24	Signal Hill
R0030616	STORM004	848.	1/24	South El Monte
R0030620	STORM004	849.	1/24	South Gate
R0030624	STORM004	850.	1/30	Torrance
R0030626	STORM004	851.	1/25	Vernon
R0030632	STORM004	852.	2/8	Vernon
R0030640	STORM004	853.	1/29	WestCovina
R0030644	STORM004	854.	1/22	Whittier

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				ATTORNEYS
R0030656	STORM004	855.	5/17/96	Burke, Williams and Sorensen representing Santa Clarita, El Segundo. Downey, Bellflower, and Alhambra
R0030663	STORM004	856.	5/17/96	Sidley and Austin representing Los Angeles County
R0030756	STORM004	857.	5/22/96	Sidley and Austin representing Los Angeles County
R0030759	STORM004	858.	5/17/96	Transmittal from Barb Garrett, City of LA addressed to Catherine Tyrrell
R0030761	STORM004	859.	5/17/96	City of Los Angeles Informal Staff Comments
R0030848	STORM004	860.	5/17/96	David B. Brearley and J. David Fitzsimons (City of Vernon) -Comments on Draft (pp 12, 17-19).
R0030875	STORM004	861.	5/17/96	Richards Watson and Gershon - Comments on Draft (pp 22-23, 40-43,46-47,51-53).
R0030884	STORM004	862.	5/17/96	Richards, Watson and Gershon
R0030886	STORM004	863.	5/17/96	Oliver, Vose, Sandifer, Murphy, and Lee
R0030889	STORM004	864.	5/17/96	City of Santa Clarita
R0030890	STORM004	865.	5/16/96	Environmental Group - Heal the Bay

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				GOVERNMENT OFFICIALS AND PUBLIC AGENCIES
R0030891	STORM004	866.	6/25	Castaic Lake Water Agency
R0030892	STORM004	867.	6/25	California Coastal Commission
R0030917	STORM004	867.5	6/27	Southern California Association of Governments
R0030919	STORM004	868.	7/1	Independent Cities Association
R0030924	STORM004	869.	7/5	CRWQCB Response to 6/27, Councilman Dawidziak letter and Fact Sheet
R0030928	STORM004	870.	6/28	State Board Response to Citizen Letters-Attached Citizen Letters
R0030959	STORM004	871.	6/18	State Board Response-From Chairman John Caffrey to San Gabriel Valley Council of Governments, President Ms. Beatrice JS La Pisto-Kirtley
R0030961	STORM004	872.	7/3	Southern California Association of Governments – SCAG's position NPDES Stormwater Permit
				ENVIRONMENTAL GROUPS
R0030965	STORM004	873.	6/26	Heal the Bay
R0030971	STORM004	874.	6/28	Natural Resources Defense Council
R0030982	STORM004	875.	7/3	Letter from Santa Monica Baykeeper on Legal Authority regarding pet waste in New Permit
				BUSINESS ASSOCIATIONS
R0030990	STORM004	876.	6/24	Building Industry Association of Southern California, Inc.
R0030994	STORM004	877.	6/25	California Restaurant Association
R0030997	STORM004	878.	6/14	Western States Petroleum Association
R0031001	STORM004	879.	6/24	Western States Petroleum Associates
				CONSULTANTS TO PERMITTEES
R0031003	STORM004	880.	5/2	Sidley & Austin – Monitoring Language From L.A. County/NRDC Agreement
R0031016	STORM004	881.	6/5	Burke, Williams & Sorensen – For Cities of Alhambra, Bellflower, Downey, El Segundo, and Santa Clarita
R0031020	STORM004	882.	7/1	Oliver, Vose, Sandifer, Murphy & Lee – For: Covina, Bell, South Pasadena, and Calabasas
R0031022	STORM004	883.	6/26	Richards, Watson & Gershon – For Cities of Carson, West Hollywood, Westlake Village, Norwalk, Cudahy, La Habra Heights, San Marino, Diamond Bar, Rolling Hills, and Artesia
R0031047	STORM004	884.	6/26	Rutan & Tucker, LLP – For Cities of Baldwin Park, Lawndale, Signal Hill and West Covina
R0031063	STORM004	885.	6/26	Burke, Williams & Sorensen – For City of Downey

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				PERMITTEES
R0031074	STORM004	886.	6/14	Board of Supervisors County of Los Angeles
R0031075	STORM004	887.	7/15	LA County, Dept. of Public Works – Year Six Annual Report
R0031076	STORM004	888.	6/26	LA County, Dept. of Public Works
				CITIES OF:
R0031084	STORM004	889.	6/24	Alhambra
R0031087	STORM004	890.	6/25	Azusa
R0031091	STORM004	891.	5/28	Baldwin Park
R0031093	STORM004	892.	6/26	Bell Gardens
R0031095	STORM004	893.	6/25	Commerce
R0031099	STORM004	894.	6/28	Cerritos
R0031100	STORM004	895.	6/20	Covina
R0031103	STORM004	896.	6/24	Cudahy
R0031105	STORM004	897.	6/24	Culver City
R0031108	STORM004	898.	6/26	Downey
R0031111	STORM004	899.	6/12	Duarte
R0031134	STORM004	900.	6/26	El Monte
R0031136	STORM004	901.	5/28	El Monte
R0031140	STORM004	902.	6/26	Glendale
R0031142	STORM004	903.	6/26	Hermosa Beach
R0031151	STORM004	904.	6/25	Industry
R0031153	STORM004	905.	7/10	La Canada Flintridge
R0031155	STORM004	906.	6/26	La Verne
R0031157	STORM004	907.	6/26	Lomita
R0031162	STORM004	908.	6/26	LA County, Dept. of Public Works
R0031166	STORM004	909.	6/26	Los Angeles
R0031175	STORM004	910.	6/25	Manhattan Beach
R0031283	STORM004	911.	6/24	Maywood
R0031285	STORM004	912.	6/26	Monrovia
R0031288	STORM004	913.	6/28	Monterey Park

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R0031295	STORM004	914.	6/26	Paramount
R0031297	STORM004	915.	6/25	Pomona
R0031312	STORM004	916.	5/30	Pomona
R0031314	STORM004	917.	6/26	Redondo Beach
R0031327	STORM004	918.	6/25	Rolling Hills Estates
R0031332	STORM004	919.	7/10	Rolling Hills Estates
R0031334	STORM004	920.	6/26	Rosemead
R0031336	STORM004	921.	5/28	San Marino
R0031337	STORM004	922.	6/26	Santa Clarita
R0031343	STORM004	923.	6/26	Santa Fe Springs
R0031345	STORM004	924.	6/27	Sierra Madre
R0031347	STORM004	925.	6/26	Signal Hill
R0031352	STORM004	926.	7/3	South El Monte
R0031357	STORM004	927.	6/26	South Gate
R0031363	STORM004	928.	6/25	Vemon
R0031366	STORM004	929.	6/26	Vernon
R0031377	STORM004	930.	6/26	Whittier
				OTHER COMMENTERS
R0031381	STORM004	931.	6/16	Angus Alexander

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R0031383	STORM004	932.	6/18/96	Workshop Agenda: Los Angeles County Municipal Storm Water NPDES Permit
R0031385	STORM004	933.	6/18/96	Workshop: Record of Participation (sign-in sheets)
				Workshops:
R0031397	STORM004	934.	5/96	Permit "Lite" for the Non-Technical Reader"
R0031402	STORM004	935.	6/10/96	Comparison of LA County Draft Storm Water Permit with Similar Permits in Orange and Santa Clara Counties; EPA Region 9
R0031412	STORM004	936.	6/10/96	Draft Interim Permitting Approach for Water Quality-Based Effluent Limitations in Storm Water Permits

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R0031422	STORM004	937.	6/17/96	Regional Board Letter Regarding EPA Revisions to the May 23, 1996, Tentative
R0031426	STORM004	938.	6/10/96	Comparative Cost of the LA County Storm Water Management Program
R0031431	STORM004	939.	6/18/96	Slide Presentation Copies for Comparative Cost of the Los Angeles County Storm Water Management Program by Marianne Yamaguchi & Dr. Guangyu Wang of Santa Monica Bay Restoration Project
R0031445	STORM004	940.	6/17/96	NPDES Tentative Permit Costs - City of Manhattan Beach
R0031446	STORM004	941.	6/20/96	Tourism and Beach Use Valuation
R0031455	STORM004	942.	6/18/96	Partial Audio Tapes

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				ATTORNEYS
R0031457	STORM004	943.	7/7/96	John Samuel Brantley
R0031458	STORM004	944.	7/12/96	Richards, Watson and Gershon
				GOVERNMENT/PUBLIC ORGANIZATION
R0031471	STORM004	945.	7/2/96	Board of Supervisors County of Los Angeles (From Joanne Sturges addressed to Michael Keston)
R0031475	STORM004	946.	7/11/96	Las Virgenes Municipal Water District (From James E. Colbaugh addressed to Mr. Keston & members)
R0031476	STORM004	947.	7/12/96	South Bay Association of Chamber of Commerce (From John Parsons addressed to Chairman Jack Coe)
R0031477	STORM004	948.	7/11/96	Dominic L. Cortese, Assemblyman from 23rd District - addressed to Robert P. Ghirelli
R0031480	STORM004	949.	5/30/96	Assembly California Legislature, Wally Knox: addressed to Governor Pete Wilson
R0031482	STORM004	950.	6/S//96	Senate California Legislature, Tom Harden: addressed to Chairman Keston and Members of the Regional Board
R0031483	STORM004	951.	6/14/96	Board of Supervisors County of Los Angeles, Zev Yaroslavsky -addressed to Chairman Michael Keston
R0031485	STORM004	952.	6/18/96	State Board of Equalization (From Brad Sherman - addressed to LA Regional Board Member Mr. Dane)
R0031499	STORM004	953.	7/2/96	Assemby California Legislature, Richard Katz: Democratic Floor Leader -addressed to Michael

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				Keston
R0031504	STORM004	954.	7/5/96	Assemby California Legislature, Antonio R. Villarigosa: Forty-Fifth District - addressed to Michael Keston and Members of Board
R0031505	STORM004	955.	7/9/96	Southern California Edison
R0031507	STORM004	956.	7/15/96	California Contract Cities Association
R0031508	STORM004	957.	7/12/96	Los Angeles County Boards of Real Estate
R0031510	STORM004	958.	7/12/96	Pacific Enterprises
R0031512	STORM004	959.	7/12/96	South Bay Association of Chambers of Commerce
R0031513	STORM004	960.		Various Comment Letters: May 13 - July 12
COMMENTS FROM CITIES AND COUNCIL RESOLUTIONS				
R0031522	STORM004	961.	7/8/96	Alhambra
R0031531	STORM004	962.	7/1/96	Azusa
R0031538	STORM004	963.	7/8/96	Baldwin Park
R0031547	STORM004	964.	7/9/96	Burbank
R0031550	STORM004	965.	7/15/96	Calabasas
R0031553	STORM004	966.	7/2/96	Carson
R0031556	STORM004	967.	7/15/96	Cerritos
R0031563	STORM004	968.	7/9/96	Commerce
R0031566	STORM004	969.	7/12/96	Cudahy
R0031567	STORM004	970.	7/9/96	Downey
R0031571	STORM004	971.	7/10/96	Duarte
R0031575	STORM004	972.	7/2/96	El Segundo
R0031579	STORM004	973.	7/9/96	Glendale (with Fax transmittal 7/10/96)
R0031604	STORM004	974.	7/10/96	Glendora
R0031609	STORM004	975.	7/12/96	Hawthorne
R0031611	STORM004	976.	7/12/96	Irwindale
R0031615	STORM004	977.	7/11/96	Lakewood
R0031621	STORM004	978.	7/15/96	Long Beach
R0031631	STORM004	979.	7/11/96	Los Angeles
R0031634	STORM004	980.	7/12/96	Lynwood

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R0031641	STORM004	982.	7/15/96	Pico Rivera
R0031645	STORM004	983.	7/11/96	Pomona
R0031649	STORM004	984.	7/3/96	Redondo Beach
R0031654	STORM004	985.	7/10/96	Rosemead
R0031659	STORM004	986.	7/9/96	San Dimas
R0031661	STORM004	987.	7/12/96	San Gabriel
R0031663	STORM004	988.	7/10/96	San Marino
R0031665	STORM004	989.	7/17/96	Santa Fe Springs
R0031675	STORM004	990	7/9/96	Santa Monica
R0031687	STORM004	991.	7/11/96	Torrance
R0031689	STORM004	992.	7/15/96	Whittier
R0031697	STORM004	993.	7/15/96	Comments from the Cities of Carson, West Hollywood, Westlake Village, Norwalk, Cudahy, La Habra Heights, San Marino, Diamond Bar, Rolling Hills, and Artesia
R0031714	STORM004	994.	7/14/96	List of Resolutions/Letters Received after 7/9/96 Summary
R0031716	STORM004	995.	7/15/96	Petition for a Clean Santa Monica Bay

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R0031752	STORM004	996.	A. Video tape (1tape) on storm water pollution and the Tentative mayors and used in staff presentations to elected officials. Permit mailed out to mayors and used in staff presentations to elected officials.
R0031753	STORM004	997.	B. Mailing List for Video Tape A
		998.	C. Video taped recording (3 tapes) of the July 15, 1996 Regional Board Hearing (transcripts in the administrative record item 1404)

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R0031757	STORM004	999.	7/10/96	Beverly O'Neill, Mayor for City of Long Beach - addressed to Maribel Marin	Regarding Public Records Act Request attached to the letter

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R0031761	STORM004	1000.	7/5/96	Councilmember Joseph Dawidziak from Catherine Tyrrell, Assistant Executive Officer	SCAG
R0031765	STORM004	1001.	7/5/96	California Newspaper Service Bureau, Inc.	Public Notice
R0031767	STORM004	1002.	7/5/96	Memo from Catherine Tyrrell addressed to Bette Worthman (SCAG)	Changes to LA County Municipal Storm Water Permit Requested By SGVCOG
R0031772	STORM004	1003.	7/3/96	Honorable Dominic L. Cortese, Member of the State Assembly from Catherine Tyrrell	Update on status of Permit
R0031773	STORM004	1004.	6/28/96	Letter from CRWQCB addressed to Mayor and City Council Members	Re: Participation in reviewing the LA County Municipal Storm Water Permit
R0031775	STORM004	1005.	6/28/96	Beatrice J.S. LaPisto-Kirtley, President of San Gabriel Valley Council of Governments	Proposed County of LA Municipal NPDES Storm Water Discharge Permit
R0031777	STORM004	1006.	6/28/96	Amy L. Glad, Executive Vice President, Building Industry Assoc. of Southern California, Inc.	Tentative NPDES Municipal Storm Water Discharge Permit for Los Angeles County
R0031778	STORM004	1007.	6/21/96	Michael Kantor, Storm Water Management Division, Board of Public Works, City of Los Angeles	LA County Storm Water Workshop at City of LA Board of Public Works Hearing Room (June 18, 1996)

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R0031779	STORM004	1008.	6/21/96	John J.Agoglia, President of NBC Enterprises	Response to Support Letter for Permit
R0031780	STORM004	1009.	6/21/96	J.P. Ellman, President, Board of Public Works, City of Los Angeles	LA County Storm Water Workshop at City of LA Board of Public Works Hearing Room June 18, 1996
R0031781	STORM004	1010.	6/17/96	Interested Parties	Tentative Municipal Storm Water Permit for the County of Los Angeles
R0031785	STORM004	1011.	6/17/96	Rufus C. Young, Jr., Burke, Williams, & Sorensen	Response to Development of Provisions for the Municipal Permit
R0031786	STORM004	1012.	5/23/96	J.P. Ellman, President, Board of Public Works, City of Los Angeles	Use of City of LA Board of Public Works Hearing Room for Public Workshop on June 18, 1996
R0031787	STORM004	1013.	5/23/96	Interested Parties	Enclosed Documents: Response-to-Comments and Revised Tentative Permit for Review
R0031961	STORM004	1014.	5/22/96	Robert H. Sulnick, Executive Director, American Oceans Campaign from Michael Keston	Response to Mr. Sulnick's Previous Support Letters of Permit
R0031963	STORM004	1015.	5/14/96	Jim Noyes, LA County Department of Public Works	Message for Carlos Urrunaga having Phoned Joanne Sturges regarding the Use of County Board of Supervisors Hearing Room
R0031964	STORM004	1016.	5/13/96	Joanne Sturges, Executive Officer, County of LA Board of Supervisors	Use of County of LA Board of Supervisors Hearing Room for Public Hearing
R0031965	STORM004	1017.	5/2/96	CRWQCB - From Catherine Tyrell addressed	Municipal Storm Water Permit: Revised Draft of Development Planning/ Construction Section.

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				to Amy Glad	
R0031972	STORM004	1018.	4/29/96	Harry W. Stone, Director of Department of Public Works	National Pollutant Discharge Elimination System Municipal Storm Water Discharge Permit for Los Angeles County and Co-Permittee (NPDES No. CA0061654)
R0031974	STORM004	1019.	4/23/96	Donald Wolfe (LACDPW) - addressed to Catherine Tyrrell	Proposed NPDES Permit Adoption Schedule
R0031976	STORM004	1020.	4/5/96	Mark Pisano, Executive Director (SCAG)	1 996 Association of Governments General Assembly, Standing Committee on Planning
R0031988	STORM004	1021.	4/4/96	Carl's Jr. Environmental Specialist, Mike Kissel letter - Addressed to Frank Kuo, LACDPW	Re: Suggested Restaurant Checklist items to assist in controlling materials from entering storm drains.
R0031989	STORM004	1022.		List and addresses to city Mayors	Mailing List
				LETTERS SENT FROM CRWQCB TO:	**REGARDING NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM MUNICIPAL STORM WATER FOR LA COUNTY (NPDES CA0061 654, CI 6948)**
R0031992	STORM004	1023.	4/3/96	Hon. Beverly O'Neil, Mayor	City of Long Beach
R0032005	STORM004	1024.	4/3/96	Hon. Rita Velenzuela, Mayor	City of Monterey Park
R0032008	STORM004	1025.	4/3/96	Hon. John Heilman, Mayor	City of West Hollywood
R0032011	STORM004	1026.	4/3/96	Hon. Carl Boyer, Mayor	City of Santa Clarita
R0032014	STORM004	1027.	4/3/96	Hon. Albert G. Perez, Mayor	City of South El Monte
R0032017	STORM004	1028.	4/3/96	Hon. Albert T. Robles, Mayor	City of South Gate
R0032020	STORM004	1029.	4/3/96	Hon. Tom Breazeal, Mayor	City of Temple City
R0032023	STORM004	1030.	4/3/96	Hon. Dorothy Ramirez, Mayor	City of Maywood
R0032026	STORM004	1031.	4/3/96	Hon. Robert T. Barlett,	City of Monrovia

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R0032029	STORM004	1032.	4/3/96	Hon. Stephen Alexander, Mayor	City of Azusa
R0032032	STORM004	1033.	4/3/96	Hon. George A. Maurer, Mayor	City of Sierra Madre
R0032035	STORM004	1034.	4/3/96	Hon. Isidro Menezes, Mayor	City of Artesia
R0032038	STORM004	1035.	4/3/96	Hon. Sara Hanlon, Mayor	City of Signal Hill
R0032041	STORM004	1036.	4/3/96	Hon. Thomas M. O'Leary, Mayor	City of Covina
R0032044	STORM004	1037.	4/3/96	Hon. Algird Leiga, Mayor	City of Claremont
R0032047	STORM004	1038.	4/3/96	Hon. Paul W. Bowlen, Mayor	City of Cerritos
R0032050	STORM004	1039.	4/3/96	Hon. Mark Flewelling, Mayor	City of Bradbury
R0032053	STORM004	1040.	4/3/96	Hon. Randy Bomgaars, Mayor	City of Bellflower
R0032056	STORM004	1041.	4/3/96	Hon. Fidel A. Vargas, Mayor	City of Baldwin Park
R0032059	STORM004	1042.	4/3/96	Hon. Thomas E. Jackson, Mayor	City of Huntington Parlc
R0032062	STORM004	1043.	4/3/96	Hon. Carol Liu, Mayor	City of La Canada, Flintridge
R0032065	STORM004	1044.	4/3/96	Hon. Paul H. Richards II, Mayor	City of Lynwood
R0032068	STORM004	1045.	4/3/96	Hon. Talmage V. Burke, Mayor	City of Alhambra
R0032071	STORM004	1046.	4/3/96	Hon. Mary B. Young, Mayor	City of Arcadia
R0032074	STORM004	1047.	4/3/96	Hon. George Cole, Mayor	City of Bell
R0032077	STORM004	1048.	4/3/96	Hon. Arnold Alvarez-Glasman, Mayor	City of Montebello
R0032080	STORM004	1049.	4/3/96	Hon. Judith Brennan, Mayor	City of Norwalk
R0032083	STORM004	1050.	4/3/96	Hon. Wayne Piercy, Mayor	City of Lakewood
R0032086	STORM004	1051.	4/3/96	Hon. Jon. H. Blickenstaff, Mayor	City of La Verne

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R0032089	STORM004	1052.	4/3/96	Hon. Michael Sullens, Mayor	City of Whittier
R0032092	STORM004	1053.	4/3/96	Hon. Betty Wilson, Mayor	City of Santa Fe Springs
R0032095	STORM004	1054.	4/3/96	Hon. Curtis Morris, Mayor	City of San Dimas
R0032098	STORM004	1055.	4/3/96	Hon. Edward S. Cortez, Mayor	City of Pomona
R0032101	STORM004	1056.	4/3/96	Hon. Pamela Boothe, Mayor	City of Hidden Hills
R0032104	STORM004	1057.	4/3/96	Hon. Louis Perez, Mayor	City of La Puente
R0032107	STORM004	1058.	4/3/96	Hon. David C. Peters, Mayor	City of La Mirada
R0032110	STORM004	1059.	4/3/96	Hon. John Powers, Mayor	City of La Habra Heights
R0032113	STORM004	1060.	4/3/96	Hon. Dee Hardison, Mayor	City of Torrance
R0032116	STORM004	1061.	4/3/96	Hon. Julian A. Miranda, Mayor	City of Irwindale
R0032119	STORM004	1062.	4/3/96	Hon. Henry Harkema, Mayor	City of Paramount
R0032122	STORM004	1063.	4/3/96	Hon. Garth G. Gardener, Mayor	City of Pico Rivera
R0032125	STORM004	1064.	4/3/96	Hon. Robert Canada, Mayor	City of Hawaiian Gardens
R0032128	STORM004	1065.	4/3/96	Hon. John Ferrero, Mayor	City of Industry
R0032131	STORM004	1066.	4/3/96	Hon. Phyllis R. Reyes, Mayor	City of Duarte
R0032134	STORM004	1067.	4/3/96	Hon. Larry Glenn, Mayor	City of Glendora
R0032140	STORM004	1068.	4/3/96	Hon. Gary P. McCaughan, Mayor	City of Downey
R0032143	STORM004	1069.	4/3/96	Hon. Eileen Ansari, Mayor	City of Diamond Bar
R0032146	STORM004	1070.	4/3/96	Hon. Donald L. Dear, Mayor	City of Gardena
R0032149	STORM004	1071.	4/3/96	Hon. Larry Guidi, Mayor	City of Hawthorne
R0032152	STORM004	1072.	4/3/96	Hon. Edward Vincent, Mayor	City of Inglewood
R0032155	STORM004	1073.	4/3/96	Hon. Harold E. Hoffman, Mayor	City of Lawndale
R0032158	STORM004	1074.	4/3/96	Hon. Lawson Pedigo, Mayor	City of Lomita
R0032161	STORM004	1075.	4/3/96	Hon. Ed. Corridori, Mayor	City of Agoura Hills
R0032164	STORM004	1076.	4/3/96	Hon. Dennis Washburn,	City of Calabasas

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R0032167	STORM004	1077.	4/3/96	Hon. Joan House, Mayor	City of Malibu
R0032170	STORM004	1078.	4/3/96	Hon. James Emmons, Mayor	City of Westlake Village
R0032173	STORM004	1079.	4/3/96	Hon. Michael I. Mitoma, Mayor	City of Carson
R0032176	STORM004	1080.	4/3/96	Hon. Godfrey Pernell, Mayor	City of Rolling Hills
R0032179	STORM004	1081.	4/3/96	Robert Beck, Mayor	City of Rolling Hills Estates
R0032182	STORM004	1082.	4/3/96	Hon. Paul Rosenstein, Mayor	City of Santa Monica
R0032185	STORM004	1083.	4/3/96	Hon. June Wentworth, Mayor	City of Walnut
R0032188	STORM004	1084.	4/3/96	Hon. Steve Herfert, Mayor	City of West Covina
R0032191	STORM004	1085.	4/3/96	Hon. Leonis C. Malburg, Mayor	City of Vernon
R0032194	STORM004	1086.	4/3/96	Hon. John Bowler, Mayor	City of Hermosa Beach
R0032197	STORM004	1087.	4/3/96	Hon. Richard J. Riordan, Mayor	City of Los Angeles
R0032200	STORM004	1088.	4/3/96	Hon. Steve Barnes, Mayor	City of Manhattan Beach
R0032203	STORM004	1089.	4/3/96	Hon. Raymond Mattingly, Mayor	City of Palos Verdes Estates
R0032206	STORM004	1090.	4/3/96	Hon. Marilyn Lyon, Mayor	City of Rancho Palos Verdes
R0032209	STORM004	1091.	4/3/96	Hon. Brad Parton, Mayor	City of Redondo Beach
R0032212	STORM004	1092.	4/3/96	Hon. Rick Reyes, Mayor	City of Glendale
R0032215	STORM004	1093.	4/3/96	Hon. Steven Gourley, Mayor	City of Culver City
R0032218	STORM004	1094.	4/3/96	Hon. Allan Alexander, Mayor	City of Beverly Hills
R0032221	STORM004	1095.	4/3/96	Hon. Carl Jacobson, Mayor	City of El Segundo
R0032224	STORM004	1096.	4/3/96	Hon. Maria Chacon, Mayor	City of Bell Gardens
R0032227	STORM004	1097.	4/3/96	Hon. Dave Golonski, Mayor	City of Burbank
R0032230	STORM004	1098.	4/3/96	Hon. Artemio E. Nevarro, Mayor	City of Commerce
R0032233	STORM004	1099.	4/3/96	Hon. Omar Bradley, Mayor	City of Compton

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R0032236	STORM004	1100.	4/3/96	Hon. Alex F. Rodriguez, Mayor	City of Cudahy
R0032239	STORM004	1101.	4/3/96	Hon. Patricia A. Wallach, Mayor	City of El Monte
R0032242	STORM004	1102.	4/3/96	Hon. Bernard Lasage, Mayor	City of San Marino
R0032245	STORM004	1103.	4/3/96	Hon. Joe Vasquez, Mayor	City of Racemate
R0032248	STORM004	1104.	4/3/96	Hon. Paul Zee, Mayor	City of South Pasadena
R0032251	STORM004	1105.	4/3/96	Hon. Harry Baldwin, Mayor	City of San Gabriel
R0032254	STORM004	1106.	4/3/96	Hon. Joanne Baltierrez, Mayor	City of San Fernando
R0032257	STORM004	1107.	4/3/96	Hon. William M. Paparian, Mayor	City of Pasadena
				LETTERS SENT FROM CRWQCB TO:	**REGARDING:**
R0032260	STORM004	1108.	3/22/96	Donald Wolfe, Deputy Director of Dept. of Public Works	Report of Storm Water Monitoring Under NPDES Municipal Storm Water Discharge Permit for LA County (NPDES No. CA0061 654, CI 6948)
R0032264	STORM004	1109.	3/20/96	John. R. Mundy, Utilities Manager	Los Angeles County Municipal Storm Water Discharge Permit Schedule Change
R0032266	STORM004	1110.	3/20/96	Marcelino M. Martinez, P.E. Municipal Civil Engineer	Los Angeles County Municipal Storm Water Discharge Permit Schedule Change
R0032268	STORM004	1111.	3/20/96	Robert Rugroden, Office Engineer	Los Angeles County Municipal Storm Water Discharge Permit Schedule Change
R0032270	STORM004	1112.	3/20/96	Gerald E. Greene, D. Envr., Associate Planner	Los Angeles County Municipal Storm Water Discharge Permit Schedule Change
				LETTERS SENT BY CARLOS URRUNAGA	**Los Angeles County Municipal Storm Water Permit Draft Handbook**
R0032272	STORM004	1113.	2/16/96	Elroy Keipke, City Engineer	City of Agoura Hills
R0032273	STORM004	1114.	2/16/96	Amy Glad	Building Industry Association of Southern California

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R0032274	STORM004	1115.	2/16/96	Melissa Beard	California Environmental Association
R0032275	STORM004	1116.	2/16/96	Rick Morgan, Deputy City Engineer	City of Malibu
R0032276	STORM004	1117.	2/16/96	Susan Damron, Department of Water and Power	City of Los Angeles
R0032277	STORM004	1118.	2/16/96	Phil Richardson, Department of Public Works	City of Los Angeles
R0032278	STORM004	1119.	2/16/96	Fullmer Chapman, Department of Public Works	City of La Canada Flintridge
R0032279	STORM004	1120.	2/16/96	Pam Keyes, Department of Public Works	City of Culver City
R0032280	STORM004	1121.	2/16/96	Dee Zinke, Building Industry Association	Los Angeles and Ventura County
R0032281	STORM004	1122.	2/16/96	Tom Kennedy. Department of Public Works	City of Vernon
R0032282	STORM004	1123.	2/16/96	Craig Perkins, Env. and Public Works Management Department	City of Santa Monica
R0032283	STORM004	1124.	2/16/96	Don Williams, Department of Public Works	City of Santa Clarita
R0032284	STORM004	1125.	2/16/96	Sam Wise	Rolling Hills Estates
R0032285	STORM004	1126.	2/16/96	Cynthia Kurtz	City of Pasadena
R0032286	STORM004	1127.	2/16/96	Gail Feuer	Natural Resources Defense Council
R0032287	STORM004	1128.	2/16/96	Charles Bergson, Assistant City Engineer	City of Monterey Park
R0032288	STORM004	1129.	2/16/96	Ora Lampman, Department of Public Works	City of Burbank
				OTHER	

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R0032289	STORM004	1130.	2/13/96	Joe Dawidziak, City of Redondo Beach - addressed to Catherine Tyrrell	Invitation to appear at the South Bay Cities Council of Governments (SBCCOG)
R0032291	STORM004	1131.	2/08/96	County of Los Angeles Letter : Second Quarter Progress Report	
R0032332	STORM004	1132.	4/11/96	City of Carson Letter Addressed to Gary Hildebrand, LA County of Public Works	Attendance at EAC Meeting of April 18, 1996 and Report on informal meeting with Board Staff
R0032333	STORM004	1133.	4/23/96	County of Los Angeles Letter from Don Wolfe to Catherine Tyrrell Re: Proposed NPDES Permit Adoption Schedule	

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R0032337	STORM004	1134.	12/28/95	Burke, Williams & Sorensen addressed to Catherine Tyrrell	Draft Waste Discharge Requirements for the Discharge of Storm Water in Los Angeles County
R0032339	STORM004	1135.	12/28/95	CRWQCB to Members of the Public Outreach Committee	Public Education Section of the Draft Los Angeles County Municipal Storm Water Discharge Permit
				CRWQCB ADDRESSED TO:	**Los Angeles County Municipal Storm Water Permit Municipal Guidance Document Meeting on January 8, 1996**
R0032341	STORM004	1136.	12/22/95	Phil Richardson, Department of Public Works	City of Los Angeles

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R0032342	STORM004	1137.	12/22/95	Ora Lampman, Department of Public Works	City of Burbank
R0032343	STORM004	1138.	12/22/95	Don Wolfe, Department of Public Works	City of Los Angeles
R0032344	STORM004	1139.	12/22/95	Pam Keyes, Department of Public Works	City of Culver City
R0032345	STORM004	1140.	12/22/95	Fullmer Chapman, Department of Public Works	City of La Canada Flintridge
R0032346	STORM004	1141.	12/22/95	Cynthia Kurtz	City of Pasadena
R0032347	STORM004	1142.	12/22/95	Sam Wise	Rolling Hills Estate
R0032348	STORM004	1143.	12/22/95	Nancy Delange, Department of Public Works	City of Santa Clarita
R0032349	STORM004	1144.	12/22/95	Craig Perkins, Department of Public Works	City of Santa Monica
R0032350	STORM004	1145.	12/22/95	Tom Kennedy, Department of Public Works	City of Vernon
R0032351	STORM004	1146.	12/22/95	Susan Damron	Department of Water & Power
R0032352	STORM004	1147.	12/22/95	Dee Zinke	Building Industry Association of LA/Ventura
R0032353	STORM004	1148.	12/22/95	Amy Glad	Building Industry Association of LA/Ventura
R0032354	STORM004	1149.	12/22/95	Melissa Beard	California Environmental Associates
R0032355	STORM004	1150.	12/22/95	Gail Feuer	Natural Resources Defense Council
R0032356	STORM004	1151.	12/22/95	Mark Gold	Executive Director of Heal the Bay
R0032357	STORM004	1152.	12/18/95	All Permittees and Interested Parties	Regarding Draft of Waste Discharge Requirements for the Discharge of Storm Water in Los Angeles County
R0032470	STORM004	1153.	10/25/95	CRWQCB to Public Works Officials and Interested Parties	Los Angeles County Municipal Storm Water Discharge Permit (NPDES No. CA0061654. CI 6948) - Schedule Change

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R0032483	STORM004	1154.	10/17/95	Dept. of Public Works addressed to Catherine Tyrrell	Review of Draft NPDES Permit
R0032485	STORM004	1155.	10/12/95	CRWQCB to Public Works Official	Los Angeles County Municipal Storm Water Discharge Permit (NPDES No.0061 654, CI 6948)
R0032487	STORM004	1156.	10/7/95	Sidley & Austin Letter - address to Catherine Tyrrell	Draft Monitoring Program
R0032489	STORM004	1157.	9/20/95	LA County Dept. of Public Works - addressed to Catherine Tyrrell	Proposed Monitoring Program for Draft NPDES Permit
R0032515	STORM004	1158.	9/15/95	CRWQCB - to County of Los Angeles Municipal Permittees	General Meeting to Discuss Draft NPDES Permit
R0032516	STORM004	1159.	9/15/95	California Regional Water Quality Control Board	Order No. 95-XXX, Waste Discharge Requirements for Storm Water Management/Urban Runoff Discharges within the County of Los Angeles
R0032559	STORM004	1160.	9/5/95	Gary Hildebrand from Dept. of Public Works - addressed to all Permittees	General meeting to discuss new NPDES Permit development
R0032560	STORM004	1161.	8/4/95	Natural Resources Defense Council - to CRWQCB	Comments on July 21, 1995 Draft Permit
R0032566	STORM004	1162.	7/26/95	Dave Yamahara, Planning Division from the City of Malibu - addressed to Carlos Urrunaga	Review of Environmental Documents, Attachment of Establishment of Marine Sanctuary
R0032589	STORM004	1163.	6/14/95	LA County Dept. of Public Works - Addressed to Catherine Tyrrell	Phase II and III Monitoring Program
R0032604	STORM004	1164.	5/30/95	LA County Dept. of	Review of Revised Program Management Chapter for the new

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				Public Works - Addressed to Dr. Robert P. Ghirelli	NPDES Storm Water Permit
R0032617	STORM004	1165.	5/25/95	LA County Dept. of Public Works - Addressed to Dr. Robert P. Ghirelli	Review of Revised Illicit Discharge Chapter for the New NPDES Storm Water Permit
R0032627	STORM004	1166.	5/24/95	State Water Resources Control Board - addressed to Gail Feuer (NRDC) and Howard Gest (Sidley & Austin)	County of Los Angeles Stormwater Permit
R0032629	STORM004	1167.	5/18/95	Frank Kuo (LA County Dept. of Public Works) - addressed to All Phase II Co-Permittees	NPDES Legal Notice
R0032631	STORM004	1168.	5/3/95	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelli	Return of application fee for Stormwater Permit Renewal
R0032634	STORM004	1169.	4/21/95	CRWQCB - addressed to Kenneth M. Graham, Chairman of Los Angeles/Long Beach Harbor Safety Committee	Trash and debris in Los Angeles and Long Beach Harbors
R0032637	STORM004	1170.	4/18/95	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelli	National Pollutant Discharge Elimination System Permit No. CA006 1654 -3rd Quarter Progress Report

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R0032668	STORM004	1171.	4/14/95	CRWQCB - addressed to Harry Stone, Director of County of Los Angeles, Department of Public Works	Approval of Phase II and III Monitoring Sites (NPDES No. 0061654, CI 6948, Board No. 90-079)
R0032671	STORM004	1172.	4/10/95	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelli	Approval of Phase II and III Monitoring Sites
R0032673	STORM004	1173.	3/29/95	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelli	New Storm Permit for Los Angeles County
R0032676	STORM004	1174.	3/23/95	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelli	Meeting to update the new permit
R0032678	STORM004	1175.	3/22/95	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelli	Storm Water Permit Renewal
R0032680	STORM004	1176.	3/17/95	Los Angeles/Long Beach Harbor Safety Committee	Trash and Debris in Los Angeles/ Long Beach Harbors
R0032684	STORM004	1177.	3/15/95	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelli	NPDES Permit No. CA0061 654 (CI 6948) Board Order No. 90-079 Action Item Progress Report
R0032696	STORM004	1178	3/13/95	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelli	Municipal Stormwater Permit Confirmation of Discussion on Stormwater Permit Program
R0032699	STORM004	1179.	3/13/95	LA County Dept. of	Boundary Correction for the Santa Clara River Watershed

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R0032701	STORM004	1180.	2/23/95	NPDES Storm Water Permit Monitoring Program Meeting	Agenda and Attached Monitoring Requirements
R0032718	STORM004	1181.	2/15/95	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelli	NPDES Permit No. CA0061654. CI 6948, Board No. 90-079 Action Item Progress Report
R0032726	STORM004	1182.	2/08/95	NRDC letter addressed to Mark Pumford, CRWQCB	New Municipal Permit
R0032729	STORM004	1183.	2/01/95	Illegal dumping complaint form faxed from Frank Kuo (LACDPW) to Carlos Urrunaga	
R0032731	STORM004	1184.	1/31/95	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelli	Confirmation of January 10, 1995 meeting
R0032732	STORM004	1185.	1/17/95	Agenda	NPDES Storm Water Permit Renewal Meeting Representatives of Santa Monica Bay Cities
R0032734	STORM004	1186.	1/13/95	CRWQCB - addressed to Jim Noyes, LA County Dept. of Public Works	NPDES Municipal Storm Water Discharge Permit. NPDES renewal application letter of receipt (NPDES No. CA0061 654, CI 6948)
R0032736	STORM004	1187.	1/12/95	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelli	NPDES Permit No. CA0061 654. CI 6948, Board No. 90-079 Action Item Progress Report
R0032740	STORM004	1188.	1/4/95	LA County Dept. of Public Works	Listing of Common Non-Stormwater Discharge to the Storm Drain System

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R0032744	STORM004	1189.	1/4/95	CRWQCB - addressed to Jim Noyes, LA County Dept. of Public Works	NPDES Municipal Storm Water Discharge Permit (NPDES No. CA0061 654, CI 6948)
R0032746	STORM004	1190.	1/95	Report addressed to Natural Resources Defense Council , Los Angeles Office	Recommended Program for Urban Runoff Pollutant Control for Los Angeles County and Co-Permittees Subject to Storm Water NPDES Permit

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R0032770	STORM004	1191.	12/28/94	LA County Dept of Public Works -addressed to Dr. Robert P. Ghirelli (along with attachments)	NPDES Municipal Storm Water Permit No. CA0061654-2nd Quarter Progress Report
R0032795	STORM004	1192.	12/20/94	LA County Dept of Public Works - addressed to Dr. Robert P. Ghirelli	NPDES Permit - Report of Waste Discharge Submittal
R0032797	STORM004	1193.	12/14/94	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelli	NPDES Permit No. CA0061 654, CI 6948-Action Item Progress Report
R0032800	STORM004	1194.	12/13/94	CRWQCB - addressed to Gary Hildebrand	Watershed Boundaries
R0032801	STORM004	1195.	11/15/94	LA County Dept of Public Works - addressed to Dr. Robert P. Ghirelli	NPDES Permit - Action Item Progress Report
R0032804	STORM004	1196.	11/1/94	Heal the Bay	Comments on Los Angeles County Dept. of Public Works Report of Waste Discharge (ROWD)
R0032809	STORM004	1197.	10/31/94	CRWQCB - addressed to Jim Noyes, Chief Deputy Director	Draft Report of Waste Discharge/Storm Water Management Program Plan

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				of DPW	
R0032841	STORM004	1198.	10/24/94	CRWQCB - addressed to Gary Hildebrand	Final Date of Submittal of Report of Waste Discharge/Storm Water Management Program Plans
R0032842	STORM004	1199.	10/13/94	LA County Dept. of Public Works	NPDES Permit -1st Quarter Progress Report
R0032866	STORM004	1200.	10/06/94	Letter from LADPW requesting digital and tabular data for NPDES	
R0032867	STORM004	1201.	9/22/94	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelli	County of Los Angeles NPDES Permit
R0032869	STORM004	1202.	9/13/94	CRWQCB - addressed to Jack Ainsworth from Cal. Coastal Commission	Monitoring Requirements Under Board Order No. 90-079 Installation of an Automated Water Sampler at Malibu Creek
R0032872	STORM004	1203.	9/13/94	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelli	Municipal Storm Water Permit - Response to May 4. 1994 letter
R0032875	STORM004	1204.	9/13/94	CRWQCB - addressed to Harry W. Stone, Director of LA County DPW	Tentative Cease and Desist Order for County of Los Angeles and Co-Permittees
R0032883	STORM004	1205.	7/26/94	LA County Dept of Public Works - addressed to Mark Pumford	Municipal Storm Water Permit Preparation of Report of Waste Discharge (ROWD)
R0032885	STORM004	1206.	7/20/94	CRWQCB - addressed to Harry W. Stone and Brain Sasaki from DPW	Section 401 Water Quality Certification Waiver - Malibu Creek Monitoring Station Project. Malibu Creek. City of Malibu, Los Angeles County
R0032887	STORM004	1207.	7/19/94	LA County Dept. of Public Works -	NPDES Permit - Fourth Year Annual Report

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				addressed to Dr. Robert P. Ghirelli	
R0032888	STORM004	1208.	5/4/94	CRWQCB - addressed to David Yamahara, Assistant Deputy Director of DPW	Municipal Storm Water Permit for Los Angeles County
R0032890	STORM004	1209.	4/21/94	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelli	NPDES Permit -Quarterly Progress Report
R0032939	STORM004	1210.	4/21/94	LA County Dept. of Public Works - addressed to Phase I Co-Permittees	Annual Progress Report
R0032945	STORM004	1211.	3/16/94	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelli	Response to Comments on December 21, 1993 letter - Includes Attachment, Title 20
R0033014	STORM004	1212.	3/9/94	CRWQCB - addressed to David Yamahara, Assistant Deputy Director of DPW	Los Angeles County Area - Wide NPDES Municipal Storm Water Discharge Permit
R0033015	STORM004	1213.	1/13/94	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelli	NPDES Permit-Quarterly Progress Report
1993 CORRESPONDENCE					
R0033021	STORM004	1214.	12/21/93	CRWQCB - addressed to James A. Noyes (Deputy Director of LA County DPW)	Santa Monica Bay Drainage Basin Proposed Storm Water/Urban Runoff Monitoring Program (NPDES No. CA0061 654, CI 6948).
R0033024	STORM004	1215.	10/21/93	LA County Dept of Public Works -addressed to Dr.	NPDES Permit No. CA0061654, (CI 6948) - Quarterly Progress Report (7/1/93 - 9/1/93)

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				Robert P. Ghirelli (with attachments)	
R0033077	STORM004	1216.	9/16/93	CRWQCB - In-house Memo	Caltrans Non-Compliance Meeting on 9/15/93
R0033078	STORM004	1217.	9/15/93	CRWQCB - Letter addressed to Rod Kubomoto LA County DPW	Sample Letter Regarding Compliance with Requirement to Obtain an Industrial Storm Water Permit
R0033086	STORM004	1218.	8/27/93	CRWQCB - addressed to Rod Kubomoto, LA County DPW	Reply to Request for all NPDES Permitted Discharges in Upper Los Angeles and Upper San Gabriel River Drainage Basins
R0033087	STORM004	1219.	8/16/93	LA County Dept of Public Works - addressed to Dr. Robert P. Ghirelli	Municipal Storm Water Permit Confirmation of Discussion on Second Year Compliance Review
R0033091	STORM004	1220.	7/29/93	County of Los Angeles - DPW	Transmitting copy of letter dated 7/28/93 from LA County Board of Supervisors Chair to Mayor Ciraulo regarding the 24-Hour Hotline for Illegal Discharges and Dumping into Storm Drains
R0033094	STORM004	1221.	7/28/93	LA County Dept of Public Works - addressed to Dr. Robert P. Ghirelli	Request for copies of all NPDES Permits and most recent associated monitoring data in the Upper LA and San Gabriel River Drainage Basins
R0033095	STORM004	1222.	7/19/93	CRWQCB - Agenda	366th Regular Meeting (Slide Presentation of Second Year Compliance with LA County Storm Water Permit
R0033110	STORM004	1223.	7/8/93	LA County Dept of Public Works - addressed to Dr. Robert P. Ghirelli	Comment on the Second Review of Phase I. Year Two Compliance with NPDES Permit No. CA0061654
R0033112	STORM004	1224.	6/30/93	LA County Dept. of Public Works -addressed to Environmental Coordinators,	Compliance with and Enforcement of Industrial Activities Permit

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R0033119	STORM004	1225.	6/17/93	CRWQCB - Addressed to Thomas A. Tidemanson, Director of DPW, LA County	Municipal Storm Water Permit for Los Angeles County - Review of Second Year Compliance (Staff review dated 6/1 4/93 attached)
R0033135	STORM004	1226.	6/4/93	CRWQCB - Addressed to Jerry Baxter of Caltrans	Inadequacies of Caltrans compliance with Waste Discharge Requirements for Storm Water/Urban Runoff Discharge for Los Angeles County
R0033139	STORM004	1227.	4/29/93	LA County Dept. of Public Works addressed to Robert P. Ghirelli	NPDES Permit - Quarterly Progress Report (1/1/93 to 3/1/93)
R0033150	STORM004	1228.	2/8/93	LA County Dept. of Public Works addressed to Robert P. Ghirelli	Municipal Stormwater Permit for Los Angeles County - Comments on CRWQCB's Review of Second-Year Compliance
R0033158	STORM004	1229.	1/22/93	USEPA	Comments on Staffs evaluation of Los Angeles County's compliance with the second year requirements of Stormwater NPDES permit
R0033160	STORM004	1230.	1/11/93	CRWQCB - addressed to Thomas Tidemanson, Director of LA County DPW	Municipal Storm Water Permit for Los Angeles County - Review of Second Year Compliance and Notice of Workshop
R0033179	STORM004	1231.	1/11/93	LA County DPW	Ballona Creek Cleanup Task Force - BMP List (Final Draft)
R0033183	STORM004	1232.	1/5/93	LA County DPW	Storm Water NPDES Permit - Quarterly Progress Report (Oct. 1 to Dec. 31, 1992)- Attached are Phase I and II
1992 CORRESPONDENCE					
R0033190	STORM004	1233.	11/19/92	County of Los Angeles, Chief Administrative Officer, memo to LA County Supervisors	Formation of Ballona Creek Cleanup Task Force
R0033198	STORM004	1234.	11/13/92	Regional Board in-house memo	Ballona Creek Cleanup Task Force - Storm Drain Committee Meeting

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R0033201	STORM004	1235.	10/30/92	Memo from Michael Lyons - Regional Board In-house memo	Ballona Creek Cleanup Task Force Meeting
R0033203	STORM004	1236.	10/6/92	LA County, Dept. of Public Works	NPDES Permit No. CA0061654, (CI6948) Quarterly Progress Report (July 1 to Sept 30, 1992)
R0033205	STORM004	1237.	9/22/92	Minutes of the Board of Supervisors, County of Los Angeles	Formation of the Ballona Creek Cleanup Task Force
R0033207	STORM004	1238.	7/8/92	Agenda for breakfast Workshop for Local Government Officials held by LA County Dept. of Public Works	Focus on Urban Runoff Impact of Stormwater Regulation on Local Authorities
R0033210	STORM004	1239.	7/1/92	LA County Dept. of Public Works	NPDES Permit No. CA0061 654 (CI 6948)-Second Year Report
R0033212	STORM004	1240.	6/17/92	Heal the Bay addressed to Jim Noyes Waste Management Division LA County Dept. of Public Works	Comments on proposed additional Best Management Practices (BMPS)
R0033216	STORM004	1241.	4/23/92	Xavier Swamikannu, CRWQCB	Compliance Inspection Report (CA0061 654)
R0033218	STORM004	1242.	5/14/92	LA County Dept. of Public Works	NPDES Permit No. CA0061 654 (CI 6948)-Quarterly Progress Report (1/1/92 - 3/1/92)
R0033220	STORM004	1243.	1/31/92	CRWQCB - addressed to Pamela Emerson, Cal. Coastal Commission	LA County DPW Application for Storm Drain Construction in Coastal Zone
R0033221	STORM004	1244.	1/27/92	CRWQCB - Agenda	353rd Regular Meeting, Staff Report on Review of First Year's compliance with the Municipal Storm Water Permit
R0033232	STORM004	1245.	1/22/92	LA County Dept. of	Storm Discharge Permit - NPDES Permit No. CA0061654 (CI

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				Public Works - addressed to Dr. Robert P. Ghirelli	6948): Early Action Best Management Practices (BMP) Plan Submittal
R0033249	STORM004	1246.	1/22/92	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelli	NPDES Permit No. CA0061654 (CI 6948)-Quarterly Progress Report (Oct. 1 to Dec.31, 1998)
R0033252	STORM004	1247.	1/15/92	CRWQCB - addressed to Thomas A. Tidemanson, Director LAC Dept. of Public Works	Municipal Stormwater Permit for Los Angeles County (NPDES No. CA0061654, CI6948) -First Year Compliance Review and Notice of Workshop
1991 CORRESPONDENCE					
R0033259	STORM004	1248.	1 1/25/91	Proof of Publication - Daily News and Daily Breeze	Early Action of BMP's Plan
R0033261	STORM004	1249.	11/4/91	LA County, Dept. of Public Works - addressed to Dr. Robert P. Ghirelli	NPDES Permit No. CA0061 654 (CI 6948)-Quarterly Progress Report (July 1 to Sept. 30,1991)
R0033264	STORM004	1250.	7/15/91	LA County, Dept. of Public Works - addressed to Dr. Robert P. Ghirelli	NPDES Permit No. CA0061 654 -First Year Report (July 1 , 1 990 to June 30, 1991)
R0033269	STORM004	1251.	6/13/91	LA County, Dept. of Public Works (Xavier Swamikannu Board Stuff)	Facilities Inspection Report of LA County, Dept of Public Works
R0033270	STORM004	1252.	6/13/91	CRWQCB - addressed to John Mitchell (Waste Management Division, LA County Dept. of Public Works)	Copies of NPDES Permit for Discharges to Santa Monica Bay
R0033271	STORM004	1253.	5/8/91	LA County Dept. of	NPDES Permit No. CA0061 654, CI 6948-Quarterly Progress

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				Public Works - addressed to Dr. Robert P. Ghirelii	Report (Jan. 1 to March 31, 1991)
R0033274	STORM004	1254.	2/19/91	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelii	NPDES Permit No. CA0061654, CI 06948-Quarterly Progress Report (Oct. 1 to Dec. 31, 1990)
R0033277	STORM004	1255.	1/10/91	CRWQCB - addressed to John K. Mitchell (Waste Management Division, LA County Dept. of Public Works)	Standard Industrial Code Categories for Drainage Area Characterization (NPDES Permit No. CA0061654)
1990 CORRESPONDENCE					
R0033278	STORM004	1256.	12/20/90	USEPA to SWRCB	Approval of Los Angeles County Urban Runoff Public Education Campaign
R0033279	STORM004	1257.	12/19/90	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelii	NPDES Permit No. CA0061654 -Standard Industrial Code (SIC) Categories
R0033293	STORM004	1258.	10/16/90	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelii	NPDES Permit No. CA0061654 -Quarterly Progress Report (July 1 to Sept. 30, 1990)
R0033314	STORM004	1259.	7/25/90	LA County Dept. of Public Works - addressed to Dr. Robert P. Ghirelii	NPDES Permit No. CA0061654(CI6948)-request for copies of NPDES permits and most recent monitoring data
R0033316	STORM004	1260.	6/13/90	CRWQCB - addressed to Orville McCollom, LA County Department of	Tentative Waste Discharge Requirements - Stormwater/Urban Runoff Discharge Permit for County of Los Angeles (NPDES No. CA0061654)

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R0033335	STORM004	1261.	2/28/90	USEPA - addressed to Dr. Robert P. Ghirelli	Region 9's position with respect to Municipal Storm Water NPDES permit

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A. STATEWIDE					
R0033337	STORM004	1262.	Comparison of the Storm Water Program with the Hazardous Waste and Pollution Prevention Programs	Presentation to the California Storm Water Task Force	July 1994
R0033374	STORM004	1263.	1990 Water Quality Assessment (WQA)	Division of Water Quality, State Water Resources Control Board/Regional Board	1 990 & 1996
R0033643	STORM004	1264.	1996 Water Quality Assessment	Division of Water Quality, State Water Resources Control Board/Regional Board	
R0033798	STORM004	1265.	Changing the Course of California's Water	USEPA (The Lindsay Museum)	1995
R0033835	STORM004	1266.	California's Rivers and Streams - Working Toward Solutions	State Water Resources Control Board Cal/EPA	
R0033896	STORM004	1267.	Urban Runoff Technical Advisory Committee Report and Recommendations	Prepared for the State Water Resources Control Board Nonpoint Source Management Program	November 1 994
R0033974	STORM004	1268.	California Storm Water Best Management Practice Handbook - Municipal	Camp Dresser & McKee Larry Walker Associates Uribe and Associates Resources Planning Associates	March 1993
R0034249	STORM004	1269.	California Storm Water Best	Camp Dresser & McKee Larry Walker	March 1993

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			Management Practice Handbook - Construction Activity	Associates Uribe and Associates Resources Planning Associates	
R0034578	STORM004	1270.	California Storm Water Best Management Practice Handbooks - Industrial/Commercial	Camp Dresser & McKee Larry Walker Associates Uribe and Associates Resources Planning Associates	March 1993
R0034865	STORM004	1271.	ASIWPCA - EPA Transmittal of Draft of Non-point Source and Grants Guidance for 1997	ASIWPCA - EPA	Dec. 14, 1995
R0034922	STORM004	1272.	Fax - Review of SWPP's by Municipalities	EPA	July 26, 1995
R0034925	STORM004	1273.	Alameda County - California Industrial/Commercial Storm Water Inspection Program Handbook		March 1996
B. FEDERAL					
R0035594	STORM004	1274.	Final Report of the Nationwide Urban Runoff Program	EPA	December 1993
R0035798	STORM004	1275.	National Water Quality Inventory 1992 Report to Congress	EPA	1992
R0036099	STORM004	1276.	Selected Urban Storm Water Runoff Abstracts	EPA	July 1968 -June 1970
R0036451	STORM004	1277.	Urbanization and Water Quality: A Guide to Protecting the Urban Environment	Terrene Institute Washington, D.C.	March 1994
R0036524	STORM004	1278.	Urban Runoff Management Information/Education Products	USEPA, Region 5 (Water Division, Wetlands and Watershed Section, Watershed Management Unit), USEPA Office of Wastewater Enforcement and Compliance Permit Division NPDES Program and Stormwater Section	
R0036734	STORM004	1279.	Water: The Challenge of Cleansing	Pollution Program Affiliates, Inc.	April 7, 1994

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			Rivers and Oceans		
R0036767	STORM004	1280.	Handbook on Urban Runoff Pollution Prevention and Control Planning	USEPA - EPA(625/R-93/004) Office of Research and Development Washington, DC 20460	September 1993
R0036950	STORM004	1281.	Estuaries on the Edge: The Vital Link Between Land and Sea	American Oceans Campaign	1996
R0037232	STORM004	1282.	Investigation of Inappropriate Pollutant Entries into Storm Drainage Systems - A User's Guide	EPA/600/R-92-238 Office of Research and Development Washington, DC 20460	January 1993
R0037330	STORM004	1283.	Storm Water Discharges Potentially Addressed by Phase II of The National Pollutant Discharge Elimination System Storm Water Program - Report to Congress	EPA 833-K-94-002 Office of Water (4203)	March 1995
R0037924	STORM004	1284.	NPDES Storm Water Sampling Guidance Document	EPA 833-B-02-001 Office of Water (EN - 336)	July 1992
R0038104	STORM004	1285.	A State and Local Government Guide to Environmental Program Funding Alternatives	EPA841-K-94-001 Office of Water (4503F)	January 1994
R0038121	STORM004	1286.	Proposed Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters - Under Section 6217 (g) of the Coastal Zone Act Reauthorization Amendments of 1990	USEPA Office of Water (WH - 533)	May 1991
R0038471	STORM004	1287.	Guidance Manual for Implementing Municipal Storm Water Management Programs - (Chapter 1-4)	USEPA (Draft)	August 17, 1994
R0038679	STORM004	1288.	National Water Quality Inventory -	USEPA 841-R-95-005 Office of	December 1995

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			1994 Report to Congress	Water Washington, D.C.	
R0039243	STORM004	1289.	Guidelines for Urban Erosion and Sediment Control	Urban Soil Erosion and Sediment Control Committee	October 1991
R0039732	STORM004	1290.	Saving Bays and Estuaries: A Handbook of Tactics	USEPA 503/8-88-001 Office of Marine and Estuaries Protection	June 1988
R0039770	STORM004	1291.	Coastal Nonpoint Pollution Control Program-Development and Approval Guidance	USEPA Office of Water	January 1993
R0039854	STORM004	1292.	Fundamentals of Urban Runoff Management: Technical and Institutional Issues	Watershed Management Institute and Terrene Institute in Cooperation with USEPA	August 1994
R0040158	STORM004	1293.	Poison Runoff: A Guide to State and Local Control of Nonpoint Source Water Pollution	NRDC	April 1989
R0040658	STORM005	1294.	Stormwater NPDES Related Monitoring Needs	Edited by Harry C. Torno	
R0041343	STORM005	1295.	Urban Stormwater Quality Enhancement - Source Control, Retrofitting, and Combined Sewer Technology	Edited by Harry C. Torno	
R0041936	STORM005	1296.	Seminar Publication, National Conference on Urban Runoff Management: Enhancing Urban Watershed Management at the Local, County, and State Levels	EPA	March 30 - April 2, 1993
R0042397	STORM005	1297.	Economic Valuation of Natural Resources: A Handbook for Coastal Resource Policymakers	U.S. Department of Commerce, National Oceanic and Atmospheric Administration	June 1995
R0042527	STORM005	1298.	Hazardous and Toxic Wastes Associated with Urban Storm Water		1990

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			Runoff, Pitt and Field, Document No. EPA 600-9-90-037 Remedial Action, Treatment and Disposal of Hazardous Waste		
R0042544	STORM005	1299.	1990 Census of Population and Housing, Bureau of the Census, U.S. Department of Commerce		1991
R0042548	STORM005	1300.	Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters, Document No. EPA-840-B-92-002		1993
R0043370	STORM005	1301.	Urban Storm Water Toxic Pollutants: Assessments, Sources, and Treatability		1995
R0043387	STORM005	1302.	Storm Water Management For Construction Activities -Developing Pollution Prevention Plans and Best Management Practices	USEPA 832-R-92-005 Office of Water (WH-547)	September 1992
R0043657	STORM005	1303.	Guidance manual for the Preparation of NPDES Permit Applications for Storm Water Discharges Associated with Industrial Activity	USEPA 505/8-91 -002 Office of Water (EN-336)	April 1991
R0043866	STORM005	1304.	Storm Water Management for Industrial Activities -Developing Pollution Prevention Plans and Best Management Practices	USEPA 832-R-92-006	September 1992
C. LOS ANGELES REGIONAL					
R0044234	STORM005	1305.	California State Mussel Watch	Ten Year Data Summary 1977-1987	May 1988
R0044602	STORM005	1306.	Toxic Substances Monitoring Program	Ten Year Data Summary 1978-1987	August 1990

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R0045054	STORM005	1307.	BPTC Sites Region 4 LA Harbor	Electronic Data Print Out	
R0045066	STORM005	1308.	Ventura Countywide Stormwater Quality Management Program Annual Report	Alex Sheydayi, Chair of Management Committee	September 1995
R0045328	STORM005	1309.	Caltrans: District 7 Stormwater Monitoring Plan "System Design Report"	Tetra, Inc.	November 1996 - May 1997
R0045395	STORM005	1310.	Report of Stormwater Monitoring Winter of 1 994-1995	Los Angeles County Public Works	March 1996
R0045947	STORM005	1311.	Caltrans: District 7 Stormwater Monitoring Plan "Stormwater Monitoring Plan"	Tetra, Inc.	November 1996 - May 1997
R0046275	STORM005	1312.	Heal the Bay 1993 Third Annual Beach Pollution Report Card	Roger Gorke with technical review by Mark Gold	1993
R0046290	STORM005	1313.	Caltrans District 7 -Stormwater Monitoring Summary Report	Tetra Tech, Inc.	
R0046355	STORM005	1314.	Malibu Creek Watershed Natural Resources Plan (Draft)	USDA - Natural Resources Conservation Service	March 1995
R0046511	STORM005	1315.	UCLA Storm Water Pollution Control Transportation Industries Outreach and Education		June 8, 1995
R0046548	STORM005	1316.	Santa Monica Bay Restoration Plan	Santa Monica Bay Restoration Project. The Coastal Watersheds	September 1994
R0046967	STORM005	1317.	UC Davis Final Report Site Specific Study for Effluent Dominated Streams (San Gabriel River, Santa Clara River, Calleguas Creek)		April 18, 1994
R0047128	STORM005	1318.	An Assessment of Inputs of Fecal Indicator Organisms and Human Enteric Viruses from Two Santa	Santa Monica Bay Restoration Project	June 1990

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			Monica Storm Drains - Technical Report		
R0047175	STORM005	1319.	An Epidemiological Study of Possible Adverse Health Effects of Swimming in Santa Monica By - Final Report	Santa Monica Bay Restoration Project	May 7, 1996
R0047458	STORM005	1320.	Basin Plan for the Coastal Watersheds of Los Angeles and Ventura Counties	Adopted by CRWQCB, LA Region	June 13, 1994
R0047688	STORM005	1321.	Pathogens and Indicators in Storm Drains Within the Santa Monica Bay Watershed	Prepared for the Santa Monica Bay Restoration Project (Mark Gold, Melinda Bartlett, Charles McGee, and Greg Deets)	June 1992
R0047749	STORM005	1322.	Storm Drains as a Source of Surf Zone Indicators and Human Viruses to Santa Monica Bay	Prepared for the Santa Monica Bay Restoration Project (Mark Gold, Melinda Bartlett, John Dorsey, and Charles McGee)	August 1991
R0047781	STORM005	1323.	An Assessment of Monitoring and Data Management Needs in Santa Monica Bay - Final Report	Submitted to The Santa Monica Bay Restoration Project by Southern Cal. Costal Water Research Project and EcoAnalysis, Inc.	May 13, 1991
R0047927	STORM005	1324.	Review of Monitoring and Response Protocol for the Malibu Creek Watershed	Santa Monica Bay Restoration Project - Report Prepared by Heather Trim	November 1 994
R0048071	STORM005	1325.	Water Quality and Beneficial Use Investigation of the Los Angeles River: Prospects for Restored Beneficial Uses	James M. Danza Environmental Studies M.S. California State University, Fullerton	June 1994
R0048205	STORM005	1326.	Southern California Coastal Water Research Project -Annual Report	Southern California Coastal Water Research Project	1987
R0048305	STORM005	1327.	Monitoring Southern California's Coastal Water	National Research Council	1990
R0048475	STORM005	1328.	Toxicity of Stormwater Runoff in Los Angeles County - Annual Report	Southern California Coastal Water Research Project	1988-1989

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R0048484	STORM005	1329.	Santa Monica Bay Stormwater Pollutant Reduction Study	By Engineering-Science for City of Los Angeles Wastewater Program Management Division	December 1987
R0048562	STORM005	1330.	Santa Monica Bay Characterization Study	MBC Applied Environmental Sciences Prepared for Santa Monica Bay Restoration Project	April 1993
R0049018	STORM005	1331.	Ozone Disinfection and Treatment of Urban Storm Drain Dry-Weather Flows: A Pilot Treatment Plant (Demonstration on the Renter Canyon Storm Drain Systems in Santa Monica)	Gerald E. Greene, Associate Civil Engineer Prepared for The Santa Monica Bay Restoration Project	June 1992
R0049133	STORM005	1332.	The Metropolitan Water District of Southern California - Annual Report	MWD - Fiscal year July 1, 1988 to June 30, 1989	1989
R0049255	STORM005	1333.	The Metropolitan Water District of Southern California - Annual Report	MWD - Fiscal Year July 1, 1989 to June 30, 1990	1990
R0049380	STORM005	1334.	Assessment of Storm Drain Sources of Contaminants to Santa Monica Bay - Vol. I (Annual Pollutant Loadings to Santa Monica Bay from Storm Water Runoff)	Michael K. Stenstrom Dept. of Civil and Environmental Engineering (UCLA) Eric W. Strecker (Woodward-Clyde Consultants)	May 1993
R0049633	STORM005	1335.	Assessment of Storm Drain Sources of Contaminants to Santa Monica Bay - Vol. II (Review of Water and Wastewater Sampling Techniques with an Emphasis on Stormwater Monitoring Requirements)	Michael K. Stenstrom Dept. of Civil and Environmental Engineering (UCLA) Eric W. Strecker (Woodward-Clyde Consultants)	May 1993
R0049735	STORM005	1336.	Assessment of Storm Drain Sources of Contaminants to Santa Monica Bay - Vol. III (Surface Drainage Water Quality Monitoring Program Plan)	Michael K. Stenstrom Department of Civil and Environmental Engineering (UCLA) Eric W. Strecker (Woodward-Clyde Consultants)	May 1993

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R0049803	STORM005	1337.	Assessment of Storm Drain Sources of Contaminants to Santa Monica Bay - Vol. IV (Selection of Best Management Practices for Control of Storm Water Pollution to Santa Monica Bay)	Michael K. Stenstrom Department of Civil and Environmental Engineering (UCLA) Eric W. Strecker (Woodward-Clyde Consultants)	May 1993
R0049850	STORM005	1338.	Assessment of Storm Drain Sources of Contaminants to Santa Monica Bay - Vol. V (Toxicity of Dry Weather Urban Runoff)	Simlin Lau and Michael K. Stenstrom Dept. of Civil and Environmental Engineering (UCLA) Steven Bay from Southern California Coastal Water Research Project	June 14, 1994
R0049982	STORM005	1339.	Los Angeles River - Park and Recreation Area Study	State Coastal Conservancy	December 1993
R0050076	STORM005	1340.	Port of Long Beach -Nonpoint Source Storm Water Program	Presented to the L.A. Regional Water Quality Control Board by Port of Long Beach	July 19, 1994
R0050211	STORM005	1341.	Los Angeles County Drainage Area Review -Draft Feasibility Report	US Army Corps of Engineers, Los Angeles District	September 1991
R0050674	STORM005	1342.	Response, California Regional Water Quality Control Board, Los Angeles Petition of NRDC for Review of Stormwater/Urban Runoff Discharge Permit (Order No. 90-79)	Los Angeles Regional Water Quality Control Board, Los Angeles	October 19, 1990
R0050984	STORM005	1343.	Progress Update 1 990	Santa Monica Bay Restoration Project	1990
R0050997	STORM005	1344.	Heal the Bay -1993 State of the Marina Report, Marina Del Rey	Roger Gorke, Aimee Bower	July 9, 1993
R0051024	STORM005	1345.	Marine Studies of San Pedro Bay, California Part 2-H - The Marine	Harbors Environmental Projects University of Southern California	October 1991 -June 1992

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R0051345	STORM006	1346.	Final Report to American Oceans Campaign -Chemical Contaminant Release into The Santa Monica Bay: A Pilot Study	Environmental Health Sciences UCLA. School of Public Health	June 12. 1993
R0051558	STORM006	1347.	Public Summary of the Santa Monica Bay Restoration Plan	Santa Monica Bay Restoration Project	December 1994
R0051635	STORM006	1348.	NPDES Permit No. CA0061654 - Santa Monica Bay Drainage Basin (Proposed Stormwater/Urban Runoff monitoring Program)	Los Angeles County Dept. of Public Works: Waste Management Division Water Quality Management Section	August 17, 1993
R0051797	STORM006	1349.	NPDES Permit No. CA0061654 (Phases II and III) - Proposed Stormwater/Urban Runoff Monitoring Program (Mass Emissions Sites)	Los Angeles County Department of Public Works - Waste Management Division	1994
R0051949	STORM006	1350.	Waterbodies, Wetlands, and their Beneficial Uses in the Los Angeles Region (4) – A Report Presented to L.A. Regional Water Quality Control Board – Volume 1 Volume 2	Prem K. Saint. Ted L. Hanes. William J. Lloyd California State University. Fullerton	July 1993
R0052394	STORM006	1351.	Marine Studies of San Pedro Bay, California, Part 20F - The Marine Environment of Marina Del Rey (A Report to the Department of Beaches and Harbors, County of Los Angeles)	Dorothy F. Soule. Mikihiko Oguri. and Burton H. Jones Harbors Environmental Projects University of Southern California	March 1991
R0052722	STORM006	1352.	American Oceans Campaign - Chemical Contaminant Releases into Santa Monica Bay (Executive Summary Based on a Pilot Study)	(See 84)	June 1993

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R0052737	STORM006	1353.	Los Angeles County Department of Public Works: Hydrologic Report	Prepared by the Hydraulic/Water Conservation Division	1987-1988
R0052946	STORM006	1354.	Los Angeles County Department of Public Works: Hydrologic Report	Prepared by the Hydraulic/Water Conservation Division	1988-1989
R0053171	STORM006	1355.	Los Angeles County Department of Public Works: Hydrologic Report	Prepared by the Hydraulic/Water Conservation Division	1990-1991
R0053375	STORM006	1356.	Los Angeles County Department of Public Works: Hydrologic Report	Prepared by the Hydraulic/Water Conservation Division	1991-1992
R0053576	STORM006	1357.	Los Angeles County Department of Public Works: Hydrologic Report	Prepared by the Hydraulic/Water Conservation Division	1993-1994
R0053787	STORM006	1358.	Ventura Countywide Stormwater Quality Management Program	Illicit Discharge Investigation Approach	February 1995
R0053863	STORM006	1359.	Santa Monica Bay Stormwater Pollutant Reduction Study: Volume I Study Results and Recommendation	Prepared for City of Los Angeles Wastewater Program Management Division by Engineering-Science	June 1994
R0053999	STORM006	1360.	Southern California Coastal Water Research Project (SCCWRP) Annual Report 1990-1991 and 1991-1992		November 1992
R0054122	STORM006	1361.	Storm Runoff in Los Angeles and Ventura Counties, Final Report	California Regional Water Quality Control Board, Los Angeles California Regional Water Quality Control Board, Los Angeles	1988
R0054214	STORM006	1362.	Technical Memorandum -Newport Bay Watershed: Construction Activities/Best Management Practices Plan for Sediment Control	Boyle Engineering Corporation - Water Resources Division	November 1981
R0054347	STORM006	1363.	Brash Industries	Pie Grant	Dec. 30, 1995
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R0054355	STORM006	1364.	Santa Clara Valley Nonpoint Source Study. Vol 1 : Loads Assessment Report (Final Report)	Woodward - Clyde Consultants	February 22, 1991

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R0054936	STORM006	1365.	Orange County - NPDES Stormwater Permit Program Proposed Monitoring Program	Orange County Flood Control District. The County of Orange and Its Twenty -Nine Incorporated Cities	February 20. 1 991
R0054987	STORM006	1366.	1 993 Summary Report. Vehicle Service Facility Waste Minimization Program	Uribe and Associates	
R0055055	STORM006	1367.	Analysis of Urban BMP Performance and Longevity - Final Report	Dept. of Environmental Programs, Metropolitan Washington, Council of Govt.	August 1 992
R0055287	STORM006	1368.	Riverside County Flood Control and Water Conservation District (NPDES Municipal Stormwater Application for Permit Renewal)	Flood Control District, County and Cities of Riverside County, Santa Ana Watershed	Januarys, 1995
R0055408	STORM006	1369.	Developing Successful Runoff Control Programs for Urbanized Areas	North Virginia Soil District, Fairfax Virginia	July 1, 1994
R0055507	STORM006	1370.	Actions Speak Louder than Legislation - Positive Experiences Provide Direction for Urban Runoff . Management	Water Environment and Technology	January 1996
R0055511	STORM006	1371.	Stormwater Management Manual for the Puget Sound Basin - The Technical Manual	Washington State Department of Ecology	February 1992
R0056335	STORM006	1372.	A Current Assessment of Urban Best Management Practices - Techniques for Reducing Nonpoint Source Pollution in the Coastal Zone	Anacostia Restoration Team Department of Environmental Programs Metropolitan Washington Council of Governments	March 1992
R0056455	STORM006	1373.	1994 Puget Sound Water Quality Management Plan	Puget Sound Water Quality Authority	May 18. 1994
R0056744	STORM006	1374.	Urban Storm Drainage -Criteria Manual Vol. 3 (Best Management	Urban Drainage and Flood Control District Denver, Colorado	September 1992

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			Practices)		
R0057027	STORM006	1375.	Storm Water Compliance: Municipal Techniques and Strategies	American Public Works Association California Chapter - Training Seminar	December 10, 1993
R0057133	STORM006	1376.	Urban Stormwater: An Overview for Municipalities	Public Works	December 1990
R0057140	STORM006	1377.	The Clock is Ticking to Comply with New Stormwater Regulations	Monica M. Oakley, and Carol L. Forrest	March 1991
R0057146	STORM006	1378.	The New Federal Stormwater Regulations	Public Works (City, County and State)	February 1991
R0057151	STORM006	1379.	Impervious Surface Reduction Study - Final Report	City of Olympia Dept. of Public Works - Water Resources Program	May 1995
R0057365	STORM006	1380.	Impervious Surface Reduction Study - Executive Summary	City of Olympia Dept. of Public Works - Water Resources Program	January 1996
R0057402	STORM006	1381.	The Importance of Imperviousness	Watershed Protection Techniques, Vol. 1, Number 3	Fall 1994
R0057414	STORM006	1382.	City and County of San Francisco Department of Public Works : Best Management Practices Study	Prepared by James M. Montgomery, Consulting Engineers, Inc.	August 1992
R0057738	STORM006	1383.	Thermal Impacts Associated with Urbanization and Stormwater Management, Best management Practices: Final Report	Prepared by John Galli, Department of Environmental Programs, Metropolitan Washington Council of Governments	December 1990
R0057936	STORM006	1384.	Thermal Impacts Associated with Urbanization and Stormwater Management, Best management Practices: Appendices	Prepared by John Galli & Robert Dubose, Department of Environmental Programs, Metropolitan Washington Council of Governments	December 1990
R0058073	STORM006	1385.	Comprehensive Watersheds Ordinance for City of Austin, TX	Prepared by Curtis Williams & Associates Planning and Environmental Consultants	1986
R0058151	STORM006	1386.	Performance Measures for the National CSO Control Program	AMSA: Association of Metropolitan Sewerage Agencies	January 1996

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R0058253	STORM006	1387.	Action Plan Demonstration Project: Demonstration of Gasoline Fueling Station Best Management Practices, Final Report	Submitted to U.S. Environmental Protection Agency, Region IX	October 1994
R0058399	STORM006	1388.	Orange County NPDES Stormwater Program: Drainage Area Management Plan	Submitted to the San Diego and Santa Ana Regional Water Quality Control Boards	April 1993
R0058690	STORM006	1389.	Santa Clara Valley Non-Point Source Program -Proposed Storm Water Management Plan	Section 9	December 20, 1994
R0058767	STORM006	1390.	Service Station Storm Water Runoff Study Contract No. DT 308-02	Prepared for Western States Petroleum Association	Octobers. 1993
R0058922	STORM006	1391.	Best Management Practices for Industrial Storm Water Pollution Control	Alameda County Urban Runoff Clean Water Program - A Consortium of Local Agencies	
R0058946	STORM006	1392.	Good Practices to Protect Our Creeks and Bay -Guidelines for Restaurants, Grocery Stores, Cafeterias, Bakeries, and Delicatessens	Santa Clara Valley Nonpoint Source Pollution Control Program	
R0058963	STORM006	1393.	Blueprint for a Clean Bay -Best Management Practices to Prevent Stormwater Pollution from Construction Related Activities	Bay Area Stormwater Management Agencies Association	1995
R0058975	STORM006	1394.	Water Quality Protection for Automotive Businesses -1 st Edition	Business Partners for Clean Water Woodward-Clyde Consultants	November 1990
R0059050	STORM006	1395.	Storm Water Best Management Practices for Retail Gasoline Outlets	By Geomatrix Prepared for Western States Petroleum Association, Project No. S2498	January 12, 1996
R0059101	STORM006	1396.	Best Management Practices for Storm	Santa Clara County Non-Point Source	

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			Water and Industrial Sanitary Sewer Pollution Control	Pollution Control Program	
R0059116	STORM006	1397.	Results: A Retail Gasoline Outlet and Commercial Parking Lot Storm Water Runoff Study	Geomatrix Consultants, Inc. for Western States Petroleum Association and American Petroleum Institute Project N. S2498	September 26, 1994
R0059166	STORM006	1398.	Industrial Stormwater Pollution Control Compliance - A Comprehensive Source Book for Federal, State, and Regional Regulatory Requirements and Information Resources	Santa Clara Valley nonpoint Source Pollution Control Program	December 1992
R0059533	STORM006	1399.	Water Quality Best Management Practices Manual - For Commercial and Industrial Businesses	Resource Planning Associates	June 30, 1989
R0059730	STORM006	1400.	Storm Water Runoff Management Literature Review - Prepared for Caltrans		March 1996
R0059785	STORM006	1401.	Controlling Toxic Pollution in Urban Storm Water Runoff - Options for Local Government		August 1988

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R0059825	STORM006	1403.	Speaker Cards from the July 15, 1 996 Regional Board Hearing

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R0060008	STORM006	1404.	1. Official Transcripts of the July 15, 1996 Regional Board Hearing
R0060208	STORM006	1405.	2. Sign-in Sheet for July 15, 1996, Regional Board Hearing

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R0060223	STORM006	1406.	12/20/94	Transmittal Letter of Report of Waste Discharge (ROWD) Los Angeles County Department of Public Works Waste Management Division, Water Quality Section
R0060225	STORM006	1407.		Summary of Best Management Practices (BMP's) By Cities Summary and Evaluation of Baseline BMP's
R0060458	STORM006	1408.		Santa Monica Bay - Malibu Creek and Other Rural Areas Stormwater Management Plan
R0060526	STORM006	1409.		Santa Monica Bay - Ballona Creek and Other Urban Areas Stormwater Management Plan
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R0060673	STORM006	1411.		Los Angeles River Stormwater Management Plan
R0060748	STORM006	1412.		San Gabriel Stormwater Management Plan
R0060820	STORM006	1413.		Santa Clara Stormwater Management Plan
R0060888	STORM006	1414.		Countywide Evaluation of Existing Stormwater Quality Monitoring Data (Section A - 1 of 2)
R0060998	STORM006	1415.		Countywide Evaluation of Existing Stormwater Quality Monitoring Data (Section A - 2 of 2)
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R0061401	STORM006	1417.	3/8/96	NPDES Permit No. CAS 618033 & Waste Discharge Requirements Order No. 96-30 for The Riverside County Flood Control, and Water Conservation District, The County of Riverside, and The Incorporated Cities of Riverside County within the Santa Ana Region Area-Wide Urban Storm Water Run-off (CRWQCB) - Santa Ana Region)
R0061430	STORM006	1418.	3/8/96	Order No. 96-31 - NPDES No. CAS618030 Waste Discharge Requirements for the County of Orange. Orange County Flood Control District and The Incorporated Cities of Orange County Within the Santa Ana Region. Areawide Urban Storm Water Run-Off - Orange County (CRWQCB - Santa Ana Region)
R0061460	STORM006	1419.	3/8/96	NPDES Permit and Waste Discharge Requirements NPDES No. CAS618036. Order No. 96-32 for The San Bernardino County Transportation/Flood Control Department. The County of San Bernardino County Transportation Cities of San Bernardino County Within the Santa Ana Region. Areawide Urban Storm Water Run-off (CRWQCB - Santa Ana Region)
R0061493	STORM006	1420.	8/22/94	Order No. 94-082 - NPDES No. CAS063339. Waste Discharge Requirements for Storm Water Management/Urban Runoff Discharges for Ventura County Flood Control District. County of Ventura.

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R0061511	STORM006	1421.	9/29/94	Transmittal of Adopted Waste Discharge Requirements for Fresno Metropolitan Flood Control District, City of Fresno, City of Clovis, County of Fresno, California State University Fresno, and Caltrans, Urban Storm Water Discharges, Fresno County (CRWQCB - Central Valley Region)
R0061530	STORM006	1422.	6/18/90	Order No. 90-079 - NPDES No. CA0061654 (CI6948). Waste Discharge Requirements for Storm Water/Urban Runoff Discharge for Los Angeles County and Co-Permittee (CRWQCB - Los Angeles Region)
R0061547	STORM006	1423.	7/13/90	Waste Discharge Requirements for the Riverside County Flood Control and Water Conservation District, the County of Riverside, and the Incorporated Cities of Riverside County Within the Santa Ana Region. Stormwater Runoff Management Program, Riverside County, Order No. 90-104 - NPDES No. CAS000192.
R0061585	STORM006	1424.	5/10/96	Adopted Waste Discharge Requirements, Order 96-105, County of Sacramento, Cities of Sacramento, Folsom, & Gait.
R0061636	STORM006	1425.	8/23/95	California Regional Water Quality Control Board, San Francisco Bay Region; CAS029718, Order 95-180, Reissuing Waste Discharge Requirements for Santa Clara Valley Water District, County of Santa Clara, City of Campbell, City of Cupertino, City of Los Altos, Town of Los Altos Hills, Town of Los Gatos, City of Milpitas, City of Monte Sereno, City of Mountain View. City of Palo Alto, City of San Jose, City of Santa Clara, City of Saratoga, and City of Sunnyvale which have joined together to form the Santa Clara Valley Nonpoint Source Pollution Control Program
R0061652	STORM006	1426.	10/14/94	California Regional Water Quality Control Board - Central Coast Region; Order No. 94-099 (NPDES No. CAS04883) - Waste Discharge Requirements for City of Santa Cruz, Neary Lagoon Storm Water Discharge and Lagoon Management, Santa Cruz County
R0061666	STORM006	1427.	12/01/94	Sarasota County - Municipal Separate Storm Sewer System Permittees: United States Environmental Protection Agency Region IV; Authorization to Discharge Under the National Pollutant Discharge Elimination System

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R0061805	STORM006	1429.	2/1/95	United States Environmental Protection Agency - Region 10. NPDES Permit No. AKS052426 Port of Anchorage NPDES Municipal Storm Water Permit

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R0061868	STORM006	1431.	1994	July 1,1993 -June 1994	Storm Water Discharge Monitoring
R0062007	STORM006	1432.	1995-1996	July 1,1 995 -June 30, 1996	Storm Water Discharge Monitoring
R0062162	STORM006	1433.	6/27/96	Annual Report - Sixth Year : Enclosure B-1	Evidence of Implementation: Long Beach
R0062201	STORM006	1434.	6/27/96	Annual Report - Sixth Year : Enclosure B-2	Evidence of Implementation: Long Beach
R0062244	STORM006	1435.	4/20/95	Phase III Additional Best Management Practices for Residential, Commercial, and Industrial Areas	

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R0062858	STORM007	1438.	Feb. 22, 1996	Vol. II	
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R0064132	STORM007	1441.	8/22/94	July 18, 1994	376th Regular Meeting
R0064139	STORM007	1442.	10/31/94	September 26, 1994	378th Regular Meeting
R0064145	STORM007	1443.	2/27/95	January 23, 1995	381st Regular Meeting
R0064152	STORM007	1444.	4/1/96	Study Session with attached materials presented to Board	Following 392nd Regular Meeting
R0064198	STORM007	1445.	5/6/96	April 1, 1996	393rd Regular Meeting
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R0064239	STORM007	1451.	8/19/93	LA Times
R0064240	STORM007	1452.	8/18/93	LA Times
R0064244	STORM007	1453.	7/9/96	Six District News - "L.A. City Council Approves Galanter Motion to Support Sweeping Coastal Anti-Pollution Program"
R0064246	STORM007	1454.	7/2/96	Pasadena Star-News - "Clean oceans start at home"
R0064247	STORM007	1455.	4/3/93	Los Angeles Time - "Flotsam and Jetsam"
R0064250	STORM007	1456.	N/A	Daily News - "PR firms to do dirty work in cleanup plan"
R0064250.1	STORM007	1457.	5/6/96	ADASC - BayKeeper and the Auto Dismantler - Missing
R0064251	STORM007	1458.	6/27/96	Beach Reporter - "Redondo councilmember key player in water debate"
R0064253	STORM007	1459.	6/19/96	The Outlook - "A new chapter for bay cleanup"

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R0064771	STORM007	1462.	Citizens Letters received Jun 21 - Jul 5, 1996	
R0065156	STORM007	1463.	List of persons/agencies/companies from Business, Industry, & Citizens that sent letters of support for the adoption of the storm water permit.	

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R0065243	STORM007	1465.	9/8/94	Memorandum on Municipal Storm Water Management Plan Components	
R0065264	STORM007	1466.	9/2/94	Draft Monitoring Position Paper	
R0065276	STORM007	1467.		Final NPDES Permit Application Regulations for Storm Water - Areas of Significant Change From the Proposed Regulations	
R0065287	STORM007	1468.		NPDES Permit Application Requirements for Storm Water	Fact Sheet
R0065292	STORM007	1469.	2/6/96	Storm Water Permit Comparisons	
R0065303	STORM007	1470.	12/22/94	United States Environmental Protection Agency - Region 6, Fact Sheet for draft NPDES Permit No. OKS000101, for the Oklahoma City Municipal Separate Storm Sewer System to discharge to waters of the United States	
R0065351	STORM007	1471.	5/19/95	Order No. 95-76 - NPDES No. CA0108758. Waste Discharge Requirements for Storm Water and Urban	

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				Runoff from the County of San Diego, The Incorporated Cities of San Diego County, and the San Diego Unified Port District. (SDRWQCB) May 19,1995	
R0065391	STORM007	1472.	10/31/95	NPDES No. CAS618033 and Waste Discharge Requirements Order No. 95-47 for the Riverside County Flood Control and Water Conservation District, the County of Riverside and the Incorporated Cities of Riverside County within the Santa Ana Region Areawide Urban Storm Water Runoff. (Santa Ana RWQCB)	
R0065417	STORM007	1473.	10/27/95	Revised Draft of Waste Discharge Requirements for the San Bernardino County Transportation/Flood Control Department, the County of San Bernardino and Incorporated Cities, Order No. 95-53, NPDES No. CAS008036, Urban Storm Water Runoff, San Bernardino County. (Santa Ana RWQCB) Nov. 1, 1995	
R0065450	STORM007	1474.	7/21/95	Renewal of Waste Discharge Requirements for the Orange, Riverside, and San Bernardino County Areas, Urban Storm Water Runoff. 7/26/95	
R0065456	STORM007	1475.	7/21/95	NPDES No. CA8000192 and Waste Discharge Requirements Order No. 95-47 for The Riverside County Flood Control and Water Conservation District, the County of Riverside, and the Incorporated Cities of Riverside County within the Santa Ana Region Areawide Urban Storm Water Runoff.	
R0065527	STORM007	1476.	8/25/95	Permit No. AZS000003 - Authorization to Discharge Under the National Pollutant Discharge Elimination System.	
R0065561	STORM007	1477.	7/21/95	Tentative Waste Discharge Requirements for Sacramento County Water Agency Cities of	

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				Sacramento County Water Agency, Cities of Sacramento, Folsom, and Gait Area-Wide Storm Water Dischargers from Municipal Separate Storm Sewer Systems - Sacramento County. 8/7/95	
R0065622	STORM007	1478.	4/20/95	Tentative Order - NPDES No. CAS029718. Reissuing Waste Discharge Requirements for Santa Clara Valley Water District, County of Santa Clara, City of Campbell, City of Cupertino, City of Los Altos, town of Los Altos Hills, Town of Los Gatos, City of Milpitas. City of Monte Sereno, City of Mountain View, City of Polo Alto, City of San Jose, City of Santa Clara, City of Saratoga, and City of Sunnyvale which has joined together to form the Santa Clara Valley Nonpoint Source Pollution Control Program.	
R0065634	STORM007	1479.	12/12/94	Proposed Draft by Riverside County Flood Control and Water Conservation District (Santa Ana RWQCB)	
R0065651	STORM007	1480.	NA	General Requirements of Permittee	
R0065663	STORM007	1481.	4/13/95	NPDES No. 95-?? Waste Discharge Requirements for Storm Water/Urban Runoff from the County of San Diego, the Incorporated Cities of San Diego County. and the San Diego Unified Port District. April 13,1995	
R0065703	STORM007	1482.	5/19/95	CRWQCB San Diego Region - addressed to San Diego Municipal Co-Permittee or Interested Party Tentative Order No. 95-76 (NPDES Permit No. CA0108758) Waste Discharge Requirements for Storm Water and Urban Runoff from the County of San Diego. The Incorporated Cities of San Diego County, and the San Diego Unified Port District.	
R0065779	STORM007	1483.	3/8/96	California Regional Water Quality Control Board - Santa Ana Region Fact Sheet on Waste Discharge	

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				Requirements for the Riverside County Flood Control and Water Conservation District, the County of Riverside, and the Incorporated cities of Riverside County within the Santa Ana Region, Storm Water Run-off Management Program, Order No. 96-30 (NPDES No. CAS 618033)	
R0065784	STORM007	1484.	2/23/96	California Regional Water Quality Control Board Santa Ana Region - Michael J. Adackapara addressed to Ronald J. Novello Renewal of Waste Discharge Requirements for the County of Orange, Orange County Flood Control District and Incorporated Cities of Orange County, Order 96-31, NPDES No. CAS 618030, Area-Wide Urban Storm Water Runoff, Orange County	
R0065814	STORM007	1485.	7/21/95	California Regional Water Quality Control Board Santa Ana Region - Michael J. Adackapara addressed to Robert F. Wingard	Renewal of Waste Discharge Requirements for the County of Orange, Orange County Flood Control District and Incorporated Cities of Orange County, Order 95-52, (NPDES No. CA8000180) Areawide Urban Storm Water Runoff, Orange County
R0065856	STORM007	1486.		Sarasota County Permittees - Permit No. FLS000004	NPDES Permit for Municipal Separate Storm Sewer Systems
R0065918	STORM007	1487.	2/1/95	United States Environmental Protection Agency, Region 10	NPDES Permit No. AKS052426 - Port of Anchorage NPDES

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R0065984	STORM007	1489.	12/83	Results of the Nationwide Urban Runoff Program, Executive Summary, USEPA
R0066014	STORM007	1490.	5/87	Attorney's General's Statement for the State National Pollutant Discharge Elimination System Program and State Pretreatment Program - State of California Office of the Attorney General May 1987
R0066189	STORM007	1491.	12/7/88	Federal Register Environmental Protection Agency 40 CFR Parts 1 22, 123, 124, and 504 National Pollutant Discharge Elimination System Permit Application Regulations for Storm Water Discharges; Proposed Rule
R0066263	STORM007	1492.	9/22/89	NPDES Memorandum of Agreement Between the USEPA and CSWRCB
R0066317	STORM007	1493.	11/16/89	Letter from EPA to Regional Board
R0066322	STORM007	1494.	11/16/90	Federal Register Environmental Protection Agency, 40 CFR Parts 122, 123, and 124 National Pollutant Discharge Elimination System Permit Application Regulations for Storm Water Discharges; Final Rule
R0066425	STORM007	1495.	1/9/91	Memo from E. Donald Elliot, Asst. Adm. & General Counsel, U.S. EPA, regarding compliance with Water Quality Standard in NPDES Permits Issued to Municipal Separate Storm Sewers Systems.
R0066431	STORM007	1496.	5/16/91	State of California State Water Resources Control Board - Order No. WQ 91-03
R0066491	STORM007	1497.	5/16/91	State of California State Water Resources Control Board - Order No. WQ 91-04
R0066512	STORM007	1498.	6/92	EPA - Environmental Impacts of Stormwater Discharges: A National Profile
R0066557	STORM007	1499.	7/1/92	Code of Federal Regulations Part 122
R0066576	STORM007	1500.	11/92	Guidance Manual For The Preparation Of Part 2 Of The NPDES Permit Applications For Discharges From Municipal Separate Storm Sewer System, USEPA
R0066722	STORM007	1501.	12/2/92	Memo addressed to Archie Matthews (Division of Water Quality) from Elizabeth Jennings,

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				Senior Staff Counsel regarding compliance with Coverage of State Highways Under Municipal Storm Water Permits
R0066727	STORM007	1502.	4/23/93	Memo addressed to William H. Crooks (Executive Officer) regarding compliance with Municipal Storm Water For Stockton
R0066731	STORM007	1503.	7/93	USEPA NPDES Storm Water Program Question and Answer Document Volume 2
R0066791	STORM007	1504.	12/93	Role of Municipalities in the Implementation of State General NPDES Permits for Storm Water Associated with Industrial Activity from Eugene Bromley USEPA region 9 to Maryann Jones, SWRCB
R0066798	STORM007	1505.	3/3/94	Memo addressed to Regional Water Board (Executive Officer) regarding compliance with Transmittal of the Final Storm Water Compliance Strategy - California Storm Water Compliance and Enforcement Strategy
R0066826	STORM007	1506.	1/12/94	Memo addressed to Water Management Division Directors Region I - X regarding compliance with Storm Water Enforcement Strategy
R0066850	STORM007	1507.	4/7/95	Memo addressed to Urban Runoff Task Force regarding compliance with Non-storm Water Discharges - Municipal Permits
R0066858	STORM007	1508.	7/9/96	CRWQCB Los Angeles Region - Comparative Cost of the LA County Storm Water Management Program
R0066862	STORM007	1509.	9/8/94	Memorandum addressed to Storm Water Permit Program Coordinators – Municipal Storm Water Management Plan Components
R0066878	STORM007	1510.	9/95	EPA - Economic Benefits of Runoff Controls
R0066895	STORM007	1511.	10/3/95	Memo Addressed to Bruce Fujimoto (Division Of Water Quality) from Elizabeth Jennings of SWRCB regarding Municipal Storm Water Permits: Compliance With Water Quality Objectives
R0066898	STORM007	1512.	1994	EPA National Water Quality Inventory. 1994 Report to Congress –Executive Summary
R0066947	STORM007	1513.	1/10/96	Memo addressed to Catherine Tyrrell, et al.. from Jorge Leon SWRCB Senior Staff Counsel regarding legal issues Raised in Draft Storm Water WDRs/NPDES Permit for LA County, et al.
R0066951	STORM007	1514.	3/25/96	Comparison of Los Angeles County Draft Storm Water Permit with Similar Permits in Orange and Santa Clara Counties
R0066961	STORM007	1515.	5/96	Liquid Assets: A Summertime Perspective on the Importance of Clean Water to the Nation's Economy. USEPA Document No. 800-R-96-002. (see Table of Contents attached)
R0066991	STORM007	1516.	5/17/96	EPA - Interpretative Policy Memorandum on Re-application Requirements for Municipal

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R0067054	STORM007	1519.	10/12/95	Memo to Catherine Tyrrell From Gary Hildebrand	NPDES Stormwater Permit Task Schedule - Draft List of Task Attached
R0067128	STORM007	1520.	11/9/95	County of Los Angeles Department of Public Works letter addressed to Catherine Tyrrell	Comments on the September 15, 1995 Draft NPDES Stormwater Permit
R0067133	STORM007	1521.	11/9/95	County of Los Angeles Department of Public Works letter addressed to Catherine Tyrrell	Narrative Comments on the September 15, 1995 Draft NPDES Stormwater Permit -Revised 11/1 3/95
R0067140	STORM007	1522.	10/27/95	City of Alhambra	Draft of September 1 5, 1995 NPDES Permit No. CAS0051654.
R0067142	STORM007	1523.	10/11/95	City of Alhambra	Draft of September 15, 1995 NPDES Permit No. CAS0051654.
R0067146	STORM007	1524.	10/3/95	City of Azusa	Comments on the September 15th Draft Permit
R0067149	STORM007	1525.	10/31/95	City of Bellflower	Comments September 1 5th Draft NPDES Permit CAS0061654
R0067152	STORM007	1526.	10/28/95	Berryman & Henigar	Review of Draft NPDEs Permit
R0067154	STORM007	1527.	12/13/95	Building Industry Association of Southern California (BIA)	Proposed Update to NPDES Permit for Stormwater/Urban Runoff Discharge

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R0067176	STORM007	1530.	9/26/95	City of Covina	Letter addressed to Mr. Frank Kuo of Los Angeles County Department of Public Works, Waste Management Division, Storm Water Discharge Program
R0067180	STORM007	1531.	9/26/95	City of Covina	Fax attention to Catherine Tyrrell regarding a letter address to Mr. Frank Kuo
R0067185	STORM007	1532.	10/12/95	City of Diamond Bar	Draft NPDES Permit No. CAS0061654
R0067186	STORM007	1533.	10/11/95	City of Downey	Draft L. A. County Municipal Storm Water Discharge Permit
R0067188	STORM007	1534.	10/17/95	City of Duarte	NPDES Permit
R0067190	STORM007	1535.	10/12/95	City of El Monte	Letter addressed to Mr. Frank Kuo, County of Los Angeles, Department of Public Works Division of Waste Management
R0067195	STORM007	1536.	10/12/95	City of El Monte, Community Development Department	Letter addressed to Mr. Frank Kuo, County of Los Angeles, Department of Public Works Division of Waste Management
R0067200	STORM007	1537.	10/10/95	City of El Segundo	Comments to September 15, 1995 Draft NPDES Permit
R0067260	STORM007	1538.	10/26/95	City of Gardena	Draft NPDES Municipal Permit September 15, 1995
R0067321	STORM007	1539.	10/13/95	City of Glendale	Comments on the September 15th Draft Permit
R0067323	STORM007	1540.	10/10/95	City of Glendora	Comments September 1 5th Draft NPDES Permit CAS0061654
R0067326	STORM007	1541.	10/16/95	City of Hermosa Beach	Comments on September 15, 1995 Draft Waste Discharge Requirements for Stormwater Management/Urban Runoff Discharges Within the County of Los Angeles (NPDES No.

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R0067402	STORM007	1543.	10/20/95	City of Manhattan Beach	Comments on Draft NPDES Permit (NPDES No. CAS0051654)
R0067461	STORM007	1544.	10/12/95	City of Monrovia	Draft NPDES Permit/Comments to EAC
R0067467	STORM007	1546.	~~10/12/95~~ 12/7/95	Natural Resources Defense Council (NRDC)	Thresholds for Triggering the Urban Runoff Mitigation Plan Requirement
R0067468	STORM007	1547.	10/17/95	NRDC	Response to the EAC's Comments on the September 15. 1995, Draft Permit
R0067471	STORM007	1548.	10/13/95	NRDC	Comments on the September 15, 1995, Draft Permit
R0067487	STORM007	1549.	9/26/95	NRDC	Comments on the September 15, 1995, Draft Permit
R0067492	STORM007	1550.	10/16/95	City of Paramount	Comments on the September 15 Draft Permit
R0067494	STORM007	1551.	10/16/95	City of Pomona	Proposed Los Angeles County Storm Water Discharge Permit Comments
R0067501	STORM007	1552.	12/1/95	Rutan & Tucker	Draft NPDEs Permit No. CAS0061654
R0067502	STORM007	1553.	10/18/95	Rutan & Tucker	Comments to September 15, 1995 NPDES Draft Permit No. CAS0061654-Cities of Baldwin Park, Lawndale, Signal Hill and West Covina
R0067512	STORM007	1554.	11/1/95	Santa Monica Bay Restoration Project (SMBRP)	Renewal of the Los Angeles County Municipal Storm Water NPDES Permit
R0067514	STORM007	1555.	10/25/95	City of San Dimas	Draft Municipal N.P.D.E.S Permit
R0067519	STORM007	1556.	11/1/95	City of Santa Fe Springs	Few comments regarding the latest draft of the proposed new NPDES Permit
R0067521	STORM007	1557.	10/12/95	City of San Marino	Comments on the September 15th Draft NPDES Permit CAS0061654
R0067523	STORM007	1558.	12/8/95	Sidley & Austin	Disk with Monitoring Program Documents
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R0067533	STORM007	1563.	10/11/95	City of West Hollywood	Comments on September 15, 1995, Draft Waste Discharge Requirements for Stormwater Management/Urban Runoff Discharges within the County of Los Angeles (NPDES No. CAS0061654)
R0067540	STORM007	1564.	12/7/95	Transmittal Letter from NRDC to Catherine Tyrrell	Thresholds for Triggering the Urban Runoff Mitigation Plan
R0067541	STORM007	1565	12/14/95	Letter from NRDC to Catherine Tyrrell	Background Data for URMP Thresholds
R0067543	STORM007	1566.	12/14/95	Attached: NRDC to Catherine Tyrrell	List of Building Permits issued by CLA1 994 & 1995
R0067607	STORM007	1567.	2000	**Administrative record for State Board Adopted Order - Petition of the City of Bellflower, et al., Permit for Municipal Storm Water and Urban Run-Off Discharges (SUSMPs) Within Los Angeles County (order WQ 2000-011) (October 2000)**	

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R0067995	STORM007	1593.	1/18/00	Staff Report and Record of Decision for Standard Urban Storm Water Mitigation Plans and Numerical Standards For Best Management Practices
R0068048	STORM007	1594.		Los Angeles County Municipal Storm Water Permit - Order No. 96-054
R0068052	STORM007	1595.	1/26/00	Standard Urban Storm Water Mitigation Plan, Statement of Dennis Dickerson, Executive Officer
R0068068	STORM007	1596.		Dennis Dickerson's Notes From Meetings with Various Cities, Business and Environmental Groups, and Board Members and Staff
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R0069170	STORM007	1691.	9/13/99	City of Santa Monica
R0069173	STORM007	1692.	1/26/00	City of Simi Valley
R0069174	STORM007	1693.	1/12/00	City of South Gate
R0069176	STORM007	1694.	8/ 26/99	City of South Gate
R0069178	STORM007	1695.	1/14/00	City of Vernon
R0069182	STORM007	1696.	1/8/99	City of Vernon
R0069185	STORM007	1697.	1/11/00	City of West Covina

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R0069211	STORM007	1702.	1/10/00	California Coastal Commission- State of California Resources Agency
R0069212	STORM007	1703.	12/17/99	California Regional Water Quality Control Board Los Angeles Region
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R0069249	STORM007	1706.	1/11/00	Center for Watershed Protection
R0069261	STORM007	1707.	9/15/99	County of Los Angeles Board of Supervisors
R0069267	STORM007	1708.	1/11/00	County of Los Angeles Department of Public Works
R0069271	STORM007	1709.	12/28/99	County of Los Angeles Department of Public Works
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R0069301	STORM007	1711.	7/21/99	County of Los Angeles Department of Public Works
R0069349	STORM007	1712.	7/12/00	County of Los Angeles Department of Public Works
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R0069368	STORM007	1715.	1/14/00	County of Ventura Public Works
R0069370	STORM007	1716.	8/11/99	Los Angeles County Urban Runoff and Stormwater NPDES Permit Standard Urban Stormwater Mitigation Plan
R0069385	STORM007	1717.	9/15/99	San Gabriel Basin Water Master
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R0069388	STORM007	1719.	12/16/99	San Gabriel Valley Council of Governments
R0069392	STORM007	1720.	12/16/99	Santa Monica Mountain Conservancy State of California Resources Agency
R0069396	STORM007	1721.	12/20/99	South Bay Cities Council of Governments
R0069400	STORM007	1722.	1/21/00	Southern California Association of Governments
R0069401	STORM007	1723.	1/18/00	Southern California Association of Governments- Meeting of the Water Quality Task Force
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R0069492	STORM008	1736.	1/20/00	Coalition for Clean Air
R0069494	STORM008	1737.	12/06/99	Community Coalition for Change
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R0069497	STORM008	1739.	1/5/00	Earth Communications Office
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R0069501	STORM008	1742.	1/17/00	Friends of the Los Angeles River
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R0069506	STORM008	1745.	4/17/00	Heal the Bay SUSMP 6.0 Numeric Standard Version
R0069507	STORM008	1746.		Heal the Bay Announcement for RWQCB Public Hearing
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R0069516	STORM008	1748.	9/7/99	Heal the Bay
R0069524	STORM008	1749.	6/10/99	Heal the Bay
R0069526	STORM008	1750.		Heal the Bay Form Letters Sent out to the Public for Signatures (104)
R0069527	STORM008	1751.	9/9/99	Los Angeles River Watershed Management Committee
R0069573	STORM008	1752.	9/9/99	Los Cerritos Wetlands Task Force
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R0069618	STORM008	1763.	1/11/00	Santa Monica Bay Keeper
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R0069637	STORM008	1765.	12/8/99	Sierra Club Angeles Chapter
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R0069793	STORM008	1772.	1/24/00	Ann Romano Associates
R0069794	STORM008	1773.	9/16/99	Apartment Association California Southern Cities, Inc.
R0069795	STORM008	1774.	12/28/99	ASCE- Los Angeles Section
R0069798	STORM008	1775.	1/24/00	B & E Engineers
R0069800	STORM008	1776.	1/25/00	BIA
R0069804	STORM008	1777.	1/21/00	BIA
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R0069843	STORM008	1786.	1/25/00	California Apartment Association, California Building Industry Association. California Business Property Association, California Chamber of Commerce. California Manufacturers Association, California Restaurant Association
R0069845	STORM008	1787.	1/14/00	California Restaurant Association
R0069851	STORM008	1788.	1/25/00	Cabrillo Economic Development Corporation
R0069853	STORM008	1789.	1/14/00	California Environmental Associates
R0069858	STORM008	1790.	12/16/99	California Environmental Associates
R0069859	STORM008	1791.	12/15/99	California Public Interest Research Group
R0069861	STORM008	1792.	1/5/00	CDS TECHNOLOGIES, INC.
R0069862	STORM008	1793.	9/15/99	Centex Homes
R0069864	STORM008	1794.	9/15/99	Centex Homes
R0069867	STORM008	1795.	1/20/00	Citation Homes
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R0069871	STORM008	1797.	1/24/00	Del Webb's Sun City Palm Desert
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R0069873	STORM008	1799.	1/24/00	DeVere Anderson Enterprises
R0069876	STORM008	1800.	1/19/00	Executive Advisory Committee Version of SUSMP
R0069896	STORM008	1801.	12/22/99	Executive Advisory Committee
R0069906	STORM008	1802.	12/16/99	Executive Advisory Committee
R0069908	STORM008	1803.	8/31/99	Executive Advisory Committee Letter with Final Tentative SUSMP (12/07/99)
R0069926	STORM008	1804.	9/14/99	Engineering Contractors: Association
R0069928	STORM008	1805.	1/24/00	First American Title Company
R0069929	STORM008	1806.	9/14/99	FORMA
R0069930	STORM008	1807.	1/26/00	Greystone Homes
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R0069933	STORM008	1809.	9/15/99	Greystone Homes
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R0069950	STORM008	1814.	1/5/00	JBI Process Equipment
R0069952	STORM008	1815.	1/25/00	JCC Homes
R0069957	STORM008	1816.	9/15/99	JTL Development Corporation
R0069959	STORM008	1817.	1/25/00	Justice & Associates
R0069964	STORM008	1818.	1/2400	Kaufman Broad
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R0069970	STORM008	1820.	9/15/99	John Laing Homes
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R0069985	STORM008	1827.	10/14/99	Long Beach Area Chamber of Commerce
R0069987	STORM008	1828.	1/20/00	Los Angeles County Board of REAL ESTATE
R0069989	STORM008	1829.	1/18/00	Malibu Bay Company
R0069990	STORM008	1830.	1/21/00	MIA LEHRER & Associates, Landscape Architecture
R0069992	STORM008	1831.	9/13/99	Mid-Cities Escrow
R0069993	STORM008	1832.	1/14/00	New Hall Land
R0069996	STORM008	1833.	12/13/99	New Hall Land
R0069998	STORM008	1834.	9/8/99	New Hall Land
R0070003	STORM008	1835.	9/16/99	New Urban West, Inc.
R0070005	STORM008	1836.	9/14/99	Pace Engineering, Inc.
R0070007	STORM008	1837.	1/24/00	Pacific Bay Homes
R0070012	STORM008	1838.	9/14/99	Pacific Bay Homes
R0070014	STORM008	1839.	9/14/99	Pacific Bay Homes
R0070015	STORM008	1840.	1/24/00	Pacific Soils Engineering, Inc.
R0070020	STORM008	1841.	9/15/99	Pacific Soils Engineering, Inc.
R0070022	STORM008	1842.	9/15/99	Pacific Soils Engineering, Inc.

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R0070031	STORM008	1846.	9/14/99	Ramseyer and Associates, Inc.
R0070033	STORM008	1847.	9/13/99	James S. Rasmussen
R0070036	STORM008	1848.		Rex B. Link & Associates
R0070037	STORM008	1849.	1/24/00	Rottman Froman Communities
R0070040	STORM008	1850.	12/22/99	Rutan & Tucker
R0070049	STORM008	1851.	1/25/00	Shea Homes
R0070050	STORM008	1852.	1/24/00	Shea Homes
R0070053	STORM008	1853.	9/13/99	Shea Homes
R0070059	STORM008	1854.	9/14/99	SIKAND Engineering, Planning, Surveying
R0070061	STORM008	1855.	9/13/99	SIKAND Engineering, Planning, Surveying
R0070062	STORM008	1856.	1/20/00	Southern California Contractors Association, Inc.
R0070063	STORM008	1857.	1/24/00	Southern California Ready Mixed Concrete Association
R0070064	STORM008	1858.	9/15/99	Southern California Ready Mixed Concrete Association
R0070066	STORM008	1859.	9/13/99	South Place Corporation
R0070068	STORM008	1860.	1/12/00	Stainless Industrial Companies
R0070069	STORM008	1861.	1/24/00	SunCal Companies
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R0070075	STORM008	1863.	9/15/99	SunCal Companies
R0070077	STORM008	1864.	1/20/00	Taylor Woodrow
R0070079	STORM008	1865.	9/13/99	Taylor Woodrow
R0070082	STORM008	1866.	9/15/99	TETRA TECH, INC.
R0070084	STORM008	1867.	9/1/99	Joseph C. Truxaw and Associates, Inc.
R0070087	STORM008	1868.	1/26/00	Ventura Affordable Home, Inc.
R0070088	STORM008	1869.	1/20/00	Ventura Affordable Home, Inc.
R0070089	STORM008	1870.	1/20/00	VTN West, Inc.
R0070090	STORM008	1871.	9/14/99	Warmington Homes California
R0070092	STORM008	1872.	9/15/99	Western Pacific Housing
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R0070109	STORM008	1877.		Notice of Public Hearing
R0070123	STORM008	1878.		Opening Statement
R0070124	STORM008	1879.		Correspondence Between Dennis Dickerson, Xavier Swamikannu, and Jorge Leon regarding the Board Meeting
R0070132	STORM008	1880.	7/15/96	Los Angeles County Municipal Storm Water Permit Order No. 96-054 Part 2.I.G. and 2I.H.
R0070140	STORM008	1881.	7/15/96	Los Angeles County Municipal Storm Water Permit Order No. 96-054
R0070145	STORM008	1882.	12/7/99	The Los Angeles County Standard Urban Storm Water Mitigation Plans
R0070150	STORM008	1883.	12/7/99	SUSMP Summary of Comments Received and Responses
R0070158	STORM008	1884.	9/8/99	Letter from American Oceans Campaign to Dennis Dickerson Regarding SUSMPs
R0070160	STORM008	1885.	9/9/99	Letter from Santa Monica Baykeeper to Regional Board Members regarding SUSMPs
R0070164	STORM008	1886.	9/16/99	Statement of Eduardo Olivo
R0070167	STORM008	1887.	9/16/99	Comments on Proposed Standard Urban Storm Water Mitigation Plans Presented by Natural Resources Defense Council
R0070188	STORM008	1888.		SUSMP's Regional Water Quality Control Board Meeting Sept. 16, 1999
R0070189	STORM008	1889.	12/6/99	Memorandum to SUSMP
R0070194	STORM008	1890.	11/17/99	Ventura Countywide Stormwater Quality Management Program Document with Methodology for BMP Calculations
R0070208	STORM008	1891.	11/17/99	Ventura Countywide Stormwater Quality Management Program Drainage Examples
R0070214	STORM008	1892.	12/7/99	Proposed SUSMP and Supporting Regional Board Resolution
R0070245	STORM008	1893.	12/7/99	Copy of the Standard Urban Storm Water Mitigation Plan for Los Angeles County and Cities in Los Angeles County
R0070269	STORM008	1894.	11/10/99	Draft SUSMP Requirements for Stormwater Runoff Mitigation Calculations
R0070277	STORM008	1895.	12/8/99	Numerical Mitigation Criteria for Development Planning Sample Calculations, BMP Cost Estimates, Calculations to Determine Equivalent Percent Volume Capture Criterion
R0070316	STORM008	1896.		Various Studies and Presentations from throughout the Nation on SUSMP

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R0070717	STORM008	1898.	8/10/99	Sign in Sheet for the Standard Storm Water Mitigation Plans Workshop at the City of Alhambra
R0070724	STORM008	1899.	7/15/99	Outline for Discussion of NPDES Permit CAS614001 Part 2.III.A.1.c (Development of SUSMPs)
R0070727	STORM008	1900.		List of Region 4 Interested Parties
R0070733	STORM008	1901.	6/17/99	City of Los Angeles Comments on Draft Standard Urban Stormwater Mitigation Plans
R0070738	STORM008	1902.	8/12/99	County of Los Angeles, Department of Public Works Standard Urban Mitigation Plans
R0070787	STORM008	1903.	7/21/99	County of Los Angeles, Department of Public Works. Compliance File No. 6948. Standard Urban Mitigation Plans
R0070843	STORM008	1904.	7/12/99	County of Los Angeles, Department of Public Works Proposed Standard Urban Stormwater Mitigation Plans
R0070940	STORM008	1905.	8/13/99	Memorandum from John Hunter regarding NPDES Requirements for New Development Projects Numerical Limits and Anticipated Costs to Developers
R0070943	STORM008	1906.	10/20/99	City of Signal Hill, SUSMP
R0070944	STORM008	1907.	12/23/99	NRDC, Chpt. 3 of the County's Development Planning Volume, explaining the scope of projects to which the 0.75 inch capture volume standard applies
R0070948	STORM008	1908.	9/7/99	A Resolution of the City of Rancho Palos Verdes not to Require Cities to Impose Numeric Limits on the Treatment of Retention of Stormwater Runoff
R0070950	STORM008	1909.	9/9/99	Tom Richman & Associates. Workshop on Post-Construction Stormwater Controls in Los Angeles
R0070952	STORM008	1910.	12/2/99	Los Angeles County Municipal Storm Water And Urban Runoff Permit Status and Tracking Sheet
R0070955	STORM008	1911.	12/8/99	Los Angeles County NPDES Stormwater Executive Advisory Committee Meeting Sign-in Sheet
R0070958	STORM008	1912.	2/99	Draft Permittee SUSMP 6.0 Numerical Standard Version
R0070966	STORM008	1913.		**LOS ANGELES REGIONAL WATER QUALITY CONTROL BOARD ADMINISTRATIVE RECORD INDEX:** *Water Quality References*

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R0071788	STORM008	1916.	9/16/99	California Regional Water Quality Control Board, Los Angeles Region, 424th Regular Board Meeting Transcripts
R0071901	STORM008	1917.	1/26/00	California Regional Water Quality Control Board, Los Angeles Region, 427th Regular Board Meeting Transcripts

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R0072245	STORM008	1919.	4/22/99	Notice of Public Hearing
R0072251	STORM008	1920.	4/22/99	Consideration of Recommended Best Management Practices (BMP's) for Development Planning and Construction for Municipal Storm Water Programs in Los Angeles County
R0072335	STORM008	1921.	6/14/99	Letter from Xavier Swamikannu to LA County regarding Approving BMP's for Development Planning and Construction (Board Resolution No. 99-03) with attachments

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R0072346	STORM008	1923.	1/26/00	California Regional Water Quality Control Board, Los Angeles Region Resolution No. R-00-02 Approving the Standard Urban Water Mitigation Plan for Municipal Storm Water and Urban Runoff Management Programs in Los Angeles County
R0072350	STORM008	1924.	3/8/00	California Regional Water Quality Control Board, Los Angeles Region Staff Report and Record of Decision Standard Urban Storm Water Mitigation Plans and Numerical Design Standards for Best Management Practices—Supplement Board Directed Changes
R0072354	STORM008	1925.	1/25/00	Standard Urban Storm Water Mitigation Plan Development Planning Change Sheet (Revised)

R0072358	STORM008	1926.	3/8/00	Los Angeles county Urban Runoff and Storm Water NPDES Permit Standard Urban Storm Water Mitigation Plan

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R0072392	STORM008	1928.	4/14/00	Letter Regarding Amendment of Parties to Petition from Elizabeth M. Jennings to Richard Montevideo and Lyman C. Welch.
R0072401	STORM008	1929.	4/18/00	Letter Requesting Extention of Time to Respond to Xavier Swamikannu and David Beckman from Elizabeth M. Jennings.
R0072404	STORM008	1930.	5/17/00	Dismissal of Stay Request from Edward C. Anton to Richard Montevideo. Lyman C. Welch and Stephen P. Deitsch.
R0072408	STORM008	1931.	5/12/00	SWRCB,Office of Chief Counsel-Notice of Public Hearing
R0072412	STORM008	1932.	5/25/00	Response to the letter dated 05/23/00 from Elizabeth M. Jennings to Richard Montevideo.
R0072414	STORM008	1933.	6/12/00	Fax to Dennis Dickerson from Jorge Leon regarding Post Hearing Briefs.
R0072416	STORM008	1934.	8/28/00	Board Meeting Notification from Craig L. Wilson to Richard Montevideo. Lyman C. Welch and Stephen P. Deitsch. Draft Order attached.
R0072456	STORM008	1935.	9/25/00	SWRCB Board Meeting,Office of Chief Counsel October 5, 2000-Item 16
R0072488	STORM008	1936.	10/4/00	SWRCB Workshop and Board Meeting Agenda, Wednesday, October 4, 2000.
R0072491	STORM008	1937.	10/5/00	SWRCB Board Meeting-Office of Chief Counsel, Oct. 5, 2000-Errata Sheet
R0072492	STORM008	1938.	3/8/00	SUSMP and Board Resolution Approving Post-Construction BMP Requirements for Development Planning and Construction from Dennis Dickerson to Harry Stone with a copy of the Resolution No R-00-02
R0072530	STORM008	1939.	5/4/00	Letter from Xavier Swamikannu to Elizabeth Jennings in regards to the Transmittal and Certification of the Administrative Record
R0072532	STORM008	1940.	5/5/00	Response to Petition from Dennis Dickerson to Elizabeth Jennings.
R0072574	STORM008	1941.	6/6/00	Presentation by Jorge Leon on Legal Issues.
R0072584	STORM008	1942.	6/6/00	Presentation by Dr. Xavier Swamikannu, including Script for Hearing.
R0072595	STORM008	1943.	7/7/00	Letter of Transmittal from Dennis Dickerson to Elizabeth M. Jennings including a copy of the Post-Hearing Brief
R0072608	STORM008	1944.	9/27/00	Letter of Transmittal from Dennis Dickerson to Craig Wilson. Including Regional Board Comment On Proposed Order.
R0072623	STORM008	1945.	10/2/00	California Coastal Commission-Letter from Jaime C. Kooser to Craig M. Wilson.

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R0072626	STORM008	1946.	4/11/00	Natural Resources Defense Council- Petitions of the Cities of Artesia from David S. Beckman to Elizabeth Jennings.
R0072628	STORM008	1947.	4/18/00	Natural Resources Defense Council-Petitions of the Cities of Bellflower from David Beckman to Richard Montevideo.
R0072630	STORM008	1948.	5/2/00	Natural Resources Defense Council- Fax from Alex N. Helperin of Memorandum of points & Authorities in response to petitions for Review.
R0072668	STORM008	1949.	5/24/00	Natural Resources Defense Council- Fax from Alex N. Helperin of Scheduling of Expert Testimony from David S. Beckman to Elizabeth Jennings.
R0072671	STORM008	1950.	6/7/00	NRDC Presentation
R0072690	STORM008	1951.	7/6/00	Post-Hearing Brief on Behalf of NRDC, The Santa Monica Baykeeper, and Heal the Bay.
R0072703	STORM008	1952.	7/25/00	Objections to Petitioners' Post-Hearing Brief.
R0072707	STORM008	1953.	10/3/00	Draft Order to Chairman Arthur G. Baggett Jr. and Members of the Board from David S. Beckman, Mark Gold and Steve Fleischli.
R0072714	STORM008	1954.	2/25/00	Best Best & Krieger LLP-Petition for Review of 01/26/00 Action of the RWQCBLA and Action and Failures to Act by it and Its Executive Officer from Stephen P. Deitsch to SWRCB Office of Chief Counsel.
R0072718	STORM008	1955.	7/10/00	Petitioner City of Arcadia's Post-Hearing Reply Brief to June 12, 2000 State Board Inquiry.
R0072722	STORM008	1956.	2/24/00	Petition for Review of the Regional Water Quality Control Board—Los Angeles Region's 01/26/00 Approval of The Standard Urban Storm Water Mitigation Plan Regulation.
R0072729	STORM008	1957.	2/28/00	Mayer, Brown & Platt- Request for Preparation of the Regional Board Record of the January 26, 2000 SUSMP Approval.
R0072730	STORM008	1958.	4/11/00	Amendment to Western States Petroleum Association's Petition for Review of the Regional Water Quality Control Board-Los Angeles Region's 01/26/00 Approval of The Standard Urban Stormwater Mitigation Plan Regulation.
R0072765	STORM008	1959.	6/2/00	Mayer, Brown & Platt-Fax of declaration to appear in court from Lyman C. Welch to Dennis Dickerson.

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R0072769	STORM008	1960.	2/25/00	Petitioner's Statement of Points and authorities in Support of Legal Issues in Petition of Actions and Inactions of the California Regional Water Quality Control Board, Los Angeles Region and its Executive Officer, Dennis Dickerson, Pursuant to Order NO. 96-054 (NPDES NO. CAS614001).

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R0072793	STORM008	1961.	2/25/00	Rutan & Tucker- Letter of transmittal of Petition for Review of Jan. 26. 2000 Action of the CRWQCBLA and Actions and Failurs to Act by its Executive Officer.
R0072935	STORM008	1962.	5/22/00	Rutan & Tucker-Letter from Terence J. Gallagher to Parvaneh Khayat regarding the Administrative Record for Standard Urban Storm Water Mitigation Plan.
R0072938	STORM008	1963.	6/1/00	Petitioner's Summary of Arguments and Reply to Oppositions Filed by Respondents and By NRDC, Santa Monica Bay Keeper and Heal the Bay.
R0072961	STORM008	1964.	7/10/00	Petitioner's Pos-Hearing Reply Brief to June 12, 2000 State Board Inquiry.
R0072989	STORM008	1965.	7/31/00	Petitioner's Response to NRDC's Objections to Petitioner's Post-Hearing Brief.
R0072997	STORM008	1966.	9/27/00	Western State Petroleum Association's Comments on the Board's Tentative Order.
R0073001	STORM008	1967.	9/27/00	Rutan & Tucker- Letter from Richard Montevideo to Craig M. Wilson. Including Petitioner's Written Comments to August 24, 2000 Draft Order of the State Water Resources Control Board.
R0073024	STORM008	1968.	10/4/00	Petitioner's Objections to Regional Board's Reference to Extra Record Evidence in Regional Board's September 27, 2000 Written Comments.
R0073031	STORM008	1969.	3/8/00	County of San Diego- Letter from Robert R. Cooper to John Robertus regarding Proposed Numeric Sizing Criteria for Post-Construction BMPs.

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R0073038	STORM008	1970.	6/7/00	Supplemental Evidence for the SUSMP State Board Meeting
R0073039	STORM008	1971.	5/31/00	Evidence and Exhibits Supplement to the Administrative Record sent to Elizabeth Jennings from Dennis Dickerson.
R0073041	STORM008	1972.	1/11/00	Center for Watershed Protection-Support for the ¾ Inch Standard to Reduce Runoff From New and Redevelopment from Thomas R. Schueler to Dennis Dickerson.
R0073053	STORM008	1973.	1/00	*Better Site Design*. Watershed Protection Techniques, Vol. 3, No. 2, January 2000.
R0073087	STORM008	1974.	9/14/98	Cost and Benefits of Storm Water BMPs for Parsons Engineering Schience. EPA Contract 68-C6-0001, WA 2-15, Task 6.
R0073146	STORM008	1975.	1/00	*Housing Density and Urban Land Use as Indicators of Stream Quality*. Watershed Protection Techniques, Vol. 3, No. 2, January 2000.
R0073151	STORM008	1976.	11/1/99	Study of the Impact of Stormwater Discharge on Santa Monica Bay. A Southern California Coastal Water Research Project for the Los Angeles County Dept of Public Works.
R0073171	STORM008	1977.		"Stormwater Management: Pointless Pollution" Techno 2100 TV Special to Air on February 26.
R0073172	STORM008	1978.	2/11/93	Definition of "Maximum Extent Practicable" from Elizabeth M. Jennings to Archie Matthews
R0073177	STORM008	1979.	5/23/00	Rutan & Tucker: Failure of Executive Officer to Respond to Notice of Intent to Implent Permittees'

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				August, 1999 SUSMP—Order No. 96-054, Part 2.I.G.1.A from Richard Montevideo to Dennis Dickerson.
R0073179	STORM008	1980.	5/31/00	Maryland Department of the Environment. Explanation of Maryland's Stormwater Management Program.
R0073187	STORM008	1981.	11/88	Maryland's Stormwater Management Program by Maryland Department of the Environment, Water Management Administration.
R0073193	STORM008	1982.	10/90	Controlling Stormwater: Some Lessons From The Maryland Experience, prepared by Greg Lindsey and Molly Cannon. Maryland Department of the Environment, Water Management Administration.
R0073206	STORM008	1983.	6/92	Stormwater Management in Maryland An Administrative Evaluation of Local Programs. Maryland Department of the Environment, Water Management Administration.
R0073234	STORM008	1984.	5/25/00	State of Washington, Department of Ecology, Response to Mr. Swamikannu's email of nine questions, dated 05/19/00
R0073249	STORM008	1985.	8/99	Public Review Draft: Stormwater Management in Washington State. Volume I, Minimum Technical Requirements. Washington State Department of Ecology.
R0073379	STORM008	1986.	5/31/00	Fax of Petition for Review Concerning the Los Angeles County SUSMP (SWRCB Files A-1280, A-1280(a), and A-1280(b))
R0073385	STORM008	1987.	5/31/00	State of Florida, Department of Environmental Protection. Resplies to Mr. Swamikannu's email Requesting Information About Stormwater Treatment Requirements Dated May 19, 2000.

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R0073435	STORM008	1988	6/30/99	Regional Board Meeting Transcripts of Proceedings
R0073624	STORM008	1989	6/7/00	State Board Meeting SUSMP's Transcripts.
R0073894	STORM008	1990	6/8/00	State Board Meeting SUSMP's Transcripts.
R0074054	STORM008	1991		EPA Industry Sector Notebooks - Profile of the Agricultural Chemical, Pesticide and Fertilizer Industry (2000)
R0074257	STORM008	1992		EPA Industry Sector Notebooks - Profile of the Agricultural Crop Production Industry (2000)
R0074442	STORM008	1993		EPA Industry Sector Notebooks - Profile of the Agricultural Livestock Production Industry (2000)
R0074609	STORM008	1994		EPA Industry Sector Notebooks - Profile of the Aerospace Industry (1998)
R0074743	STORM008	1995		EPA Industry Sector Notebooks - Profile of the Air Transportation Industry (1997)
R0074847	STORM008	1996		EPA Industry Sector Notebooks - Profile of the Dry Cleaning Industry (1995)
R0074938	STORM008	1997		EPA Industry Sector Notebooks - Profile of the Electronics and Computer Industry (1995)
R0075090	STORM008	1998		EPA Industry Sector Notebooks - Profile of the Fossil Fuel Electric Power Generation Industry (1997)
R0075259	STORM008	1999		EPA Industry Sector Notebooks - Profile of the Ground Transportation Industry (1997)
R0075397	STORM008	2000		EPA Industry Sector Notebooks - Profile of the Inorganic Chemical Industry (1995)
R0075526	STORM008	2001		EPA Industry Sector Notebooks - Profile of the Iron and Steel Industry (1995)
R0075641	STORM008	2002		EPA Industry Sector Notebooks - Profile of the Lumber and Wood Products Industry (1995)

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R0075769	STORM008	2003		EPA Industry Sector Notebooks - Profile of the Metal Casting Industry (1997)
R0075930	STORM008	2004		EPA Industry Sector Notebooks - Profile of the Metal Fabrication Industry (1995)
R0076085	STORM008	2005		EPA Industry Sector Notebooks - Profile of the Metal Mining Industry (1995)
R0076222	STORM008	2006		EPA Industry Sector Notebooks - Profile of the Motor Vehicle Assembly Industry (1995)
R0076369	STORM008	2007		EPA Industry Sector Notebooks - Profile of the Nonferrous Metals Industry (1995)
R0076508	STORM008	2008		EPA Industry Sector Notebooks - Profile of the Non-Fuel, Non-Metal Mining Industry (1995)
R0076608	STORM008	2009		EPA Industry Sector Notebooks - Profile of the Oil and Gas Extraction Industry (1999)
R0076775	STORM008	2010		EPA Industry Sector Notebooks - Profile of the Organic Chemical Industry (1995)
R0076909	STORM008	2011		EPA Industry Sector Notebooks - Profile of the Petroleum Refining Industry (1995)
R0077054	STORM008	2012		EPA Industry Sector Notebooks - Profile of the Pharmaceutical Industry (1997)
R0077213	STORM008	2013		EPA Industry Sector Notebooks - Profile of the Plastic Resins and Man-made Fibers Industry (1997)
R0077411	STORM008	2014		EPA Industry Sector Notebooks - Profile of the Printing Industry (1995)
R0077524	STORM008	2015		EPA Industry Sector Notebooks - Profile of the Pulp and Paper Industry (1995)
R0077661	STORM008	2016		EPA Industry Sector Notebooks - Profile of the Rubber and Plastic Industry (1995)
R0077805	STORM008	2017		EPA Industry Sector Notebooks - Profile of the Shipbuilding and Repair Industry (1997)
R0077944	STORM008	2018		EPA Industry Sector Notebooks - Profile of the Stone, Clay, Glass and Concrete Industry (1995)
R0078059	STORM008	2019		EPA Industry Sector Notebooks - Profile of the Textiles Industry (1997)
R0078209	STORM008	2020		EPA Industry Sector Notebooks - Profile of the Transportation Equipment Cleaning Industry (1995)
R0078280	STORM008	2021		EPA Industry Sector Notebooks - Profile of the Water Transportation Industry (1997)
R0078378	STORM008	2022		EPA Industry Sector Notebooks - Profile of the Wood Furniture and Fixtures Industry (1995)
R0078502	STORM008	2023		EPA Industry Sector Notebooks - Profile of Local Government Operations (1999)
R0078820	STORM008	2024		EPA Industry Sector Notebooks - The Sector Notebook Data Refresh (1997)
R0079032	STORM008	2025	6/00	National Pollutant Removal Performance Database for Stormwater Treatment Practices, 2nd Edition – Rebecca Winer Center for Watershed Protection.
R0079253	STORM008	2026	9/93	Handbook – Urban Runoff Pollution Prevention and Control Planning. USEPA Office of Research and Development. EPA/625/R-93/004.
R0079435	STORM008	2027		The Importance of Imperviousness article from Watershed Protection Techniques http://www.stormwatercenter.net/Practice/1-Importance%20of%20Imperviousness.pdf
R0079470	STORM008	2028		All Articles from The Practice of Watershed Protection - Stormwater Manager's Resource Center (SMRC) web site http://www.stormwatercenter.net/
R0080203	STORM008	2029	10/01	New York State Stormwater Management Design Manual


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SUSMP FORMS

Prior to being issued a grading permit, the following forms and checklist(s) must be completed and submitted by the project applicant, as part of the SUSMP package, to the Stormwater and Urban Runoff Program of the City of Culver City for review and approval. Mail completed forms, checklist, and attachments to: City of Culver City Engineering Division; Stormwater and Urban Runoff Program; 9770 CulverBlvd., Culver City, CA 90232.

<u>Blank Forms</u>

- SUSMP/SITE SPECIFIC PLAN CHECK LIST
- STORMWATER OBSERVATION REPORT
- COVENANT & AGREEMENT (C&A)
- TERMINATION OF C&A

<u>Sample Forms</u>

- C&A
- TERMINATION OF C&A
- OPERATIONS AND MAINTENANCE (O&M) PLAN

City of Culver City - Stormwater & Urban Runoff Program

SUSMP/SITE SPECIFIC PLAN CHECK LIST

On March 8, 2000, the final Standard Urban Storm Water Mitigation Plan for Los Angeles County and Cities in Los Angeles County (SUSMP) was approved by the Los Angeles Regional Water Quality Control Board. The SUSMP requirements focus on stormwater/urban runoff mitigation measures for specified categories of new development and redevelopment projects.

Date of Submittal: ____/____/ 200__
Project Title/Address: ______________________________
Building/Grading Permit No.: ________________
Contact Name (for SUSMP): ________________ Contact Phone: ____________
Owner Name: ________________ Owner Phone: ____________
Developer Name: ________________ Developer Phone: ____________
Culver City Project Planner: ________________ Phone No.: ____________
Culver City Project Engineer: ________________ Phone No.: ____________

The following is a list of outstanding items that are required for the SUSMP approval process. (Note to applicant: Place ax "X" next to the items included as part of your SUSMP package).

__ Form PC
__ Form P1
__ Completed SUSMP/Site Specific Plan checklist (this form)
__ A narrative SUSMP compliance report that contains:
  __ project title
  __ project address
  __ contact information of owner and developer, and
  __ detailed description of the type and the size of the development/redevelopment and how the project satisfies the SUSMP requirements.
  __ hydrology calculation.
  __ date, name, signature, and PE seal of the Engineer who prepared the SUSMP compliance report.
__ Completed Covenant & Agreement Form with Operation and Maintenance Plan (must indicate that a copy of the O&M plan will be mailed to the City Stormwater Program by May 30th of each year).
__ Four (4) sets of plans with Engineer's wet stamp and signature (SURP keeps one set) that includes:
  __ Roof drains layout and connection to treatment system(s).
  __ Stencil at all drainage inlets (i.e. catch basins, trench drains) and a sample stencil design.
  __ Labeled Trash Enclosures (required to be covered and walled) on plans.
  __ Identify Vegetated areas on plans
  __ Detailed drawings (specifying size & model number) of the structural BMP device including inlet and outlet elevations shown on plans.
  __ Others: ______________________________
__ SUSMP review fee

The following outstanding item is required to complete the SUSMP process and to receive the final occupancy certificate or other building permits. This form must be submitted after the SUSMP BMP(s) has been constructed and inspected by the developer's engineer for proper installation.

__ Completed (must contain P.E. seal and signature) stormwater SUSMP observation report

CITY USE ONLY
Date of SUSMP Approval: ____/____/ 200__
Name and Signature of Stormwater Program Manager: ________________________
Date of SUSMP Stormwater BMP Observation Report Receipt: ____/____/ 200__
Date completed & notorized Covenant & Agreement Form with Operation and Maintenance Plan mailed to the Los Angeles County Recorder's Office: ____/____/ 200__

City of Culver City

STORMWATER OBSERVATION REPORT FORM

STANDARD URBAN STORMWATER MITIGATION PLAN (SUSMP) - SITE SPECIFIC MITIGATION PLAN -

STORMWATER OBSERVATION means the visual observation of the stormwater related Best Management Practices (BMPs) for conformance with the approved SUSMP/Site Specific Mitigation Plan at significant construction stages and at completion of the project. Stormwater observation does not include or waive the responsibility for the inspections required by other sections of the City of Culver City Code.

STORMWATER OBSERVATION must be performed by the engineer or architect responsible for the approved SUSMP/Site Specific Mitigation Plan or designated staff in their employment.

STORMWATER OBSERVATION REPORT must be signed and stamped (see below) by the engineer or architect responsible for the approved SUSMP and submitted to the city prior to the issuance to the certificate of occupancy.

Project Address:	Building Permit No.:
Name of Engineer or Architect responsible for the approved SUSMP/Site Specific Mitigation Plan:	Phone Number:
Name of SUSMP/Site Specific Mitigation Plan Observer:	Phone Number:

I DECLARE THAT THE FOLLOWING STATEMENTS ARE TRUE TO THE BEST OF MY KNOWLEDGE:

1. I AM THE ENGINEER OR ARCHITECT RESPONSIBLE FOR THE APROVED SUSMP/SITE SPECIFIC MITIGATIONPLAN, AND

2. I, OR DESIGNATED STAFF UNDER MY RESPONSIBLE CHARGE, HAS PERFORMED THE REQUIRED SITE VISITS AT EACH SIGNIFICANT CONSTRUCTION STAGE AND AT COMPLETION TO VERIFY THAT THE BEST MANAGEMENT PRACTICES AS SHOWN ON THE APPROVED PLAN HAVE BEEN CONSTRUCTED AND INSTALLED IN ACCORDANCE WITH THE APPROVED SUSMP/SITE SPECIFIC MITIGATION PLAN.

Signature Date

Stamp of Engineer or Architect responsible for the approved SUSMP

Recording requested by and mail to:

Name: ______________________

Address: ______________________

____

____

** Space Above This Line For Recorder's Use **

MASTER COVENANT AND AGREEMENT
REGARDING ON-SITE BMP MAINTENANCE

The undersigned hereby certifies I am (we are) the owner(s) of the hereinafter legally described real property located in the City of Culver City, County of Los Angeles, State of California (please give the legal description):

____

Site Address ____

And in consideration of the City of Culver City allowing ______________________________ on said property, we do hereby covenant and agree to and with said City to maintain according to the O&M Plan (Attachment 1), all on-site structural stormwater pollution removal devices including but not limited to: Detention/Sedimentation System, Filtration Systems, Infiltration Systems, Oil and Water Separators, Water Quality Inlets and Dry Wells. The specific structural BMPs are listed as follows:

____

____

This covenant and agreement shall run with the land and shall be binding upon any future owners, encumbrancers, their successors, heirs or assigns and shall continue in effect until the Engineering Division of the City of Culver City approves its termination.

______________________ (Print Name of Property Owner)	______________________ (Print Name of Property Owner)
______________________ (Signature of Property Owner)	______________________ (Signature of Property Owner)

Dated this _________ day of ____________ 20____.

** Space Below This Line For Notary's Use **

ALL-PURPOSE ACKNOWLEDGMENT

STATE OF CALIFORNIA, COUNTY OF LOS ANGELES

On ______________________ before me, ______________________ (name and title of officer), personally appeared ______________________, personally known to me (or proved to me on the basis of satisfactory evidence) to be the person(s) whose name(s) is/are subscribed to the within instrument and acknowledged to me that he/she/they executed the same in his/her/their authorized capacity (ies), and that by his/her/their signature(s) on the instrument the person(s), or the entity upon behalf of which the person(s) acted, executed the instrument.

WITNESS my hand and official seal.

______________________ (SEAL)
Notary Public Signature

*** Space Below This Line For City Use **

Permit No. ______________________
Attachment 1 – O&M Plan included? Y____ N____

Approved for recording by ______________________ Date: ______________
(Stormwater & Urban Runoff Program)

INSTRUCTIONS FOR FILING COVENANT AND AGREEMENT FORMS

Note: *This Covenant & Agreement Form is for* Ministerial and Discretionary Projects.

1. Fill out, in BLACK INK ONLY, one copy of the Covenant and Agreement Form.

2. Property owner(s) must print and sign their name(s) – signature(s) must be notarized.

3. Submit the completed Covenant & Agreement (C&A) Form with the Operation and Maintenance (O&M) Plan to the Stormwater & Urban Runoff Program, Engineering Division for approval and signature.

4. Record the C&A Form and the O&M Plan with the Los Angeles County Registrar-Recorder and obtain a certified copy. Nearest County Recorder branch offices are located at:

   1) LAX Courthouse
      11701 S. La Cienega Blvd, 6th floor
      Los Angeles, CA 90045

   2) 14340 Sylvan Street
      Van Nuys, CA 91401
      (Near Van Nuys City Hall)

5. Return the certified copy of the recorded form to the Stormwater & Urban Runoff Program requiring the covenant (should be a purple stamp on the back of the last document recorded).

FINAL SUSMP APPROVAL/CLEARANCE WILL ONLY BE GRANTED UPON RECEIPT OF THE CERTIFIED COPY OF THE C&A WITH THE O&M.

Recording requested by and mail to:

Name: ______________________

Address: ______________________

____

____

** Space Above This Line For Recorder's Use **

MASTER TERMINATION OF COVENANT AND AGREEMENT
REGARDING ON-SITE BMP MAINTENANCE

The undersigned hereby certifies I am (we are) the owners of the hereinafter legally described real property located in the City of Culver City, County of Los Angeles, State of California (please give the legal description):

____

Site Address ____

We do hereby, with approval of the City of Culver City, Engineering Division, terminate the covenant and agreement entered into with the City of Culver City as recorded on the ________ day of ______________________ 20 _____, as Document No. ______________________.

This covenant and agreement is terminated for the reason that:

____

____

______________________ (Print Name of Property Owner)

______________________ (Print Name of Property Owner)

______________________ (Signature of Property Owner)

______________________ (Signature of Property Owner)

Dated this _________ day of ____________ 20____.

Termination approved by: ______________________ (Stormwater & Urban Runoff Program)

Date: ______________________

** Space Below This Line For Notary's Use **

ALL-PURPOSE ACKNOWLEDGMENT

STATE OF CALIFORNIA, COUNTY OF LOS ANGELES

On ______________________ before me, ______________________ (name and title of officer), personally appeared ______________________, personally known to me (or proved to me on the basis of satisfactory evidence) to be the person(s) whose name(s) is/are subscribed to the within instrument and acknowledged to me that he/she/they executed the same in his/her/their authorized capacity (ies), and that by his/her/their signature(s) on the instrument the person(s), or the entity upon behalf of which the person(s) acted, executed the instrument.

WITNESS my hand and official seal.

______________________ (SEAL)

Notary Public Signature

INSTRUCTIONS FOR FILING TERMINATION OF COVENANT AND AGREEMENT FORMS

Note: This Termination of Covenant & Agreement Form is to be used to terminate existing Covenant & Agreement Forms for *Ministerial and Discretionary Projects.*

1. Fill out, in BLACK INK ONLY, one copy of the Termination of Covenant and Agreement Form.

2. Property owner(s) must print and sign their name(s).

3. Submit the completed Termination of Covenant & Agreement (C&A) Form to the Stormwater & Urban runoff Program Engineering Division for termination approval and signature – **City staff signature must be notarized.**

4. Record the C&A Form with the Los Angeles County Registrar-Recorder and obtain a certified copy. Nearest County Recorder branch offices are located at:

   1) LAX Courthouse
      11701 S. La Cienega Blvd, 6th floor
      Los Angeles, CA 90045

   2) 14340 Sylvan Street
      Van Nuys, CA 91401
      (Near Van Nuys City Hall)

5. Return the certified copy of the recorded form to the Stormwater & Urban Runoff Program requiring the covenant (should be a purple stamp on the back of the last document recorded).

Recording requested by and mail to:

Name: John Doe

Address: 123 ABC St.

Culver City, CA

90232

SAMPLE

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MASTER COVENANT AND AGREEMENT
REGARDING ON-SITE BMP MAINTENANCE

The undersigned hereby certifies I am (we are) the owner(s) of the hereinafter legally described real property located in the City of Culver City, County of Los Angeles, State of California (please give the legal description):

Tract No 355 Lot 2

Site Address 244 South Rd, Culver City, CA 90232

And in consideration of the City of Culver City allowing Apartment Building on said property, we do hereby covenant and agree to and with said City to maintain according to the O&M Plan (Attachment 1), all on-site structural stormwater pollution removal devices including but not limited to: Detention/Sedimentation System, Filtration Systems, Infiltration Systems, Oil and Water Separators, Water Quality Inlets and Dry Wells. The specific structural BMPs are listed as follows:

- 2 Catch basins with filter inserts
- 1 CDS unit

This covenant and agreement shall run with the land and shall be binding upon any future owners, encumbrancers, their successors, heirs or assigns and shall continue in effect until the Engineering Division of the City of Culver City approves its termination.

JOHN DOE
(Print Name of Property Owner)

(Print Name of Property Owner)

(Signature of Property Owner)

(Signature of Property Owner)

Dated this 5 day of Nov 2004.

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ALL-PURPOSE ACKNOWLEDGMENT

STATE OF CALIFORNIA, COUNTY OF LOS ANGELES

On November 5 2004 before me, ______________ (name and title of officer), personally appeared ______________, personally known to me (or proved to me on the basis of satisfactory evidence) to be the person(s) whose name(s) is/are subscribed to the within instrument and acknowledged to me that he/she/they executed the same in his/her/their authorized capacity (ies), and that by his/her/their signature(s) on the instrument the person(s), or the entity upon behalf of which the person(s) acted, executed the instrument.

WITNESS my hand and official seal.

Commission # 1333260
Notary Public - California
Los Angeles County
My Comm. Expires Jun 1, 2006

(SEAL)

Notary Public Signature

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Permit No. G4000-2000-C1000

Attachment 1 – O&M Plan included? Y ✓ N ___

Approved for recording by ______________ Date: 11-5-04

(Stormwater & Urban Runoff Program)

4896133

Recording requested by and mail to:

Name: John Doe

Address: 123 ABC St

Culver City, CA

90232

SAMPLE

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MASTER TERMINATION OF COVENANT AND AGREEMENT

REGARDING ON-SITE BMP MAINTENANCE

The undersigned hereby certifies I am (we are) the owners of the hereinafter legally described real property located in the City of Culver City, County of Los Angeles, State of California (please give the legal description):

Tract No. 355 Lot 2

Site Address 244 South Rd, Culver City, CA 90232

We do hereby, with approval of the City of Culver City, Engineering Division, terminate the covenant and agreement entered into with the City of Culver City as recorded on the 20 day of April 20 05, as Document No. 05-2760400.

This covenant and agreement is terminated for the reason that:

< Explain change or reason for termination >

John Doe

(Print Name of Property Owner)

(Signature of Property Owner)

(Print Name of Property Owner)

(Signature of Property Owner)

Dated this Aug day of 20 20 05.

Termination approved by: Stormwater program manager (Stormwater & Urban Runoff Program)

Date: August 26, 2005

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ALL-PURPOSE ACKNOWLEDGMENT

STATE OF CALIFORNIA, COUNTY OF LOS ANGELES

On August 26, 2005 before me, X (name and title of officer), personally appeared Stormwater prog mgr, personally known to me (or proved to me on the basis of satisfactory evidence) to be the person(s) whose name(s) is/are subscribed to the within instrument and acknowledged to me that he/she/they executed the same in his/her/their authorized capacity (ies), and that by his/her/their signature(s) on the instrument the person(s), or the entity upon behalf of which the person(s) acted, executed the instrument.

WITNESS my hand and official seal.

NOTARY PUBLIC-CALIFORNIA
LOS ANGELES COUNTY
COMM. EXP. DEC. 20, 2007

X

Notary Public Signature (SEAL)

OPERATION & MAINTENANCE PLAN FOR FILTER INSERT (SAMPLE)

The maintenance program will include the following key components:

1. **REGULAR SWEEPING AND REMOVAL OF DEBRIS:**
   Vehicle parking lot will be swept on a regular basis. Sediment and debris (litter, leaves, papers and cans, etc.) within the area, especially around the drainage inlet, will be collected and removed. The frequency of sweeping will be based on the amount of sediment and debris generated.

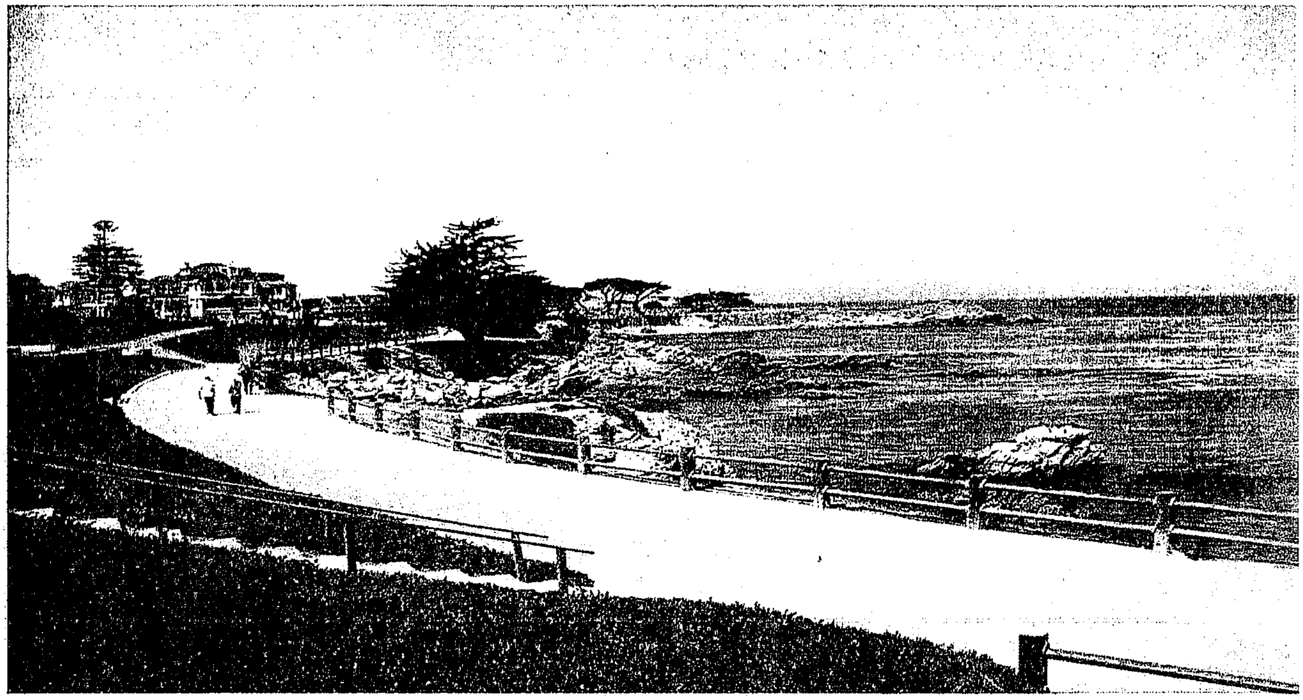
2. **REGULAR INSPECTIONS:**
   The catch basin, downspout, or trench drain filter insert will be inspected on a regular basis. The frequency of inspection will be based on pollutant loading, amount of debris, leaves, etc., and amount of runoff. At a minimum, there will be three inspections per year.

3. **CONDUCT OF THE VISUAL INSPECTION:**
   a. Broom sweep around the inlet and remove the inlet grate.
   b. Inspect the filter liner for serviceability. If called for, the filter body will be replaced.
   c. Check the condition of the adsorbent pouches and visually check the condition of the enclosed adsorbent. If the surface of the granules is more than 50% coated with a dark gray or black substance, the pouches will be replaced with new ones.
   d. Check for loose or missing nuts (on some models) and gaps between the filter and the inlet wall, which would allow bypass of the filter during low flows.
   e. The filter components will be replaced in the inlet and the grate replaced.

4. **CLEANING OUT THE FILTER INSERT:**
   Regardless of the model of filter insert, the devices must be cleaned out on a recurring basis. The manufacturer recommends at least three cleanings per year – more in high exposure areas. For the Hydro-Cartridge filters, the filter must be cleaned when the solids level reaches close to the fullel tip.
   a. The Standard Filter, in most cases, can be cleaned out by removing the device from the inlet and dumping the contents into a DOT approved drum for later disposal. If the oil-absorbant pouches need to be changed, the time to change them is immediately after dumping and before the filter is replaced in the inlet.
   b. Because of weight, method of installation and so forth, some filter inserts will be cleaned with the aid of a vactor truck. If necessary, the oil-absorbant pouches will be changed after the pollutants have been removed and as the filter is being returned to service.

5. MAINTENANCE LOG:
   a. Keep a log of all inspections and maintenance performed on the catch basins, trench drains, and filter inserts. Keep this log on-site.
   b. Mail a copy of the yearly maintenance log to City of Culver City Stormwater Program (9770 Culver Blvd, Culver City, CA 90232) by May 30th of each year.

California's AquaGems: Areas of Special Biological Significance



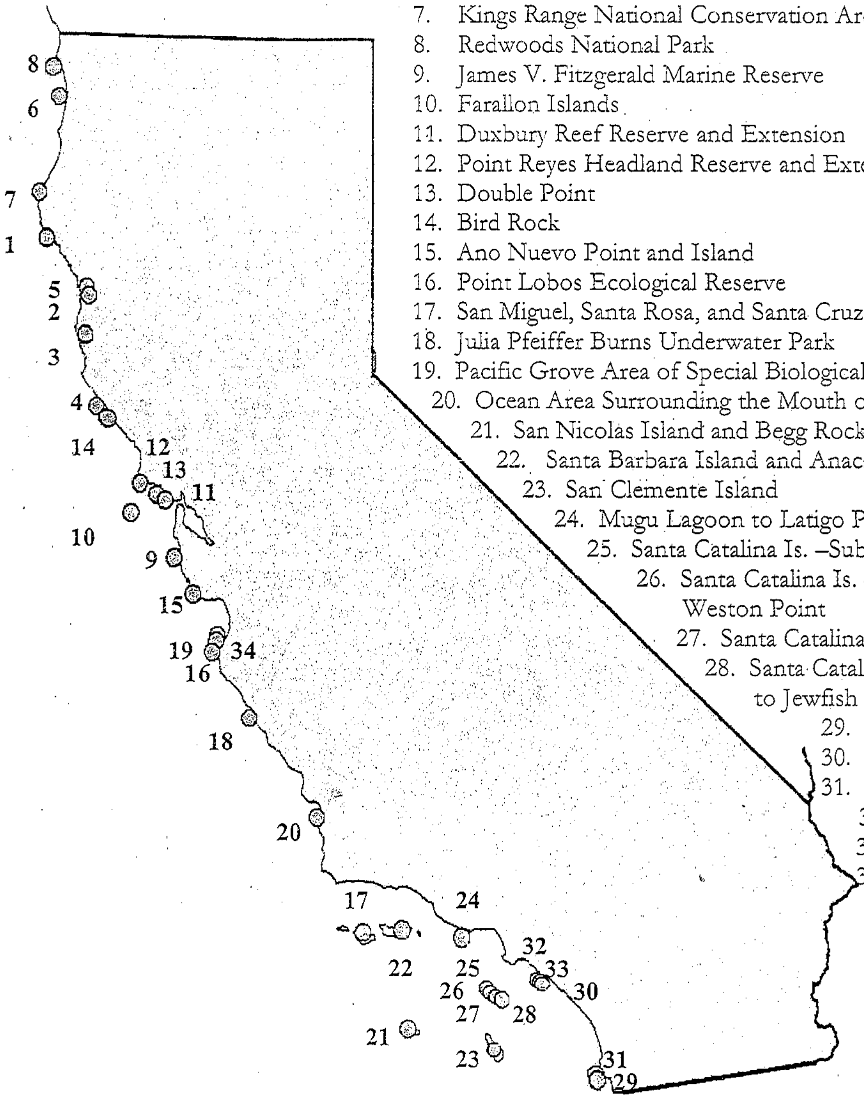
The Ocean Conservancy

NRDC

THE EARTH'S BEST DEFENSE

California's AquaGems:
Areas of Special Biological Significance

1. Pygmy Forest Ecological Staircase
2. Del Mar Landing Ecological Reserve
3. Gerstle Cove
4. Bodega Marine Life Refuge
5. Kelp Beds at Saunders Reef
6. Kelp Beds at Trinidad Head
7. Kings Range National Conservation Area
8. Redwoods National Park
9. James V. Fitzgerald Marine Reserve
10. Farallon Islands
11. Duxbury Reef Reserve and Extension
12. Point Reyes Headland Reserve and Extension
13. Double Point
14. Bird Rock
15. Ano Nuevo Point and Island
16. Point Lobos Ecological Reserve
17. San Miguel, Santa Rosa, and Santa Cruz Islands
18. Julia Pfeiffer Burns Underwater Park
19. Pacific Grove Area of Special Biological Significance
20. Ocean Area Surrounding the Mouth of Salmon Creek
21. San Nicolas Island and Begg Rock
22. Santa Barbara Island and Anacapa Island
23. San Clemente Island
24. Mugu Lagoon to Latigo Point
25. Santa Catalina Is. –Subarea 1, Isthmus Cove to Catalina Head
26. Santa Catalina Is. –Subarea 2, North End of Little Harbor to Ben Weston Point
27. Santa Catalina Is. –Subarea 3, Farnsworth Bank Ecological Reserve
28. Santa Catalina Is. –Subarea 4, Binnacle Rock to Jewfish Point
29. San Diego-La Jolla Ecological Reserve
30. Heisler Park Ecological Reserve
31. San Diego Marine Life Refuge
32. Newport Beach Marine Life Refuge
33. Irvine Coast Marine Life Refuge
34. Carmel Bay



California's AquaGems:
Areas of Special Biological Significance

California has 34 **"Areas of Special Biological Significance"** (ASBSs) along its world-renowned coastline. Under the California Ocean Plan, these "AquaGems" were given special status over 30 years ago to protect the unique and sensitive biological species and communities they harbor.

These sensitive marine ecosystems strung along California's coast are home to rich kelp forests and ocean canyons filled with corals, sea otters, seals, dolphins, yellowfin tuna, rockfish, and numerous species of whales and sharks.

Trinidad Head, SWRCB.

Each AquaGem possesses unique biological characteristics, which support complex yet fragile ecosystems. Some areas are rocky reef habitats while others are nutrient-rich deep waters containing rare marine life.

Californians and tourists alike are drawn to these 34 magnificent AquaGems. They comprise some of the most beautiful tourist destinations in the State. The areas are used for scenic viewing, swimming, scuba diving, photography, and scientific research. In addition to their resource value, the AquaGems are vital to California's economy.

California has the largest ocean economy in the United States. Coastal tourism and recreation far outperform all other ocean-related activities, such as oil and gas production, shipping, and fishing. Total travel spending in California coastal counties was $82.5 billion and supported 892,600 jobs in 2004. Protecting our AquaGems is an investment in our ocean economy.

The State banned pollution into the AquaGems more than 30 years ago. Unfortunately, the clear prohibition on pollution into these biologically important areas has been largely ignored over the years. In fact, these precious and unique coastal resources are threatened by the largest source of coastal pollution—urban stormwater runoff. As a result, some of the AquaGems have become so polluted that they cannot even be safely used for wading, let alone as habitats for sensitive species. Three national reports, including one conducted by the United States Commission on Ocean Policy, have concluded that our coastal waters and oceans are in crisis and in critical need of more protection.

The State Water Board is at a crossroads in its approach to protecting these AquaGems. In 2003, the State Water Board discovered more than 1,600 illegal discharges into these areas. Some of those who are illegally discharging pollution are unwilling to commit the resources to cleanup. Instead, they are hiring lobbyists to weaken the law protecting these valuable marine resources.

Fitzgerald Marine Reserve and Tidepool, Linda Sheehan.

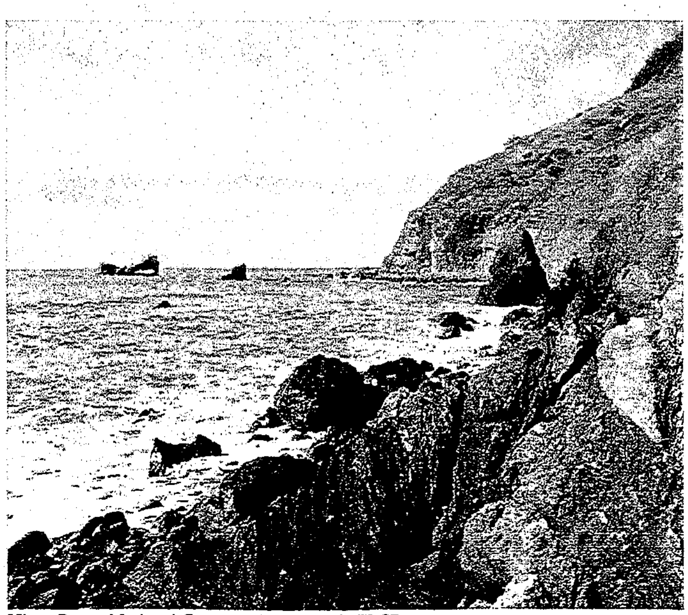
Conservation, community, and recreational groups favor preserving the waste discharge prohibition instead of weakening the law. What's needed is a practical framework that enforces the law and allows, where appropriate, cities and other polluters a reasonable timeframe to design and implement cleanup plans to protect our AquaGems. Under this practical framework, water pollution dischargers would use off-the-shelf technologies and cost-effective options tailored to their circumstances to come into compliance on a time schedule set by the State Water Board based on the circumstances applicable to the situation. The State Water Board must show strong leadership to implement this framework and ensure protection of our most valuable coastal resources.

North Coast AquaGems

Marked by lush Redwood Forests along its coastal mountains, the magnificent North Coast has 14 Areas of Special Biological Significance:

- Redwoods National Park
- Kelp Beds at Trinidad Head
- Kings Range National Conservation Area
- Pygmy Forest Ecological Staircase
- Kelp Beds at Saunders Reef
- Del Mar Landing Ecological Reserve
- Gerstle Cove
- Bodega Marine Life Refuge
- Bird Rock
- Point Reyes Headland Reserve and Extension
- Double Point
- Duxbury Reef Reserve and Extension
- Farallon Islands
- James V. Fitzgerald Marine Reserve

The North Coast region extends from Del Norte County to San Mateo County. The coastal areas support a wide variety of species from arrowgrass to humpback whales. The ocean economy represents nearly 10 percent of the jobs in the northern rural regions of Humboldt, Del Norte, Mendocino, and San Francisco counties, and about 7 percent of total employment in the entire North Coast region. The Northern California ocean economy is worth nearly $13 billion annually and employs more than 194,000 people.



Kings Range National Conservation Area, SWRCB.

<u>Most Threatened AquaGems</u>

The AquaGems with the greatest number of pollutant discharges along the North Coast are:

- Redwoods National Park (41 discharges)
- James V. Fitzgerald Marine Reserve (28 discharges)
- Kelp Beds at Trinidad Head (17 discharges)
- Kings Range National Conservation Area (17 discharges)

Del Mar Landing Ecological Reserve, SWRCB.

According to the State Water Board's 2003 report, there are 159 illegal discharges of pollutants into 12 of the 14 North Coast AquaGems. The only AquaGems with no pollution discharges were Bird Rock and Double Point. Much of the waste discharge contains harmful pollutants such has heavy metals and petroleum products from Highway 1, where the road parallels the cliffs along the coastline.

Featured AquaGem: Fitzgerald Marine Reserve

Location

James V. Fitzgerald Marine Reserve in San Mateo County has 5.5 miles of coastline and occupies 518 acres of marine habitat. San Mateo County manages the Marine Reserve, which lies entirely within the boundaries of the Monterey Bay National Marine Sanctuary.

Outstanding tide pools are one of the reasons the Fitzgerald Marine Reserve receives more than 135,000 visitors annually, SWRCB.

Resources

The Fitzgerald Marine Reserve is one of the richest intertidal areas on the California coast. Extensive shale reefs are home to a wide variety of marine life, such as giant green anemones, limpets, purple sea urchins, crabs, and snails. In fact, over 25 new species have been discovered at the Reserve. It's best to see the tide pools during low tides, which expose the rocky shoreline to view. The intertidal zone, which contains rocky reefs at sea level and pocket beaches, is renowned for its richness and diversity of species. Accessible at low tide, the reefs receive high levels of use because of their proximity to the San Francisco Bay Area.

Stormwater Runoff

There are 28 direct discharges of polluted urban runoff into the Reserve. San Vicente Creek, which drains an urban watershed and is chronically contaminated with coliform bacteria, also flows directly into the Reserve.

The Fitzgerald Marine Reserve is home to extensive shale reefs, teeming with life, which become exposed at low tide, SWRCB.

Impacts

The discharges flowing into the Fitzgerald Marine Reserve are causing significant contamination, threatening both aquatic life and human health. After heavy rains, the plume of contamination from San Vicente Creek may flow into the intertidal area of the Reserve, extending several meters north and south of the creek mouth. The beach at Fitzgerald Marine Reserve is regularly closed or posted with contamination warnings, and has received an "F" grade in Heal the Bay's Beach Report in 27 percent of the dry weather samples taken in 2004. Despite this contamination, the Reserve receives more than 135,000 visitors annually.

The Fitzgerald Marine Reserve is regularly closed or posted with warnings of bacterial contamination, Linda Sheehan.

Central Coast AquaGems

From the unparalleled beauty of Big Sur to the picturesque beaches of Santa Barbara, the Central Coast is home to eight Areas of Special Biological Significance:

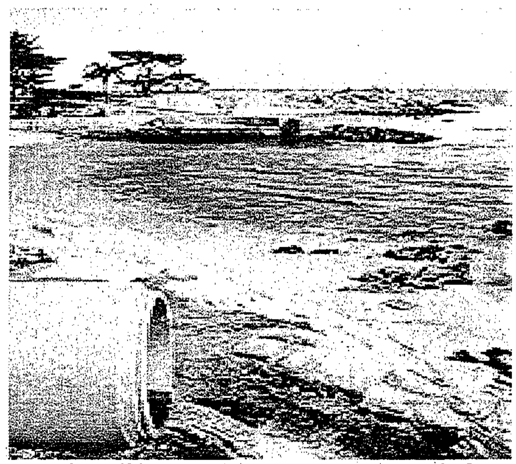
- Ano Nuevo Point and Island
- Pacific Grove Area of Special Biological Significance
- Carmel Bay
- Point Lobos Ecological Reserve
- Julia Pfeiffer Burns Underwater Park
- Ocean Area Surrounding the Mouth of Salmon Creek
- San Miguel, Santa Rosa & Santa Cruz Islands
- Santa Barbara Island and Anacapa Island

The natural splendor of the Central Coast supports a wide variety of migratory birds, plants, and marine mammals. Chief among the marine mammals is the California sea otter, a threatened species. In fact, the region from Monterey to Santa Barbara is home to a well-documented subpopulation of sea otters, which lives within the local waters year round.

Sea otter naps off Monterey, Marc Shargel. Reprinted with Permission.

Sea otters play an important role in maintaining healthy kelp beds by controlling the population of herbivores, such as sea urchins. However, the sea otter remains a threatened species, with an estimated population of only 2,700. A major threat to sea otters is diseases caused by land-based pollution from human activity.

Visitors from around the state and the world visit the Central Coast to admire its stunning marine ecosystems. In fact, the ocean economy in Central California (Santa Cruz, Monterey, San Luis Obispo, Santa Barbara, Ventura) is worth nearly $6 billion. Central California has the fastest growing ocean economy of any region in the state. It grew by more than $1 billion between 1990 and 2000.



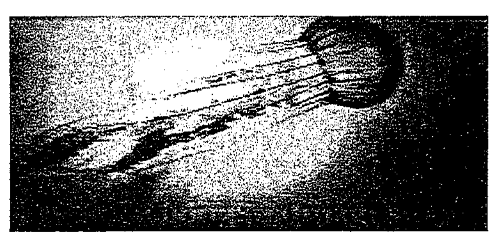
Polluted runoff flows into Bay at Lover's Point in Pacific Grove, Monterey Bay National Marine Sanctuary.

Most Threatened AquaGems

The AquaGems with the greatest number of pollutant discharges along the Central Coast are:

- Carmel Bay (348 discharges)
- Pacific Grove (246 discharges)
- Mouth of Salmon Creek (35 discharges)
- Julia Pfeiffer Burns Underwater Park (25 discharges)

According to the State Water Board's 2003 report, the Central Coast has 687 illegal discharges of pollutants into its AquaGems. Many of the discharges are from pipes that dump contaminated urban runoff directly into ocean waters. These discharges include city drains, road runoff, golf courses, and seawalls with drainage pipes from private homes.



Brown Sea Nettle floats off Pacific Grove, Marc Shargel. Reprinted with Permission.

Featured AquaGem: Carmel Bay

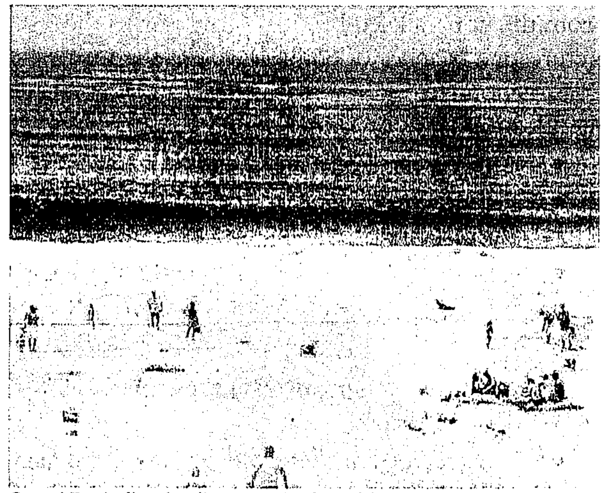
<u>Location</u>

Carmel Bay is located in Monterey County, immediately adjacent to the town of Carmel, and includes 6.2 miles of coastline, extending from Pescadero Point to Granite Point. Carmel Bay lies entirely within the Monterey Bay National Marine Sanctuary, and contains the Carmel Bay State Marine Conservation Area. The Point Lobos Ecological Reserve is adjacent to the mouth of Carmel Bay.

<u>Resources</u>

Investigations to support designating Carmel Bay as an Area of Special Biological Significance highlighted the significance for scientific study of the Bay's resources. These resources include various species of special interest such as the rare purple hydrocoral (Allopora californi); several deep-water marine invertebrates; previously unstudied sponges; and the California (southern) sea otter (Enhydra lutris). According to the State Parks Department: "The presence of the Carmel Submarine Canyon causes seasonal upwellings of nutrient-rich deep seawater. This phenomenon makes Carmel Bay an extremely rich, diversified, and highly productive marine ecosystem of statewide, if not national, significance."

Carmel Bay is home to extensive kelp forests and a diverse community of unusual invertebrates, Marc Shargel. Reprinted with Permission.



Carmel Bay is directly adjacent to the City of Carmel, and receives many visitors to its beaches, SWRCB.

<u>Stormwater Runoff</u>

Carmel Bay has the second largest number of pollutant discharges of any Area of Special Biological Significance in the State – a total of 348 direct discharges including polluted runoff from streets, highways, golf courses, and private homes. Approximately 60 percent of the runoff from the City of Carmel flows through storm drains directly into Carmel Bay, and 40 percent drains directly into the Carmel River, which also flows into Carmel Bay.

<u>Impacts</u>

The Central Coast Ambient Monitoring Program has observed high levels of coliform at the coastal confluence of the Carmel River, as well as chloride, dissolved solids, and sodium and sulfate levels that exceed water quality standards. High levels of silt, together with nutrient pollution, increase turbidity and threaten the corals that reside in Carmel Bay. Bacterial contamination may contribute to recent high levels of sea otter mortality. Scientists found that 34 percent of sea otters tested in the region were infected with a parasite associated with cat feces. Stillwater Cove Beach in Carmel Bay received Heal the Bay's "Beach Bummer" award for 2003-2004, indicating that it was one of the ten most polluted beaches in California.

Southern California AquaGems

Renowned for its world-famous sandy beaches, Southern California is home to 12 Areas of Special Biological Significance:

- Mugu Lagoon to Latigo Point
- San Nicolas Island and Begg Rock
- Santa Catalina Island, Subarea One, Isthmus Cove to Catalina Head
- Santa Catalina Island, Subarea Two, North End of Little Harbor to Ben Weston Point
- Santa Catalina Island, Subarea Three, Farnsworth Bank Ecological Reserve
- Santa Catalina Island, Subarea Four, Binnacle Rock to Jewfish Point
- Newport Beach Marine Life Refuge
- Irvine Coast Marine Life Refuge
- Heisler Park Ecological Reserve
- San Clemente Island
- San Diego Marine Life Refuge
- San Diego-La Jolla Ecological Reserve

Irvine Coast Marine Life Refuge, SWRCB.

Stretching from Ventura County to San Diego County, Californians and tourists use these waters for swimming, fishing, and snorkeling. The waters also are habitat for seals, leopard sharks, birds, gray whales, and a diverse population of fish and plant life. The ocean economy employs nearly 375,000 people in this region, and is worth more than $24 billion in the Southern California counties of Los Angeles, Orange and San Diego alone. Tourism is the Los Angeles region's second largest industry, with nearly four million tourists annually, and over 45 million beach visits per year.

The greatest threat to these waters is polluted stormwater runoff. Increasing urban development and paved sprawl result in increased pollutant load, volume and velocity into these waters, harming public health, marine life, and local economies.

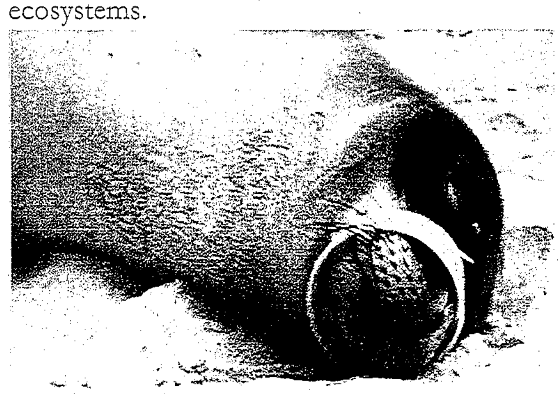
Mugu Lagoon to Latigo Point, SWRCB.

Most Threatened AquaGems

The AquaGems with the greatest number of pollutant discharges in Southern California are:

- Mugu Lagoon to Latigo Point (410 discharges)
- San Diego-La Jolla Ecological Reserve (184 discharges)
- San Diego Marine Life Refuge (92 discharges)
- Santa Catalina Island, Subarea One, Isthmus Cove to Catalina Head (38 discharges)

According to the State Water Board's 2003 report, Southern California's AquaGems have 812 illegal discharges. The majority of discharges are pipes and holes through seawalls, bluffs, and landscape areas. These pipes carry bacteria and pollutants from urban streets and surfaces directly into these sensitive ecosystems.



Pollution harms marine life. NRDC/Heal the Bay.

Featured AquaGems: San Diego Marine Life Refuge & San Diego-La Jolla Ecological Reserve

Location

The San Diego Marine Life Refuge and the San Diego-La Jolla Ecological Reserve are contiguous ocean areas adjoining the La Jolla district of the City of San Diego. These areas have other state-protected area designations – Marine Life Refuge and Ecological Reserve – that recognize their value as outstanding marine wildlife habitat areas.

The San Diego-La Jolla Ecological Reserve is adjacent to the City of San Diego, and receives runoff from holes in seawalls, SWRCB.

Resources

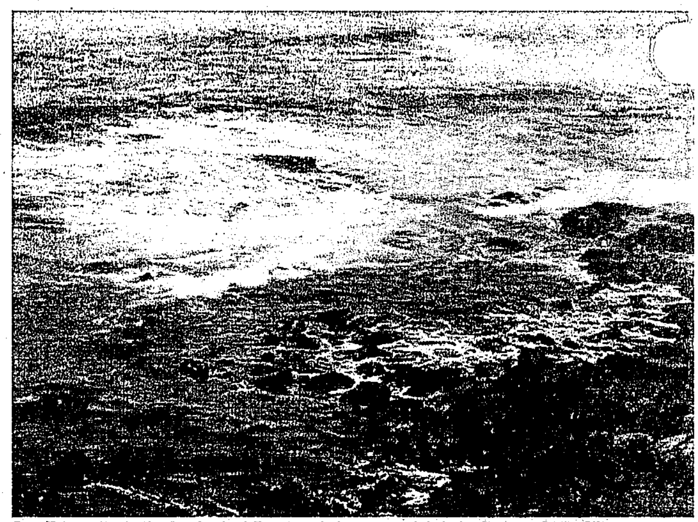
Both AquaGems are characterized by rocky intertidal reef habitats, and the San Diego-La Jolla Ecological Reserve also features extensive kelp forests. Both areas are habitat for spiny lobsters and squid, as well as multitudes of fish species. Endangered brown pelicans are known to roost in the cliffs near La Jolla Caves at the southern end of the San Diego-La Jolla Ecological Reserve, and gray whales are known to pass through the vicinity of both areas on their annual migration.

Stormwater

A recent report documented 92 pollutant discharges into the San Diego Marine Life Refuge, and 184 pollutant discharges entering the neighboring San Diego-La Jolla Ecological Reserve. Many of these pollutant discharges are from pipes and/or holes coming through seawalls, draining storm runoff from the University of California at San Diego campus, private residences, bluffs, and landscaped areas. The City of San Diego itself has several larger storm drains that discharge to the areas, including a drain at the foot of Avenida de la Playa.

Impacts

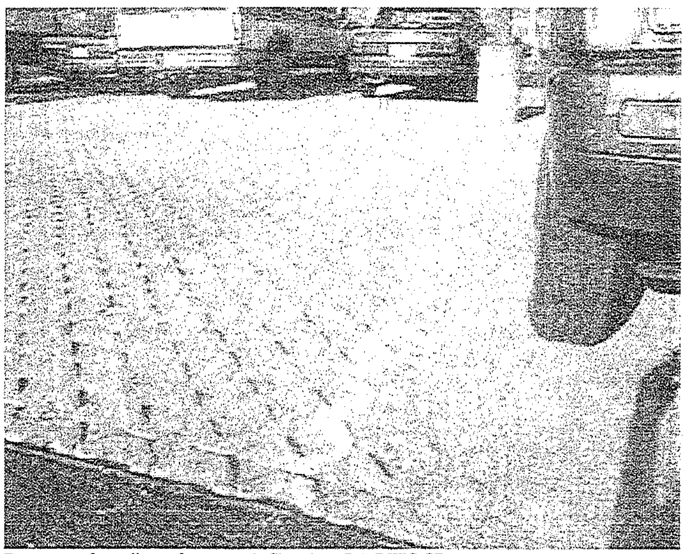
San Diego's stormwater runoff is commonly contaminated with pathogens (fecal coliform and streptococcus) and heavy metals (such as cadmium, copper, lead, and zinc) that exceed state and federal water quality criteria. Stormwater within the region also has been found to contain the pesticides diazinon and chlorpyrifos at levels that can cause chronic or acute toxicity. The shorelines of both the San Diego Marine Life Refuge and the San Diego-La Jolla Ecological Reserve regularly exceed water quality standards for bacterial indicators.



San Diego-La Jolla Ecological Reserve is home to rich kelp forests, SWRCB.

Practical Solutions For Protecting California's AquaGems

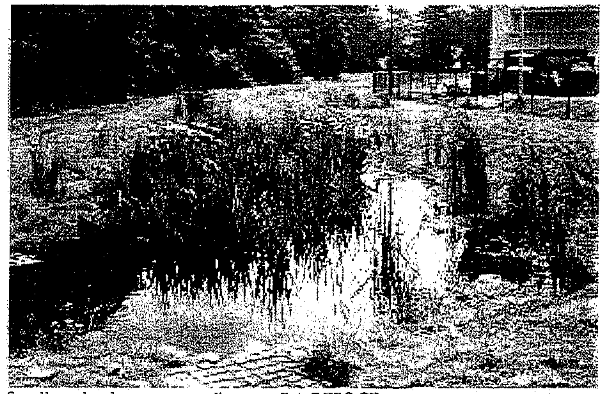
One of the best ways to protect California's 34 AquaGems is to stop pollution at the source. Along with pollution prevention methods, information and knowledge about pollution control practices have increased dramatically over the past decade. Today, there are many cost-effective, practical solutions used throughout California to protect water quality. In fact, dozens of construction, industry, and government handbooks detail off-the-shelf tools for preventing pollution. These tools have 80-90 percent pollutant removal rates. In other words, these proven technologies used in combination with other pollution control measures can stop pollution before it reaches our AquaGems.



Porous surface allows for water infiltration, LA RWQCB.

Common-Sense Practices Include

- Preserving natural areas so that stormwater can infiltrate the ground
- Installing storm drain filters
- Employing detention and filtration basins
- Using sand traps and filters
- Raising public awareness
- Preventing illicit discharges
- Retrofitting parks with dry wells and catch basins
- Using porous surfaces that allow drainage into the ground



Small wetland removes pollutants, LA RWQCB.

Sources of Funding

Protecting California's AquaGems is an investment in our coastal economy. Californians support water pollution cleanup with grants and ballot measures because they recognize the value of our coasts. Since 2001, Californians have dedicated nearly $2 billion for protecting our water quality. For example:

- Coastal Nonpoint Source Control $43.1 million
- Clean Beaches Initiative $76 million
- Nonpoint Source Pollution Control $19 million
- Nonpoint Source Implementation $4.5 million
- Agricultural Water Quality Grants $14 million
- Urban Stormwater Projects $14.25 million
- Integrated Watershed Management $47.5 million
- CALFED Programs $9.4 million

Innovative funding solutions, such as Los Angeles' Prop O, are also possible. Over 76 percent of voters in the City of Los Angeles voted for a $500 million bond measure that will be used to finance capital improvements to prevent pollution. Partnership grants with government agencies, such as the Coastal Conservancy, are also available.

Virginia Avenue Park Retrofit produces zero net runoff. Santa Monica.

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Water Quality Control Plan (Basin Plan) for the San Francisco Bay Basin.

Acknowledgements

Principal Authors: Anjali Jaiswal and Sarah Newkirk.

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Cover Page Photographs: Pacific Grove ASBS, Anjali Jaiswal; Pacific Grove Runoff Drain, Monterey Bay National Marine Sanctuary; Fitzgerald Marine Reserve Warning, Linda Sheehan; Sea Otter, Friends of the Sea Otter.

Home > Bills > AB 1003 > Bill Status

CURRENT BILL STATUS

MEASURE : A.B. No. 1003
AUTHOR(S) : Nava.
TOPIC : Ventura County Watershed Protection District.
HOUSE LOCATION : ASM
+LAST AMENDED DATE : 03/31/2005

TYPE OF BILL :
Active
Non-Urgency
Non-Appropriations
2/3 Vote Required
Non-State-Mandated Local Program
Non-Fiscal
Non-Tax Levy

LAST HIST. ACT. DATE: 08/15/2005
LAST HIST. ACTION : Consideration of Governor's veto pending.
VETOED

TITLE : An act to amend Section 12 of the Ventura County Watershed Protection Act (Chapter 44 of the Statutes of 1944, Fourth Extraordinary Session), relating to the Ventura County Watershed Protection District.

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AB 1003 (Nava)
Ventura County Watershed Protection District.

Bill Text:
- AB 1003 (Tabbed view of all versions) (beta)
- Introduced: 02/22/05 | PDF
- Amended: 03/31/05 | PDF
- Enrolled: 07/13/05 | PDF

Bill Status:
- Consideration of Governor's veto pending. VETOED

Bill Location:
- Location: Assembly Governor
- File date: 09/08/05
- File item: 41

Bill Analysis
- Assembly committee analysis (04/08/05)
- Assembly floor analysis (04/14/05)
- Senate committee analysis (06/10/05)
- Senate floor analysis (06/16/05)
- Assembly floor analysis (08/17/05)

New vote tracking system (undergoing testing)
- Assembly Water, Parks and

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Tag List

Wildlife - 04/12/05

Motion: Do pass.
Ayes: 12, Noes: 0,
Abstentions: 2

- Assembly Floor - 04/18/05

Motion: AB 1003 Nava
Assembly Third Reading

Ayes: 43, Noes: 29,
Abstentions: 7

- Senate Local Government - 06/15/05

Motion: Do pass.
Ayes: 6, Noes: 3,
Abstentions: 0

- Senate Floor - 07/11/05

Motion: Assembly 3rd
Reading AB1003 Nava
By Kuehl
Ayes: 23, Noes: 13,
Abstentions: 4

Bill History:
- History

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Introduced 03/31/05 Enrolled

PASSED THE SENATE JULY 11, 2005
PASSED THE ASSEMBLY APRIL 18, 2005
AMENDED IN ASSEMBLY MARCH 31, 2005

ASSEMBLY BILL No. 1003

Introduced by Assembly Member Nava

INTRODUCED BY Assembly Member Nava

July 13, 2005

An act to amend Section 12 of the Ventura County Watershed Protection Act (Chapter 44 of the Statutes of 1944, Fourth Extraordinary Session), relating to the Ventura County Watershed Protection District.

LEGISLATIVE COUNSEL'S DIGEST

AB 1003, Nava Ventura County Watershed Protection District.

Existing law, the Ventura County Watershed Protection Act, authorizes the Ventura County Watershed Protection District to levy an assessment upon all taxable real property in the district to pay the costs and expenses of the district and to carry out any of the objects or purposes of the act. The act also authorizes the district to levy an assessment upon all taxable real property in any of the zones according to the benefits derived, or to be derived, in the respective zones, to pay the costs and expenses of carrying out any of the objects or purposes of the act in the respective zones.

This bill would authorize the district to impose fees on a districtwide or per zone basis for those same purposes.

THE PEOPLE OF THE STATE OF CALIFORNIA DO ENACT AS FOLLOWS:

SECTION 1. Section 12 of the Ventura County Watershed Protection Act (Chapter 44 of the Statutes of 1944, Fourth Extraordinary Session) is amended to read: SEC. 12. The board of supervisors of the district shall have power, in any year to do any of the following:

1. To levy an ad valorem tax upon all taxable property or an assessment or fee upon all taxable real property in the district to pay the costs and expenses of the Ventura County Watershed Protection District and to carry out any of the objects or purposes of this act of common benefit to the district as a whole.

2. To levy an ad valorem tax upon all taxable property or an assessment or fee upon all taxable real property in each or any of the zones, according to the benefits derived or to be derived by the respective zones, to pay the cost and expenses of carrying out any of the objects or purposes of this act of special benefit to the respective zones, including the constructing, maintaining, operating, extending, repairing, or otherwise improving any or all works or improvements within the respective zones. It is declared that all property within a given zone is equally benefited under this act.

The taxes, assessments, or fees shall be levied and collected together with, and not separately from, taxes for county purposes, and the revenues derived from the taxes, assessments, or fees shall be paid into the county treasury to the credit of the district, and the board of supervisors shall have the power to control and order the expenditure thereof for those purposes except that no revenues, or portions thereof, derived in any of the several zones from the taxes, assessments, or fees levied under the provisions of subdivision 2 of this section shall be expended for constructing, maintaining, operating, extending, repairing, or otherwise improving any works or improvements located in any other zone except as provided in Section 14. The aggregate taxes, assessments, or fees levied under this act for any one fiscal year shall not exceed thirty-two cents ($0.32) on each one hundred dollars ($100) of the assessed valuation of the taxable property in zone 1, shall not exceed forty cents ($0.40) on each one hundred dollars ($100) of the assessed valuation of the taxable property in zones 2 and 4, shall not exceed twenty-seven cents ($0.27) on each one hundred dollars ($100) of the assessed valuation of the taxable property in any special zone in addition to the aggregate taxes or assessments levied for zone 1, 2, 3, or 4 and exclusive of any tax, assessment, or fee levied to pay the cost and expenses of any project or facility for importing water into the district or to meet any bonded indebtedness of the zones or district and the interest thereon.

BILL NUMBER: AB 1721 ENROLLED
BILL TEXT

PASSED THE ASSEMBLY SEPTEMBER 8, 2005
PASSED THE SENATE SEPTEMBER 7, 2005
AMENDED IN SENATE SEPTEMBER 6, 2005
AMENDED IN SENATE AUGUST 31, 2005
AMENDED IN SENATE JUNE 28, 2005

INTRODUCED BY Assembly Member Pavley
(Coauthors: Senators Alquist, Romero, Soto, and Torlakson)

FEBRUARY 22, 2005

An act to amend Section 60041 of the Education Code, to amend Sections 71301, 71302, 71303, 71304, and 71305 of the Public Resources Code, and to add Section 13383.6 to the Water Code, relating to environmental education.

LEGISLATIVE COUNSEL'S DIGEST

AB 1721, Pavley Environmental education.

(1) Existing law establishes the Office of Education and the Environment within the California Integrated Waste Management Board, and requires the office to develop and implement a unified education strategy on the environment for elementary and secondary schools. Existing law requires school district governing boards, when adopting instructional materials for use in schools, to include only materials that accurately portray the educational principles for the environment.

This bill would repeal that instructional materials requirement.

(2) Existing law requires the Instructional Materials Advisory Panel, before adopting criteria for textbook adoption, to consult with the office to incorporate, where feasible, education principles for the environment. Existing law requires the education principles for the environment to be incorporated in criteria developed for textbook adoption.

This bill would repeal that consultation requirement and would instead provide that if the State Board of Education determines that the education principles for the environment are not appropriate for inclusion in the textbook adoption criteria, the board would be required to collaborate with the office to make the changes necessary to ensure that the principles are included in the textbook adoption criteria.

(3) Existing law requires the State Department of Education to incorporate materials developed by the office that provide information on the education principles for the environment into publications that provide examples of curriculum resources for teacher use.

This bill would provide that if the Superintendent of Public Instruction determines that materials developed by the office that provide this information are not appropriate for inclusion in publications that provide examples of curriculum resources for teacher use, the Superintendent of Public Instruction would be required to collaborate with the office as specified.

(4) Existing law requires that materials produced and distributed in the public schools be aligned to the educational principles for

the environment that are incorporated into the content standards.
This bill would repeal that requirement.

(5) Existing law establishes the Environmental Education Account and authorizes the deposit of funds from prescribed sources for expenditure for purposes of developing and implementing the unified education strategy, upon appropriation by the Legislature.

This bill would allow a state agency that requires the development of, or encourages the promotion of, environmental education for elementary and secondary school pupils, to contribute to the account.

This bill would provide that, on and after January 1, 2007, if a California regional water quality control board or the State Water Resources Control Board issues a specified permit that requires elementary and secondary public schools to be provided with educational materials on stormwater pollution, the permittee would be allowed to contribute an equivalent amount of funds to the account.

THE PEOPLE OF THE STATE OF CALIFORNIA DO ENACT AS FOLLOWS:

SECTION 1. Section 60041 of the Education Code is amended to read:

60041. When adopting instructional materials for use in the schools, governing boards shall include only instructional materials that accurately portray both of the following, whenever appropriate:

(a) Humanity's place in ecological systems and the necessity for the protection of our environment.

(b) The effects on the human system of the use of tobacco, alcohol, and narcotics and restricted dangerous drugs, as defined in Section 11032 of the Health and Safety Code, and other dangerous substances.

SEC. 2. Section 71301 of the Public Resources Code is amended to read:

71301. (a) As part of the unified education strategy, the office, under the direction of the Secretary for Environmental Protection and the board, in cooperation with the Resources Agency, the State Department of Education, the State Board of Education, and the Secretary for Education, shall develop education principles for the environment for elementary and secondary school pupils. The principles may be updated every four years beginning July 1, 2008. The principles shall be aligned to the academic content standards adopted by the State Board of Education pursuant to Section 60605 of the Education Code. The principles shall be used to do all of the following:

(1) To direct state agencies that include environmental education components for elementary and secondary education in regulatory decisions or enforcement actions.

(2) To align state agency environmental education programs and materials that are developed for elementary and secondary education.

(b) The education principles for the environment shall include, but not be limited to, concepts relating to the following topics:

(1) Environmental sustainability.
(2) Water.
(3) Air.
(4) Energy.
(5) Forestry.
(6) Fish and wildlife resources.

(7) Oceans.
(8) Toxics and hazardous waste.
(9) Integrated waste management.
(10) Integrated pest management.
(11) Public health and the environment.
(12) Pollution prevention.
(13) Resource conservation and recycling.
(14) Environmental justice.

(c) The principles shall be aligned to the applicable academic content standards adopted by the State Board of Education and shall not duplicate or conflict with any academic content standards.

(d) (1) The education principles for the environment shall be incorporated, as the State Board of Education determines to be appropriate, in criteria developed for textbook adoption required pursuant to Section 60200 or 60400 of the Education Code in Science, Mathematics, English/Language Arts, and History/Social Sciences.

(2) If the State Board of Education determines that the education principles for the environment are not appropriate for inclusion in the textbook adoption criteria cited in paragraph (1), the State Board of Education shall collaborate with the office to make the changes necessary to ensure that the principles are included in the textbook adoption criteria in Science, Mathematics, English/Language Arts, and History/Social Sciences.

(e) If the content standards required pursuant to Section 60605 of the Education Code are revised, the education principles for the environment shall be appropriately considered for inclusion into part of the revised academic content standards.

SEC. 3. Section 71302 of the Public Resources Code is amended to read:

71302. (a) Using the education principles for the environment required in Section 71301, the office, under the direction of the Secretary for Environmental Protection and the board, shall develop, in cooperation with the California Environmental Protection Agency, the Resources Agency, the State Department of Education and the State Board of Education, a model environmental curriculum that incorporates these education principles for the environment. The model curriculum shall be aligned with applicable State Board of Education adopted academic content standards in Science, Mathematics, English/Language Arts, and History/Social Sciences, to the extent that any of those content areas are addressed in the model curriculum.

(b) The model curriculum shall be submitted to the Curriculum Development and Supplemental Materials Commission for review. The commission shall submit its recommendation to the Secretary for Environmental Protection and to the Secretary of the Resources Agency by July 1, 2005.

(1) The Secretary for Environmental Protection and the Secretary of the Resources Agency shall review and comment on the model curriculum by January 1, 2006.

(2) The model curriculum along with the comments by the Secretary for Environmental Protection and the Secretary of the Resources Agency shall be submitted to the State Board of Education for its approval.

SEC. 4. Section 71303 of the Public Resources Code is amended to read:

71303. (a) As determined appropriate by the Superintendent of Public Instruction, the State Department of Education shall incorporate into publications that provide examples of curriculum resources for teacher use, those materials developed by the office that provide information on the education principles for the environment required in Section 71300.

(b) If the Superintendent of Public Instruction determines that materials developed by the office that provide information on the education principles for the environment are not appropriate for inclusion in publications that provide examples of curriculum resources for teacher use, the Superintendent of Public Instruction shall collaborate with the office to make the changes necessary to ensure that the materials are included in that information.

(c) The model environmental curriculum approved by the State Board of Education, pursuant to Section 71302 shall be made available by the office to elementary and secondary schools to the extent that funds are available for this purpose. The State Department of Education shall make the model curriculum available electronically including posting on its Web site.

(d) The State Department of Education, to the extent feasible and to the extent that funds are available for this purpose, shall encourage the development and use of instructional materials and active pupil participation in campus and community environmental education programs. To the extent feasible, the environmental education programs should be considered in the development and promotion of after school programs for elementary and secondary school pupils and state and local professional development activities to provide teachers with content background and resources to assist in teaching about the environment.

(e) (1) The board shall assume costs associated with the printing of the approved model curriculum as set forth in subdivision (c). The board shall use, for these purposes, funds that are available for its administrative costs.

(2) From funds available for its administrative costs, the State Department of Education shall post and maintain the model curriculum on its Internet site and pay any costs associated with any related online questionnaire on its Internet site as set forth in subdivision (c).

(3) The State Department of Education shall explore implementation of this section from its baseline resources dedicated to this purpose and if funding is not available from that source, then funding may be provided to the department, pursuant to appropriation by the Legislature, under Section 71305.

SEC. 5. Section 71304 of the Public Resources Code is amended to read:

71304. (a) The office, under the direction of the Secretary for Environmental Protection, shall be responsible for the statewide coordination of regulatory administrative decisions that require the development or encourage the promotion of environmental education for elementary and secondary school pupils.

(b) All California Environmental Protection Agency or Resources Agency boards, departments, or offices that take regulatory actions or take enforcement actions requiring the development of or encouraging the promotion of environmental education for elementary and secondary school pupils shall, prior to adoption or approval of the action, seek comments on the action from the office in order to promote consistency with this part and cross-media coordination.

(c) The office shall coordinate with all state agencies to develop and distribute environmental education materials.

SEC. 6. Section 71305 of the Public Resources Code is amended to read:

71305. (a) The Environmental Education Account is hereby established within the State Treasury. Moneys in the account may, upon appropriation by the Legislature, be expended by the California Environmental Protection Agency, in consultation with the board, for the purposes of this part. The board shall provide recommendations to the Secretary for Environmental Protection regarding expenditures from the account. The Secretary for Environmental Protection shall administer this part, including, but not limited to, the account.

(b) Notwithstanding any other provision of law to the contrary, the agency may accept and receive federal, state, and local funds and contributions of funds from a public or private organization or individual. The account may also receive proceeds from a judgment in state or federal court, when the funds are contributed or the judgment specifies that the proceeds are to be used for the purposes if this part. The account may receive those funds, contributions, or proceeds from judgments, that are specifically designated for use for environmental education purposes. Private contributors shall not have the authority to further influence or direct the use of their contributions.

(c) Notwithstanding any other provision of law, a state agency that requires the development of, or encourages the promotion of, environmental education for elementary and secondary school pupils, may contribute to the account.

(d) The agency shall immediately deposit any funds contributed pursuant to subdivision (b) into the account.

SEC. 7. Section 13383.6 is added to the Water Code, to read:

13383.6. On and after January 1, 2007, if a regional board or the state board issues a municipal stormwater permit pursuant to Section 402(p) of the Clean Water Act (33 U.S.C. Sec. 1342(p)) that includes a requirement to provide elementary and secondary public schools with educational materials on stormwater pollution, the permittee may satisfy the requirement, upon approval by the regional board or state board, by contributing an equivalent amount of funds to the Environmental Education Account established pursuant to subdivision (a) of Section 71305 of the Public Resources Code.

SOME OBSERVATIONS ON ATMOSPHERIC DUST FALLOUT IN THE DENVER, COLORADO AREA OF UNITED STATES

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ABSTRACT

Dust fallout, as a contributor to the pollutants found on urban surfaces, has been discussed for years and many studies have been done to quantify it (Sartor and Boyd, 1972; Pitt and Amy, 1973; Pitt, 1979; Mustard *et. al.,* 1985; Schroder and Hedley, 1986; Schroder *et. al.,* 1987; Illinois State Water Survey, 2003). Despite these, there remains controversy as to how much of the total pollutants that are present on various urban surfaces come from atmospheric fallout. In the spring of 2003, the senior author had an opportunity to personally observe some of the accumulations of solids in roof gutters of a single-family house and the accumulation of sediment in a winterized swimming pool, both located in Denver, Colorado. This paper presents a summary of these findings and interpretations attributed to these observations in light of findings related to atmospheric dust fallout by other investigators.

CLEANING OUT ROOF GUTTERS

In May of 2003, clogged roof downspouts at one of the author's homes prompted the cleaning of roof gutters. These gutters were not cleaned for about 5- to 7-years. The grit and grime removed from the gutters serving approximately 700 square feet of the roof (horizontal projection) were collected in a plastic bag. These materials consisted of wet leaves, fine sediment and grit typically found on asphalt-composition roofs. Although these materials were not segregated and weighed separately, the following was observed:

1) Total weight of material was removed from the gutters serving 700 square feet (horizontal projection) of the roof was 30 to 40 lbs (13.6 to 18 kg).
2) Approximately 1/3 of the mass consisted of grit particles from the composition roof.
3) Approximately 1/3 of the mass consisted of wet leaves and water.
4) Approximately 1/3 of the mass consisted of very fine sediments.

Thus, over the 5- to 7-year period the gutter accumulated about 12 lbs (5.5 kg) of very fine sediment that would be classified as part of the Total Suspended Solids (TSS) found in stormwater runoff, or about 2 lbs (1 kg) of TSS per 100 square feet (9.3 m^2) of roof or 870 lbs/acre (977 kg/ha). This loading rate compares with a value of 700 lbs/acre (785 kg/ha) obtained from other studies of atmospheric dust accumulation completed in the Denver area (Mustard *et. al.,* 1985). *What is not known is the quantity of fine solids that were not trapped in the gutter during these years and were washed down onto lawns or onto streets and paved alleys that have a direct hydraulic connection to the streams in the Denver area.* Clearly, this example illustrates that roofs in the Denver area are significant sinks for atmospheric fallout and significant contributors of TSS found in stormwater runoff reaching our streams, especially if their downspouts discharge directly onto hydraulically connected paved surfaces, street gutters or storm sewers.

CLEANING OUT A SWIMMING POOL

On Memorial Day weekend, one of the authors observed the cleaning of a residential swimming pool. This presented an additional opportunity to document the effects of atmospheric dust fallout. Photograph 1 illustrates the difference in the pool bottom before and after cleanout. The area on the left side shows the bottom before it was vacuumed and the right side shows the results after vacuuming. The dark materials on left side of this photograph consist of the atmospheric dust fallout that was deposited on the pool's bottom since it was closed in September of 2002; namely, the amount that was deposited over a nine month period.

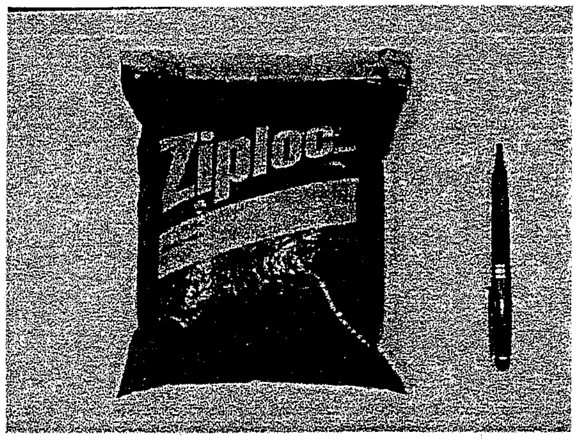
Photograph 2 shows a Ziploc™ bag filled with fine sediment that was washed off the vacuum's filter after 200 to 250 square feet of the bottom was cleaned. This sample does not contain all of the sediment that was on the filter; approximately 15% to 25% of the sediment was not captured and went down the drain during the filter washing process. These data indicate:

1. The total wet weight of the sample was 3 lbs (1.4 kg).
2. Assuming 50% water content and 20% bypass, the weight of the accumulated solids removed was around 1.5 lbs (0.7 kg), or 0.9 lbs (0.4 kg) of solids per 100 square feet (9.3 m^2) of surface area. Extrapolating this to a 12-month period, we get 1.2 lbs/100 square foot (5.6 kg/m^2) or 700 lbs/acre/year (785 kg/ha/y).
3. This material would be part of the TSS load in stormwater runoff when it was washed off impervious surfaces that have a direct hydraulic connection to the stormwater conveyance system.

Photograph 1. Difference between vacuumed pool bottom on the right and not vacuumed on the left, after nine months of dust fallout accumulation.

What is interesting to the authors is that these findings are similar to the findings reported by Beecham (2001) in Sydney, Australia. He reported that a load of 11 lbs (5 kg) of sediment is generated from a typical single-family residential roof on an average annual basis. Assuming an average roof area of 1,000 square feet (93 m^2) for Sydney, this rate corresponds to a unit-area loading of 1.1 lbs/100 square feet (4.7 kg/100m^2) of roof, as compared to the 1.2 lbs/100 square feet (5.2 kg/100m^2) of roof found by the authors from this single informal measurement in Denver.

A gradation test was performed of the pool sediments. This test roughly indicates what the distribution of particle sizes is within the atmospheric fallout in the Denver area. The results of the gradation test are shown in Figures 1 and 2. Approximately one-third of the sample can be classified as fine sand (larger than 74 microns) and two-thirds of the sample as silt and clay. Little more than 20-percent of the particles are clay-sized (2 microns or less). Studies have shown an inverse relationship between particle size and pollutant concentrations on street surfaces (Sartor and Boyd, 1972; Pitt and Amy, 1973; Pitt, 1979) and in bottom sediments in the South Platte River (Steele and Doerfer, 1983). Because of their small size, the clay- and silt-sized particles are difficult to remove from stormwater runoff using sedimentation processes.



Photograph 2. Wet solids collected from 200 to 250 square feet of pool's bottom.

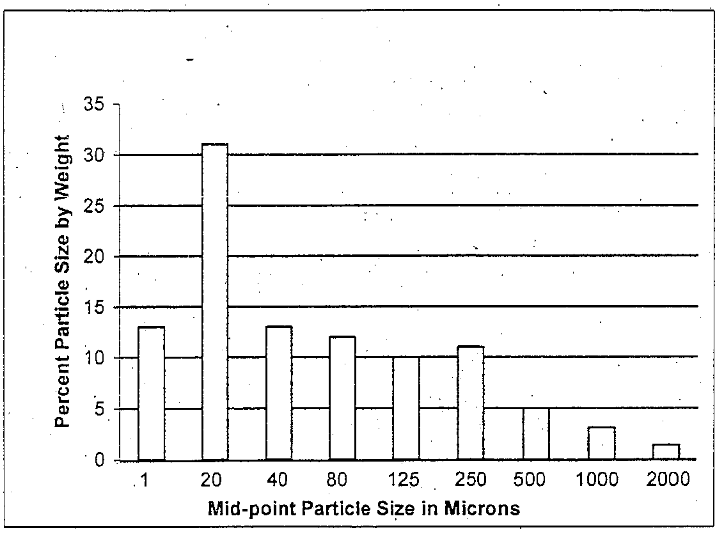


Figure 1. Distribution of particle mid-point sizes in the sample from bottom of a swimming pool.

WHAT DOES ALL THIS MEAN?

The two informal observations clearly imply that atmospheric fallout is a significant contributor of TSS found in stormwater runoff in the Denver. In addition, rooftops can be significant contributors of TSS and, potentially, of other pollutants in stormwater runoff.

Where do these solids come from? Air emissions from industry, commerce, fireplaces, diesel engines and other human activities are potential contributors. In addition, in a semi-arid climate such as Denver, wind picks up much dust and fine sediment from land surfaces within and adjacent to the urban area, including rangeland, farmland, streets, parking lots, construction sites, etc. Eventually these suspended materials settle to the ground. Unlike climates with more rainfall and humidity, the atmosphere in a semi-arid climate does not have as many opportunities to cleanse itself. In addition, native vegetated surfaces comprised of bunch grasses instead of turf grasses do not protect the soils from scour by wind, nor do they provide the trapping of dust particles that turf-forming grasses provide after particles settle to the ground.

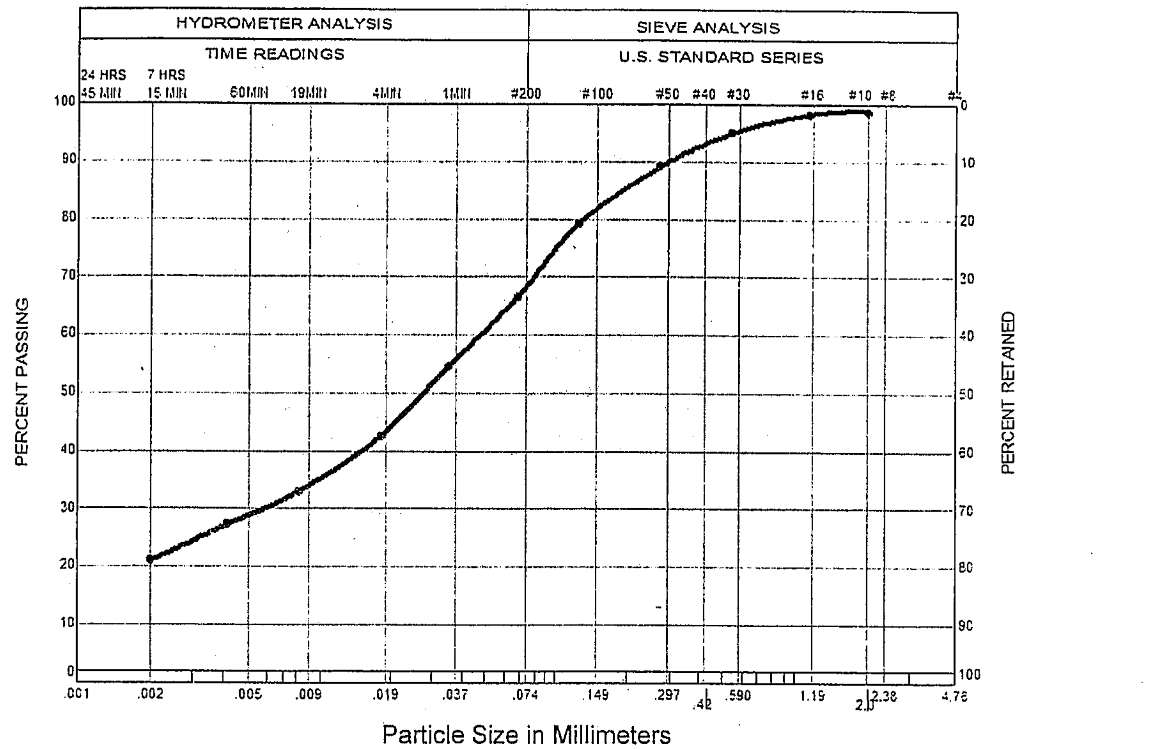


Figure 2. Complete size distribution of particles in the sample from bottom of a swimming pool. Note that 70% of the particles are less than 80 micron in size and 80% are less than 125 micron in size (i.e., slow to settle and hard to remove from the water column).

It was found by more formal studies (Sartor and Boyd, 1972; Pitt, 1979; Mustard *et. al.,* 1985) that TSS initially builds up rapidly on impervious surfaces and then the buildup rate approaches an asymptotic equilibrium. This phenomenon of tapering off of the buildup rate can be attributed to wind resuspension and scour of deposited particles so that the buildup of sediment deposits do not continue at the same rate forever. In a swimming pool, all solids that fall out of the atmosphere cannot resuspend into the atmosphere. As a result, a swimming pool, a pond or a lake acts as a perfect sink for these solids.

The findings reported in this paper are not based on accurate scientific measurements. Nevertheless, they do provide a realistic assessment of what the atmospheric fallout of dust and other particles in the Denver area may be and how it affects stormwater runoff quality. It is recommended that these non-scientific initial data be better quantified through the use of more precise controlled measurements in existing sinks for atmospheric fallout (e.g., winterized swimming pools that have mesh type winter covers, lined ponds, etc.) in the Denver area. Unlike wet/dry samplers used by data collection agencies such as the Illinois Water Survey (2003), sinks like swimming pools provide large surface areas for the collection of these particles and can produce much more reliable data than wet/dry samplers used today because of their much larger surface area for trapping atmospheric fallout.

Nevertheless and despite this less-than-scientific methods employed, the data suggest that each 100 square feet (9.3 m^2) of impervious surface can yield as much a 1.0 to 1.2 lbs (0.45 to 0.55 kg) of solids on an annual average basis in stormwater runoff. What fraction of that range actually makes it into stormwater has yet to be determined. If, however, we assume that 100% of it makes it into stormwater runoff and an average of 30% of impervious surfaces have a direct hydraulic connection to the conveyance systems, each square mile (259 ha) of an average mixed-use urban development *can produce about 40 to 50 tons (18 to 23 metric tons) of TSS in stormwater runoff each year.* Considering that the Nationwide Urban Runoff Program data collected in the Denver area by USGS indicates an average TSS concentration for commercial and residential land uses in excess of 200 mg/L (EPA, 1983), the estimate using the unscientific samples collected informally by the authors in 2003 compare well to the annual stormwater TSS loads one calculates using the USGS and other data.

CONCLUSIONS

The observations made using simple atmospheric fallout dust capture techniques clearly show that:

1. Atmospheric fallout in the Denver area is a significant source of TSS and potentially of other pollutants found in stormwater runoff.
2. The fallout consists of very fine particles that are difficult to remove from the water column using dynamic and quiescent sedimentation facilities or devices.
3. It does not matter if the impervious surface is a street, a parking lot, sidewalk or a roof; they all accumulate this atmospheric fallout, which is then washed off by stormwater runoff.
4. The amount of this TSS that eventually arrives at the region's receiving waters depends on how the runoff from impervious surfaces is handled. The less of it that has a direct hydraulic connection to the conveyance system, the greater the chances for the turf lawns and landscaping to capture these particles before they reach the conveyance system.
5. The BMPs currently recommended in Volume 3 of the District's Urban Storm Drainage Criteria manual are well suited for the removal of these very fine solid particles from the water column before stormwater is discharged to the conveyance system or to the receiving waters.

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Raingarden / Bioinfiltration design:

Introduction to some Wisconsin stormwater approaches and the RECARGA Infiltration Model

January 30th 2007

Robert Montgomery
Linda Severson

A000162

Federal Regulations

- 1972 Clean Water Act
- 1987 Amendment to the Clean Water Act
- 1990 EPA NPDES Phase I
  - Municipal Separate Storm Sewer System (MS4) communities
  - Regulated
    - 11 categories of industrial activity
    - Construction sites that disturb greater than 5 acres
- 1999 EPA NPDES Phase II

Wisconsin Stormwater Regulations

- In response to NPDES regulations
  - 1997 Act 27
  - 1999 Act 9
- Acts of the WI Legislature Required
  - DNR to establish agricultural and non-agricultural performance standards & process for developing technical standards
  - DATCP to establish agricultural conservation practices & technical standards

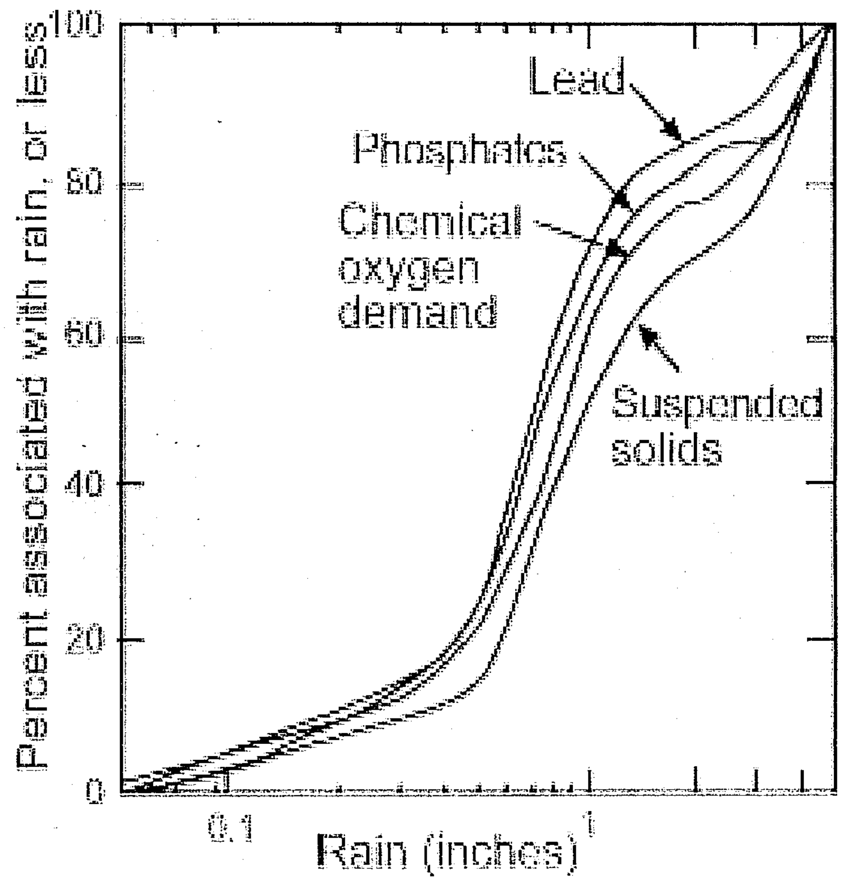
Wisconsin Stormwater Regulations

- **Resulting Wisconsin Administrative Code**
  - NR 151: Performance standards
  - NR 152: Model ordinances
  - NR 153: Targeted runoff management grants
  - NR 154: BMPs and cost share conditions
  - NR 155: Urban grants
  - NR 120: Priority watersheds
  - **NR 216: Stormwater permit program**
  - NR 243: Animal feeding operations
  - ATCP 50: Soils and water resource management program

A000165

Stormwater Quality

- Relatively small storms produce most pollutant loading –
  – WQ design storm or annual loading criteria



Milwaukee NURP

NR 151

Standards oriented toward stormwater quality per CWA

- TSS reduction
- Infiltration for water quality

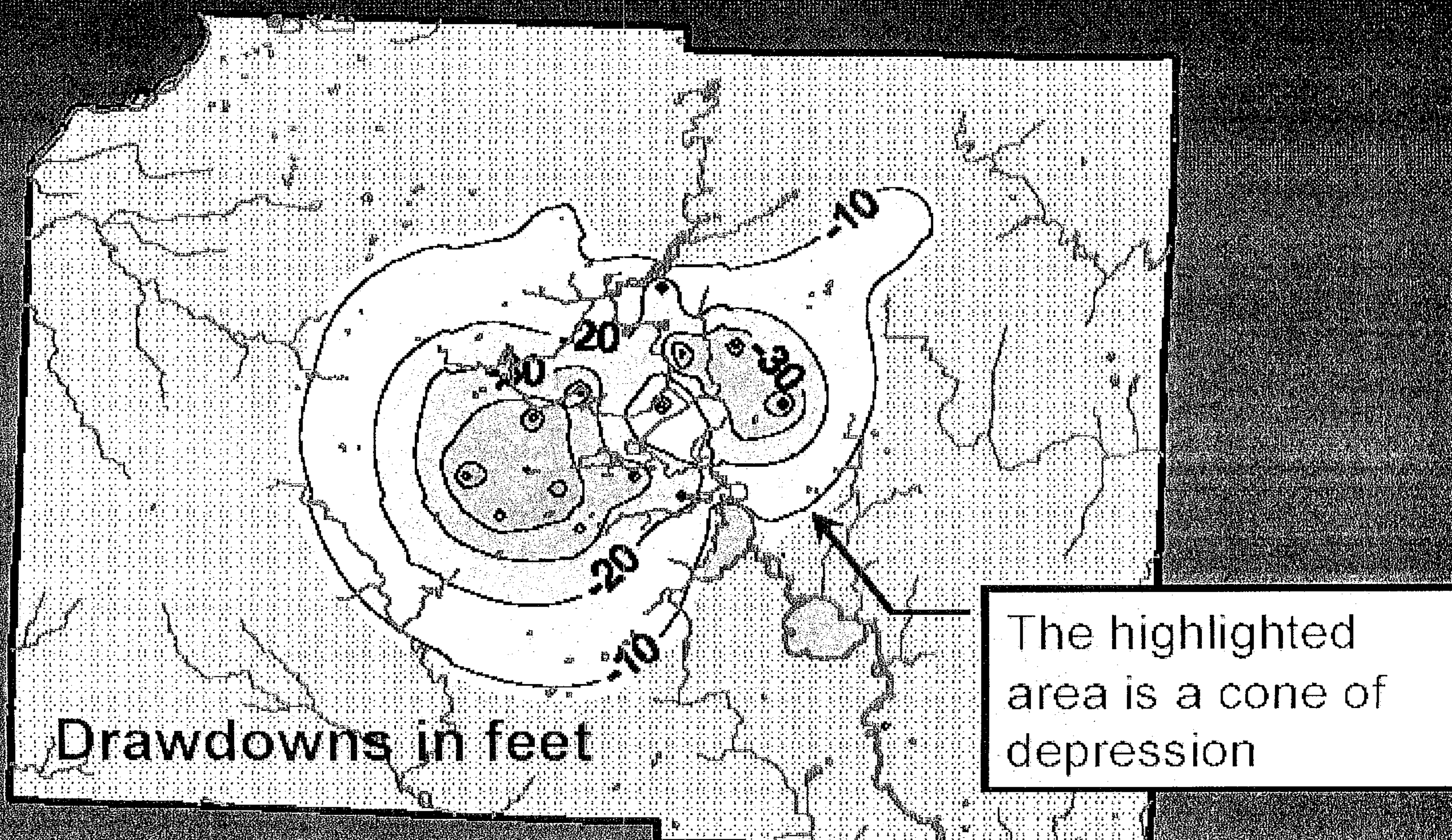
Post Construction Standards

- Stormwater management plan
- 80% TSS reduction (from no controls)
- Pre-Post 2-year 24-hour peak flow control
- Protective areas (buffers) adjacent to streams and wetlands
- Standards for fuel and maintenance areas

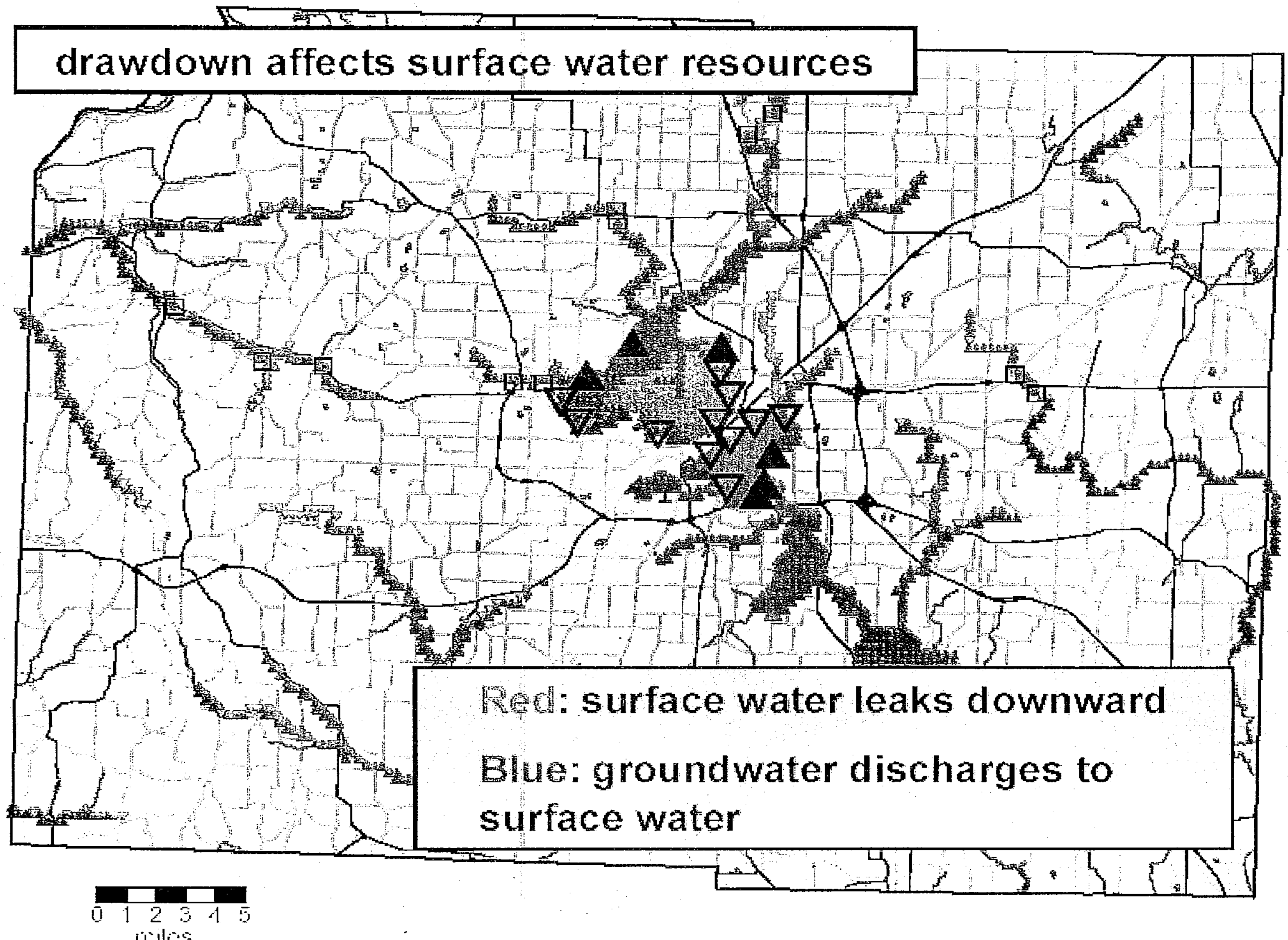
NR 151

- Infiltration standards
  - New Residential Development
    - Infiltrate 90% average annual predevelopment infiltration volume, or
    - 25% of the 2-year, 24 hour storm
    - Requires no more than 1% of site area dedicated to infiltration (cap)
  - New Non-Residential Development
    - Infiltrate 60% average annual predevelopment infiltration volume, or
    - 10% of the 2-year, 24-hour storm
    - 2% cap
  - Exclusions for groundwater protection/Exemptions for practicality reasons

Municipal water use in the Madison area causes significant drawdown, or lowering of water levels, in the deep sandstone aquifer...



Groundwater discharge to lakes and streams



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Dane County Requirements

- BOTH Stormwater quality and groundwater recharge are important in Dane County
- Applicable to sites > 20,000 sf
- Peak Runoff Control
  - State: Pre-Post 2 year event
  - County: Pre-Post 2 & 10 year event, safely pass the 100 year
- TSS
  - State: new dev. reduce 80% avg. annual basis compared to no controls
  - County: new dev. reduce 80% avg. annual basis compared to no controls (40% for redevelopment)

Dane County Compared to State

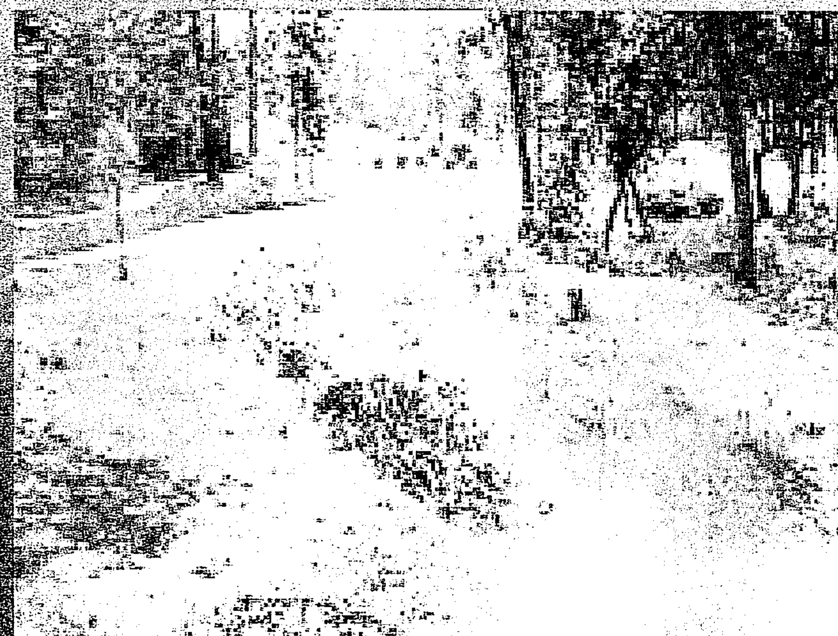
- Infiltration
  - State
    - Residential (1% cap)
    - Non-Residential (2% cap)
    - Exclusions for groundwater protection/Exemptions for practicality reasons
  - County: same as state but cap modified:
    - Meet infiltration goals regardless of cap **OR**
    - Recharge 7.6 inches average annual basis

Specialized Analytical Tools used in NR151 Compliance

- Stormwater Quality Management Plans
  - SLAMM
  - P8
- Wet Detention Basin Design
  - DETPOND
- Bio/Infiltration System Design
  - RECARGA

Why Develop a New Model

- Many models couple surface and subsurface flow
  - Agricultural Models: CREAMS, GLEAMS, HELP
  - SWMM
  - PRMS
- Limitations:
  - Does not simulate ponded conditions!



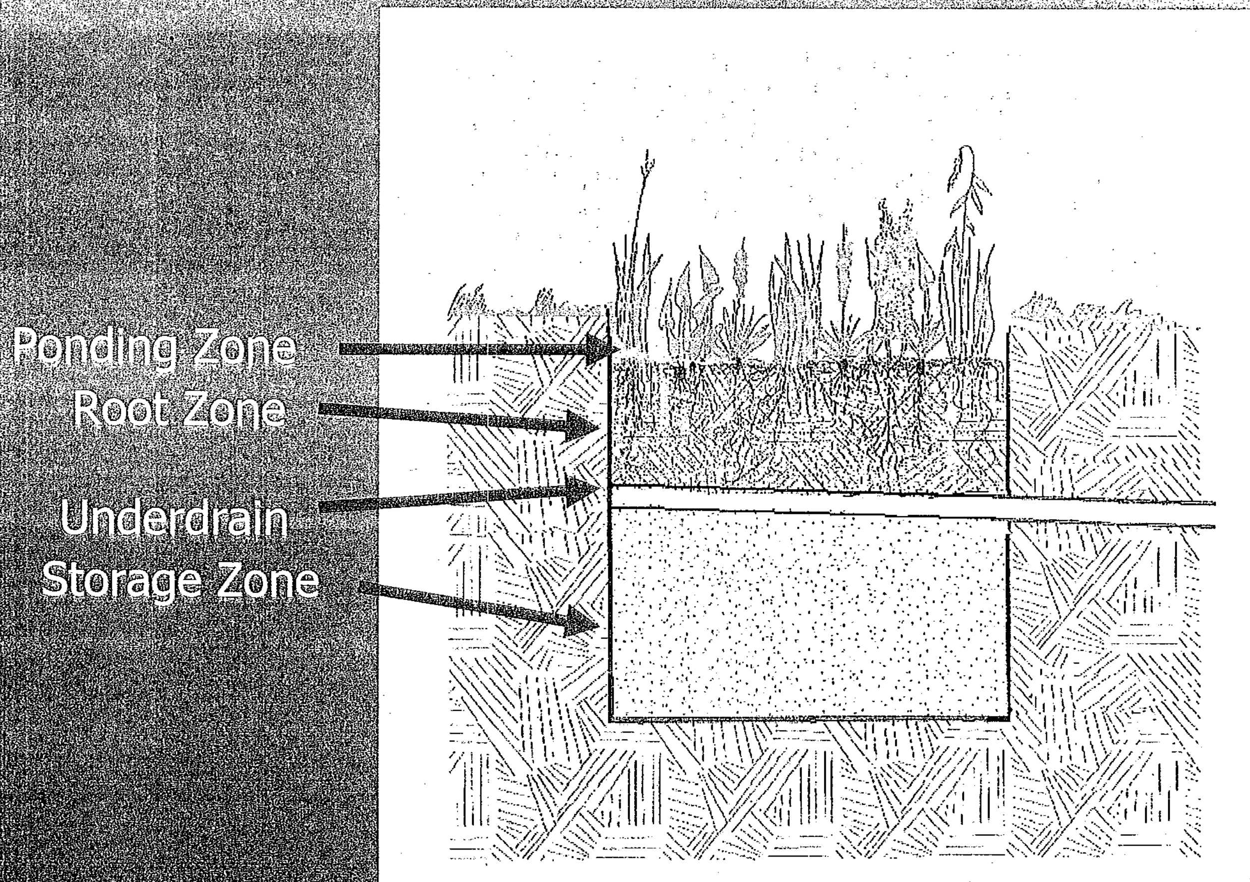
Development Process

- RECHARGE (Alejandro, 2002)
  - Richard's Equation-detailed input parameters
- RECARGA (Alejandro, 2002)
  - Green-Ampt Model
  - Current version modified from original (Atchison, Severson)
- Experimental Raingarden (Alejandro, Atchison, Severson)
  - Used to verify RECARGA

Objectives of RECARGA

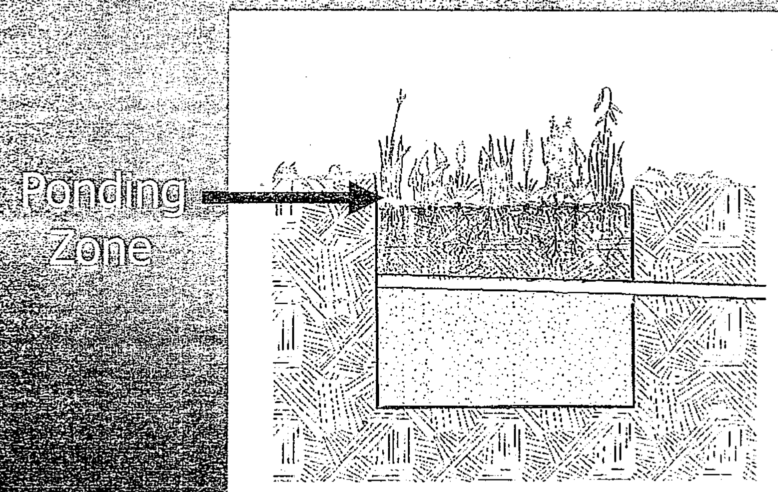
- Hydrologic modeling of Bio/Infiltration systems
  - Quantify ponding, infiltration, overflow, ET and recharge
- Does not directly model water quality but many inferences on water quality performance can be obtained from quantifying runoff reduction and adsorption / filtration

Elements of Bio/Infiltration Systems



Ponding Zone

- Provides initial storage volume to capture runoff
- Consider drawdown time (<24 hours to ensure plant survivability)

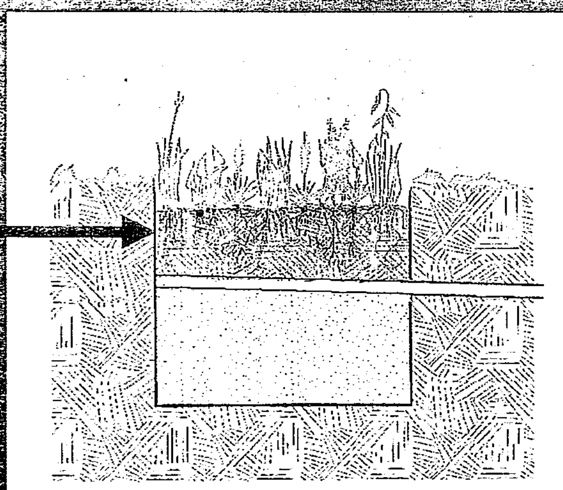


Plantings

- Maintain soil structure of root zone
- Facilitate pollutant removal
- Considerations
  - Frequency/duration of inundation
  - Drainage of soils
  - Exposure
- Plant a variety of species
  - Anticipate some replacement after first growing season

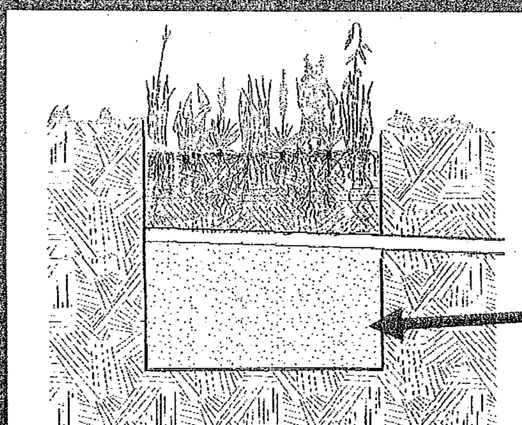
Root Zone

- Facilitates growing conditions for plants
  - Provides adequate depth, nutrients, and drainage for plant roots (approx. 24-36 inches)
- Engineered soils
  - WDNR soils specification: 40% sand, 25% topsoil, and 35% compost
- Primary site of pollutant removal



Storage Zone

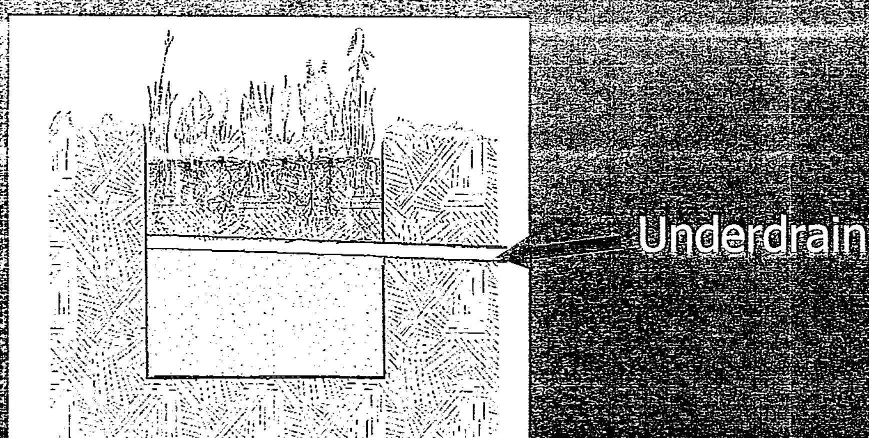
- Reduces the frequency and duration of saturated and ponded conditions above the underdrain
- Increases the volume of water captured within the facility



Storage Zone

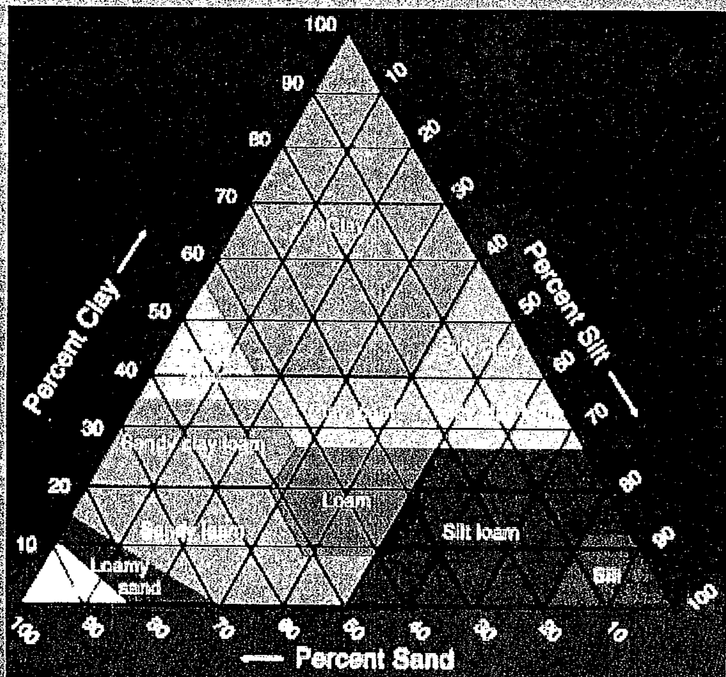
Underdrain

- Decreases drawdown times
  - Ensures plant survivability
- Recommended to design with removable cap
- Water flowing through the underdrain has water quality treatment, however, still contributes to surface runoff



Native Soils

- Most important factor affecting feasibility, design, and performance
- Consider texture at proposed grade
- Infiltration tests recommended
- Soil texture as estimator of infiltration Rate (Rawls, et al. 1998)

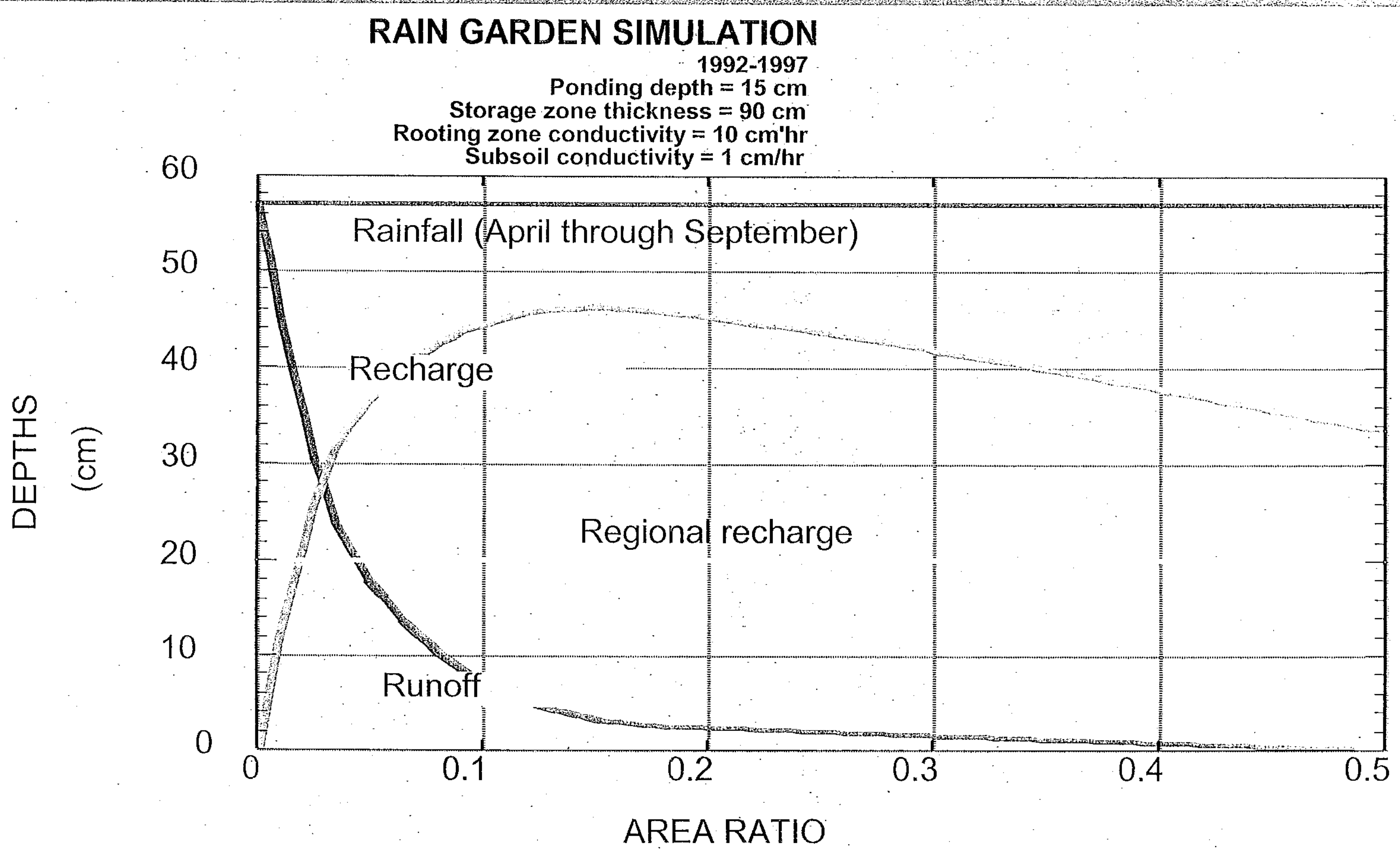


Soil Texture	Sat. Hydraulic Conductivity (in/hr)[1]
Sand	3.60
Loamy Sand	1.63
Sandy Loam	0.50
Loam	0.24
Silt Loam	0.13
Sandy Clay Loam	0.11
Silty Clay Loam	0.19
Clay Loam	0.03
Sandy Clay	0.04
Silty Clay	0.07
Clay	0.07

How do we design Bio/Infiltration devices?

- Rule-of-Thumb Approach
  - (NC State-5% Impervious Ratio)
- Retain Design Storm
  - (Prince George's County)
- Modeling
  - Try to match design to performance objective

The benefit of having a design tool is to evaluate design options and tradeoffs



RECARGA Version 2.3

Bioretention/Raingarden Sizing Program

Units: English

Planview Data

Facility Area	4356	[sf]
Tributary Area	1	[acre]
Percent Impervious	30	
Pervious CN	80	

Files

Regional Ave. ET	0.13	[in./day]
Simulation Type	Continuous	
Input File Length	266	days
Precip. File Name	Mad1981us	
Output File Name	MadkXXAXX	

Summary   Record

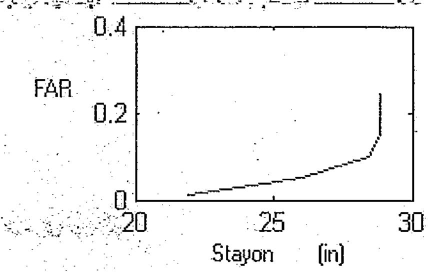
Facility Inputs

	Soil Texture	Hydraulic Conductivity [in/hr]	Thickness [in.]
Ponding Zone			6
Root Zone	Sandy Loam	3.94	24
Storage Zone	Sand	5.91	0
Limiting Subsoil Layer	Silt Loam	.13	

Underdrain
Flowrate 0 [in/hr]
Diam. 0 [in.]

Target Stay-on	16	[in]
Facility Area Ratio	0.0001816	

Run FAR



Results

Plant Survivability
(Less than 48 hours max. ponding is desirable)

	max.	Total
Hrs. Ponded	71.75	237.75
Number of overflows		2

Tributary Runoff [in]

Precipitation	28.81
Impervious Runoff	20.8212
Pervious Runoff	4.7784

Raingarden Water Balance

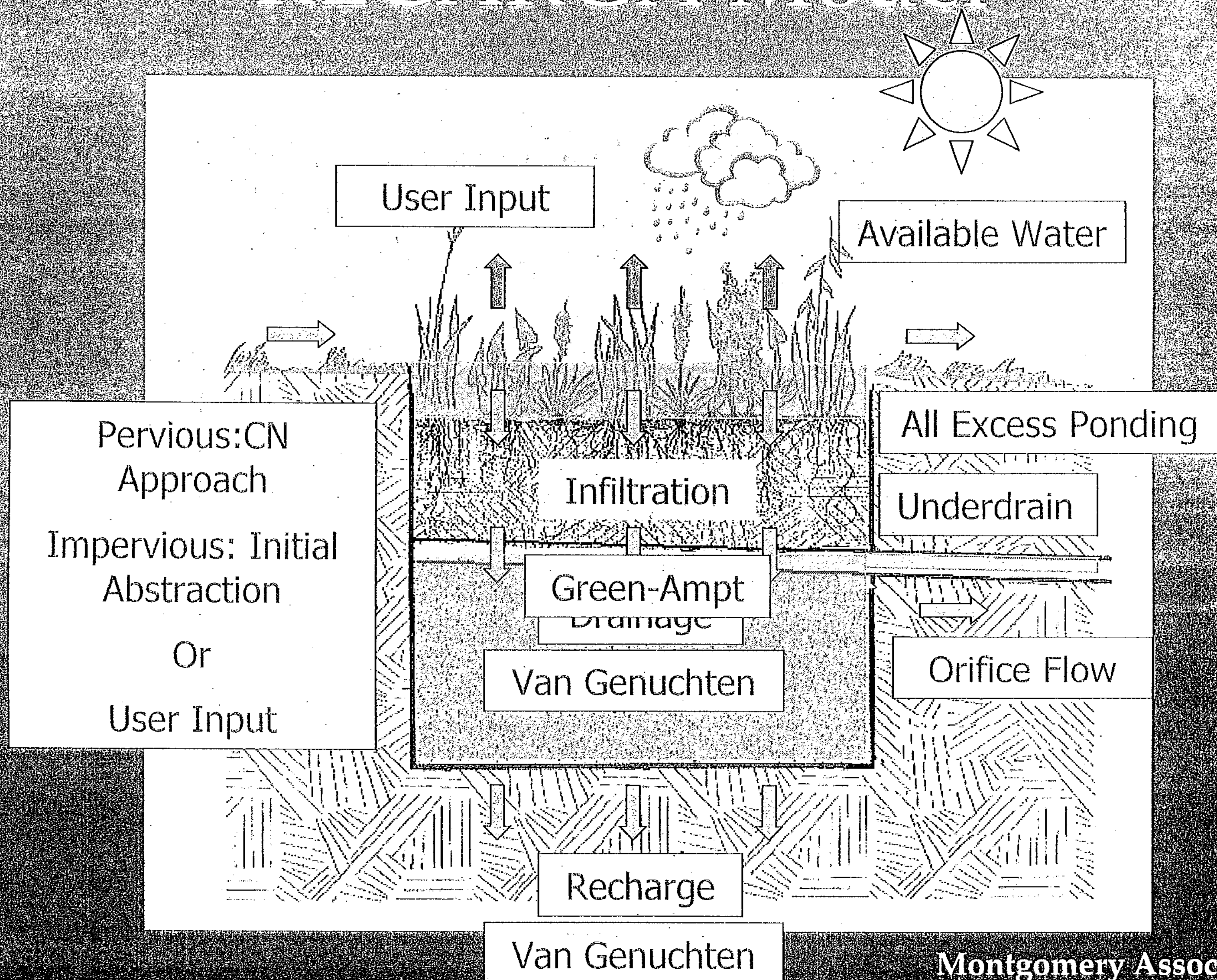
	[in.]	%
Runon	10.6122	36.835
Runoff	0.4879	1.6935
Recharge	7.5074	26.0582
Evaporation	2.8357	9.8427
Underdrain	0	0
Soil Moisture	-0.21877	-0.75935
Stay-on	28.322	98.3065

RUN SIMULATION

CLEAR RESULTS

Developed by the University of Wisconsin-Madison
Civil & Environmental Engineering Water Resources Group
(D. Atchison, A. Dussailliant, L. Severson)

RECARGA Model



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RECARGA Modeling Modes

- Continuous Simulation
  - Model-generated runoff
  - User-supplied inflow to the rain garden
  - Evaporation and percolation simulated between storm events
- Design-Storm
  - Type I, IA, II, III
  - 24-hour storm event plus 3 additional days without rain
  - Summarizes mass balance terms over 4-day period
  - Unit hydrographs scaled by rainfall depth
  - Regional ET value read from GUI

Precipitation

- Precipitation
  - User supplied in .txt file containing hourly precipitation for region of interest

Mad1992.txt - Notepad

File Edit Format Help

t(h)	rain (mm)	evap (mm)
0	0	0.190822929
1	0	0.190822929
2	0	0.190822929
3	0	0.190822929
4	0	0.190822929
5	0	0.190822929
6	0	0.190822929
7	0	0.190822929
8	0	0.190822929
9	0	0.190822929
10	0	0.190822929
11	0	0.190822929

Runoff

- Impervious Areas
  - Runoff=Rainfall at each time step-available depression storage
- Pervious Surface: SCS curve number methodology
  - User characterizes pervious surface with a CN
  - Each timestep the runoff is calculated as the difference in cumulative runoff between timesteps

$$Q = \frac{\left(P_i - 0.2 * S\right)^2}{P_i + 0.8 * S}$$

$$s = \frac{100}{CN} - 10$$

$$Q_i = Q - Q_{i-1},$$

Infiltration
(Green-Ampt)

- Infiltration rate = inflow intensity for time periods less than the time of ponding

$$i = f \quad \text{if} \quad 0 \le t \le t_p \qquad t_p = \frac{SMi}{\frac{i}{K_s} - 1}$$

  - i = inflow intensity
  - f = infiltration rate
  - tp = time of ponding
  - M = initial soil moisture deficit ($\theta_{sat} - \theta_{ini}$)
  - S = Average capillary suction head at wetting front
  - Ks = Saturated Hydraulic Conductivity

- Else $f = K_s + \frac{K_s SM}{F}$ if $t \ge t_p$
  - F = cumulative infiltration

Evapotranspiration

- Maximum Potential Evaporation Included as pan evaporation data in precipitation
- Pan coefficient = 0.75 applied in program

$$ET = E_{p(\max)}\left(1-\left[1-A_W\right]^{-b}\right) \qquad A_W = \frac{(\theta-\theta_{wp})}{(\theta_{fc}-\theta_{wp})}$$

Campbell and Norman, 1997

- If $\theta < \theta_{wp}$ ET = 0
- If $\theta > \theta_{fc}$ ET = E_{pMax}
- Otherwise ET=function of available water

Aw = available water fraction
θ = water content of the root zone
θfc = field capacity of the root zone
θwp= wilting point of the root zone
b = exponent of moisture release

Moisture Flux Below the Surface

- Drainage is assumed to be gravity driven only
- User supplies Saturated Hydraulic Conductivity
- Program calculates Unsaturated Hydraulic Conductivity from Van Genuchten Relationship based on moisture content (Van Genuchten, M. T. 1980)

$$Drainage = K_{sat}\Theta^{\frac{1}{2}}\left[1-\left(1-\Theta^{\frac{1}{2}}\right)^{m}\right]^{2}$$

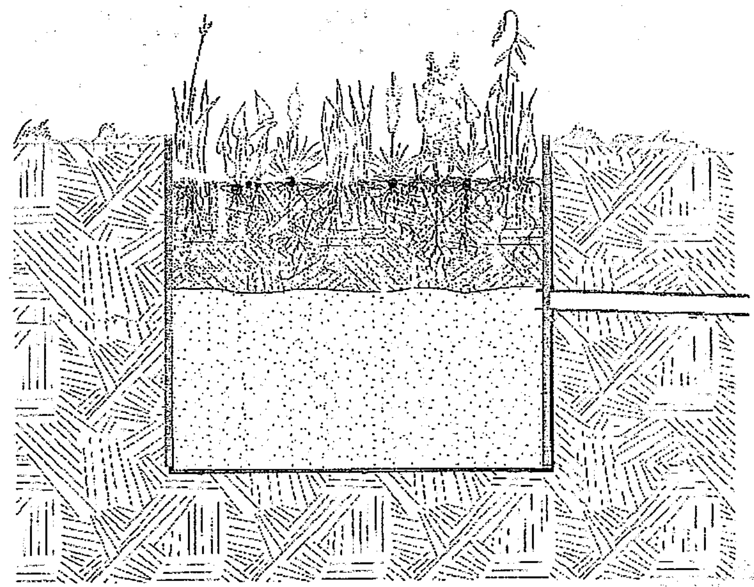
Ksat = Saturated Hydraulic Conductivity
Θ = dimensionless water content
m = 1-1/n
n = Van Genuchten Parameter

Underdrain

- Discharge occurs only after storage zone is saturated
- Orifice equation:
  - C = Constant (0.62)
  - Q = Flow through orifice
  - Au = Cross-sectional area or orifice
  - Hu = Total head over the underdrain
  - g = Gravity
  - hp = Head in ponding zone
  - θ = Volumetric water content of soil

$$Q = C_o A_u \sqrt{2gH_u}$$

- Actual flow is the difference in maximum theoretical flow through orifice and percolation through layers



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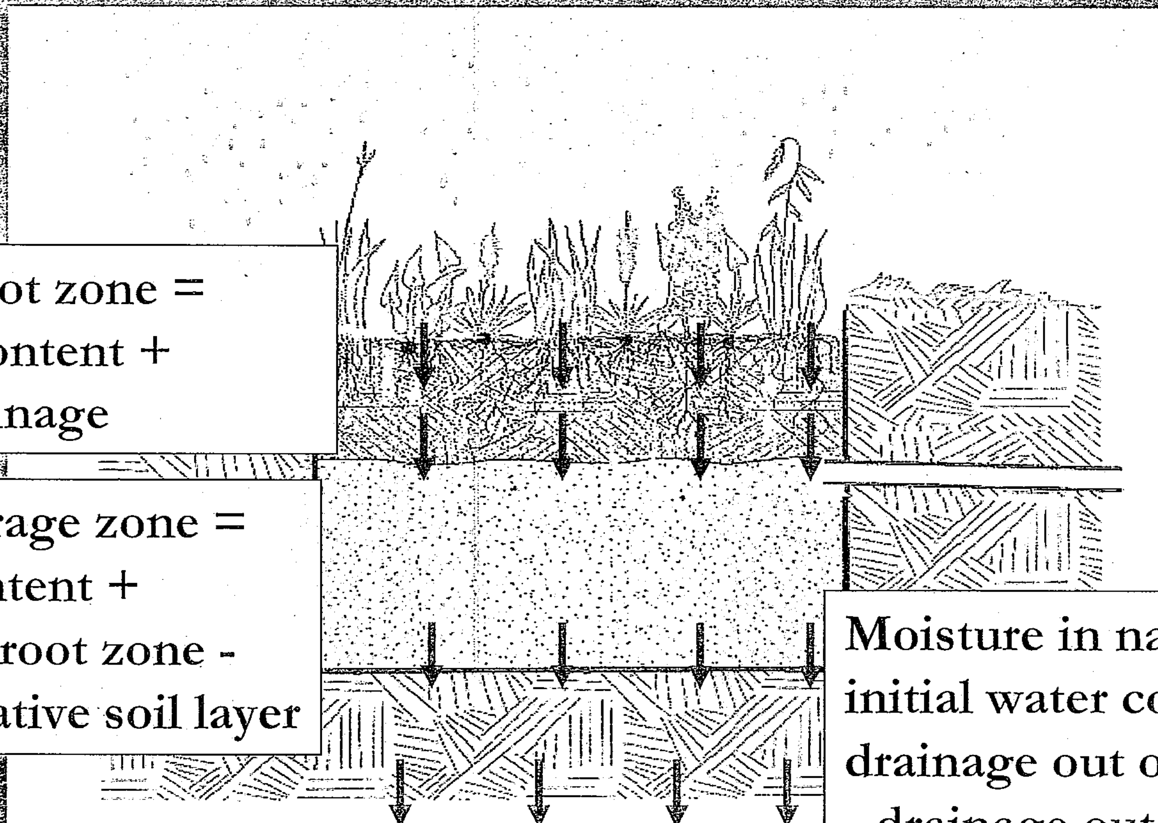
Mass Balance

- Mass balance performed in each of three layers
  - root zone
  - storage zone
  - native soil
- Each zone is classified by a dropdown menu
  - (Rawls, et al 1998)

	Porosity	Effective Porosity	Ksat (cm/hr)
'Sand'	0.42	0.39	9.14
'Loamy Sand'	0.4	0.35	4.14
'Sandy Loam'	0.41	0.3	1.28
'Loam'	0.42	0.27	0.62
'Silt Loam'	0.45	0.31	0.34
'Sandy Clay Loam'	0.39	0.18	0.28
'Clay Loam'	0.42	0.18	0.07
'Silty Clay Loam'	0.46	0.23	0.49
'Sandy Clay'	0.4	0.17	0.09
'Silty Clay'	0.48	0.21	0.18
'Clay'	0.44	0.14	0.18

Mass Balance



Moisture in root zone = initial water content + infiltrated-drainage

Moisture in storage zone = initial water content + drainage out of root zone - drainage into native soil layer

Moisture in native soil = initial water content + drainage out of storage zone - drainage out of native soil layer (assumed 10 ft)

- Saturated zones limit drainage from above layer

Summary Screen

RECARGA 2.3
Date: 12-Jan-2004 10:51:45
Output File: Example.txt
Input File: Mad1981.txt
Number of time steps= 25537
CPU elapsed time (s)= 46

INPUT TERMS
%Impervious= 80
Pervious CN= 80
Facility Area (m2)= 100
Trib. Area (m2)= 1000
RATIOimp2rg= 6
RATIOperv2rg= 4

LAYER	DEPTH (cm)	Ksat (cm/hr)	TEXTURE
Depression	15	---	---
Root Zone	45	10.00	2
Storage	30	15.00	1
Native	---	0.34	5

Init. Cond.: suction head (cm)= -100
Max. Underdrain flow (cm/hr)= 0.31
Underdrain diam (mm)= 7

WATER BALANCE TERMS

	Volume(m3)	Depth (cm)	%of Inflow
Inflow	400.52	36.41	100.00
Runoff	23.66	2.15	5.91
Recharge	208.58	18.96	52.08
Evaporation	79.38	7.22	19.82
Underdrain	95.73	8.70	23.90
Storage	-6.83	-0.62	-1.71
Infiltrated	376.86		
Precip.		73.18	
Imp. Inflow	317.31	52.89	79.23
Perv.Inflow	30.32	7.58	7.57
Basin Stayon(cm)		38.41	

Mass Balance Checks:
Vinsoil=input-roff-dvh
Vinsoil (m3)= 3.768642e+002
Vinf difference (%)= -0.0
Vrecharg1=inf-et-dsws
Vrecharg1 (m3)= 2.085808e+002
Vrech difference (%)= 0.0
dVsoil=inf-rech-et
dVsoil= 8.889862e+001
dVsfce (m3)= 0.000000e+000
dVs2=input-roff-inf

PLANT SURVIVABILITY TERMS
total time ponded (h)= 129.8
max time ponded (h)= 27.5
total time RZ saturated (h)= 146.5
total time RZ at wilting point (h)= 1851.3
total time TZ saturated (h)= 252.3
max time RZ saturated (h)= 28.8
max time RZ at wilting point (h)= 648.5
max time TZ saturated (h)= 45.8
near saturated times for simulation= 11
727.8 9.5
2319.8 28.8
2946.0 0.5
2981.3 27.0
3764.0 28.8
4043.8 4.5
4058.8 12.5
4073.0 8.5
4172.3 22.3
4310.0 0.8
5276.3 3.5
wilting point times for simulation= 11
554.3 145.3
652.3 25.3
1132.0 75.5
1884.8 648.5
2128.5 141.8
2233.0 11.5
2918.0 187.5
3727.3 67.3
4012.5 34.3
4643.8 54.5
6068.0 460.0
ponded times for simulation= 10
726.3 8.0
2318.5 27.5
2945.8 0.3
2979.8 25.3
3762.5 27.3
4042.3 2.3
4057.3 10.8
4071.8 7.0
4170.8 20.8
5274.8 0.8
overflow times for simulation= 3
2294.3 2.8
2956.0 0.3
3738.5 1.3

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Record Output

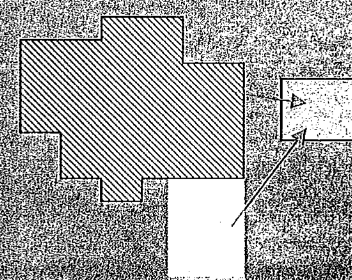
Time(hr)	Runon(cm)	Ponding(cm)	Infil(cm)	Runoff(cm)	Drain(cm)	Recharge(cm)	ET(cm)	ThetaRZ	ThetaSZ	ThetaCZ
653	0.817	0	0.817	0	0	0.002	0	0.134	0.194	0.39
654	1.978	0	1.978	0	0	0.002	0	0.204	0.194	0.39
655	4.385	0	4.385	0	0.028	0.002	0	0.292	0.194	0.39
656	2.559	0	2.559	0	0.201	0.002	0	0.327	0.199	0.39
657	0.6	0	0.6	0	0.239	0.002	0	0.322	0.209	0.39
658	0	0	0	0	0.236	0.002	0.017	0.312	0.216	0.39
659	0	0	0	0	0.232	0.002	0.017	0.304	0.219	0.39
660	0	0	0	0	0.228	0.002	0.017	0.297	0.221	0.391
661	0	0	0	0	0.225	0.002	0.017	0.292	0.221	0.391
662	0	0	0	0	0.206	0.002	0.017	0.287	0.221	0.391
663	0	0	0	0	0.18	0.002	0.017	0.283	0.221	0.391
664	0	0	0	0	0.159	0.002	0.004	0.279	0.221	0.392
665	0	0	0	0	0.143	0.002	0	0.276	0.221	0.392
666	0.422	0	0.422	0	0.132	0.002	0	0.289	0.221	0.392
667	1.778	0	1.778	0	0.203	0.002	0	0.33	0.224	0.393
668	2.2	0	2.2	0	0.241	0.002	0	0.353	0.244	0.393
669	0.956	0	0.956	0	0.249	0.002	0	0.343	0.27	0.395
670	0.111	0	0.111	0	0.245	0.002	0	0.328	0.286	0.398
671	0	0	0	0	0.239	0.003	0.017	0.317	0.293	0.403
672	0	0	0	0	0.234	0.004	0.017	0.308	0.296	[illegible]

Example RECARGA Analysis

Reduce Runoff

Design raingarden to eliminate roof and driveway runoff on an average annual basis

- Watershed description
  - Native soils = loam
  - Impervious Area = .077 acres
- Start with raingarden 15% of impervious area=503 sq. ft.
- Manipulate
  - Raingarden area
  - Storage zone
  - Depth of root zone
  - Ponding depth



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Water Quality Objective

Effects of an Underdrain

	Without an Underdrain	With a 4 in. Underdrain
Stayon (in.)	24.77	19.01
Underdrain (in.)	0	8.63
Overtopping (in.)	4.04	1.17
Total (in.)	28.81	28.81
Total Ponding Time (hr.)	*303.5*	*19*

- Facility Area =300 sq. ft.
- Tributary Area=0.077 acre
- 100% Impervious
- Ponding Depth=6 in.
- Root Depth=24 in.
- Root Zone Ksat=3.94 in/hr
- Native Soil Ksat=0.24 in/hr
- Madison, WI Rainfall 1981

Groundwater Recharge Objective

Effects of a Storage Zone

	Without a Storage Zone	With a 3 ft. Storage Zone
Stayon (in.)	24.77	26.87
Groundwater Recharge	14.05	16.24

- Facility Area =300 sq. ft.
- Tributary Area=0.077 acre
- 100% Impervious
- Ponding Depth=6 in.
- Root Depth=24 in.
- Root Zone Ksat=3.94 in/hr
- Native Soil Ksat=0.24 in/hr
- Madison, WI Rainfall 1981

References

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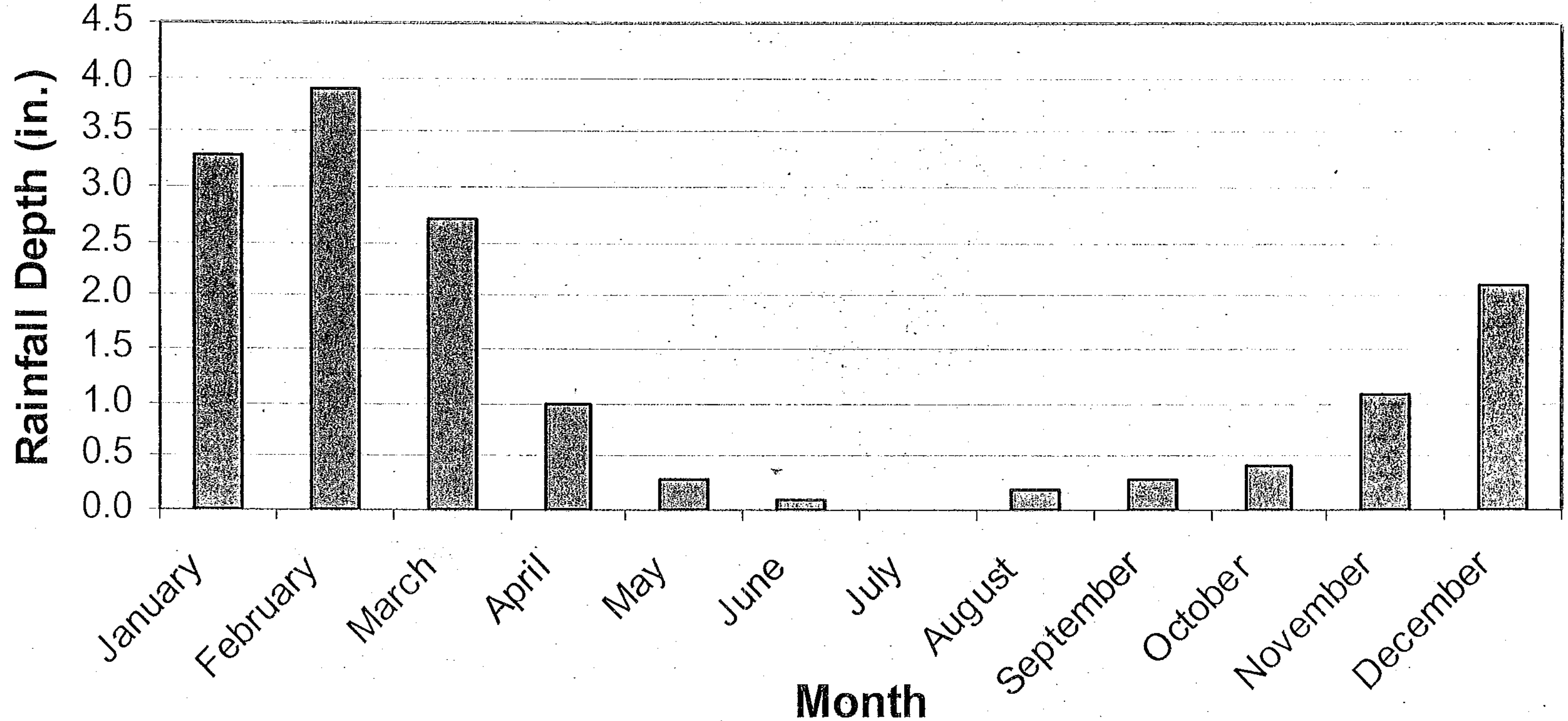
- Van Genuchten, M. T. 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Sci. Soc. Am. J.* 44:892-98.

LA Climate and Bio/Infiltration Design



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Bio/Infiltration Area Surface Treatment

- Native forbs and grasses
- Wide variety of species
- Seasonal transpiration and maintenance of infiltration capacity

Bio/Infiltration Area Surface Treatment

- Stone mulch
- No transpiration, almost no evaporation
- Migration of fines may reduce subsoil infiltration capacity

Bio/Infiltration Area Surface Treatment

- Shredded bark mulch, with selected plantings
- Some transpiration, little evaporation
- Mulch easily replaced
- Migration of fines may reduce subsoil infiltration capacity

Discussion

- Thank You
- Possible action plan in our agenda

WERF

Water Environment Research Foundation

INTERNATIONAL STORMWATER BMP DATABASE

EPA Meeting
Washington, DC
January 24, 2007

What is the BMP Database?

- Provides a mechanism for scientifically based collection and management of BMP field data and information linked to site conditions and design parameters.
- Contains data from sites throughout the United States and other countries.
- All data submitted undergoes a QA/QC check.
- www.bmpdatabase.org

BMP Database Coalition Partners

- Water Environment Research Foundation (WERF)
- Federal Highway Administration (FHWA)
- American Society of Civil Engineers – Environmental & Water Resources Institute (ASCE-EWRI)
- American Public Works Association (APWA)
- Environmental Protection Agency (EPA)

Steering Committee Members

- Jeff Moeller, WERF
- Patricia Cazenas, FHWA
- Brian Parsons, ASCE-EWRI
- Colene Carter, APWA
- Eric Strassler, EPA

WERF

ASCE
American Society of Civil Engineers

EWRI

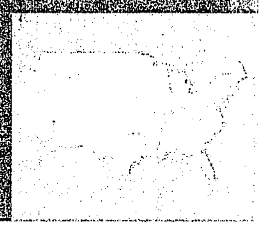
EPA

U.S. Department of Transportation
Federal Highway Administration

APWA

Project Subcommittee (PSC) Members

- Ben Urbonas, Urban Drainage and Flood Control District (PSC Chair)
- Michael Barrett, University of Texas
- Bob Carr, Water Resources Modeling
- Gregory Granato, U.S. Geological Survey
- David Graves, New York State DOT
- Jesse Pritts, EPA
- Richard Tveten, Washington State DOT



Project Team

Co-Principal Investigators:

- Jon Jones, Wright Water Engineers, Inc.
- Eric Strecker, GeoSyntec Consultants

- Jane Clary, Wright Water Engineers, Inc.
- Jon O'Brien, Wright Water Engineers, Inc.
- Marcus Quigley, GeoSyntec Consultants

Why was the BMP Database developed?

The Problem in '94 and Now:

- Widespread use of BMPs without sufficient understanding of performance and factors affecting performance
- Inconsistent data collection and reporting
  - Limited objective comparisons and evaluations
  - Wide range of reported "effectiveness"

Addressing the Problem
(Efforts from 1995-2007)

- History: Initial funding from USEPA in 1995 of the Urban Water Resources Research Council of ASCE.
- Goal: To gather and distribute sufficient technical design/performance information to:
  - Provide technical data for research
  - Improve BMP selection
  - Improve BMP design
  - Foster cost-effective stormwater solutions

Key Tasks

- Develop standardized BMP performance data reporting protocols
- Compile data of BMP performance in USA and other countries
- Develop a database and store data on BMP performance, the facility's site conditions, and design parameters
- Analyze data using rigorous standardized statistical protocols
- Continue populating the database to help improve BMP designs and their proper applications.

International Stormwater Best Management Practices (BMP) Database

Project Sponsors

WERF

ASCE

EWRI

EPA

U.S. Department

New Download! Analysis of Treatment System Performanace Provides a summary analysis of BMPs entered into the database through 2005.

New Link! November 29, 2006 Center for Transportation and Environment Telecast

Welcome to the International Stormwater Best Management Practices (BMP) Database project web site, which features technical documents, software and database developed over the past decade. The overall purpose of the project is to provide scientifically sound information to improve the design, selection and performance of BMPs. To accomplish this goal, the Project Team has developed tools to promote scientifically-based collection and management of the data needed to evaluate the effectiveness of stormwater runoff BMPs. These tools include standardized BMP monitoring and reporting protocols, a stormwater BMP database, BMP performance evaluation protocols, and BMP monitoring guidance. Continued population of the database and assessment of its data will ultimately lead to a better understanding of factors influencing BMP performance and help to promote improvements in BMP design, selection and implementation.

The project, which began in 1996 under a cooperative agreement between the American Society of Civil Engineers (ASCE) and the U.S. Environmental Protection Agency (USEPA), now has support and funding from a broad coalition of partners including the Water Environment Research Foundation (WERF), ASCE Environmental and Water Resources Institute (EWRI), USEPA, Federal Highway Administration (FHWA) and the American Public Works Association (APWA). Wright Water Engineers, Inc. and GeoSyntec Consultants are the entities maintaining and operating the database clearinghouse and web page, answering questions, conducting analyses of newly submitted BMP data, conducting updated performance evaluations of the overall data set, disseminating project findings, and expanding the database to include other approaches such as Low Impact Development techniques. The database itself is downloadable to any individual or organization that would like to conduct its own assessments.

On this web site, you can obtain:

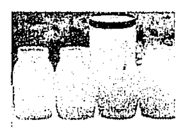
- the minimum protocols for submitting BMP monitoring studies for inclusion into the

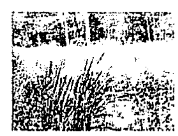
What information is available on the BMP Database web site?

- Guidance for monitoring stormwater BMPs.
- Data entry software to store BMP monitoring data.
- Performance summaries for individual BMPs through the on-line searchable database containing roughly 200 BMPs.
- Statistical summaries of the overall BMP database and summaries of performance by BMP types (e.g., wet ponds).
- Results of performance evaluations.

Analysis of Treatment System Performance

International Stormwater Best Management Practices (BMP) Database [1999-2005]





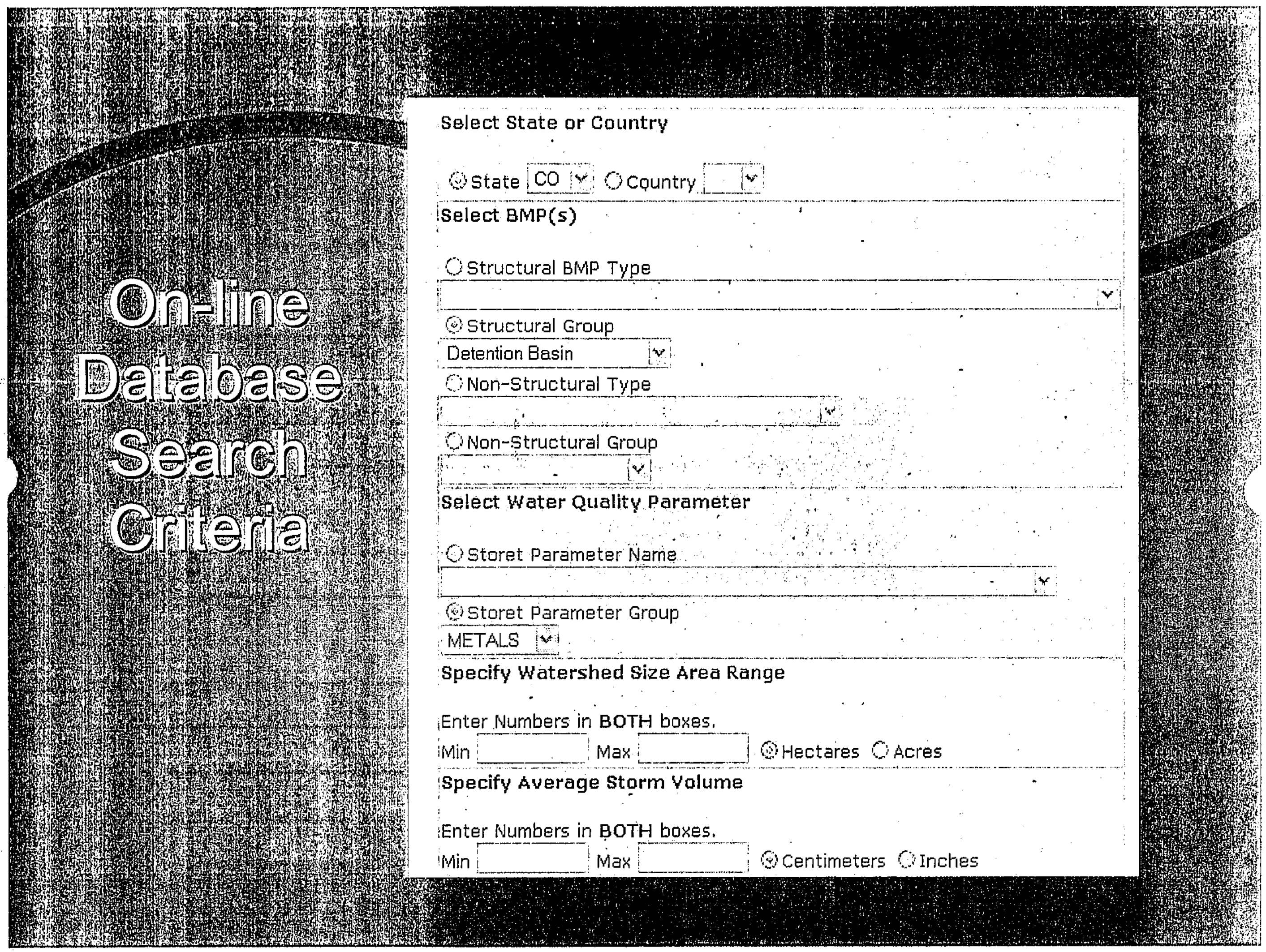
Prepared by:
GeoSyntec Consultants
Wright Water Engineers, Inc.

Prepared for:
Water Environment Research Foundation
American Society of Civil Engineers (Environmental and Water Resources Institute Urban Water Resources Research Council)
U.S. Environmental Protection Agency
Federal Highway Administration
American Public Works Association

February 2006

Stormwater BMP Database: Current Number of BMPs

BMP CATEGORY	NUMBER OF BMPS
Structural	
Biofilter	59
Detention Basin	26
Hydrodynamic Device	23
Infiltration Basin	1
Media Filter	38
Percolation Trench/Well	1
Porous Pavement	5
Retention Pond	37
Wetland Basin	15
Wetland Channel	14
Total Structural	219
Non-Structural	
Maintenance Practices	28


On-line Database Search Criteria
Select State or Country
State CO Country
Select BMP(s)
Structural BMP Type
Structural Group
Detention Basin
Non-Structural Type
Non-Structural Group
Select Water Quality Parameter
Storet Parameter Name
Storet Parameter Group
METALS
Specify Watershed Size Area Range
Enter Numbers in BOTH boxes.
Min Max Hectares Acres
Specify Average Storm Volume
Enter Numbers in BOTH boxes.
Min Max Centimeters Inches

Standardized Data Reporting Protocols (Software and/or Spreadsheets)

Microsoft Access - [General Test Site Information]

File Edit Help

General Test Site Information

BMP Test Site Name: Lakewood Sand Filter Vault (95-99)

City	Lakewood	USGS Quadrangle Map Name	Fort Logan, CO
County	Jefferson	Principal Meridian	6 Range 69W Township 4S
State	CO	Section	4 Quarter-Quarter-Quarter NE NE SW
Zip Code	80215-0000	Latitude	39 degrees 43 minutes 45 seconds
Country	US	Longitude	105 degrees 7 minutes 10.8 seconds
Time Zone	-6	Altitude	5600 Unit ft
Hydrologic Unit Code		EPA Reach Code	

Comments: This BMP is located in the City of Lakewood's Maintenance Shops.

Note: Fields in blue are required, those in black are not.

Why is WERF interested in the BMP Database?

WERF Subscriber Stormwater Survey

Ranking by Mean Score of

Stormwater Research Topics

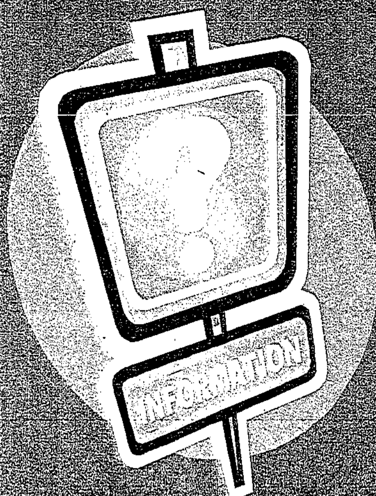
Rank	Research Topic
1	Stormwater Controls (BMPs)
2	Receiving Water Effects
3	TMDLs
4	Source Identification and Control
5	Monitoring
6	Indicators
7	Modeling
8	Program Management
9	Conveyance and Storage
10 (tie)	Land Use
10 (tie)	Communication/Public Education

Ranking by Mean Score of

Need for Information on Various Aspects of Stormwater Controls (BMPs)

Rank	Need for Information on Aspects of BMPs
1	Effectiveness
2	Operation and Maintenance
3	Whole Life Costs
4	Performance Standards
5	Fate of Captured Pollutants
6	Mechanical vs. Natural Systems
7	Retrofitting
8	Regional vs. Smaller Systems

WERF Stormwater Research Program

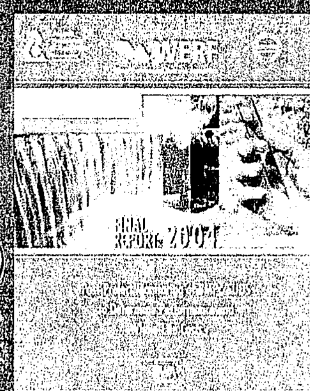


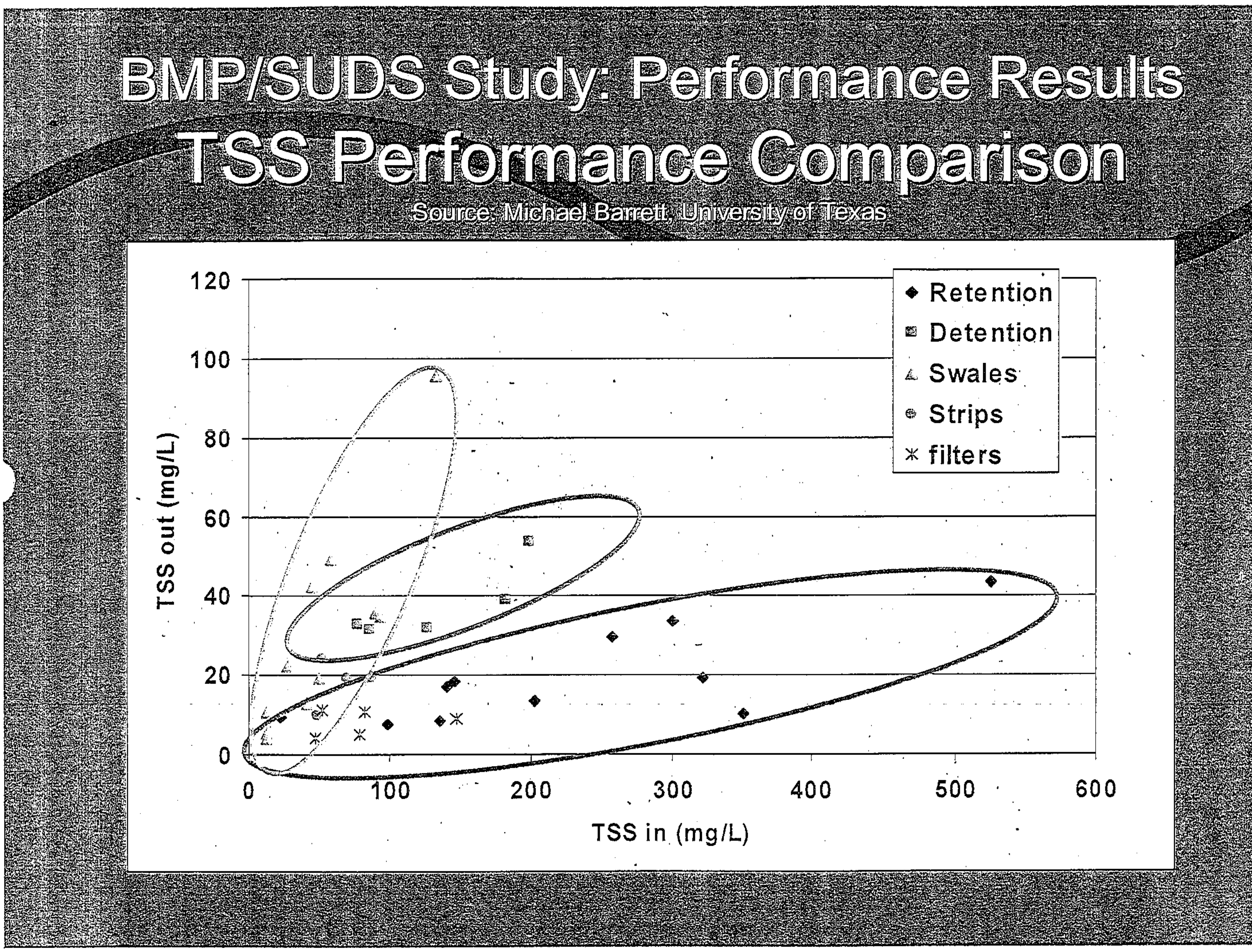
- Over 60+ ongoing and completed stormwater projects to date valued at $17+ million

- www.werf.org

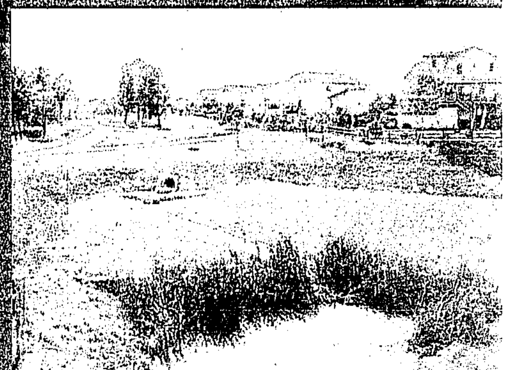
WERF Research Project: BMP/SUDS Study (01-CTS-21Ta)

- Co-funded by UKWIR and AwwaRF
- $700k Total
- Phase 1 published May 2004:
  - *Post-Project Monitoring of BMPs/SUDS to Determine Performance and Whole Life Costs* (Stock No. 01CTS21T)
    - Literature Review
    - Performance Protocols & Study Plan
- Phase 2 published Aug. 2005:
  - *Performance and Whole Life Costs of BMPs and SUDS* (Stock No. 01CTS21Ta)
    - BMP Performance
    - Whole Life Costs
    - O&M Practices




BMP/SUDS Study: Performance Results
TSS Performance Comparison
Source: Michael Barrett, University of Texas
TSS out (mg/L)
TSS in (mg/L)
0
20
40
60
80
100
120
0
100
200
300
400
500
600
Retention
Detention
Swales
Strips
filters

Research Project: Stormwater Control Selection Issues (02-SW-1)

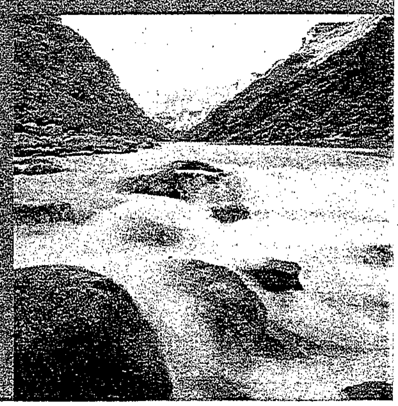


- Published fall 2005
- PI: Eric Strecker, GeoSyntec Consultants
- Objective: To apply fundamental environmental engineering principles of unit operations to evaluation and selection of BMPs for urban areas.

New Research Challenge (06-SW-1):
Linking BMP Systems Performance to Receiving Water Protection to Improve BMP Selection and Design

GOAL:

To link BMP control effectiveness for specific pollutants and flow to receiving water loadings, impacts and water quality objectives to improve selection and design of BMP systems.



DURATION: 2-3 years

FUNDING: $670,000

WHAT SUCCESS WOULD LOOK LIKE?

- Provide basic science on forms and fates of pollutants of concern.
- Improve understanding of the uncertainty of effectiveness of systems of BMPs.
- Link/quantify BMP systems performance to receiving water impacts mitigation.
- Tools to understand the collective effectiveness of stormwater controls in attaining watershed goals.

The International BMP Database

Jeff Moeller, WERF
Eric Strecker, Geosyntec Consultants

BMP Performance Information: The Problems

- Inconsistent data collection and reporting:
  - Constituents
  - Sample collection techniques
  - Sampling approaches/strategies
  - Data reporting
  - Effectiveness estimation
  - Statistical validation of results

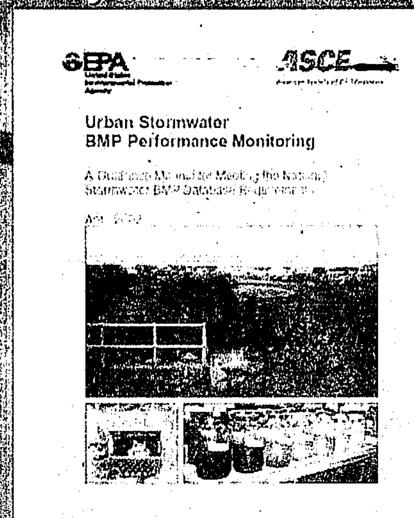
- Result in wide range of reported "effectiveness" (e.g. – to + percent removals)
- Widespread use of BMPs and faulty BMP performance information without sufficient understanding of performance and factors leading to performance

Estimated BMP Pollutant Removal Performances in BMP Manuals

	TSS	TP	COD	PB	CU	ZN
Stormwater Ponds						
Wet Pond	80	45	40	75	NA	60
Dry Extended Detention	45	25	20	50	NA	20
Wet Extended Detention	80	65	NA	40	NA	20
Stormwater Marsh	**-20 to 98**	**-140 to 98**		**6 to 94**		
Vaults/Tanks	60	30	NA	30	NA	30
Infiltration						
Infiltration Trenches/Dry Well	75	60	65	65	NA	65
Infiltration Basins	75	60	65	65	NA	65
Porous Pavements	90	65	80	100	NA	100
Filtration						
Sand FIlter	85	55	55	82	53	76
Vegetated Swale	83	29	NA	63-72	63-72	63-72

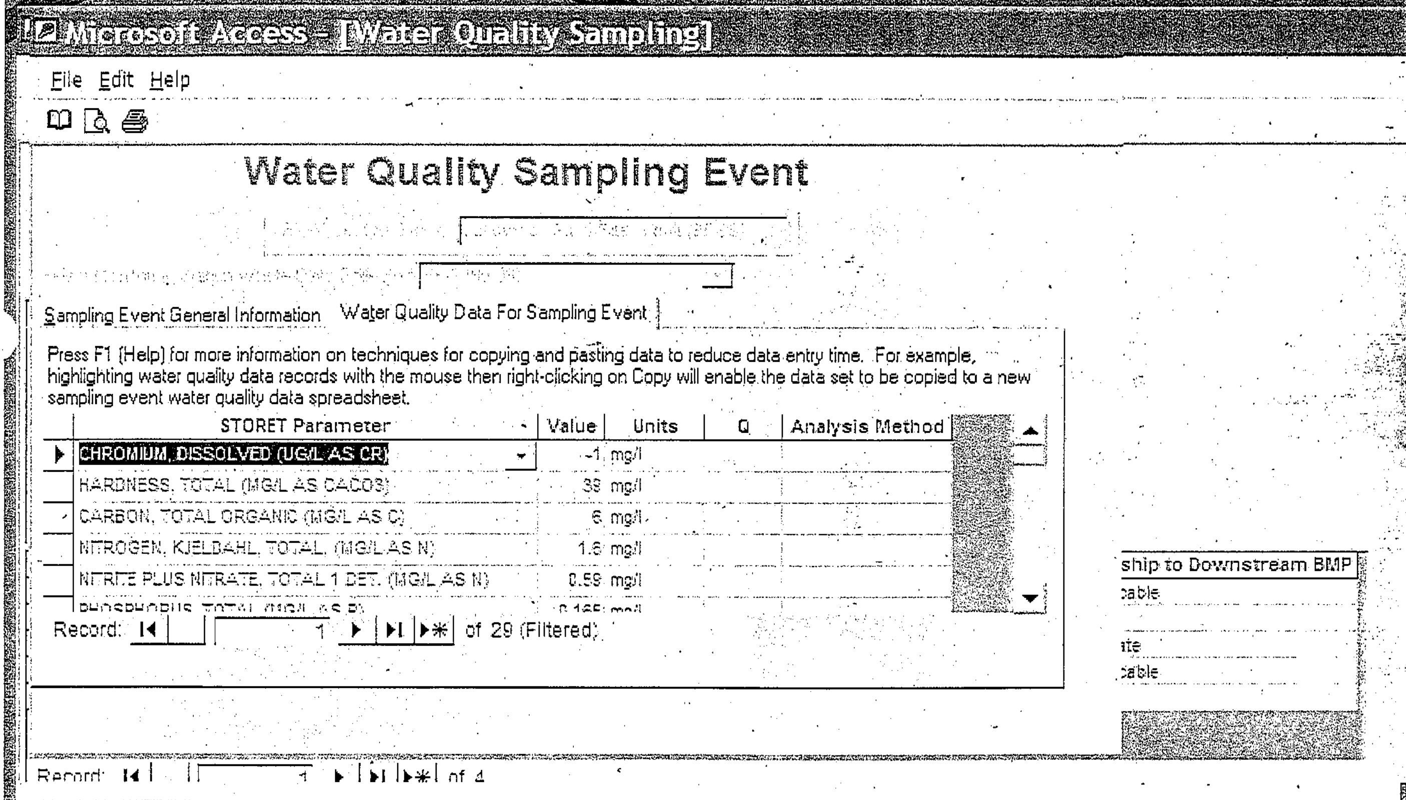
Source: Portland, OR, Stormwater Quality Facilities: A Design Guidance Handbook

Project Approach - A Scientifically Rigorous BMP Data Collection and Analysis Effort



- Development of protocols for collection and reporting of BMP performance information
- Establishment of data base
- Establishment of standard techniques for data collection, storage, reporting, and analysis (guidance document)
- Conduct data analysis and exploration
- Disseminate data and findings: www.bmpdatabase.org
  - ✓ **Flat File Database**
  - ✓ **Guidance Manual**
- Promote technically based BMP selection and design improvements

BMP Monitoring and Reporting Protocols: BMP Database Data Entry Module



Distribution of Current Studies (Summer/04)

BMP TOTALS BY CATEGORY

BMP CATEGORY	NUMBER OF BMPS
Structural	
Biofilter (Grass Swales)	32
Detention Basin	24
Hydrodynamic Device	17
Media Filter	30
Percolation Trench/Well	1
Porous Pavement	5
Retention Pond	33
Wetland Basin	15
Wetland Channel	14
Total	**171**
Non-Structural	
Maintenance Practice	28
Total	**28**
Grand Total	**199**

About 25 additional studies added

BMP TOTALS BY STATE/COUNTRY

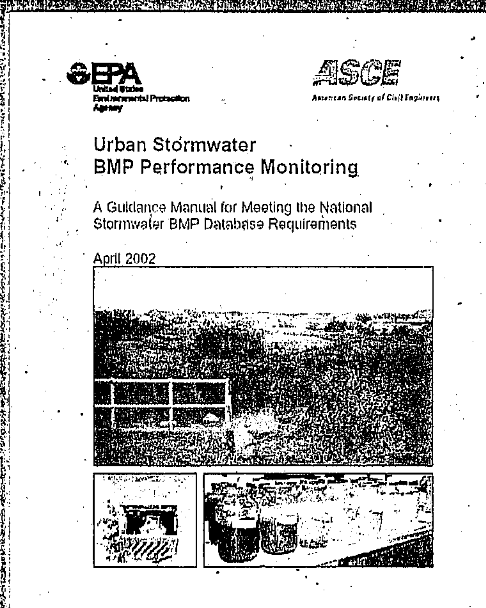
STATE	NUMBER OF BMPS
Domestic	
AL	13
CA	**41**
CO	4
FL	24
GA	2
IL	5
MD	5
MI	5
MN	7
NC	6
NJ	3
OH	1
OR	3
TX	19
VA	29
WA	20
WI	10
International	
Sweden	1
Canada	1

Current Database

BMP CATEGORY	NUMBER OF BMPS
Structural	
Biofilter	59
Detention Basin	26
Hydrodynamic Device	23
Infiltration Basin	1
Media Filter	38
Percolation Trench/Well	1
Porous Pavement	5
Retention Pond	37
Wetland Basin	15
Wetland Channel	14
Non-Structural	
Maintenance Practice	28

Total Structural	219
Total Non-Structural	28
Total BMPs	247

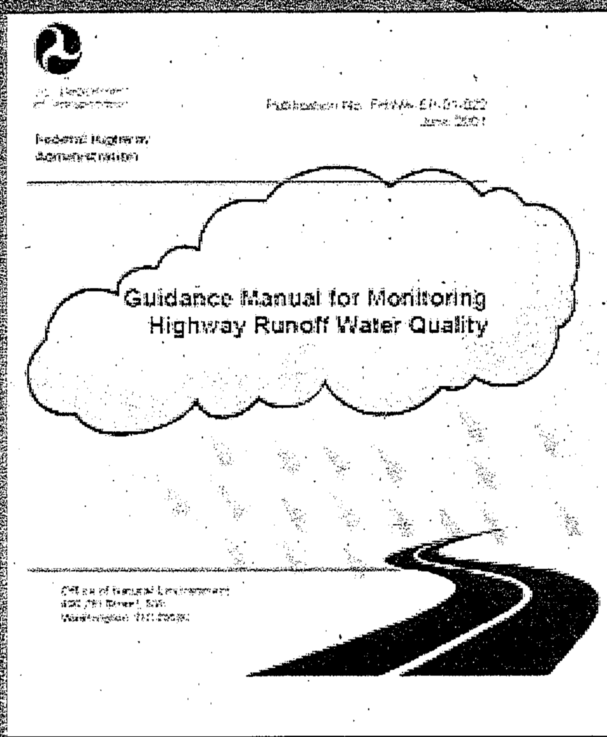
BMP Monitoring Protocols in Practice: The Manual



- Available for download
- Over 25,000 downloads to date from Web site
- Guidance is highly relevant for various levels of BMP monitoring

www.bmpdatabase.org

Related FHWA Manual



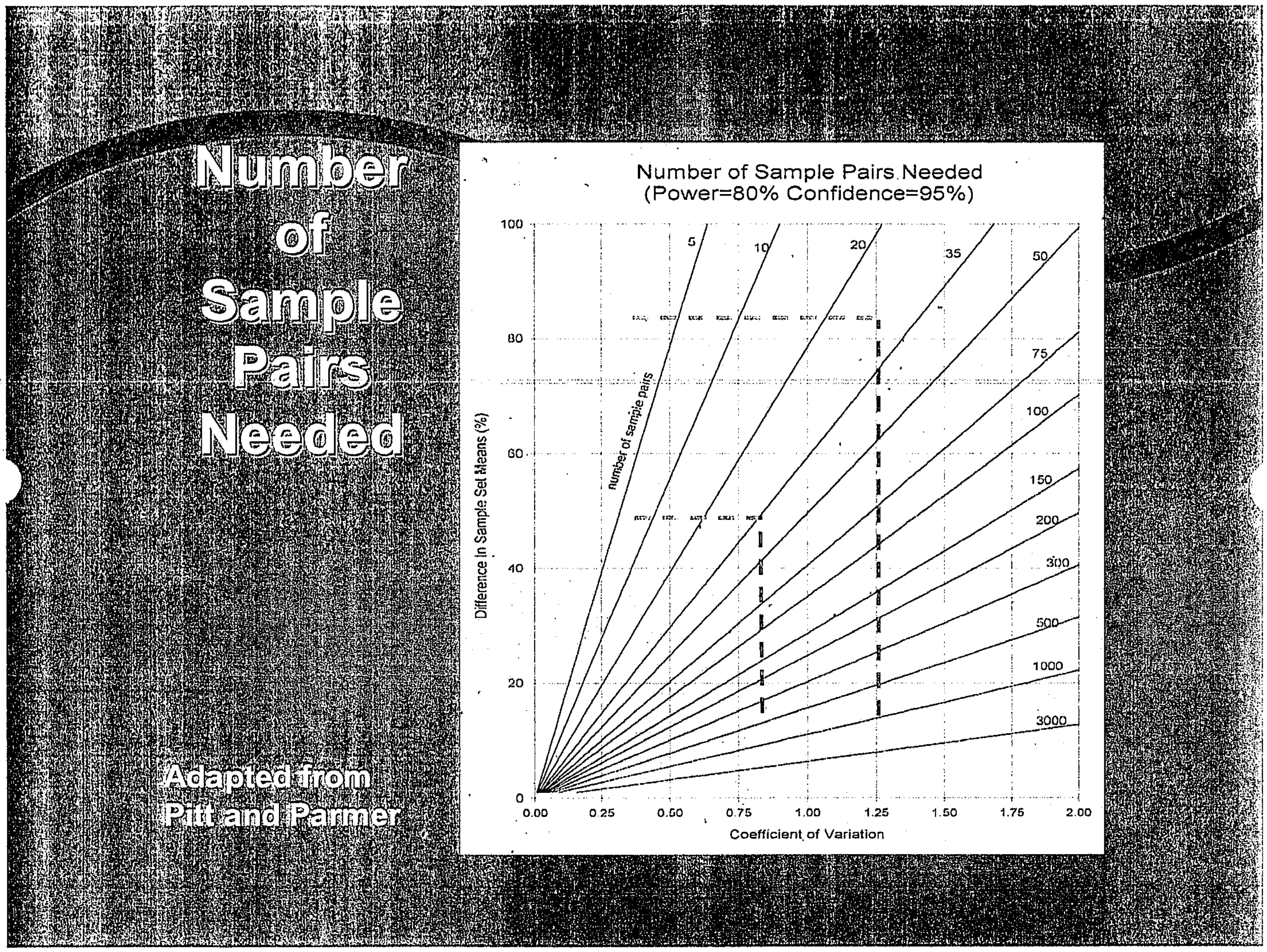
- Manual specifically focused monitoring in highway environment and runoff
- Provides specific equipment selection guidance

Key Guidance Recommendations

- Flow monitoring must be rigorous
- Water quality performance should ultimately be assessed by hydrology/hydraulic as well as effluent quality performance
- Statistically sound approaches must be used to assess water quality performance and should be an integral component of BMP monitoring plan development and implementation as well as data analyses

Understanding Water Quality Variability

- Many sampling programs do not yield useful results – yet they are reported as valid assessments of performance
- Number of samples to obtain a statistically valid result from monitoring program often not considered


Number of Sample Pairs Needed
Adapted from Pitt and Parmer
Number of Sample Pairs Needed
(Power=80% Confidence=95%)
Difference in Sample Set Means (%)
Coefficient of Variation
number of sample pairs
5
10
20
35
50
75
100
150
200
300
500
1000
3000
0
20
40
60
80
100
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00

A000242

Flow Measurement Errors

- Propagate throughout monitoring study (Loads and EMCs)
- Often little or no opportunity for calibration under actual field conditions
- Field conditions problematic (unsteady flow conditions)
- Upstream conditions required for operation of weirs and flumes are often not satisfied
- Many types of devices are not well suited for flows which may vary by three or more orders of magnitude

FHWA/USGS Study Demonstrates the Large Variability in Flow Measurements

-25% to +100% on Average!

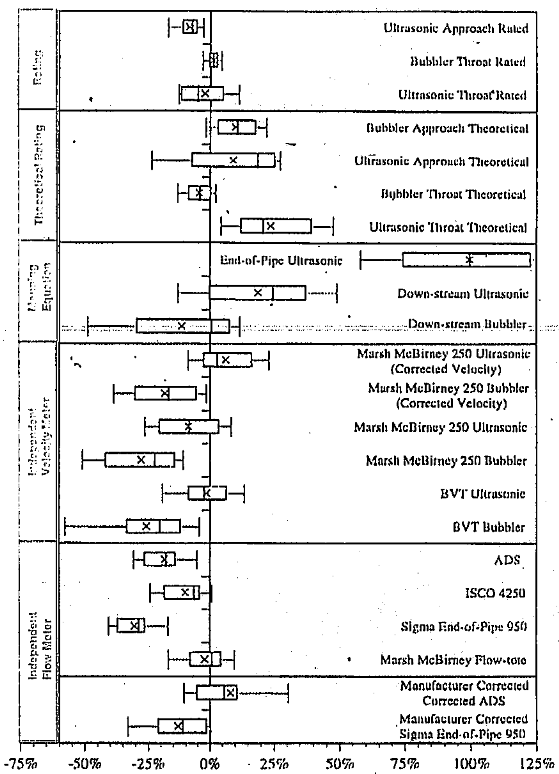
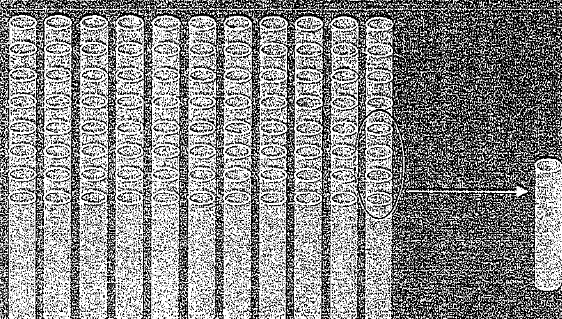


Figure 7. Boxplot of the percent differences between total storm volumes computed using various flow estimation methods and the total storm volume of the bubbler approach rated discharge (bold line at 0%).

Results From Analysis of Flow-Weighted Composite Sampling

- USGS Monitoring Data Set Used
  - Initial Set of 80 sub-samples



What Number of Sub-Samples are Required?

- A minimum of between 12 and 16 sub-samples should be collected during an event

Monitoring Equipment Selection

- Monitoring Location
  - Watershed Type
  - Specific Site Characteristics
  - Location Within a Watershed
    - On the surface (gutter flow, typically grab sample)
    - At inlets (typically grab sample)
    - Mid-conveyance (manhole, in-pipe or open channel)
    - Outfall
- Monitoring Frequency
- Range of Flows to be Monitored

Flow Measurement Equipment Selection Factors

- Site location
- Site condition
- Expected discharge rates
- Allowable loss of capacity
- Accuracy
- Expense
- Installation requirements
- Operations and maintenance requirements
- Special considerations for small watersheds

Sampling Equipment

- Grab Versus Composite Samples
- Manual Versus Automated Sampling Methods
  - Cost
  - Study Objectives
  - Sampling issues with regards to larger particles/debris
- Composite Sampling Approaches
  - Constant volume - time proportional to flow volume increment
  - Constant time - constant volume
  - Constant time - volume proportional to flow increment
  - Constant time - volume proportional to flow rate

Recommended Measures of BMP Performance

- How much stormwater runoff is prevented? ("hydrological source control")
- How much of the runoff that occurs is treated by the BMP or not ("hydraulic performance")?
- Of the runoff treated, what is the effluent quality? ("concentration characteristics achieved")
- Does BMP address downstream erosion impacts?

Percent Removal is Very Problematic and SHOULD NOT be used as a performance measure for BMPs.

Measures of Performance Cont.

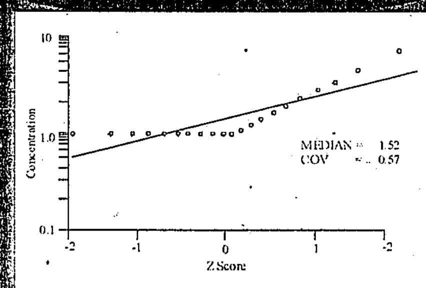
- Recommended approach for water quality
  - Effluent Probability Method
  - Statistically determine that the BMP removes pollutants or not
  - Focus on **EFFLUENT QUALITY**

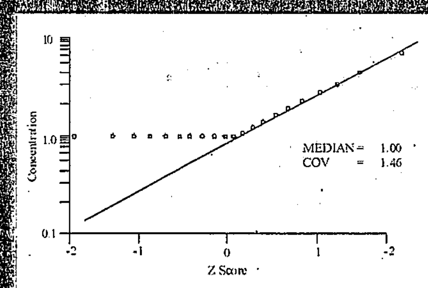
Guidance Manual Appendices

- Data Evaluation and Statistical Hypothesis Testing
- Generic Health and Safety Plan for Monitoring
  - Specific to the Near-Highway Environment
- Example Standard Operating Procedures for Field Sampling
  - Plan Used for Monitoring Work for Field Studies

Data Evaluation and Statistical Hypothesis Testing

- Understanding Detection Limits and Effects on Analysis
- Descriptive Statistics for Log-Normal Data
- Hypothesis Testing
  - Are Two Data Sets Statistically Different from One Another?
  - Are Changes in Water Quality Statistically Significant?
  - Upstream/Downstream or Temporal Comparisons

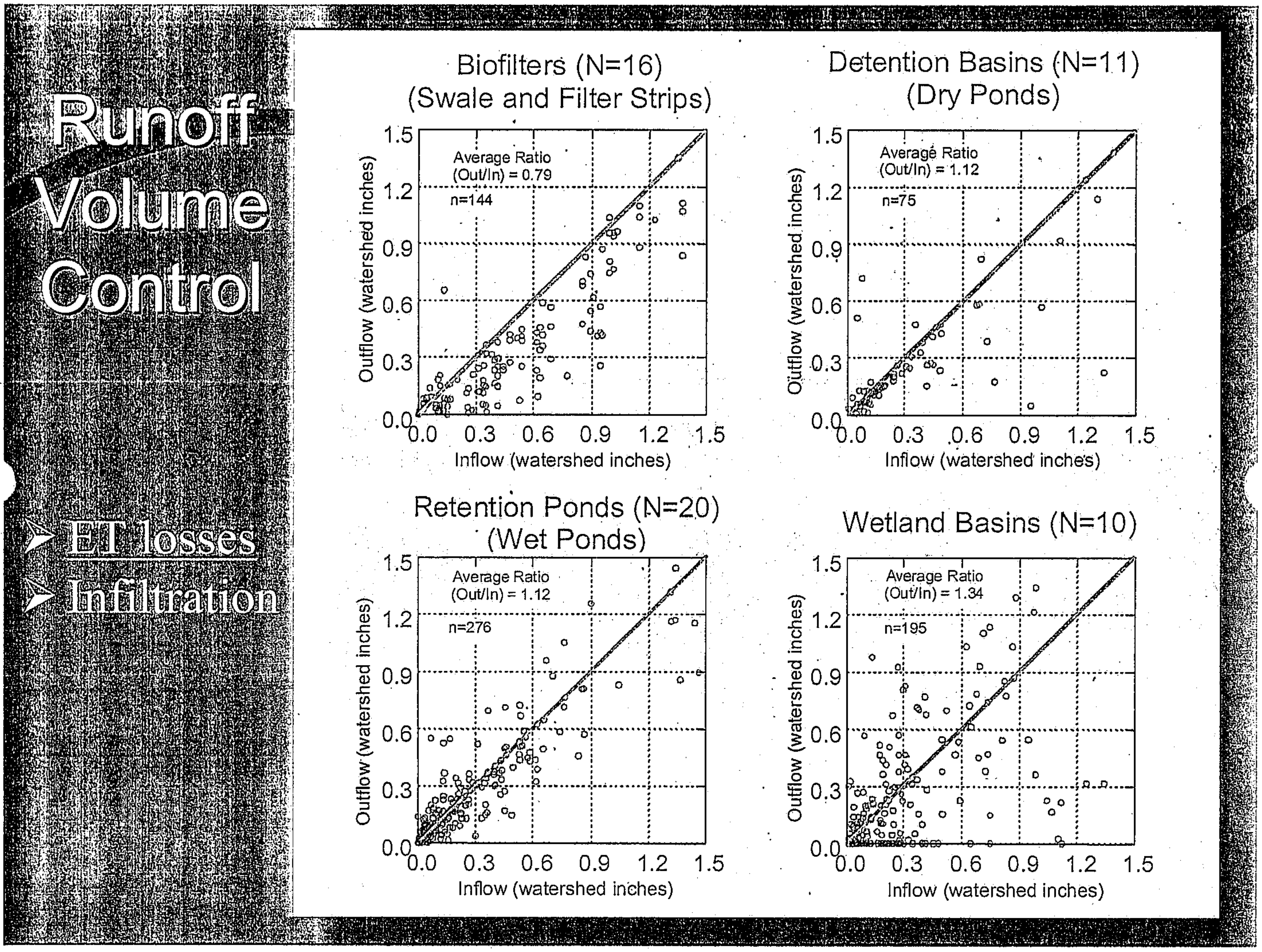




Recommended Measures of BMP Performance

- How much stormwater runoff is prevented? ("hydrological source control")
- How much of the runoff that occurs is treated by the BMP or not ("hydraulic performance")?
- Of the runoff treated, what is the effluent quality? ("concentration characteristics achieved")
- *Does the BMP address downstream erosion impacts?*

Percent Removal is Very Problematic and SHOULD NOT be used as a performance measure for BMPs.



Runoff Volume Control
➤ ET losses
➤ Infiltration
Biofilters (N=16)
(Swale and Filter Strips)
Average Ratio
(Out/In) = 0.79
n=144
Detention Basins (N=11)
(Dry Ponds)
Average Ratio
(Out/In) = 1.12
n=75
Retention Ponds (N=20)
(Wet Ponds)
Average Ratio
(Out/In) = 1.12
n=276
Wetland Basins (N=10)
Average Ratio
(Out/In) = 1.34
n=195
Outflow (watershed inches)
Inflow (watershed inches)
0.0 0.3 0.6 0.9 1.2 1.5

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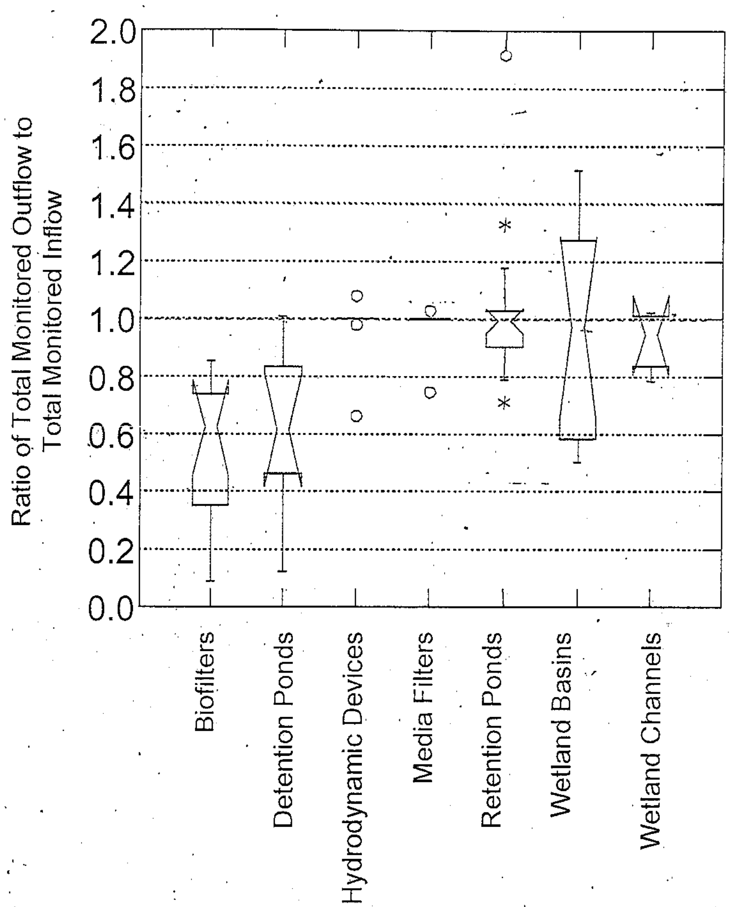
Runoff Volume Control

Statistical Summary



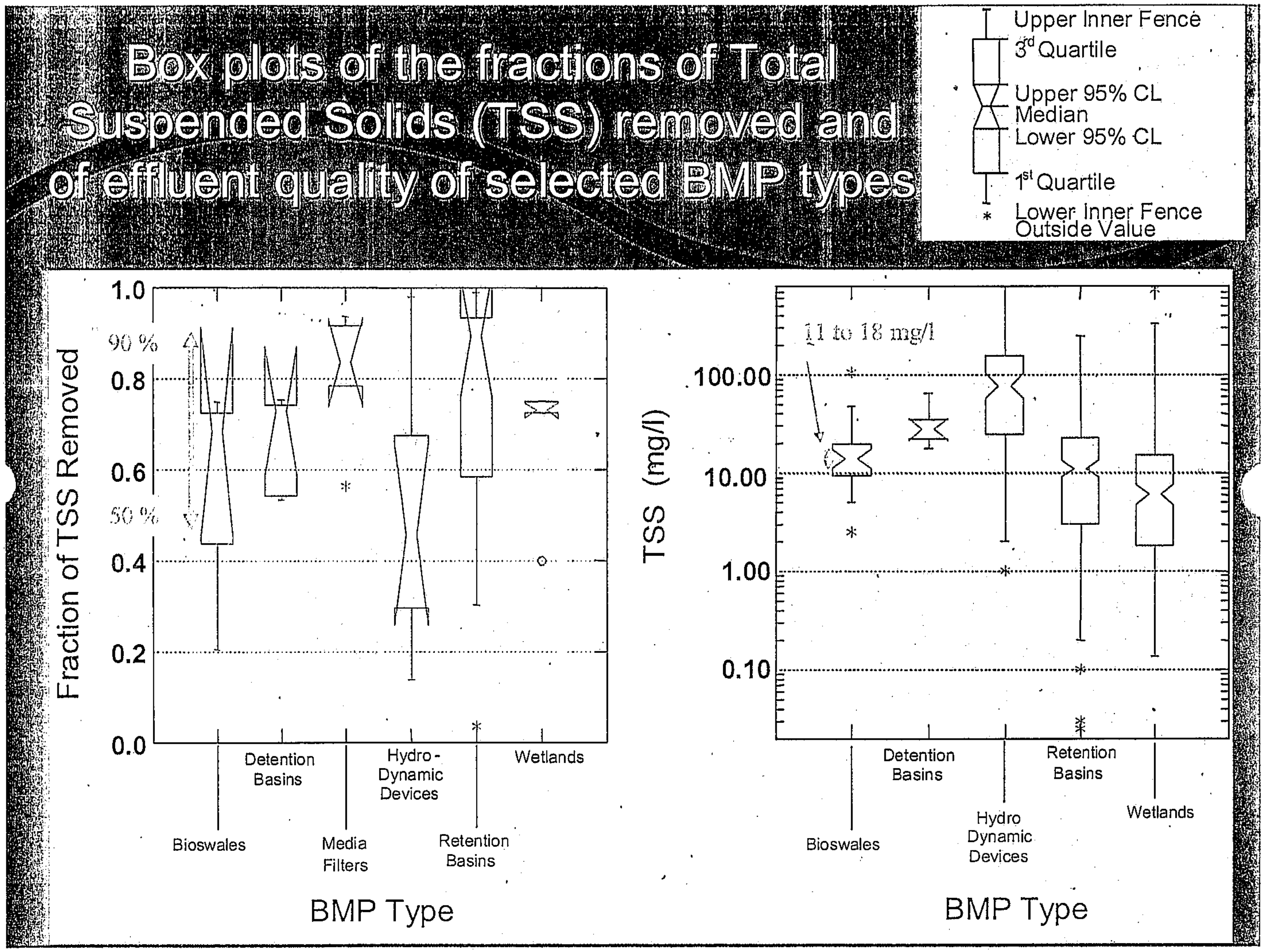
Runoff Volume Control

Consider "credit" for volume reduction in design requirements

BMP Type	Mean Monitored Outflow/Mean Monitored Inflow for Events Where Inflow is Greater Than or Equal to 0.2 Watershed Inches
Detention Basins	0.70
Biofilters	0.62
Media Filters	1.00
Hydrodynamic Devices	1.00
Wetland Basins	0.95
Retention Ponds	0.93
Wetland Channels	1.00

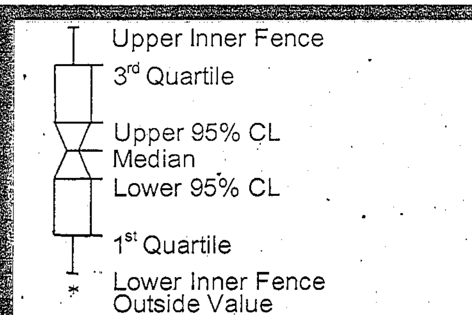
Potential Future Volume Reduction Analyses

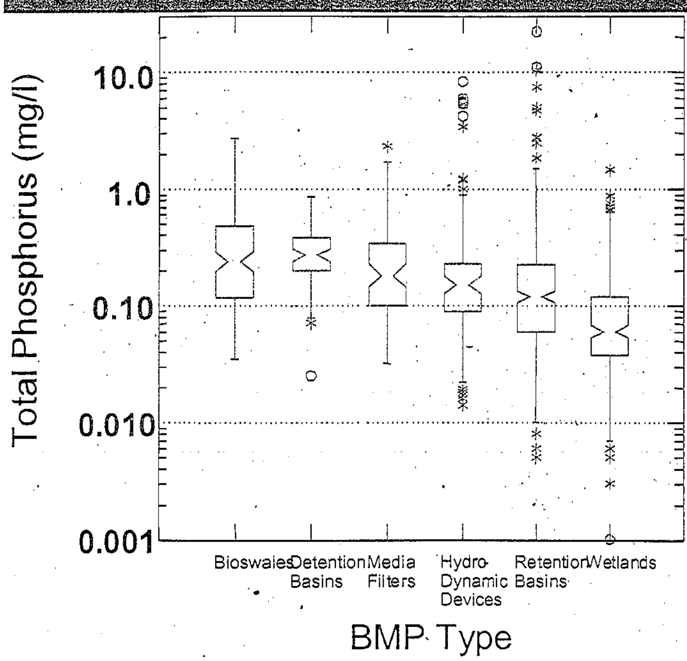
- **Characterize based upon storm sizes (volumes and/or rates of inflow – hydraulic loading rate)**
- Assess if BMPs in certain soil types and/or with amended soils/growing media perform better
- Infiltration vs. evapotranspiration as a loss mechanism

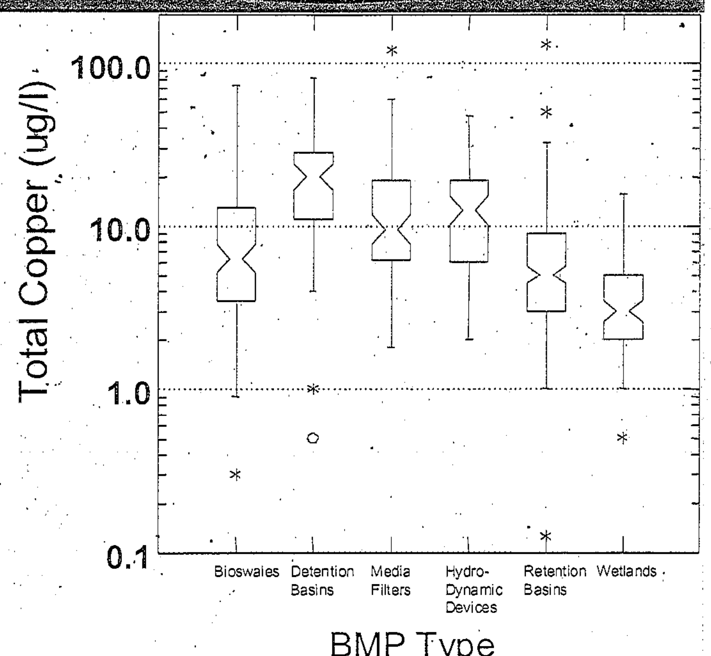


Box plots of the fractions of Total Suspended Solids (TSS) removed and of effluent quality of selected BMP types
Upper Inner Fence
3rd Quartile
Upper 95% CL
Median
Lower 95% CL
1st Quartile
Lower Inner Fence
Outside Value
Fraction of TSS Removed
1.0
0.8
0.6
0.4
0.2
0.0
90 %
50 %
Bioswales
Detention Basins
Media Filters
Hydro-Dynamic Devices
Retention Basins
Wetlands
BMP Type
TSS (mg/l)
100.00
10.00
1.00
0.10
11 to 18 mg/l
Bioswales
Detention Basins
Hydro Dynamic Devices
Retention Basins
Wetlands
BMP Type

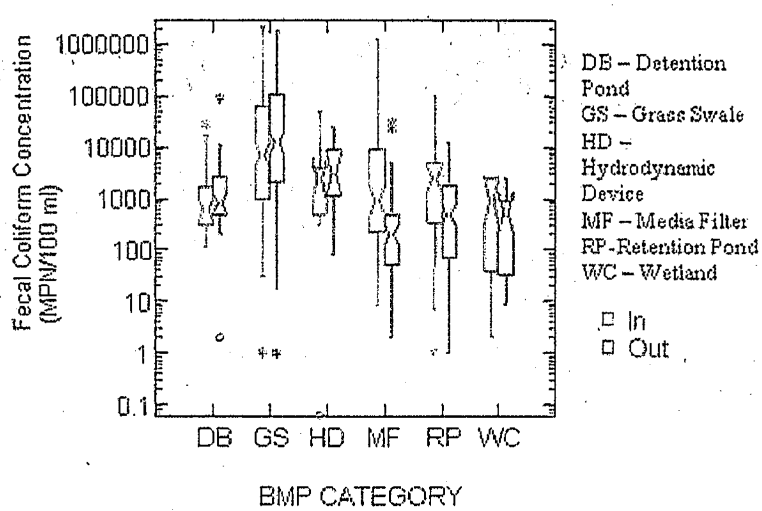
Box plots of effluent quality of selected BMP types for Total Phosphorus and Total Copper

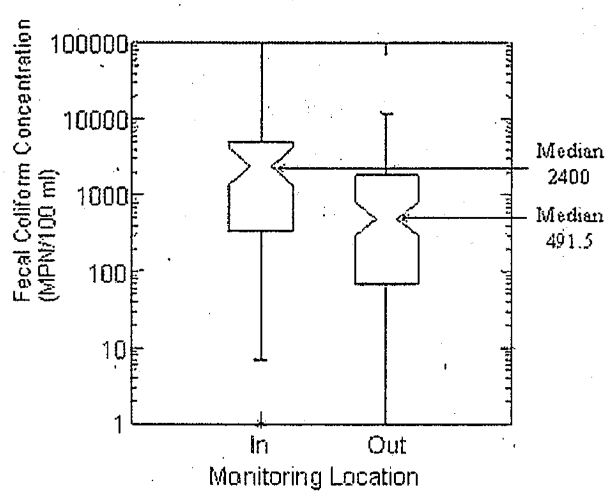






Box plots of effluent quality of selected BMP types for Fecal Coliform and Fecal Coliform inflow and outflow by event.

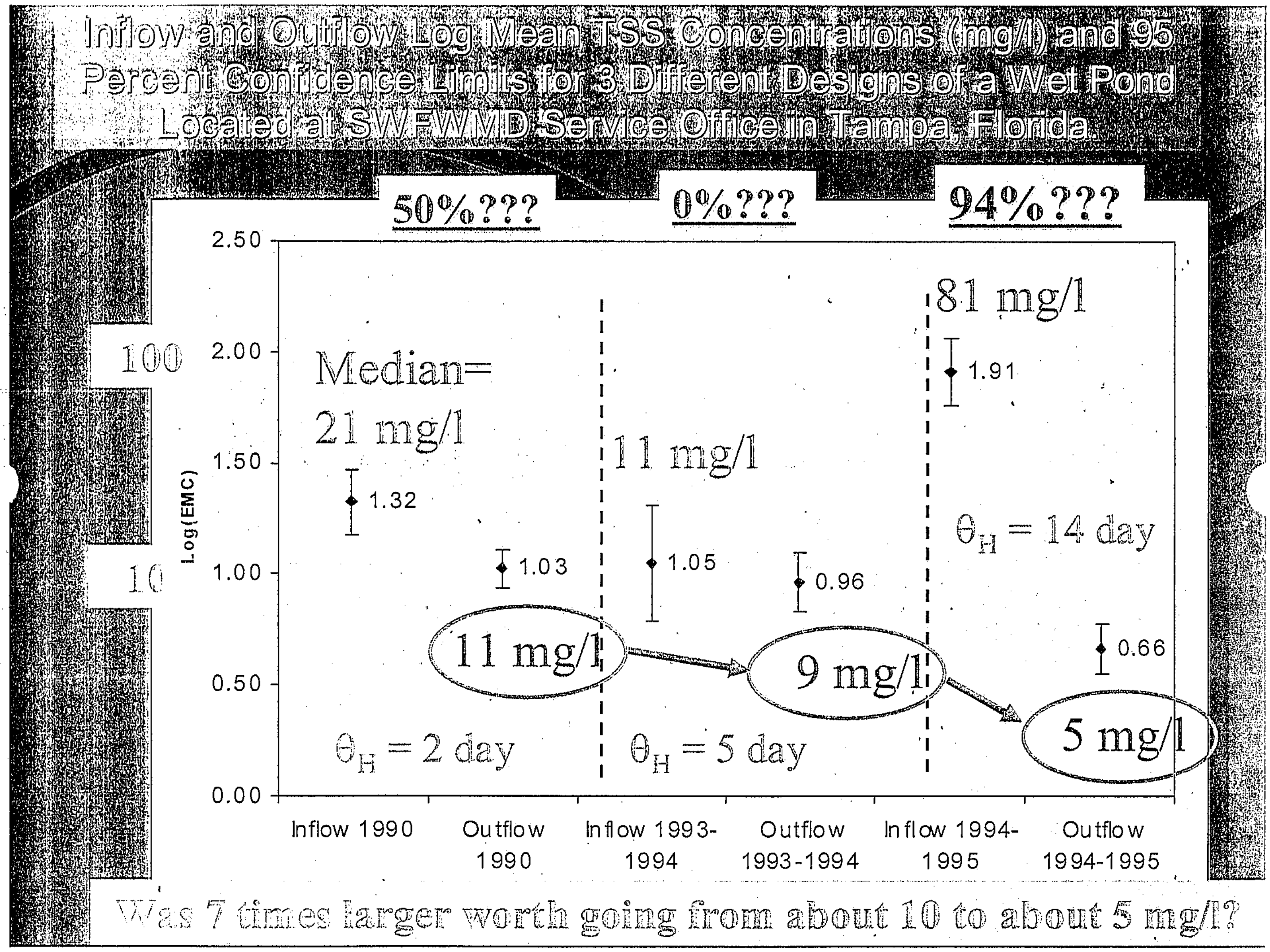




Retention Ponds

Percent Removal? Example Study -SWFWMD Tampa Pond

- Drainage area, 6.5 acres
- Land use (commercial, office)
  - 30% roof tops and parking lots, 6% crushed stone, 64 % grassed
  - Drained by swales to pond
- Five year study with two design modifications
  - 1990 (shallow and vegetated, θ_H = 2 day)
  - 1993 (volume increased, 35% veg, θ_H = 5 day)
  - 1994 (area enlarged, replant littoral zone,
    θ_H = 14 day)


Inflow and Outflow Log Mean TSS Concentrations (mg/l) and 95 Percent Confidence Limits for 3 Different Designs of a Wet Pond Located at SWFWMD Service Office in Tampa, Florida
50%???
0%???
94%???
2.50
2.00
1.50
1.00
0.50
0.00
Log(EMC)
100
10
Median=
21 mg/l
11 mg/l
81 mg/l
1.32
1.03
1.05
0.96
1.91
0.66
11 mg/l
9 mg/l
5 mg/l
θ_H = 2 day
θ_H = 5 day
θ_H = 14 day
Inflow 1990
Outflow 1990
Inflow 1993-1994
Outflow 1993-1994
Inflow 1994-1995
Outflow 1994-1995
Was 7 times larger worth going from about 10 to about 5 mg/l?

Lake George Field Study Evaluation Vortechs model 11000

Runoff Event #	TSSin (mg/L)		TSSout (mg/L)		% Reduction	
	Interpolated	Arithmetic	Interpolated	Arithmetic	Interpolated	Arithmetic
1	987.48	693.52	263.18	205.98	73%	70%
2	128.73	88.57	59.23	59.18	54%	33%
3	1040.04	882.42	337.87	486.75	68%	45%
4	213.73	225.42	359.14	388.08	-68%	-72%
5	1673.57	1217.53	71.39	102.84	96%	92%
6	535.16	603.54	70.14	85.23	87%	86%
7	180.81	132.22	29.76	34.88	84%	74%
8	2491.55	2202.78	35.41	35.47	99%	98%
9	89.99	76.60	31.98	33.14	64%	57%
10	1047.02	2257.46	37.08	31.22	96%	99%
11	439.45	344.86	16.57	13.83	96%	96%
12	445.19	291.58	17.36	14.91	96%	95%
13	1156.16	674.94	44.72	37.91	96%	94%
Averages	802.2215	745.4954	105.6792	117.6477	87%	84%

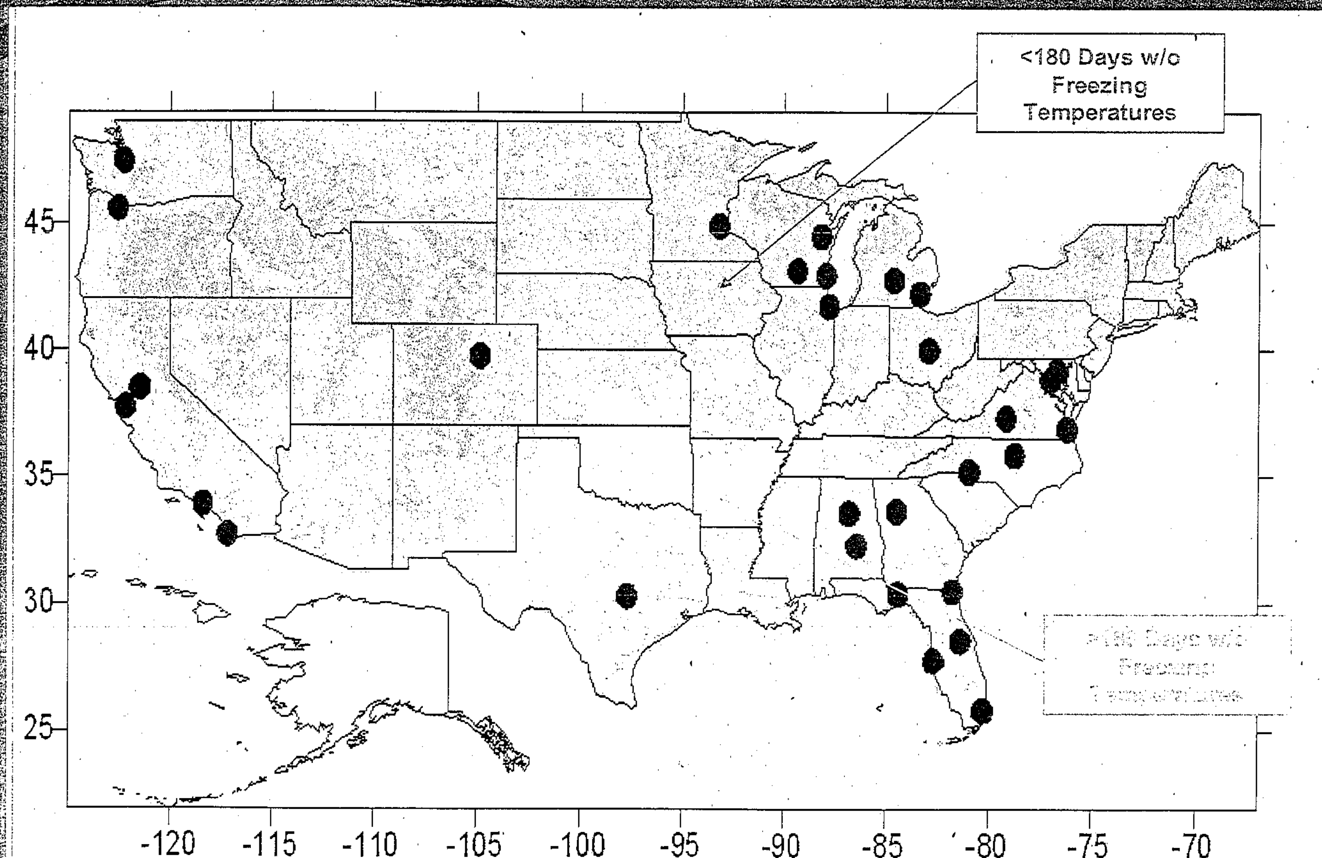
(Winkler and Guswa 2002)

- Is an average of 100+ mg/l TSS acceptable performance?

Percent Removal Use Results

- BMPs improperly "rejected"
- BMPs improperly "accepted"
- "Daisy-Chaining" BMPs and applied % removals at each step that highly over predicts performance
- Improper use of TSS as the sole indicator of performance
- Etc. Etc.

NSW Database Sites Analyzed Relative to Median Freeze-free Period (Days)



BMP Studies – Cold Regions

- Number of BMPs located in cold regions
  - 144 BMPs in 'Warm' Climates
  - 24 in "Cold" Climates
- Number of BMPs with apparent cold season/weather data (by BMP Type)

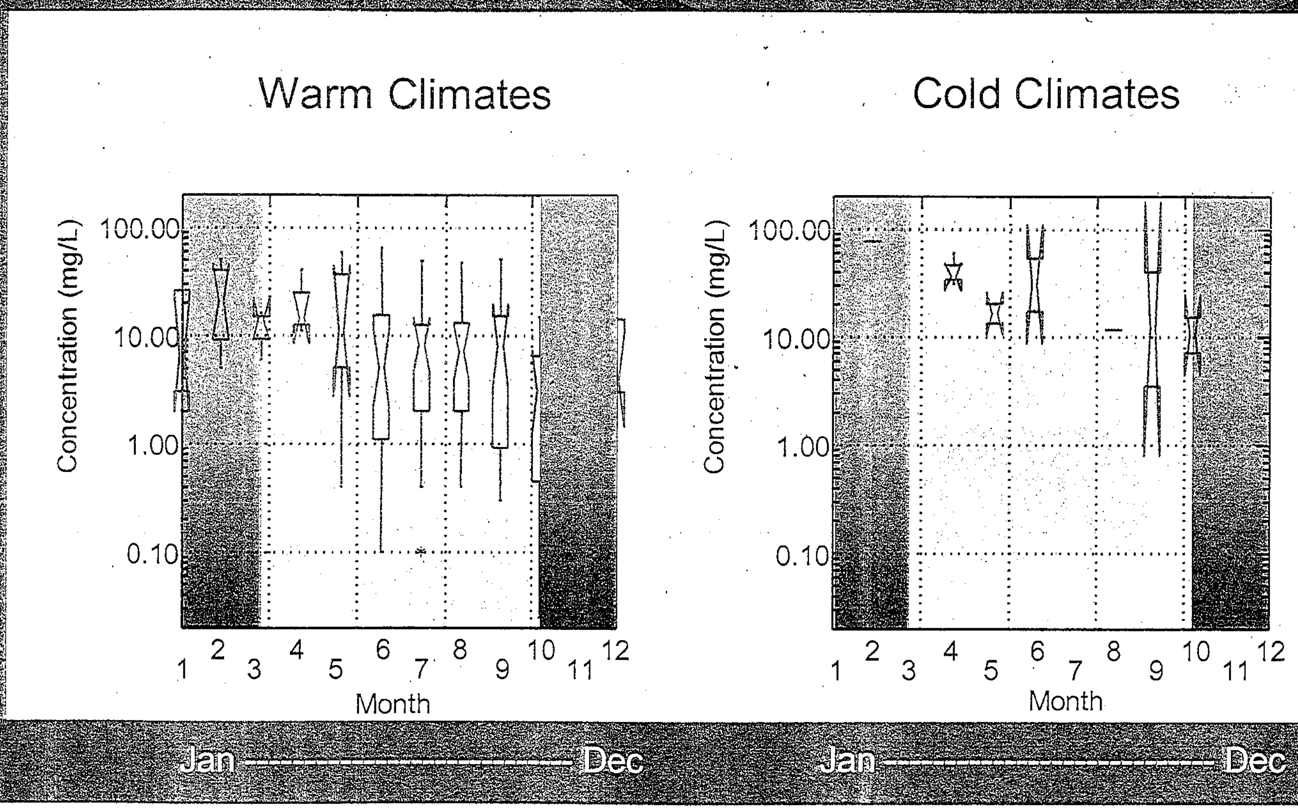
"WARM CLIMATE"

BMP Category	Number of BMPs
Detention Basin	22
Biofilter	32
Hydrodynamic Device	15
Media Filter	27
Porous Pavement	4
Percolation Trench/Well	1
Retention Pond	21
Wetland Basin	13
Wetland Channel	9

"COLD CLIMATE"

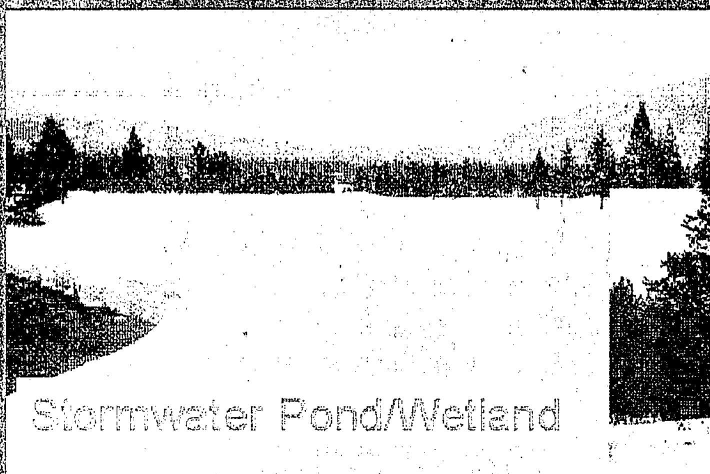
BMP Category	Number of BMPs
Detention Basin	2
Hydrodynamic Device	3
Porous Pavement	1
Retention Pond	12
Wetland Basin	2
Wetland Channel	4

Wet Pond – Cold Climate TSS Effluent Concentration



Conclusion – Cold Weather BMP Data

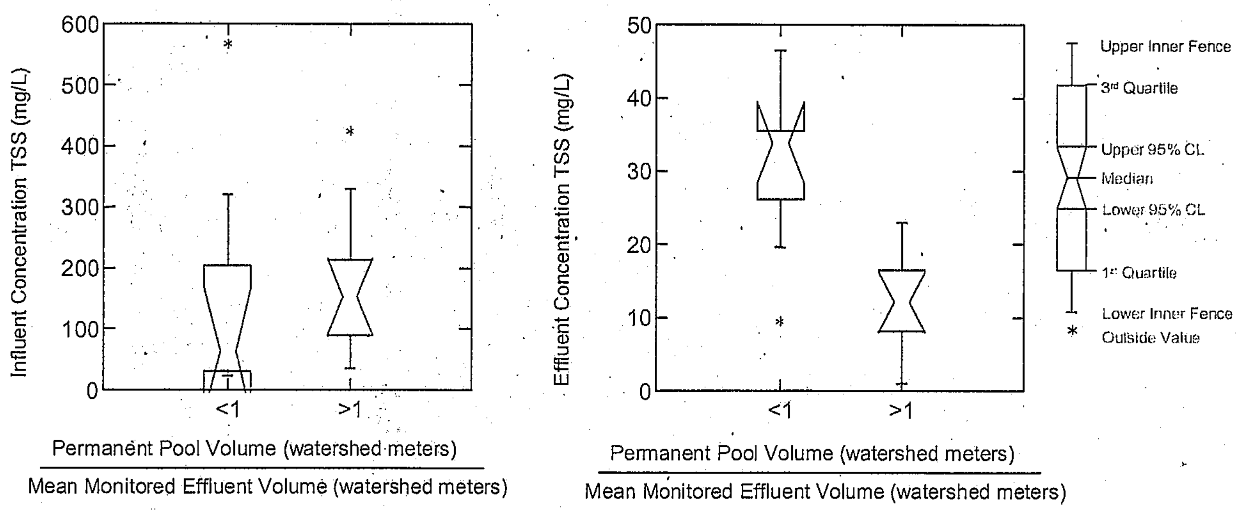
- People don't like to sample when it is cold out.
  - Statistically proven



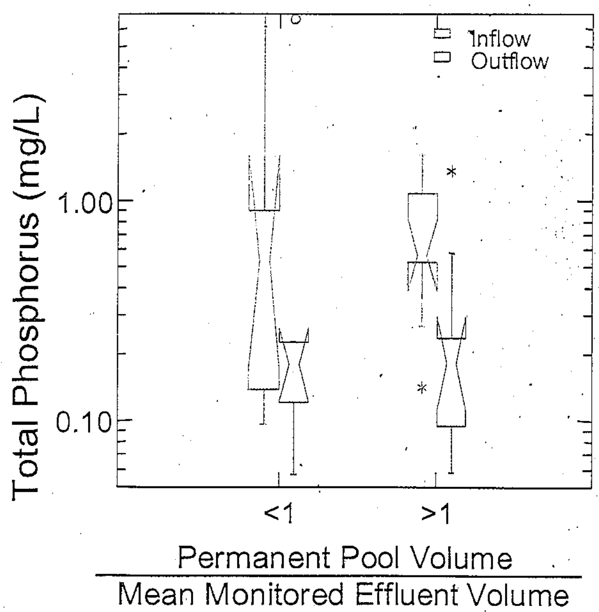
Relating Design to Performance

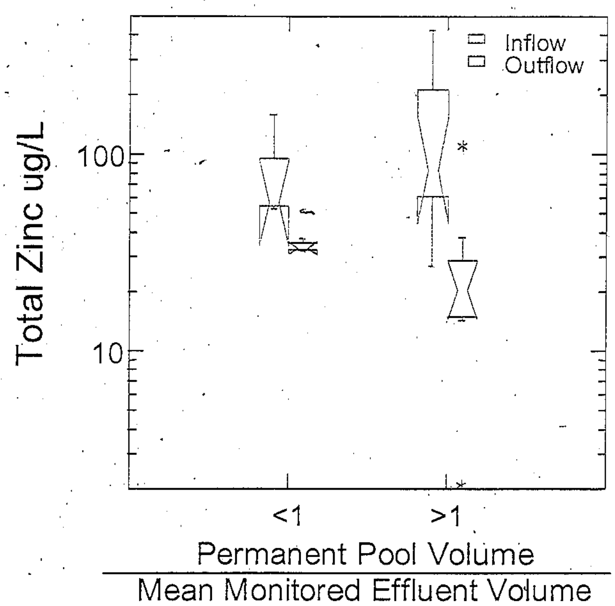
- One of the primary long-term project objectives
- Multiple regression analysis
- Sub-sample parameter analysis

Box Plot Showing Effluent Water Quality as a Function of the Permanent Pool Design Volume Ratio



Box plots of the total phosphorus and total zinc effluent quality of sites grouped by a ratio of less than or greater than 1 for the ratio of the permanent pool volume to mean monitored effluent volume by BMP study





For the First Time We Can Say
(and back-up with statistics):

"Big Wet Ponds (in Relationship to Storm Inflow Sizes) Work Better Than Little Wet Ponds"

and

"Some BMPs beside infiltration systems appear to provide significant volume reductions that should be accounted for in performance"

WERF

ASCE
American Society of Civil Engineers
Urban Water Resources Research Council

EWRI

EPA

U.S. Department of Transportation
Federal Highway Administration

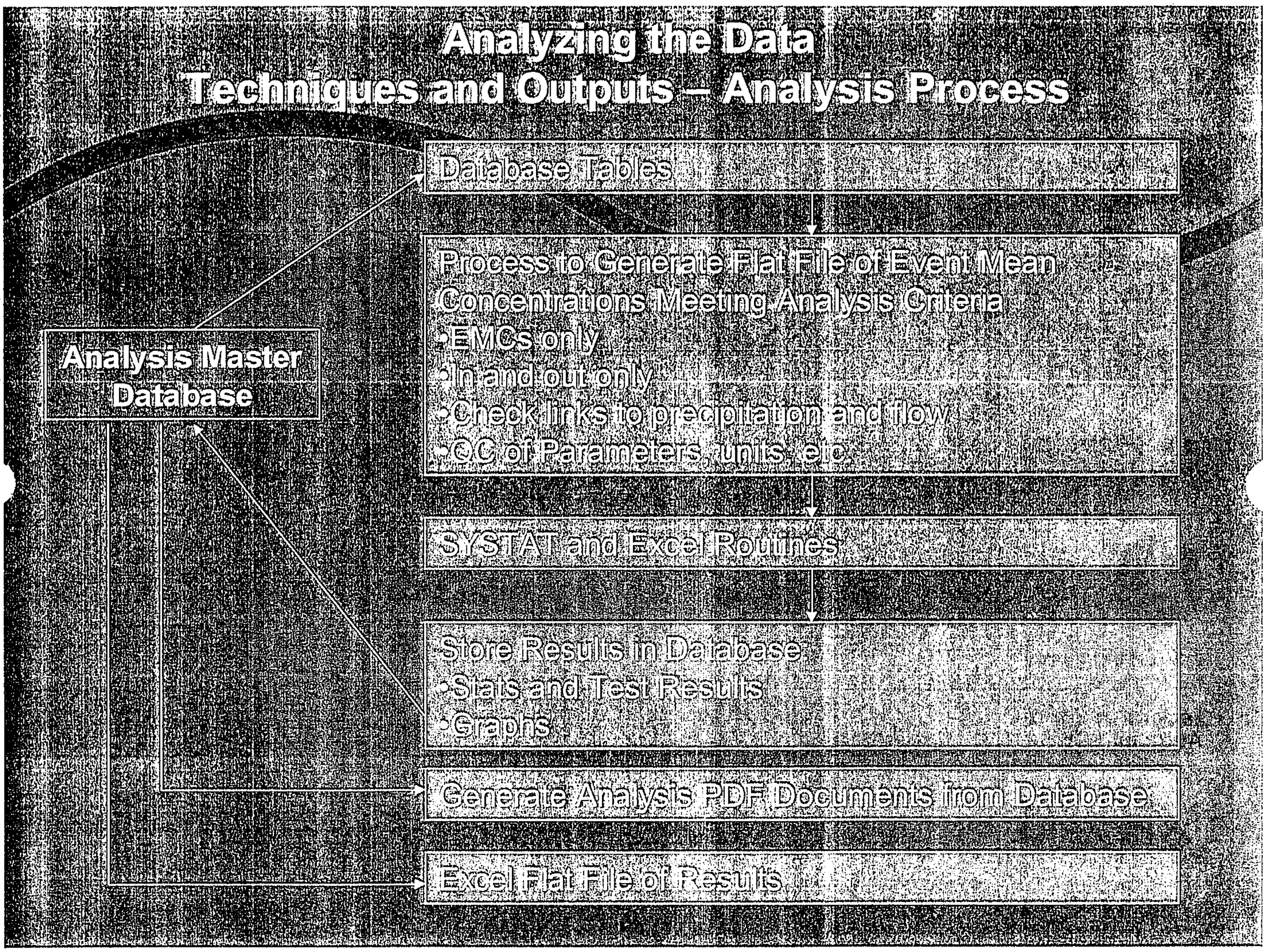
APWA

Project 03-SW-1CO International Stormwater Best Management Practice (BMP) Database

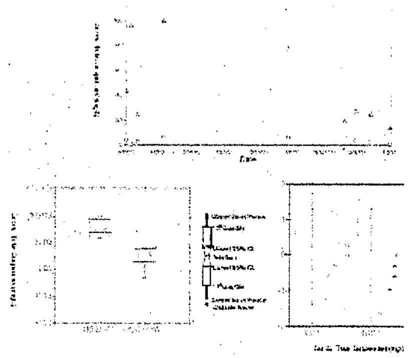
Analyzing the Data: Techniques and Outputs

GEOSYNTEC CONSULTANTS

WWE


Analyzing the Data
Techniques and Outputs – Analysis Process
Analysis Master Database
Database Tables
Process to Generate Flat File of Event Mean Concentrations Meeting Analysis Criteria
•EMCs only
•In and out only
•Check links to precipitation and flow
•QC of Parameters, units, etc
SYSTAT and Excel Routines
Store Results in Database
•Stats and Test Results
•Graphs
Generate Analysis PDF Documents from Database
Excel Flat File of Results

Standard Statistical Analysis Sheets
Page 1 - Inflow/Outflow Descriptive Statistics



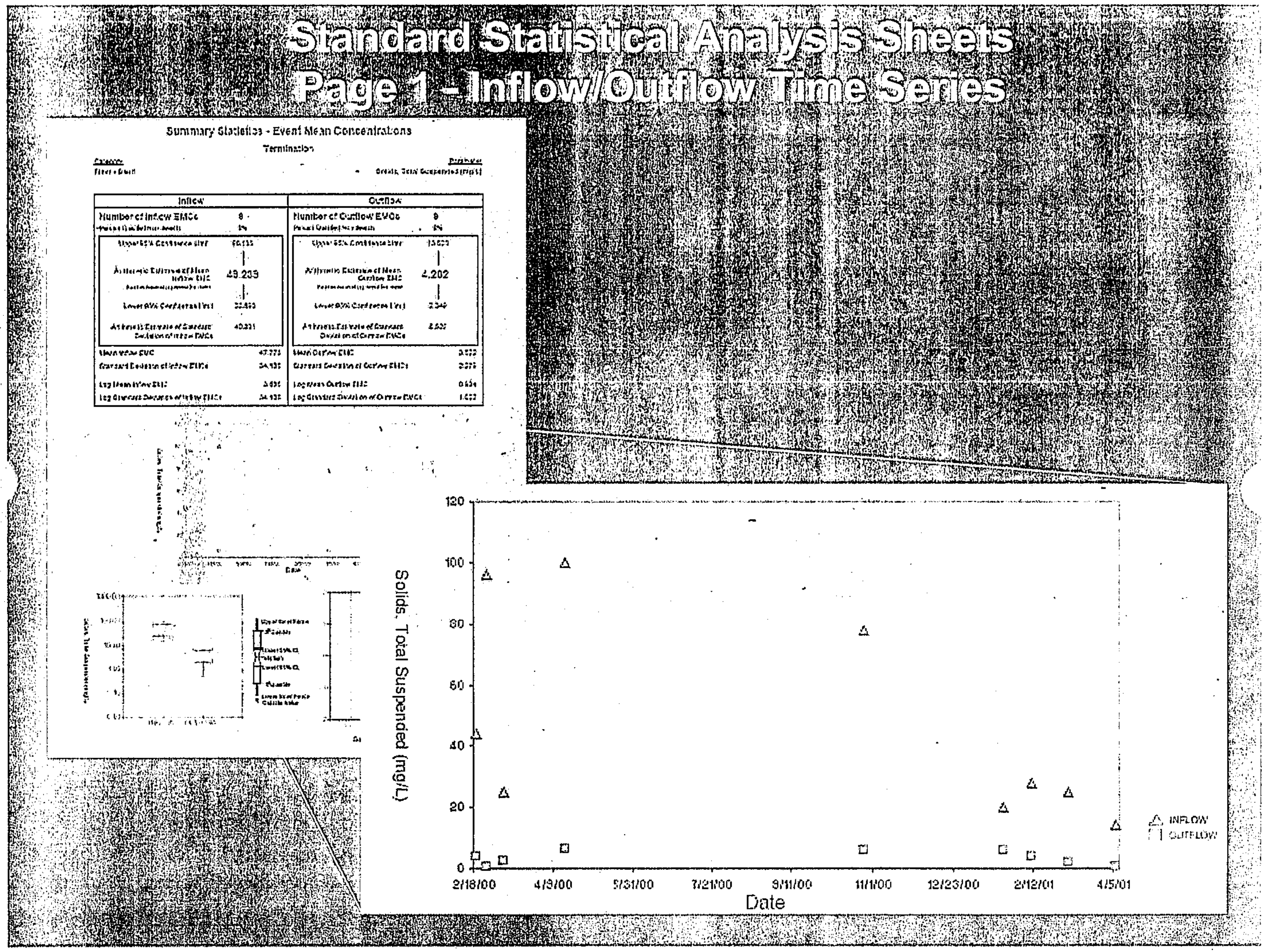
Summary Statistics - Event Mean Concentrations

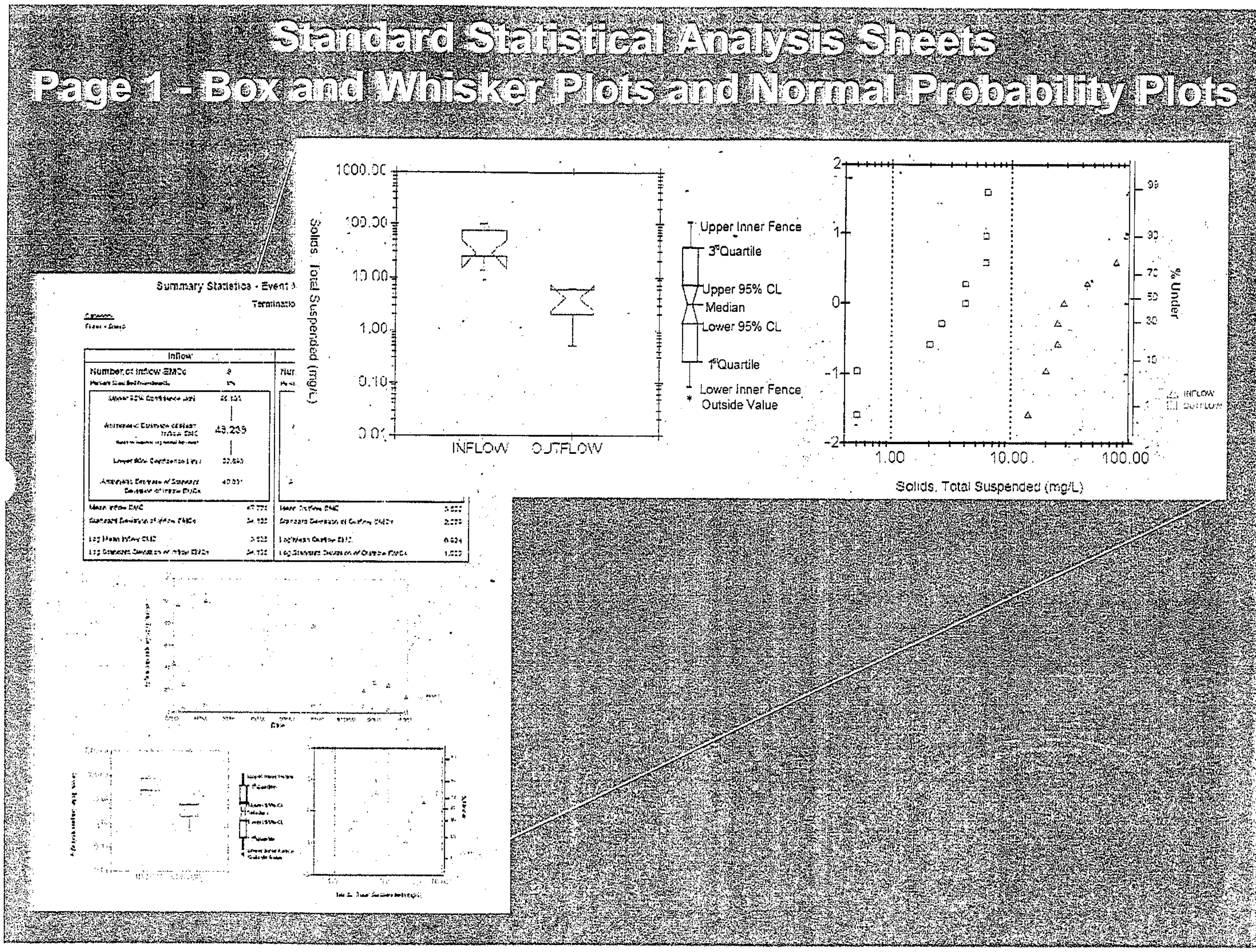
Termination

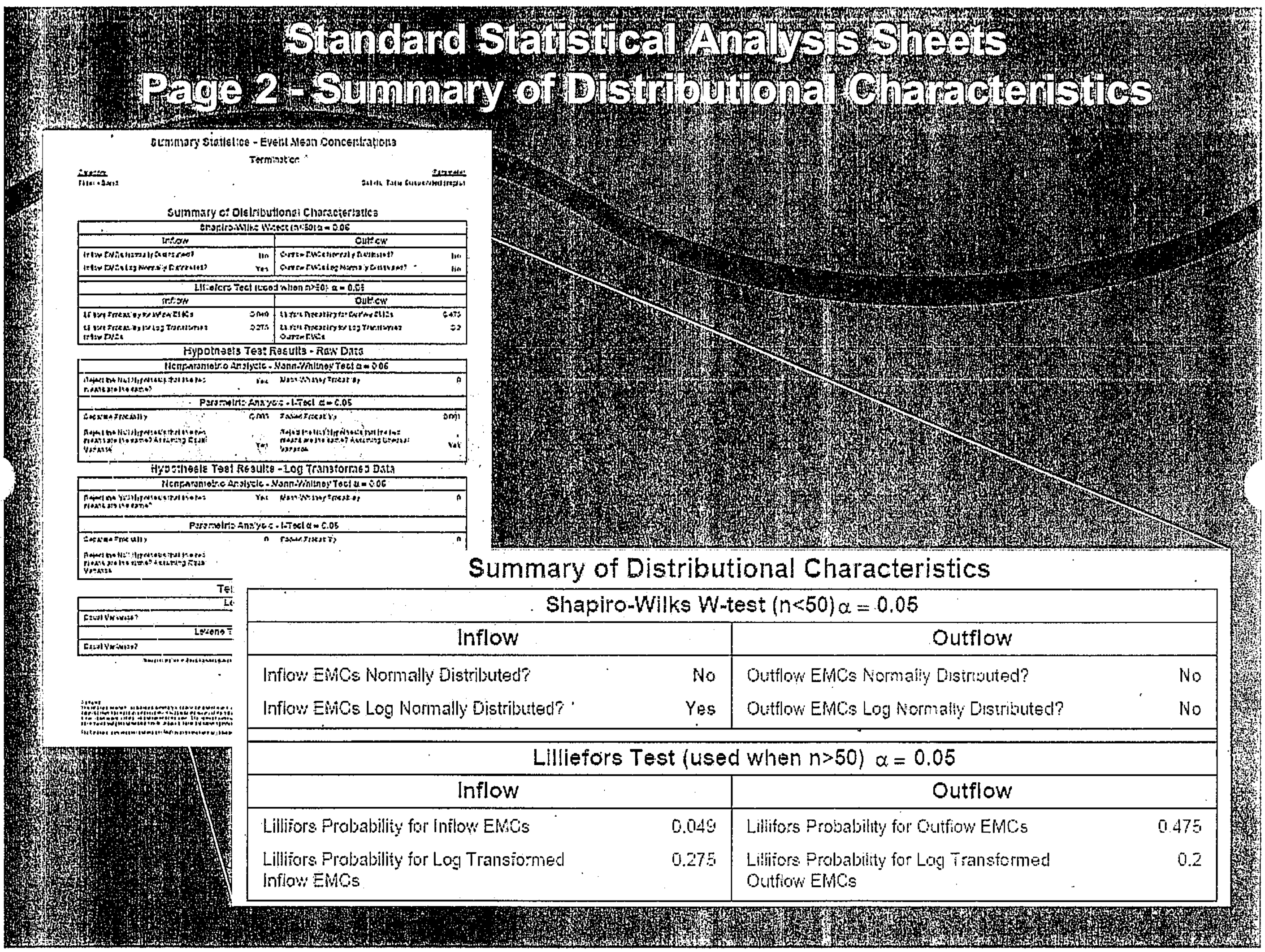
Category: Filter - Sand

Parameter: Solids, Total Suspended (mg/L)

Inflow		Outflow	
Number of Inflow EMCs	9	**Number of Outflow EMCs**	9
Percent Qualified Non-detects	0%	Percent Qualified Non-detects	0%
Upper 95% Confidence Limit	98.135	Upper 95% Confidence Limit	13.526
Arithmetic Estimate of Mean Inflow EMC (Based on Assumed Log-normal Distribution)	49.239	Arithmetic Estimate of Mean Outflow EMC (Based on Assumed Log-normal Distribution)	4.202
Lower 95% Confidence Limit	32.693	Lower 95% Confidence Limit	2.349
Arithmetic Estimate of Standard Deviation of Inflow EMCs	40.831	Arithmetic Estimate of Standard Deviation of Outflow EMCs	5.522
Mean Inflow EMC	47.778	Mean Outflow EMC	3.522
Standard Deviation of Inflow EMCs	34.135	Standard Deviation of Outflow EMCs	2.279
Log Mean Inflow EMC	3.635	Log Mean Outflow EMC	0.934
Log Standard Deviation of Inflow EMCs	34.135	Log Standard Deviation of Outflow EMCs	1.002


Standard Statistical Analysis Sheets
Page 1 - Inflow/Outflow Time Series
Summary Statistics - Event Mean Concentrations
Termination
Inflow
Outflow
Number of Inflow EMCs
Number of Outflow EMCs
49.239
4.202
Solids, Total Suspended (mg/L)
Date
2/18/00
4/9/00
5/31/00
7/21/00
9/11/00
11/1/00
12/23/00
2/12/01
4/5/01
INFLOW
OUTFLOW

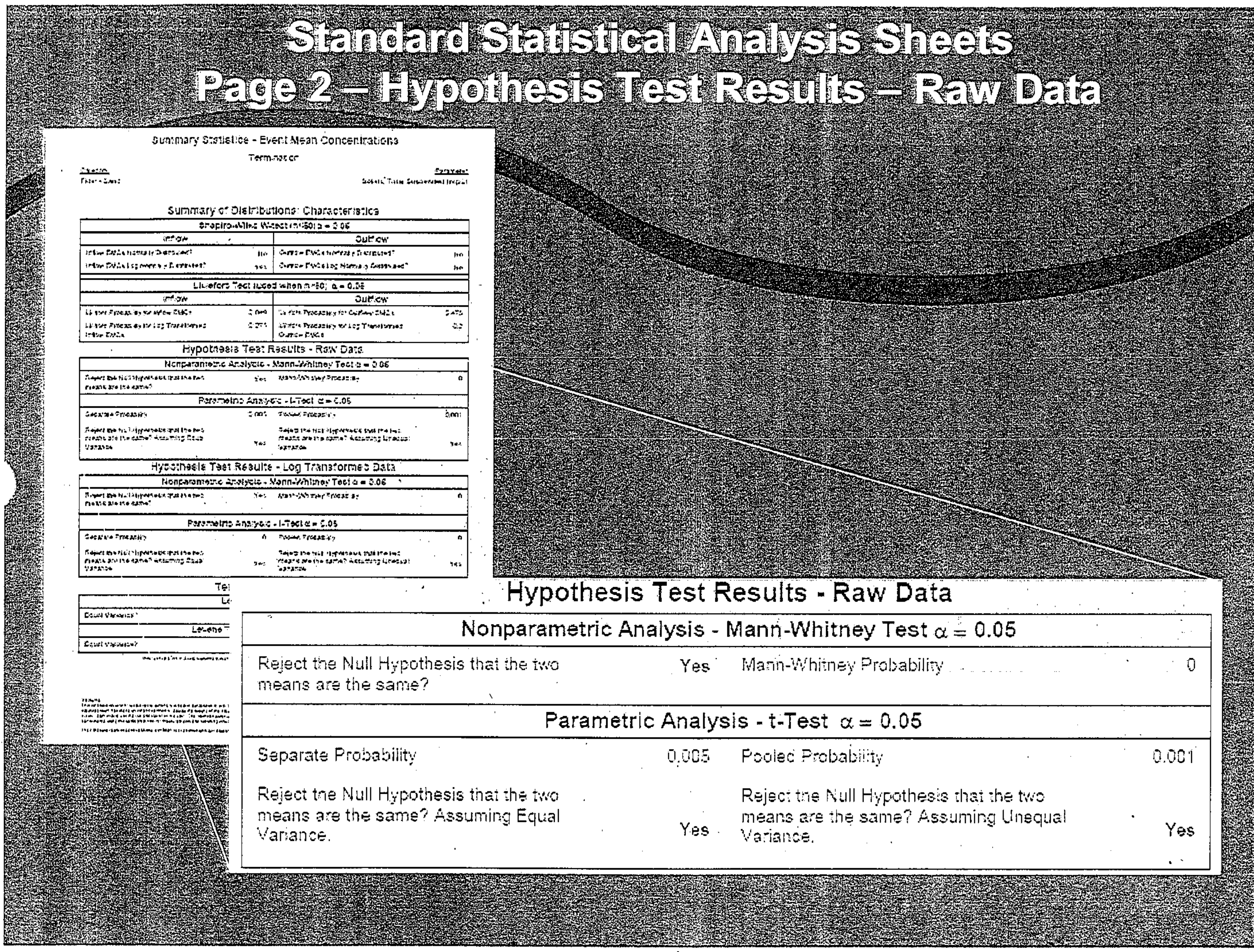

Standard Statistical Analysis Sheets
Page 1 - Box and Whisker Plots and Normal Probability Plots
Summary Statistics - Event
Inflow
Number of Inflow EMCs
49.235
Solids, Total Suspended (mg/L)
1000.00
100.00
10.00
1.00
0.10
0.01
INFLOW
OUTFLOW
Upper Inner Fence
3rd Quartile
Upper 95% CL
Median
Lower 95% CL
1st Quartile
Lower Inner Fence
Outside Value
1.00
10.00
100.00
Solids, Total Suspended (mg/L)
% Under
INFLOW
OUTFLOW



Summary of Distributional Characteristics

Shapiro-Wilks W-test (n<50) α = 0.05			
Inflow		**Outflow**	
Inflow EMCs Normally Distributed?	No	Outflow EMCs Normally Distrinuted?	No
Inflow EMCs Log Normally Distributed?	Yes	Outflow EMCs Log Normally Distributed?	No
Lilliefors Test (used when n>50) α = 0.05			
Inflow		**Outflow**	
Lillifors Probability for Inflow EMCs	0.049	Lillifors Probability for Outflow EMCs	0.475
Lillifors Probability for Log Transformed Inflow EMCs	0.275	Lillifors Probability for Log Transformed Outflow EMCs	0.2

A000278


Standard Statistical Analysis Sheets
Page 2 – Hypothesis Test Results – Raw Data
Hypothesis Test Results - Raw Data
Nonparametric Analysis - Mann-Whitney Test α = 0.05
Reject the Null Hypothesis that the two means are the same?
Yes
Mann-Whitney Probability
0
Parametric Analysis - t-Test α = 0.05
Separate Probability
0.005
Pooled Probability
0.001
Reject the Null Hypothesis that the two means are the same? Assuming Equal Variance.
Yes
Reject the Null Hypothesis that the two means are the same? Assuming Unequal Variance.
Yes

Standard Statistical Analysis Sheets
Page 2 – Hypothesis Test Results – Raw Data

Hypothesis Test Results - Log Transformed Data

Nonparametric Analysis - Mann-Whitney Test α = 0.05			
Reject the Null Hypothesis that the two means are the same?	Yes	Mann-Whitney Probability	0

Parametric Analysis - t-Test α = 0.05			
Separate Probability	0	Pooled Probability	0
Reject the Null Hypothesis that the two means are the same? Assuming Equal Variance.	Yes	Reject the Null Hypothesis that the two means are the same? Assuming Unequal Variance.	Yes

Test of Equal Variance

Levene Test - Raw Data			
Equal Variance?	Yes	Probability	0
Levene Test - Log Transformed Data			
Equal Variance?	No	Probability	0.454

Results of the Test of Equal Variance (Levene Test) may be used to evaluate the appropriateness of a "Separate" or "Pooled" t-test.

Standard Statistical Analysis Sheets Disclaimer

- The database on which this statistical summary is based is intended to provide a consistent and scientifically defensible set of data on BMP designs and related performance.
- Although the database team has made an extensive effort to assess the quality of the data entered for consistency and accuracy, the use of the database information or any analysis results provided by the project team is solely at the risk and option of the user.
- The intended purpose of the database is to provide a data exchange tool that permits characterization of BMPs solely upon their measured performance using the same protocols for measurements and reporting information.
- The Database team does not endorse any BMP over another and any assessments of performance by others should not be interpreted or reported as the recommendations of the Database team.

Flat File Statistical Summary

- Users were having difficulty downloading useful data from site so two "Flat Files" (spreadsheets) of the data were created
- Posted on the Project Web Site
- Statistical Analysis of Each BMP for Each Pollutant
- Second Flat File with all of the data

Summary Statistics for Inflow Data	
[illegible]	Number of inflow EMCs – no statistics calculated for samples n<3
[illegible]	Mean of inflow EMCs
[illegible]	Standard deviation of inflow EMCs
[illegible]	Coefficient of variation of inflow EMCs
[illegible]	Mean of the natural log of inflow EMCs
[illegible]	Standard deviation of the natural log of inflow EMCs
[illegible]	Coefficient of variation of the natural log of inflow EMCs
[illegible]	Arithmetic estimate of the mean inflow EMCs (for log-normally distributed data this estimate is a good estimate of the central tendency of the data)
[illegible]	Arithmetic estimate of the standard deviation of inflow EMCs (for log-normally distributed data this estimate is a good estimate of the dispersion in the data)
[illegible]	Land's lower 95% confidence limit of the inflow mean (this value should be used in conjunction with the EST Inflow Mean)
[illegible]	Land's upper 95% confidence limit of the inflow mean (this value should be used in conjunction with the EST Inflow Mean)
Shapiro-Wilks Test for Normality and Log-normality of Inflow	
[illegible]	Difference between Shapiro-Wilks W-statistic and the corresponding test quantile for inflow untransformed data.
[illegible]	Interpretation of the Shapiro-Wilks test for untransformed inflow data – "Yes" if the null hypothesis (data is normally distributed) cannot be rejected, "No" if the null hypothesis can be rejected.
[illegible]	Difference between Shapiro-Wilks W-statistic and the corresponding test quantile for log-transformed inflow data.
[illegible]	Interpretation of the Shapiro-Wilks test for LN transformed inflow data – "Yes" if the null hypothesis (data is log-normally distributed) cannot be rejected, "No" if the null hypothesis can be rejected.
Lilliefors Test for Normality and Log-normality of Inflow	
[illegible]	P-value (SL=0.05) for the Lilliefors' form of the Kolmogorov-Smirnov test of normality for untransformed inflow data.
[illegible]	Interpretation of the KS test for untransformed inflow data – "Yes" if the null hypothesis (data is normally distributed) cannot be rejected, "No" if the null hypothesis can be rejected.
[illegible]	P-value (SL=0.05) for the Lilliefors' form of the Kolmogorov-Smirnov test of normality for log-transformed data.
[illegible]	Interpretation of the KS test for log-transformed data – "Yes" if the null hypothesis (data is log-normally distributed) cannot be rejected, "No" if the null hypothesis can be rejected.

Statistical Analysis - Outflow

Summary Statistics for Outflow Data	
Outflow n	Number of outflow EMCs – no statistics calculated for n<3
Raw Outflow Mean	Mean of outflow EMCs
Raw Outflow StDev	Standard deviation of outflow EMCs
Raw Outflow CV	Coefficient of variation of outflow EMCs
LN Outflow Mean	Mean of the natural log of outflow EMCs
LN Outflow StDev	Standard deviation of the natural log of outflow EMCs
LN Outflow CV	Coefficient of variation of the natural log of outflow EMCs
Est Outflow Mean	Arithmetic estimate of the mean outflow EMCs (for log-normally distributed data this estimate is a good estimate of the central tendency of the data)
Est Outflow StDev	Arithmetic estimate of the standard deviation of outflow EMCs (for log-normally distributed data this estimate is a good estimate of the dispersion in the data)
Outflow LCL	Land's lower confidence limit of the outflow mean (this value should be used in conjunction with the EST Outflow Mean)
Outflow UCL	Land's upper confidence limit of the outflow mean (this value should be used in conjunction with the EST Outflow Mean)
Shapiro-Wilks (SW) Test for Normality and Log-normality of Outflow	
SW SL	Significance level used for Shapiro-Wilks test for normality.
Raw Outflow diff (SW)	Difference between Shapiro-Wilks W-statistic and the corresponding test quantile for untransformed outflow data.
Indicate Outflow N (SW)	Interpretation of the Shapiro-Wilks test for untransformed outflow data – "Yes" if the null hypothesis (data is normally distributed) cannot be rejected, "No" if the null hypothesis can be rejected.
LN Outflow diff (SW)	Difference between Shapiro-Wilks W-statistic and the corresponding test quantile for log-transformed outflow data.
Indicate Outflow LN (SW)	Interpretation of the SW test for log-transformed data – "Yes" if the null hypothesis holds, "No" if the null hypothesis is rejected.
Kolmogorov-Smirnov (KS) Lilliefors Test for Normality and Log-normality of Outflow	
Raw Outflow Lil Prob (KS)	P-value (SL=0.05) for the Lilliefors' form of the Kolmogorov-Smirnov test of normality for untransformed outflow data.
Indicate Outflow N (KS)	Interpretation of the KS test for untransformed outflow data – "Yes" if the null hypothesis (data is normally distributed) cannot be rejected, "No" if the null hypothesis can be rejected.
LN Outflow Lil Prob (KS)	P-value (SL=0.05) for the Lilliefors' form of the Kolmogorov-Smirnov test of normality for log-transformed outflow data.
Indicate Outflow LN (KS)	Interpretation of the Shapiro-Wilks test for LN transformed outflow data – "Yes" if the null hypothesis (data is log-normally distributed) cannot be rejected, "No" if the null hypothesis can be rejected.

Statistical Analysis Parametric and Non-Parametric Hypothesis Testing

Kruskal-Wallis (KW) Test (Wilcoxon Rank Sum test) – Nonparametric test for shift in central tendency between inflow and outflow	
KW SL	Significance level used for the Kruskal-Wallis rank sum test of variance.
Raw p (KW)	Reported p-value for the KW test for untransformed data.
Raw Sig Diff (KW)	Interpretation of the KS test for untransformed data – "Yes" if the null hypothesis holds, "No" if the null hypothesis is rejected.
LN p (KW)	Reported p-value for the KW test for log-transformed data.
LN Sig Diff (KW)	Interpretation of the KS test for log-transformed data – "Yes" if the null hypothesis holds, "No" if the null hypothesis is rejected.

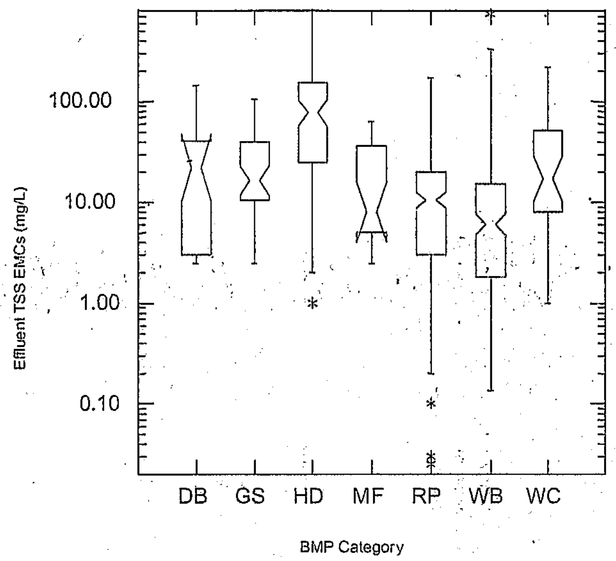
Levene Test for Homogeneous Variance – Test of equal variance between log-transformed inflow and outflow	
DW stat (Levene)	Reported Durbin Watson statistic for the Levene test of homogeneous variance
Levene SL	Significance level used for the Levene test for homogeneous variance
F ratio (Levene)	Ratio of variances for influent and effluent data
p value (Levene)	Reported p-value for the Levene test.
Indicate Inflow/Outflow Equal Variance (Levene)	Interpretation of the Levene test for homogeneous variance – "Yes" if the null hypothesis (the variance of the two data sets are equal) cannot be rejected, "No" if the null hypothesis can be rejected.

Independent Sample t-Test for Untransformed Inflow and Outflow	
Raw Mean diff	The difference in mean influent and effluent values for untransformed data.
Raw Sep p (t-test)	P-value for the t-test of the raw (untransformed) data assuming that the two samples come from Normally distributed populations with unequal variances (i.e., a separate estimate is used for the variance of each sample).
Indicate Sep Raw Sig Diff (t-test)	Interpretation of separate variance t-test on untransformed data – "No" if the null hypothesis (means are the same) cannot be rejected "Yes" if the null hypothesis can be rejected.
Raw Pool p (t-test)	P-value for the t-test of the raw (untransformed) data assuming that the two samples come from Normally distributed populations with equal variances (i.e., a pooled estimate for the variance of both samples is used in the test).
Indicate Pool Raw Sig Diff (t-test)	Interpretation of pooled variance t-test on untransformed data. "No" if the null hypothesis that the means are the same cannot be rejected "Yes" if the null hypothesis can be rejected.

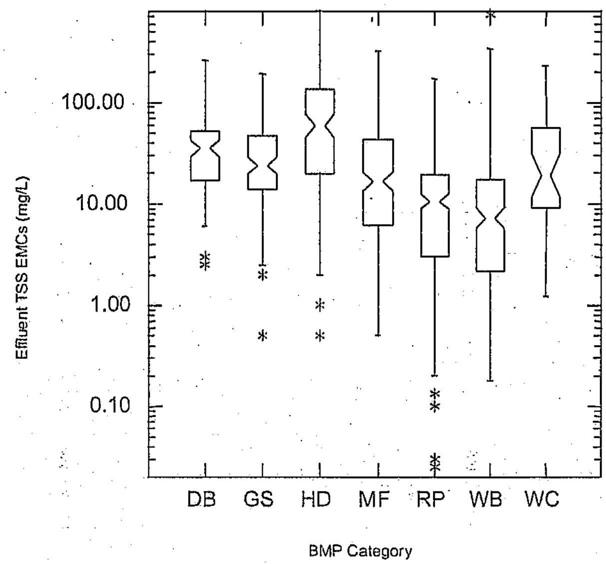
Independent Sample t-Test for Log-transformed Inflow and Outflow	
LN Mean diff	The difference in mean influent and effluent values for LN transformed data.
LN Sep p (t-test)	P-value for the t-test of the LN transformed data assuming that the two samples come from Normally distributed populations with unequal variances (i.e., a separate estimate is used for the variance of each sample).
Indicate Sep LN Sig Diff (t-test)	Interpretation of pooled variance t-test on the LN transformed data. "No" if the null hypothesis that the means are the same cannot be rejected "Yes" if the null hypothesis can be rejected.
LN Pool p (t-test)	P-value for the t-test of the LN transformed data assuming that the two samples come from Normally distributed populations with equal variances (i.e., a pooled estimate for the variance of both samples is used in the test).
Indicate Pool LN Sig Diff (t-test)	Interpretation of pooled variance t-test on LN transformed data – "No" if the null hypothesis that the means are the same cannot be rejected "Yes" if the null hypothesis can be rejected.

Total Suspended Solids (mg/L)

Individual Effluent TSS by BMP Category



Previous Data Set



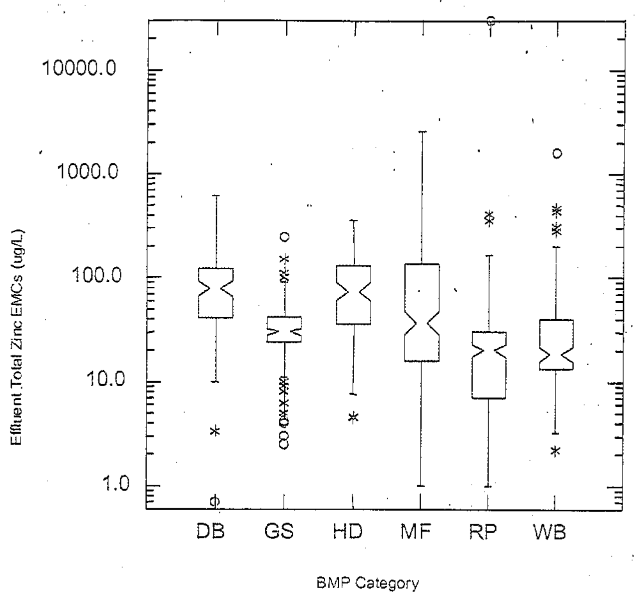
Updated Data Set

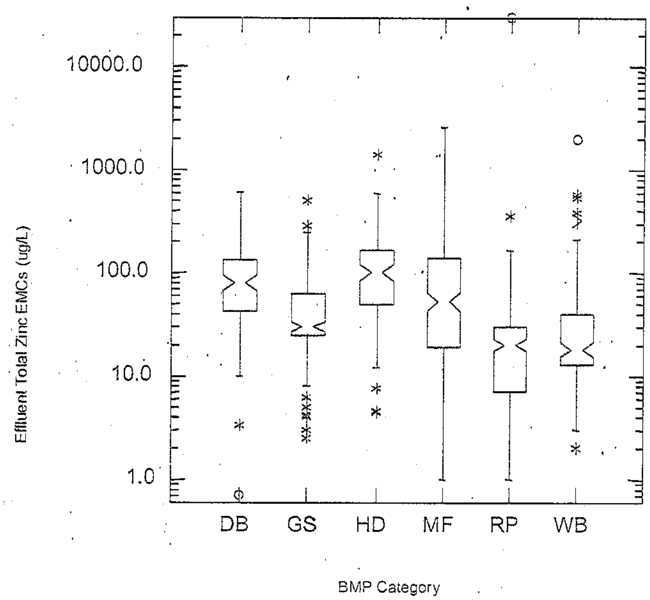
Project Effort to Date

5/2/05

Total Zinc (ug/L)

Individual Effluent Total Zinc by BMP Category





Previous Data Set

Updated Data Set

Project Effort
to Date

5/2/05

Analysis Findings

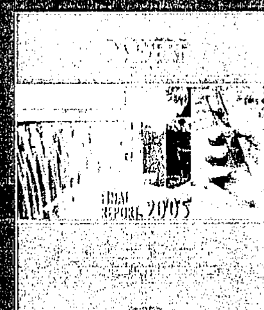
Results of the analyses of the now expanded database have reinforced the initial finding that BMPs are best described by:

1. how much they reduce runoff volumes [Hydrological Source Control Performance],
2. how much of the runoff that occurs is treated (and not) by the BMP (e.g., bypass or overflow) [Hydraulic Performance],
3. of the runoff treated, what effluent quality (concentrations and toxicity potential) is achieved? [Water Quality Performance]
4. And does the BMP reduce downstream erosion impacts [Physical Stream Impact Performance]

Analysis Findings Cont.

- These Basic BMP performance description elements can be utilized to more accurately:
  - ✓ assess the concentrations that BMPs are able to achieve (concentration TMDLs),
  - ✓ assess effects on total loadings (TMDLs),
  - ✓ estimate the frequency of potential exceedances of water quality criteria or other targets, and
  - ✓ develop other desired water quality performance measures.

Applied Research that is Partially Relying on BMP Database



- Projects:
  - Water Environment Research Foundation
    - Project 02-SW-1:
      Critical Assessment of Stormwater Control Selection Issues
    - Jeff Moeller PO, Bob Pitt Chair of PSC
  - National Cooperative Highway Research Program Project 25-20(01)
    - "Development of a BMP Evaluation Methodology for Highway Applications"
    - Chris Hedges PO, Ed Herricks Chair of PSC

    <u>Evaluation of Best Management Practices for Highway Runoff Control (with supporting material on CD-ROM)</u> NR565
- Primary Deliverables
  - Guidance Manuals on BMP Selection and Design

Achieving Project Goals

- Emphasize
  - Treatabilty
  - Evaluation and design by examination of fundamental unit processes
- Include criteria of practicability, performance, and hydrologic assessment on a control-specific and regional basis
- Provide technical guidance documents and related reports/research findings

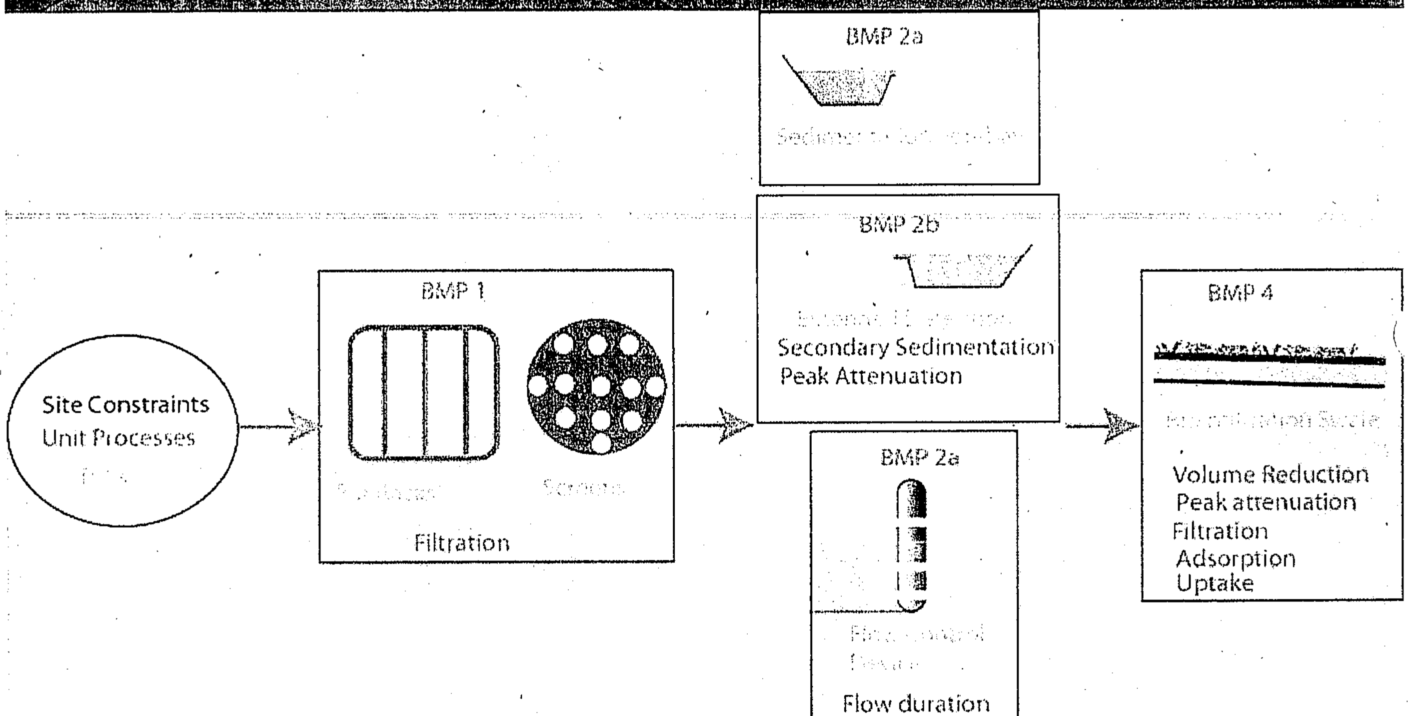
Applying Unit Process Approach to BMP Selection and Design WERF/NCHRP Guidance Manual TOCs

1. Introduction
2. Characterize Conditions and Constraints
3. Identify Fundamental Unit Process Categories
4. Integrated Unit Process Design Approach
5. Critically Assess BMP Options
6. Design BMP or BMP Systems
7. Low-Impact Development/Distributed BMP Systems
8. Example Applications of BMP Selection and Design
9. Monitoring and Evaluation
   - BMP Performance and Evaluation
   - Data Needs for improving URC Selection and Design
10. Conclusions and Recommendations

Consider each of the Fundamental Process Categories (FPCs)

- Physical Processes:
  - Hydrologic/Hydraulic
  - Treatment
- Biological Treatment Processes
- Chemical Treatment Processes

Trash/Debris, TSS and Dissolved Copper – TMDL -Alternative 1



WERF BMP Performance Fact Sheets

FOR INTERPRETATION OF THESE FIGURES SEE SECTION [illegible] - INTRODUCTION

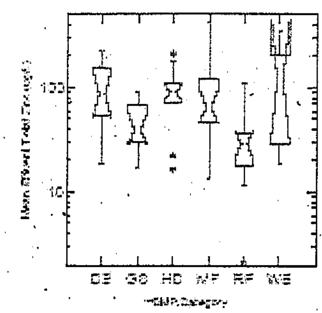


Figure 1. Mean effluent Total Zinc concentration by BMP category

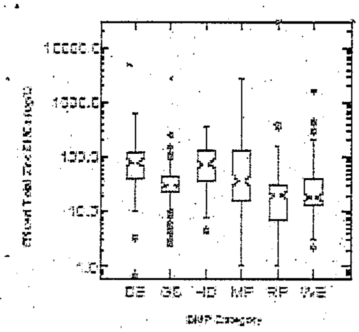


Figure 2. Individual effluent Total Zinc EMCs by BMP category

	BMP Category	Number of BMPs	Median of Avg. Effluent (95% Confidence Interval)[1]: Median	LCL	UCL	Significant Difference Between Average Influent and Effluent[2]	Median of Effluent EMCs (95% Confidence Interval)[1]: Median	LCL	UCL	Significant Difference Between Influent and Effluent EMCs[2]
DB	Detention Basin	15	65.25	53.9	140.85	YES	71.5	[illegible]	[illegible]	YES
GS	[illegible]	14	39.44	[illegible]	[illegible]	YES	30	[illegible]	[illegible]	YES
HD	Hydrodynamic Devices	11	[illegible]	[illegible]	108.71	YES	[illegible]	[illegible]	[illegible]	YES
MF	Media Filter	15	64.90	[illegible]	[illegible]	NO	37	[illegible]	[illegible]	YES
RP	Retention Pond	17	[illegible]	21.4	[illegible]	YES	20	17.4	[illegible]	YES
WB	Wetland Basin	5	[illegible]	[illegible]	[illegible]	NO	11	[illegible]	[illegible]	YES

1. [illegible]
2. [illegible]

Total Zinc (µg/L)

Total Zinc, which encompasses both the particulate [illegible] and dissolved fraction, is one of the most commonly reported metals in the International Stormwater Best Management Practices (BMP) Database. Zinc is particularly prevalent in urban and highway environments due to atmospheric [illegible] and automobile-related [illegible] and deposition. The wear and [illegible] building materials are thought to be two of the larger sources.

Analysis of Mean Effluent Total Zinc Concentrations by BMP Category (one value per BMP Study)

With the exception of media filters (MF) and wetland basins (WB), each BMP category exhibited a significant difference between the medians of average influent and average effluent concentrations (note that the small number of WB studies in the dataset may influence this result). Overall, retention ponds appear the lowest distribution of average effluent zinc levels.

Analysis of Effluent Total Zinc Concentrations by BMP Category (all EMCs, combined in dataset)

All BMP categories report significantly lower median effluent EMCs than median influent EMCs [illegible]. The distribution of effluent EMCs is lowest for retention ponds and wetland basins. As with results for total suspended solids, detention basins and hydrodynamic devices represent the highest effluent values.

A000295

BMP Effluent Quality Data Use

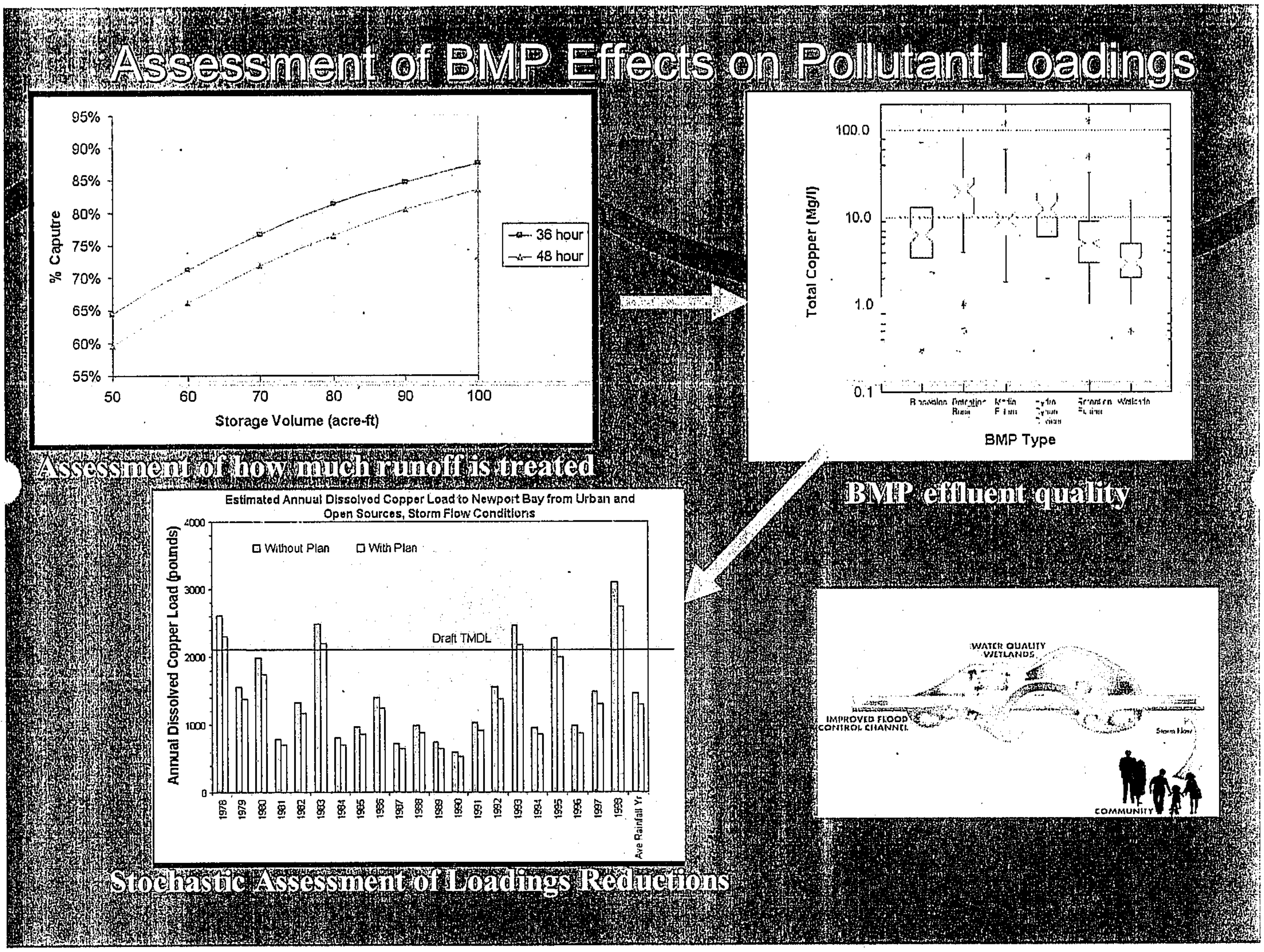
Figure 2. Individual effluent Total Zinc EMCs by BMP category

	BMP Category	Number of BMPs	Median of Avg. Effluent (95% Confidence Interval)[1]			Significant Difference Between Average Influent and Effluent[2]	Median of Effluent EMCs (95% Confidence Interval)[1]			Significant Difference Between Influent and Effluent EMCs[2]
			Median	LCL	UCL		Median	LCL	UCL	
DB	Detention Basin	12	87.92	50.08	154.35	NO	73.48	62.33	86.64	YES
GS	Biofilter	43	60.23	47.26	76.75	YES	30	27.25	33.03	YES
HD	Hydrodynamic Device	11	97.96	70.32	136.51	NO	100	83.77	119.37	YES
MF	Media Filter	19	68.65	45.71	103.68	NO	50.5	41.03	62.15	YES
RP	Retention Pond	19	31.97	24.6	41.55	NO	21	18.69	23.6	YES
WB	Wetland Basin	6	118.74	32.82	429.62	NO	18	15.2	21.32	YES
WC	Wetland Channel	1	Insufficient sample size for analysis.				33.67	22.58	50.22	NO

1. Calculation of confidence interval based on McGill et al (1978), from the natural log of the quantiles.
2. Based on non-parametric analysis of difference in median values.

San Diego Creek Watershed, Orange County, CA

- ~118 square miles
- Main channels are San Diego Creek and Peters Canyon Wash
- Discharges to Upper Newport Bay, an important State Ecological Reserve
- <u>~80% of developable land is built-out!</u>
- Build-out projections
  - 72% Urban
  - 27% open space
  - 1% agriculture


Assessment of BMP Effects on Pollutant Loadings
95%
90%
85%
80%
75%
70%
65%
60%
55%
% Caputre
50
60
70
80
90
100
Storage Volume (acre-ft)
36 hour
48 hour
Assessment of how much runoff is treated
100.0
10.0
1.0
0.1
Total Copper (Mg/l)
BMP Type
BMP effluent quality
Estimated Annual Dissolved Copper Load to Newport Bay from Urban and Open Sources, Storm Flow Conditions
Without Plan
With Plan
Draft TMDL
Annual Dissolved Copper Load (pounds)
4000
3000
2000
1000
0
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Ave Rainfall Yr
WATER QUALITY WETLANDS
IMPROVED FLOOD CONTROL CHANNEL
COMMUNITY
Stochastic Assessment of Loadings Reductions

Other Examples

- Design of BMPs and Urban Drainage Water Quality Facilities
- California Expert Panel on Feasibility of Numeric Effluent Limits
- Lake Tahoe TMDL Development (what is achievable for setting of TMDLs)
- Los Angeles BMP Performance Tool
- Numerous Environmental Impact Reports
- WashDOT BMP for ESA Efforts
- WashDOT and Harris County BMP Performance DBs

Incorporating LID into the Database

- LID – Low Impact Development
- Distributed Controls
- Combinations of Volume loss, Source Controls, Treatment Controls
- Various impervious surfaces being drained to different "facilities"
  - Street – biofiltration swales, etc.
  - Roofs/Driveways to Rain Gardens
  - Roofs to Landscaping
  - Parking areas to biofiltration areas
  - Green Roofs
  - Above areas to Cisterns

LID/Distributed Controls - Tasks

Task 1: Database Design/Protocols

Task 2: Graphical User Interface Development

Task 3: Web Search Engine Upgrade

Task 4: Software Documentation Update and Beta Testing

Task 5: Entry and Review of Existing LID Data

Task 6: Update of the BMP Monitoring Manual

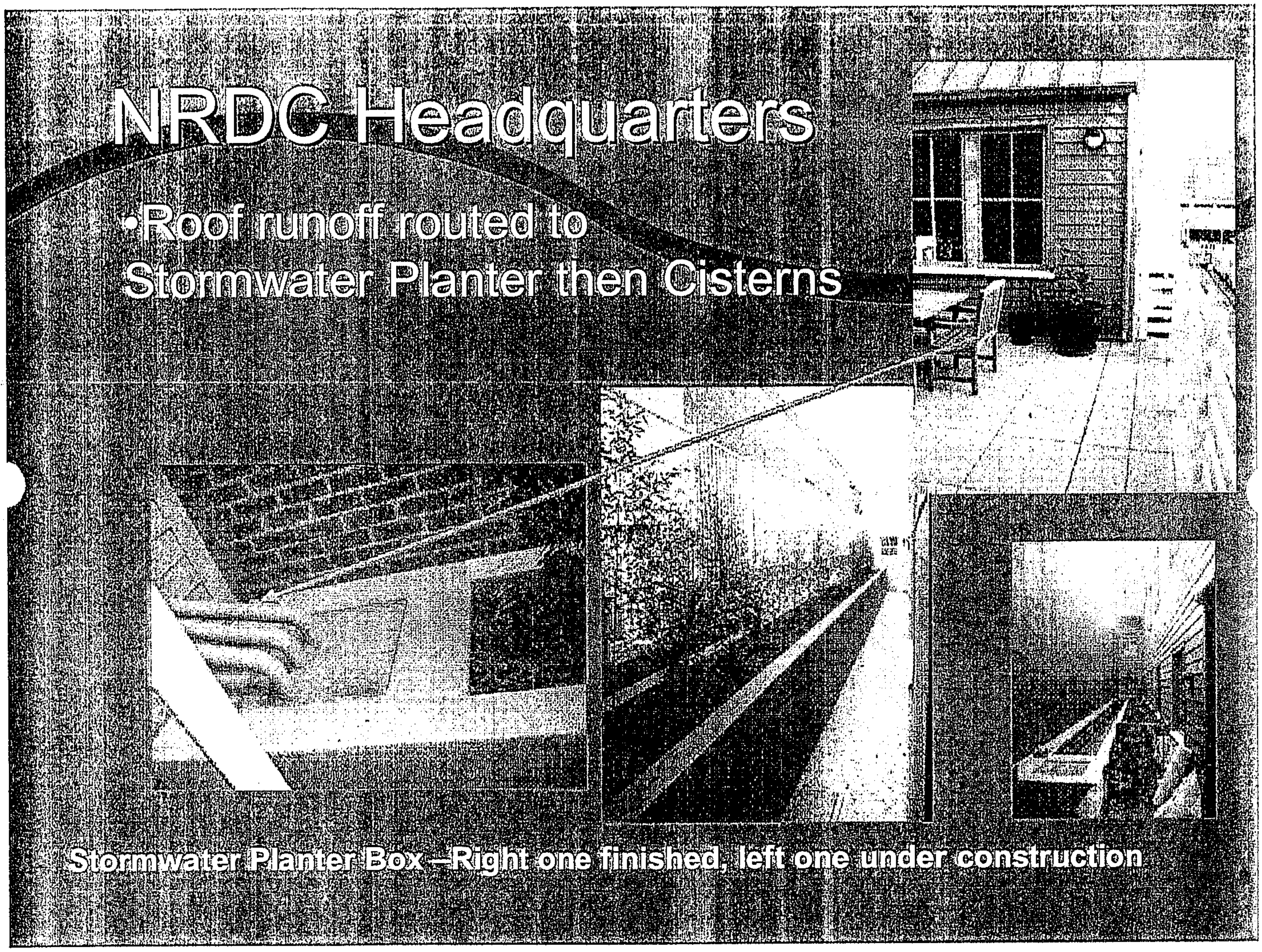
Task 7: Project Publicity and Coordination

Task 8: Analysis of New Studies

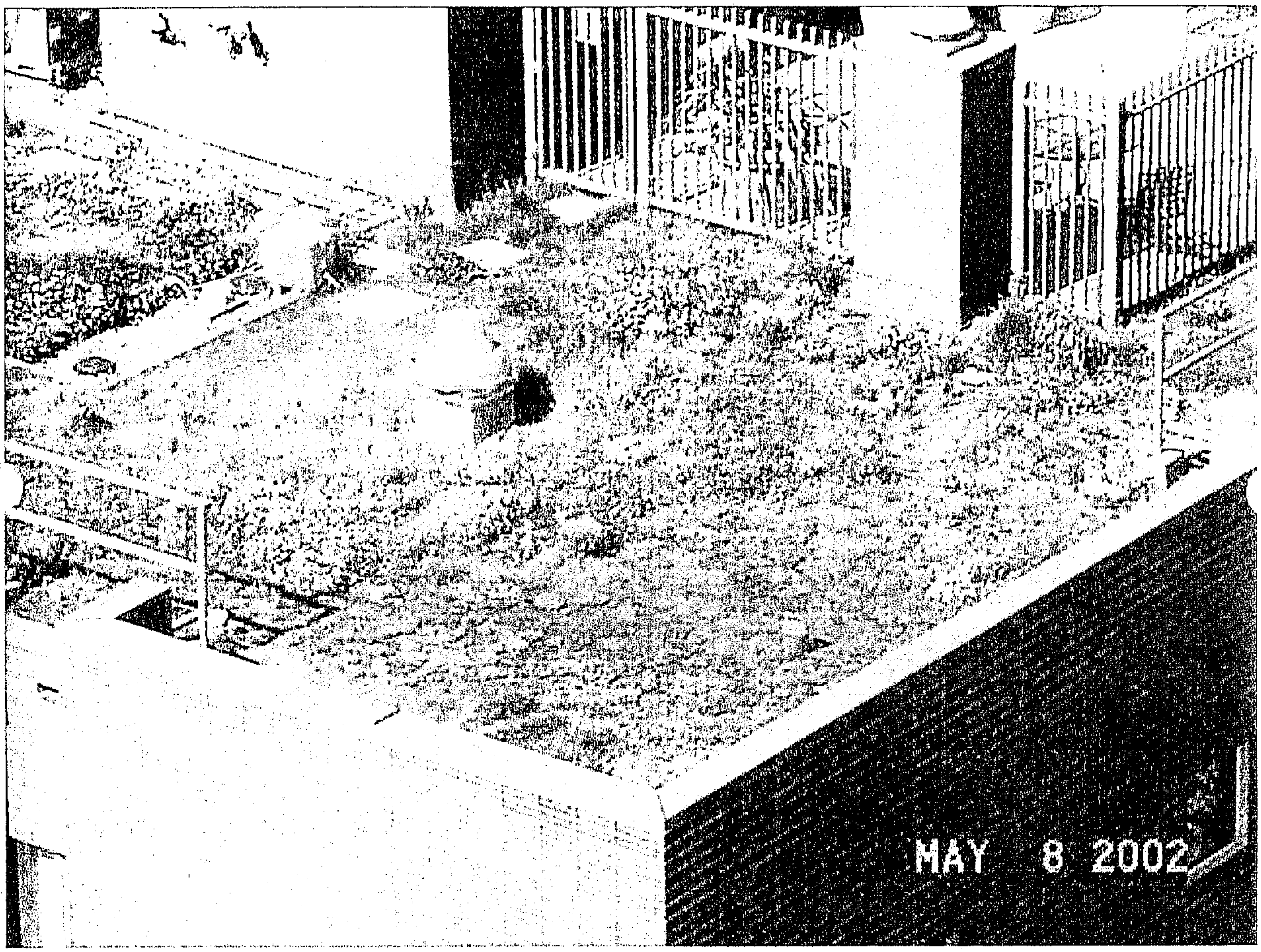
Task 9: Project Coordination

Entryway with Porous Pavers, Gravel Filters and Infiltration Areas

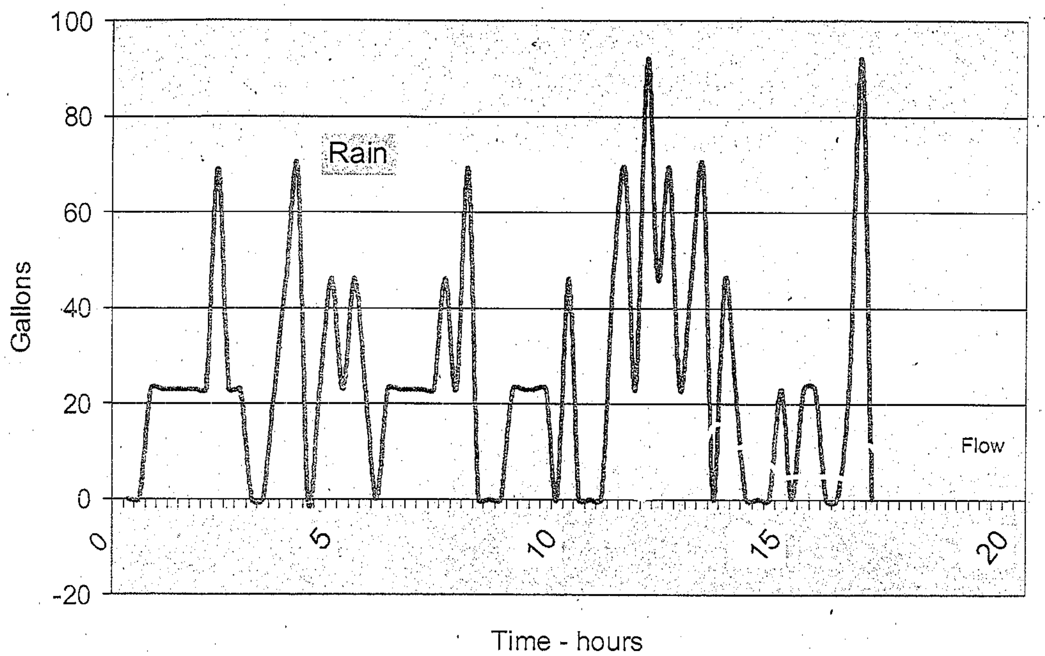

Note - no curb
Parking Lot with BioSwale and Gravel Filters


NRDC Headquarters
•Roof runoff routed to
Stormwater Planter then Cisterns
Stormwater Planter Box –Right one finished, left one under construction


Hamilton Apartments Ecoroof


MAY 8 2002

Hamilton Ecoroof westside rainfall and runoff June 28-29, 2002 storm event 0.73"



Hydrological Source Control-

ET Losses

- Total catchment 3,692 sf, ecoroof 2,690 sf, * impervious surfaces 527 sf, pavers on sand base 475 sf
- *If the 239 gallons of rainfall from the impervious surfaces is removed then no runoff would have occurred

Traditional vs. Integrated Landscape Stormwater Design Approaches – Getting Costs "Right"

Project	Integrated Approach	Cost: Traditional vs. Integrated Approach	Savings
OMSI (commercial)	"Naturescaped" bioswales in parking lots	$273K vs $195K	$78,000
Walnut Park Police Station (commercial)	Bioswale and infiltration area in parking lot	$10K vs. $1K	$9,000
Flex Alloy (industrial)	Flow-through grass filters and swale	$79K vs. $68K	$11,000
Canby Village (31-home subdivision, including streets)	Open channel bioswales and soakage trenches	$79K vs. $58K	$21,000

BMP Costs vs. Change in Project Costs

Recommendations for Setting of BMP Design Requirements

- Recommended BMP Performance requirements should not use percent removal

- Design standards should account for the hydrologic losses (HSC) that can occur with some BMP types to encourage their use.
  - Both biofiltration systems and dry extended detention ponds appear to show significant reductions in runoff that is routed through them.
  - Much of this "loss" is likely evapotranspiration losses.

Recommendations for Setting of BMP Design Requirements

- Continuous simulation techniques with local rainfall data and local conditions should be employed in developing design requirements to assess potential BMP design sizing vs. "percent capture" to ascertain hydrologic/hydraulic performance
  - Given the expenditures of resources by the private and public sector on BMPs, it is imperative that those setting standards should conduct more detailed assessments with local rain gages and conditions to assess the hydrologic, hydraulic and water quality performance of BMPs.

Recommendations for Designers:

- We urge designers to utilize a treatment train approach for BMPs wherever possible that considers:
  - the pollutants of concern and their form,
  - the unit processes that are needed to remove those pollutants,
  - and the unit processes that occur in significance in various BMP types.
- Using a treatment train will help to account for the inherent variability and uncertainties that are associated with BMP performance.
- Designers should employ conservative criteria, including sizing and focusing on longer residence times for volume based BMPs as well as larger sizing of filters and other flow-through BMPs

ACKNOWLEDGEMENTS

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- Members of ASCE's Urban Water Resources Research Council and Others:
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- John Sansalone provided valuable input into this Overview.

What's Next for the International BMP Database?

- ADD more data!
- Add LID Techniques
- Website and database enhancements
- Data analysis tools
- Add more user friendly summaries/tools
- Additional partners

WERF

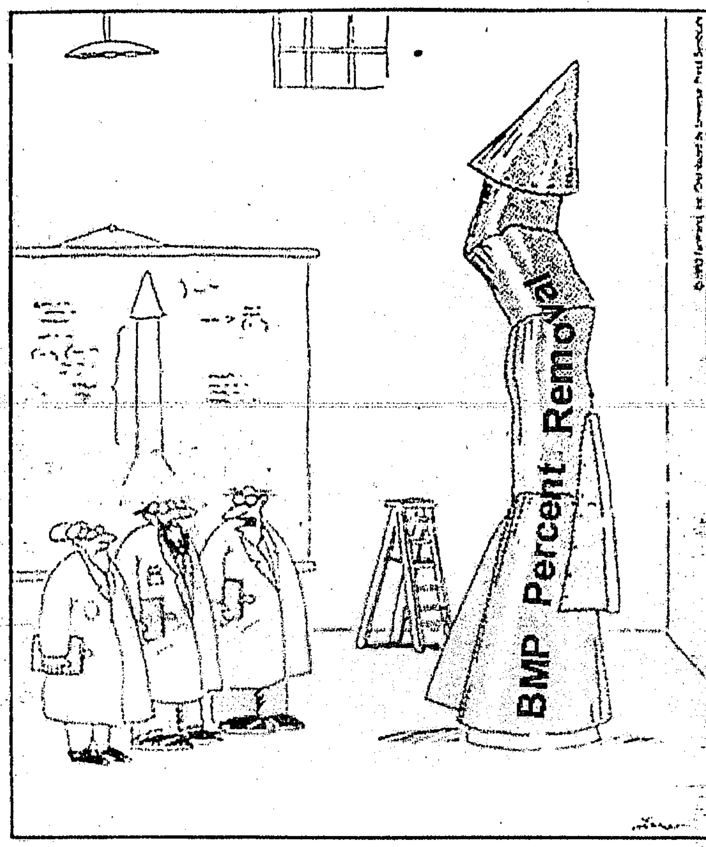
ASCE
American Society of Civil Engineers

EWRI

EPA

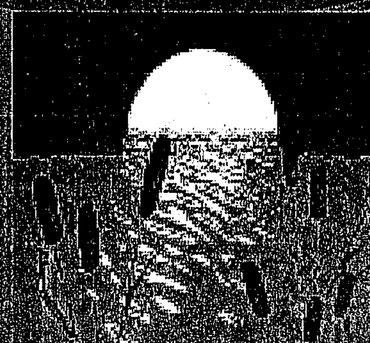
U.S. Department of Transportation
Federal Highway Administration

APWA



"It's time we face reality, my friends. ...
We're not exactly rocket scientists."

The End



www.bmpdatabase.org

www.naturaltreatmentsystem.org

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Increasing Compost Use by Caltrans Project

Board Meeting
August 15, 2006

Agenda Item 15

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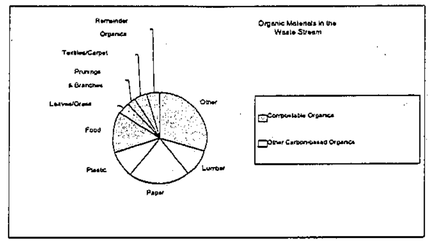
WHAT'S THE PROBLEM?



Compostable Organics = 30% of Disposal

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DIVERSION POTENTIAL

- Processing of disposed organics could increase State diversion rate to 63%
- Increased production of compost and mulch could contribute a significant amount to diversion

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FUTURE ORGANICS FLOWS TO LANDFILLS?

- **Rice straw and other agricultural residuals from burning phase-outs**
- **Waste from logging, wood processing (e.g. sudden oak death and So. Cal. Bark Beetle issue)**
- **Biosolids and dairy manure**
- **Increased green waste due to population increase**

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Green Procurement Action Plan

- Organics
- Construction and Demolition (C&D)
- Rubberized Asphalt Concrete (RAC)
- Environmentally Preferable Purchasing (EPP)
- Green Procurement Toolbox (including Ogilvy)

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Organics

- Complete project with Caltrans to write compost/mulch specifications
- Specifications go into toolbox
- Double the amount of compost and mulch purchased by Caltrans

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Caltrans has the Potential to Greatly Increase Compost/Mulch Purchases

- Caltrans uses compost statewide, primarily in hydroseeding for erosion control
- US Composting Council (USCC) estimates that Caltrans has a potential market for compost of between 3.35-6.72 M cu. yds.
- Approximately 90% used in construction, the remainder in maintenance

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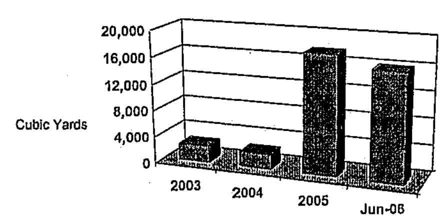
How Much Compost is Caltrans Using?



Caltrans Construction Database

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Construction Site Sediment

- #1 Discharged Pollutant
- 80,000,000 Tons/Year
- 20-1,000 Times More Sediment than Other Land Uses

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Compost and Mulch Benefits the Environment in a Number of Ways

- Decreases runoff and erosion
- Improves roadside revegetation establishment
- Reduces irrigation requirements
- Supplies significant quantities of organic matter
- Improves drainage of clay-based soils and water-holding capacity of sand-based soils
- Improves and stabilizes soil pH
- Improves cation exchange capacity (CEC) of soils, improving their ability to hold nutrients for plant use

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Compost and Mulch Benefits the Environment in a Number of Ways

- Supplies macro- and micronutrients
- Supplies beneficial microorganism
- Suppresses certain soil-borne diseases
- Binds and degrades specific pollutants
- Reduces the need for fertilizers and pesticides
- Encourages slow release of nitrogen
- Improves drought tolerance
- Improves plant health and vigor

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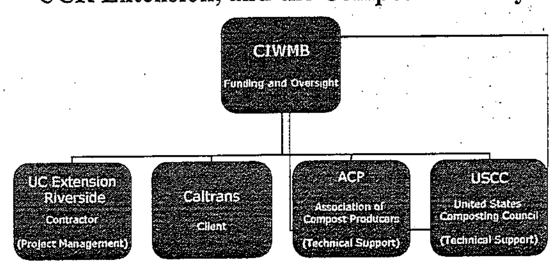
A Partnership Between CIWMB, Caltrans, UCR Extension, and the Compost Industry



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Project Goals

- Determine barriers to increasing compost use by Caltrans
- Address identified barriers
- Revise Existing Compost Specifications
- Develop a Compost Applications "Best Management Practices" Manual
- Utilize the U.S. Composting Council's Seal of Testing Assurance Certification (STA)
- Develop collaborative relationships with stakeholders
- Develop a Compost Classification System

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Barriers to Increased Compost Use

- Cost
- Product quality
- Lack of compost specifications
- Compost and mulch producing infrastructure
  - An increase in annual procurement of 3,000,000 cubic yards of compost would require doubling of compost production
- Education

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Cost Barrier

- Current weighted average (applied) >$300/CY
- High price due to:
  - Bagged materials
  - Application method (primarily hydroseeding)
- Caltrans goals:
  - Reduce cost to $40/CY (applied)
  - More bulk purchases, less bagged

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Product Quality Barrier

- Caltrans did not require STA-certified compost
- Answer: USCC Seal of Testing Assurance Program (STA)
  - TMECC (standard testing methodologies)
  - STA certified labs
  - Testing of compost product

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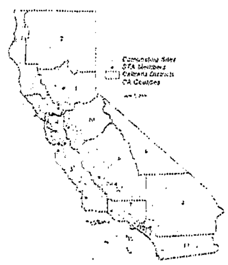
California Composting Sites



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Compost Specifications Barrier

- **No requirement for STA-certified compost (product quality issues)**
- **No specifications for compost blankets, filter socks, or filter berms**
- **All specifications in need of updating**

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New/Revised Compost Specifications

- **STA**
  - **Compost technical data sheet**
  - **Detailed certificate of compliance**
  - **Lab test results**
- **pH**
- **Moisture content**
- **Organic matter content**
- **Soluble salts**
- **Maturity**
- **Stability**
- **Particle size**
- **Phytotoxicity**
- **Pathogens (pass CIWMB standard)**
- **Heavy metals (pass CIWMB standard)**

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ACP Compost Index

- **The Compost Product Index (CPI) is designed to:**
  - **Help compost users quickly identify products that will meet their particular needs**
  - **Eliminate inappropriate use**

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Compost Product Index (CPI)

- Reflects the most important physical, chemical, and biological properties of the compost needed to determine its appropriate use
  - 12 test parameters of compost measured by STA-certified laboratories using TMECC
  - Broken into six categories from low to high values and indexed
  - CPI can be used to reference a specific product for a specific application

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CPI Test Methods and Result Ranges

No.	Parameter	Test Method[a]	Title	Units	Ranges 1	2	3	4	5	6
1	Total N	TMECC 04.02-D	Nitrogen	%TN (dw basis)[1]	0% (ND)[2]	>0-<0.5%	0.5-1.0%	>1.0-<2.0%	2.0-5.0%	>5.0%
2	Total P	TMECC 04.03-A	Phosphorus	%P (dw basis)	0% (ND)	>0-<0.2%	0.2-0.5%	>0.5-<1.0%	1.0-2.0%	>2.0%
3	Na	TMECC 04.05-Na	Sodium	%Na (dw basis)	0% (ND)	>0-<0.05%	0.05-0.1%	>0.1-<0.2%	0.2-0.5%	>0.5%
4	Cl	TMECC 04.05-Cl	Chlorine (water soluble chloride)	%Cl (dw basis)	0% (ND)	>0-<0.05%	0.05-0.1%	>0.1-<0.2%	0.2-0.5%	>0.5%
5	Boron	TMECC 04.05-B	Boron	mg kg[-1] dw	0 (ND)	>0-20	>20-40	>40-100	>100-300	>300
6	EC	TMECC 04.10	Electrical Conductivity	dS m[-1] (mmhos cm[-1])	0 (ND)	>0-<3.0	3.0-5.0	5.0-<10.0	10.0-20.0	>20.0
7	pH	TMECC 04.11-A	pH	0-14	0-4	>4.0	>6.7	>7.8	>8-<10	>10
8	Stability	TMECC 05.08-F	Biologically available Carbon	mg CO_2-C g[-1] OC d[-1]	0 (ND)	>0-2	>2-4	>4-8	>8-10	>10
9	Particle Size	No TMECC method	Particle Size Distribution	percent passing 4 mm [illegible] dry wt	<30%	30-70	70-80	80-90	[illegible]	[illegible]
10	Phytotoxicity	TMECC 05.05-B	Phytotoxicity Germination Rate	Growth %	0%	>0-<70%	70-<80%	[illegible]	[illegible]	[illegible]
11	Organic Matter	TMECC 05.07-A	Organic Matter	% g g[-1] dw	0 (ND)	>0-20%	>20-40%	[illegible]	[illegible]	[illegible]
12	Safety	TMECC 07.00 [illegible]	Safety Parameters	Pass/Fail	-	-	-	-	-	-

Footnotes:
[a] Test methods are outlined in the TMECC manual ([illegible])
[1] dw = dry weight
[2] ND = non detectable using the listed method

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Determining CPI of a Compost Sample

- Samples must be tested at a USCC certified laboratory
- Test results determine Compost Index or class
- Expressed automatically by the lab performing the test

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Best Uses

- In future versions of the CUI, the Product Index of a given material will be used to generate a list of "best uses"
- The "Best Use List" identifies a set of suitable compost uses based on the experience of industry experts

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Compost-Based BMPs

- Reduce Runoff Volume
- Reduce Runoff Rate
- Improve Infiltration
- Improve Soil Fertility
- Improve Vegetation Establishment

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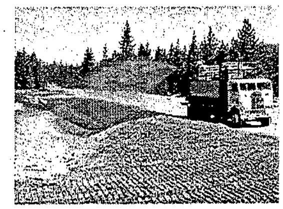
Hydroseed (Type C & Type D)

- Used to control erosion on disturbed slopes
- Type C - straw required
- Type D – straw not required
- Seed
- Compost – fine material Bagged material only
- Stabilizing emulsion



Compost and hydroseeding application, Lake Tahoe, courtesy of Caltrans

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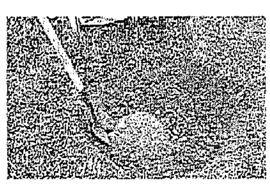
Backfill

- Also referred to as amendment or "soil prep"
- Compost used as a component of backfill
- Use as a soil amendment/backfill for container sized plant material
- Planting backfill benefits trees and shrubs that would otherwise be planted in poor soils



Backfill, photo courtesy of Caltrans

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Blanket (Incorporated)

- Placed in disturbed areas
- Incorporated to a depth of 18 inches
- Alternative to netting, stabilizing emulsions or polymers
- Typically vegetated by broadcasting seed onto the surface after incorporation

Compost incorporation, Placer County, Route 267, photo courtesy of Caltrans

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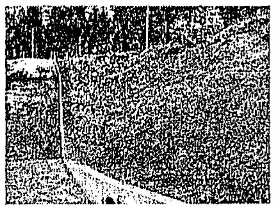
Benefits of Compost Blankets

- Provides soil protection from rain "splash impact"
- Adds organic material to soil
- Promotes percolation/infiltration
- Reduces need for irrigation
- Removes pollutants, improving downstream water quality



Slope after incorporation of compost, photo courtesy of Caltrans

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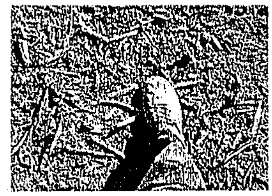
Blanket (Not Incorporated)

- Layer of loosely applied compost placed over disturbed areas to control erosion
- Seed can be incorporated into compost before placement or broadcast onto surface after placement



Compost blanket (not incorporated), courtesy of Caltrans

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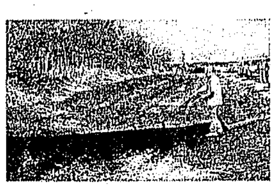
Filter Berm

- Compost placed perpendicular to sheet flow runoff to control erosion
- Alternative to silt fencing
- Generally placed along perimeter of site or at intervals along slope
- Can be used as a check dam in small drainage ditches
- Can be vegetated or unvegetated
- Retains sediment and other pollutants while allowing cleaned water to flow through



Installation of filter berm, photo courtesy of Caltrans

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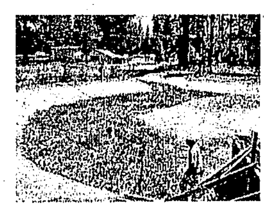
Biofiltration Strips (Biostrips)

- Vegetated land areas over which storm water flows as sheet flow
- Removes pollutants
- Traps litter, total suspended solids, and particulate metals
- Compost may be used to improve filtration and vegetation establishment
- Vegetated
- Preferred plant material has a dense continuous top growth



Biofiltration strip, photo courtesy of Caltrans

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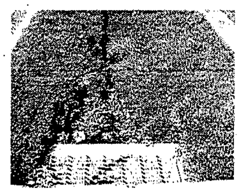
Biofiltration Swales (Bioswales)

- Vegetated channels or drainage swales, typically trapezoidal or v-shaped channels that receive and convey storm water while
- Other characteristics are similar to biostrips



Biofiltration swale, courtesy of Caltrans

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Mulch

- Applied to highway roadside to prevent erosion, suppress weed growth, and biodegrade slowly
- Coarse to very coarse particle size
- Ideally would not have to be reapplied for 2-3 years
- Not seeded or hydroseeded after application
- Used to cover ground between existing container-sized plants
- Minimal trash may be okay

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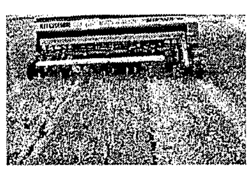
Drill Seed

- Seed applied with agricultural drill seeding equipment after compost is applied and incorporated into topsoil
- Used on flat areas, such as highway medians
- Purpose is to amend the soil to enhance seed germination and vegetation establishment



Drill seeding equipment, courtesy of Caltrans

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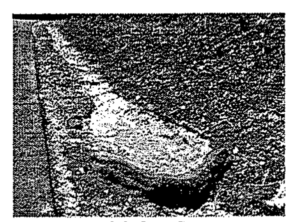
Filter Sock

- Stabilization of disturbed slopes, storm water pollutant reduction/removal
- Can be used in place of silt fence or straw bale barrier
- Can be vegetated or non-vegetated
- Pollutants removed by filtration and adsorption to compost particles
- Traps total suspended solids, particulate metals, oil



Filter sock – courtesy of Dr. Britt Faucette, Filtrexx

36

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Education Barrier

- Correct misinformation such as:
  - "Compost mulch not suitable for 2:1 slopes"
  - "Compost isn't suited for native plants"
- Roll out new/revised specifications
- Educate Caltrans staff and its contractors on compost-based BMPs
- Compost applications best practices manual
- Follow-up

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Compost Applications Best Practices Manual

- Designed primarily for use by Caltrans and its contractors
- Ties into compost classification system and Caltrans specifications

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Caltrans Workshops

- Improving Revegetation and Stormwater Quality Through Compost-Based BMPs
  - Los Angeles - August 22, 2006
  - San Diego - August 24, 2006
  - Oakland - September 26, 2006
  - Fresno - September 28, 2006
  - Sacramento – October 11, 2006

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Track Results and Follow-up

- Caltrans use of compost and mulch will be measured in 2007 and succeeding years
- Will develop recommendations on further increasing compost use by Caltrans

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For Further Information

www.ciwmb.ca.gov/Organics/

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Any Questions?

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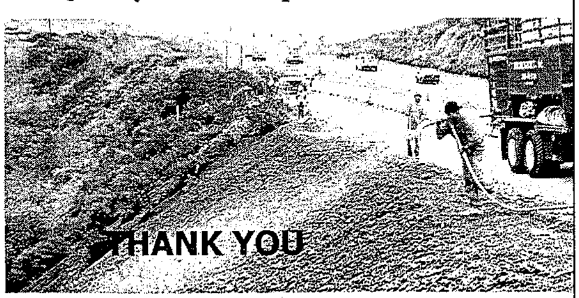
Improving Revegetation and Stormwater Quality with Compost-Based BMPs



California Integrated Waste Management Board

Board Meeting

Increasing Compost Use by Caltrans

August 15, 2006

Agenda Item 15

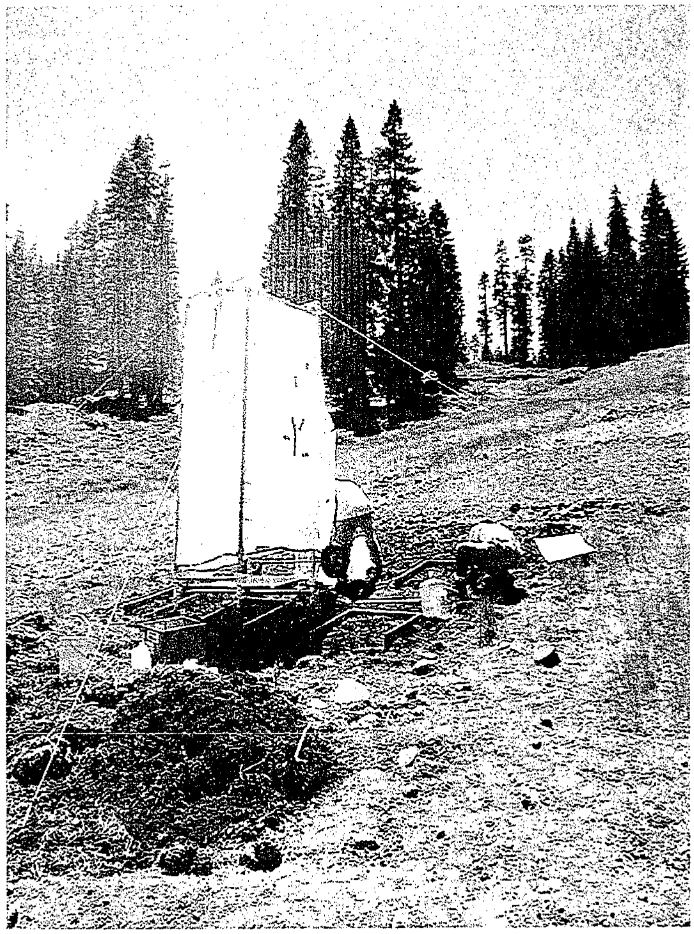
www.ciwmb.ca.gov

RESEARCH ARTICLE

Erosion control reduces fine particles in runoff to Lake Tahoe

by Mark E. Grismer and A.L. Ellis

Sediment in hillslope runoff from disturbed soils in the Lake Tahoe Basin is the source of many fine suspended particles that transport nutrients and contribute to a loss in lake clarity. In previous studies, we used rainfall simulation to assess and quantify infiltration, runoff and erosion rates from hillslope soils. Building on this research, our current study evaluates the relationship between particle sizes in runoff sediments and slope, and compares the relationships between restored soil treatments and bare and undisturbed (native) forest soils. Soil restoration combined with pine needle mulch treatments substantially reduced sediment yields in runoff water, and increased the size of runoff particles when compared to that from bare soils. Very little, if any, runoff and erosion occurred from relatively undisturbed "native" soil plots at similar slopes.



A rainfall simulator was used to measure sediments in runoff under a variety of soil and groundcover conditions in the Lake Tahoe Basin.

Ever-increasing recreational use and housing development have increased the flow of sediments and nutrients into Lake Tahoe, decreasing its once-famous clarity by 30%, from approximately 100 to 69 feet (30 to 21 meters), over the last 3 decades. This loss of clarity and a tripling of algal primary productivity (growth) indicate the onset of lake eutrophication (Goldman et al. 1989; TRG 2002). Swift et al. (see page 49) have demonstrated the importance of 1 to 8 micron (μm) fine-sediment particles in diminishing the lake's clarity, both by transporting attached nutrients into the lake and scattering light when suspended in the water.

Road cuts and ski runs are important sources of damaging erosion and runoff in the Lake Tahoe Basin. Recently, regulators have increasingly focused on preventing runoff and retaining sediments within their original drainages (CTC 2001, 2004). The erosion-control treatments used at road cuts, ski runs and other sites in the basin can be broadly categorized, in order of decreasing runoff potential at a given slope, as: (1) bare soils (no treatment); (2) surface-treated soils, such as hydroseeded grasses, straw or mulch covers; (3) soil restoration treatments, such as tillage, the incorporation of woodchips, or compost combined with mulch covers; and (4) undisturbed "native" forest soils (Grismer and Hogan 2005b) (table 1). Unfortunately, several examples of erosion-control failures are visible in the semiarid, high-altitude environment of the Lake Tahoe Basin, especially along road cuts and ski runs.

Despite years of work, quantitative information has only recently been developed about the effectiveness of measures employed at road cuts and hillslopes to control erosion in the basin. In general, the literature related to erosion control involves agricultural activities and practices in relatively humid environments. There are few scientific field evaluations of erosion-control efforts involving revegetation and restoration in semiarid, subalpine environments such as the Lake Tahoe Basin. The information that is available on such environments is often limited to the "gray" literature of "white" papers from agencies or professional societies; these papers — while important — are not peer-reviewed or widely available, and so are not readily available for scientific scrutiny.

Nonetheless, erosion-control research and work are not new in the Tahoe Basin. For example, Maholland (2004) used geographic information system (GIS) assessment methods to determine that

Sediment yields were nearly 10 times greater from volcanic ski-run soils and both types of road-cut soils than from undisturbed (native) sites.

As expected, runoff from bare ground was greater than mulched and seeded plots, with a higher proportion of fine sediment particles.

TABLE 1. Estimated or known erosion-control treatment characteristics at Tahoe Basin rainfall simulation sites

Site*	Seed mix†	Amends‡	Fertilizer¶	Mulch Type	Mulch Depth	Tillage depth
					mm	mm
Granitic soils						
Bliss (RC)	None	Forest duff	None	Pine needle (PN)	25	150
Cave Rock (RC), Heavenly Mt. (SR)	Br ca, El el (100 kg/ha)	Compost	Biosol	PN over straw	50	150
Luther Pass — GV (RC)	El el, El gl, Br ca	Compost	Biosol	PN	25	None
Rubicon (RC)	Caltrans type-B grasses — planted	Compost	16-16-16	Straw and PN	~ 25	None
Volcanic soils						
Brockway (RC)	Various grass mixes (unknown)	Compost	Biosol	PN	10	100
Dollar Hill — west (RC)	Various bunchgrass mixes	None	Biosol	PN, hand-applied	30	None
Dollar Hill — east (RC)	Native grasses over std. mix w/yarrow	None	Biosol	Ground PN	50	None
Northstar Unit 7 (RC)	El el, El gl, Br ca	100 mm compost	Biosol	PN	25	300
Northstar (SRs) (Lookout Mt.)	Native and adapted grasses	None	Biosol	Straw	0	
Snowking (SR) (Juniper Mt.)	El el, El gl, Br ca	Compost and woodchips	Biosol	PN	25	300

* SR = ski run; RC = road cut.
† Various grass species: Br = Bromus, El = Elymus, ca = carinatus; el = elymoides; gl = glaucus. Caltrans type-B grasses include fescues.
‡ Forest duff = broken-down organic litter matter on forest floor (fine powder).
¶ Biosol is a proprietary soil amendment; 16-16-16 refers to the N-P-K content of the amendment.

forest roads and ski runs subject to hillslope rilling (small channels created by concentrated runoff) were the greatest sources of sediment in the mixed granitic and volcanic soils of the Squaw Creek watershed, northwest of Lake Tahoe.

Furthermore, White and Franks (1978) documented the near total destruction of benthic (stream bottom) communities from the excessive discharge of sediments following development of the Rubicon Properties on Lake Tahoe's west shore. Their important demonstration study of various erosion-control nettings at the Rubicon housing development and Northstar-at-Tahoe ski area was "largely ignored in the erosion-control literature" (Sutherland 1998). As a white paper, White and Frank's study was not circulated widely and the results were not incorporated in other studies. Yet while it lacked scientific rigor, this was a model study with rarely seen cooperation between agencies in attempting to limit erosion in the Tahoe Basin. Other studies relevant to erosion in the Tahoe Basin include those conducted in the basin by Fifield et al. (1988) and in semi-arid, alpine western Colorado by Fifield et al. (1989), Fifield and Malnor (1990) and Fifield (1992a, 1992b).

Standardized erosion evaluation

Rainfall simulations are a useful method for standardizing the evaluation of erosion-control measures. These studies entail replicated rainfall events of the same intensity (or kinetic energy) on multiple plots, enabling the statistical evaluation of erosion-control treatments on hydrologic parameters. Grismer and Hogan (2004, 2005a, 2005b) employed rainfall simulation on disturbed road cuts and ski runs with granitic and volcanic soils in the Tahoe Basin to evaluate how slope, groundcover and surface roughness (microtopography) affect infiltration and runoff rates, as well as sediment concentrations and yields in runoff.

Soil survey information is limited for the Tahoe Basin, but all the soils can be broadly grouped into granitic, volcanic or a mix of the two, with surface soil textures of cobbly or stony sandy loams. Grismer and Hogan (2004, 2005a, 2005b) determined that surface roughness and cross-slope (the slope diagonal to straight downslope) had no effect on sediment concentrations or yields in runoff under all treatments encountered. In addition, for nearly all groundcover conditions, volcanic soils had greater runoff rates, sediment concentrations and yields than granitic soils (Grismer and Hogan 2004).

In these studies, runoff rates and sediment yields from bare soils were significantly correlated with slope. Sediment yields from bare granitic soils at slopes of 28% to 78% ranged from about 1 to 12 grams per millimeter per square meter ($g/mm/m^2$) runoff, while sediment yields from bare volcanic soils at slopes of 22% to 61% ranged from about 3 to 31 $g/mm/m^2$ runoff (Grismer and Hogan 2005a). Furthermore, sediment yields were nearly 10 times greater from volcanic ski-run soils and both types of road-cut soils than from undisturbed (native) sites. Similarly, sediment yields were nearly four times greater from granitic ski-run soils than from native areas.

For both volcanic and granitic ski-run soils, revegetation or pine needle mulch decreased sediment concentrations and yields by 30% to 50%. Regardless of rainfall intensity, there was little or no runoff or sediment yield from either soil type after the soil was restored by either incorporating woodchips or tilling amendments such as Biosol or compost into the soil, or applying mulch covers (with or without plant seeding).

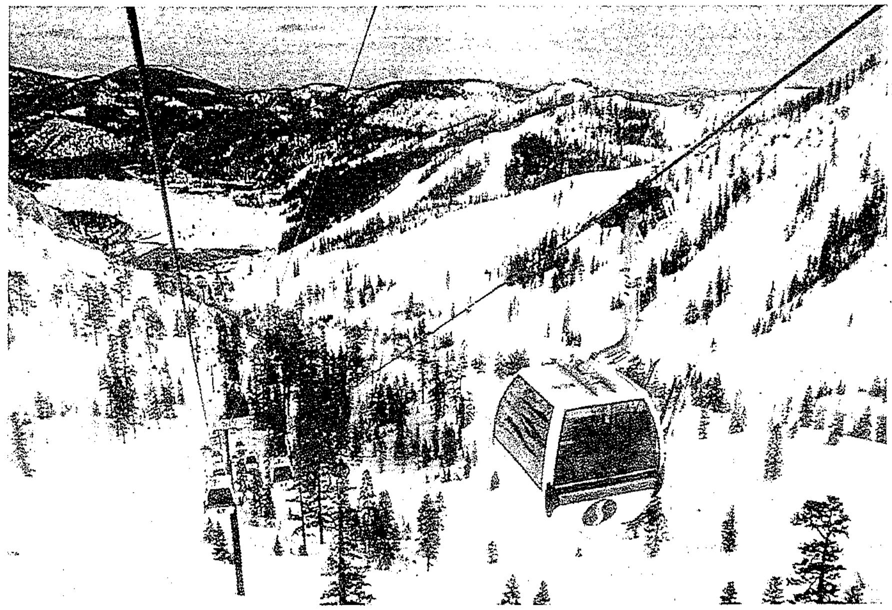
Sediment size in Lake Tahoe

However, these previous studies did not analyze the particle-size distributions in runoff water, which is a critical component of Lake Tahoe's famed clarity and water quality. This paper reports on our study of the relationships between sediment concentration and yield, sediment yield and slope, and sediment particle size and slope for native (forest) and treated (at ski runs and road cuts) soils following rainfall simulation.

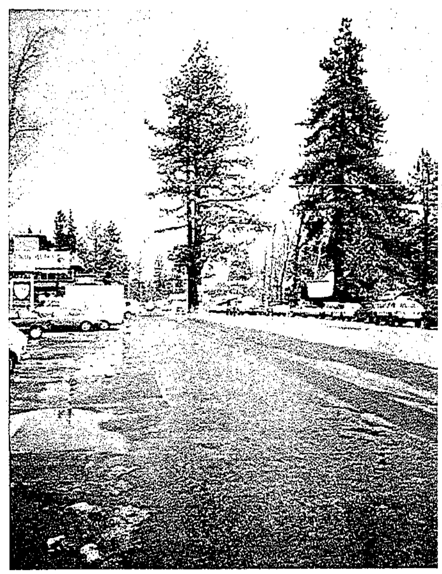
Battany and Grismer (2000) and Grismer and Hogan (2004) provide detailed descriptions of the rainfall simulation methodology that we used. The rainfall simulator consisted of a needle tank, tower assembly and associated plumbing hardware necessary to obtain steady rainfall intensity. Following a preliminary land survey of each site selected across the basin, several plots were established, the metal plot frame (31.5 inches by 31.5 inches [0.8 meter by 0.8 meter]) was installed, and the rainfall simulator was centered over the frame and leveled. Rainfall was allowed to continue until either steady runoff was obtained or about 60 minutes elapsed.

Following field measurements (including time to runoff, times of sample collection and surface topography), collected runoff samples were taken to the laboratory for filtration and analyses. Samples were vacuum-filtered first through a Whatman #541 filter and then through a 0.45 μm filter. Split samples were analyzed directly for particle-size distributions using the laser (Coulter) counting method (Eshel et al. 2004). The filter papers with sediment were dried at 105° C and then weighed, and total sediment mass per volume of runoff was determined. Sediment yield was determined as the slope of the linear regression (R^2 values ranged from 0.90 to 0.98) between cumulative sediment in the runoff and cumulative runoff. Steady sediment concentration in runoff was taken as the average of the last two-to-four individual sediment concentrations determined after runoff rates stabilized.

Several rainfall simulation tests were conducted during the summers of 2003 and 2004 on three soil types: volcanic, at Northstar (ski runs), Snowking (ski run) and Truckee highway interchanges (road cuts) on the north shore of Lake Tahoe; mixed, at a forest mastication test site near Tahoma on the west shore (see page 77); and granitic, at Heavenly Mountain Resort (ski run) and State Highway 89 (road cuts) on the south shore. At each site, rainfall simulation tests were conducted on three to six plots per treatment (bare, treated or native) and slope, depending on the relative consistency in measured val-



Phil Schermeister



Laurence R. Costello/UCCE San Francisco-San Mateo

Runoff from, *top*, ski areas and urban roads such as in, *above*, Tahoe City, are important sources of sediments that are having an adverse impact on the storied clarity of Lake Tahoe.

TABLE 2. Laser particle-size distribution measurements (means and standard deviations) for Tahoe Basin disturbed soils

Soil type	n	D_{10}	D_{30}	D_{60}	D_{90}	Sand	Silt	Clay
		μm				%		
Granitic mean	16	70.4*	294.8a	785.6a	1,589a	90.7a	7.82a	1.52a
Std. dev.	16	30.2	91.9	146.4	83.5	3.19	2.90	0.55
Volcanic mean	48	3.98b	41.3b	390.1b	1,227a	64.9b	28.2b	6.92b
Std. dev.	48	2.06	26.0	175.7	342.9	7.43	4.82	2.97
Tahoma mean	4	8.67b	66.0b	297.8b	1,194a	74.0c	21.8c	4.20ab
Std. dev.	4	3.06	6.39	54.2	245.6	2.11	1.45	0.85

* Mean values followed by different letters differ significantly ($P < 0.05$).

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ues from plot to plot at similar slopes. Slope and soil type were taken as the independent variables, while sediment yield and particle-size fraction were the response variables as affected by plot treatment.

We characterized the particle-size distributions using the maximum size (D_{xx}), with xx corresponding to the percentage of particles less than that size. For example, the D_{50} particle size is the median, with 50% of the particles larger and 50% smaller; similarly, 10% of the soil particles are smaller than the D_{10} size. We considered particle sizes associated with less than 10%, 30%, 60% and 90% of the total sample (D_{10}, D_{30}, D_{60} and D_{90}, respectively). We then focused on the D_{30} size, since it is often used to estimate soil infiltration rates and also roughly corresponds to the less-than-8-µm particle size from the volcanic soils that are important to Lake Tahoe water clarity. Because we took measurements across a gradient (slope) and obvious differences resulted from soil type and treatment, we used regression analyses to develop possible causal relationships between slope and the response variables (sediment yield and particle-size fraction) (Cottingham et al. 2005).

Reducing fine sediments

Runoff and erosion rates from disturbed soils in the Tahoe Basin are primarily dependent first on soil type (granitic or volcanic), followed by the extent of soil restoration, and then slope and cover conditions (Grismer and Hogan 2004). While both soils are considered sand or sandy loam for any particular particle-size fraction, the average granitic particle sizes differed significantly (at 95% level using Tukey standardized range test) from and were several times larger than those of the volcanic soils (table 2). The Tahoma soils at the mastication site are mixed volcanic and granitic, and this was reflected in the particle-size fractions that we found, which fell between those two soil types. Perhaps more importantly, there were more 1-to-8-µm particles in volcanic soils than granitic. Furthermore, Grismer and Hogan (2005a) found that soil

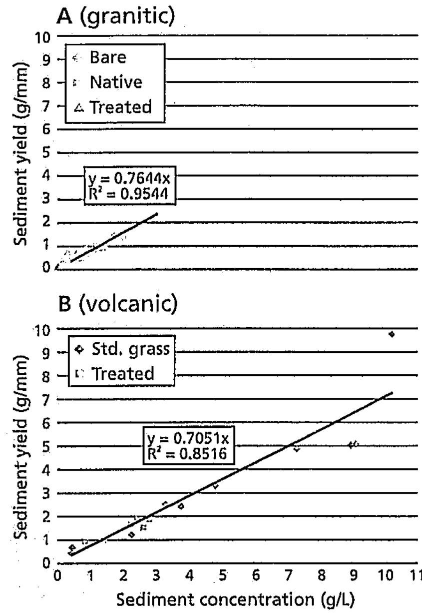

Fig. 1. Relationship between sediment yields and concentrations for all conditions from (A) granitic and (B) volcanic soils.

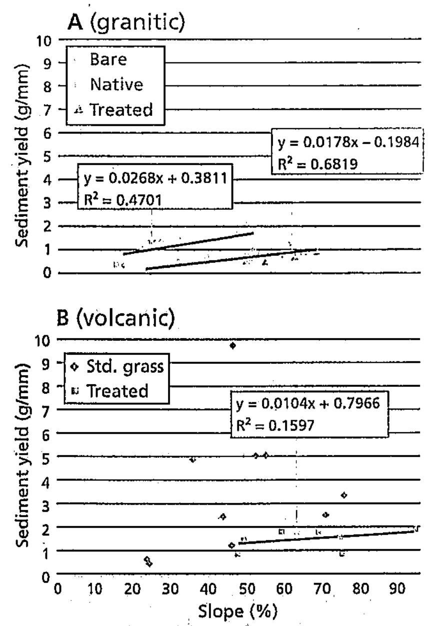

Fig. 2. Relationship between sediment yields and slope for all conditions from (A) granitic and (B) volcanic soils.

particle-size distributions tended toward the smaller sizes as slope increased in bare and treated disturbed soils.

To verify the consistency of using either sediment yield or sediment concentration to display our study results, we compared these two parameters for the two different soil types and all soil conditions (fig. 1). Not surprisingly, sediment yield was closely correlated with sediment concentration, particularly from bare soils (fig. 1A). However, the standard grass treatment was an annual grass (*Fescue* spp.) that provides 20% to 50% soil cover and does not include soil restoration (fig. 1B). In terms of runoff and erosion rates, this treatment was often similar to bare soils, although its ranges of cover caused greater variability in the relationship between sediment yield and concentration; nonetheless, it appears that these two parameters can be used interchangeably (table 3).

Generally, runoff and erosion rates (sediment yields) increased with increasing plot slope, since gravity helps soil to detach and flow downward. We found this to be true for the granitic soils in our study, but much less so for the volcanic soils; in some cases no runoff occurred from native volcanic soil plots even as slope increased (fig. 2). Furthermore, the range of sediment yields from the volcanic soils was on average four times greater than that from the granitic soils. For example, at slopes of 50% to 55%, sediment yields of about 5 grams per

TABLE 3. Statistics associated with regression relationships shown in figures 1, 2 and 3

Soil type	Soil treatment	n	Relationship*	R^2	F	*P* value
Granitic	All	25	SY vs. SC	0.954	477	< 0.0001
Volcanic	All	16	SY vs. SC	0.852	80.595	< 0.0001
Granitic	Bare	9	SY vs. slope	0.470	6.2075	0.04151
Granitic	Treated, native	16	SY vs. slope	0.682	30.025	< 0.0001
Volcanic	Treated	7	SY vs. slope	0.160	0.9524	0.37393
Granitic	Native	4	D_{30} vs. slope	0.979	93.238	0.01056
Granitic	Bare	9	D_{30} vs. slope	0.611	10.995	0.01284
Granitic	Treated	12	D_{30} vs. slope	0.321	4.7275	0.05477
Volcanic	Std. grass (*Fescue* sp.)	7	D_{30} vs. slope	0.312	2.2674	0.19246
Volcanic	Treated soil	10	D_{30} vs. slope	0.439	6.2603	0.03682

* SY = sediment yield; SC = sediment concentration; D_{30} is the particle-size fraction larger than 30% of the total sample.

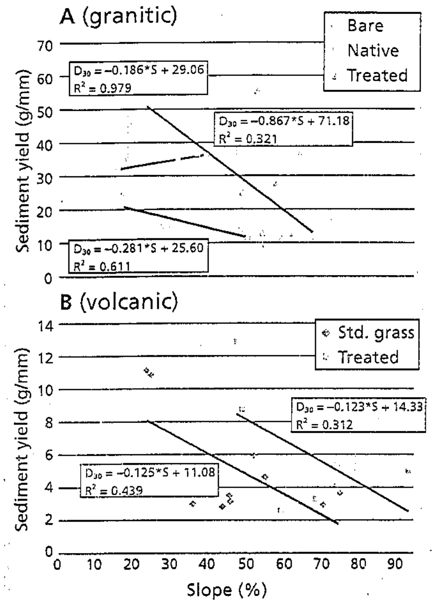

Fig. 3. Relationship between D_{30} particle-size fraction and slope for all conditions from (A) granitic and (B) volcanic soils. Y-axis scales differ by a factor of five between granitic and volcanic soils.

millimeter occurred from the standard grass-covered volcanic soils, roughly three times greater than that from bare granitic soils and nearly seven times greater than that from treated or native granitic soils. Soil treatments — either mulch and grass covers only or more complete soil restoration — significantly decreased runoff rates and sediment yields as compared to bare soils. However, for many of these plots, the original treatment specifications and date of treatment were not well known, thus the longer-term efficacy of these different treatments and erosion-control approaches is not known and is currently under investigation.

While sediment yield, or total sediment deposition, is an important factor in evaluating the efficacy of various revegetation and soil restoration efforts, the smaller particle size of less than 8 μm is potentially more critical, because it contributes suspended particles — possibly with attached nutrients such as nitrogen and phosphorus — into receiving water bodies. As observed by Grismer and Hogan (2005b), in our study particle sizes also tended to decrease with increasing plot slope for bare and treated soils regardless of soil type (fig. 3). Four of the five regression relationships were significant at the 95% level; however, given the limited results available for the native plots (where runoff rarely occurs), particle size in runoff did not appear to depend on plot slope. Clearly, this trend requires additional investigation; these studies are presently under way.

The D_{30} particle sizes in runoff samples from volcanic soils were generally less than about 8 μm for all conditions, while those from granitic soils generally exceeded about 10 μm (fig. 3). As with the decreased sediment yields associated with soil treatment, larger particle sizes were observed from the treated or restored soils as compared to bare or standard grass-cover soils of both soil types.

Effective erosion control

The degree to which runoff particle size can be increased by an erosion-control treatment has important implications for developing best management practices (BMPs) for disturbed soils at road cuts, ski runs and construction sites in the Tahoe Basin. The development of effective erosion-control strategies is critical to preserving water clarity in Lake Tahoe, meeting total maximum daily load (TMDL) goals, and improving overall water quality. We found that volcanic soils have smaller particle sizes than granitic soils, and that they release particle sizes in the 1-to-8-μm range of concern with respect to Lake Tahoe's clarity. Revegetation, mulch covers and soil restoration tended to increase infiltration, decrease sediment yields and increase particle sizes in runoff across a range of slopes. We are currently trying to verify these results further, to help local agencies with limited resources to focus erosion-control work on, for example, volcanic soils that may yield the greatest reduction in fine-particle delivery to the lake.

M.E. Grismer is Professor, Departments of Land, Air and Water Resources, and Biological and Agricultural Engineering, and A.L. Ellis is M.S. Student, Department of Soils and Biogeochemistry, UC Davis. *Caltrans supported this research.*

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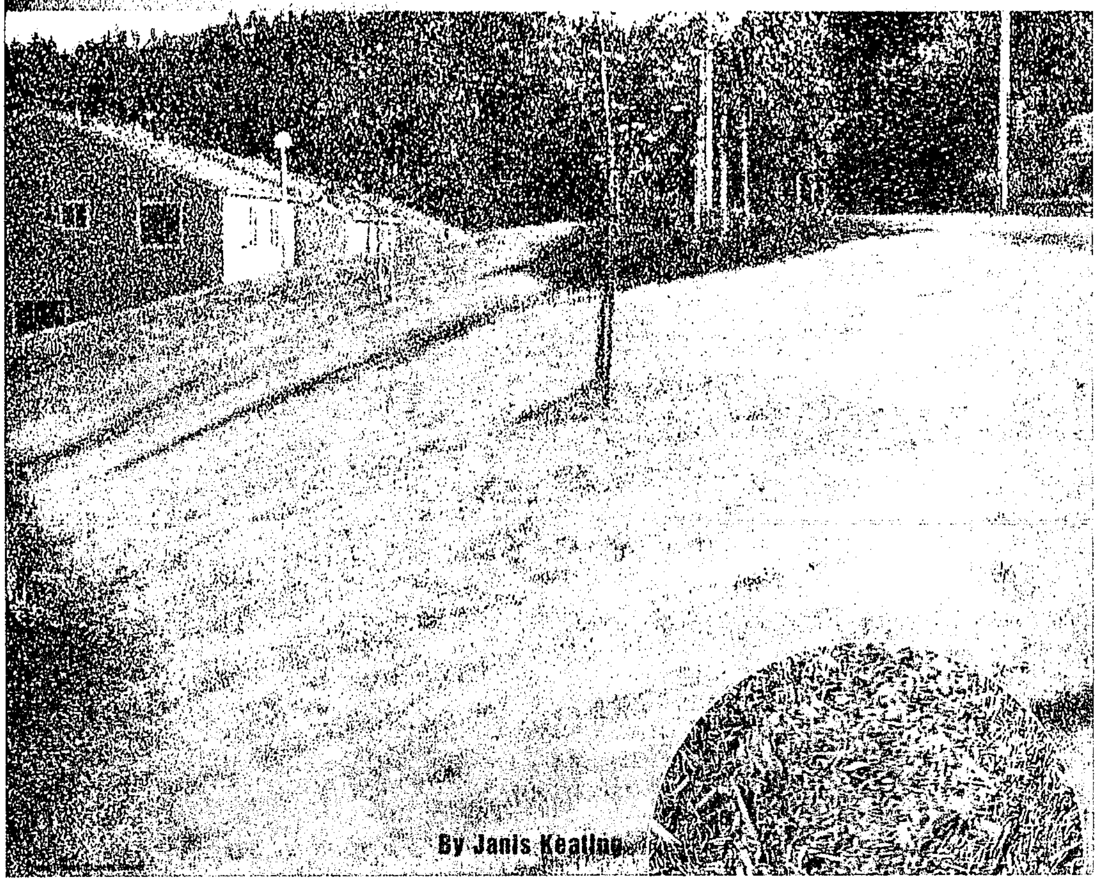
Compost Coverage



By Janis Keating

Into each construction job. some rain must fall. When that happens, the first task at hand is likely staying upright and not ending up with a shirttail full of mud. Another priority: keeping the site from eroding away.

Silt fences, straw and hay bales, and rock- or sand-filled berms are commonly used as temporary sediment dams during construction. Some firms also use spray-on tackifier products to cover large areas of disturbed soil. In many cases, however, these erosion and sediment control methods are only moderately effective; in addition, because they must be removed before final grading and landscaping, they are time- and labor-intensive. In many parts of the nation, compost is now being touted as the better alternative for temporary erosion control.

"A compost filter berm costs about $2 to $3 per linear foot installed roughly the same as a silt fence," points out Green Horizons" Rod Tyler from his Grafton, OH, office. "Yet compost is five-to-one better at stopping erosion. Why not use a compost berm? It's annually renewable, all organic, 100% recycled, and it works better!"

An erosion control material that enhances the soil and is made from readily available, inexpensive materials? Compost is winning fans at construction sites and roadside projects.

Compost's Correlation and Composition

Basically, compost is decomposing organic materials. In a natural setting, leaves, conifer needles, twigs and wood, dead animals, and insects can be compost's building blocks. Add moisture, time, microorganisms, and heat (the microorganisms throw off a lot of heat as they work), and these disparate elements transform into a rich, nutrient-filled product that feeds the surrounding plants.

During the course of its life, compost becomes a "parent" of top-soil. As the drawing shows, the top layer (about 2 in.) of a healthy soil profile, called the "O" horizon, is organic material. Because of its composition—materials in the process of decay—this layer is characterized by large particle size, which creates pore spaces that fill with the air and moisture plants need to thrive. The warmth the "O" horizon creates helps seeds germinate.

Topsoil, the "A" horizon, is filled with beneficial bacteria, fungi, and small animals and insects. It eventually contains organic matter as time, water, and burrowing creatures move through it and the "O" horizon, making it darker and more nutrient-filled than the lower soil horizons. Reaching 10 in. in depth, this horizon is filled with roots; the greatest percentage of a plant's roots remains in the A horizon. Because of its mixture of soil and organic matter, this layer's particle size (albeit smaller than the one above) also creates all-important pore spaces.

Subsoil, or the "B" horizon, contains fewer organisms and less topsoil. Although a few deep roots reach it to glean the various elements located there, plants don't thrive in this horizon, which reaches about 30 in. below the surface. This horizon is more compressed than those above, resulting in small particle size and few pore spaces.

Reaching approximately 48 in. down, the lowest layer, or "C" horizon, is the other "parent" of soil, so called because it's the weathered rock and soil from which the A and B horizons are formed. Further compressed by everything above it, the C horizon contains less living matter and offers scarce pore space. There's virtually no pore space below it, either, as below it (not shown) is bedrock.

Excavation disrupts this soil profile, virtually eliminating the first two horizons and breaching well into the third. (For huge structures needing to be well anchored, crews also drill into the bedrock.) Stripped of the water-using layers above, the C horizon easily yields to erosion; when construction is complete and the landscape phase is underway, an application of topsoil alone might not give plantings the correct nutrients and medium they require for vigorous growth. Without a blanket of organic material, weather conditions may even wash or blow away some of the topsoil before the plantings take root.

"Where before you may have had undifferentiated soil, with organic matter and biological activity you begin to cement those particles together and create humus. Humus does not erode nearly as easily as raw soil—and raw soil is what you usually have on a construction site," notes Richard Pete, president of Planet Green in Charlotte, VT, which offers a pelletized compost mulch. With his degree in plant

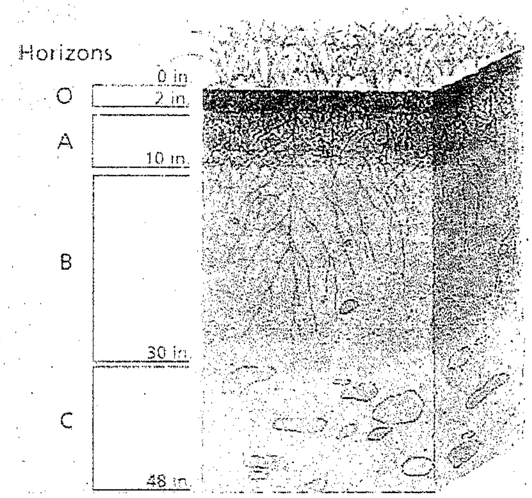
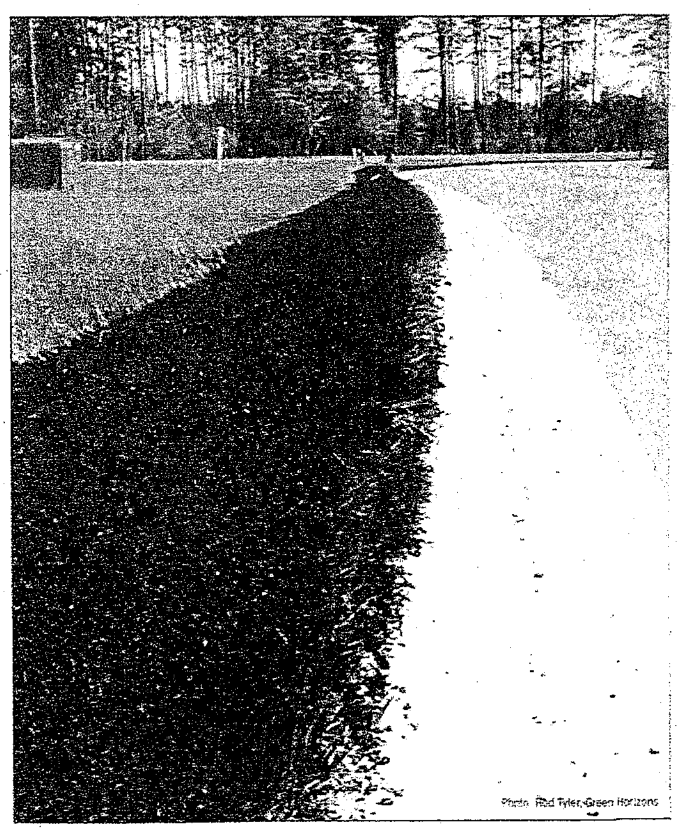


Illustration: Natural Resources Conservation Service

A healthy soil profile



This roadside compost berm keeps the sidewalk clear as new grass grows.

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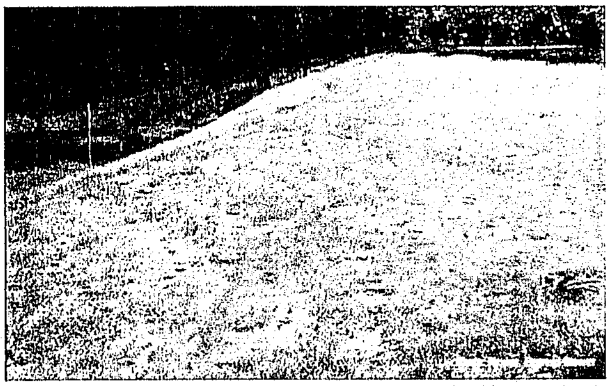
science, he encourages landscapers to understand the carbon cycle of the soil. "Just a small understanding of biological processes and soil biology can save a lot of money."

Compost: The Gift That Keeps On Giving

Because of its water-retaining properties, compost not only makes a good topsoil cover but also makes an excellent berm to stop erosion. In addition, unlike silt fences, hay bales, and rock- or sand-filled berms, compost need not be removed from the site: because of its benefits for the soil, it's actually better to leave the compost there.

In both his capacities as a businessman (Maine's New England Organics) and as an industry advocate (a US Composting Council member), Chris Bales is an enthusiastic proponent of compost berms. "Composted berms will adjust to the lay of the land and settle with the ground, not like the fabrics sometimes used," Bales says. "Compost berms are also continuous, not jointed like hay bales. After construction, you can work it in or remove it, but that's not usually done. You can just leave it, if it fits into the landscape—say, if the site's surrounded with wood. Up here, we see it as turtle-, or 'critter-,' friendly."



The hydroseeding process did not do an adequate job for this slope. Seed injection was later used.

Since compost evolves from a variety of organic materials, different areas of the nation use whatever's most available locally. "Maine's a forested state, with forest-product industries, and bark is one byproduct. We're using this for erosion control purposes," Bales reports. "Not landscape bark, though: the byproducts of making logs and lumber have a lower pH." He adds, "Berms don't really have to be that big. Maine puts berms along the roads next to lakes; people can walk over them." In addition to controlling erosion, Bales says these roadside berms "tie up some of the contaminants from the asphalt."

Bales notes a recently published University of Connecticut study conducted for the New England Transportation Consortium (Demars, Long, and Ives: "Use of Wood Waste Materials for Erosion Control," Project #97-3). Four materials (straw/hay bales, composted wood mulch, and fabric; soil was used as an experimental control) were studied for their erosion control properties. The materials were used as both a slope treatment and a barrier. "In all cases, wood mulch did the best— a factor from two-to-one to four-to-one more effective." Bales says proudly. The New England Transportation Consortium (NETC) plans to make its research materials available on the Web; those wanting in-depth results from Project #97-3 should periodically visit NETC's site at (www.cti.uconn.edu/ti/Research/netc_home.htm for updates

Compost's Wide Availability

"Compost happens" in the wild, but as Chris Bales' tale illustrates, civilization also creates a wealth of compostable material. Yardwaste (leaves and grass clippings), wastewater sludge, various paper products, and some animal manures can also be converted into nutrient-rich compost. This particular municipal wastestream can be a potential gold mine of erosion-combating compost.

In the past, yardwaste usually went into landfills; with landfill space rapidly becoming scarce, however, more communities are banning yardwaste from "regular" refuse pickup. According to a US Composting Council (USCC) fact sheet, states are setting aggressive recycling goals. The USCC estimates that "adding composting to traditional recycling can divert as much as 70% of the wastestream." Atop these state restrictions, EPA has noted that composting can play a key role in diverting organic waste from landfills and that applying compost to combat nutrient runoff helps prevent natural-water pollution.

The mandates are there, but what about real-world solutions? "States don't create the market for what their laws create," Rod Tyler says. "You can't put yardwaste in landfills, but states haven't made a market for reusing the stuff."

In temperate states, yardwaste is a partial-year concern; in warmer states, however, yardwaste is generated year-round. With this fact likely in mind Florida set a goal: 30% less solid waste would enter landfills by 1998. The Solid Waste Authority (SWA) of Palm Beach County, (www.swq.org |^. met that goal two years early, and it currently recycles 50% of its waste. In addition, the SWA found a market for its yardwaste. "We make so much compost, we sell it to nurseries and citrus growers," SWA Public Information Officer Linda Hodgkins says. "We also give it free to the public we serve and to the Florida Department of Transportation, which uses it along roadsides."

SWA's $15-million composting plant in West Palm Beach began operating in September 1991 as a pilot program to recycle yardwaste and wastewater sludge into compost. Three years later, the facility expanded from a four-bay to a 36-bay system, which daily processes more than 300 tons of waste. In fiscal year 1997-98. when the facility exceeded Florida's goals, it turned 55,984 tons of wastewater residuals and 48,929 tons of screened yardwaste into 73,605 tons of organic compost. The SWA also has plans to further expand its recycling success.

"We are going to build a recalcination plant here," Hodgkins adds. "Water treatment plants go through a lot of lime during their process, and instead of disposing of this lime, we will reclaim it, and the treatment plants will buy our [recycled] lime."

Deep in the Heart of Texas

Although Texas homeowners produce a hefty amount of yardwaste, the Lone Star State is most concerned with keeping feedlot and dairy waste out of its watersheds. Texas's Senate Bill 1, made law in 1997, mandated protection and preservation of the state's valuable groundwater supplies. In response, the Texas Natural Resource Conservation Commission (TNRCC), in conjunction with the Texas Department of Transportation (TxDOT) and the Texas State Soil and Water Conservation Board (TSSWCB), developed a composting program that could reduce the animal waste, thus saving the watersheds while helping battle drought and erosion problems.

The working theory: Although in its "raw" state cattle manure could leach into groundwater and pollute Texas waterways, that same manure, worked with yardwaste, could become a nutrient-rich, moisture-retaining compost. Retaining soil moisture was another large concern for the agencies, because in some areas the state has suffered greatly from recent multiyear droughts.

Realizing public support would benefit the program, TNRCC and TxDOT worked together to demonstrate compost's benefit along Texas roadsides; it was hoped the public and potential contractors would quickly recognize compost's potential. To create this compost, however, not just any organic waste would do. "We work with citizens' yardwaste," says TxDOT Landscape Architect Barrie Cogburn. "Many cities and private entities collect it. However, we have a specification written, telling them what yardwaste can and can't be. We also have specifications for feedlot and dairy-industry manure."

Compost Resources On-Line

From backyard gardeners to state-run agencies, anyone interested in compost's benefits will find a wealth of information on the US Composting Council's Web site

www.compostingcouncil.org/pub_list.html.

A wide variety of documents are available, ranging from "Home Composting" and "Organic Soil Amendments" to the USCC's comprehensive "Field Guide to Compost Use" and EPA's "Environmental Regulations and Technology: Control of Pathogens and Vector Attraction in Sewage Sludge, Revised October 1999." The USCC also displays links to federal agencies concerned with com-post; for example, one link lists the US Department c* Agriculture's National Water Management Center/Natural Resources Conservation Service, where there is a Web page with further details on Connecticut and Texas compost studies:

http://wmc.gr.nrcs.usda.gov/tech.dir/compost-rogd.html

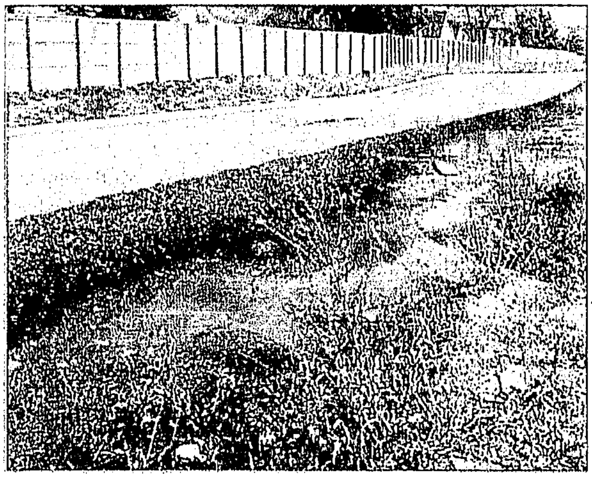
Information on the TxDOT project is available on-line at

www.tnrcc.stgte.tx.js/exec/oppr/compost/demos.html

www.dot.state.tx.us/insdtdot/orgchart/des/landscape/corrpost/ropsoii.htm

and www.tnrcc.state.tx.us/exec/oppr/compost/erodible.html

Although final results of the Caltrans project are not expected until fall 2001, the preliminary report, "Compost Demonstration Project, Placer County: Use of Compost and Co-Compost as a Primary Erosion Control Material" (publication #443-99-018), is available for download from the California Integrated Waste Management Board at www.ciwmb.ca.gov/Publications/



In addition to controlling erosion, roadside berms tie up some of the contaminants from asphalt.

TNRCC and TxDOT presented their demonstration in May 1999 in Big Spring, TX, at a highway overpass built in 1968. TxDOT tried five times since construction of the overpass to establish vegetation on the steep, severely eroded site: if compost could work its magic there, it would work anywhere.

The compost, created from feedlot manure, cotton burrs, and yard-trimming wood chips, was applied at a 3-in. depth. Incorporated because they reduce water and wind erosion, wood chips were blended with the compost at a 3:1 ratio (three parts compost, one part wood). Six weeks later, thick grass was growing on the long-barren site.

Cogburn explains how costly erosion can be to a state. "Topsoil sources have become depleted over the past few years, leading to severe erosion on many projects. If erosion occurs while the project is still under contract, the contractor must reapply topsoil, seed, fertilizer, mulch, and or erosion control blankets and cannot leave the project until sufficient grass growth occurs. If erosion results on existing highway sections, [TxDOT] maintenance is left to deal with the resulting problem."

Noting the excellent results on the Big Spring project, she says that with compost, "poor soils can be amended, revegetation can occur, erosion is avoided, and TxDOT saves time and money." Considering that Texas contains 1.3 million ac. of highway right-of-way, the potential cost savings could be substantial. In addition, TxDOT's use of compost would create a huge market for the product, spurring the composting industry to remove large volumes of organic material from high-impact watersheds.

There's another financial bonus to this project. "EPA will give TxDOT a rebate if we use the feedlot waste, because they want to keep it out of the watershed," Cogburn says. Further information on the project is available on the Internet (see sidebar).

California's Gold Rush for Compost

Studies conducted by the California Department of Transportation (Caltrans) and the University of California, Davis also revealed that compost made from municipal yard trimmings and other organic materials is excellent amendment material for roadside erosion control. As their data documented, composts vary in physical and chemical characteristics, and more research has been suggested.

One such research project is Caltrans' compost demonstration, currently underway at Brockway Summit. Placer County. The demonstration site was constructed in the fall of 1998 on State Highway 267, at the Lake Tahoe Basin's north end. This project involves a long series of southwest-facing road cuts totalling 9 ac.; the cuts display 2:1 horizontal-to-vertical slope angles. The parent materials are volcanic mudflows cut to 5-8 m below the previous soil surface.

The site's existing erosion control specification was modified to create three additional treatments (zero control, compost, and compost plus specified), each designed to contrast the performance of various slope amendments. The four treatments specified were all repeated on three separate slopes. As of the 1998-99 winter (the latest published data), the slope amendments showed only small areas of slippage. According to the report, plant growth and soil nutrient content will be monitored for several years after application (see sidebar).

In the meantime, other composting methods are slowly gaining acceptance in California. Noting that native plants are the ones most likely to thrive in the climate (as opposed to plant varieties from other areas). URS Corporation Vice President Carol For-rest encourages the native regrowth method. "This is not new; it's been around 20 years. although it's not widely used," states Forrest. "You have to want the native plants there to do this; if you have a good growth of native. this is the way to go."

Using the native regrowth method requires clearing and grubbing the site of its existing vegetation, then placing the materials in a chipper. The chipped material is then combined with enough topsoil to result in a 3- to 6-in. layer and stockpiled until it's needed during the regrading process. "When you're regrading, put this mixture onto the slope. The existing vegetation will grow back. It's effective and inexpensive—no irrigation, seed, or fertilizer." Forrest says. "Contractors have been resistant to handling the stuff twice, but vegetation, both green plantings and woody, is the erosion control. The different heights of plants—the canopy—keeps the rainfall from smashing the ground."

Getting Into Compost

Many states are creating guidelines and specifications for compost, especially for that used on state-owned sites. "Erosion management is dictated by the state. Maine runs workshops and certifies contractors—this is voluntary training—but you *must* have an erosion control plan and have someone on the project to write the plan, then you must follow it," Chris Bales explains.

Once you have the information you need about compost and a materials source, all that remains is applying the compost to your site—and various equipment manufacturers have made this a less labor-intensive step. Finn, located near Cincinnati, OH, calls its Bark Blower "A Smarter Way to Work." The multimodel line ranges from the 1.5-yd.^{3} (hopper capacity) Model 302 tow-behind to the 36- to 40-yd.$^?$ Model 1240, which is available in either truck- or trailer-mount. Finn states that its products allow 20-30% material savings, depending on the material and its moisture content, because blown material offers a more even, consistent surface than could be achieved by hand-raking. As to the machines" versatility, one project used a Bark Blower to deliver product to a rooftop garden—six stories up. Rod Tyler agrees that blowing is the way to go. "You can add compost just after the rough grading. By blowing it on, you end up with more even soil, eliminating the fine-grading step, which is usually done by hand."

Another supplier, Rexius, located in Eugene, OR, sells hoses, blowers, and mulch spreaders. "Our customer base is an even split of various markets—contractors, landscapers, et cetera," says Rexius's Dan Sutton. "Many are getting involved in erosion control projects, and some have purchased our Express Blower patented seed-injection system, which allows you to blow-apply compost and seed at the same time." The four current Rexius models range from 20- to 90-yd.^{3} capacities. The machines offer dry or moist application, with the ability to deliver products with a moisture content between 0 and 60%. Depending on the model, Express Blowers cost between $119,000 and $272,000—"and that includes a brand-new truck chassis," Sutton adds.

Since seeing them in action, Bales is a fan of Rexius's products. "In Portland, a local contractor composted the street medians. Because the city wanted wildflowers in the medians, the company mixed the seeds right into the compost mix and applied it all at once."

Conclusion: Compost!

Many advantages make compost an attractive choice for both temporary and continuing erosion control. Not only is it a highly effective erosion control medium, it's also the premium choice for enriching depleted soils. And considering that compost can be made from America's wastewater and yardwaste (which, unlike many of our natural resources, are abundant), creating and using compost is an environmentally smart idea that *everyone* can "dig." **EC**

***Janis Keating** is a frequent contributor to horticultural magazines.*

Performance Comparison of Structural Stormwater Best Management Practices

Michael E. Barrett

ABSTRACT: This paper describes a method for comparing the pollutant removal of a number of structural stormwater treatment devices, commonly referred to as best management practices (BMPs). Historically, the pollutant removal ability of a BMP has been expressed as a percent reduction in concentration or load. Unfortunately, the calculated percent reduction in pollutant concentration is strongly affected by the influent concentration, with the calculated reduction generally being much lower when the event mean concentrations (EMCs) in the untreated runoff from the test watershed are low. The objective of the proposed methodology is to eliminate this problem by predicting BMP performance for an arbitrary influent concentration, so that BMPs evaluated in different watersheds can be compared as if the influent quality at all sites were the same. This method allows BMPs to be compared based on the quality of effluent produced and the mass reduction. The proposed method uses linear regression as the primary tool to compute the expected effluent concentration from a BMP, given a specific influent concentration of interest and was developed using data collected in the California Department of Transportation BMP Retrofit Pilot Program. This technique reveals that for media filters, the concentration of sediment and other particle-associated pollutants in treated runoff is generally unrelated to influent quality and is relatively constant. Wet basins with large permanent pool volumes also have effluent concentrations that are constant for most constituents and unrelated to influent concentrations. In these situations, the "percent reduction" in a pollutant EMC is not an inherent characteristic of the BMP, but a function of the influent EMC, because the quality of effluent produced is constant. Predicting the effluent quality of several types of conventional BMPs based on a common influent concentration allows an objective comparison of their performance and the selection of a BMP that addresses specific constituents of concern. *Water Environ. Res.*, 77, 78 (2005).

KEYWORDS: stormwater, best management practices, water quality, highway runoff.

Introduction

As concerns about the environmental impacts of stormwater runoff increase, implementation of structural treatment devices is becoming more widespread. To assess if a particular technology would be preferred at a given site, one must have an accurate assessment of its pollutant removal ability and an unbiased comparison of the performance with other structural controls to assess that particular device's relative water quality performance. Consequently, there is an interest in the regulatory and environmental communities in having an accurate comparative assessment of the pollutant removal of these devices.

According to Strecker et al. (2001), there are at least four techniques for estimating the pollutant reduction of best management practices (BMPs). These include the statistical characterization of inflow and outflow concentrations, sum of loads, storm-by-storm comparison, and regression of loads. The statistical characterization defines removal as the ratio between the average influent and effluent concentrations. The sum-of-loads method takes the ratio of the sums influent and effluent loads of the monitored events. The storm-by-storm procedure averages the ratio of influent to effluent concentration for individual events, while the regression of loads determines the removal by a regression analysis of paired influent and effluent loads.

Historically, however, pollutant removal efficiency has been expressed almost universally as a percent reduction in the concentration or load for the constituents of concern using a statistical characterization based on flow-weighted samples collected of the untreated and treated runoff. One example of a study, among many, that compares BMPs in this fashion was described by Glick et al. (1998). Expressed as a percent reduction, a relationship between the concentrations of treated and untreated runoff is implied. This relationship would necessarily consist of a linear relationship between influent and effluent quality with the slope of the regression line corresponding to the fraction of the pollutant remaining in the effluent.

This traditional measure of the performance of BMPs may not truly reflect the relative performance of the devices when the influent concentration is relatively low or when the concentration of the BMP effluent is unrelated to influent concentration. For instance, low percent removal is often reported for low influent concentrations in BMP monitoring studies (i.e., Horner and Horner, 1999). In addition, the use of percent removal may lead the reader into improperly applying these published "efficiencies" to watersheds with substantially different runoff characteristics, and existing upstream and upland control practices where these efficiency values are not valid. Another use of "removal efficiency" would be to estimate the discharge quality from an event with particularly high pollutant concentrations to estimate compliance with water quality standards. This paper will demonstrate that, in many cases, both of these applications of a published "percent reduction" produce results that do not accurately characterize the quality of the treated runoff.

Strecker et al. (2001) describe one method that uses the efficiency ratio method based on log-transformed influent and effluent event mean concentrations (EMCs) and the use of analysis of variance to determine the significance of the differences between influent and effluent concentrations. Although this method is one way to evaluate the data, it does not make use of the fact that the samples are paired, with each effluent concentration corresponding to a particular influent concentration.

The objective of this paper is to present a methodology that allows for comparison of BMP performance using a common influent concentration of interest for a number of conventional stormwater constituents. This methodology is based on a linear regression analysis of paired influent and effluent EMCs for each of the BMPs being considered. This method is similar to that used by Martin and Smoot (1986), except that the regression analysis is carried out on concentrations rather than loads. This elimin

Table 1—Best management practices evaluated.

BMP Type	Location in California	Land Use	Tributary Area (ha)	Number of Paired EMCs
Extended Detention Basin (Earthen)	I-5/SR-56, San Diego	Highway	2.14	16
	I-15/SR-78, Escondido	Highway	5.42	17
		Highway	0.4	10
	I-605/SR-91, Cerritos	Highway	1.94	12
	I-5/Manchester, Encinitas			
Austin Sand Filter	I-5/La Costa, Carlsbad	Park/and/ride	1.1	16
	I-5/SR-78, Vista	Park/and/ride	0.3	16
	Whittier	Maintenance	0.6	10
	Monrovia	Maintenance	0.7	12
	Norwalk	Park/and/ride	1.1	9
Delaware Sand Filter	Kearney Mesa, San Diego	Maintenance	0.3	13
Multi-Chambered Treatment Train (MCTT)	Lakewood, Downey	Park/and/ride	0.76	10
	Via Verde, San Dimas	Park/and/ride	0.44	8
Vegetated Swale	Melrose/SR-78, Vista	Highway	0.96	5
	I-5/Palomar, Carlsbad	Highway	0.92	10
	Cerritos	Maintenance	0.16	8
	I-605/SR-91, Cerritos	Highway	0.08	4
	I-5/I-605, Cerritos	Highway	0.28	9
	I-605/Del Amo, Lakewood	Highway	0.28	6

scatter in the data caused by differences in antecedent moisture conditions that affect the volume losses that occur in a BMP due to infiltration and evapotranspiration.

The data for this analysis were developed in a four-year study of the water quality performance of structural BMPs in Los Angeles and San Diego that was conducted by the California Department of Transportation (Caltrans). Thirteen different types of BMPs, which were potentially appropriate for retrofit into existing highway and related infrastructure, were evaluated. These included extended detention basins, Austin and Delaware sand filters, a perlite/zeolite filter, swales, buffer strips, drain inlet inserts, multi-chamber treatment trains, infiltration trenches and basins, an oil/water separator, a continuous deflection separator, and a wet basin. Of these, seven public domain types of devices had automated monitoring stations installed upstream and downstream of each BMP to determine influent and effluent EMCs from flow-weighted composite samples and are discussed in this paper. Constituents monitored in the runoff included suspended solids, metals, and nutrients, and all concentrations reported in this paper refer to EMCs and not instantaneous values.

Methodology

A list of the BMPs and site characteristics of each that were evaluated for this report are presented in Table 1. Additional BMP types were monitored in the study; however, the results of those analyses are not presented here in the interest of brevity. Additional information for other BMPs and constituents is available in the study final report (Caltrans, 2004) and from the American Society of Civil Engineers (ASCE). BMP database (www.bmpdatabase.org). Most of the BMPs are conventional stormwater treatment devices that are relatively common and descriptions are available from many sources (i.e., http://www.epa.gov/npdes/menuofbmps/post.htm). An exception is the multi-chambered treatment train (MCTT). Additional information on this device was presented by Pitt et al. (1999), which was the source of the design of the tested facilities.

Each of the BMP types was designed using the same guidelines and was sized to treat the runoff generated by the one-year, 24-hour rainfall event. The extended detention basins were all designed to drain from basin full conditions in 72 hours, used multiple outlet orifices, and had a minimum length-to-width ratio of 3.0. The wet basin permanent pool was sized to be three times the water quality volume and the outlet was designed so that water quality volume surcharge was discharged over 24 hours. The Austin sand filters consisted of separate sedimentation and filtration basins. The filter area was sized to drain in 48 hours using guidelines provided by the city of Austin, Texas (www.ci.austin.tx.us/watershed/regulation.htm). The Delaware sand filter design was based on the description by Young et al. (1996). Each of the buffer strips was designed with a width of 8 meters, regardless of tributary area. The swales were designed as trapezoidal channels that provided a minimum hydraulic residence time of at least five minutes, although much longer times were obtained at sites where more space was available.

Where the same type of BMP was installed at a number of locations, the influent and effluent quality data were aggregated to determine the average expected performance for that type of device. For the types of BMPs for which there were a number of locations like the Austin sand filters, more than 60 paired composite samples were collected and analyzed. For the types of facilities where there was only a single site, the number of paired samples was approximately 15.

The BMPs were monitored to determine their effectiveness at removing a number of conventional constituents commonly observed in highway runoff. Analytes discussed in this report are limited to total suspended solids (TSS), nitrate, orthophosphorus, dissolved zinc, and dissolved and particulate (total minus dissolved) copper. All the sites examined in this analysis were outfitted with automatic samplers (Sigma 900 Max Series, Hach Company, Loveland, Colorado) and flow meters (Sigma 950 Series, Hach Company) to collect flow-weighted composite samples of the influent and effluent of the BMPs. Rain gauges (Sigma 2149, Hach Company) were installed at all sites.

Flow measurements were taken at the BMP sites to allow the collection of flow-weighted samples and calculation of constituent loads. For extended detention basins, media filters, MCTTs, and the wet basin, the influent flowrate was measured using a Parshall flume or H-flume. The effluent flows were measured using a v-notch weir.

The influent and effluent of biofiltration strips and swales were measured using flumes. All of the flow monitoring equipment was calibrated according to the manufacturer specifications. All sampling occurred between 1999 and 2001. Approximately 286 total storms were monitored over the 22 sites discussed in this paper, which is an average of approximately 13 storms per site. All the water quality data for individual events, rainfall data, and details on the design criteria of each of the facilities are available from the ASCE BMP database.

A linear regression analysis was performed on the paired influent and effluent EMCs from each type of device to develop a relationship so that effluent quality could be predicted from any arbitrary influent quality. Only storm events with both influent and effluent EMCs were used in the analysis. Best management practices with large amounts of volume losses from infiltration and evapotranspiration, such as swales, often had storms where influent concentration was measured, but the runoff volume was insufficient to produce enough discharge to analyze. These events were not used to estimate the change in concentration within the BMP. However, total influent and effluent volumes during the monitoring period (including storms where neither the influent nor effluent data were available) were used to estimate the average runoff volume reduction. This value was then incorporated to the analysis to estimate total pollutant mass retained by the BMP. The goal of this analysis was to predict the performance based on the runoff captured and treated by each BMP. Estimating the total system performance, including treated and bypassed runoff, was not an objective. Neither bypassed volume nor quality was measured in the study; however, all facilities in this study were designed using the same design storm sizing criteria.

The regression line of the paired influent and effluent EMCs was tested for statistical significance at the 90% confidence level. Where the relationship between influent and effluent concentration was not statistically significant, the effluent quality can be expressed as a constant value. As suggested by Gilbert (1987), the mean and uncertainty (used to calculate the 90% confidence interval of the estimate of the mean) for these constituents are calculated using nontransformed values because the coefficient of variation of the data was normally approximately 1.2 or less.

Where a significant linear relationship exists, the effluent EMC for any influent EMC of interest is calculated as shown in eq 1.

$$C_{eff} = aC_{\text{inf}} + b \qquad (1)$$

Where

C_{eff} = Predicted effluent EMC,
C_{inf} = Influent EMC,
a = slope of the regression line, and
b = y intercept.

Note that as $C_{inf} \to 0$, $C_{eff} \to b$. This would appear as a lower percent reduction or even export of a constituent at low influent concentrations, a phenomenon often reported in BMP monitoring studies and described in detail by Minton (2002). When expressed in this way, b can often be interpreted in a physical sense as the "irreducible minimum effluent concentration," which is a term introduced by Schueler (1996). This would be the expected effluent concentration for influent concentrations approaching zero. Consequently, this linear relationship reproduces the behavior often observed for low influent concentrations. This convenient physical interpretation may not apply when b is negative or not significantly different from zero. For large influent concentrations, $C_{inf} \cong aC_{eff}$. Consequently, in this situation the value $1 - a$ would correspond to what has conventionally been termed *percent reduction*.

The uncertainty in the location of the regression line fo constituents that exhibit a linear relationship was calculated according to the methodology presented in many statistical text books including Wonnacott and Wonnacott (1990) and shown in eq 2.

$$t_{0.05}s\sqrt{\frac{1}{n} + \frac{(X - \bar{X})^2}{\sum_{i=1}^{n}(X_i - \bar{X})^2}} \qquad (2)$$

Where

t = value of the t statistic for the appropriate degrees of freedom $(n - 2)$,
s = standard error of the regression,
n = number of paired data points,
X = average influent EMC at which the confidence interval is calculated,
$\bar{X}$ = mean of observed influent EMCs from monitoring data, and
X_i = individual observed influent EMCs from monitoring data.

The formulation in eq 2 describes the uncertainty in the position of the regression line, which can also be interpreted as the uncertainty in the average effluent concentration for an influent concentration of interest. Because the regression coefficients were determined from a finite set of data, an additional year of monitoring would generate additional points and the line fit through the entire dataset would be different from, although one would expect it to be similar to, the regression equation for the smaller data set. Equation 2 bounds the possible location of the "true" regression line for all values of the influent concentration, should the analysis be performed with an infinite number of measurements. That is, we are 90% sure that given infinitely more points, the predicted value for any influer concentration would lie within the confidence limits given in eq 2. Note that the size of the confidence interval is a function of the number of paired samples and the value of the influent concentration for which the confidence interval is calculated. The confidence interval is smallest when the influent concentration of interest equals the average observed influent concentration.

One can also calculate the uncertainty associated with predicting the effluent concentration of a single event. At the 90% confidence level, this takes the very similar form shown in eq 3 (Wonnacott and Wonnacott, 1990). The difference between eqs 2 and 3 results from the difference in uncertainty for predicting the average performance of the device (many similar storms) versus the performance for an individual event (single storm).

$$t_{0.05}s\sqrt{1 + \frac{1}{n} + \frac{(X - \bar{X})^2}{\sum_{i=1}^{n}(X_i - \bar{X})^2}} \qquad (3)$$

The use of regression techniques to estimate pollutant removal means that the paired values with higher concentrations tend to more strongly affect the slope of the regression line and the predicted effluent concentration. This is in contrast to other techniques for calculating average removal that might rely on the mean of the log-transformed concentrations observed in individual events (all samples weighted equally), or percent reduction based on cumulative load removed (samples weighted by flow volume). Consequently, each of these methods leads to slightly different results.

Because outliers can have such a dominant influence (parameters of the regression line, the regression analysis was

Table 2—Water quality design storm concentrations.

Constituent	Influent EMC
TSS (mg/L)	114
Nitrate (mg/L as N)	0.97
Orthophosphorus (mg/L)	0.12
Dissolved zinc (μg/L)	122
Dissolved copper (μg/L)	18

initially conducted using all the available data points. If there were points that had the potential to exert a substantial effect on the regression, the analysis was performed again without those points. If inclusion of the outliers strongly skewed the results of the analysis, then those points were not included in the final analysis. There are several statistical techniques for identifying outliers in a linear regression analysis. One of these, Chauvenet's criterion, which is described by Taylor (1982), was applied for selected constituents and sites to confirm that the points were indeed outliers. Only 25 points were eliminated from over 2400 observed measurements, which was approximately 1.0% of the total.

An important factor in a linear regression analysis is that the validity of the procedure is independent of the underlying distribution of the paired values, so no transformation of the data is required. If the water quality data has a lognormal distribution, then more points will be clustered near the origin with relatively fewer points with high concentration. It is important, however, that the residuals resulting from the regression be normally distributed.

To compare the relative performance of the various types of BMPs, a hypothetical water quality design storm was developed by calculating the mean influent concentrations for all runoff samples from highways and maintenance yards collected in the Caltrans study. Data from park-and-rides were excluded because of the very low concentrations observed from this land use. The concentrations for the various constituents are shown in Table 2. Because stormwater runoff concentrations tend to have a lognormal distribution, these concentrations are somewhat higher than the median concentration observed in the study. These mean influent concentrations were used to develop a normalized comparison of the performance of the BMPs using this common influent quality.

Once the predicted effluent quality has been calculated, an expected load reduction was also estimated based on the reduction in concentration and the reduction in runoff volume observed at each of the sites. The following equation was used:

$$L_r = 1 - \left(\frac{C_{eff}}{C_{\inf}}(1 - I)\right) \qquad (4)$$

Where

L_r = Load reduction, and
I = Fraction of runoff lost to infiltration and evapotranspiration in the BMP.

Results

Examining the results for Austin sand filters can illuminate several striking aspects of the regression analysis. Figure 1 presents the influent and effluent EMCs for TSS. The regression line shown on the graph is not statistically significant at the 90% confidence level ($R^2 = 0.004$), so the effluent EMC is independent of the influent concentration. Therefore, the expected TSS concentration of treated runoff is better characterized as a constant value, 7.8 mg/L,

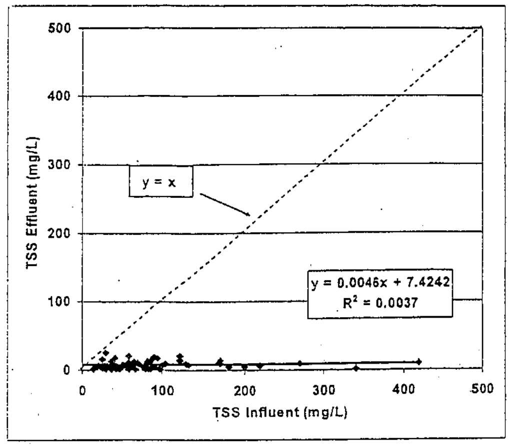


Figure 1—Influent and effluent concentrations of total suspended solids (TSS) in Austin sand filters.

with uncertainty at the 90% confidence level of only 1.2 mg/L. This small uncertainty highlights the very consistent performance of sand filters for TSS removal. In addition, the constant effluent concentration means that a calculated percent reduction for TSS and other constituents with similar behavior to Austin sand filters is a secondary characteristic of the device and depends primarily on the specific average influent concentrations observed. For instance, a conventional analysis of this sand filter data indicates a removal of approximately 90% for TSS. This is due primarily to the fact that the average influent concentration was approximately 75 mg/L. The distinction between a constant effluent quality and a percent reduction is extremely important to recognize if the results are to be used to estimate effluent quality from sand filters installed at other sites with different influent concentrations or for estimating compliance with water quality standards for storms with high concentrations of particulate constituents.

The stable effluent concentration of a sand filter under very different influent TSS concentrations implies something about the properties of the influent particle size distribution. If one assumes that only the smallest size fraction can pass through the filter, then the similarity in effluent concentrations suggests that there is little difference in the total mass of the smallest sized particles even when the total TSS concentration varies greatly. Further, the difference in TSS concentration must then be caused by changes in the relative amount of the larger size fractions. Because no particle size distribution for particles in the runoff was collected during this study, there is not sufficient information to determine what size particles are retained in the filter media. This dependence of removal level on influent particle size suggests that one could expect differences in removal based on differences in particle size distribution in runoff at other sites. However, the TSS reduction in this study is very similar to that observed in previous studies (Glick et al., 1998), which suggests that the differences are not large.

The result of the regression analysis at the Austin sand filter sites for dissolved copper is presented in Figure 2. On this graph, the centerline is the best-fit regression line with the associated equation and coefficient of determination ($R^2 = 0.60$) presented. The solid lines on either side of the regression line mark the 90% confidence interval for the average effluent concentration. Also shown as dashed lines is the 90% confidence interval for the prediction of the effluent concentration for an individual event. This graph highlights

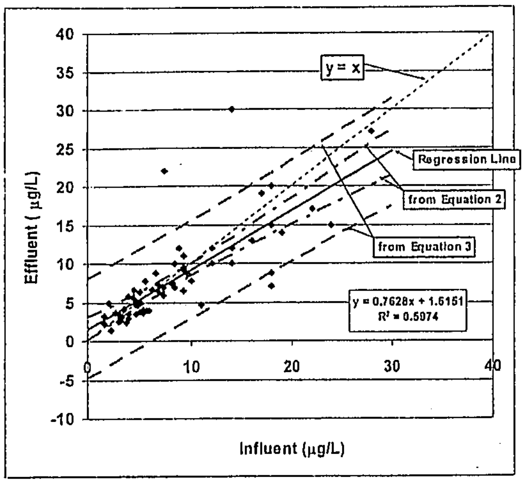


Figure 2—Influent and effluent concentration of dissolved copper.

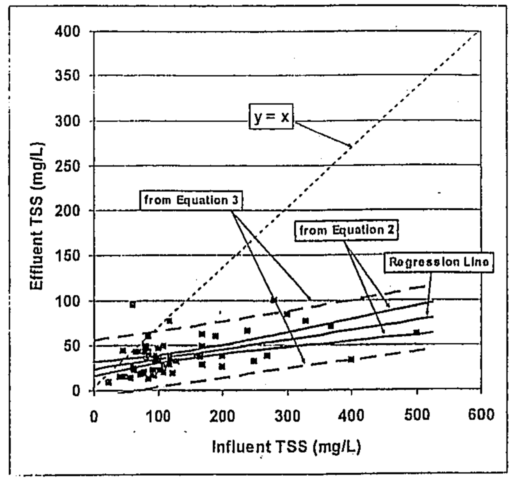


Figure 3—Regression analysis for total suspended solids (TSS) in extended detention basins.

why a single calculated removal efficiency for a constituent does not fully described the observed behavior. One can see that, for influent concentrations less than approximately 10 µg/L, the effluent concentration is not significantly different from the influent concentration. In other words, the removal efficiency is zero. This is consistent with more traditional measures of performance using this same dataset, which indicate no significant reduction in dissolved copper concentration, because most of the monitored storms had relatively low influent concentrations.

At concentrations above approximately 15 µg/L, the predicted effluent concentration at the 90% confidence level is statistically less than the influent concentration. As the influent concentration increases, one would expect the effluent concentration to approach approximately 76% of the influent concentration (the slope of the regression line), resulting in an average reduction of approximately 24% when the influent concentrations are relatively large. Consequently, it would only be appropriate to characterize the change in concentration for dissolved copper in a sand filter as a constant percent reduction at high influent concentrations.

For many of the statistically significant relationships, the R^2 is not particularly high and one might argue that little can be gained from an analysis that explains so little of the variability of the effluent concentrations. An example of a regression equation with a low R^2 is that presented for TSS for extended detention basins in Figure 3. However, the true test of the usefulness of the approach is whether the resulting confidence interval associated with the prediction of an effluent concentration is sufficiently small to allow one to discriminate among the performance of the various BMPs.

Table 3 summarizes the results of the regression analysis for selected constituents in this study. Where a constant is shown, the effluent concentration is statistically independent of the influent concentration. If the effluent concentration is correlated with the influent concentration, then that functional relationship is shown. In each case, the uncertainty of the estimate of the mean effluent EMC at the 90% confidence level is also presented in Table 3. There are a number of interesting observations that one can make from these results. The effluent TSS concentration is independent of influent concentration for all of the sand filter variations (Austin, Delaware, and MCTT). Although not shown here, the same generally holds true for the particulate phases of metals and other constituents.

In addition, effluent concentrations from the wet basin are independent of the influent concentrations for almost all constituents. This suggests that for wet ponds with a large permanent pool volume (three times the volume of the one-year, 24-hour storm in this case) the primary process during periods of storm runoff is plug flow displacement of the permanent pool with some minor mixing with the influent runoff. Consequently, the expected effluent quality during wet weather from a wet basin is determined primarily by the quality of the perennial flow that sustains the permanent pool and the transformations that occur to that water during its residence with the basin. This also suggests that a good estimate of the expect effluent quality during wet weather can be obtained by sampling the wet basin ambient discharge or permanent pool during dry weather.

It is also noteworthy that the concentrations of orthophosphorus in the effluent of the biofiltration devices (vegetated swales and buffer strips) are also relatively constant. During this study, these devices almost always had higher concentrations of orthophosphorus in the effluent than the influent. Under the requirements of the study, a high level of vegetated cover was mandated. Because of the relatively dry climate (approximately 300 mm/yr [12 in/yr] of rainfall), portions of the vegetated areas were repeatedly hydroseeded to try to maintain the grass coverage, and fertilizer was used to establish the vegetation during the first year of operation. In addition, the salt grass used in the vegetated controls is dormant during the wet season and additional testing documented leaching of nutrients from the decaying vegetation.

Now that the expected concentration of the effluent from each of these BMPs has been established using this regression technique, it is possible to compare the relative performance of each on a normalized basis. Using the influent EMCs shown in Table 2, the predicted effluent concentration and 90% confidence interval for each of the devices is shown in Figures 4 through 8. In each graph, the BMPs are listed in order of whole life costs incurred in the Caltrans study, normalized by the device's water quality volume. Consequently, one might expect that the devices shown on the left side of the graphs would have the lowest expected effluent concentrations; however, this is clearly not always the case.

These whole life costs, normalized by the design water quality volume (excluding land cost), for these BMPs are shown in Tabl[e] For the flow through BMPs, such as swales, the volume used w[as]

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Table 3—Results of regression analysis for selected constituents.

BMP	TSS (mg/L)	Nitrate (mg/L as N)	Orthophosphorus (mg/L)	Dissolved Zn (µg/L)	Dissolved Cu (µg/L)
Delaware Sand Filter	16.2 (5.6)	$0.96x + 0.47$ $0.96(\frac{1}{13} + \frac{(x-0.34)^2}{0.93})^{0.5}$	$0.5x + 0.03$ $0.048(\frac{1}{8} + \frac{(x-0.08)^2}{0.042})^{0.5}$	$0.054x + 1.0$ $7.62(\frac{1}{10} + \frac{(x-213)^2}{67096})^{0.5}$	$0.52x + 0.53$ $3.09(\frac{1}{13} + \frac{(x-6.81)^2}{340})^{0.5}$
MCTT	9.8 (2.4)	$0.52x + 0.57$ $0.48(\frac{1}{16} + \frac{(x-0.41)^2}{2.69})^{0.5}$	$0.55x + 0.05$ $0.10(\frac{1}{9} + \frac{(x-0.11)^2}{0.04})^{0.5}$	$0.19x + 5.2$ $17.5(\frac{1}{17} + \frac{(x-73)^2}{35565})^{0.5}$	$0.39x + 2.4$ $5.20(\frac{1}{17} + \frac{(x-6.1)^2}{456})^{0.5}$
Wet Basin	11.8 (4.0)	0.45 (0.25)	0.33 (0.28)	33 (7.8)	8.7 (3.1)
Austin Sand Filter	7.8 (1.2)	$0.93x + 0.37$ $0.86(\frac{1}{64} + \frac{(x-.67)^2}{24.01})^{0.5}$	$0.62x + 0.02$ $0.14(\frac{1}{33} + \frac{(x-0.18)^2}{1.74})^{0.5}$	$0.23x + 10.6$ $42.1(\frac{1}{63} + \frac{(x-92)^2}{296,910})^{0.5}$	$0.76x + 1.62$ $6.27(\frac{1}{63} + \frac{(x-8.8)^2}{2195})^{0.5}$
Extended Detention Basin	$0.11x + 23.6$ $30.9(\frac{1}{55} + \frac{(x-139)^2}{498318})^{0.5}$	$0.74x + 0.19$ $0.77(\frac{1}{57} + \frac{(x-1.06)^2}{35})^{0.5}$	$1.0x + 0.02$ $0.19(\frac{1}{31} + \frac{(x-0.11)^2}{0.166})^{0.5}$	$0.57x + 19.1$ $44.1(\frac{1}{57} + \frac{(x-68)^2}{198956})^{0.5}$	$0.91x + 1.3$ $5.31(\frac{1}{57} + \frac{(x-12.4)^2}{2310})^{0.5}$
Swales	$0.42x + 11.0$ $54.6(\frac{1}{39} + \frac{(x-84.5)^2}{139,000})^{0.5}$	$1.31x - 0.03$ $0.69(\frac{1}{38} + \frac{(x-0.71)^2}{6.1})^{0.5}$	0.40 (0.12)	$0.40x + 7.7$ $58.6(\frac{1}{39} + \frac{(x-99)^2}{213,600})^{0.5}$	$0.55x + 3.3$ $8.13(\frac{1}{39} + \frac{(x-16)^2}{4256})^{0.5}$
Strips	$0.074x + 19.2$ $29.2(\frac{1}{27} + \frac{(x-101)^2}{200,000})^{0.5}$	$1.31x - 0.03$ $0.59(\frac{1}{26} + \frac{(x-0.38)^2}{0.98})^{0.5}$	0.50 (0.26)	$0.31x + 12.4$ $38.8(\frac{1}{26} + \frac{(x-68)^2}{35,000})^{0.5}$	$0.11x + 4.6$ $8.57(\frac{1}{28} + \frac{(x-17)^2}{8421})^{0.5}$

* Upper number in each cell represents expected value and lower value is the uncertainty at 90% confidence level.

that which would have been associated with any of the capture and treat devices installed at the same location. The construction costs are adjusted to eliminate costs associated with monitoring and any extraordinary costs incurred because of site-specific conditions. The operation and maintenance costs are based on the estimated amount of time and equipment required. A life cycle of 20 years and a 4% discount rate was used to calculate the present value. Care should be taken in using these numbers for estimating costs for other agencies and sites. Because these facilities were all constructed as stand-alone retrofits in the highway environment, costs incurred by others to construct BMPs may be substantially less, especially if they are constructed as part of a larger development, although the relative ranking would be expected to be similar. In addition, site-specific considerations such as soil and subsurface characteristics, topography, buried utilities, and other factors can have dramatic effects on the cost for construction at any particular site.

Figure 4(a) compares the expected effluent concentration for TSS for each of the BMPs. A detailed explanation of how this graph was developed can be used as an example of how the other figures were created. For the Delaware sand filter, the average TSS concentration in the effluent is a constant 16.2 mg/L (from Table 3) with an uncertainty of 5.6 mg/L; consequently, the 90% confidence interval in Figure 4(a) ranges from 10.6 to 21.8 mg/L. Because the TSS effluent concentration for Delaware sand filters is independent of the influent concentration, these values are not affected by the selected influent concentration. In contrast, the TSS effluent concentration for swales is dependent on influent concentration and is represented by eq 5 (from Table 3).

$$0.42x + 11.0 \qquad (5)$$

Substituting the selected influent concentration of 114 mg/L in the equation gives a predicted effluent concentration of approximately 59 mg/L. The uncertainty in this estimate is given by eq 6 (from Table 3).

$$54.6\left(\frac{1}{39} + \frac{(x-84.5)^2}{139,000}\right)^{0.5} \qquad (6)$$

Substituting the influent concentration of 114 mg/L into this equation gives a calculated uncertainty of 9.8 mg/L. Consequently, the confidence interval ranges from approximately 49 to 69 mg/L in Figure 4(a). Expected concentrations and confidence intervals for the other BMPs are, likewise, obtained from the tabulated values and/or equations presented in Table 3.

In addition to the expected concentration, a load reduction has also been estimated for this design storm based on the predicted change in concentration and the observed difference in influent and

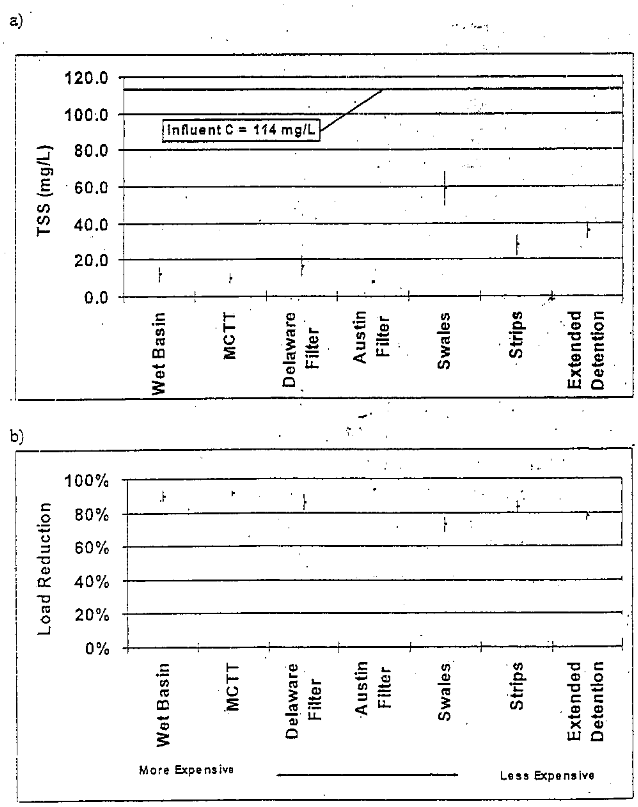

Figure 4—Expected effluent concentrations (a) and mass reduction (b) for total suspended solids (TSS) for influent concentration of 114 mg/L.

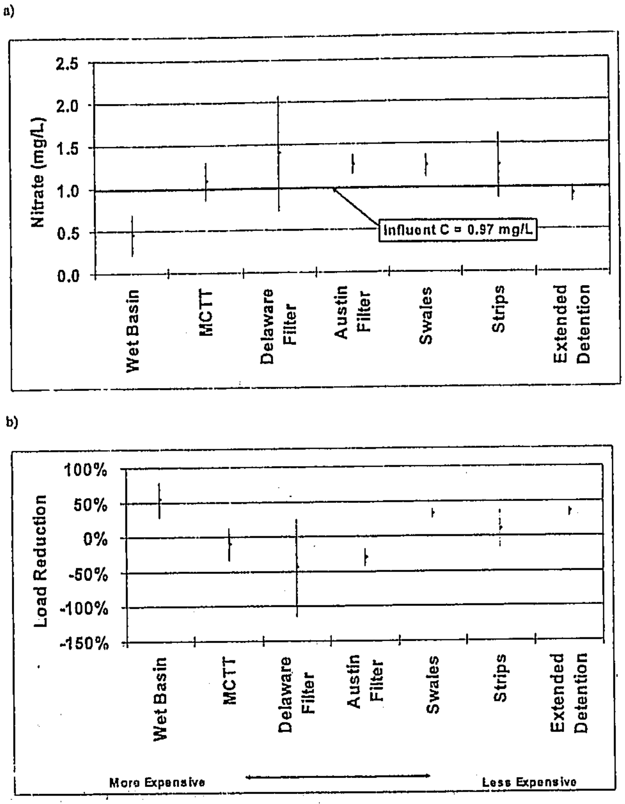

Figure 5—Expected effluent concentrations (a) and mass reduction (b) for nitrate for influent concentration of 0.97 mg/L-N.

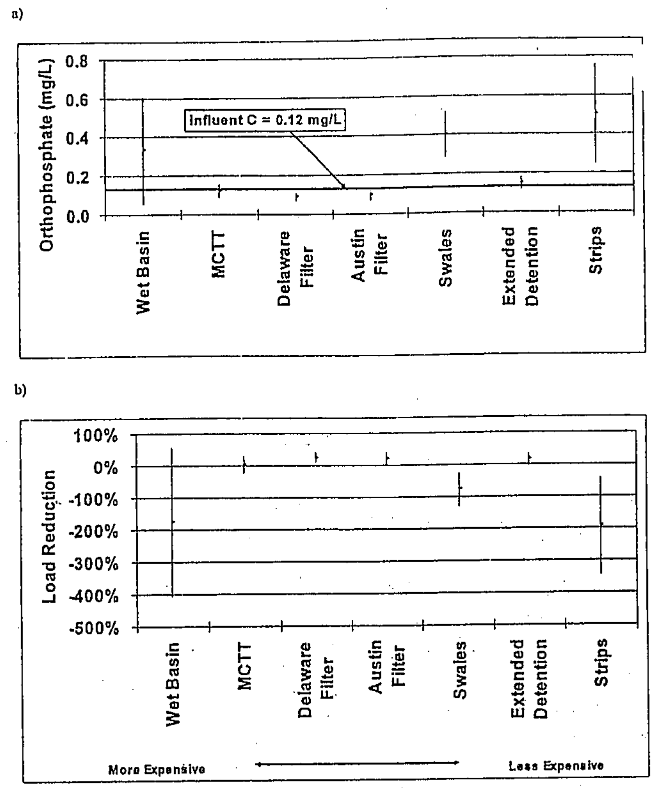

Figure 6—Expected effluent concentrations (a) and mass reduction (b) for orthophosphorus for influent concentration of 0.12 mg/L.

effluent volumes over the course of the study. This allows the BMPs to be compared based on a strict mass balance approach. The sand filters (Austin and Delaware) and MCTTs are constructed of concrete; consequently, no infiltration can occur. Little infiltration is also expected in the wet basin because this particular site has an impervious liner and the soil is assumed to remain saturated because of the permanent pool. On average, runoff volume was reduced by approximately 30% in extended detention basins and vegetated buffer strips and 47% of the runoff in the swales. Clearly, these proportions depend substantially on the local soil and climatic conditions at these particular sites.

Figure 3a demonstrates the comparatively low TSS concentrations produced by the sand filters (Delaware, Austin, and MCTT) and the wet basin. The small error bars for these devices are a testament to the consistent effluent created. Despite the relatively higher effluent concentrations for extended detention basins and the vegetated controls, the TSS mass reduction should exceed approximately 80% for all the devices (Figure 3b) when the influent concentration is 114 mg/L.

The expected performance of the various BMPs for nitrate removal is compared in Figure 4. The wet basin is the only device in this study with a predicted effluent concentration of nitrate statistically less than the influent concentration of interest (0.97 mg/L-N). Media filters are reported to be consistent exporters of nitrate in every published study, presumably the result of nitrification of TKN in the filter. The quality of the effluent of the extended detention basins is not significantly different from the influent concentration (90% confidence level), while the swales and strips are predicted to have higher effluent than influent concentrations (1.24 mg/L-N vs. 0.97 mg/L-N). The performance of the strips is consistent with the results of a more conventional analysis of concentration reduction; however, those analyses predict slight removal of nitrate by swales on average. A reduction in nitrate concentration from the swales actually occurred during only 12 of the 39 storms where paired data were available. Despite the higher concentrations in the effluent from the vegetated controls, Figure 4(b) shows that there is a net mass reduction of nitrate when runoff volume reduction is accounted for.

Predicted effluent concentrations and mass reduction for orthophosphorus are presented in Figure 5. Swales, strips, and the wet basin all exhibit much higher effluent than influent concentrations. For the swales and strips, this again may be related to leaching of nutrients from the dormant vegetation or fertilizer and hydroseed applied to establish and maintain the vegetation. The effluent quality of the wet basin is related primarily to the quality of the dry weather flow that is displaced from the permanent pool during storms and is independent of influent concentration as noted earlier. Consequently, these data should be used with care in estimating the performance of a wet basin relative to other BMPs if implemented at a site with higher quality perennial flow.

Figures 6 and 7 compare the removal of dissolved copper and zinc for the subject BMPs. For these constituents, the mass reductions associated with the swales and strips are among the best of all the technologies. These results support the conclusions of Barrett et al. (1998), who reported that vegetated controls can be as effective sedimentation/filtration systems for treating highway runoff.

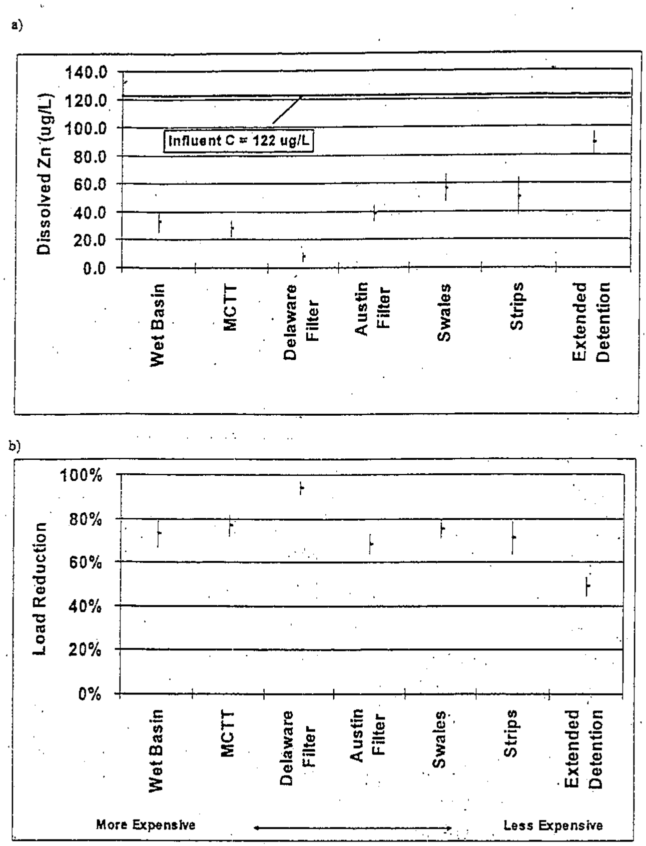

Figure 7—Expected effluent concentrations (a) and mass reduction (b) for dissolved zinc for influent concentration of 122 ug/L.

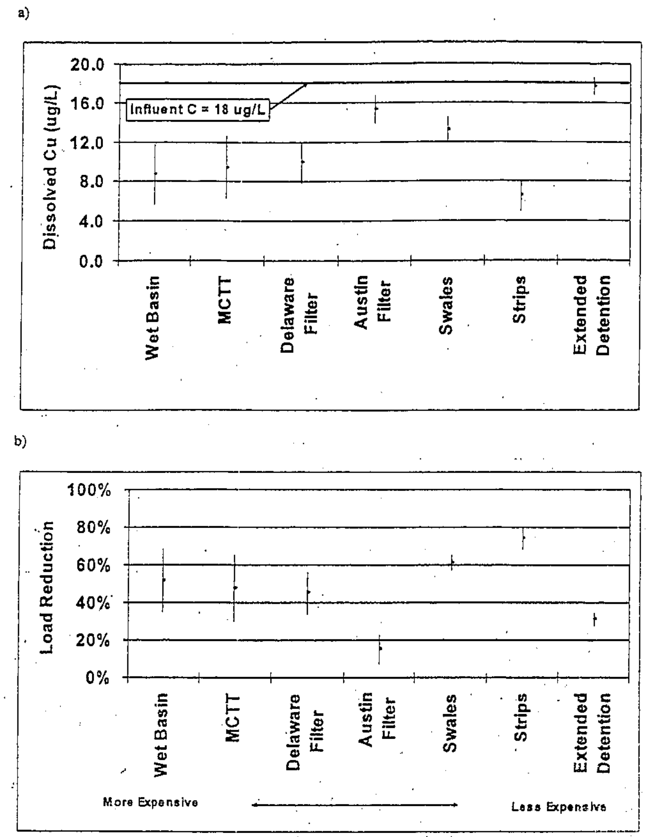

Figure 8—Expected effluent concentrations (a) and mass reduction (b) for dissolved copper for influent concentration of 18 ug/L.

Conclusions

The use of regression analysis for analyzing monitoring data collected during the evaluation of structural stormwater BMPs had a number of benefits. First, it allowed an identification of the constituents and devices for which the effluent EMC is unrelated to influent EMC. This phenomenon was particularly important in the performance of sand filters and the wet basin evaluated in this study. For sand filters, effluent concentrations of sediment and other particle associated constituents was relatively constant and unaffected by changes in the influent concentration. The wet basin also produced a fairly consistent quality effluent for all constituents, which was largely a function of the concentration of that constituent in the permanent pool before the beginning of runoff.

These data support the notion that pollutant percent removal is not necessarily a characteristic of the BMP itself, but reflects the interaction between the BMP and influent water quality. In other words, a single removal efficiency for a selected constituent may not adequately characterize the performance that would be expected if the device were implemented in a watershed with different runoff water quality. When the effluent concentration is constant, the percent removal calculated at a particular site is a function of the influent runoff quality and does not accurately indicate the amount of removal that would be observed at a site with a different influent EMC. In particular, the percent removal would appear to be much lower for storms with low influent concentrations and higher for storms with high influent concentration, despite the fact that the effluent quality is the same in both cases. In this study, that was particularly evident for the MCTTs, which produced an effluent quality similar to the Austin sand filters but which were implemented at park-and-ride lots that had significantly cleaner runoff than other sites. Consequently, characterizing the performance of the MCTTs by percent removal made them appear less effective. This independence of influent and effluent EMCs may help explain the wide range of percent removals reported in the literature for similar BMPs.

This analysis also provides a method for the calculation of the effluent quality for any influent quality of interest using the equations presented in Table 3. This may allow the performance observed in one watershed to be accurately applied to other watersheds that might have substantially different runoff quality. The use of regression facilitates the calculation of a confidence interval for the estimated effluent quality for each constituent. Because the confidence interval for constituents where influent and effluent concentrations are related is a function of the selected influent concentration, the confidence interval will be larger for concentrations where little data are available. In many cases, the confidence limits for the average expected effluent EMC are sufficiently small so that differences in performance among the BMPs are statistically significant.

The regression technique also illuminated the fundamental differences in the pollutant removal of dissolved and particulate phases in runoff, especially for sand filters. These differences indicate that the removal of these phases should always be analyzed separately, because the same analysis performed on the total concentration of a constituent will often obscure the more fundamental processes

Table 4—Whole life costs for Caltrans best management practices installations.

BMP Type	Avg. Adjusted Construction Cost	Adjusted Construction Cost/m^3 of the Design Storm	Annual Adjusted O&M Cost	Present Value O&M Cost/m^3	Life-Cycle Cost/m^3
Wet Basin	$448,412	$1,731	$16,980	$452	$2,183
Multi-chambered Treatment Train	$275,616	$1,875	$6,410	$171	$2,046
Delaware Sand Filter	$230,145	$1,912	$2,910	$78	$1,990
Austin Sand Filter	$242,799	$1,447	$2,910	$78	$1,525
Vegetated Swale	$57,818	$752	$2,750	$74	$826
Biofiltration Strip	$63,037	$748	$2,750	$74	$822
Extended Detention Basin	$172,737	$590	$3,120	$83	$673

involved in the removal and transformation of pollutants in runoff. Significant removal of dissolved metals at higher influent concentrations was observed in sand filters and other devices where the physical processes of sedimentation and filtration are dominant.

The results of this analysis allow one to easily compare the performance of the BMPs for a number of common constituents based on a common influent concentration. With the devices ordered by construction cost, it is easy to identify when a less expensive alternative may provide water quality benefit comparable to, or better than, a more expensive technology. Application of this technique to the aggregated data of this and other studies may provide a robust estimate of expected water quality performance of the universe of structural BMPs. In addition, this technique may help resolve some of the reported differences in efficiency from different studies and the uncertainty regarding the relative benefits of different types of BMPs. As agencies continue to address water quality issues related to highway construction and urban development, the need for accurate methodologies to assessment of relative performance of structural BMPs will only continue to grow in importance.

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Mosquito Production in Stormwater Treatment Devices in South Lake Tahoe, California

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ABSTRACT: In response to increasing evidence of mosquito production in stormwater best management practices (BMPs), a collaborative project was initiated in and around the city of South Lake Tahoe, California. The primary objective was to document mosquito production in selected BMP structures and to determine if these BMPs provide habitats suitable for extended mosquito breeding seasons of certain species. Mosquito production in selected natural sites in the surrounding area was used to gain insight on naturally occurring populations, species composition, and seasonal abundance. Thirty-two project sites were selected including 17 BMPs of three design types – dry systems; systems with sumps, vaults, or basins; and man-made vegetated treatment systems (VTS) – and 15 natural sites. Between December 2003 and October 2004, the percentages of weekly site visits in which mosquito production was observed were 1.7% in dry systems, 24.2% in sumps/vaults/basins, 10.4% in VTS, and 9.4% at natural sites. Natural sites were observed to hold water and breed mosquitoes most frequently during the colder months of early spring, whereas BMPs were more likely to hold water and breed mosquitoes during the warmer summer and fall months. The implications of mosquito production in urban and suburban BMPs, as well as possible extended mosquito breeding of certain species, for the risk of human infection with mosquito-borne diseases are discussed.

INTRODUCTION

In 1997, litigation between the California Department of Transportation (Caltrans) and several environmental organizations resulted in a requirement that Caltrans conduct an extensive benefit-cost study of stormwater treatment devices in southern California. This undertaking became known as the Best Management Practice (BMP) Retrofit Pilot Program. Stormwater treatment controls such as structural BMPs are mandated under Federal (Clean Water Act) and California State (Porter-Cologne Act) laws and are being implemented at an accelerated pace to comply with deadlines (Copeland 1999, 2003). Stormwater BMPs are designed to mitigate the harmful environmental impacts of urbanization on receiving waterways caused by both increased water runoff volume and the concomitant transport of pollutants. The majority of structures implemented by Caltrans control both water volume and pollutant discharges by temporarily detaining runoff and allowing passive treatment mechanisms such as trapping, settling, adhesion, and biological processes to improve water quality (Metzger et al. 2002, CDOT 2004).

In 1998, the California Department of Health Services-Vector-Borne Disease Section (CDHS-VBDS) raised concern that certain BMPs could impact public health by increasing available habitat for aquatic stages of disease vectors, particularly mosquitoes (CH2M Hill 1999, Chanda and Shisler 1980, Dorothy and Staker 1990, Florida Coordinating Council on Mosquito Control 1998, Kluh at al. 2002, McLean 2000, Metzger 2004, Metzger et al. 2003, 2002, O'Carroll 1978, Santana et al. 1994, Schimmenti 1979, Schmidt 1980, Smith and Shisler 1981). As a result, in 1999 CDHS-VBDS entered into a contractual agreement with Caltrans to provide technical expertise on vectors and vector-borne diseases potentially associated with BMPs. It was the intent of this agreement to protect public health by documenting and, where possible, mitigating vector production and harborage at these BMPs. In collaboration with several local southern California vector control agencies, CDHS-VBDS established a comprehensive mosquito surveillance and monitoring program, developed vector abatement protocols, and recommended design modifications to reduce or eliminate the potential for BMPs to produce or harbor vectors (CDHS 2002).

The Lake Tahoe Basin is of special concern with regard to the implementation of BMPs. Lake Tahoe is one of the three clearest alpine lakes in the world, but its clarity is threatened by both waterborne and airborne pollutants such as suspended solids, nutrients, and hydrocarbons. In particular, certain nutrients cause algal growth which decreases Lake Tahoe's clarity and interferes with natural ecosystems. Lake Tahoe has been losing approximately 0.5 m of clarity a year leading some researchers to believe it could become a turbid, ordinary lake within a single generation (Tahoe Regional Planning Agency 1980). In an effort to slow this degradation, the United States Federal Government and Tahoe Regional Planning Agency (TRPA) created strict constituent limitations for stormwater effluent that drains to the lake (Table 1) (Clinton 1997, Tahoe Regional Planning Agency 1980). State highways ring Lake Tahoe's 72 mile circumference, so roadside projects aimed at improving water quality are an important component of this comprehensive effort.

Table 1. National Pollutant Discharge Elimination System (NPDES) permit surface discharge limits for Lake Tahoe stormwater treatment.

Constituent	Max concentration allowed in surface H_2O discharges
Turbidity	20 NTU
Total Nitrogen	0.5 mg/L
Total Phosphorous	0.1 mg/L
Total Iron	0.5 mg/L
Oil and Grease	2.0 mg/L

NTU = nephelometric turbidity units
mg/L = milligrams per liter

VBDS currently recommends that stormwater BMPs hold water for less than 72 hours – the minimum time required for certain mosquito species to complete their lifecycle under optimum conditions (California Department of Health Services 2002; Metzger et al. 2003, 2002). However, many types of stormwater BMPs currently in use in the Tahoe Basin exceed this recommendation and can become highly conducive to mosquito production. In 2003, VBDS, Caltrans, and El Dorado County Vector Control (EDCVC) initiated a collaborative project to assess mosquito production in selected BMP structures in and around the city of South Lake Tahoe, California. The primary objective of this project was to document the presence, seasonality, and species composition of mosquitoes in BMPs compared to those present in natural sites in the surrounding area.

METHODS AND MATERIALS

Study area

The city of South Lake Tahoe, California, is located at approximately 1908 meters elevation in east-central California along the California-Nevada Border south of Lake Tahoe in the Sierra Mountain Range (latitude: N 38° 57' 9.180", longitude: W - 120° 6' 24.228"). The city covers approximately 26 square kilometers. The city's topography varies from level to mountainous, with vegetation ranging from willows to manzanita shrubs to aspens to conifers. Average annual rainfall is approximately 66 cm, the majority of which accumulates between November and March. Average annual snowfall at lake level is 318 cm.

Mosquito sources

In this study, a mosquito source was identified as an area that had the potential to hold stagnant water sufficient to breed mosquitoes. A site was defined as a single area of standing water. Pools of standing water within one meter of each other were considered a single site. The exceptions to this rule were large wet basins, meadows, and marshes, which were considered one site.

Thirty-two sites in or around the city of South Lake Tahoe were selected for the project, consisting of 17 BMPs (man-made sites) and 15 natural sites. Five BMPs were built and maintained by Caltrans and the remaining 12 were randomly selected from a list provided by EDCVC of known mosquito sources. The natural sites were chosen at random from an EDCVC list of historically problematic sites.

The BMPs chosen were separated into three groups (types) based on design and function: dry systems; systems with sumps, vaults, or basins; and vegetated treatment systems (VTS). Dry systems are designed to drain completely following a storm event

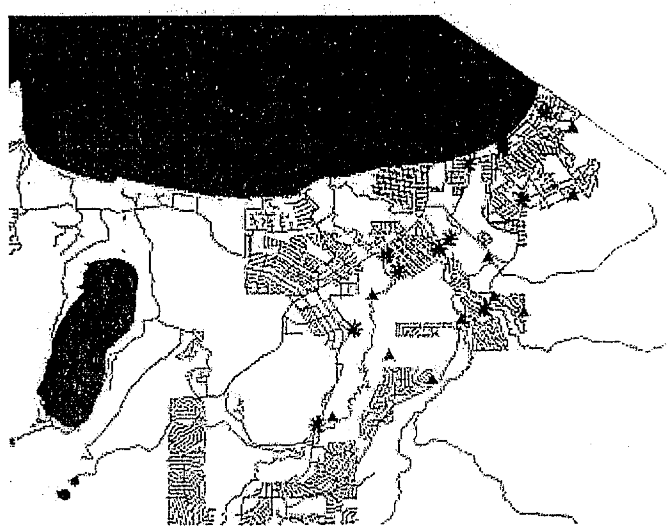

Figure 1. Digitized map of South Lake Tahoe, CA with geo-referenced project sites. black asterisk = BMP site; black triangle = natural site

and to remain dry. Examples include detention basins, vegetated swales, infiltration devices, and media filters. Systems with sumps, vaults, or basins include those BMPs with features that hold permanent or semi-permanent standing water. Examples include above- and below-ground media filters, hydrodynamic separators, and vault-type devices. Vegetated Treatment Systems are wetlands that have been constructed or modified to receive and treat runoff (Metzger 2004).

All 32 sites in the project were geo-referenced (Figure 1) using a Trimble GeoExplorer 3 GPS device. Waypoint data was converted into Microsoft Access database files and shapefiles using Pathfinder Office software. The shapefiles were imported into ArcView 3.2a for GIS mapping. Digitized maps (e.g., street and topographical) of the Tahoe Basin area were provided by the El

Dorado County Surveyor's Office. Microsoft Excel and Microsoft Access were used to compile and analyze the data.

Data collection

Each study site was visited weekly from December 2003 to October 2004 (48 weeks). Data were collected at each site on each of the following features/variables: BMP type (i.e., dry system; sump, vault, or basin; VTS; natural); habitat type (e.g., pool, spring, meadow, marsh, ditch, etc.); water flow and turbidity; exposure to sun and/or shade; bottom type (e.g., cement, rocks, mud, etc.); vegetation present (e.g., cattails, marsh or meadow grass, algae, pine needles, etc.); mosquito presence (i.e., number/dip and species); larvicide use, if any (i.e., chemical used, quantity, rate and equipment used); daily high and low temperature and rainfall data from the National Oceanic and Atmospheric Administration weather station located at the South Lake Tahoe Airport.

Immature mosquitoes were collected using a standard dipstick with a .47 liter (1 pint) cup. The number of dips for each site was dependent on area and vegetation and kept constant throughout the project (e.g., 2 dips for a catch basin; 1 dip every 2 meters for larger sites). Dips were taken at each site to determine whether immature mosquitoes were present. Immature mosquitoes (larvae and pupae) collected were counted and identified to species. To help protect public health in the Tahoe basin, BMPs that harbored immature mosquitoes were treated with methoprene (Altosid EC®) to prevent the successful development of adults.

RESULTS

A total of 1536 visits were made to the 32 study sites during the 48-week study period. Of 816 site visits to individual BMPs, immature mosquitoes were collected on 97 (11.9%) occasions. Separated by BMP type, immature mosquitoes were collected on four of 240 (1.7%) visits to dry systems, 58 of 240 (24.2%) visits to sumps and basins, and 35 of 336 (10.4%) visits to VTS. Immature mosquitoes were collected on 68 of 720 (9.4%) visits to natural sites (Table 2).

Table 2. Number of weeks (%) positive for mosquito breeding at project sites itemized into different BMP types in South Lake Tahoe, CA over the Winter months, Summer months, and over all 48 weeks (Dec 03 – Oct 04).

Mosquito Source	Winter months (Dec 03 - Apr 04)	Summer months (May 04 - Oct 04)	Total months (Dec 03 – Oct 04)
5 Dry Systems	0 (0%)	4 (3.08%)	4 (1.67%)
5 Sumps, Basins, Vaults	1 (0.91%)	57 (43.85%)	58 (24.17%)
7 VTS*	0 (0%)	35 (19.23%)	35 (10.42%)
15 Natural Sources	24 (7.27%)	44 (11.28%)	68 (9.44%)

* Vegetated Treatment System.

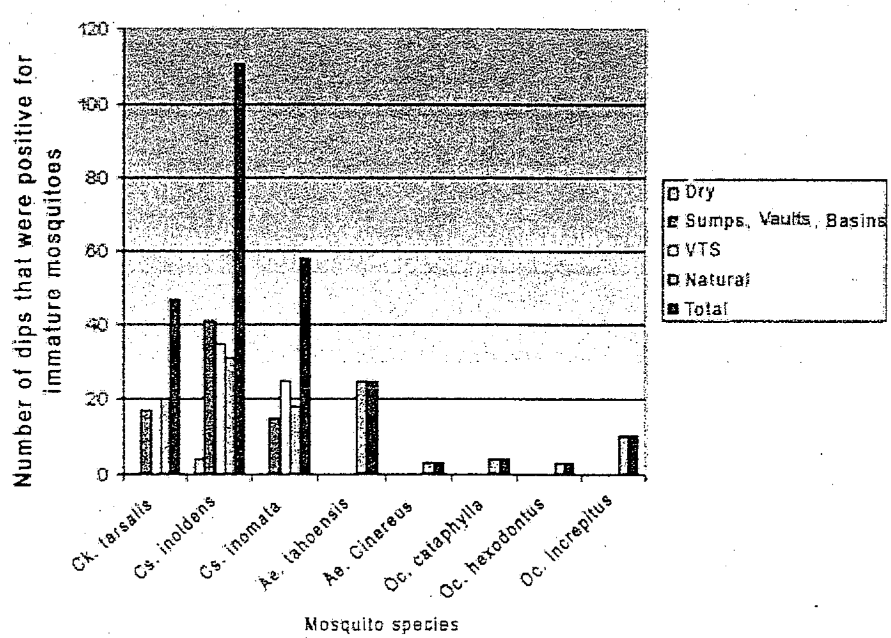

Figure 2. Number of positive dips where immature mosquitoes were observed during weekly project site visits. VTS = Vegetated Treatment System.

During the coldest months (average daily temperature = 33°F), between weeks 1 and 20 (December 2003 to April 2004), immature mosquitoes were collected from BMPs only once (i.e., underground vault) over the course of 110 (0.9%) visits. No immature mosquitoes were observed at dry systems and VTS during this period. In contrast, immature mosquitoes were collected during 24 of 330 (7.3%) visits to natural sites. After snow melt, between weeks 21 and 48 (May 2004 to October 2004) (average daily temperature = 53°F), immature mosquitoes were collected on 4 of 130 (3.1%) visits to dry systems, 57 of 130 (43.8%) visits to sumps and basins, and 35 of 182 (19.2%) visits to VTS. Immature mosquitoes were collected on 44 of 390 (11.3%) visits to natural sites during this period.

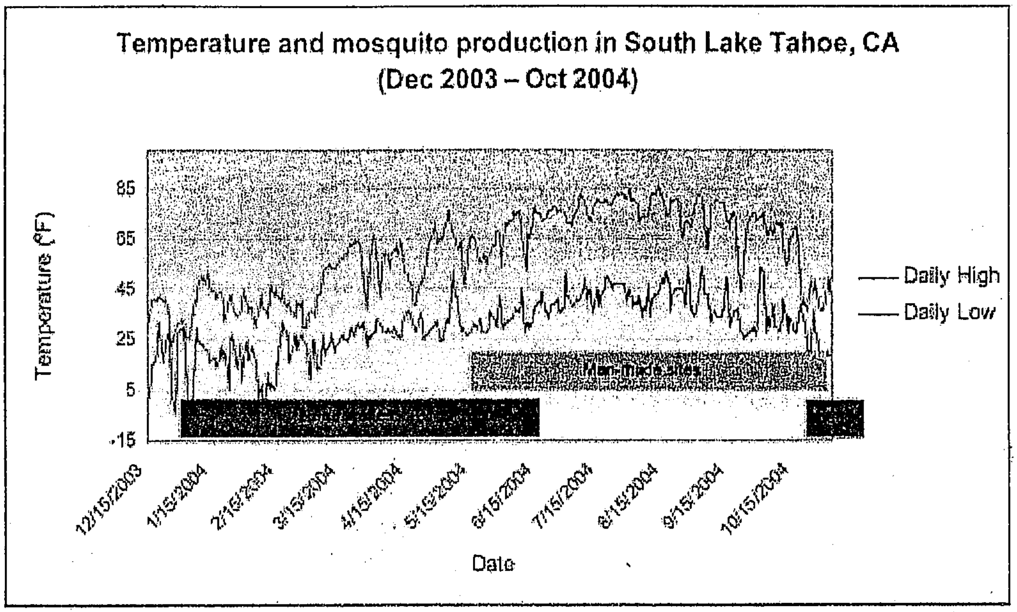

Figure 3. Daily temperature and mosquito production in South Lake Tahoe, CA from Dec 2003 to Oct 2004. Natural sites have a tendency to breed mosquitoes in the colder months, whereas the man-made sites have a tendency to breed mosquitoes more regularly in the warmer months.

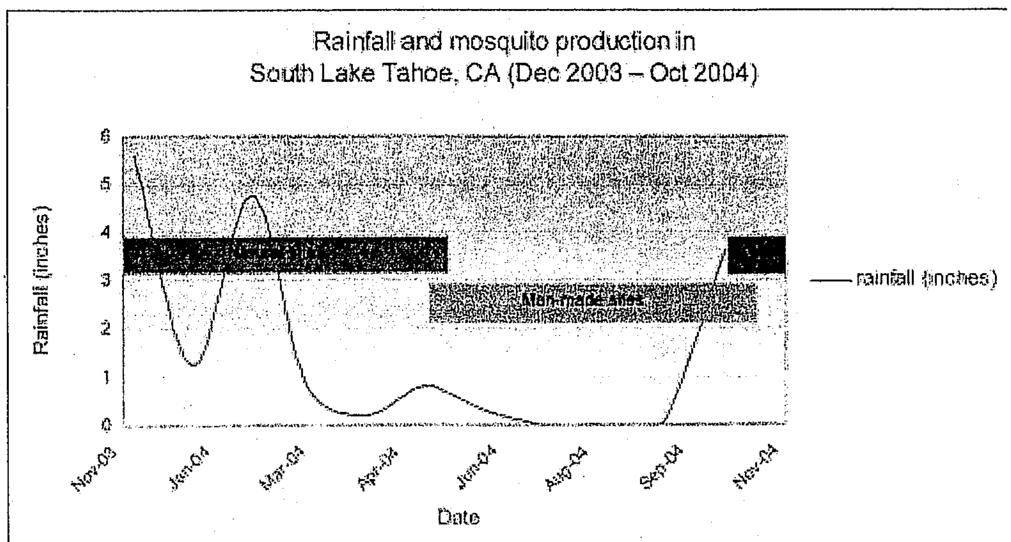

Figure 4. Monthly rainfall and mosquito production in South Lake Tahoe, CA from Dec 2003 to Oct 2004. Natural sites have a tendency to breed mosquitoes in the wetter months, whereas the man-made sites have a tendency to breed mosquitoes more regularly in the drier months.

Eight species of mosquito, representing four genera, were collected from study sites (Figure 2). The genus *Culex* was represented by a single species (*Cx. tarsalis*), the genus *Culiseta* by two species (*Cs. incidens*, *Cs. inornata*), the genus *Aedes* by two species (*Ae. tahoensis* and *Ae. cinereus*) and the genus *Ochlerotatus* by three species (*Oc. cataphylla, Oc. increpitus* and *Oc. hexodontus*). Overall, *Culex* and *Culiseta* mosquitoes were observed most often, especially in sumps, vaults and basins.

When average daily temperatures were low and monthly rainfall totals were high (average monthly rainfall greater than 2.54 cm) (weeks 1 to 20), immature mosquitoes were present more frequently in natural sites. When the average daily temperatures were warmer and monthly rainfall totals dropped, mosquito production was more frequent in BMPs (Figures 3 and 4).

DISCUSSION

This study provides preliminary evidence that certain BMPs in the Tahoe Basin increase available habitat to mosquitoes that may allow opportunistic species to extend their breeding season. BMPs that are poorly designed, improperly constructed, or inadequately maintained may retain water suitable for mosquitoes. Historically, the mosquito breeding season in South Lake Tahoe ended around the month of June; however, with the widespread deployment of BMPs, particularly below-ground devices protected from weather extremes, mosquitoes may be capable of breeding year round and over-winter as adults (CDHS, unpublished data). This potentially increases the risk of disease transmission to residents, companion animals, and wildlife. It may also create a

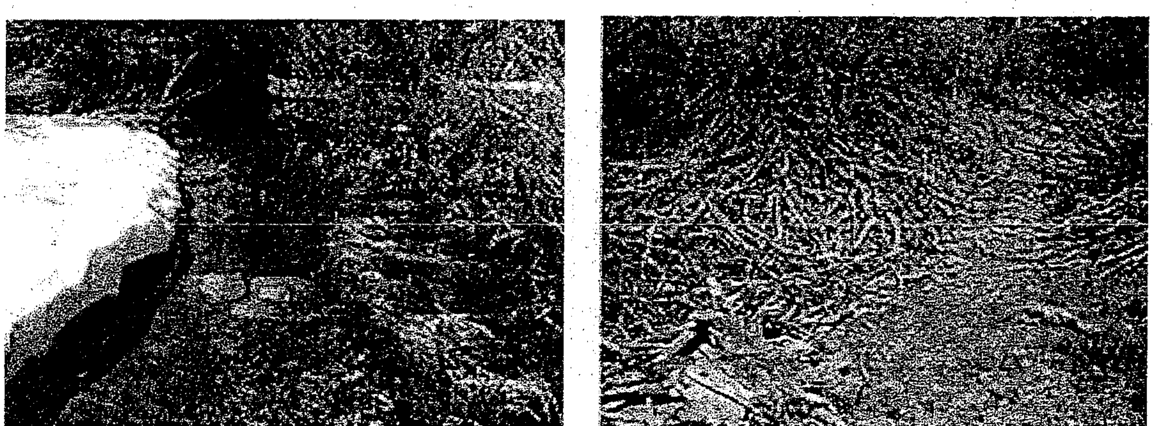

Figure 5. Natural site with stagnant snow melt water on the left April 1, 2004, and the same site dried up on June 10, 2004.

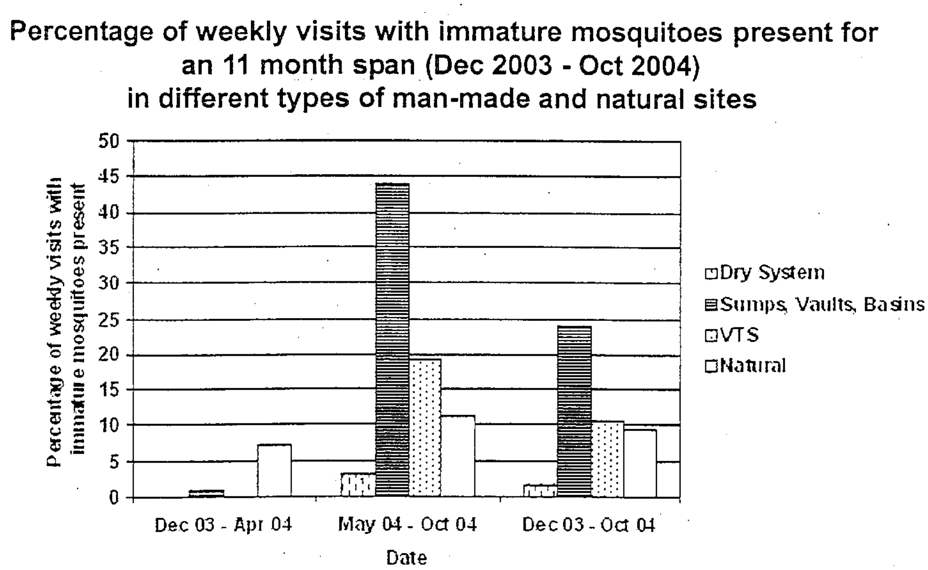

Figure 6. Number of weeks (%) positive for mosquito breeding at project sites itemized into different mosquito breeding site types in South Lake Tahoe, CA over the winter months, summer months and over all 48 weeks (Dec 03 – Oct 04). VTS = Vegetated Treatment System.

financial burden for the city by increasing yearly costs for vector control.

The extension of the mosquito breeding season can be attributed to seasonal temperature and rainfall. The fluctuations in temperature and rainfall appeared to be dependent variables of when and where mosquitoes would breed (Figure 3 and 4). During the colder months from December 2003 to April 2004, natural sites contained stagnant, cold, clear water, mostly from snow melt, preferred by the snow melt mosquito genera *Aedes* and *Ochlerotatus*. In contrast, during the warmer months of May 2004 to October 2004, the natural sites dried (Figure 5) while urban irrigation filled the BMPs, creating mosquito breeding habitats throughout the city (Fig. 6).

The mosquitoes identified at study sites (Table 3) correspond with species commonly found in South Lake Tahoe. These mosquito species differ in their preferred season and habitat for breeding. The majority of the *Culex* and *Culiseta* species in South Lake Tahoe breed in warm, murky waters typical of many BMPs. Two of these mosquito species, *Cx. tarsalis* and *Cs. inornata*, are directly involved with disease cycles that can be transmitted to humans. In California, *Cx. tarsalis*, a mosquito that prefers to breed in warmer weather, is the primary vector of St. Louis encephalitis (SLE) and western equine encephalomyelitis (WEE) and has proven itself to be an effective vector for West Nile virus (WNV) (Goddard et al. 2002, Reeves and Hammon 1962). *Culex tarsalis* is also capable of flying considerable distances (up to 26 km with estimates indicating they can fly 32-40 km if assisted by winds). This is an important variable in the distribution and transmission of mosquito-borne viruses (Durso 1996).

Table 3. Common mosquito species found in South Lake Tahoe

Genus	Species
Aedes	*ventrovittis*
Culiseta	*inornata* * #
	incidens #
	impatiens
	particpeps
Culex	*tarsalis* * #
	pipiens (quinquefaciatus) *
	stigmatosoma *
	territans *
	restuans *
Ochlerotatus	*cataphylla* #
	increpitus #
	hexodontus #
	tahoensis #

*These species are known potential vectors for West Nile virus
#These species were collected from the BMPs and natural sites during the project

Culiseta inornata is a mosquito that is also active during the colder months and has the potential to maintain WNV, SLE, and WEE transmission cycles when *Culex* mosquitoes are dormant (Goddard et al. 2002, Tempelis and Washino 1967, Anderson and Galloway 1987, Tempelis 1964). Another method of maintaining the mosquito-borne disease cycle when most mosquitoes are dormant is the mosquito's ability to search and over-winter in underground BMP devices. Three underground BMPs were checked during the winter months and one was found to house *Cx. tarsalis* and *Cs. incidens*.

The design of the dry systems allows for complete drainage within 72 hours following a storm event. A construction flaw with one of the dry system sites allowed it to hold stagnant water for mosquito breeding. The VTS had many cattails and willows in and around the edge of the pond that created ideal breeding habitat for mosquitoes. However, due to the low water table, many VTS became dry, like the natural sites, as the temperature increased and rainfall decreased in the summer. By design, water in sumps, basins, and vaults never fully drains. At these project sites there was always at least a few centimeters of water that mosquitoes could capitalize upon for breeding.

City planners, transportation agencies, and others should consider the potential for BMPs to support mosquito breeding habitat when designing and constructing these devices in areas where people live. BMPs are being installed at an accelerated rate in and around the city of South Lake Tahoe in an effort to comply with National Pollutant Discharge Elimination System (NPDES) runoff regulations (State Water Resources Control Board 1999). South Lake Tahoe is the most populous city around Lake Tahoe, and thus in theory has the potential to create the most runoff pollution into the lake. In order for South Lake Tahoe to accommodate an increasing number of residents and visitors, it will need to construct new neighborhoods, commercial property, and public use areas. Many of these development projects will require the installation of curbs and gutters that drain into catch basins and underground BMPs. If these BMPs fail to drain completely, their proximity to human residences may contribute to increased transmission of mosquito-borne disease agents, such as WNV. To help prevent any outbreaks of mosquito-borne diseases, vector control agencies should be consulted when these developments are in their blue print phase, as well as after they are in place and operational. These agencies can offer important perspectives that can curtail any threats and prevent unnecessary mitigation costs.

Mosquito production differed by season in man-made versus natural sites. Winter precipitation in South Lake Tahoe during the study period was below average for the preceding 9 years. Under normal conditions, natural sites may not have dried up as early in the year as they did for this project and would have continued breeding mosquitoes well into the summer. Further data collection over several years is necessary to better define the seasonal mosquito production in BMPs in South Lake Tahoe.

Acknowledgements

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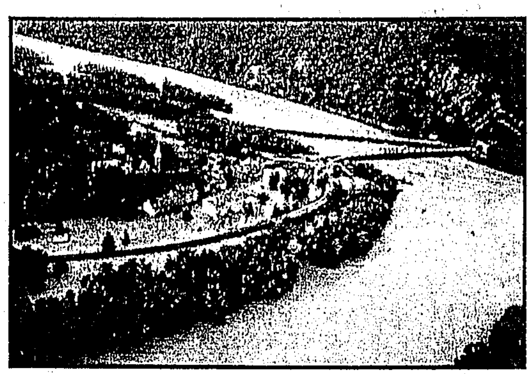
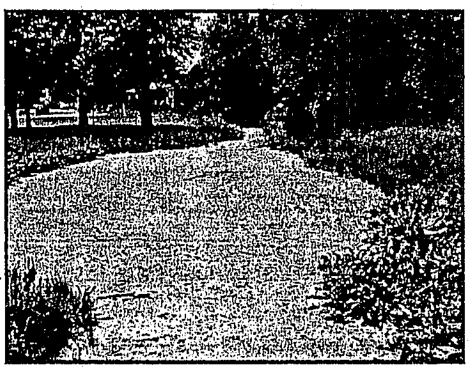
STORMWATER MANAGEMENT & MOSQUITO ISSUES

Clearly, any standing water has the potential to promote mosquito growth. Some stormwater management practices use ponded water to promote water quality improvement. Therefore, there is the potential for contributing to mosquito problems. However, stormwater management is essential to mitigate the adverse effects of development on the environment. These effects include increased flooding, water quality impairment, reduced groundwater recharge, and stream channel erosion.

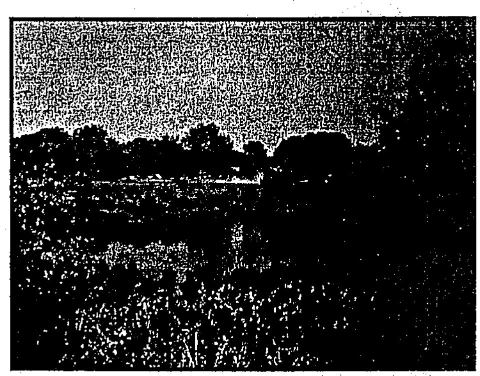




Maintenance of constructed facilities is of paramount importance to their function. The State and local governments make efforts to inspect both publicly and privately owned stormwater management facilities. These efforts can certainly improve. A greater public awareness of the value of these facilities will help in making increased funding available so that better maintenance can be achieved. A lack of maintenance typically results in diminished pond performance, poor drainage, and promotes mosquito population growth. Temporary sediment and erosion control measures employed during construction also benefit from increased maintenance activity.

The State of Maryland revised its stormwater management regulations in the year 2000. Included in the revisions were changes in design requirements that reduce the potential for mosquito breeding. Specific changes include:

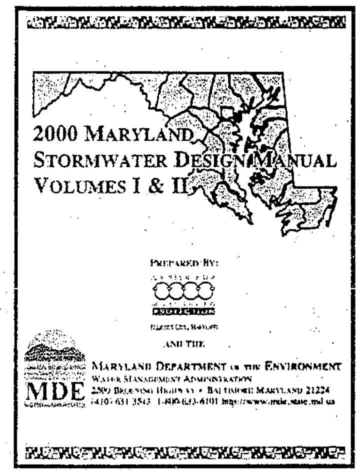
- **Greater flexibility of practice selection based on site specific conditions.** Previously, certain practices were required because it was believed they would provide the greatest improvement to water quality. Over time it became evident that site conditions had a significant influence on practice performance. Forcing a specific practice to be used where it was impractical often led to poor drainage and eventually failure. Using the appropriate practice will result in less frequent occurrences of poor drainage and stagnant water.



- **Improved drainage performance.** Not all stormwater management practices require extended ponding of water. Any practice that is not designed with a permanent pool is required to drain within 48 hours after a storm event. If a practice does involve longer retention times, then features are to be incorporated to promote mixing of incoming runoff and reduce stagnation.

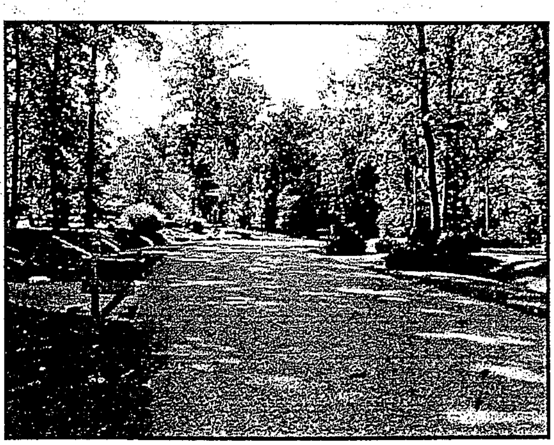
Improving the design of permanent pools. Research clearly shows that varying the depths of permanent pools reduces mosquito breeding habitat. Portions of all new ponds have to be a minimum of 4 feet deep. Other areas of ponds that have varying shallower depths are to be planted with aquatic vegetation. This results in habitat for natural predators of mosquitoes such as dragonflies, birds, fish, and frogs.

Encouraging better site design practices that reduce the need for structural stormwater management features. Development alters natural drainage and creates the need for stormwater management. Following new design criteria minimizes the generation of pollutants and reduces the concentration of runoff. Following the nonstructural measures promoted by the State in some cases can eliminate the need for a pond altogether.



For more help & information on West Nile Virus...

- Dead Birds – State Call Center: 1-866-866-CROW (2769)
- State Mosquito Control Program: 410-841-5870
  Maryland Department of Agriculture - Mosquito Control Section
- Maryland Department of Health & Mental Hygiene:
  www.edcp.org/html/west_nile.html



In summary, Maryland has made efforts to improve stormwater management practices to reduce the potential for mosquito problems. If you have any additional questions please contact Charlie Wallis of the Nonpoint Source Program of the Maryland Department of the Environment at 410–537–3543 or email at cwallis@mde.state.md.us.

APPLICATION OF PARTICLE SIZE DISTRIBUTION IN HIGHWAY RUNOFF: OPTIMIZATION OF SETTLING TANK DESIGN TO REMOVE PARTICLES

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ABSTRACT

Sedimentation was evaluated for removing particles from highway runoff. Particle size distribution was measured over several wet seasons to establish sizes and trends. Simulations and column measurements using particle size distribution suggested that low efficiencies would be obtained if no coagulation-flocculation was performed. Coagulation-flocculation studies, using metal salts (alum and ferric chloride) and one organic polymer in three molecular weights, were evaluated over the 2004-2005 storm seasons. Only the first flush or approximately the first hour of runoff was coagulated. Previous studies at these sites showed that the first flush, corresponding to 20% of the runoff flow, had 30 to 50% of the pollutant mass. Efficiencies were quantified with particle size distribution measurements and turbidity. Results with low dosages of metal salts were ineffective and did not improve water quality. High dosages of metal salts using a sweep floc mechanism were effective in dramatically lowering runoff turbidity, but resulted in large quantities of sludge production and required pH control. A cationic organic polymer at low dosages (< 10 mg/l) was effective in coagulating highway runoff and producing neutral charges on particles. Extended mixing was required to achieve low turbidities. A combination of organic polymer, followed by small doses of alum (< 10 mg/l), reduced mixing time and produced high quality effluent. Therefore, it can be concluded that treated stormwaters with turbidities less than 5 NTU are possible.

KEYWORDS

Stormwater, particle size distribution, settling, coagulation, zeta potential

1. INTRODUCTION

In an effort to understand and mitigate the impacts of highway runoff, the California Department of Transportation (Caltrans) sponsored a five year highway runoff characterization study at three monitoring sites in West Los Angeles from 1999 to 2004. Table 1 shows the sites, which were located near the UCLA Campus. The catchment areas range from 0.39 to 1.69 hectares and annual average daily traffic (AADT) is over 269,000 vehicles per day. The average annual rainfall is approximately 330 mm. All sites were equipped with American Sigma (Loveland, Colorado) 950 Flow Meters, tipping bucket rain gauges, and composite auto samplers.

A great proportion of pollutants in highway runoff, such as heavy metals and polynuclear aromatic hydrocarbons (PAHs) are bound to particles (Oliver, et al., 1974; Herrmann, 1981; Ongley, et al., 1981; Hoffman, et al., 1985; Hewitt and Rashed, 1992; Legret and Pagotto, 1999). The large surface-to-volume ratios of particles in highway runoff provide reactive locations for partitioning and transport of pollutants and may serve as reservoirs of these pollutants in downstream locations (Oliver, et al., 1974; Thomson, et al., 1997; Cristina, et al., 2002). In addition, pollutants sorbed to particles generally have less mobility and bioavailability than in their dissolved form. Consequently, understanding characteristics of particles in highway runoff is crucial for future runoff management and best management practice (BMP) selection, which are often selected based upon total suspended solid (TSS) removal.

Table 1. Summary Description of Sampling Sites

Site No.	Location	Freeway/Post Miles	Area (h)	AADT (x1000)	Imperviousness (%)
1 (7-201)	Eastbound US 101	HWY101 PM 17	1.28	328	100
2 (7-202)	I-405 Freeway and Sepulveda Blvd	FW405 PM 34	1.69	269	95
3 (7-203)	Santa Monica Blvd N. Bound Exit on I-405	FW 405 PM 30.8	0.39	322	100

This paper reports on particle size distributions in highway runoff and the methods used to remove them, as well as their associated pollutants. It is our first attempt to increase particle size through coagulation in order to enhance removal rates. Particles in samples collected in the 2004-2005 wet season were subjected to a variety of coagulation and flocculation methods using both metal salts and organic polymers. In general, it was found that almost no removal of small particles (< 30 μm) was possible in untreated samples. The results presented in this paper are supported by earlier studies, which analyzed for water quality data, first flush mass ratios, litter information, and other data (Han, et al., 2004; Kim, et al., 2004; Kim, et al., 2005; Lee, et al., 2004).

2. BACKGROUND

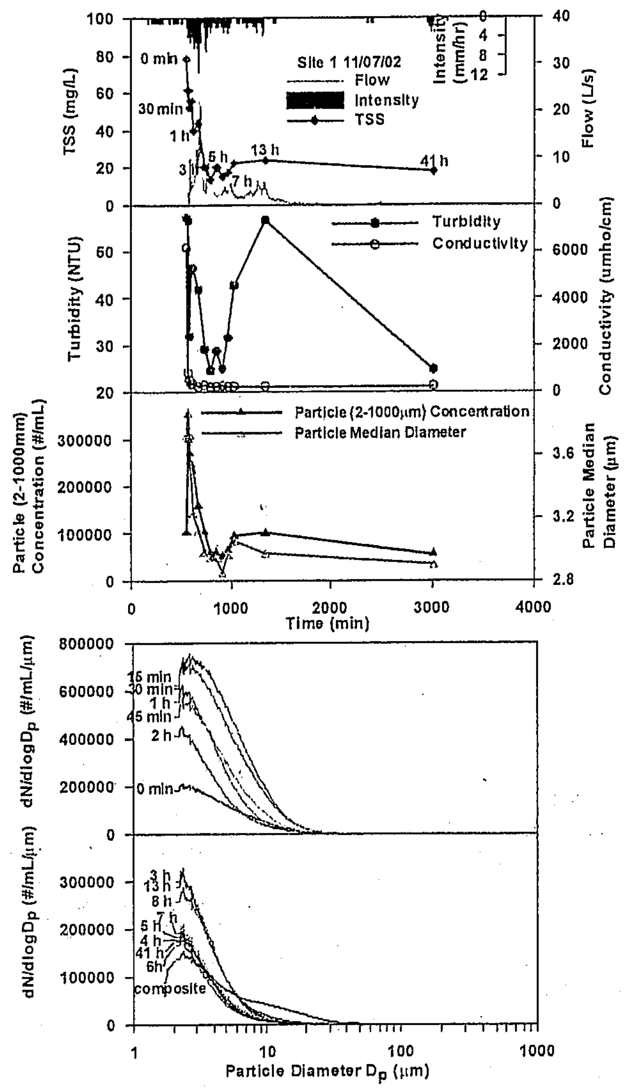
2.1. PARTICLE SETTLING

Settling velocities of particles is one of the most important factors for BMP design. It depends on the particles' size, shape, density, and is influenced by the liquid characteristics, such as temperature and viscosity. Particle size distribution (PSD) monitored in our three highway sites showed that 97% of particles were less than 30 μm in diameter (Li, et al., 2005), which makes small particle removal extremely important in BMP design. Fig. 1 shows the typical PSD of a series of grab samples collected through a storm event. Turbidity, total suspended solids (TSS), specific conductivity are also shown, and additional information about measuring techniques and more events are available elsewhere (Li, et al., 2005).

Removal efficiencies of the particles and associated pollutants for the entire 2002-2003 wet year were simulated using particle settling velocities calculated with Newton's and Stokes' law. Spherical particles corresponding to the measured PSD and having a uniform density 2.6 g/cm^3 were assumed. Continuous flow clarifiers with volumes sized to contain 1.6mm to 26 mm of rainfall were simulated and were able to remove 75% to 92% of the particles between 2 and 1000 μm, respectively. The clarifier could remove only 3% to 29% of particles between 2 and 10 μm and were able to remove only 13% to 72% of particles between 2 and 25 μm. A series of settling column tests with fresh stormwater samples showed much less removal than predicted, which connotes that settling velocities of smaller particles are much lower than calculated by Newton's and Stokes' law with the stated assumptions. The difference is probably due to a distribution of densities and deviation from spherical shape. These results support anecdotal observations of poor performance of BMPs using sedimentation for removing smaller particles.

It is unfortunate that the smaller particles are not removed since they routinely have higher concentrations of heavy metals and PAHs than the larger particles (Sansalone and Buchberger, 1997; Roger, et al., 1998; German and Svensson, 2002; Morquecho and Pitt, 2003; Lau and Stenstrom, 2004). It is clear that using sedimentation for smaller particle removal will require some type of particle destabilization in order to increase particle size and improve settling velocity. This is challenging because stormwater BMPs usually operate unattended in many locations. In addition, managing coagulation/flocculation systems will be difficult.

Figure 1: Hydrograph with TSS, turbidity, conductivity and PSD for site 1, event 11/07/02 or for site 1, event 10/26/04



2.2 PARTICLE DESTABILIZATION

Destabilization of dispersed particles in aqueous systems can be achieved by several different mechanisms. The formation of deltas in estuaries is a common example of the double layer compression mechanism. Engineered systems, however, typically use coagulants and coagulant aids for colloid destabilization involving either charge neutralization, bridging, sweep floc, or a combination of those mechanisms. Among the metal ions, Al^{3+} and Fe^{3+} are commonly used in the water and wastewater treatment. Depending on their dosage and water characteristics, Al^{3+}, Fe^{3+}, and their hydrolysis products neutralize the negatively charged particles (stoichiometric destabilization) or precipitate as amorphous forms to enmesh colloidal particles (sweep floc coagulation) [Summ and O'Melia, 1968]. Natural and synthetic polymers have been used as a flocculating aid in water and wastewater treatment systems for many years. Cationic polymers are used to reduce the repulsive force between particles, both by neutralization and bridging mechanisms. Polymers bridge two or more particles by attaching themselves on the available sites of the particles. Anionic polymers are commonly used to flocculate negatively charged particles via bridging with the risk of restabilization resulting from charge reversal.

In the stormwater treatment, coagulation and flocculation have also been considered to enhance colloid destabilization. Polyaluminum chloride (PACl) has frequently been employed because its low acidity is advantageous for weakly buffered stormwater. Heinzmann (1994) has shown that the mixture of PACl and cationic polymer (polyacrilamide) was effective in the filtration system of urban stromwater. Annadurai, et al. (2003) investigated the efficiency of PACl to treat high turbidity stormwater (1,650 NTU). They stated that a high dose of PACl (>100 mg/L) is preferable to generate large flocs for easy solid-liquid separation (i.e., bridging). The California Department of Transportation (Caltrans, 2003) has recently conducted comprehensive coagulation studies using PACl along with polymer and ballast sand as coagulant aids to remove the turbidity and phosphorus in stormwater entering Lake Tahoe. From their tests in a pilot scale facility, Caltrans reported that the optimum dose of PACl ranged from 75 to 100 mg/L. The high dose requirement of the coagulant will result in large sludge production, which may create problems for field application. In addition, excess coagulant doses above the optimum range may cause particle restabilization.

3. METHODOLOGY

Multiple composite samples were collected during the first hour of runoff from site 2 during the 2004-2005 storm season. One-hour composites were selected because an hour is generally equal to the time of the first flush. Samples were returned to the laboratory within one-hour and a series of jar tests were performed using different coagulants and mixing strategies. Table 2 shows a brief summary showing the range of sample characteristics.

Table 2: Characteristics of 1 hr composite samples from Site 2

Parameter	Range of Untreated Composite Samples
pH	6.3~7.1
Temp (°C)	13.2~19.8
Turbidity (NTU)	51~197
EC (uS)	141~1,014
ZP (mV)	-46.54 ~ -26.54

The jar tests were divided into three different experimental regimes: low dose coagulation, sweep floc coagulation, and flocculation using organic polymers.

In the low dose coagulation, relatively small doses of alum or ferric chloride were applied and then slowly mixed for 4 to 8 hours. These procedures were intended to investigate the effect of metal ions on neutralizing and aggregating negatively charged particles in the water. The second regime used higher doses to produce sweep floc coagulation. The high alum or ferric chloride dosage formed a sweep floc enmeshing the colloidal particles. The optimum dose for each coagulant was estimated based on turbidity removal. pHs were always adjusted to 7 for both low dose and sweep floc coagulation tests. Finally, a more extensive series of flocculation tests were performed using cationic organic polymers--polydiallyldimethylammonuim chloride (polyDAFMAC) with different molecular weights (Table 3) was used. Long periods of slow mixing were provided after 1 minute of rapid mixing because sufficient contacting time was required for particle aggregation. The general procedures of each coagulation/flocculation test are shown in Table 3.

Table 3: Protocols for the coagulation / flocculation tests

	Rapid mixing	Slow mixing	Settling	Coagulant	Remark
Low dose coagulation	1min 100rpm	4~8 hr 5~10 rpm	16~20hr	Alum Ferric Chloride	pH adjusted to 7
Sweep floc coagulation	1min 100rpm	10 min 5~10 rpm	40 min	Alum Ferric Chloride	pH adjusted to 7
Flocculation with polymer	1min 100 rpm	4~8 hr 5~10 rpm	16~20 hr	PolyDADMAC HMW: 400,000-500.000 MMW: 200,000-350,000 LMW: 100,000-200,000	

Turbidity, zeta potential (ZP), and particle size distribution (PSD) were the major parameters measured in the tests. PSD was measured with the Nicomp Particle Sizing System's AccuSizer 780 Optical Particle Sizer Module (Santa Barbara, California) equipped with an auto-dilution system and a light scattering/extinction sensor. A representative sample ranging in volume from 0.5 to 10 ml was removed from the 4L sample bottle using a wide-bore glass pipette after gently inverting the 4L bottle 5 to 6 times and then injected into the AccuSizer. If the particle concentrations were too high, the sample was injected to a 25 mL or 50 mL volumetric flask for predilution. Sample bottle and glassware cleaning procedures were discussed in Li, et al. (2005). Between samples, the system was flushed for at least three cycles, which reduced the background particle concentrations to less than 3 ml.

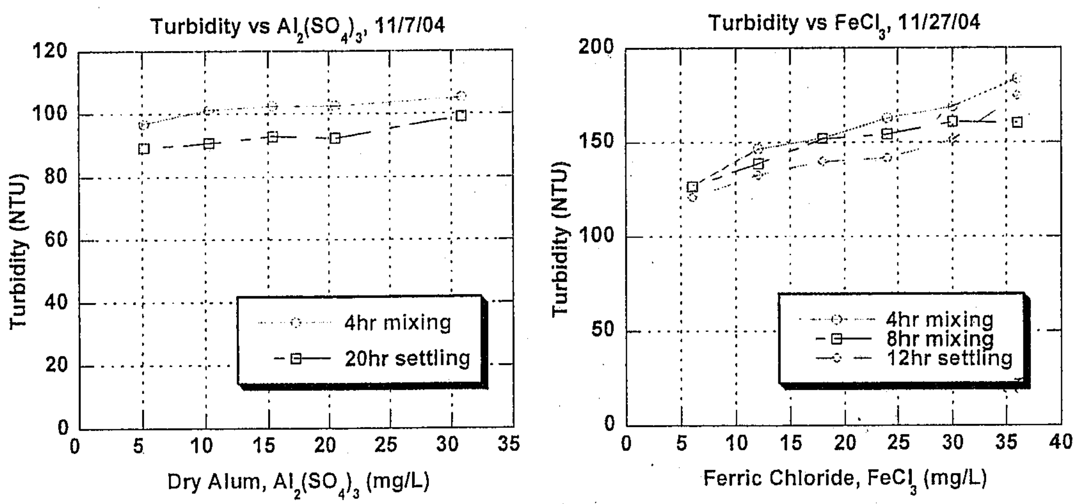
Particle ZP was measured with ZetaPlus (Brookhaven Instruments Corp., NY). Water samples were sometimes diluted with de-ionized (DI) water before measuring because they contained too high turbidity for measurement. Dilution with DI water was compared with samples diluted with filtered stormwater using a 0.1um filter and were not significantly different, which shows that pre-dilution with DI water does not significantly alter the measured ZP of the particles.

4. RESULTS

4.1 LOW DOSE FLOCCULATION

Fig. 2 shows the turbidity removals in the low dose coagulation tests for two different storm events using alum and ferric chloride. In these tests, alum or ferric chloride was added in varying amounts, up to 40 mg/L, which did not produce sweep floc. Fig. 2 shows that in low dosages, the coagulants are not able to produce settable particles, but instead form pin flocs, which increases turbidity. Settable particles were never produced even though extended periods of slow mixing were investigated. This conditioning might have been useful for granular media filtration, although it was not investigated.

Figure 2: Turbidity changes in the samples with (a) alum and (b) ferric chloride



4.2 SWEEP FLOC COAGULATION

Fig. 3 shows the results of turbidity removal using sweep floc coagulation with alum and ferric chloride, respectively. Different sample characteristics of each storm event resulted in a range of optimum doses from approximately 40 to 500 mg/l. Optimum dose was defined as the minimum coagulant concentration producing less than 5 NTU or less. The optimum dose was plotted as a function of specific conductivity in Fig. 4. This demonstrates that the optimum dose is proportional to the initial conductivity. This relationship is not due to changing electro-chemical properties with conductivity, but is due from the higher concentrations of dissolved and colloidal material, which consume more coagulants for destabilization. We have found (Han, et al., 2004) that initial turbidity is related to the dilution of the stormwater, with more heavily contaminated stormwater having higher initial conductivity. Other parameters, such as TSS might be better indicators of coagulant dose, but conductivity can easily be measured in real-time allowing it to be used for control. This result suggests that an automatic controller could provide the optimum dose using initial conductivity.

Figure 3: *Turbidity removal from sweep floc coagulation for (a) alum and (b) ferric chloride*

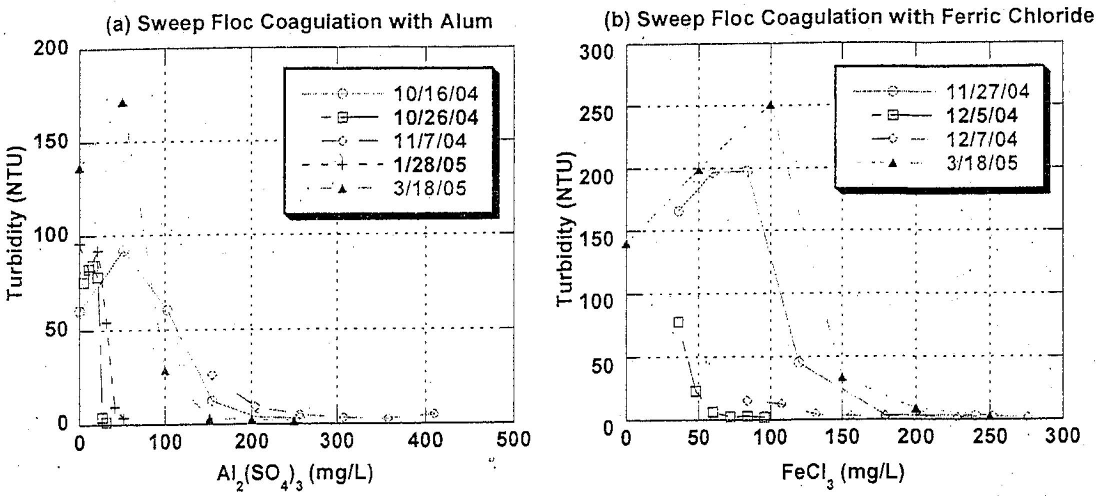


Figure 4: *Optimum coagulant dose and initial sample conductivity*

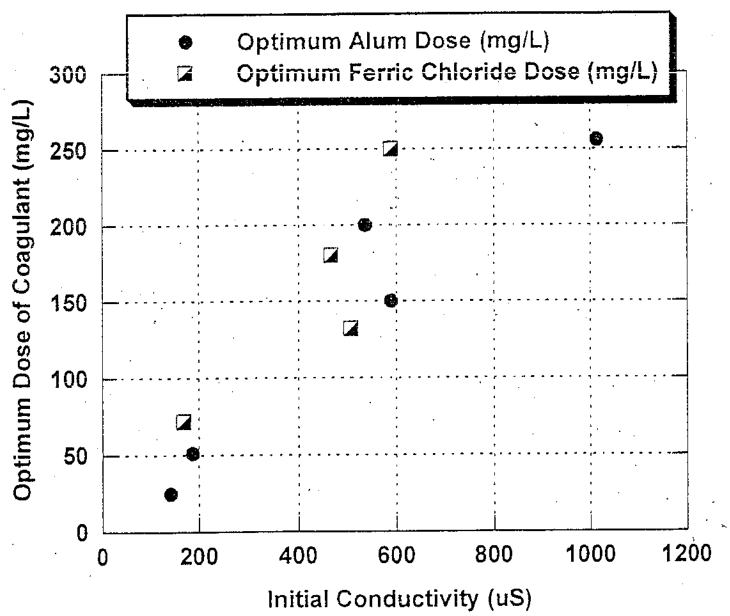
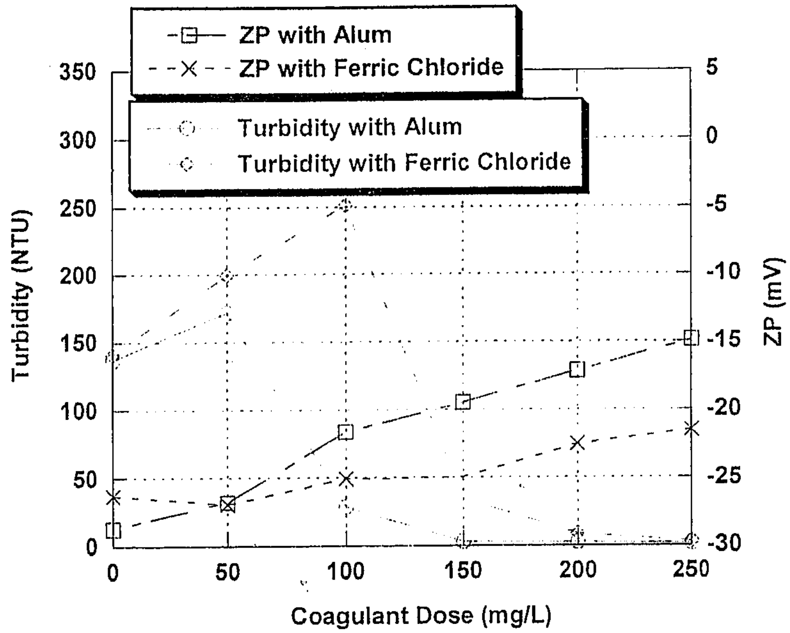


Fig. 5 shows the turbidity and ZP changes as a function of alum and ferric chloride dose. Alum was slightly more effective than ferric chloride in terms of turbidity removal and ZP reduction (all experiments were performed at pH 7). Higher efficiency of alum over ferric chloride may result from its wider optimum pH range. For both alum and ferric chloride, the isoelectrical point of ZP could not be obtained and sweep floc was routinely observed at -20 to -10 mV ZP.

One test was performed to evaluate the impact of ionic strength on coagulation efficiency. Sodium chloride (NaCl) was added over a range of 10,000 to 50,000 mg/L in a series of jar tests. No significant drop in turbidity was observed in this range of salt concentration. However, the addition of NaCl at 30,000 mg/l to alum or ferric chloride reduced the required coagulant dose to approximately 25% of the dose required without salt.

Figure 5: *Turbidity and ZP changes after adding same serious of amounts for alum and ferric chloride*



4.3 FLOCCULATION WITH CATIONIC POLYMER

Fig. 6 shows the ZP changes as a function of polymer dose for two different molecular weight polyDADMACs. Both polymers were equally effective in reducing the ZP. Fig. 7 shows the isoelectric point as a function of initial conductivity, which is similar to the previous results showing optimum alum or ferric chloride dose related to initial conductivity. Fig. 8 shows the effect of mixing time on the turbidity removal with and without polymer. As can be seen, at least six hours were needed to acquire turbidity with less than 5 NTU after particles were destabilized. An extended mixing period might be required for particle aggregation and sedimentation even though the isoelectrical point is reached by adding polymers.

Figure 6: *ZP changes in the sample after adding two different molecular weight polyDADMACs*

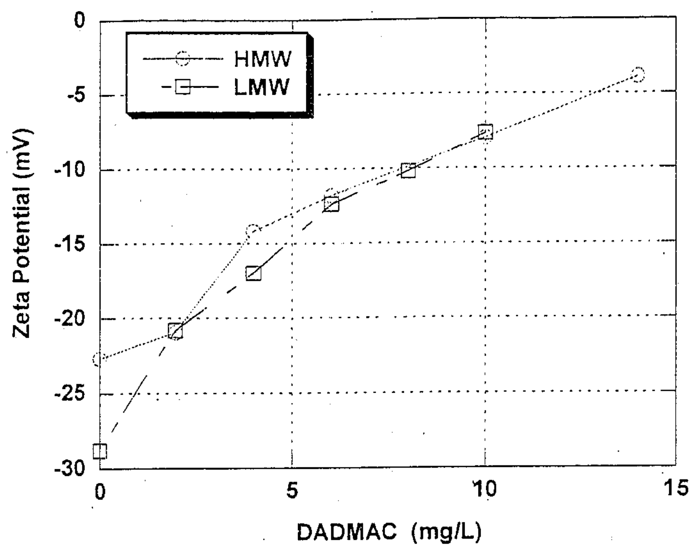


Figure 7: *Optimum polymer dose and initial sample conductivity*

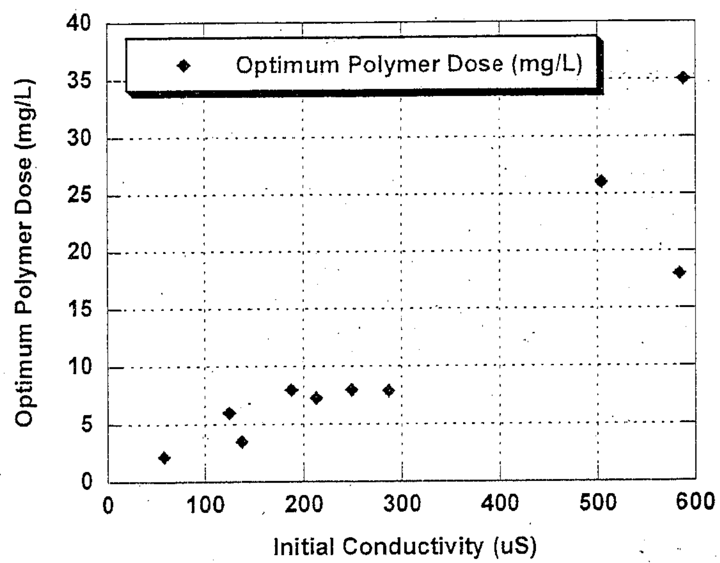


Figure 8: *Effect of mixing time on the turbidity removal with and without polymer*

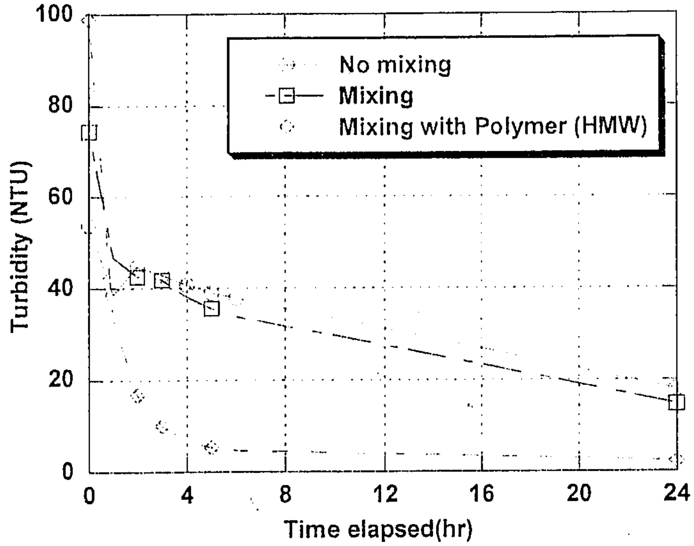


Fig. 9 shows the effect of alum addition on the mixing time in the flocculation using the polymer on 1/28/05. Turbidity removals are displayed with slow mixing and after settling for different alum doses from 2.6 to 15.4 mg/L with 8 mg/L polymer dose, which was the optimum dose for this storm event. As more alum was added, shorter mixing time was required to obtain the reduced turbidity in the supernatant. As a result, mixing time required for the flocculation by polymer might be reduced due to other coagulants, such as alum or ferric chloride.

Figure 9: *Effect of alum addition on the mixing time using polymer coagulation on 1/28/05 (polymer concentration was fixed at 8 mg/L)*

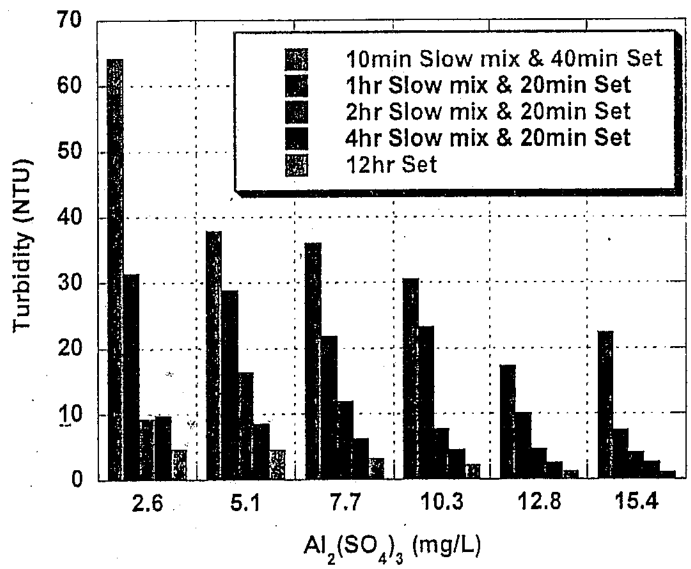
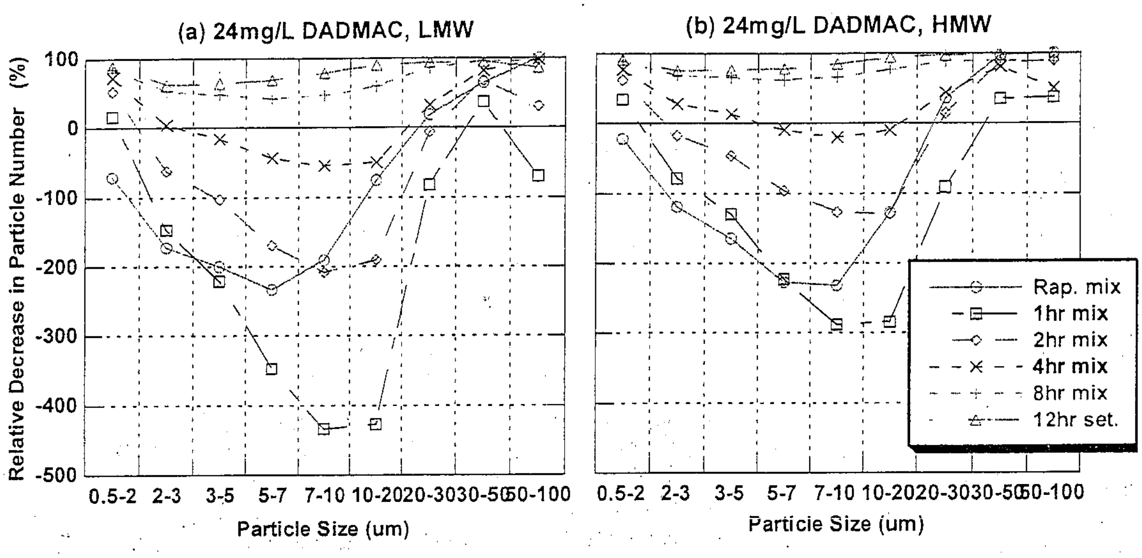


Fig. 10 shows that particle sizes were dramatically increased after coagulation. The vertical axis shows the relative decrease in the number of particles in a given size range shown on the horizontal axis. Relative decrease is calculated relative to the initial particle concentrations. The various lines show a time series from just after rapid mixing to 8 hours and the final line shows the particle concentration after sedimentation. The graph shows that the relative number of smaller particles in the 2-3 um to 20-30 um ranges increases rapidly after dosage and initial mixing. This is direct evidence for particle arrogation. After settling, the numbers of particles is much lower in all size ranges. The 12-hr settling line can also be thought of as removal efficiency. The low, medium (not shown), and high molecular weight polymers produced similar results.

Figure 10: PSD changes with different molecular weight polymers



4. DISCUSSION

Coagulation can greatly increase particle sizes in stormwater runoff, which will make sedimentation BMPs much more efficient, especially for small particle removal. Li, et al. (2005) proposed a two-compartment sedimentation tank with a first compartment to hold the initial runoff volume (first flush) for an extended period of time and a second compartment to treat the rest as a continuous flow clarifier. By holding the first flush and treating the remaining volume in a continuous flow clarifier, the two-compartment settling tank removed both small and large particles in stormwater runoff. This concept can be extended using coagulation and flocculation.

Unattended polymer addition (automatic) to the first compartment can be easily achieved by using the initial conductivity of the runoff and the fixed compartment volume. The greatly improved efficiency using coagulation can increase removals to more than 90%. Unattended polymer addition to the continuous flow compartment need further investigation due to the dynamic runoff retention time. Further studies on particle change with different mixing periods with polymer addition are on-going in our laboratory.

Jar testing using metal salts was ineffective in removing particles at low concentrations and required high dosages well into the sweep floc regime for efficient particle removal. The need for sweep floc increases costs due to coagulant cost and excess sludge production. In addition, the acidic nature of both metal salts will require neutralization, as well as further increase costs. A cationic polymer was effective in coagulating the stormwater runoff at low dosages and did not modify the pH. Additional mixing was necessary to effect efficient particle aggregation. The addition of small amounts of alum (2 to 15 mg/L) reduced the mixing time and suggests that a regime using polymer, followed by alum, is a good way to bestialize particles in highway runoff.

BMPs in the field need unattended operation, as well as robustness because pollutant concentration in the highway runoff always changes as a function of rainfall characteristics, antecedent dry days, average daily traffic, and other factors. Therefore, runoff concentration is different for each storm event and BMP must be able to cope with a range of influent concentrations and flow rate without special controls.

A combination of cationic polymer with small amounts of alum and sufficient mixing time should enable effective colloid removal without close monitoring of dosages.

6. SUMMARY

This paper has shown that highway runoff can be effectively coagulated with metal salts (alum and ferric chloride) and organic polymers. The following conclusions are made:

1. Alum or ferric chloride alone cannot effectively coagulate highway runoff at low concentrations (< 40 mg/l), suggesting that bridging and charge neutralization are not effective mechanisms for this application.

2. Alum and ferric chloride at high doses produced sweep floc that removed turbidity and suspended solids to low concentrations. Unfortunately, the sludge production and the need for pH control will probably limit this application. Alum appeared to be slightly more effective that ferric chloride.

3. Smaller dosages (< 10 mg/l) of an organic polymer in three different molecular weights were useful in obtaining the isoelectric point. Gentle mixing over extended periods (~ 8 hrs) was effective in producing low effluent turbidity.

4. The addition of alum after optimal polymer dosing reduced mixing time.

5. Optimal dosage of metal salts and polymer were proportional to the initial conductivity of the runoff.

Further research is necessary to validate this work at larger scale and over a range of conditions to provide a robust unattended operational mode.

ACKNOWLEDGEMENTS

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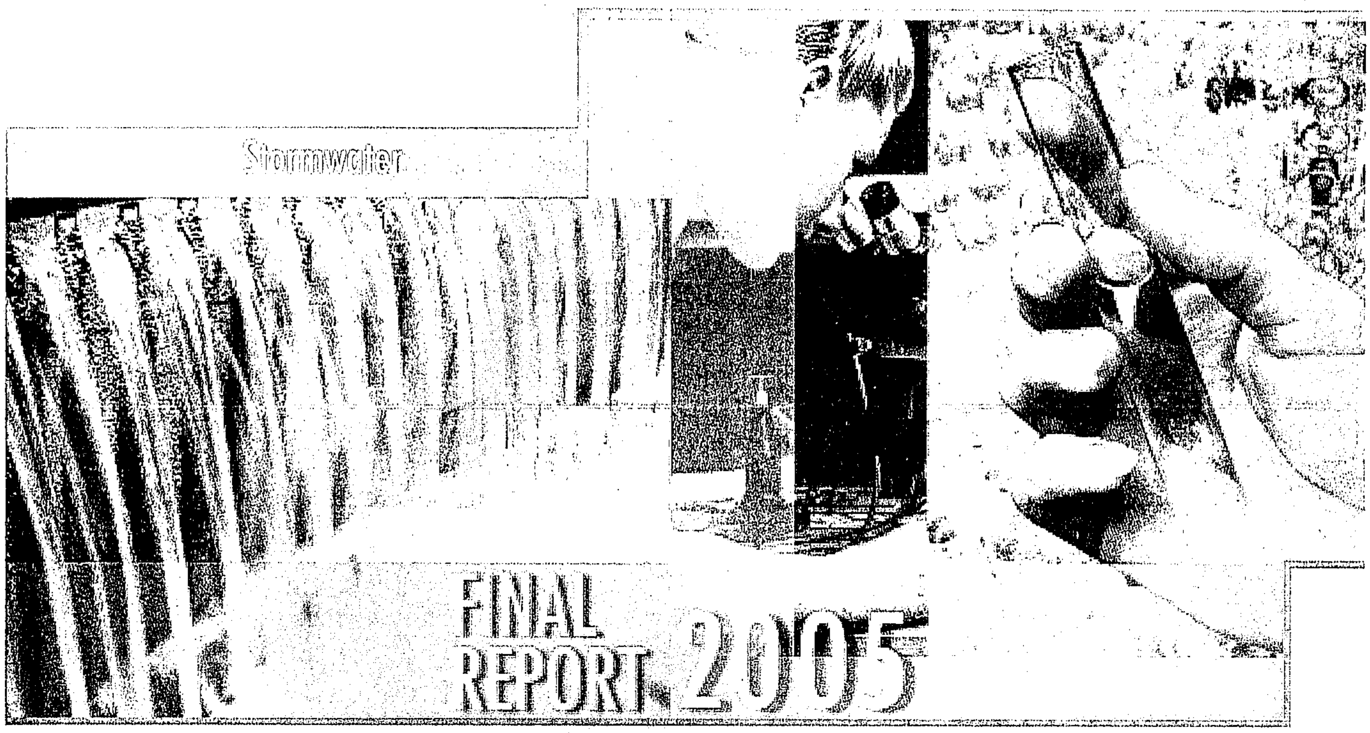

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Critical Assessment of Stormwater Treatment and Control Selection Issues

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ABSTRACT AND BENEFITS

Abstract:

Although historically the process of selecting stormwater treatment systems has centered on choosing categories of treatment systems from a menu of options, the state of the practice allows for a more fundamental approach that explicitly incorporates the concept of unit operations and processes (UOPs) in a manner analogous to the conceptual design process for wastewater treatment systems. The incorporation of one or more UOPs into specific design elements of a stormwater treatment system, or treatment system components (TSCs), places emphasis on the selection of systems that are intended, by design, to specifically address project goals and objectives. These TSCs include conventional stormwater treatment design elements (e.g., swales, ponds, tanks, etc.) that provide primary and secondary UOP mechanisms (e.g. settling, filtration, adsorption, preciptation, etc.), as well as pre-treatment devices (e.g., hydrodynamic devices, trash racks, catch basin screens, etc.), custom hydraulic controls (e.g., flow splitters, weirs, orifices, etc.), and tertiary enhancements (e.g., soil amendments, selected vegetative species and microorganisms, mixing and aeration devices, and disinfection systems). The purpose of this guidance document is to provide a framework, or conceptual design methodology, for applying fundamental principles of UOPs to aid in the evaluation and selection of runoff management and treatment control systems for urban and urbanizing areas. The steps of the conceptual design process presented herein include: 1) problem definition, 2) site characterization, 3) identification of fundamental process categories, 4) selection of treatment system components, 5) practicability assessment, 6) sizing and development of conceptual design, and 7) development of performance monitoring and evaluation plan.

Benefits:

- Presents detailed information useful for characterizing watersheds and stormwater runoff
- Demonstrates a unit operations and processes approach for evaluating and selecting stormwater treatment system components
- Provides conceptual design guidance and methods for evaluating the practicability of implementing stormwater treatment systems
- Supplies tools for evaluating the treatability of common stormwater constituents
- Demonstrates the applicability of site-based and regional hydrologic treatment system sizing methods

Keywords: unit operations and processes, urban runoff management, best management practices, treatment trains, enhanced stormwater treatment, advanced treatment processes, conceptual BMP design

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LIST OF ACRONYMS & ABREVIATIONS

API	American Petroleum Institute
ATP	Adenosine Triphosphate
BMP	Best Management Practice
BTEX	Benzene, Toluene, Ethylbenzene, and Xylene
C/F	Coagulation/Flocculation
CMA	Calcium-Magnesium Acetate
CPI	Consumer Price Index
CPS	Coalescing Plate Separator
CSO	Combined Sewer Overflow
DCIA	Directly Connected Impervious Area
DAF	Dissolved Air Flotation
ET	Evapotranspiration
FC	Field Capacity
FCV	Flood Control Volume
FPC	Fundamental Process Categories
IDF	Intensity Duration Frequency
I/I	Infiltration and Inflow
ISB	Initial Settling Basin
ISWoC	Impervious Surfaces Without Canopy
LID	Low Impact Development
LCC	Life Cycle Cost
MCTT	Multiple Chamber Treatment Train
MIT	Minimum Interevent Time
MOPM	Manganese Oxide Polymeric Media
MTBE	Methyl Tertiary-Butyl Ether
NURP	Nationwide Urban Runoff Program
O&M	Operations and Maintenance
PAHs	Polycyclic Aromatic Hydrocarbons
PSD	Particle Size Distribution
PZC	Point of Zero Charge
SBMC	Sorptive Buoyant Media Clarifier
SOR	Surface Overflow Rate
SVOCs	Semi-Volatile Organic Carbons
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TSC	Treatment System Component
TSS	Total Suspended Solids
TVC	Total Volume Concentration
UA	Urbanizing Area
UOP	Unit Operation and Process
VOCs	Volatile Organic Carbons
WP	Wilting Point
WQCV	Water Quality Control Volume
WWC	Wet-Weather Control

EXECUTIVE SUMMARY

ES.1 Introduction

Experience over the last decade has demonstrated that there continues to be significant gaps in knowledge between stormwater treatment system design/analyses and unit operations and processes that can demonstrate treatment viability as a function of the physical and chemical characteristics of stormwater loadings. However, despite these knowledge gaps, the state of the practice has advanced to the point where guidance is needed to assist practitioners in the assimilation and application of available basic laboratory and pilot scale research, theoretical modeling, and various levels of field study to the selection of stormwater treatment systems. The use of fundamental design methodologies that encourage sound application of the best science available is essential as the field of stormwater management continues to develop and existing knowledge gaps are bridged.

ES.2 Summary of Work

This project involves an examination of critical factors that influence selection, sizing, and design of stormwater treatment controls, or best management practices (BMPs), for specific locations and conditions. Work included a thorough review of literature and a synthesis of current research on fundamental principles of unit operations and processes (UOPs) applicable to stormwater treatment. This report offers assistance to stormwater managers in selection and prioritization of controls as a function of mitigation goals, site-specific needs, and regional and local characteristics. It does not attempt to be a stand-alone design manual; rather it is intended to provide a thorough background of the theory and state-of-the-practice of stormwater management supported by methods, equations, and references useful for making sound stormwater management decisions. Furthermore, while this document endorses a variety of approaches to stormwater management and design, there may be other equally effective methods that could be used. As such, the lack of recognition of those methods should not be construed as fundamental rejection of alternative methods that can be demonstrated to be well founded.

ES.3 Conceptual Design Methodology

The conceptual design methodology presented in this report is driven by well-defined stormwater management goals and a solid understanding of site characteristics, constraints, and water quality conditions. As opposed to other design approaches that recommend the selection of typical BMPs based solely on documented performance factors, such as percent removal, effluent quality and/or percent capture, the approach presented herein is to first select the UOPs that address the pollutants of concern and stormwater management goals, and then individually select the components of a treatment system based on those UOPs. The steps of the conceptual design process includes: 1) problem definition, 2) site characterization, 3) identification of fundamental process categories, 4) selection of treatment system components, 5) practicability assessment, 6) sizing and development of conceptual design, and 7) development of performance monitoring and evaluation plan.

ES.4 Selection of Unit Operations and Processes

Many unit operations and processes (UOPs) applicable to stormwater treatment have been previously developed in the fields of water and wastewater engineering. UOPs can be divided according to four fundamental process categories: 1) hydrologic operations, 2) physical operations, 3) biological processes, and 4) chemical processes. Hydrologic operations, which are essentially a subset of physical operations, include the principles of flow attenuation (e.g., peak shaving; detention) and volume reduction (e.g., infiltration; evapotranspiration). Physical operations, as referred to in this report, include the principles of particle size alteration (e.g. comminution), size separation and exclusion (e.g., screening; filtration), density separation (e.g., sedimentation; flotation), aeration and volatilization, and physical agent disinfection (e.g., ultra-violet light; heat). Biological processes include the principles of microbially-mediated transformations (e.g., redox reactions resulting from microbial respiration) and uptake and storage (e.g., bioaccumulation). Chemical processes include the principles of sorption (e.g., ion exchange, surface complexation), coagulation and flocculation (e.g., particle agglomeration; precipitation), and chemical agent disinfection (e.g., chlorine; ozone). The selection of any one of these UOPs should be based on the characteristics of the target pollutants in relation to specific stormwater management goals.

ES.5 Conceptualizing the Treatment System

Treatment system components (TSCs) are the fundamental elements of a stormwater treatment system. Each TSC provides one or more UOP mechanism. For instance, a dry detention basin is a TSC that provides both sedimentation and detention. Therefore, not until all applicable UOPs have been identified should individual TSCs be selected. TSCs include conventional design elements, such as swales, ponds, tanks, etc., but also pre-treatment devices (e.g., hydrodynamic devices, trash racks, catch basin screens, etc.), custom hydraulic controls (e.g., flow splitters, weirs, orifices, etc.), and tertiary enhancements (e.g., soil amendments, engineered media, selected vegetation, etc.). Many TSCs include multiple unit processes at varying levels of effectiveness. Therefore, the placement of these components in relation to one another in a treatment system must be carefully considered.

After complimentary and/or compatible TSCs are conceptualized into a candidate treatment system, the practicability of implementing the complete system should be evaluated. Practicability refers to both feasibility and treatability including an estimation of treatment performance and cost considerations. Also, every candidate treatment system will have various design constraints, operations and maintenance requirements, and safety and aesthetic issues that must be considered before the system is hydrologically sized and economically optimized.

ES.6 Sizing the Conceptual Design

The design of a selected stormwater treatment system must address the project goals and objectives as well as the design requirements of the regulating authority. Several methods for hydrologic design exist including: flow attenuation design, volume reduction design, and flow-duration design. Flow attenuation, also referred to as "peak shaving", is typically achieved with storage and controlled release, but increasing the flow path may also be feasible. Volume reduction is possible through infiltration and evapotranspiration, both of which are highly dependent on site-specific conditions including soils, vegetation, and climate. Flow-duration seeks to reduce both magnitude and the time period of flow by incorporating the principles from both flow attenuation and volume reduction. The applicability of any of these design methods depends on whether the system is "volume-based", such as detention basins, or "flow-based", such as sand filters and swales. These facilities can be sized using a hierarchy of procedures including simple design storm approaches, rainfall frequency analyses, and continuous runoff simulation.

Continuous simulations can be performed using a number of models such as SWMM, HEC-HMS, HSPF, or even spreadsheet models. Continuous modeling permits optimization for design on the basis of minimum cost, minimum downstream discharge, minimum downstream pollutant load, and a variety of other possibilities. This may be done heuristically with models such as SWMM or in a more integrated fashion with the spreadsheet models. Continuous simulations can be performed to develop general sizing and design criteria on a sub-regional basis and the results used for simpler design requirements, which could then employ event models. Depending upon the objective, it may not be necessary to simulate water quality as well as water quantity, since water quality simulation is much more difficult and uncertain. However, if water quality is not included, then the results for storage effectiveness are less accurate since the tradeoff between maximizing volume captured and maximizing load captured is not explicitly included.

The concepts of flexible design and adaptive control and management are important and effective components of implementation and should not be overlooked. Flexible design is defined here as having unit processes that can be readily adjusted or modified following construction or installation to achieve variations in system function and performance. Adaptive management is a means for managing these flexible design elements to allow for changes in implementation to be made based on information obtained from monitoring the effectiveness and performance of a treatment system.

ES.7 Developing the Monitoring Program

Stormwater treatment system monitoring projects are initiated to address a broad range of programmatic, management, regulatory, and research goals. Monitoring goals are often focused on the achievement of water quality objectives (including hydrology/hydraulics and water quality) downstream of the facility. Multiple methods, all with different cost and time structures, can be used for sampling including manual and automated methods for collecting grab samples as well as time-weighted and flow-weighted composite samples. Depending on the specific treatment system and the goals of the monitoring program, several samples may need to be collected at multiple locations during multiple storm events to obtain data useful for determining the actual performance.

ES.8 Conclusions and Recommendations

To meet increasingly more stringent water quality management goals and objectives, stormwater treatment techniques are becoming progressively more complex and uncertain. Significant data gaps exist for the more advanced treatment mechanisms, such as adsorption, ion exchange, precipitation, biological uptake, and microbial transformations. The study of these processes while accounting for the stochastic nature of stormwater runoff and chemistry requires carefully designed and implemented research programs. Pilot studies are needed to start bridging the knowledge gap between pollutant fate and transport theory and field observations of treatment system performance, so that some day the level of efficiency and sophistication of stormwater control and treatment methods will match or exceed those of the water and wastewater industry.

CHAPTER 1.0

INTRODUCTION

1.1 Evolution of Stormwater Management

In the early days of stormwater management and indeed at the earliest stages in the establishment of civilizations, ditches were constructed to quickly and efficiently convey runoff into the nearest stream, lake, or ocean to protect dwellings and crops from flooding and erosion. With urbanization, all surface conveyances were adapted to not only convey stormwater runoff, but to eliminate human-generated wastewater. In developed cities, the offensive sight and smell of these formal and often informal urban cesspool ditches frequently became unbearable and were recognized as a primary source of human illness. Communities eventually realized that these urban sewers should be primarily designed as underground piped systems. Both separate and combined sewer systems were born, and the wastewater problem was temporarily out of sight, out of mind. Of course the design and construction of piped sewer systems merely shifted impacts downstream. As a consequence, in many locations, it did not take long for downstream water supplies to become contaminated and resources to be adversely impacted. Public health and welfare came to the forefront of wastewater management, initiating the need for treatment of collected wastewater flows and with this need emerged the field of wastewater engineering.

Over the past century, wastewater engineers have made significant gains in their ability to process, treat, and discharge wastewater, and to predict urban wastewater quality, quantity, and pollutant removal efficiencies. Initially, wastewater treatment plants relied primarily on physical treatment operations that targeted the removal of solids and floating matter. As the knowledge and understanding of the biological and chemical characteristics of water improved, so did the treatment technologies. The "treatment train" approach to water treatment was soon developed, and the number of treatable pollutants grew significantly. Dissolved constituents and pathogenic organisms were quickly added to the list of targeted pollutants, and the quality of receiving waters began to improve rapidly. However, water quality problems were far from over.

As urbanization grew, the hydrology of impacted areas changed significantly, resulting in increases in runoff volume and flow rates, major changes to the timing of flows, and the introduction and transport of a host of pollutants from the built environment. Where combined systems were in place, existing wastewater treatment plants had to be expanded and new ones constructed to keep pace with the ever expanding need for control of both sanitary and non-sanitary treatment. Where expansions of wastewater treatment plants did not keep pace with development, discharges of combined sewage resulted. These combined sewer overflows (CSOs) often undermined the objectives of wastewater treatment, and from a water quality and economic perspective, it no longer made sense to treat relatively clean stormwater in wastewater treatment plants. In a process that continues into the present, separate sewers were constructed in an effort to separate stormwater from the sanitary sewer system. Locations that either by design or by accident constructed separate sewer systems at early stages in development were able to avoid costly retrofit of combined systems. As the more pressing needs for the design of wastewater treatment systems were decoupled from the problems of receiving water and resource impairment resulting from urban stormwater, the fields of wastewater engineering and stormwater engineering diverged.

As was originally the case during the early days of stormwater management, design goals of stormwater engineering were focused primarily on erosion (e.g., protection of the built environment) and flood control (Durian et al., 1999). As the wastewater problems affecting receiving waters were addressed, a much more difficult problem emerged, as it was clear that improvement of receiving water quality required not only addressing point sources of pollution, but also nonpoint sources (NPS). The inherent complexities in addressing nonpoint sources have been explored over the past four decades; the need for scientifically sound engineering approaches to designing stormwater treatment systems has become of major importance for the engineering community and is the primary focus of stormwater engineering research today.

1.2 Background and Purpose of this Guidance Manual

The Clean Water Act was revised in 1987 in an attempt to address NPS pollution via the National Pollutant Discharge Elimination System (NPDES). As a result, cities, counties, and municipalities were required to meet discharge requirements for runoff originating within their jurisdictions. Best management practice (BMP) became probably the three most common words in the stormwater management vocabulary and were used to describe everything from street sweeping to constructed wetlands, regardless of whether a particular management measure was the "best" management practice for the site conditions and constraints. Many organizations developed their own stormwater BMP design manuals, and currently there are a large number in existence. While many of these manuals are quite good and provide helpful recommendations on choosing and sizing structural stormwater BMPs, a number of them lack a conceptual framework for addressing specific stormwater quality and quantity issues occurring at a particular site. The general approach in most manuals that are currently available is to choose a BMP that has been shown to address the pollutants of concern and then apply "rules-of-thumb" sizing and design methods. While this is often an appropriate and valid approach, it does not adequately build upon more than a century of accumulated experience in the fields of environmental process and wastewater engineering (e.g., Metcalf and Eddy, 2003) and indeed the full suite of technical skills and experience available to the professional civil and environmental engineer. Use of treatment trains and integration of fundamental unit operations and processes are some of the most basic and profound concepts of environmental engineering. Unfortunately these concepts have only recently been advocated as a design approach for stormwater treatment. As stormwater regulations continue to become more stringent, the need for more advanced treatment technologies will grow. However, in order to meet this need, the collective knowledge and understanding of stormwater treatment must be reduced to a more fundamental level, which may require stormwater engineers to step away, at least temporarily, from the "cook book" BMP design methodologies and be open to both new ideas, as well as the tried-and-true treatment technologies of the wastewater industry. Due to the complexity of the fundamental unit processes for treating many stormwater constituents, available information on field-verified treatability is currently limited. Thus, until the knowledge base of unit operations and processes for stormwater treatment is expanded, reliance on theoretical principles and laboratory analyses will be needed. Figure 1-1 provides an illustration of available stormwater treatability information as a function of complexity and scope.

The purpose of this guidance document is to provide a framework for applying fundamental principles of unit operations and processes (UOPs), such as are commonly applied in water and wastewater engineering, to aid in the evaluation and selection of runoff management and treatment control systems for urban and urbanizing areas. As opposed to other design approaches that recommend the selection of typical BMPs based solely on documented performance factors, such as percent removal, effluent quality and/or percent capture, the design approach presented in this manual is to first select the UOPs that address the pollutants of concern, and then to individually select treatment system components (TSCs) based on those UOPs.

This guidance document attempts to offer assistance to stormwater managers in cities and other public agencies, and the consultants who serve them on selection, sizing, and design of urban runoff controls as a function of mitigation goals, site-specific needs, and regional and local characteristics. This manual does not attempt to be a stand-alone design manual; rather it is intended to provide a thorough background on the theory and state-of-the-practice of stormwater management supported by methods, equations, and references useful for making sound stormwater management decisions.

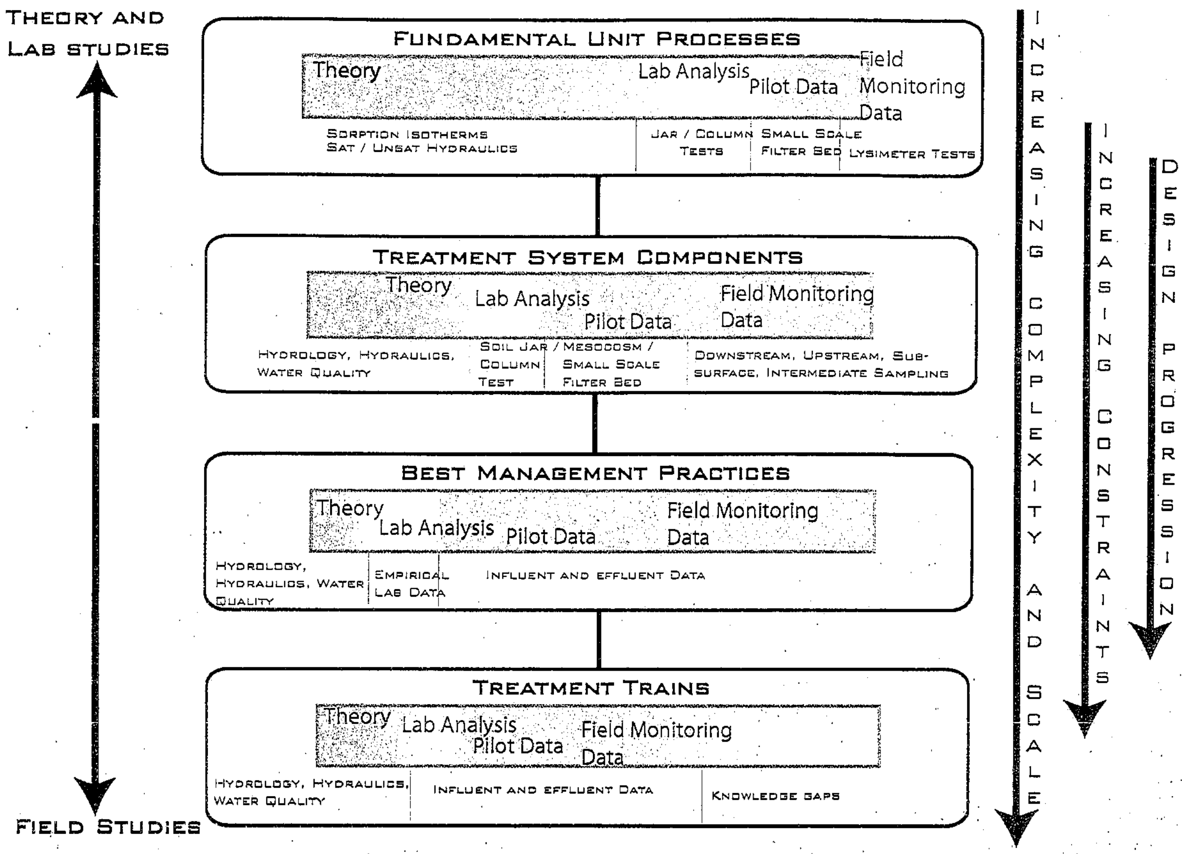


Figure 1-1. Summary of Available Stormwater Treatability Information as a Function of Complexity.

1.3 Document Organization and Design Methodology Flowchart

This document is organized according to the UOP-based treatment train design methodology recommended herein, and each chapter is a step in the decision making and conceptual design process. The flow chart illustrated in Figure 1-2 exemplifies this process. Appendix A provides pollutant-specific information on treatability and observed performance for typical target constituents in stormwater. Appendix B illustrates hypothetical examples of how the recommended design approach can be applied to real-world situations. Appendix C contains a worksheet for ranking urban runoff management objectives with respect to treatment system alternatives, as well as a matrix for evaluating various practicability factors associated with typical treatment system designs. Appendix D provides an explanation of the methodology used for generating hydrologic performs curves based on continuous rainfall-runoff simulations for 30 locations across the U.S. These curves, presented in Appendix E, can be used for preliminary screening and sizing of selected components of a stormwater treatment system.

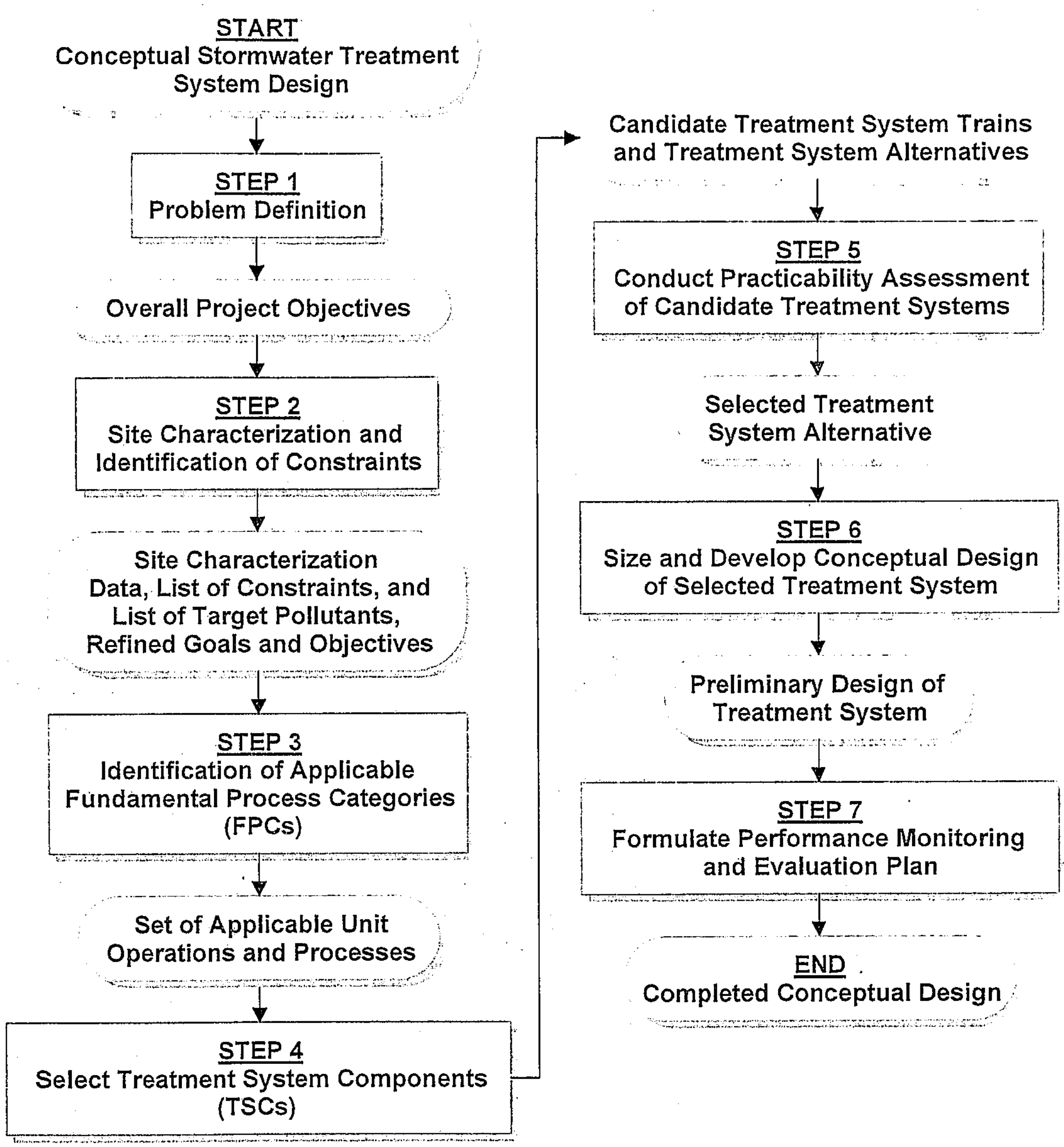
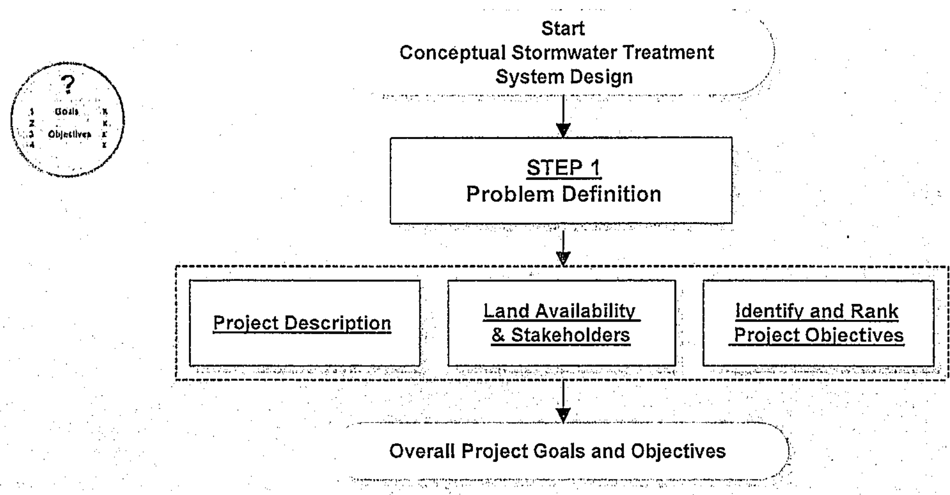


Figure 1-2. Conceptual Stormwater Treatment System Design Methodology Flow Chart.

CHAPTER 2.0

PROBLEM DEFINITION



Key Concepts:

- What is the overall project scope and what are the regulatory drivers of stormwater management?
- How do stormwater management objectives relate to or conflict with other project objectives?
- What site conditions should be evaluated to properly define the problem?

2.1 Introduction

The design of any engineering system requires a clear definition of the problem. Without clear descriptions of the stormwater and dry weather runoff issues that need to be addressed at a particular site, including the desired results, it is difficult (if not impossible) to evaluate the steps needed to select and design a practicable and cost-effective urban runoff treatment system.

2.2 Project Description

As part of the problem definition, the project should be described in detail. Sometimes a project may simply include the design of a runoff treatment system for an existing urban development (i.e., a work in isolation). For this situation, typically all of the goals and objectives of the project are directly related to runoff quality management. However, runoff quality management may only be one objective of a new development or redevelopment project, and runoff quality management goals may conflict with other project goals. For example, a detention system design to control runoff quality would typically detain inflow for longer periods of time than a stormwater quantity control project wherein the detention system is drained rapidly to store runoff from the next event. A clear project description will help identify where these potential conflicts may arise and facilitate coordination of the planning and design activities among the various project managers, subcontractors, and stakeholders.

Regardless of the type of project, some of the important details to include in the project description include:

- Primary project goals (including but not limited to the runoff quality management goal).
- Current and future property owners and/or managers.
- Project activities including the approximate extent and timing of grading and construction.
- Geographic location in terms of jurisdictional and watershed boundaries.

In addition to the general project details, there also likely exist project-specific details and challenges that should be accurately described. A clear project description early in the planning phase will help maintain the focus and direction, and possibly save significant time and resources during subsequent project development and implementation steps.

2.3 Land Availability and Stakeholders

On the basis of volume of runoff controlled, project construction and maintenance costs for subsurface structural controls generally outweigh costs for surface structural controls. However, in situations where land values are high, land availability is low, or there is a concern of public acceptance, subsurface controls may be more desirable. In urban areas the term "ultra-urban" is frequently used where imperviousness is greater than 50% and land values exceed $20 per square foot, or over $87,000 per acre (FHWA, 2000). Due to the ever increasing value of real estate, most development projects strive to maximize the percentage of developed areas for each site, which reduces the available land for stormwater treatment.

Other factors to consider include access, easements and public perceptions. Treatment systems require routine maintenance, hence access to treatment systems must be considered during the site selection process. If the facility is publicly owned, the issue of easements must be addressed during the site selection process to ensure free access to the facility for maintenance, monitoring or other purposes. In addition public input is needed in situations where treatment system site selection may affect property values or the safety and security of people living in adjacent lots.

Identifying stakeholders at the beginning of a project can facilitate permitting and prevent unnecessary delays in project implementation. The space available for construction is usually provided by one or more of the stakeholders. Therefore, the identification of all the stakeholders early in a project is imperative. In some cases, stakeholders may oppose the treatment system for any number of reasons, and the cost of land or the unavailability of space for certain types of facilities could become a limiting factor for implementation. Hence both constraints must be identified and managed early in the selection and design process for a project to succeed.

2.4 Identify and Rank Runoff Management Objectives

Wet and dry weather runoff management objectives for the project should be identified and prioritized before a treatment system is designed. Table 2-1 lists typical urban runoff management objectives.

It is often helpful (but not necessary) for the engineer to identify and rank applicable project objectives. The ranked objectives can be used to help select from a list of candidate treatment systems (as described in Chapter 5.0) with the greatest potential for meeting project goals. A worksheet is provided in Appendix C for ranking project objectives. Several other approaches can be used to rank the project objectives.

Table 2-1. Urban Runoff Management Objectives Checklist.

Category	Typical Objectives of Urban Runoff Management Projects
Hydraulics	Manage flow characteristics upstream, within, and/or downstream of treatment system components
Hydrology	Mitigate floods; improve runoff characteristics (peak shaving)
Water Quality	Reduce downstream pollutant loads and concentrations of pollutants
	Improve/minimize downstream temperature impact
	Achieve desired pollutant concentration in outflow
	Remove litter and debris
Toxicity	Reduce acute toxicity of runoff
	Reduce chronic toxicity of runoff
Regulatory	Comply with NPDES permit
	Meet local, state, or federal water quality criteria
Implementation	Function within management and oversight structure
Cost	Minimize capital, operation, and maintenance (life-cycle) costs
Aesthetic	Improve appearance of site and avoid odor or nuisance
Maintenance	Operate within maintenance and repair schedule and requirements
	Design system to allow for retrofit, modification, or expansion
Longevity	Achieve long-term functionality
Resources	Improve downstream aquatic environment/erosion control
	Improve wildlife habitat
	Achieve multiple use functionality
Safety, Risk and Liability	Function without significant risk or liability
	Function with minimal environmental risk downstream
	Contain spills
Public Perception	Clarify public understanding of runoff quality, quantity and impacts on receiving waters

** Objectives adapted from ASCE/EPA, 2002.*

Frequently regulatory drivers receive top priority when establishing project objectives. Consequently, receiving water quality criteria, discharge permits, and all applicable federal, state, and local regulations should be identified early to clearly define the design problem consistent with current or future regulatory objectives. There may be several different regulations that must be met for any given project. Stormwater regulations often dictate hydrologic, hydraulic, water quality, or even design goals. The primary regulations that affect runoff management goals are summarized in the following section.

2.4.1 Hydrologic and Hydraulic Objectives

Many state and local jurisdictions have specific hydrologic and hydraulic objectives and requirements that may have a significant effect on the size, and potentially even the selection, of stormwater treatment and control facilities. These requirements may be volumetric, flow rate-based, or a combination. Examples of volumetric requirements include treating the first 0.5 inches of runoff; capturing the six-month, 24-hour storm; or capturing 85% of the runoff volume from an average year. Examples of flow rate-based requirements may include matching the two-year and 10-year, 24-hour pre-development peak discharge; treating twice the 85th percentile hourly rainfall intensity; or capturing the runoff produced from a 0.2-inch per hour rainfall intensity. Although event-based design storm methods are not recommended, these requirements are mentioned because that they are common throughout the U.S., and may have a significant influence on the selection, sizing, and design of stormwater treatment controls.

2.4.2 Receiving Water Quality / Regulations

In establishing project objectives, available literature and data on the watershed, particularly near the site, should be reviewed to identify the existing quality of the receiving water bodies, any sensitive or endangered habitats or species, and any watershed or water body-specific regulations or water quality objectives. Some of the laws and regulations directly relevant to establishing project objectives include:

- The National Environmental Policy Act (NEPA) and the Clean Water Act (CWA) of 1972, as amended. These acts hold federal decision makers accountable for activities having the potential to impact features of the natural environment—in particular, water quality. The U.S. Environmental Protection Agency (U.S. EPA) regulates water quality under the Clean Water Act (CWA). The CWA requires that the discharge of pollutants to waters of the U.S. from any point source be effectively prohibited, unless the discharge is in compliance with a National Pollutant Discharge Elimination System (NPDES) permit (discussed below). Chapter 303(d) of the CWA requires identification and listing of water-quality limited or "impaired" water bodies where water quality standards and/or receiving water beneficial uses are not met. Once a water body is listed as "impaired," total maximum daily loads (TMDLs) must be established for the pollutants or flows causing the impairment (33 U.S.C. §1313(d)(c)).
- The National Pollutant Discharge Elimination System (NPDES). This program requires discharge permits for industrial and municipal effluents containing pollutants, including discharges from municipal separate storm sewer systems (MS4s). An NPDES permit requires dischargers to comply with technology-based pollution limitations (generally according to the "best available technology economically achievable" and "best conventional control technology" or "BAT/BCT" standard for industrial discharges and "maximum extent practicable" or "MEP" standard for municipal discharges). 33 U.S.C. § 1311(b)(2)(A).
  The NPDES permit program for MS4s is being implemented in two phases. Phase I (55 FR 47990; November 16, 1990) applies to medium and large MS4s (those serving areas with populations greater than 100,000) and Phase II (64 FR 68722; December 8, 1999) applies to regulated small MS4s (those located in "urbanized areas" (UAs) as defined by the Bureau of the Census and those located outside of a UA that are designated by NPDES permitting authorities) (http://cfpub.epa.gov/npdes/stormwater/munic.cfm).
- The Nonpoint Source (NPS) Management Programs, Title 3, Clean Water Act Chapter 319. Chapter 319 was added to the CWA in 1987 to establish a national program to address nonpoint sources of water pollution, the leading cause of water quality degradation in the U.S. Chapter 319 authorizes the EPA to award grants to states with

approved Nonpoint Source Assessment Reports and Nonpoint Source Management Programs. The funds are to be used to implement programs and projects designed to reduce nonpoint source pollution. This program also promotes the implementation of best management practices, as a potential nonpoint pollutant source of surface and ground water.

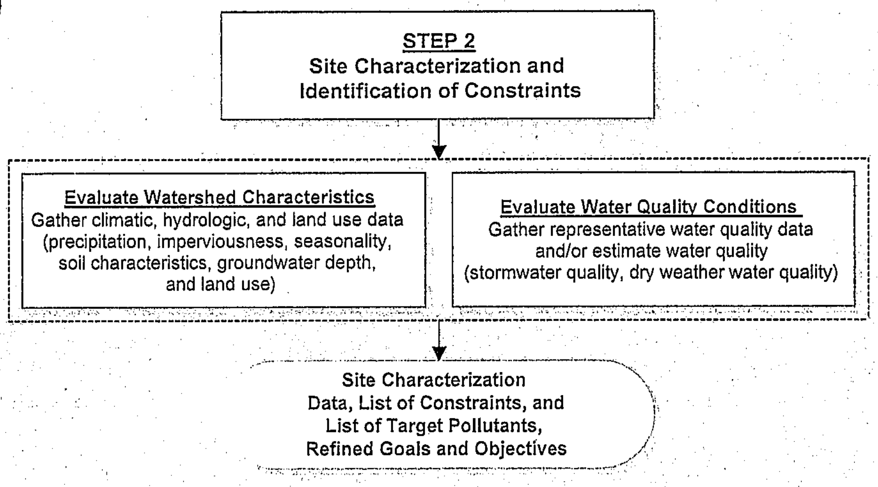
- Federal Antidegradation Policy (40 CFR §131.12). Requires states to develop statewide antidegradation policies and identify methods for implementing them. Pursuant to the CFR, state antidegradation policies and implementation methods shall, at a minimum, protect and maintain: 1) existing in-stream water uses; 2) existing water quality where the quality of the waters exceeds levels necessary to support existing beneficial uses, unless the State finds that allowing lower water quality is necessary to accommodate economic and social development in the area; and 3) water quality in waters considered an outstanding national resource.
- The Coastal Zone Act Reauthorization Amendments (CZARA). Congress amended the Coastal Zone Management Act in 1990 (CZARA) in an effort to develop a more comprehensive solution to the problem of polluted runoff in coastal areas. Chapter 6217 of CZARA requires that states with approved coastal zone management programs develop nonpoint source programs, and that programs developed under section 319 of the CWA be combined with existing coastal management programs. Many management measures required under Chapter 6217 overlap with NPDES stormwater regulations; activities covered under NPDES permits are not required to be addressed by state coastal nonpoint source control programs.
- Other legislation. Other legislation such as The Safe Drinking Water Act, the Endangered Species Act, the Resource Conservation and Recovery Act, and The National Wild and Scenic Rivers Act, and various state and local government laws may contain provisions that pertain to water quality.

After applicable water quality regulations have been identified, watershed-specific regulatory information should be obtained. Valuable watershed information can be obtained from the following sources:

- U.S. EPA Water Quality Standards (http://www.epa.gov/waterscience/standards/)
- Surf Your Watershed (http://www.epa.gov/surf/)
- Science in Your Watershed (http://water.usgs.gov/wsc/)
- Know Your Watershed (http://www.ctic.purdue.edu/KYW/KYW.html)
- State 303(d) and TMDL Websites

CHAPTER 3.0

CHARACTERIZE SITE CONDITIONS AND CONSTRAINTS



Key Concepts:
- What watershed characteristics should be evaluated during the data collection stage
- What site characteristics should be evaluated to identify site constraints?
- What water quality data should be collected for subsequent stages of the project?

3.1 Introduction

After a project has been described and the objectives identified, the next step in any development, redevelopment, or retrofit project is to characterize site conditions and constraints. This step is critical for the assessment and identification of appropriate solutions to the runoff management problem. Site conditions significantly influence runoff treatability and hydraulic and hydrologic control. Through careful characterization of the hydrologic, geologic, and anthropogenic factors that affect urban runoff quantity and quality, the applicable Fundamental Process Categories (FPCs) available for runoff management practices that meet the identified project objectives can be identified.

3.2 Watershed Characteristics

At the outset of an urban runoff management project, watershed characteristics, both upstream and downstream of the project, should be thoroughly evaluated by reviewing available documentation, and collecting and analyzing data. Some of the most important watershed-specific characteristics that should be considered include local and regional rainfall patterns, surface and subsurface hydrology, land use and land cover, geology, and climate and seasonality.

3.2.1 Precipitation

From a stormwater treatment and control perspective, probably the most fundamental and important characteristic of a watershed is expected precipitation, including the frequency, duration, intensity, and depth of rainfall. While precipitation is largely a function of other characteristics, such as climate, geography, and so forth, which are discussed later in this chapter, the focus of this section is on the acquisition and analysis of rainfall and snowfall monitoring data. This manual does not attempt to provide thorough guidance on precipitation monitoring, as many excellent sources are available on that subject and are incorporated herein by reference. This section provides a discussion of the characteristics and importance of high quality rainfall data and how the data can be analyzed to aid in the selection, sizing, and design of urban runoff controls.

3.2.1.1 Sources of Data

Precipitation data may be characterized in several ways, starting with the time series of data themselves. Precipitation as rainfall or as water equivalents where snow has fallen is routinely measured at thousands of locations across the U.S. The National Weather Service (NWS) records daily weather data (either directly or more likely, through cooperators) at 26,428 sites, hourly precipitation data at 6,892 of those sites, and 15-min precipitation at a smaller subset of these sites. The central federal repository for weather data collected in this country is the National Climatic Data Center (NCDC), operated by the National Oceanic and Atmospheric Administration (NOAA) in Asheville, NC. All weather data recorded at the thousands of sites just mentioned are eventually transferred to the NCDC, with a lag time of a few to several months. The data are stored electronically, and most data (e.g., daily, monthly) may be downloaded off the Internet at no charge (www.ncdc.noaa.gov/oa/ncdc.html). Hourly and 15-min. precipitation data sometimes require a fee, although NCDC policies do change.

There are many other sources of climatic data in general and precipitation data in particular. Private companies, such as Earth Info and HydroSphere (both in Boulder, Colorado), offer climatic (and hydrologic) data from the U.S. and Canada for sale on CD-ROMs. State climatological offices often provide good access to some data, although not typically to hourly or 15-min precipitation data. However, these state offices often process the data in real time, so daily records are available instantly or on the following day. The offices may be found on the Internet; for example, for Oregon at http://www.ocs.orst.edu/, which has links to other state and federal data sources. These offices may also be able to offer advice on quality control (e.g., the reliability of data from specific gages), which is not obtainable from the NCDC.

Still other sources of climatic and precipitation data include:

- local water utilities may have a rain gage at their treatment plant;
- local departments of public works and stormwater management agencies may operate rain gage networks for large cities (e.g., 23 gages for Portland, OR);
- other federal agencies and entities, such as the U.S. Geological Survey (USGS), Corps of Engineers, Bureau of Reclamation, U.S. Department of Agriculture (USDA) agencies, U.S. EPA, etcetera;

- state agencies, such as state environmental, agricultural, and natural resources agencies and departments;
- universities and research groups;
- television and radio stations; and
- private weather stations, some of which participate in Web-based displays (search for "personal weather stations").

Of course, data may also be collected directly by the stormwater management professional. This has the advantage of providing site-specific data in the catchment of interest (preferably with more than one gage) and has the disadvantage of not providing a long-term record. Still, site-specific data are essential for model calibration, whereas regional data from a NWS site (often a local airport) may often be used for continuous simulation and design. Several documents related to precipitation measurement are referenced by Smith (1993) as well as in most hydrology texts.

Radar-based precipitation estimates provide a useful adjunct to point measurements (surface measurements at one gage or "point"). "Next generation radar," or NEXRAD, data from the NWS may be processed commercially to provide high resolution spatial and temporal rainfall data. Such data may be relatively costly (e.g., a few thousand dollars per extended storm event), but are invaluable for refined calibration of sophisticated models (Bedient et al., 2000).

Precipitation also includes snow. However, snow fall is a slow process that typically results in little or no runoff during an event; therefore the processes of snow accumulation and melt are typically of much greater concern. The physics of snowmelt are discussed in most hydrology texts and are simulated in some models. Accumulated snow is measured daily at NWS weather stations. On hourly or 15-min precipitation records, it must be inferred on the basis of air temperature (typically snow when the surface air temperature is less than about 1°C or 34°F).

Precipitation is influenced by broad geographic and climatic patterns on the earth, as is well known. A conscientious attempt to gather the most site-specific data as possible will frequently obviate the need for more complex climatological analysis.

When weather predictions are needed, reliance may be placed on NWS forecasts readily available on the Web and on any number of media (television, newspaper, etc.) Web sites. If predictions need to be more precise, such as for a monitoring exercise, professional meteorologists may be hired for this purpose.

3.2.1.2 Data Analysis

Good precipitation data, most often rainfall but sometimes snow as well in cold climates, are at the heart of any hydrologic analysis. Careful investigation of the sources and quality of such data is one of the early elements of a successful stormwater management and treatment system design project. The fundamental use of rainfall (and snowmelt) data is in the form of a hyetograph, a plot or table of rainfall intensity versus time. Such data may be used in standard hydrological techniques (such as a unit hydrograph) or used as input to models. The previous section emphasized sources of information for extraction of historic ("real") rainfall data. Design storms may also be constructed artificially by the following simple process:

1. Select a design frequency and event duration.

2. Obtain a depth from intensity-frequency-duration curves, discussed below.
3. Distribute the depth in time to create a hyetograph according to a prescribed rainfall distribution. In the U.S., dimensionless 24-hr hyetographs developed by the Natural Resources Conservation Service (NRCS) are often used, such as the Type II distribution in the Southeast and the Type I-A in the Pacific Northwest (e.g., Bedient and Huber, 2002; King County, 1998).

While being an easy procedure to follow, synthetic design storms have the disadvantage of not corresponding to historic, measured storms, and have a very high intensity near the center of the 24-hr period. Also, they are burdened by the (usual, artificial) 24-hr duration. Nonetheless, because of their standardized nature and ease of construction, they are very often encountered in stormwater drainage design. However, they are usually too "extreme" for stormwater quality design in the sense of designing for too high a magnitude and too long a duration for most water quality treatment systems.

Rainfall data may also be processed in other ways. A common form of processed data is as intensity-frequency-duration (IDF) curves, an example of which is shown in Figure 3-1 for the Willamette Valley of Oregon (Oregon Department of Transportation, 1990). While fundamental to application of the Rational Method for estimating peak flows (Bedient and Huber, 2002), IDF curves are less useful for management of stormwater quality, since treatment systems are usually designed for more frequent events than, say, the two-year return period shown on Figure 3-1. Furthermore, depths equal to the product of intensity and duration taken from IDF curves are fundamentally a function of the selected duration, the choice of which is not obvious for other than the Rational Method (for which duration equals time of concentration). Finally, IDF curves are sometimes mistakenly thought to represent the time history of actual storms; that is, they are taken to represent a hyetograph, which is fundamentally untrue. For all these reasons, IDF curves, although very common, are not of significant use for stormwater quality analysis.

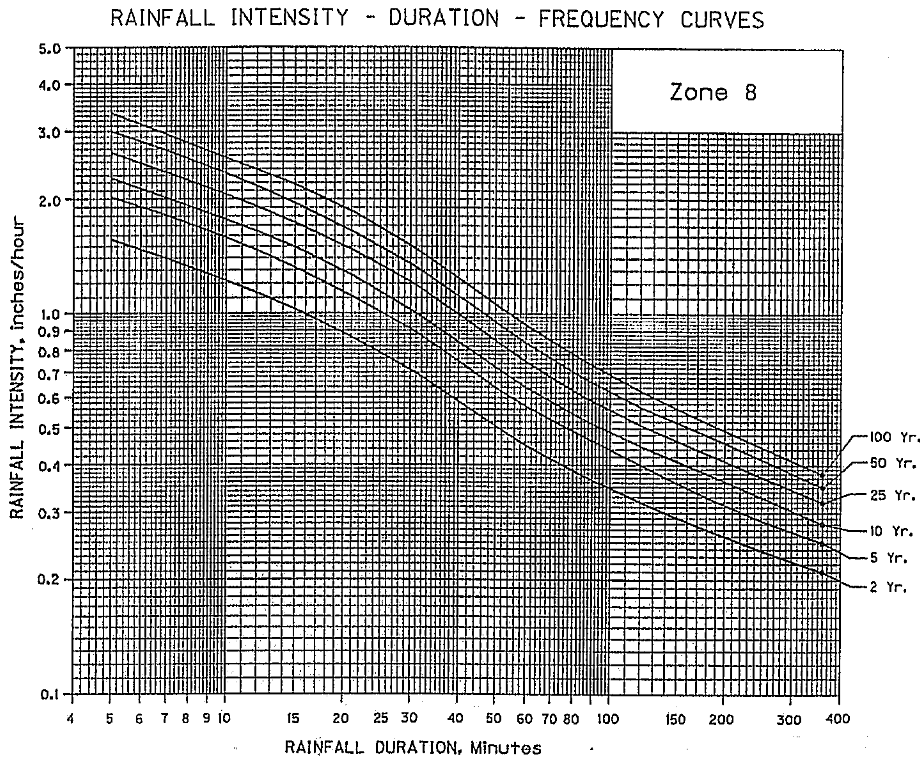


Figure 3-1. Example IDF Curve for the Willamette Valley in Oregon.
Source: Oregon Department of Transportation (1990).

Another frequent form of published precipitation summary information is in the form of depth-frequency relationships, for example, magnitude versus return period, or magnitude versus percent time not exceeded. Several examples of this kind of analysis are provided in Chapter 7.0 of this report.

3.2.2 Soil Characteristics

Soil is an integral part of the hydrologic cycle, as it regulates the processes of surface runoff, infiltration and percolation, and is a major controlling factor in evapotranspiration (evaporation and water uptake and transpiration by plants) through the capacity of the soil to store and release water. The characteristics of soils at any particular site should be carefully considered during the development of stormwater management strategies for the following reasons:

- Runoff volumes and flow rates can be reduced through infiltration and storage in the pore space of the soil substrata.
- Pollutants can be removed from the water column via sorption to soil particles

The ability of surface soil layers to infiltrate and their capacity to store stormwater are important modeling and design parameters that are usually represented by the two respective soil properties: the hydraulic conductivity and the storage capacity. The hydraulic conductivity (a.k.a coefficient of permeability) is the rate at which water flows through the soil pore structure, given as a velocity (e.g., in./hr, mm/day, gal/ft^2-day). It is a function of the porosity (volume of voids to total volume of soil), the connectivity of the pore spaces, the degree of saturation, the chemistry and temperature of the pore fluids, and the hydraulic gradient in unsaturated soils. One measure of water storage capacity is the field capacity, the maximum fraction of soil water (volume of water to volume of soil) that can be held in the pore spaces under the action of gravity. It is primarily a function of the porosity, temperature, and organic content of the soil. A lower bound on water storage is the wilting point, the soil water fraction at which plants can no longer extract water for transpiration. The hydraulic conductivity, porosity, and field capacity, as well as the antecedent moisture condition (degree of saturation) at the onset of a rainfall-runoff event, are the most commonly needed factors for continuous simulation and mass-balance modeling. However depending on project objectives and the treatment system type, some of these factors may not have a direct impact on design. The hydrologic implications of soil properties are discussed in Section 4.2, Hydrologic Operations, but it is important to note that for some locations and soil types, long-term stormwater infiltration may eventually impact groundwater resources as pollutants migrate through the soil column over time.

In addition to water quantity benefits, soil may also provide significant water quality benefits. Particulate material can be filtered, metals and organic compounds can be adsorbed, and hydrophobic compounds, such as oil and grease, can be absorbed during the passage of water through soil layers. The process of filtration is discussed in detail in Section 4.3.2, Size Separation and Exclusion, and the processes of adsorption and absorption are covered in Section 4.5.1, Sorption Processes. Other soil properties related to water quality benefits are discussed in Section 5.5.1, Soils and Soil Amendments. Besides the physiochemical processes, beneficial biological processes also occur in soil. Soils support microbial and plant activities that can degrade organic and immobilize inorganic compounds. By supporting plant life, a soil is integral to the processes of vegetative storage and recycling of nutrients and can thus be an important component in helping to reduce runoff of nutrients to nutrient limited aquatic systems. The biological aspects of soils are discussed in Section 4.4, Biological Processes, as well as.

3.2.2.1 Data Sources

For some projects where soil properties are a key component of the treatment train, detailed soil characteristics information should be collected, as there is a wide range of physical (e.g., bulk density, infiltration rate, and drainage) and chemical (e.g., soil pH, sorption capacity for metals and nutrients) properties among the different soil types. In other projects soil properties needed for design may be limited to hydrologically relevant factors. The need for detailed hydrologically relevant soil data may be obviated through direct monitoring of runoff flows.

Published soil survey reports from the USDA Natural Resources Conservation Service (NRCS; formerly the Soil Conservation Service) are available for most counties throughout the U.S. Soil types within the county are categorized by a unique soil map symbol and soil name; collectively referred to as the soil map unit. Much of this information is now on the Web for example, for the Pacific Northwest at: http://www.or.nrcs.usda.gov/pnw_soil/. Each soil survey includes data related to soil and water properties for all soil map units, which are commonly grouped into the following tables:

Physical analyses/properties of selected soils. This table includes detailed physical, chemical and mineralogical properties based on laboratory analyses of selected soils at various depths below the ground surface. Soils in each map unit are generally subdivided into four to eight layers, or soil horizons, down to a typical depth of 80 inches. For each layer, the particle size distribution, moist bulk density, and water content at 10 kPa, 33 kPa, and 1500 kPa (approximately 1/10 atm, 1/3 atm, and 15 atm, respectively) are tabulated.

Physical and chemical properties of the soil. This table includes estimates of the moist bulk density, based on field observations and on laboratory test data for these and similar soil types. Soils in each map unit are generally subdivided into one to five soil horizons, down to a typical depth of 80 inches. For each layer, moist bulk density estimates are expressed as a range of values (e.g., 1.45-1.60 g/cm^3). In addition, the tables frequently include chemical properties, such as organic carbon content, pH, cation exchange capacity (CEC) and extractable iron, which provide valuable information on the sorption capacity of soils.

Soil and water features. This table includes the hydrologic soil group (HSG) and the seasonal high water table (HWT) depth for each map unit. There are four HSG categories: Groups A, B, C, and D. Group A soils have a high infiltration potential and low runoff potential, and Group D soils have a low infiltration potential and a high runoff potential. Group B and C soils are designated in between these two categories. Dual soil groups indicate infiltration properties that depend on local drainage activities. For example, Group A/D indicates poorly drained soils that could be well drained in the vicinity of roadside ditches or swales, which tend to draw down the local groundwater levels. Open water features represent entirely impervious surfaces and are not assigned to a specific HSG. The HWT depth is measured in feet below the surface and represents the highest sustained elevation of the saturated zone. Often a range of depths is given along with an estimate of the duration in months.

One of the most useful forms of soils data, particularly if the project encompasses large areas with multiple subwatersheds, is digital geographic information system (GIS) format. Data in GIS format can be easily summarized and prepared for direct use in watershed models. Along with numerous local and state GIS systems, there are two USGS websites where digital soils data can be obtained:

- Soil Survey Geographic (SSURGO) Database (http://www.ncgc.nrcs.usda.gov/branch/ssb/products/ssurgo/index.html), and
- State Soil Geographic (STATSGO) Database (http://www.ncgc.nrcs.usda.gov/branch/ssb/products/statsgo/index.html)

The primary difference between the two data sources is the resolution of the data. SSURGO mapping scales generally range from 1:12,000 to 1:63,360, while the STATSGO mapping scale is 1:250,000 (with the exception of Alaska, which is 1:1,000,000). Nearly all stormwater projects will require the more detailed data sets offered by SSURGO.

3.2.2.2 Data Analysis

Geologic conditions will influence the quantity and possibly the quality of runoff from a site. Low permeability soils (e.g. clays) and steep slopes will contribute to larger runoff volumes for a given amount of rainfall. Some soils can have naturally elevated levels of elements or minerals that may be of concern; for example some areas of southern California have elevated levels of selenium in the soils.

At some sites, the storage capacity of a soil horizon may never be reached because of the hydraulic conductivity of adjacent horizons (e.g., the infiltration rate of the surface soil layer is less than the hydraulic conductivity of the underlying soil layer). Therefore, not only are the individual characteristics of soil horizons important, the combined characteristics of all layers should be assessed. Both water storage capacity and infiltration rate need to be considered when investigating soils as a sink for stormwater runoff. Current methods for estimating soil storage capacity are often based on very general characteristics. For instance, the SCS runoff curve number method uses a predetermined soil storage capacity based on the assigned hydrologic soil group and land use category. Since the soil storage capacity is more dependent on other variables (e.g., water table depth and specific soil properties such as infiltration rate), more accurate estimates can be made using characteristic soils data rather than using the SCS curve number.

Soil characteristics are extremely variable, even for locations just a few meters apart. Moreover, in urban areas, disturbed (often compacted) soils bear little resemblance in their physical properties to their natural state (Pitt et al., 1999; Pitt et al., 2001). The importance of local, site-specific measurements of infiltration cannot be overemphasized. Guidelines to infiltrometer equipment and measurements are included in many hydrology and geotechnical engineering books (e.g., Chow et al., 1988; Fang, 1997; Ferguson, 1994; Maidment ed., 1993), and on the Internet (e.g., www.rickly.com; www.turf-tec.com; www.soilmeasurement.com). However, it should be noted that small-scale infiltration tests tend to overestimate infiltration rates (WADOE, 2001). In fact the Washington Department of Ecology recommends that larger, pilot-scale infiltration tests, such as the Pilot Infiltration Test (PIT) be used for sizing infiltration facilities (WADOE, 2001).

3.2.3 Land Use/Land Cover

Two important interconnected watershed characteristics that affect both water quality and hydrology (and therefore affect watershed management) are land use and land cover. Land cover refers to a physical system characterized by the type of vegetation and structures covering land surfaces, while land use refers to an anthropogenic system characterized by human activities, most notably the extraction, refinement, and use of environmental resources. Because human activities alter the landscape, land use and land cover are intimately interconnected. In fact, the term land use is used to describe both land use, and land cover and land use data sets often contain both land use and land cover attributes, such as vegetation type. Thus, land use will be used to describe both of these watershed characteristics throughout the remainder of this document. It should also be noted that in practice the "land use" data sets frequently reflect zoning more than on-the-ground conditions and as such, may not reflect actual land cover at all.

Typical urban land use categories include: residential, commercial, industrial, transportation, and open space. Each of these can be further subcategorized according to the type or level of activity or cover. For instance, residential is often divided into high-density single-family residential, low-density single-family residential, multifamily residential, and mixed residential. The other land use types can be similarly subdivided, but the level of land use discretization should only be as detailed as the associated data available for analyzing differences in land use types. Some examples of associated land use data include imperviousness (and associated runoff coefficient), pollutant event mean concentrations (EMCs), dry-weather discharge rates, and evapotranspiration rates.

3.2.3.1 Land Use-Pollutant Loading Correlation

In some cases, the type of land use, such as commercial, residential, highway, etcetera, can be correlated with differences in both the volume of runoff, due to varying impervious area percentages (discussed in Section 3.2.3.2), and types of constituents that may be found on the site. In addition, the distinction between an urban and rural setting for each land use type may be indicative of the relative magnitude of pollutants at a site. For instance, the concentrations of contaminants, especially metals and nutrients, have been found to increase as the surrounding setting becomes increasingly urban (Driscoll et al., 1990). This manual emphasizes the use of local water quality information in the design process to the extent that it is available. Land use information is often the key factor for selecting water quality data to use in establishing project water quality conditions, whether the designer has extensive local data or must rely on regional or national data sets.

The impacts that land use and urbanization have on stormwater quantity and quality have been highly studied and noted since even before the EPA Nationwide Urban Runoff Program (NURP) (U.S. EPA, 1983; Manning et al., 1977). From a water quality perspective, increasing the urbanized area within a watershed can result in accelerated erosion and sediment transport due to alteration of the land surface, increased surface particulate matter from transportation and anthropogenic activities, and increased atmospheric depositional rates associated with industrial and energy production activities (U.S. EPA, 1983). Generally within an urban environment, different land use types, such as low-density (single family homes and open space) and high density (apartment buildings) residential land uses, would be expected to yield distinct differences in pollutant load accumulation and runoff volumes due the level of imperviousness and anthropogenic use. For example, Hoffman and Quinn (1987) found that the type of land use, whether commercial, residential, highway or industrial, highly affected the relative transmission of petroleum hydrocarbons. Plotting the discharge of hydrocarbons versus the relative rainfall, the residential and highway land use showed a tapering of hydrocarbon discharge after about 2 cm of rainfall, while commercial land use showed noticeable source depletion after about 3.2 cm of rainfall (Hoffman and Quinn, 1987). Industrial land use did not show a tapering of hydrocarbon discharge, likely due to the much larger amount accumulating on the site as compared to the other land uses. For all land uses except industrial, there was a noticeable yet variable exhaustion during longer rainfall events (Hoffman and Quinn, 1987).

3.2.3.2 Imperviousness Estimation

The preferred method for establishing an accurate hydrologic model of a watershed is though direct monitoring of rainfall and runoff. Where this information is not available or conditions have not been established, assessment of imperviousness (most importantly directly connected imperviousness) is a key component of establishing an understanding of watershed hydrology. Typically where budgets are limited or watersheds are relatively large, imperviousness and/or runoff coefficients are frequently assumed according to land use type. Land use-based imperviousness and volumetric runoff coefficients, as well as equations that relate runoff coefficients to imperviousness, are available in most introductory hydrology texts and hydrologic design manuals (e.g. Bedient and Huber, 2002; Chow et al., 1988).

Some common equations relating runoff coefficients to percent imperviousness include:

$R_v = 0.05 + 0.9 \cdot I$ (Schueler, 1987) [3-1]

$$R_v = 0.1 + 0.7 \cdot I \text{ (FHWA, 1990)} \qquad [3\text{-}2]$$

$$R_v = 0.04 + 0.774 \cdot I - 0.78 \cdot I^2 + 0.858 \cdot I^3 \text{ (WEF and ASCE, 1998)} \qquad [3\text{-}3]$$

Where R_v is the volumetric runoff coefficient and I is the imperviousness expressed as a fraction. All of these equations assume that even if the watershed is 100% impervious, not all of the rainfall will result in runoff, which indirectly accounts for losses due to depression storage and evapotranspiration. Caution should be exercised when using these equations, however, because the relationship between imperviousness and the runoff coefficient can be very site-specific depending on the methods used to estimate imperviousness, as well as the characteristics and conditions of the soils and vegetation cover.

Rather than estimating the total impervious area of a watershed it is often more desirable to estimate the directly connected impervious area (Lee and Heaney, 2003). Directly connected impervious areas (DCIA) are the impervious areas such as roofs and pavement that drain directly to the street drainage system in an urban area. DCIA is a better measure for predicting runoff volumes because it considers the possibility of impervious runoff to infiltrate into pervious areas before discharging to receiving streams. Estimating the directly connected impervious area may be an infeasible task for large drainage areas because it requires an analysis of impervious areas and flow directions at the sub-parcel level.

Lee and Heaney (2003) analyzed rainfall events from four sites in south Florida to evaluate the importance of DCIA on the generation of urban runoff for smaller storm events. Results were consistent with previous studies cited by the authors, indicating that DCIA is responsible for between 50-100% of the total runoff and that DCIA runoff generally exceeds all other runoff for most land use types. Specifically, for a highway environment studied, the DCIA only contributed 18% of the total land area while yielding 80% of the total runoff. For the commercial development area studied, DCIA contributed to 98% of the total land area and essentially 100% of the total runoff volume (Lee, 2003; Lee and Heaney, 2002).

In residential settings, a majority of the DCIA is a result of connected roof downspouts and driveway areas. Huber and Cannon (2002) used SWMM as a means to model runoff events in a dense residential neighborhood in Portland, OR and showed that infiltration of direct surface runoff from all roofs and driveway areas in their test site resulted in over a 50% reduction in runoff volume. Lee and Heaney (2002) found that high density residential areas, with approximately 44% total area as DCIA, contribute approximately 70% of the total runoff over all rainfall events and a majority of runoff for 90% of the rainfall events. In comparison, low density residential settings with 6% of the total area as DCIA, contribute about 36% of the total runoff; however, significant runoff from such areas is only observed for larger storm events (Lee and Heaney, 2002).

Minimization of DCIA can be incorporated both into new design and retrofit scenarios. The use of low impact development (LID) practices for new development, such as porous pavement, planter strips, and eco-roofs, all minimize impervious areas on a site, thus allowing for reduced flow rates, increased infiltration, evapotranspiration (ET), and groundwater recharge rates and therefore a reduction in the pollutant load reaching a runoff treatment system and receiving water body. Retrofit practices, such as the disconnection or relocation of roof drains, may be possible in some older development areas, specifically low to medium residential and low density commercial areas (Urbonas and Stahre, 1993). Disconnection and relocation of roof downspouts to pervious areas allows runoff to discharge first into grass for infiltration instead of directly into the sewer system or onto the pavement or roadway area (Urbonas and Stahre, 1993). This practice is not a panacea, however, since concerns over possible groundwater contamination and localized drainage problems must be addressed.

The imperviousness (total or directly connected) of a watershed as a whole, or individual land uses, can be estimated a number of ways, including direct field assessment, digitization, or multi-spectral analysis of remotely sensed data. Direct field assessment is typically the most accurate and most expensive imperviousness estimation method. As the name implies, it requires field surveys of all impervious surfaces (e.g., roadways, roof tops, driveways, etc.) within the area of interest. Depending on the aerial extents, data are generally collected using either a global positioning system (GPS) receiver or a surveyor's total station. For very small areas, an engineer's level and a tape measure may suffice.

Digitization involves delineating impervious surfaces using aerial photographs, satellite images, development plans, as-built drawings, or other spatial data sources that accurately depict the future or existing land uses of a site. Before the advent of GIS, nearly all digitization was done manually using a hard copy of the spatial data and a hand digitizer. Today, the term "heads-up" digitization is used to refer to on-screen digitization of electronic images of spatial data using GIS software. The accuracy of digitization is a function of the spatial, spectral, and temporal resolution of the data, as well as the accuracy of the digitizer and/or robustness of the digitizing algorithms.

With the increased availability of high quality satellite imagery, multi-spectral (4-band including infrared and true-color) analysis of remotely sensed data is becoming popular and is beginning to be used in a variety of innovative applications, most notably, the estimation of impervious surfaces (Rogers et al., 2004). The method involves the use of sophisticated GIS software, such as Visual Learning System's Feature Analyst™ extension for ESRI's ArcGIS 9™, which has the capability of distinguishing between pervious and impervious areas through the analysis of the multi-spectral reflectivity of those areas. Since satellite images are often taken during the growing season, impervious area extraction will typically only capture "impervious surfaces without canopy" (ISWoC). ISWoC are those impervious surfaces that are not covered or obscured by mature trees or other vegetation. While further research needs to be conducted to fully assess ISWoC relative to typical imperviousness assessments, under some conditions it has been shown that healthy tree canopy can significantly reduce stormwater runoff even when the ground below is impervious (Keating, 2002). The use of multi-spectral satellite imagery for identification of impervious areas is a cost effective alternative to digitization. Rogers et al. (2004) found that with a spatial resolution of about 2 feet, it is possible to automatically delineate sidewalks and individual trees and shrubs in a fraction of the time necessary for hand digitization. However, Lee and Heaney (2003) point out the need for local ground truthing to be able to distinguish DCIA from other impervious areas.

3.2.3.3 Evapotranspiration

In addition to affecting stormwater infiltration rates, land use also affects evapotranspiration rates of retained stormwater. Evapotranspiration (ET) represents the loss of water to the atmosphere by evaporation from open water surfaces and soils, as well as transpiration from foliage. Several factors affect the ET process including net solar radiation, air and water temperature, surface area of open water bodies, wind speed, density and type of vegetative cover, availability of soil moisture, root depth, reflective land-surface characteristics, and season. Estimates of average statewide evapotranspiration for the conterminous U.S. range from about 40% of the average annual precipitation in the Northwest and Northeast to about 100% in the Southwest (Hanson, 1991). Estimates of ET for the eastern forests range from slightly less than 12 inches per year for spruce-fir forests to slightly more than 36 inches per year for pines and river-bottom hardwoods. For the western forests, evapotranspiration rates range from about 6 inches per year for pinyon and juniper forests to almost 60 inches per year for Pacific Douglas-fir forests (Kittredge, 1948).

Evapotranspiration rates are often estimated using reference evapotranspiration rates from specific vegetated surfaces. In 2001, the American Society of Civil Engineers (ASCE) Evapotranspiration in Irrigation and Hydrology Committee in cooperation with the Water Management Committee of the Irrigation Association defined and established a standardized reference ET equation for the purpose of standardizing the methodology of reference ET (EWRI, 2001). This method is discussed in detail in Section 4.2.2, Volume Reduction/Minimization of Volume Increases. An example of excellent ET data for the Pacific Northwest based on this procedure is through the U.S. Bureau of Reclamation AgriMet network of weather stations and ET prediction by the Kimberly-Penman equation (http://www.usbr.gov/pn/agrimet/index.html). Daily ET totals are provided for several crops (not for natural vegetation, unfortunately), for the growing season, with some annual ET totals also available.

3.2.3.4 Data Sources

Land use and land cover data are usually best summarized as GIS data layers. As with all types of data, the metadata, or the information accompanying the data that explains the sources, methods used, nature, and quality of the data, should be examined. Land use data may be based on zoning maps, which reflects the future built-out conditions, or the data may be based on aerial photographs or satellite imagery, which reflects existing or past conditions. Land use data can be obtained from a variety of sources including local agencies and organizations, universities, USGS, and even private vendors. For large scale projects, the USGS data may be adequate. However, more often than not higher resolution data are necessary. These land use data can usually be obtained from the City or County of the project.

As mentioned above, imperviousness, if not estimated from land use, can be estimated from aerial photographs or satellite images. There are numerous sources of aerial photography and satellite imagery data online. Aerial photographs and satellite imagery at various scales can be obtained from the USGS:

- National Aerial Photography Program (NAPP), 1:40,000 scale in color infrared or black and white, http://edc.usgs.gov/products/aerial/napp.html
- National High Altitude Aerial Photography Program (NHAP), 1:58,000 scale for color infrared and 1:80,000 for black and white, http://edc.usgs.gov/products/aerial/nhap.html
- Urban Areas High-Resolution Orthoimagery, http://seamless.usgs.gov/
- USGS mapping projects at various scales, http://edc.usgs.gov/products/aerial/mapping.html
- Other Federal agency mapping projects, various scales, http://edc.usgs.gov/products/aerial/survey.html

- Earth Explorer, http://edcsns17.cr.usgs.gov/EarthExplorer/

In addition, several private vendors provide high resolution and "value-added" aerial photographs and satellite images for a nominal fee:

- SPOT Satellite, http://www.spot.com/
- Microsoft TerraServer, http://www.terraserver.microsoft.com/
- Digital Globe Inc, http://www.digitalglobe.com/index.php
- Image Scans, http://www.imagescans.com/
- Intermap Technologies, LTD, http://www.intermap.ca/
- Aerials Express, http://www.aerialsexpress.com
- National Aerial Resources, http://www.nar.com/

Few ET data sources exist at the national level. Pan evaporation is measured at a very few stations in each state (e.g., four in Oregon), from which evaporation estimates maybe made through the use of pan coefficients. But estimates based on meteorological data are usually preferred, as discussed earlier (EWRI, 2001). Therefore, the reliance on data collected from local or regional studies is often necessary. The USGS (www.usgs.gov), the USDA (www.usda.gov), and the NOAA (www.noaa.gov) are good sources for finding reports with ET data. For the Pacific Northwest, the Bureau of Reclamation's AgriMet website provides reference evapotranspiration data (www.usbr.gov/pn/agrimet/index.html). The USDA PLANTS Database provides ET data for various plant types (plants.usda.gov). ASCE also has an extensive list of ET publications that may be useful for tracking down data sources (www.pubs.asce.org).

In addition to spatial data, ancillary land use data such as average event mean concentrations (EMCs) are often useful for modeling and/or estimating pollutant loads from individual land uses. If local or regional land use-based EMC datasets are unavailable or limited for a particular site, probably the best current source of this type of data is the National Stormwater Quality Database (NSQD), which contains monitoring data collected over nearly a ten-year period from more than 200 municipalities throughout the country, mostly as part of NPDES Phase I monitoring efforts (Pitt et al., 2004). This database can be downloaded in various formats from: http://unix.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml.

3.2.4 Groundwater Hydrology

Groundwater is an important element in the hydrologic cycle. For many areas, the majority of groundwater originates from the infiltration of precipitation after the water has passed through the vadose (unsaturated) zone, while in other areas the groundwater is also transported laterally from adjacent lands. As the infiltrated water moves downward, losses may occur due to evaporation, plant transpiration, soil storage, and interflow. Prior to infiltration, water on the surface is subject to runoff, depression storage, interception, and evaporation. During long periods of dry weather, groundwater is generally responsible for baseflow in rivers, sewer systems, and stormwater drainage systems especially in shallow groundwater regions. In many arid but urbanized areas, baseflow sustains small perennial streams due to wet urban discharges and infiltration of irrigation water.

Stormwater infiltrates naturally and as a consequence of designed wet-weather controls. This infiltration can have some water quality impacts on the groundwater due to the nature of constituents in stormwater, including nutrients, heavy metals, pesticides, bacteria, pathogens, suspended solids, oil and grease (Pitt et al., 1996). Nitrate is a highly soluble and mobile nutrient that has a high potential for groundwater contamination and is commonly attributed to agriculture and fertilizers. Impacts include the potential for methemoglobinemia (blue baby disease), for which drinking water nitrate standards are typically set at 10 mg/L as N, or less. Nitrate and soluble phosphorus, another common nutrient, contribute to eutrophication. Heavy metals have a low potential to contaminate groundwater, due to their high affinity to soil (i.e., their tendency to adsorb) caused by the attraction between positively charged heavy metals and generally negatively charged soil particles. Pesticides, including insecticides, fungicides, herbicides, and nematocides, have the potential for groundwater leaching and mobility. Leaching depends on the pesticide decay rate, repetitive use, and soil properties. Adsorption depends heavily on the amount of organic matter in the soil. Bacteria and pathogens also pose some risk for groundwater contamination depending on bacteria type and soil sorption properties. Suspended solids and oil and grease pose very little or no threat of groundwater contamination due to stormwater infiltration and are generally filtered out in the top few inches of soil. In fact, suspended solids are a maintenance issue in many treatment systems since they may clog infiltration facilities.

The depth to groundwater is an important factor when considering water quality, as well as soil properties that govern infiltration of surface water. Information such as distance between the ground surface and the groundwater table, depth and direction of groundwater flow, seasonal groundwater variation, regional geology, and the slope of the water table are all needed to evaluate a potential stormwater infiltration site (see Section 5.2.1, Infiltration/Exfiltration Trenches and Basins and Section 5.5.1 Soils and Soil Amendments, for more information on soil properties and determining the appropriateness of infiltration). The groundwater properties can be coupled with other information such as location of production wells and the use of pumped water to determine the water quality impact potential. Infiltration parameters such as hydraulic conductivity and porosity are a function of regional geology and soil conditions, which can vary greatly from location to location. Hydraulic conductivity is the measure of how fast water can move through a soil, while porosity is the measure of how much pore space is available in a given soil. When stormwater is infiltrated as a means of disposal, there is always a potential for groundwater contamination, especially if the water table is near the ground surface and the soil has a high hydraulic conductivity (i.e., less opportunity for sorption of contaminates to occur). This information is especially important when stormwater disposal occurs near potable water supply wells. Negative water quality impacts could occur if a stormwater infiltration site is up-gradient of a production well used for human consumption. The soil infiltration properties, groundwater use, and groundwater flow characteristics must all be considered when infiltrating stormwater to ensure that the water quality of the groundwater is not negatively impacted. When evaluating groundwater flow characteristics, it is important to note that an underground drainage area, sometimes called a groundwatershed, will not necessarily coincide with a surface watershed.

3.2.4.1 Data Sources

Groundwater data can be obtained through a number of sources such as: USGS, State Departments of Water Resources, counties, and municipalities. Groundwater data are sparsely available throughout the U.S. from the USGS, even though the agency annually monitors thousands of groundwater wells throughout the country and currently has 850,000 records. Most groundwater data are available in the form of discrete groundwater level measurements while some wells have a continuous record, and few wells have data available in real time. The data can be viewed as graphical, tabulated, and tab-separated and are available on the Internet at http://water.usgs.gov. The USGS data include well latitude and longitude, elevation, total depth, depth to water surface, and type of subsurface formation. The USGS data may not be sufficient to meet assessment requirements because well data are spread throughout the U.S. and multiple well data may not be available for a small region.

Each Water Resources (WR) branch of the state government has groundwater well information that can be used in conjunction with other data sources. WR data are usually much more abundant than the USGS data, and they provide more in depth descriptions of well characteristics. Many water resources agencies or branches have interactive websites that contain groundwater elevation data and aquifer formation type located on state government websites. Most states have very comprehensive groundwater recording throughout the state, containing greater in depth information about each well. This is due in part to the requirement for permitting of most agricultural and other water supply wells. Counties and municipalities across the U.S. may also have some groundwater data, especially if the municipality uses groundwater as a water supply.

3.2.4.2 Data Analysis

To fully understand the potential for groundwater quality impacts, numerous seasonal monitoring well data should be obtained, as well as geologic information about the local region. It is highly recommended that a hydrogeologist and/or groundwater engineer be employed for any large-scale stormwater management project where infiltration is proposed to be the primary treatment mechanism or the local groundwater table is shallow. Pertinent analysis that would be needed for a region of interest would include:

- Seasonal variability in groundwater depths
- Flow direction
- Hydraulic gradient
- Flow velocity
- Geologic and soil parameters

Seasonal variability in groundwater depths, soil texture, and soil type will help gauge potential water quality issues associated with and the feasibility of stormwater infiltration. Shallow depths between groundwater and ground surface could result in potentially negative groundwater impacts, while deep depths could provide a lesser chance of negative groundwater quality impacts due to increased soil and water contact time. Coarse, inert soils allow water to move rapidly through the soil column with little opportunity for soil-water contact, while fine-textured and organic soils allow for better physical filtration, ion exchange, and microorganism habitat (Ferguson, 1994). Therefore, the consideration for stormwater infiltration should be evaluated based on two primary factors: 1) depth to groundwater, and 2) soil texture. The primary methods for determining the seasonal changes in groundwater depths are to conduct a long-term water balance simulation or analyze observation well or soil boring log data (Ferguson, 1994).

Groundwater flow direction is a function of hydraulic gradient which can be estimated if water depths are known in at least three nearby wells. Groundwater flow velocity can be calculated once the hydraulic conductivity and gradient are known, usually from laboratory experiments, and the application of Darcy's law. Flow velocities are obviously necessary for fate and transport studies, for which models can also be employed.

3.2.5 Seasonality and Long-term Variation

In addition to the fluctuation of the groundwater table, there is also significant seasonal variation in the hydrologic and water quality characteristics of urban runoff that should be considered during the planning phases of runoff control and treatment strategies. This variability is evident in both wet and dry season stormwater, as well as in urban dry weather runoff. The physical and chemical variation in runoff quality has a direct influence on the treatability of constituents. These treatability challenges may be further complicated by seasonal regulations aimed at addressing the seasonal variation of receiving water sensitivity and recreational contact use. The following sub-sections discuss the seasonal aspects of wet and dry weather flows with respect to watershed characterization.

3.2.5.1 Stormwater Versus Dry Weather Runoff

Traditional urban runoff management activities focus primarily on stormwater runoff. An equally important issue when assessing potential impacts to receiving waters, especially in arid climates where natural drainages are dominated by ephemeral rather than perennial flows, is dry weather runoff.

The primary anthropogenic sources of dry weather runoff include flows incidental to urban activities, such as irrigation, car washing, pavement washing, construction dewatering, fire hydrant purging, and decorative fountain draining. Other sources may include leaky or directly connected sanitary sewage and septic tank systems, wash waters from laundry and car wash facilities, and many types of industrial wastewaters that discharge directly to the storm drainage system. All of these dry weather runoff sources may introduce pollutants to the storm drain system. The concentrations and even presence of these pollutants may be starkly different from typical stormwater runoff concentrations. For instance, irrigation runoff often has high concentrations of pesticides, while pesticides are rarely detected at high concentrations in urban stormwater runoff. Schiff and Tiefenthaler (2003) found that mean concentrations of organophosphorus (OP) pesticides in the runoff from three residential neighborhoods were typically greater during dry weather than during wet weather. Mean dry weather concentrations ranged from 20 to 572 ng/L chlorpyrifos and from 1,031 to 1,726 ng/L diazinon, while mean wet weather concentrations ranged from 6 to 156 ng/L chlorpyrifos and from 685 to 1,812 ng/L diazinon.

In another study, wet and dry weather water quality data obtained from multiple regulatory agencies and municipalities in California were statistically analyzed and compared (Duke et al., 1999). The results showed that long-term mean concentrations for most parameters were higher during storm discharges than during dry weather flows to at least 95% confidence in 20 of 45 comparative evaluations. These results were in agreement with a study by Pope and Bevans (1987) who conducted an investigation in Topeka, Kansas to estimate the effects of runoff from urban areas on the water quality characteristics of Shunganunga Creek during three different stream flow conditions: 1) dry weather streamflow—a combination of base flow and point source contributions, 2) storm streamflow—mainly provided by overland runoff from storms, and 3) snowmelt streamflow—mainly provided by overland runoff from snowmelt. The results of the study found that median concentrations of trace metals and nutrients were larger in storm streamflow than in dry weather streamflow. Median concentrations of total lead and zinc were largest in storm streamflow from the more urban basins. Median concentrations of dissolved sodium, chloride, and solids in snowmelt streamflow at all study sites averaged a 218% increase in dissolved sodium, 296% increase in dissolved chloride, and 71% increase for dissolved solids relative to median concentrations in dry weather streamflow, which is undoubtedly attributable to winter deicing activities.

Based on these studies, it is evident that there are distinct differences between wet and dry weather runoff (as well as snowmelt runoff, which will be discussed later in this chapter). Depending on the target constituents and treatment objectives, the differences in quality and quantity of stormwater runoff as compared to dry weather runoff are important factors to consider early in the planning stages of a stormwater treatment system for a particular site.

3.2.5.2 Climatological Influence

Seasonal variations in temperature and precipitation are primarily influenced by climate. The two largest factors affecting climate are latitude and oceanic currents. While the relationship between climate and oceanic currents is an extensive topic well beyond the scope of this document, the primary oceanic currents affecting the climate of the U.S. are the California Current and the Gulf Stream. The California Current is the eastern boundary current of the North Pacific gyre that brings cold arctic waters southward along the west coast, while the Gulf Stream is the western boundary current of the North Atlantic gyre that brings warm tropical waters northward on the east coast. These two currents are responsible for the wide variability in seasonal trends throughout the U.S. For example, the Pacific Northwest receives nearly all of its precipitation during the winter months, while the New England states, even though they are at similar latitude, have little variation in the total amount of precipitation occurring throughout the year. However, since the form of the precipitation (e.g., snow, rain) varies with temperature there are significant differences in the quantity and season of runoff.

If only average annual rainfall were evaluated, many areas of the U.S. would fall into the same category. For example, the southeast U.S. and the Pacific Northwest have similar annual rainfall depths. However, treatment processes may not work with the same effectiveness for both of these regions. Seasonal rainfall patterns may dictate the usefulness of treatment type. Florida, for example, with average winter temperatures above 65°F, receives the majority of its rainfall in the summer months. This contrasts with the Pacific Northwest, which receives the majority of its rainfall in the winter months, when temperatures average around 40°F. Effectiveness of treatment processes is greatly influenced by this seasonality and will be discussed in further detail in later sections. The National Oceanic and Atmospheric Administration's (NOAA) Climate Diagnostics Center (CDC) provides online plotting tools for viewing trends in rainfall, temperature, and other climatic variables for the entire U.S. (http://www.cdc.noaa.gov/USclimate/USclimdivs.html).

3.2.5.3 Seasonal Flushing

The presence or absence of the "first flush" of stormwater pollution is an area of scientific debate that is briefly discussed in Section 3.3, Water Quality Characterization. A less disputed and related phenomenon, is seasonal flushing caused by the dry weather build-up of pollutants on impervious surfaces and the subsequent flushing of those pollutants during the first rainfall-runoff event of the wet season. As opposed to "first flush" evaluations where the within-storm variance of pollutant concentrations is analyzed, seasonal flushing evaluations analyze the among-storm variance to assess whether initial storms of the season have substantially higher pollutant concentrations than storms occurring later in the season.

Tiefenthaler et al. (2001) assessed the magnitude of seasonal flushing in the Santa Ana River, an urbanized watershed in Orange County, California, by generating and analyzing a cumulative flow-weighted mean (FWM) curve for total suspended solids (TSS). The point on the curve where individual storms no longer affected the slope was used to identify the wet weather baseline FWM conditions. The study found that after 220 days of no rain the first four storms of the season had significantly higher concentrations of TSS and trace metals than the remaining storms of the season. A seasonal first flush was also observed by Lee et al. (2004) for the entire state of California. The study found that the Mediterranean climate, consisting of a high volume of rainfall in the winter and early spring, with a low volume of rainfall in the summer and fall, consistently yielded a higher pollutant load in the beginning of the winter season. This pollutant load ranged from 2-20 times greater, with organics, minerals, and heavy metals (except lead) exhibiting the greatest seasonal flush.

The existence of a seasonal flush suggests that application of treatment processes timed to coincide with the beginning of the rainy season could have much higher water quality benefits than those applied generally. Generally applied treatment processes would be more applicable to areas with consistent amounts of rainfall, such as the Northeast. Areas like Florida, which receive the majority of their yearly rainfall in the summer months, could employ a design opposite of those of California, applying the treatment processes at the beginning of summer, as opposed to the end of fall. Application of these findings to the design of structural controls could result in varied setting of hydraulic treatment system components during seasonal flush events that may not be acceptable under general conditions. A facility designed to take advantage of the seasonal flush could for example incorporate active management approaches, such as drawing down wetland facilities prior to the first few rainfall systems moving into Southern California in the late fall, or the temporary use of dual use recreational facilities for temporary water quality control.

3.2.5.4 Freezing Conditions

Freezing conditions pose serious challenges to stormwater management, such as frozen soils inhibiting infiltration, frost heave of permeable pavements, and decreased biological activity in natural treatment systems. A majority of the U.S. experiences freezing conditions for part of each year. It is important to understand the difficulties associated with treatment design in a multi-seasonal location.

Calculating infiltration rates into frozen soils can be a difficult process. The factors complicating infiltration calculations are as follows: 1) at below freezing temperatures, water and heat fluxes are strongly coupled, requiring knowledge of both hydraulic and thermic soil properties, 2) ice must be considered as a fourth phase that varies with time, along with the soil matrix, gas, and liquid, and 3) infiltrating water may refreeze and alter the soil's hydraulic properties (Stadler et al., 2000). For these reasons, infiltration calculations for treatment practices may be overestimated during winter months. In a literature review for cold climates, Backstrom and Viklander (2000) found that porous pavements, grassed swales and ditches, wet ponds, and percolation basins were most suitable. Dry basins, infiltration surfaces and stormwater reuse were not recommended for cold climates.

Backstrom and Bergstrom (2000) tested the infiltration capacity of porous asphalt during both freezing and snowmelt events. Snowmelt conditions were achieved by alternating temperatures in a climate controlled room consistent with day and night temperatures associated with a snowmelt event. At freezing temperatures, the infiltration capacity of porous asphalt was shown to be reduced by 50%. In snowmelt conditions, in which temperatures were varied above and below freezing, the porous asphalt infiltration was reduced by nearly 90% due to frozen water in the pore spaces.

In winter months, wetland treatment systems have a reduced ability to remove certain pollutants due to a decrease in biological activity. Wetland plants readily uptake nitrogen and phosphorus during the spring and summer months, resulting in lower effluent concentrations during these periods. During winter months, these systems may even cause a net increase in these nutrients due to plant decay. Decreased water temperature also decreases soil microbial activity, again reducing processes for nutrient and pollutant removal.

3.2.5.5 Snowmelt

In cold climates, snowmelt creates a unique hydrology for a treatment system. During cold weather, treatment systems experience long periods of no runoff, followed by large volumes of runoff in a short time span following a snowmelt. German et al. (2003) modeled the effects of cold weather on stormwater pond systems. They found that the increased hydrologic load during snowmelt conditions caused a decrease in removal capacities of the system from similar precipitation amounts in warm weather. They also found that temperature was not the main contributor to dissolved oxygen deprivation in winter months. The temperature effect was negligible when compared with the effect of ice cover reducing wind oxygenation to zero.

It is also difficult to predict the hydrologic effects of snowmelt due to the nature of the snow pack. The runoff from a snowmelt event is directly related to the density of the snow preceding the melting. Snow density can be altered by melting and refreezing, and the combination of more than one snowfall event can cause the density to be layered. Snow cores can be used to estimate the water content of snow pack, as well as snow pillows, which measure the pressure of snow on top of them.

Snowmelt can also alter the chemistry of a watershed. Through soil mineral weathering, snowmelt can increase the concentrations of various ions in receiving waters. Stottlemeyer and Toczydlowski (1996) showed a significant increase in stream concentrations of Ca^{2+}, Mg^{2+}, and HCO_3^- directly attributable to ion exchange at the ground level under snow pack conditions. A recent issue affecting stormwater management is the addition of extremely high concentrations of pollutants due to deicing procedures. Sources of snow pollution include: 1) atmospheric deposition, 2) traffic emissions and corrosion, 3) pavement deterioration, 4) litter, and 5) pollutants in deicing and anti-icing chemicals. The chlorides found in deicing chemicals build up in snow pack and are released in large quantities during snowmelt events. Chloride concentrations often violate state regulations for dissolved solids in runoff to receiving waters. Synthetic deicing materials, such as calcium magnesium acetate (CMA), do not introduce chloride to systems, but create a high biochemical oxygen demand (BOD) which may greatly affect water quality (Novotny et al., 1999).

3.2.5.6 Solar Radiation and Temperature

Solar radiation varies greatly throughout the year. High summer radiation leads to warm conditions and high levels of evapotranspiration in treatment systems. Low winter radiation, and the resulting cold temperatures and reduced vapor pressures can reduce evapotranspiration to fractions of their summer values. The resultant water temperature variability changes microbial activity, which directly affects microbially mediated treatment processes, and thermal stratification, which directly affects mixing and the propensity for short-circuiting in detention systems.

Dissolved oxygen capacity is also affected by changes in temperature. As the water temperature decreases, gas solubility increases, allowing colder water to contain more oxygen. During the warm summer months, solar heated water becomes oxygen depleted, creating an oxygen stratified water column. During this time, aerobic microorganisms are breaking down organic matter, using available oxygen in the water column. With the presence of an abundance of nutrients, such as phosphorus, this process can be accelerated and lead to eutrophication of the treatment area. This process can be minimized by ensuring adequate mixing at the air-water interface. The formation of an ice layer on the water surface during winter conditions can also lead to depleted dissolved oxygen levels.

3.3 Water Quality Characterization

One of the most important elements of site characterization is the assessment of existing and potential future water quality. Generally urban runoff consists of stormwater, construction site runoff, combined sewer overflows, snowmelt, and dry weather flows. Characteristics of dry weather flows and snowmelt were briefly discussed in Sections 3.2.5.1, Stormwater Versus Dry Weather Runoff) and 3.2.5.5, Snowmelt, respectively. This section describes characteristics of wet weather flows (stormwater).

3.3.1 General Characteristics and Pollutant Sources

Stormwater runoff from urban land uses is a complex, heterogeneous mixture of constituents subject to variations in flow, concentrations, and mass loadings that sometimes vary by orders of magnitude during a single storm event. The concentration of constituents in stormwater runoff can be comparable to treated domestic wastewater; when untreated urban runoff is discharged directly to receiving waters, pollutant loadings can be much higher than loadings attributable to treated domestic wastewater (U.S. EPA, 2002a). Compared to treatment of drinking water, domestic wastewater, and industrial wastewater, stormwater treatment continues to pose uniquely difficult challenges due to the unsteady and stochastic nature of many interacting phenomena. These phenomena include anthropogenic activities that occur in the watershed, stochastic hydrology that is variable and unsteady between and during events, previous loadings on the urban surface, drainage conditions and design that influence parameters such as residence time, and the physical-chemical nature of urban surfaces in the watershed. In comparison to stormwater runoff, these phenomena are relatively steady over short time periods for dry weather flows.

Stormwater pollutants often contribute to exceedances of water quality standards, and have been found to cause significant impacts to aquatic life in receiving waters. Most aquatic life impacts associated with urbanization are likely chronic effects related to habitat destruction, polluted sediment, and food web disruption. Public health impacts are generally related to pathogens in urban runoff, which are discharged into water supplies, or waters used for recreation (U.S. EPA, 1999h).

Stormwater runoff and pollutant discharges increase steadily with urbanization, due to the increase in impervious surfaces (such as roof tops and driveways), which reduces infiltration of rainfall and runoff. Pollutants associated with urban runoff can be generally categorized as solids, oxygen-demanding substances, nutrients (nitrogen and phosphorus), pathogens, organics associated with fuels and other petroleum products (e.g., diesel, PAHs), metals, and synthetic (xenobiotic) organics. Generally, sediment is the most significant pollutant in water resources. The amount of sediment contributed to watercourses by urban construction is equivalent to the combination from sources such as forestry, mining, industrial, and commercial activities (U.S. EPA, 1999h). Pollutants enter stormwater from a variety of sources in the urban landscape, as shown in Table 3-1. More specific information on pollutant sources and characteristics is provided in the Pollutant Fact Sheets (Appendix A).

Table 3-1. Commons Sources of Stormwater Pollutants.

Pollutant	Potential Sources
Gross Solids, Sediment and Floatables	Streets, lawns, driveways, roads, construction activities, atmospheric deposition, drainage channel erosion
Pesticides and Herbicides	Residential lawns and gardens, roadsides, utility right-of-ways, commercial and industrial landscaped areas, soil wash-off
Organic Materials/Oxygen Demanding Substances	Residential lawns and gardens, commercial landscaping, animal wastes
Metals	Automobiles, bridges, atmospheric deposition, industrial areas, soil erosion, corroding metal surfaces, combustion processes
Oil and Grease/ Organics Associated with Petroleum	Roads, driveways, parking lots, vehicle maintenance areas, gas stations, illicit dumping to storm drains, automobile emissions
Bacteria and Viruses	Lawns, roads, leaky sanitary sewer lines, sanitary sewer cross-connections, animal waste, septic systems
Nitrogen and Phosphorus	Lawn fertilizers, atmospheric deposition, automobile exhaust, soil erosion, animal waste, detergents

Source: US EPA, 1999h (Preliminary Data Summary of Urban Storm Water BMPs)

Various site characteristics may affect stormwater quality, which include:

- Climate—antecedent dry period between storms, average rainfall intensity, storm duration, and amount of snowmelt. Arid and semi-arid regions generally experience longer dry periods where pollutants build up and subsequently run off in higher concentrations during storm events than in areas with higher rainfall amounts (U.S. EPA, 2002a).
- Geographic factors—soil type, slope, land use patterns and amount of imperviousness in the watershed. (Refer to Section 3.2 for additional information.)
- Water chemistry (e.g., effect of pH, type of solids present, ionic strength, dissolved organic matter, etc.)
- Existing source control practices (e.g., sweeping, chemical storage methods, landscape practices, etc.).

3.3.2 Sources of Stormwater Quality Data

There has been a substantial amount of stormwater quality data collected during the last ten years throughout the U.S. However, most of these data are not readily available, and have not been subjected to rigorous statistical analysis. Some exceptions include:

- NURP data (described in more detail below).
- USGS National Stormwater Database: consists of 1,123 storms for 98 stations in 20 metropolitan cities (U.S. EPA, 2002a).
- Camp, Dresser and McKee (CDM) National Stormwater Database: consists of NURP, available USGS data, and selected Phase I data (Smullen and Cave, 2002). Analysis of the data concluded that pollutant concentrations from different land uses were not significantly different; therefore all data were pooled.
- Federal Highway Administration (FHWA): Stormwater runoff data were collected from 31 highways in 11 states during the 1970s and 1980s. The database has been summarized for urban and rural areas for two highway traffic densities (greater than and less than 30,000 average daily traffic) (WEF and ASCE, 1998). Additional data are being collected as part of a National Cooperative Highway Research Program- (NCHRP) funded project.
- NPDES Industrial Stormwater Data: Industrial NPDES permits require sampling and analysis of stormwater discharges associated with industrial activities. Data may be compiled by EPA or other permitting authorities.
- Phase I MS4 Stormwater Data: Regional databases have been developed by various municipalities in the Los Angeles area, three counties in the San Francisco Bay Area, the Oregon Association of Clean Water Agencies, and the Dallas, TX area.
- National Stormwater Quality Database (described in more detail below).

NURP was conducted from 1978 to 1983 and was the first comprehensive study to evaluate characteristics of urban runoff, similarities or differences between urban land uses, the extent to which urban runoff is a significant contributor to water quality problems nationwide, and the effectiveness of management practices to control pollutant loads (U.S. EPA, 1983). Sampling was conducted in 28 communities at 81 sites for more than 2,300 discrete storm events. Although the NURP data did not find statistically significant differences in pollutant concentrations from different land uses (i.e., residential, commercial, and mixed), the data did show a significant difference between urban and non-urban sites. The NURP studies also found that geographic location, runoff volume, and other watershed factors were of little use in explaining overall site-to-site or event-to-event variability. Median stormwater pollutant concentrations (and coefficients of variation) for all NURP sites by land use are summarized in Table 3-1. The pollutants detected most frequently were copper, lead, and zinc.

Table 3-2. Median Stormwater Pollutant Concentrations from NURP Study by Land Use.

Pollutant	Units	Residential		Mixed		Commercial		Open Space/ Non-Urban	
		Median	CV	Median	CV	Median	CV	Median	CV
BOD	mg/l	10	0.41	7.8	0.52	9.3	0.31	—	—
COD	mg/l	73	0.55	65	0.58	57	0.39	40	0.78
TSS	mg/l	101	0.96	67	1.14	69	0.85	70	2.92
Total Pb	µg/l	144	0.75	114	1.35	104	0.68	30	1.52
Total Cu	µg/l	33	0.99	27	1.32	29	0.81	—	—
Total Zn	µg/l	135	0.84	154	0.78	226	1.07	195	0.66
TKN	µg/l	1,900	0.73	1,288	0.50	1,179	0.43	965	1.00
Nitrate + Nitrite	µg/l	736	0.83	558	0.67	572	0.48	543	0.91
Total P	µg/l	383	0.69	263	0.75	201	0.67	121	1.66
Soluble P	µg/l	143	0.46	56	0.75	80	0.71	26	2.11

CV = Coefficient of variation = standard deviation/mean
Source: Nationwide Urban Runoff Program (U.S. EPA, 1983)

A National Stormwater Quality Database (NSQD) is being developed and analyzed by the University of Alabama and the Center for Watershed Protection under a U.S. EPA grant (Pitt et al., 2004). The database consists of nearly ten years of stormwater outfall data collected by MS4 permit holders throughout the U.S.. The final database and analysis will be published on the internet (such as on U.S. EPA Office of Water and Office of Wastewater Management and the Center for Watershed Protection's Stormwater Manager's Resources Center[1]). Currently the database (version 1.1) contains data from 3,770 separate events from 66 agencies and municipalities in 17 states. Current data are mostly from the southern, Atlantic, central and western parts of the U.S.; about 54% of the data are from communities located in Maryland, Virginia, Pennsylvania, North Carolina, Kentucky, and Tennessee. Subsequent phases of the project will concentrate on extending national coverage. Figure 3-2 shows the locations of municipal data that are currently in the database, according to EPA Rain Zone. The nine rain zones are based on precipitation event statistics including annual means of total storm volume, intensity, duration, and interval between storms. The database includes approximately 125 constituents, although 35 constituents are reported most frequently. Most of the data represent residential land use.

Analysis of the data will include an evaluation of the effects of the following parameters on pollutant concentrations:

- Land use
- Rainfall amounts
- Geographical area
- Season (snowmelt data are not included)
- Watershed area percent imperviousness
- Time

[1] *http://www.stormwatercenter.net*

Additional factors that will be evaluated include:

- Occurrence and magnitude of first flushes
- Effects of different sampling methods (e.g., use of grab sampling versus automatic sampling)
- Effects of infrequent wrong data in large databases
- Appropriate methods to address values below analytical method detection limits
- Necessary sampling effort needed to characterize stormwater quality

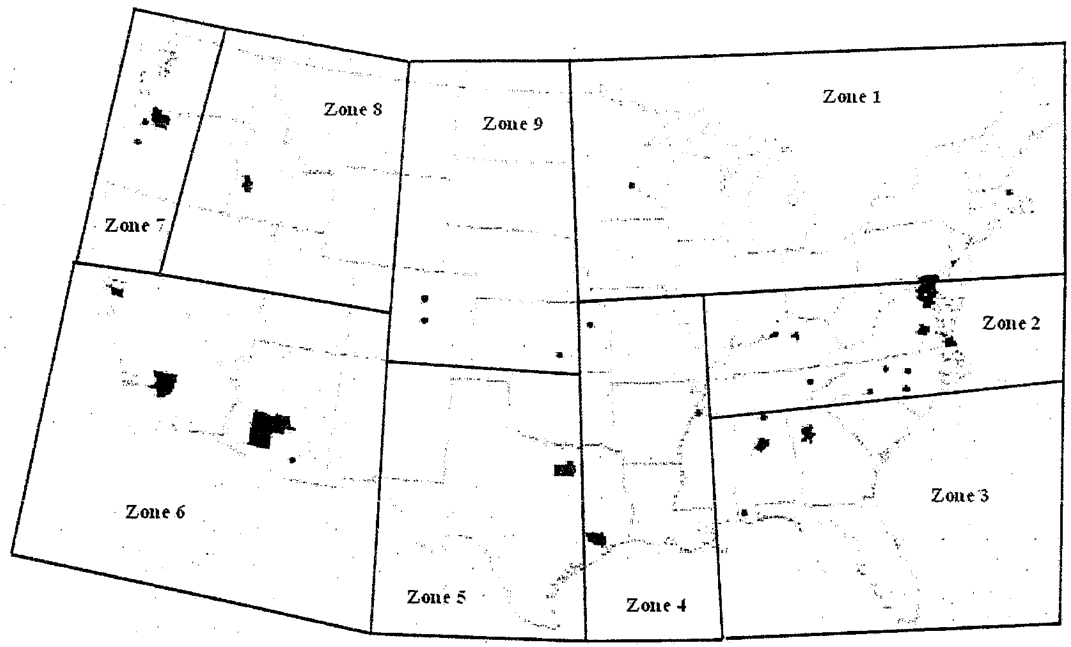


Figure 3-2. Locations of MS4 Data in the National Stormwater Quality Database (Version 1.1). Reprinted with permission from Pitt et al. (2004).

Figure 3-3 and Figure 3-4 are examples of some preliminary findings of the data analysis. Figure 3-3 (a and b) shows box and whisker plots for several constituents for different land use categories. Preliminary statistical analyses found significant differences for land use categories for all pollutants. Total Kjeldahl nitrogen, copper, lead, and zinc observations are lowest for open space areas, while the freeway locations generally have the highest median values, except for phosphorus, nitrates, fecal coliform, and zinc. The industrial sites have the highest reported zinc concentrations.

Figure 3-4 shows selected residential data (TSS, total phosphorus, fecal coliform, and total copper) for the different EPA rain zones in the U.S. Zones 3 and 7 (the wettest areas of the county) have the lowest concentrations for most constituents.

The National Stormwater Quality Database will be used to develop a method to predict expected stormwater quality for a variety of significant factors and will be used to examine a number of preconceptions concerning the characteristics of stormwater, sampling design decisions, and some basic data analysis issues. These data are to serve as an updated benchmark for comparison with locally collected data, and may also be used in lieu of general characterization monitoring, in cases where regional data have been included in the database.

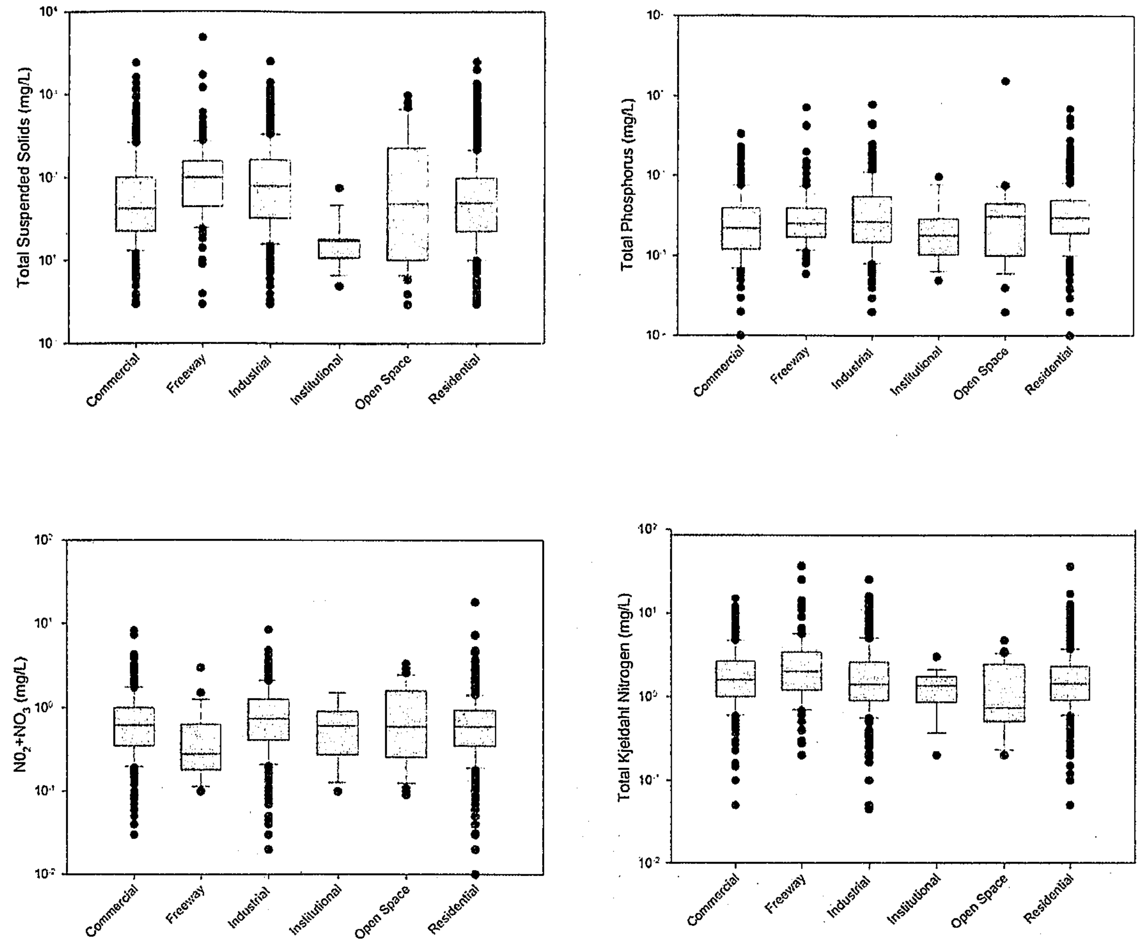


Figure 3-3a. Box and Whisker Plots for Stormwater Constituents as a Function of Land Use.
Shown are TSS, total p, nitrate and nitrite, TKN, fecal coliform, and total copper, lead and zinc. Data represent homogenous land use site only; sites with mixed land use are not represented in this analysis.
Reprinted with permission from Pitt et al. (2004).

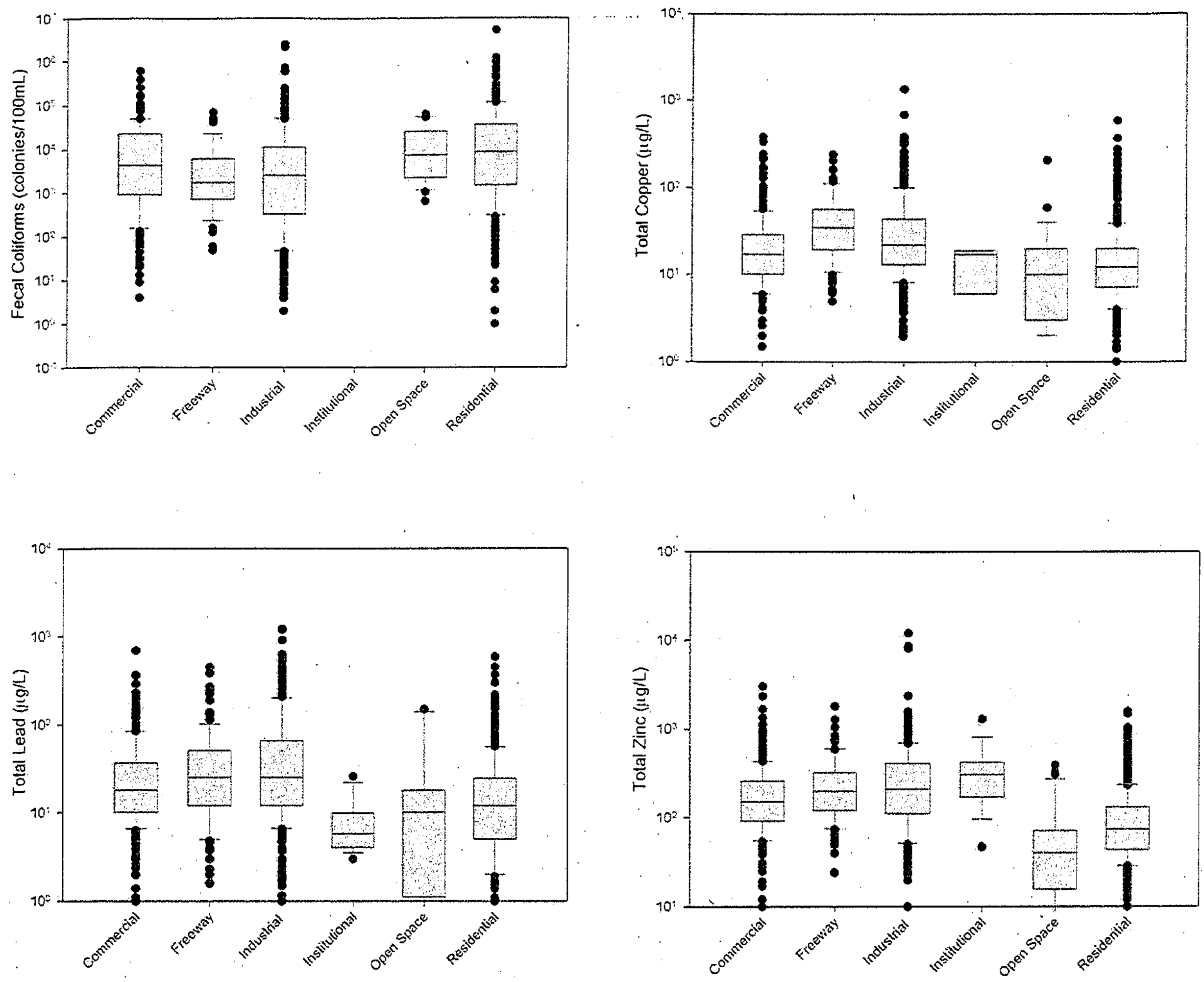


Figure 3-3b. Box and Whisker Plots for Stormwater Constituents as a Function of Land Use.
Shown are TSS, total phosphorus, nitrate and nitrite, TKN, fecal coliform, and total copper, lead and zinc. Data represent homogenous land use site only; sites with mixed land use are not represented in this analysis. Source: Pitt et al., 2004.

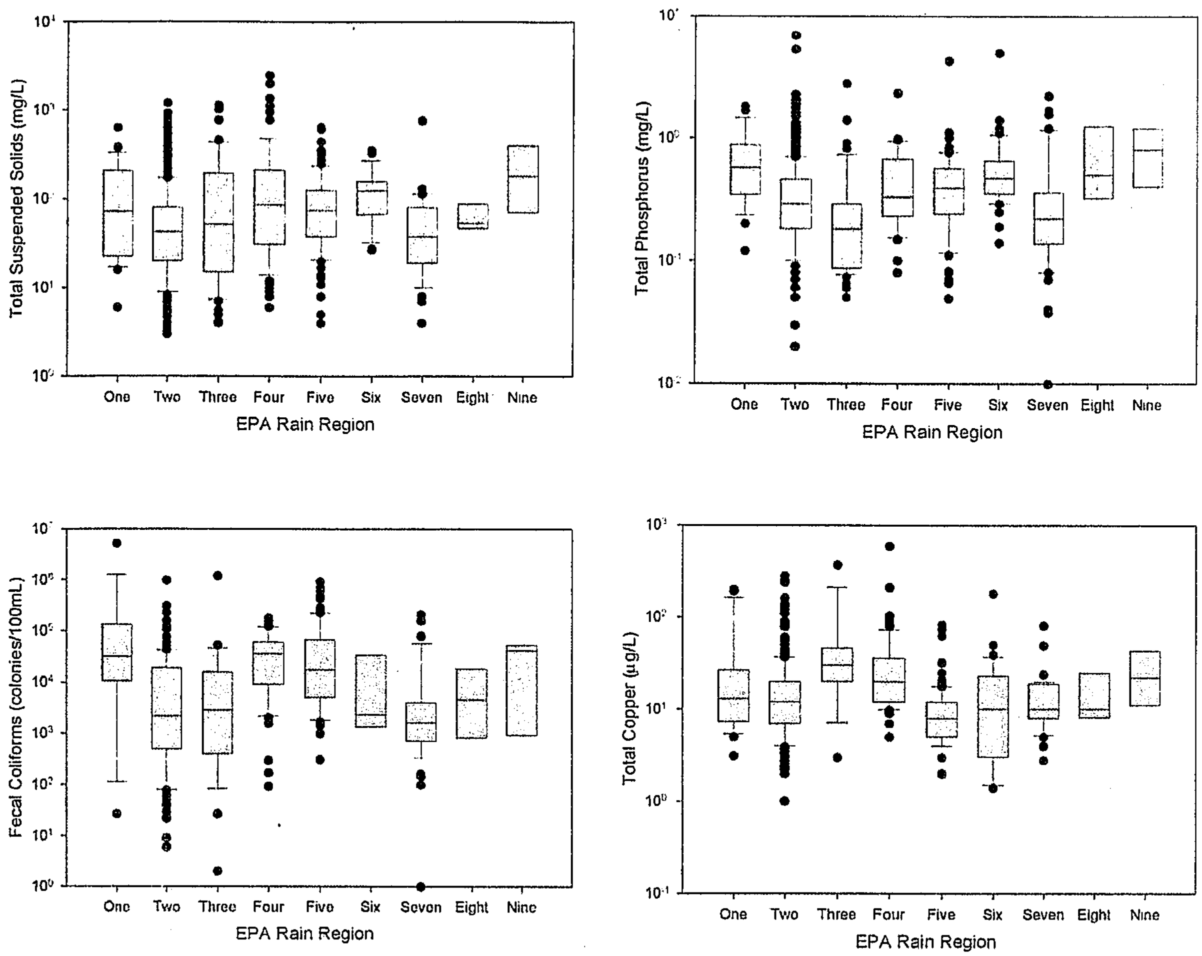


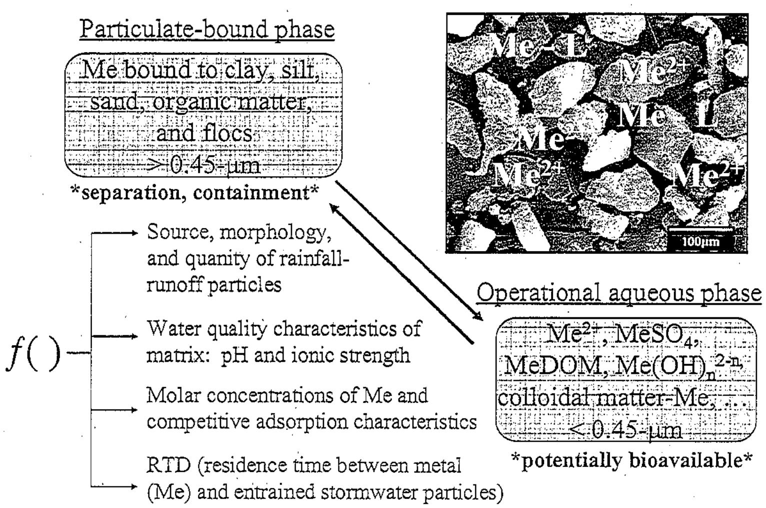
Figure 3-4. Example Residential Stormwater Data by Geographical Area (NSQD, Version 1.1). Shown are TSS, total phosphorus, fecal coliform, and total copper. Reprinted with permission from Pitt et al. (2004).

3.3.3 Effects of Water Chemistry and Hydrology on Pollutant Behavior

In wet weather flows, chemistry and hydrology are linked. These factors affect the physical and chemical characteristics of pollutants in wet weather flows, and largely influence treatability. However, experience over the last decade has demonstrated that there continues to be a significant gap in knowledge between stormwater treatment design/analysis and fundamental unit operations and processes that can demonstrate treatment viability as a function of the physical and chemical characteristics of stormwater loadings. There remains a significant lack of basic scientific knowledge (in particular peer-reviewed published knowledge) regarding the mechanisms of dissolution, leaching, speciation, partitioning kinetics and equilibrium, as well as the distribution of metals, inorganics, and organics. Yet such knowledge is a necessary first step and must serve as the foundation for control/treatment of pollutants in urban runoff. With an emphasis on the implications for treatability, the following subsections address the effects of metal partitioning, speciation, size distribution of particulate-bound metals, and the occurrence of first flush. Many conclusions presented herein are based on data collected from transportation land use sites. Also refer to the Pollutant Fact Sheets (Appendix A) for more information on treatability of specific pollutants.

3.3.3.1 Metal Partitioning

Partitioning refers to how much metal mass is associated with the dissolved fraction or the particulate-bound fraction. Partitioning between the dissolved and particulate-bound fractions in urban runoff is a dynamic process affected by pH, alkalinity, residence time, and solids characteristics. These factors vary significantly between and during hydrologic events, and with pavement type and traffic patterns (Sansalone and Buchberger, 1997). Partitioning between the two phases is depicted conceptually in Figure 3-5. The dissolved and particulate fractions and the equilibrium partitioning coefficient (K_d) are defined in Figure 3-6. Partitioning can favor the dissolved fraction for low rainfall pH levels, low pavement residence times in terms of minutes, low solids levels, and low alkalinity. Partitioning favors the particulate fraction under higher pH, alkalinity, residence time and solids levels. The dissolved fraction speciation is a function of organic and inorganic complexes including carbonates, organic matter and sulfates (as discussed in Section 3.3.3.2).



Metals of interest: Mg, Al, Ca, Cr, Mn, Fe, Ni, **Cu**, **Zn**, As, **Cd**, **Pb**

Figure 3-5. Conceptual Illustration of Partitioning Between Dissolved and Particulate Phases.
The particulate phase ranges from larger colloidal material to sand-size material as shown in the micrograph above. Me = metal.

$$C_{T,j} = C_{d,j} + C_{p,j}$$

Total metals [μg/L]

All metal, j, that pass through a 0.45-μm membrane filter: ions, aqueous complexes, metals adsorbed onto colloidal matter < 0.45-μm.

All metals retained on 0.45-μm filter: product of $C_{s,j}$ (mass of Me/mass of adsorbing solids) and SSC.

$$f_{d,j} = \frac{C_{d,j}}{C_{T,j}} = \frac{1}{[1 + K_{d,j}(m)]}$$

$$f_{p,j} = \frac{C_{p,j}}{C_{T,j}} = \frac{K_{d,j}(m)}{[1 + K_{d,j}(m)]}$$

$$K_d = \frac{(C_{p,j}/m)}{C_{d,j}} \qquad f_{d,j} + f_{p,j} = 1$$

$K_{d,j}$: equilibrium partitioning coefficient in L/Kg for metal, j

m : gravimetric concentration of adsorbing matter in rainfall runoff. SSC in kg/L for rainfall-runoff evaluations

$f_{p,j}$: Particulate fraction (unitless)

$f_{d,j}$: Dissolved fraction (unitless)

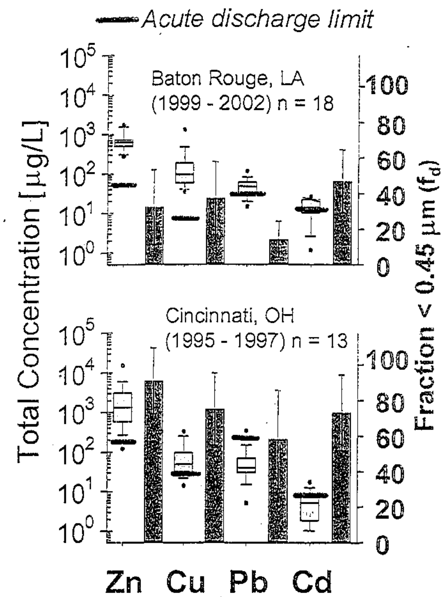
Figure 3-6. Definition of Dissolved and Particulate Fractions and Partitioning Coefficient.

Knowledge of both equilibrium partitioning and the kinetics of partitioning are important from a treatability and toxicity (bioavailability) perspective. Partitioning at sites of similar drainage characteristics and loadings can result in significantly different partitioning kinetics and partitioning endpoints. Figure 3-7 shows event mean concentrations for metals, equilibrium partitioning for metals, water chemistry, and hydrology for transportation land use sites in Baton Rouge, LA and Cincinnati, OH. The two sites are similar in that they are upper urban watershed sites of similar land use, size, geometry, loading, and drainage. The two significant differences in the sites are the lower rainfall pH in Cincinnati combined with asphalt pavement, compared to a higher yet still acidic rainfall pH in Baton Rouge and Portland cement concrete pavement.

While total concentration levels are similar, metals at the Baton Rouge site are more highly particulate-bound compared to a largely dissolved fraction in Cincinnati. Equilibrium partitioning results suggest that UOPs at the Cincinnati site should focus on mechanisms to remove the dissolved fraction such as ion exchange, surface complexation, adsorption or precipitation, as well as require a unit operation such as filtration or sedimentation depending on the gradation. In contrast, Baton Rouge partitioning results suggest that UOPs should focus on mechanisms to remove the particulate-bound fraction of metals.

As a basis of comparison, ranges for median EMCs for overall urban land use categories are 38 to 48 μg/L for total Cu, 161 to 204 μg/L for total Pb, and 179 to 226 μg/L for total Zn (Novotny and Olem, 1994). Water chemistry may be significantly different for different sites, regions and land uses. With one possible exception of paved transportation land use, which is well-defined and has readily-identifiable sources, utilization of land use alone may be of little benefit when trying to predict water quality (Novotny and Olem, 1994). There are few, if any reliable surrogates or combinations of surrogates, such as land use that have general applicability. While this will eventually change, there is little substitute for site water quality characterization data at this time. However in the absence of these site-specific data or when predicting future built-out conditions, land use and geographic region may be the only surrogate available for characterizing runoff quality including metals partitioning. The National

Stormwater Quality Database, as discussed earlier in this chapter, is probably the best source of general metals partitioning data for all major land uses currently.



Chemistry/Hydrology – Baton Rouge:

	µ	Range	Unit
SSC	272	32 - 519	mg/L
DOC	99	66 - 138	mg/L
COD	351	82 - 1101	mg/L
pH	7.2	6.5 - 8.1	S.U.
Alkalinity	37.7	8 - 107	mg
Hardness	39	30 - 43.3	$CaCO_3$/L
Rainfall	1266	968 -1583	mm

Chemistry/Hydrology – Cincinnati:

SSC	134	29 - 259	mg/L
DOC	10	2 - 25	mg/L
COD	230	115 - 332	mg/L
pH	6.8	6.0 - 8.0	S.U.
Alkalinity	39	7.8 - 130	mg
Hardness	64	18 - 171	$CaCO_3$/L
Rainfall	1161	1019 - 1357	mm

Figure 3-7. Site Comparison of Metals Partitioning, Runoff Chemistry, and Hydrology.
(µ = mean). Both watersheds are urban transportation land use. The Baton Rouge watershed is 1088 m² and the Cincinnati watershed is 300 m². Both sites capture urban pavement sheet flow.

Partitioning kinetics is also significantly different for the Baton Rouge, LA and Cincinnati, OH sites. Figure 3-8 provides an illustration of the time-dependent partitioning of Cu in stormwater samples for a fixed set of stormwater chemistry parameters at the Cincinnati, OH site (Sansalone and Buchberger, 1997). The data show partitioning to the particulate-bound fraction after 6 hours (although, Cu remains predominately in the dissolved phase). Additionally, a consistent increase in K_d as a function of time for Pb, Cu, Cd and Zn can be observed for the August 8, 1996 event on the right side of Figure 3-8 despite the inverse trend in TSS. In contrast, Baton Rouge partitioning occurs very rapidly, occurring in less than two hours for all metals.

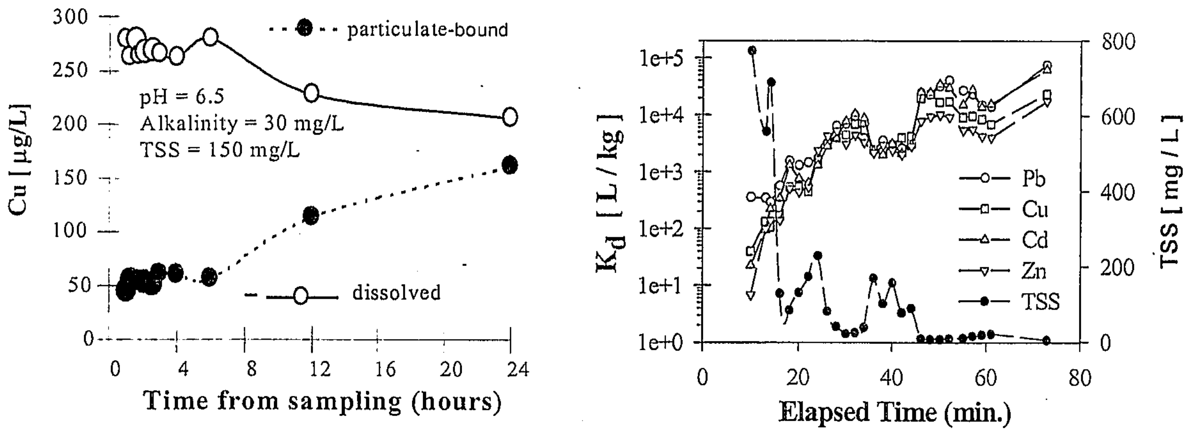


Figure 3-8. Time-Dependent Partitioning of Metals in Wet-Weather Runoff Samples.
Cu in wet weather runoff samples for 15 July, 1995 runoff event (left) and the consistent temporal increase in heavy metal partitioning coefficient, k_d for an August 8, 1996 event (right) from the Cincinnati, OH site.

As with event mean concentrations, f_d and K_d values are highly site-specific (as illustrated in the comparison between Baton Rouge and Cincinnati) and cannot be predicted based on land use. The f_d and K_d values are highly dependent on aqueous and solid phase chemistry as well as site hydrology.

3.3.3.2 Speciation

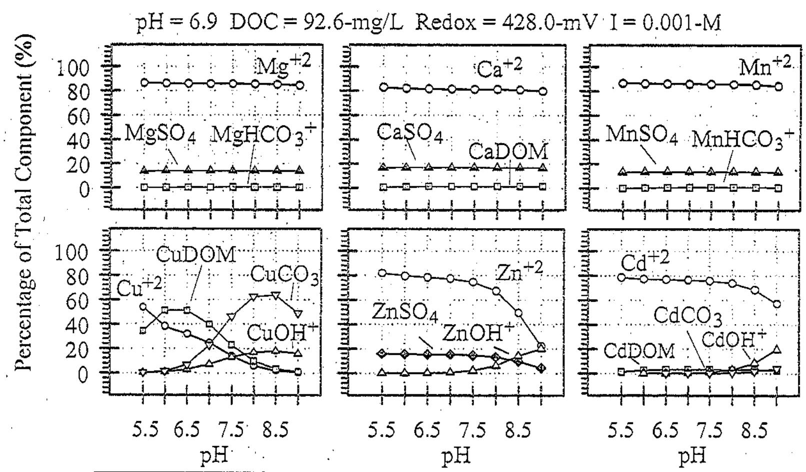
The particular chemical form in which an element exists in water is its speciation. Depending on the water chemistry, metals, inorganics, or organics will speciate depending on the presence of complexing ligands (anions or molecules that form coordination compounds) in urban runoff. In an aqueous environment, inorganic, organic or metal ions can be surrounded by anywhere from 4 to 8 water molecules, forming a hydration sphere. The coordinate number indicates the number of water molecules associated with a metal ion. In natural waters, these metals often act as acids since they tend to draw electrons from water, causing the H^+ to be easily dissociated. The following equation generalizes speciation of a metal ion in a pure water matrix.

$$Me^{n+} + H_2O \leftrightarrow MeOH^{n-1} + H^+$$

However, some metal ions form strong bonds to OH^-, causing the complex to act as a base. When a particular hydration sphere comes in contact with an anion, the two entities compete for the positively charged metal ion. Typically, the anion has a stronger affinity and will form a ligand complex with the metal. The binding strength of the complex is gauged by a stability constant. Metals can also form mixed ligand complexes with a variety of inorganic anions involved in the final product. Stormwater runoff hosts a variety of both organic and inorganic ligands originating from anthropogenic debris, fertilizer runoff, and organic and inorganic constituents. These ligands include Cl^-, NO_3^-, PO_4^{-2}, HCO_3^-, SO_4^{-2}, and dissolved organic matter (DOM). Speciation often changes with changes in water chemistry or hydrology. For example, lead associated with DOM may be exchanged in favor of carbonate species. Refer to the Pollutant Fact Sheets (Appendix A) for specific information on the relative abundance of dissolved metal species in wet weather runoff.

Figure 3-9 shows equilibrium speciation based on site mean water quality for the Baton Rouge, LA site. Speciation modeling using MINTEQ, an equilibrium speciation model that can be used to calculate the equilibrium composition of dilute aqueous solutions, is illustrated for selected metals as a function of pH. Predominant anions at the site were HCO_3^-, Cl^-, NO_3^-, PO_4^{-2}, SO_4^{-2}, and DOM. The cation and anion levels at the site, and charge balances are provided in detail by Dean et al. (2005). Results indicate that for typical metals concentrations at the site, the dissolved fraction for Mg, Ca, Mn, Zn and Cd are dominated by the divalent species of these metals. Results for Cu suggest that the dominant species below a pH of 7.2 (site mean pH) is CuDOM and above the site mean pH is $CuCO_3$.

Knowledge of metal speciation and complexation (and changes in speciation and complexation) is crucial from a treatment perspective because the complexes and species that form affect the selection of appropriate UOPs. Metal complexes can increase the tendency of metal precipitation, sequentially reducing the toxicity of the metal (Snoeyink and Jenkins, 1980). Also, the promotion of certain ligand complexes could form strong bonds with the metal ions, reducing the bioavailability of dissolved pollutants to aquatic biota. For example, Cu^{2+} is a very reactive species. The reactivity of Cu^{2+} results in bioavailability yet also allows a variety of unit processes including surface complexation, ion exchange or precipitation to be utilized to bring about mass transfer of Cu^{2+}. In comparison, Cu complexed with carbonate (i.e., $CuCO_3$) is an uncharged complex that is more challenging to control, requiring chemical precipitation or advanced UOPs such as reverse osmosis or distillation. The last two UOPs are technically feasible but generally not economically viable.



	Mg	Ca	Mn	Cu	Zn	Cd
[µg/L]	8.3E+3	3.5E+4	461.0	134.1	921.0	29.9
[mM]	0.4	3.7	8.4E-3	2.1E-3	1.4E-2	2.6E-4

Figure 3-9. Illustration of Metal Species for Selected Metals in Wet Weather Runoff.
From the Baton Rouge, LA site based on site mean water chemistry. Watershed is 1,088 m² of urban transportation land use pavement.

3.3.3.3 Distribution of Particulate-Bound Metal Mass

A concept that has been applied broadly to the treatment of metals in stormwater is that the majority of metal mass is associated with the suspended fraction. While this concept may have merit within the water column of a receiving water under equilibrium conditions because the settleable and sediment fraction have either been removed in the watershed transport process or have been settled out to the benthic layer in the receiving water, the concept provides an incomplete examination of the metal distribution across the source gradation. The entire gradation generally encompasses the following nominally-sized classes of particles: colloidal < 1 μm, suspended (1–25 μm), settleable (25–75 μm), and sediments (> 75 μm) for those materials that are not neutrally-buoyant or floatable.

Results of such metal distributions across the entire gradation are summarized in Figure 3-10 for a series of 12 fully-captured (all runoff volume captured) events from the Baton Rouge, LA site.

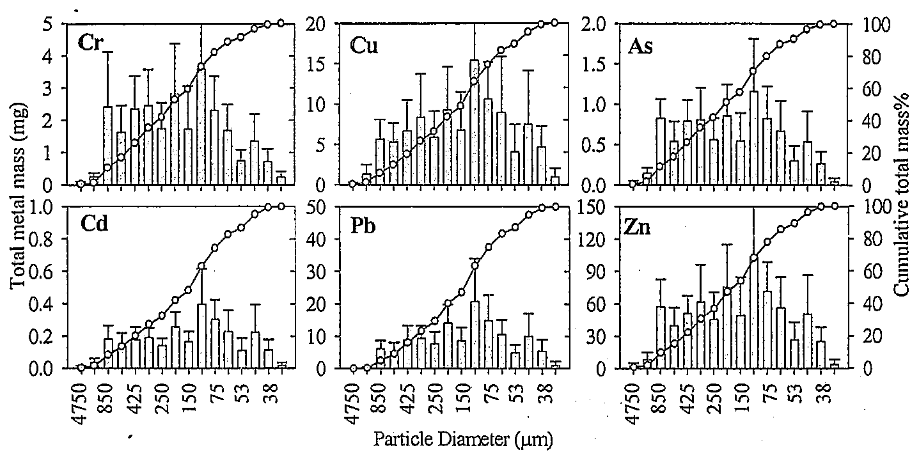


Figure 3-10. Distribution of Metal Mass Across Entire Gradation in Wet Weather Runoff.
Bars represent the mean of 12 rainfall-runoff events and the range bars represent the standard deviation. Data from a Baton Rouge watershed comprised of 1,088 m^2 of urban transportation land use pavement.

The data indicate that the predominance of metal mass is associated with the settleable and sediment-size fractions as opposed to the suspended fraction or colloidal fraction. The particulate fraction distributes across the gradation as a function of particle surface area, amphoteric (pH-dependent) surface charge, particle geochemistry, granulometry and size-based particulate loading. Results suggest that UOPs that are capable of effectively separating these sediment-size particles should also be able to demonstrate effectiveness in separating a significant fraction of particulate-bound metal mass.

3.3.4 First Flush Phenomenon

First flush refers to an assumed elevated load of pollutants discharged in the beginning of a runoff event. A number of jurisdictions base treatment system sizing criteria upon the treatment of first flush runoff based on the concept that most pollutants will be treated without having to treat the relatively clean water that discharges during the later stages of a storm event (Minton, 2002). First flush phenomena are discussed in numerous studies (Barrett et al., 1995, Driscoll et al., 1990; Field et al., 2000; Glenn et al., 2002; Hoffman et al., 1985; Hoffman and Quinn, 1987;

O'Shea et al., 2002; Sansalone and Buchberger, 1997; Sansalone et al., 1998), and a first flush has been noted for a variety of stormwater constituents such as hydrocarbons, metals, sediment and nutrients. The extent to which a first flush is observed has been found to vary according to the flow event and the relative partitioning of constituents between particulate and dissolved phases (see below).

A mass to volume curve is one method of displaying the relationship between mass transport and the storm flow event, in order to predict the strength of a first flush. The concept of a mass to volume curve is illustrated in Figure 3-11 for the Baton Rouge, LA transportation land use site from an storm event on May 31, 2001. Exponential curves illustrate a first-flush while linear patterns represent the absence of a first-flush. Notice that for the same event, some constituents exhibit a first-flush, while others do not. In this case, particulate and particulate-bound constituents exhibit a first-flush and dissolved fractions do not.

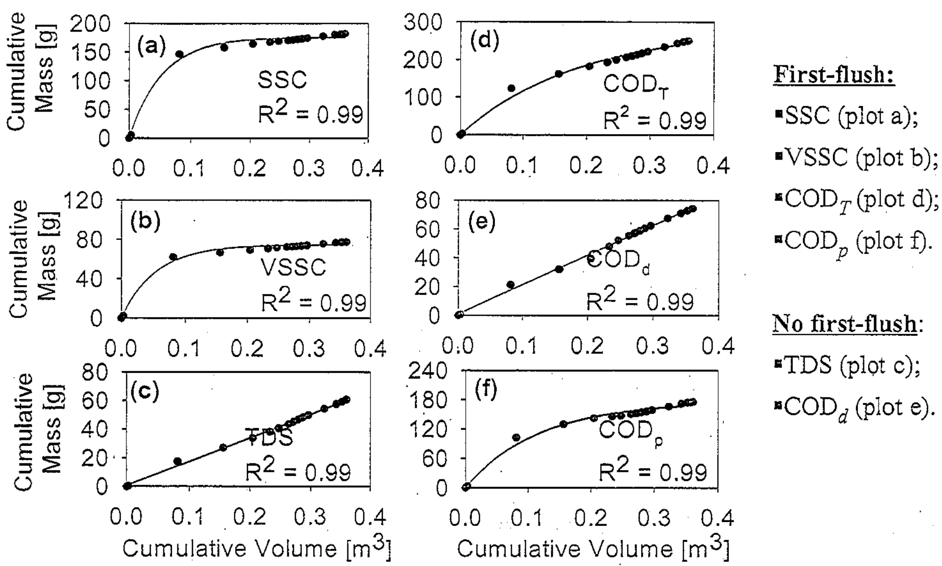


Figure 3-11. Illustration of a First-Flush or Lack-Thereof (Linear Patterns).

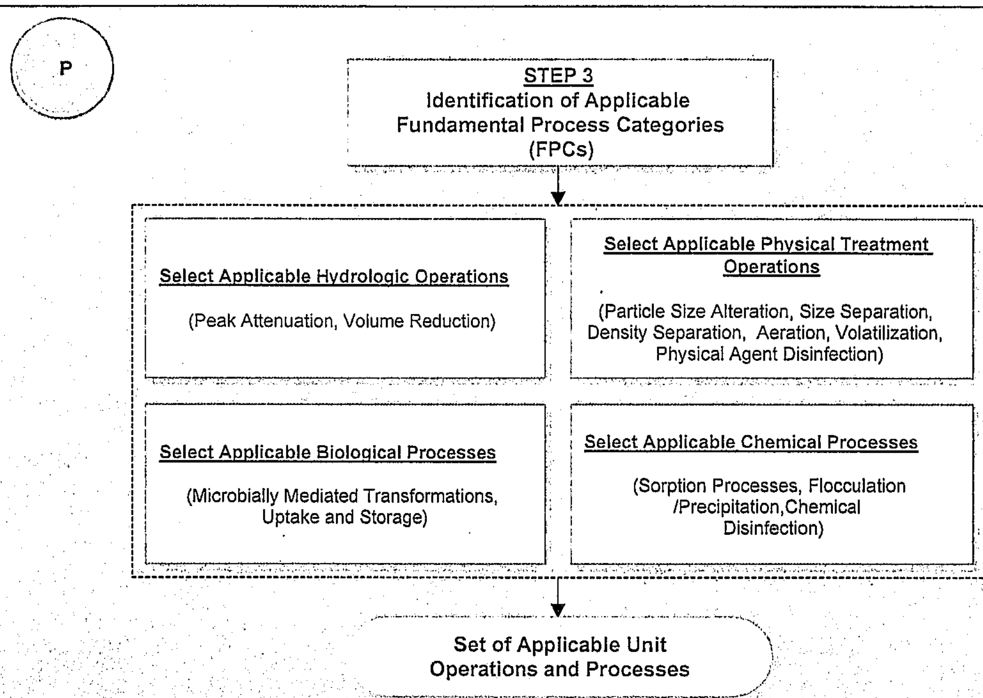
In comparison to physically-based methods, non-parametric statistical tests have been utilized to examine first flush effects using data from the National Stormwater Quality Database (version 1.1) (Pitt et al., 2004). Results of this study of many sites and 3,700 events also indicated that a first flush was not always present for all constituents or for all land uses. Commercial and residential areas were more likely to exhibit a first flush effect, especially if the peak rainfall occurred near the beginning of the event. It is expected that this effect will be more likely to occur in a watershed with a high level of imperviousness, but the data indicated first flushes less than 50% of the time for the most impervious areas. Groups of constituents showed different behavior for different land uses. All the heavy metals evaluated showed higher concentrations at the beginning of the event in the commercial land use category. Similarly all the nutrients showed a higher concentration for residential land use except for total nitrogen and orthophosphate. A first flush effect was not found in the bacteria analyses for any land use. Conventional constituents showed elevated concentrations in commercial, residential and institutional land uses.

The first flush may or may not appear at a given site for a given constituent. For instance, solids may erode more readily later during a storm event, when soils are saturated (Sutherland and Jelen, 2003). Generalizations cannot be made about whether or not there will "always" be a first flush exhibited for constituents in particulate, dissolved, or mixed forms. Sansalone and Cristina (2004) emphasize the need to characterize any possible first flush phenomenon on the basis of the particle size distribution of the constituent. Because the occurrence of first flush depends on numerous site and rainfall characteristics, stormwater treatment can seldom be based on the concept of capturing just the early part of the storm event, even though this leads to more economical treatment (because a lower volume needs to be controlled). A better practice, or least a more demonstrably justifiable practice will usually be based on capture of a specified volume for all storms, as determined by a continuous simulation. This method is illustrated in Section 7.1.

Clearly, the variability of concentration and flow during a storm event strongly influences the selection of UOPs and TSCs. High-rate devices, such as filters and some proprietary devices, are very susceptible to inefficiencies created by possible elevated concentrations late in a storm, whereas devices that typically store runoff from more than one event (e.g., ponds, wetlands) are affected less.

CHAPTER 4.0

IDENTIFY FUNDAMENTAL OPERATION AND PROCESS CATEGORIES



Key Concepts:
- What hydrologic controls may be potentially applicable for your project?
- What physical unit operations may be of use in your design?
- What chemical and biological processes may be applicable for water quality treatment?

4.1 Introduction

While the previous chapter emphasizes that the design of a stormwater treatment system should be based on a fundamental understanding of water quality (solid-phase and aqueous chemistry) and hydrology, this has not been the common approach. The more common design approach is to select "BMPs" that are expected to or have been shown in some manner to treat the pollutants of concern (or a surrogate pollutant such as TSS) consistent with some stipulated performance measure (e.g., 80% removal) with little attention paid to the physical, chemical and biological UOPs that occur within the BMPs. The recommended approach herein is to first select UOPs applicable for target constituents based on the constituent form (i.e., dissolved, colloidal, particulate), chemical speciation (e.g. ionic metal species, phosphorus species, etc.), and granulometric characteristics (e.g., particle size, specific gravity, surface area). Then individually select the components of a treatment system based on the UOPs that are effective for treating target constituents. Understanding UOPs is key to the success of the treatment system design, as well as system operation and maintenance. Successful treatment will require operation methodologies, regular maintenance and residuals management. For example, successful primary clarification of municipal wastewater requires primary sludge design and management. Similar considerations for operational, maintenance and management strategies as also needed in stormwater treatment.

Many stormwater pollutant control mechanisms are similar to fundamental UOPs used to remove various constituents found in wastewater (Metcalf and Eddy, 2003; Minton, 2002). However, experience over the last decade has demonstrated that there continues to be a significant gap in knowledge between stormwater treatment system design/analysis and fundamental UOPs that can demonstrate treatment viability as a function of the physical and chemical characteristics of stormwater loadings (Sansalone and Teng, 2004; Teng and Sansalone, 2004). Such knowledge is critical to the success of a new generation of stormwater treatment systems that are developing in response to the February 2000 U.S. EPA Phase II Stormwater Final Rule. It requires identification of treatment mechanisms and rates, chemical partitioning and speciation, physical-chemical characteristics of transported particulate matter, and management of residuals separated through treatment operations. It is also important to verify treatment effectiveness through scientific-based monitoring along with evaluations of their treatment effect on receiving waters and downstream hydraulic conditions.

All UOPs can be organized according to four fundamental process categories (FPCs): 1) hydrologic controls, 2) physical operations, 3) biological processes, and 4) chemical processes. Table 4-1 provides a summary of the FPCs, and related UOPs and treatment system components (TSCs). TSCs, which are discussed in Chapter 5.0, provide one or several UOPs, and include conventional BMPs, such as swales, ponds, tanks, and so forth, in addition to pretreatment devices (e.g., trash racks, catch basin screens, etc.), and tertiary enhancements (e.g., soil amendments, carefully selected vegetative species, and custom hydraulic controls such as weirs, etc.).

Sometimes the conventional, more passive UOPs are not feasible options for meeting water quality management goals. In these instances, additional or advanced unit operations and processes may be necessary. However rather than designing and constructing a highly controlled urban runoff treatment facility, which is certainly possible and may someday be necessary, what is more commonly done is the diversion of dry weather or some portion of wet weather runoff to a wastewater treatment plant. Because these more advanced treatment mechanisms are not common for urban runoff and are well covered in available literature on municipal treatment operations and processes (Metcalf and Eddy, 2003), only a limited subset of these advanced processes are discussed in this document.

Table 4-1. Structural Stormwater Controls and Associated Fundamental Process Categories.

Fundamental Process Category (FPC)	Unit Operation or Process (UOP) *Target Pollutants*	Typical Treatment System Components (TSCs)
Hydrologic Operations	Flow and Volume Attenuation	Extended detention basins Retention/detention ponds Wetlands Tanks/vaults Equalization basins
	Volume Reduction *All pollutant loads*	Infiltration/exfiltration trenches and basins Permeable or porous pavement Bioretention cells Dry swales Dry well Extended detention basins
Physical Treatment Operations	Particle Size Alteration *Coarse sediment*	Comminutors (not common for stormwater) Mixers (not common for stormwater)
	Physical Sorption *Nutrients, metals, petroleum compounds*	Engineered media, granular activated carbon, and sand/gravel (at a lower capacity)
	Size Separation and Exclusion (screening and filtration) *Coarse sediment, trash, debris*	Screens/bars/trash racks Biofilters Permeable or porous pavement Infiltration/exfiltration trenches and basins Manufactured bioretention systems Engineered media/granular/sand/compost filters Hydrodynamic separators Catch basin inserts (i.e., surficial filters)
	Density, Gravity, Inertial Separation (grit separation, sedimentation, flotation and skimming, and clarification) *Sediment, trash, debris, oil and grease*	Extended detention basins Retention/detention ponds Wetlands Settling basins, Tanks/vaults Swales with check dams Oil-water separators Hydrodynamic separators
	Aeration and Volatilization *Oxygen demand, PAHs, VOCs*	Sprinklers Aerators Mixers (not common for stormwater)
	Physical Agent Disinfection *Pathogens*	Shallow detention ponds Ultra-violet systems
Biological Processes	Microbially Mediated Transformation (can include oxidation, reduction, or facultative processes) *Metals, nutrients, organic pollutants*	Wetlands Bioretention systems Biofilters (and engineered bio-media filters) Retention ponds Media/sand/compost filters
	Uptake and Storage *Metals, nutrients, organic pollutants*	Wetlands/wetland channels Bioretention systems Biofilters Retention ponds
Chemical Processes	Chemical Sorption Processes *Metals, nutrients, organic pollutants*	Subsurface wetlands Engineered media/sand/compost filters Infiltration/exfiltration trenches and basins
	Coagulation/Flocculation *Fine sediment, nutrients*	Detention/retention ponds Coagulant/flocculant injection systems
	Ion Exchange *Metals, nutrients*	Engineered media, zeolites, peats, surface complexation media
	Chemical Disinfection *Pathogens*	Custom devices for mixing chlorine or aerating with ozone Advanced treatment systems

The following subsections provide a detailed discussion of the theoretical background and application of the unit operations and processes shown in Table 4-1.

4.2 Hydrologic Operations

Flow alteration is a significant unit operation for stormwater treatment; and historically has been the single major unit operation for stormwater management for decades in the U.S. and many parts of the world. Water quality and quantity cannot be separated; alterations to the hydrograph effects water quality. In large part, flow alteration is implemented as a hydrologic control. Flow alteration includes modifications to components of the hydrologic cycle such as runoff, infiltration, detention, storage and evaporation. In general, the goals of these physical operations (recognized as hydrologic controls) have been to reduce volume, reduce peak flows, generate more uniform flow rates and attenuate temporal aspects of flow. To varying degrees these hydrologic controls can have a significant impact on water quality. Applications of hydrologic modification are ubiquitous in the built environment and are intentional or inadvertent, as well as beneficial or detrimental. Examples of intentional applications that have potential water quality and quantity benefits include infiltration, detention and flow equalization, while detrimental applications include impervious paving or loss of vegetation.

The following subsections discuss the two fundamental hydrologic unit operations: flow attenuation and volume reduction (or minimization of volume increases).

4.2.1 Flow Attenuation

Flow attenuation refers to the hydrologic operations responsible for reducing peak event discharges (e.g., "peak shaving"). The primary mechanisms involved in flow attenuation include interception, conveyance, and detention; and to a lesser degree infiltration.

4.2.1.1 Interception

Interception is a form of detention storage that occurs when leaves, stems, branches, and leaf litter temporarily store rainfall. Interception is considered to be detention storage if raindrops drain off vegetation by "throughfall" (dripping off a leaf onto the ground) or by stemflow (flowing down stems or trunks). Throughfall accounts for the majority of the movement of intercepted rainfall. Intercepted rainfall that is retained is lost to the atmosphere by evaporation from the surface of leaves. The retained and evaporated fraction of rainfall is considered a volume reduction operation and is discussed in more detail in Section 4.2.2.

The percentage of rainfall that is intercepted increases with the density of vegetation, including all vertical layers from canopy to leaf litter. At maximum density, both trees and grasses may intercept 10-20% of precipitation from an individual storm. Per unit of ground area, some grass species have the same leaf area as many trees (Dunne and Leopold, 1978).

4.2.1.2 Conveyance

Conveyance is the transport of surface runoff and includes the entire flow path from where a raindrop falls to where it enters the receiving body of water. In conventional stormwater designs, conveyance is synonymous with the efficient drainage of runoff. By contrast, decentralized controls that provide conveyance also promote infiltration, improve water quality, and increase runoff travel time, or time of concentration (Tc). They are often critical components of the treatment train approach. In this guidance, "conveyance" refers to the act of transporting runoff, rather than the carrying capacity of a treatment system or other structure.

4.2.1.3 Detention

Detention is the temporary storage of stormwater, which is released over a period that can generally range from hours or days after rainfall ceases. Detained stormwater may exist as ponded free water or can be held within moist soil. In highly urbanized environments, detained runoff ultimately enters the storm drain system. In a vegetated system, ponded water and any soil moisture above the field capacity are detained, rather than retained, because that portion of the stormwater slowly percolates by gravity through the soil column into the underdrain. For small, frequently-occurring storms, the release of detained water will not usually cause flooding because the stormwater will enter the system over a much longer period of time, and at a lower rate, than if decentralized controls were not in place.

4.2.2 Volume Reduction/Minimization of Volume Increases

Volume reduction hydrologic operations are responsible for reducing the total volume of runoff via retention, infiltration, and evapotranspiration. Runoff can also be detained in storage vessels such as underground tanks and vaults and reused (e.g., irrigation water). If pollutant loads are a high concern, volume reduction should be a major unit operation in any selected treatment system design.

4.2.2.1 Retention

Retention captures stormwater permanently. The volume of retained runoff that may never enter the storm drain system can include vegetative interception, evaporation, transpiration of soil moisture, and re-use. Evaporation may occur at differing rates and extents from soil, vegetation, or hard surfaces such as pavement. Transpiration reduces the water volume within the root zone of soil. As stormwater enters a treatment system, infiltrating water will be retained up to the point that the soil moisture content equals the field capacity. If the rainfall is sufficiently light such that the soil moisture content in a vegetated system never reaches field capacity, ET alone will eliminate the volume of stormwater in the soil.

4.2.2.2 Infiltration

Infiltration is the downward movement of water into the soil after surficial entry and percolation through pore spaces. In an open system such as a meadow, this movement is unrestricted, and water can infiltrate down to and recharge the groundwater table. Groundwater recharge is a basic component of the natural hydrologic cycle. In urban areas, unrestricted infiltration may exacerbate infiltration and inflow (I/I) problems in both separate and combined sewer systems; the likelihood of this scenario must be evaluated before constructing unlined infiltration systems.

In urban areas, some of the infiltrated stormwater will be retained and its volume permanently taken "out of the system." Stormwater may also be detained, which temporarily reduces the amount of stormwater that would otherwise be in the storm drain system and allows it to enter the system over an extended period of time.

The soil moisture content determines the volumes of stormwater that are retained and detained. In a given treatment system, the volume of retained water is the volume for which the soil moisture content equals the soil's field capacity. The retained water leaves the soil through ET. The field capacity is the point at which free drainage by gravity ceases and the remaining water is held in the soil pores by capillary and osmotic forces. At this moisture content, the soil is unsaturated. The volume of additional stormwater that causes the soil moisture content to exceed the field capacity will be detained, and will drain by gravity into underdrains over a period of several hours or days.

4.2.2.3 Evapotranspiration

Evapotranspiration (ET) refers to the combined effects of evaporation and transpiration in reducing the volume of water in a vegetated area during a specific period of time. The volume of water in the root zone of soils is taken up by roots and then transpired by being diffused through leaves. (Uptake by roots may also remove a variety of pollutants from stormwater.)

For the first two to three days after a rainfall, ponding and infiltration control (i.e. detain) a large proportion of the stormwater volume even when ET is occurring. After this time, gravitational drainage into the underdrains effectively ceases and the field capacity is reached. ET becomes the dominant process because the volume of water present in the soil at field capacity will be lost to the atmosphere through ET alone. The following equation gives the maximum volume of water that ET can potentially remove once the soil moisture content equals the field capacity (FC).

$$V_{trans} = D_r \cdot A \cdot (FC - WP) \qquad [4\text{-}1]$$

Where: V_{trans} = Transpired volume
D_r = Rooting depth
A = Soil surface area
FC = Field capacity
WP = Wilting point

The wilting point is the soil moisture content beyond which plants cannot exert enough suction to draw more water out of the soil. The difference between the field capacity and the wilting point is the moisture content available for transpiration.

The field capacity of urban stormwater treatment systems can be designed to meet desired drainage characteristics. The connectivity to underlying soils, including the presence of underdrains and gravel bedding, also affects the field capacity. Many vegetated systems, such as rain gardens, have a low field capacity in order to maximize free drainage and filter pollutants.

4.3 Physical Operations

A physical operation, in contrast to chemical or biological processes, is a form of treatment that is brought about by a physical mechanism such as sedimentation. Physical unit operations form the basis for many operations that are considered as preliminary and primary treatment (or in the case of filtration, secondary) operations in wastewater treatment. Physical unit operations are also the dominant forms of treatment in most stormwater TSCs, whether these operations are an intentional or incidental design mechanism. The following sub-sections discuss physical unit operations and have been categorized according to the physical characteristics of the operation in a stormwater setting. In unit operation design, preliminary operations such as trash racks, bar racks or nets physically separate coarser size trash/debris whether this material is denser than water or floatable. Primary operations such as primary clarification, sedimentation or hydrodynamic separation, physically separate denser (specific gravity greater than 2.0) sediment and settleable size material and any trash or debris that passed through preliminary operations. Such primary operations should be capable of separating a significant fraction of the sediment

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and settleable size material on a mass basis. As a result of primary operations based on particle, solids or debris separation, primary effluents have a reduced mass-based (and to a lesser degree number-based) solids concentration that is generally in the suspended size range. Both the reduction in mass concentration and separation of the debris, sediment and settleable sizes are necessary for effective functioning (without premature failure) of secondary treatment operations such as filtration.

4.3.1 Particle Size Alteration

Particle size alteration refers to the reduction in size of coarse particles by shredding or grinding into smaller, more uniform sizes for subsequent removal by downstream unit operations. It also refers to the increase in size of smaller colloidal and suspended particles through mixing and flocculation, for subsequent removal via settling or filtration.

4.3.1.1 Coarse Solids Reduction

Coarse solids and grid reduction includes methods of comminution, maceration and grinding. While these methods are standard practice in wastewater treatment, they are currently rare for treatment of stormwater residuals. As centralized runoff control and treatment develops in conjunction with decentralized control, coarse solids reduction will be increasingly applied. The potentially hazardous waste designation for some stormwater sediment residuals will likely result in more advanced management of these residuals as compared to wastewater coarse solids. While solidification/stabilization of coarse solids has been investigated from a research perspective, such management of coarse solids is still rare in practice.

4.3.1.2 Mixing and Physical Flocculation

Mixing is commonly carried out with the intention of blending or mixing one substance or phase with another, or for the purpose of facilitating heat or mass transfer. While mixing encompasses a wide range of velocity gradients at a range of scales, mixing is generally classified in terms of velocity gradients (G) as rapid ($G > 50\ sec^{-1}$) or slow mixing ($G < 50\ sec^{-1}$). Rapid mixing residence times are generally less than 30 seconds while slow mixing such as for flocculation can range from several minutes to one hour. Mixing operations are typically applied in coagulation applications as rapid mixing to blend a chemical coagulant with entrained solids. Mixing operations are typically applied in flocculation applications as slow mixing to bring destabilized particles in contact with each other to promote floc growth. In slow mixing for flocculation, an equilibrium level is achieved between floc formation and floc breakup once the floc becomes too large and velocity gradients shear the large floc to a more moderate-sized floc that remains coherent when subject to shear forces from slow mixing and differential sedimentation. Applications of flocculation (actually coagulation-flocculation) for stormwater treatment, while relatively rare are becoming more common (Babin et al., 1992; Carr, 1999; Decker and Guo, 2003; Escobar et al., 1998; Harper et al., 1999; WsDOT, 2003).

While engineered chemical and physical flocculation is beginning to be applied more widely in specific applications for stormwater treatment and indeed has been applied in receiving waters such as lakes and ponds for some time, flocculation occurs naturally in stormwater runoff. Depending on parameters such as mixing, pH, ionic strength, and particle properties, natural flocculation can begin within several hours to 12 hours of initial runoff. Natural flocculation, while generally not accounted for, can have a significant impact on stormwater clarification in TSCs such as sedimentation basins or in detention/retention facilities.

4.3.2 Size Separation and Exclusion

Two primary physical operations fall under the size separation category: screening and filtration.

4.3.2.1 Screening

Screening is a physical exclusion mechanism consisting of a surficial straining operation. Coarse screening or netting is generally (but there are exceptions) applied as a preliminary unit operation upstream of primary unit operations and in contact with untreated influent flows. Screens are simply intended to physically exclude solids (including trash, particles, debris and organisms) that have a dimension larger than a selected screen opening. In wastewater or combined sewer overflow applications, coarse screens have diameters as large as 150 mm and can be as small as 5 mm. Fine screening is applied to treated flows (whether previously treated from primary or secondary treatment) and generally fine screens have apertures less than 50 μm. When applied to urban runoff, screening is generally applied to untreated discharges as a coarse screening treatment. Screen design is mainly based on the choice of a physical size for exclusion and headloss whether the application is stormwater, wastewater or combined sewer overflows. Typical applications are upstream trash racks or screening bags or socks located at the outlet of runoff outfalls for trash screening. While these are not common in the U.S. such devices are common in Europe, Australia, New Zealand and Japan.

4.3.2.2 Filtration

Along with sedimentation and flotation, filtration is one of the oldest unit operations; over 3,000 years old. Filtration encompasses a wide range of physical and chemical mechanisms, depending on the filter media. These mechanisms include (Metcalf and Eddy, 2003):

1. Straining (surficial straining or chance contact within the filter)
2. Sedimentation
3. Impaction
4. Interception
5. Adhesion
6. Flocculation
7. Chemical adsorption
8. Physical adsorption
9. Biological growth (can result in clogging and failure of filters)

However, a discussion of several of these mechanisms is more appropriately part of chemical or biological unit processes and is thus discussed in separate sections of this document. This section is limited to the dominant physical processes that typically occur in inert filter media.

Filtration of stormwater is not considered a primary unit operation in that there are primary unit operations and processes that generally occur upstream of the filter unit to ensure the proper functioning of the filter. In general, suspended and settleable solids concentrations need to be reduced to less than 50 mg/L for influent to a filter, depending on the media type, filter design, maintenance schedule, and other factors that may affect filter performance. Filters are designed to remove particulate matter either on the surface of the filter through surficial straining or with depth within the filter. Effective filtration requires that either surficiallystrained or depth-filtered particles are removed on a regular basis. The build up of such particles either on the filter surface or within the filter media results in a significant increase in head loss. In centralized water and wastewater plants, filters are cleaned through regular backwashing. Filter maintenance is far more challenging in stormwater treatment systems that tend to be decentralized, as these systems have far less oversight and monitoring, yet require similar or greater maintenance than centralized treatment. Many underground filters are not visible; and while this can be aesthetically and spatially beneficial; the old adage of "out of sight, out of mind" is appropriate with respect to regular management and maintenance of underground filters.

Three general classes of filtration mechanisms can be approximated based on filter media size (as d_m, the mass-based median filter media size) and filtrate particle size (as d_p, the mass-based median particle size). When the $d_m/d_p < 10$ the predominant mechanism is surficial straining. when $20 > d_m/d_p > 10$ the predominant mechanism is depth filtration (mechanisms 2 through 6 and 9 in the list provided earlier in this section), and when $d_m/d_p > 20$, the predominant mechanism is physical and chemical adsorption (mechanisms 7 and 8) (Sansalone and Teng, 2004; Teng and Sansalone, 2004).

The two parallel constraints for filters are head loss and water quality. There are a whole series of saturated flow head loss models for saturated filters, the most famous being the Kozeny-Carmen model, although there are many other models for head loss (see Metcalf and Eddy, 2003, pg 1051). Modeling water quality through a filter has been far more challenging and generally requires laboratory or pilot scale parameters, although first-order models based on an exponential decrease in particulate concentration with filter depth are common (Urbonas, 1999). Evaluation of filters becomes even more challenging when flow is variably-saturated. While water and wastewater treatment filters are saturated flow systems, most stormwater treatment filters are variably-saturated, making filtration performance even more challenging to predict without calibrated numerical models (Sansalone and Teng, 2004). Variable saturation creates pockets of aerobic and anaerobic conditions, which affects microbial activity and the reduction of reactive stormwater pollutants, such as nitrogen. Nitrification and denitrification are two important microbial processes that are responsible for the removal of nitrogen from stormwater. These processes are discussed in detail in Section 4.4.1, Microbially Mediated Transformations.

4.3.3 Density Separation

Density separation takes advantage of density differences between the pollutant and water. It includes grit separation, sedimentation, flotation and skimming, and clarification.

4.3.3.1 Coarse Solid Removal or Grit Separation

Coarse solids removal or grit separation is generally facilitated by some combination of sedimentation and hydrodynamic separation. Coarse solids or grit have a relatively high gravimetric (mass) influence on the particulate gradation and a relatively small influence as number of particles. For example, large particles provide a significant contribution to the mass of particles, yet are relatively few in number compared to small particles. In general sedimentation of these particles is discrete (Type I) since they may not generate particle-particle interactions, although smaller grit material can impact differential sedimentation. Settleable and suspended solids, higher in number concentration, can undergo natural flocculant (Type II) settling because of greater particle-particle interaction. The mechanisms associated with sediment and settleable particle separation in urban runoff, and the associated separation mechanisms have clear physical and chemical parallels to wastewater treatment. Grit is generally classified as sand (generally larger than 200 μm), gravel and larger inorganic particulate-type materials. The typical assumption is that this particulate material has a specific gravity (ρ_s) similar to quartz sand (SiO_2) of 2.65 g/cm^3. Note that while many of the solid or particulate substrates in stormwater can be largely silica, there is a wide variety of particulate minerals that include many alumina silicates and carbonates. Grit separation is not a unique fundamental unit operation but a size and density based separation technique that combines several fundamental unit operations. Generally the particle size range targeted for removal by grit separation is a 200 to 250 μm, which are medium sand-size particles in the sediment fraction (> 75 μm). Settleable and suspended fractions are treated immediately downstream by primary sedimentation.

Because a significant size fraction of stormwater particles is grit-size and grit-like materials, and because of the many multipurpose unit operation designs that currently exist, grit removal is a primary unit operation as well a preliminary unit operation for maintenance and operational considerations. Incidental grit removal can be observed in most drainage appurtenances such as catch basins and inlets. The size or density separation of grit-size material from stormwater has become common in the practice over the last five years. Most treatment systems utilize some form of separate or multipurpose unit operation for intentional grit removal. This is facilitated by a variety of devices including classes of hydrodynamic separators such as deflective separation systems and vortex or inertial separation systems. Many proprietary devices on the market, depending on the sizing criteria used for a particular installation, can function as effective design elements for coarse solids removal, if maintained properly. These systems also work well for capturing trash and floatables, making them potential multipurpose unit operations. Grit removal can, in situations where large particles constitute a significant portion of the pollutant mass (e.g., where large quantities of road sand have been applied during winter months), be an effective unit operation for achieving water quality objectives. However its utility is often dramatically overstated due to the inherent nature of the pollutants of concern for a given project (e.g., pollutants are not largely associated with coarse particles, or pollutants are dissolved).

4.3.3.2 Sedimentation (Gravitational Separation)

Gravity separation or settling of sediment (> 75 μm), settleable (25–75 μm) and suspended (< 25 μm) particles from aqueous solution is the oldest and most widely used particle separation operation in water and wastewater treatment. Effective design utilizing gravity separation requires an understanding of the theory of particle settling, for ideal and non-ideal settling. Gravity separation or settling is a solid-liquid unit operation that utilizes gravity and the difference in density of the liquid and particulate components to separate particles. Gravity separation is the most common intentional or unintentional unit operation in practice, and serves as a treatment that protects downstream operations and processes. As such, gravity separation is considered as a primary treatment for runoff. Nearly all stormwater unit operations utilize sedimentation either by design for separation of particles, or inadvertently as an inherent function of storage or relatively quiescent conditions.

There are four general classes of particle settling (Type I through IV). Type I is discrete particle settling and is the most common assumption employed when considering first-order or initial settling calculations. The assumption of discrete particle settling is reasonably valid for gravimetric concentrations of particles less than 100 mg/L, but this is dependent upon the size gradation of the particles. For example, 100 mg/L of clay particles would not generally behave as a discrete system with respect to settling, while 100 mg/L of sand particles would more closely follow Type I settling. In wide non-uniform gradations such as stormwater runoff, there is not a distinct concentration below which the assumption of discrete settling is always valid given the temporal and spatial variability of particle gradations, but 100 mg/L is an approximate value. It can be shown that theoretically, that ideal Type I settling does not depend on sedimentation depth, although in practice a depth basis is generally part of any clarifier design (Metcalf and Eddy, 2003). This depth dependence suggests, in part, either the recognition of Type II and/or occurrence of Type II settling.

The potential for particulate removal through Type I sedimentation can be determined using a number of theories, for example numerical constitutive computational fluid dynamic models, Hazen's analytical model, or surface overflow theory. All require knowledge of particle properties such as settling velocity and particle density. Most settling basin and clarifier behavior is non-ideal to varying degrees; in many cases this non-ideal behavior is very significant; but rarely quantified. Unfortunately, use of numerical constitutive settling models is rare in practice (Cristina and Sansalone, 2003). While Hazen's model has advantages as compared to overflow rate (surface loading rate) theory and can account for non-ideal settling conditions, overflow rate design still remains the conventional practice in the U.S. for design of settling basins. Measurement or calculation of particle terminal settling velocity is required for a particle of given diameter and density. Additionally, the mass or number fraction of the total gradation for a given particle size increment must be known or determined.

Terminal particle settling velocity can be developed from the equations of motion for a particle settling under gravity in a viscous fluid, yielding Newton's equation of motion for the terminal settling velocity, V_t, of a particle as shown for ideal quiescent discrete particle settling.

$$V_t^2 = \frac{4d(\rho_s - \rho_l)g}{3f_d \rho_l} \quad [4\text{-}2]$$

In Newton's equation, d is the incremental particle diameter, ρ_s and ρ_l are the particle and liquid densities respectively, g is the gravitational constant and f_d is the drag coefficient. Three separate equations are used to calculate f_d based on the Reynold's number, Re_d. These equations represent laminar flow ($Re_d < 10$), transitional flow ($Re_d < 2{,}000$) and turbulent flow ($Re_d >$ 2,000).

In its simplest form, the surface overflow rate (SOR) expression is expressed as:

$$V_c = \frac{Q}{A} \quad [4\text{-}3]$$

In this expression V_c is the terminal settling velocity of the critical design particle for the particular settling basin design, Q is the discharge flow rate and A is the surface area of the basin. The units of V_c are m^3/m^2 day, units that are equivalent to a settling velocity.

Application of this simple procedure can become more involved when applied to conditions of unsteady flow and variable basin surface area, a wide range of particle gradation, and a variable specific gravity over the gradation; all of which are common for urban runoff. In such cases, numerical models or Hazen's model have significant computational and accuracy advantages as compared to SOR. For example, even for an SOR case where Q and ρ_s are constant and a gradation of particles exists, the expression for the fraction of particles removed given as follows:

$$f = (1 - X_c) + \int_0^{X_c} \frac{V_t}{V_c} dx \qquad [4\text{-}4]$$

In this expression f is the fraction of particles removed, $1 - X_c$ is the fraction of particles with velocity V_t greater than V_c and the integral expression represents the fraction of particles removed with V_t less than V_c (Metcalf and Eddy, 2003). This expression can be numerically discretized and solved. For example, based on the measurements made of a particle gradation, the equation is discretized and summed up based in size increments.

Type II settling is flocculent settling and generally occurs at concentrations above 200 mg/L. However, the same dependence on size gradation as discussed for Type I settling is still applicable. Unlike Type I settling, Type II settling is dependent on sedimentation depth. In reality, most sedimentation basins operate under Type II flocculant nonideal settling and therefore, performance is depth-dependent. Flocculation that does occur in these basins occurs by differential sedimentation, density gradients and unintentionally by nonideal velocity gradients in the basin. Type II settling is sufficiently complicated mathematically that analytical models have not been developed and complicated numerical models have not made it into the practice. Type II designs rely on full-height settling column data from the laboratory.

Type III settling is hindered or zone settling. Particle concentrations are generally above 500 to 1000 mg/L, and the extent of this range depends on particle size. The same dependence on size gradation as discussed for Type I settling is still applicable. Type III settling generally occurs in the lower third of sedimentation basins. The physical inter-particle forces are sufficient to hinder settling of adjacent particles and the particles settle as a zone, remaining relatively fixed in relation to each other. Generally a solid-liquid interface develops at the top of this settling zone. While zone and hindered settling is a commonly investigated phenomena in wastewater treatment and the mathematics are reasonably developed, the behavior of stormwater particles under Type III settling is relatively unknown. Sedimentation basins or detention basins receiving a highly concentrated particulate loading will operate under Type III and Type IV settling in the lower depths of the basin.

Type IV settling is compression settling. Particle concentrations are measured in percent. Compression settling is a type of consolidation settling, where the particle structure is developing shear strength and water in the void space between particles is being expelled, allowing a denser structure of particles. Such settling occurs over periods of days to years and can occur in long-term deposits at the bottom of basins. Long-term mechanisms of settling are generally physical-chemical. While compression is a commonly investigated phenomenon in wastewater treatment, the behavior of stormwater particles under Type IV settling is relatively unknown. However, both Type III and IV settling occur in basins, wet vaults and many proprietary systems that capture and store particles. Type III and IV settling are important between storm events, and lead to a separation of supernatant from a well-defined sludge zone. Type IV settling also leads to increased sludge shear strength, which can result in more difficult sludge cleanout as well as reduced sludge scour over time.

While the theory of particle settling is well known, the highly variable nature of stormwater quality make it difficult to characterize a "typical" suspended solids regime. Therefore, it is highly desirable to collect stormwater samples in the study area and perform basic settling tests to develop a reasonable approximation of the expected behavior of the runoff treatment control.

4.3.3.3 Flotation and Skimming

Flotation has been used for over 2,000 years for mineral separation and oil-water separation. From a mechanistic point of view, flotation is similar to Type I and Type II gravitation sedimentation except in the opposite direction. Flotation processes utilize the net buoyancy between a gas-solid floc (usually the gas is air) and water to float particle flocs that are then removed off the surface of the clarifier or tank by skimming. In flotation gas bubbles attach to solid particles, or flocs, and cause the apparent density of the bubble-particle agglomerates to be less than that of the surrounding liquid solution (usually water), which allows the agglomerate to float to the surface. Flotation is very effective for the separation of biological particles of specific gravity close to water, and for separation of suspended and settleable particles. Flotation is more popular in Europe for clarification than in the U.S. (Droste, 2004). The four main types of flotation are: 1) electrolytic, used for sludge thickening, 2) dispersed air froth flotation, used for particle and solids density separation, 3) foam fractionation, used in saltwater sludge separation, and 4) dissolved air flotation (DAF), commonly used in water and wastewater treatment.

The basis of pressurized DAF is the generation of a significant number of very fine gas bubbles through the reduction in pressure of a water stream saturated under pressure with air (or another gas, but most economically air). Bubble size generation by various DAF systems typically ranges from 50 to 100 μm in diameter, but can be as small as 10 μm. There are three main types of DAF processes: 1) pressure flotation, 2) vacuum flotation and 3) micro-flotation, with pressure flotation being the most common. The three basic pressure DAF processes are a) full-flow, b) split-flow and c) recycle flow. For fragile flocs, pressure DAF with recycle flow is most appropriate. In recycle flow pressurized DAF, part of the clarified effluent is recycled, pressurized and saturated with air, introduced into the flotation tank through a pressure reducing valve, and mixed with the flocculated water in the tank. The pressure reducing valve lowers the pressure (from 60 to 100 psig) to atmospheric pressure and releases the air as fine bubbles. The fine bubbles attach to the flocs and particles and are enmeshed in flocs forming air-solid agglomerates that float to the surface of the liquid. The floating flocs are removed through skimming from the liquid surface and clarified water is taken from the bottom of the flotation tank. The primary design variables for pressurized DAF are: 1) gas bubble diameter, 2) air saturation, 3) physical-chemical properties of the particles and flocs, 4) hydraulic loading rate, 5) solids loading rate, 6) air to solids ratio, 7) chemical conditioning (coagulation, flocculation, ionic strength, etc.), 8) operating policy (i.e. recycle flow), 9) float solids concentration, and 10) effluent criteria.

While DAF has not been widely applied to stormwater treatment, some research applications of DAF demonstrate high effectiveness. For example, runoff contaminated with oil, grease, and sediments at a refinery in California was treated by 1) mixing with process water, 2) pumping through a dissolved air flotation unit, 3) skimming the oil and grease, and 4) settling in a sedimentation tank (Stormwater, 2004). In another application, a stormwater treatment plant in Seine-et-Marne, France used DAF after the addition of a coagulant (Bernard et al., 1995). Successful application of DAF to other waters as well as research results suggests that DAF is a viable alternative to gravitational settling. The versatility and effectiveness of DAF allows it to be applied as a primary or secondary treatment.

After particles are brought to the water surface, the next logical step is removal by skimming. Skimming can be achieved using baffles or inverted outlet designs, as well as floating booms and mechanical skimmers. The first two devices are often incorporated into the design of tanks, vaults, hydrodynamic devices, and oil-water separators, and are therefore more likely to be used in conjunction with a flotation operation. The last two devices are generally applied where there is a large open water surface, such as in ponds and lakes. Floating booms can be placed across an open channel or near the inlet of ponds to collect floating liquids and debris. Treatment system components that provide skimming operations are discussed in detail in Sections 5.3.2, 5.4.2, 5.4.3, and 5.4.4. From a unit operations perspective, skimming is similar to the operation of a sluice gate. Sluice gates, as well as other outlet structures, are discussed in Section 5.6.6.

4.3.3.4 Clarification Methods Other Than Sedimentation

These methods are generally considered high-rate clarification. They utilize additional physical and chemical treatment to achieve rapid settling. In most cases these high rate systems utilize inclined plates or tubes to enhance the sedimentation effect. The specific advantages of such systems are 1) smaller space requirements, 2) low time to operational equilibrium (i.e. low start up time), 3) low residence time (generally less than 30 minutes), and 4) a more highly clarified effluent as compared to plain sedimentation. Two common examples used in wastewater clarification are lamella plate clarification and enhanced particle flocculation. Both involve addition of a polymer and in the case of enhanced particle flocculation, an inert (insoluble and non-organic) ballasting agent such as sand. Applications of high-rate clarification to stormwater runoff are rare. However, there are a number of marked exceptions, and the use of alum and synthetic coagulants is becoming more widespread (Babin et al., 1992; Carr, 1999; WSDOT, 2003). Coagulants are frequently used in construction sediment control basins to dramatically improve discharge quality. While lamella plate clarification can have advantages for stormwater treatment, enhanced particle flocculation may be unnecessary given the wide gradation of particles in urban runoff and their relatively inorganic nature. The use of chemical coagulants such as alum or ferric chloride, as well as flocculants such as manufactured polymers, can be effective clarification and filtration aids. However the potential for toxicity of residual materials, behavior under cyclic redox conditions, and unintended discharges of these materials should be considered.

4.3.3.5 Selection Methodology for Density Separation Physical Unit Operation Mechanisms

Basic knowledge of particulate solid parameters can provide an initial assessment for selection of unit operation mechanisms. Basic parameters such as particle gradation (mass or number based), particle density (i.e. particle specific gravity) and particle loadings (i.e. concentration) can allow the initial selection of a unit operation for a specific set of conditions.

Once the basic particle data are acquired, a selection diagram for solid-liquid separation can be developed for a particle specific gravity. A detailed explanation of the development of the process selection diagram can be found elsewhere (Cristina et al., 2002). Separation boundaries between each of the solid-liquid separation mechanisms are based on a 90% particle removal by mass (separation from the aqueous solution) in one-hour criterion unless noted otherwise. Calculations to determine number-volume mean size and number of particles (particle counts) can be determined from these basic data. Particle number or counts is simply the measure of the number of particles of a given size fraction per volume of aqueous suspension. This can be carried out on a volume basis (such as μL of solids/L of aqueous suspension), or gravimetrically for each increment of particle size, with the particle density as the conversion parameter between the two methods. The number-volume mean size, l_{nv}, is the weighted average of the particle diameters based on both the number of particles in a given size increment and the volume of spherical particles of the same size. Assuming spherical particles, l_{nv} is related to mass concentration, M, of a suspended particle gradation through the following expression:

$$M = \rho_s C_3 l_{nv}^3 N_t \qquad [4\text{-}5]$$

In this expression M is the mass concentration of particulate matter in the aqueous suspension, ρ_s is the particle density, C_3 is $\pi/6$ for spherical particle geometry, and N_t is the total number of particles across the gradation for a given volume. The particle count for each particle size increment, N_i can be calculated by rearrangement of Equation 4-5 to yield the particle number per aqueous volume (cm^{-3}) for either the entire gradation or each size increment, i, of the gradation as shown in the following equation.

$$N_i = \frac{m_i}{\rho_{si} V_{si} V_l} \qquad [4\text{-}6]$$

In this expression m_i is the mass of the i^{th} particle size, ρ_{si} is the density of particles in the i^{th} particle size increment, V_{si} is the particle volume of known geometry - assumed spherical in the i^{th} size increment and V_l is the volume of aqueous suspension containing the particles. From the particle gradation, l_{nv} of the entire particle gradation can be computed.

$$l_{nv} = \left[\frac{\sum_i N_i l_i^3}{\sum_i N_i}\right]^{\frac{1}{3}} \qquad [4\text{-}7]$$

In this expression N_i is the number of particles in interval i, (cm^{-3}) and l_i is the diameter of representative particles in interval i. For individual particle increments, $l_{nv,i}$ is simply a measure of the mean particle diameter. The number-volume mean size, l_{nv}, is the weighted average of the particle diameters based on both the number of particles in a given size increment and the volume of spherical particles of the same size. The l_{nv} and N_t can also be determined directly from a cumulative power law fit of the data. An overall l_{nv} and N_t can then be determined through the application of this equation. Results are presented in terms of a selection diagram shown in Figure 4-1 for a particle density of 1.1 g/cm^3 and 2.83 g/cm^3. Diagrams such as Figure 4-1 allow an initial evaluation to be made regarding selection of a physical unit operation. Such diagrams can be applied at multiple locations and multiple times for a site or set of treatment conditions.

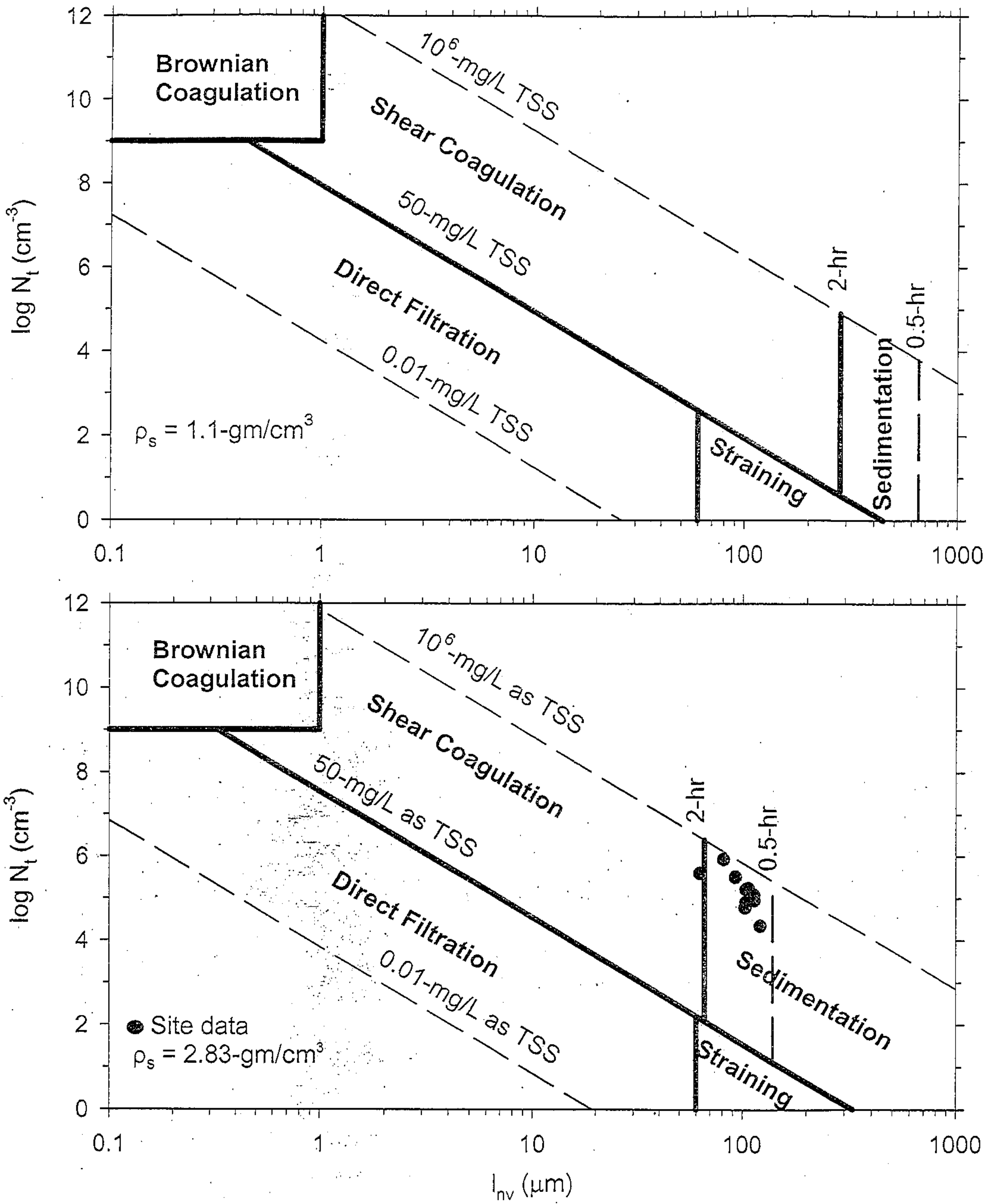

Figure 4-1. Particulate Treatment Selection Diagrams for a Two Particle Densities.
The upper figure represents a selection diagram for a particle density of 1.1 g/cm³. Notice the l_{nv} location of the 90% sedimentation removal lines for 30 minutes and 2 hours. The lower figure represents a selection diagram for a particle density of 2.83 g/cm³. Notice the l_{nv} translation of the 90% sedimentation removal lines. Each boundary line in this figure represents a 90% removal for a 1-hour residence time unless otherwise noted (as is the case for sedimentation). In this figure, "coagulation" represents a physical flocculation process.
Reprinted with permission from Cristina et al. (2002).

4.3.4 Aeration and Volatilization

Aeration and volatilization are two physical processes that occur simultaneously since the entrainment of air into the water column will promote volatilization of any volatile substances. Nonetheless, these processes are distinct and are used to target different water quality parameters.

4.3.4.1 Aeration

Aeration is the process of entraining air in the water column to: 1) increase dissolved oxygen (DO), 2) decrease the biochemical oxygen demand (BOD), and 3) decrease carbon dioxide $(CO_2)_{aq}$,. Dissolved oxygen is essential for maintaining aquatic life and the aesthetic quality of water. When a water body is subjected to high nutrient loads, the rate of bacterial respiration may accelerate to a point where it exceeds the oxygen transfer rate across the air-water interface, resulting in depleted dissolved oxygen concentrations. The amount of oxygen used during the biological breakdown of organic matter over a defined time period (usually five days) is called the biochemical oxygen demand. As microorganisms metabolize organic matter and consume oxygen, carbon dioxide is produced. Aqueous carbon dioxide controls the carbonate equilibrium, which in turn controls the pH of most natural waters. Low DO, high BOD and high CO_2 are generally undesirable water quality conditions that can be remediated through aeration and the subsequent transfer of oxygen to the water column.

Oxygen Transfer The rate of oxygen transfer to a water column (as well as the rate of carbon dioxide release) is primarily a function of the existing concentration, temperature, water-air interface area, and microbial metabolism. Fick's First Law can be used to describe the rate at which a gas transfers into (or out of) a solution via diffusion and dispersion:

$$\frac{dC}{dt} = K_L a(C_s - C_o) \qquad [4\text{-}8]$$

Where: $\frac{dC}{dt}$ is the rate of change in concentration of the gas in solution, g m^{-2} hr^{-1}
K_La is the overall mass transfer coefficient, hr^{-1}
C_s is the equilibrium concentration of the constituent, g/m^3
C_o is the initial concentration of the constituent, g/m^3

The overall mass transfer coefficient, K_La, is the product of the liquid-film mass transfer coefficient, K_L, and the ratio a = interface area / volume. K_La is often used when it is difficult to measure the air-water interface area, such as during turbulent mixing. The mass transfer coefficient is dependent on the temperature, intensity of mixing, geometry of mixing unit, and existing water chemistry. Generally, K_La is based on pilot study data and regression analysis (see Section 4.3.4.2).

According to Henry's Law, the equilibrium concentration of dissolved oxygen is a function of the partial pressure of oxygen in air:

$$x_g = K_H P_g \qquad [4\text{-}9]$$

Where: x_g is the mole fraction of the gas at equilibrium in liquid phase (solubility)

K_H is Henry's law constant[1], atm-1
P_g is the partial pressure of the gas in atmosphere, atm

If $C_s > C_o$ the gas is released to the atmosphere; if $C_s < C_o$ the gas is absorbed into the liquid phase. For open water systems, the equilibrium concentration of DO will never be below the actual DO concentration.

The following integrated form of Equation 4-8 can be used to estimate the concentration of oxygen at some future time, t, given the initial concentration, C_o, and the mass transfer coefficient, K_La, and the equilibrium concentration, C_s.

$$C_t = C_s + (C_o - C_s) \cdot e^{-K_L a \cdot t} \quad [4\text{-}10]$$

The Mass Transfer Coefficient The transfer of a gas across the air-water interface is a function of temperature, mixing intensity, geometry of the mixing unit, and the existing water quality characteristics. For any particular system, the mass transfer coefficient, K_La, must be estimated from experimentation. The general procedure for estimating the mass transfer coefficient is to set up a pilot experiment that closely mimics the final design of the system. Under system operating conditions, the dissolved gas concentrations should be measured at discrete intervals and constant temperature. Rewrite Equation 3-9 in a linear form:

$$\log(C_s - C_t) = \log(C_s - C_o) - K_L a \cdot t \quad [4\text{-}11]$$

Plot $\log(C_s - C_t)$ versus t and determine the slope, K_La, using linear regression.

To estimate the effects of temperature on the mass transfer coefficient, the van't Hoff-Arrhenius relationship can be used:

$$K_L a(T_1) = K_L a(T_2) \cdot \theta^{(T_1 - T_2)} \quad [4\text{-}12]$$

Where: $K_La(T_i)$ is the mass transfer coefficient at temperature T_i
θ is the temperature coefficient.

For diffused and mechanical aerators, a temperature coefficient value of 1.024 is typically used (Metcalf and Eddy, 2003).

Applicability Aeration should be considered if receiving waters have low dissolved oxygen concentrations or high nutrient loads, or if oxygen-demanding substances (e.g., calcium-magnesium acetate (CMA)) are expected from the site. For most stormwater treatment applications, it is desirable to have little to no energy requirements. Therefore passive aeration methods are often preferable. However, in some situations it may be necessary to have an energy source available to meet the aeration needs at a site.

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[1] *Henry's law constant is dependent on the gas type, temperature, and constituents in the water. Tabulated values for common compounds can be found in physics and chemistry handbooks.*

Favorable Conditions and Factors that Enhance Process Similar to volatilization and evaporation, aeration may be enhanced by simply increasing the amount of open surface water since oxygen diffusion will occur naturally. The rate of diffusion, as well as the saturated dissolved-oxygen concentration, depends on water temperature, salinity, and barometric pressure. Generally, as the temperature and salinity increase and the barometric pressure decreases, the dissolved oxygen diffusion rate decreases. If the microbial metabolism exceeds the oxygen diffusion rate, additional measures are necessary such as increasing the turbulence, or mechanically introducing air into the water. Turbulence can be increased by promoting supercritical flows or by mechanical agitation. Other mechanical aeration methods include the use of submerged diffusers, air jets, and sprinklers. Turbulence can be increased most effectively if there is a significant drop in elevation where cascading water flow is possible. For any inlet or outlet structure that increases flow velocities, care must be taken to avoid scour and/or resuspension of particulates.

4.3.4.2 Volatilization

Volatilization is the process whereby liquids and solids vaporize and escape to the atmosphere. Compounds that readily evaporate at normal pressures and temperatures are volatile compounds. While these compounds are not frequently detected in urban runoff, volatile organic carbons (VOCs) or semi-volatile organic carbons (SVOCs) are sometimes present including various petroleum hydrocarbons (e.g., BTEX and PAHs), gasoline oxygenates (MTBE), herbicides, and pesticides. VOCs can also be formed during some microbial and phytochemical redox transformations of other pollutants in urban runoff. Volatile compounds are usually highly soluble in water and will easily migrate to groundwater during infiltration practices. Therefore if these compounds are present, it is often desirable to remove them prior to infiltration.

Volatilization from a free water surface is considered a three-step process: 1) escape from water surface, 2) diffusion through boundary layer, and 3) advection and hydrodynamic dispersion into the atmosphere. Figure 4-2 depicts the volatilization process from a free water surface.

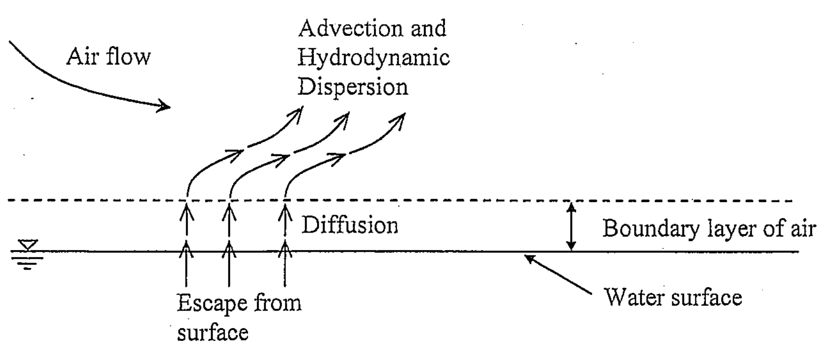

Figure 4-2. Physical Unit Process of Volatilization from a Free Water Surface.

The volatilization rate of a contaminant from a free water surface is approximately proportional to the difference between the equilibrium concentration (C_s) and the existing concentration of the contaminant (C_o):

$$R_c = K(C_o - C_s)$$ [4-13]

Where: R_c is the rate of mass transfer, g m^{-2} hr^{-1}

K is the mass transfer coefficient[2], m/hr

C_o is the initial concentration of the contaminant, g/m^3

C_s is the equilibrium concentration of the contaminant, g/m^3

If the concentration in air is low, such as is typically the case with volatile organic compounds (VOCs), then the equilibrium concentration is essentially zero. If the equilibrium concentration is greater than the initial concentration, the direction of mass transfer is reversed and gas is absorbed into the water column (e.g., oxygenation).

Volatilization may also occur during evapotranspiration processes. Plants that readily take up volatile compounds may emit these compounds from their roots, stalks and shoots.

Applicability Volatilization is a viable unit process to consider if volatile or semi-volatile compounds have been detected or are expected to be present at the site. Sufficient surface area is needed for the types of treatment systems that will promote volatilization.

Favorable Conditions and Factors that Enhance Process Volatilization can be integrated into a treatment process without the need for much (if any) additional planning or design of the treatment system. For example, volatilization may occur in systems that include a large air-water interface, promote good air flow and are open to wind, are exposed to elevated temperatures or direct sunlight, or have significant aquatic or terrestrial vegetation. Volatilization can also be promoted through the use of aeration and evaporation enhancement controls.

4.3.5 Physical Agent Disinfection

Physical agent disinfection refers to the mitigation of stormwater borne pathogens through the use of non-chemical agents such as sunlight, ultraviolet light, and heat. Physical agent disinfection minimizes the danger and liability associated with the transportation and storage of chemicals which are used in chemical disinfection. Both physical and chemical agent disinfection lead to a partial destruction of pathogens and should not be confused with sterilization that leads to a complete destruction of all of the organisms (Metcalf and Eddy, 2003).

4.3.5.1 Description

The main physical disinfection unit process is considered to be ultraviolet disinfection. A literature review shows a significantly smaller amount of data on heat and sunlight disinfection applications in stormwater as compared to ultraviolet disinfection. Ultraviolet (UV) light immobilizes stormwater-borne pathogens by penetrating pathogen cell walls and causing the formation of double bonds within the pathogens. This prevents replication and/or causes death of the organism (Metcalf and Eddy, 2003). Stormwater applications of UV disinfection are rare, but are beginning to become more popular. For example the, City of Encinitas, CA recently installed a UV disinfection system to treat stormwater discharges to Moonlight Beach (Rasmus and Weldon, 2003). In a similar application, the City of Coronado, CA installed a UV disinfection

[2] The mass transfer coefficient is primarily dependent on the contaminant type, temperature, and other water constituents. Tabulated values can be found in some chemistry and physics handbooks.

system for treating both groundwater and stormwater (combined system) prior to discharging to the ocean (Woodward Clyde, 1998).

The effectiveness of UV systems depends on system hydraulics, the presence of solids in the influent, the characteristics of the target organisms, and the chemical characteristics of the influent. Solid particles can greatly affect the performance of a UV system (Metcalf and Eddy, 2003). For example, bacteria attached to particles can be completely shielded from UV light, resulting in residual bacteria concentrations in the effluent. Solid particles can also minimize UV light penetration. Therefore, it is recommended to adequately pretreat for suspended solids prior to UV application. For example, a pilot-scale stormwater treatment plant in the eastern suburbs of Paris, France used air flotation, filtration and UV disinfection in a treatment train to reduce bacteria levels to bathing water standards (Laine et al., 1998).

Stormwater pathogens have varying degrees of resistance to UV light. The performance of a UV disinfection system therefore depends on the target. The dose of UV light to which the pathogens are exposed determines the effectiveness of UV disinfection systems. The definition for UV dose D is as follows:

$$D = Ixt \qquad [4\text{-}14]$$

Where D = UV dose, mJ/cm^2
I = UV intensity, mW/cm^2
t = exposure time, s

The UV intensity depends on the UV lamp output, cleanliness of the quartz sleeves and the transmittance of the influent. Since intensity varies with distance from the UV lamps, the average intensity of a UV system is computed mathematically (Metcalf and Eddy, 2003). For UV doses greater than 10 mJ/cm^2 Equation 4-15 can be used to model the log-linear inactivation of disperse coliform bacteria in a batch system (Metcalf and Eddy, 2003).

$$N_D = N_D(0)e^{-kIt} \qquad [4\text{-}15]$$

Where: $N_D(t)$ = total number of surviving disperse coliform bacteria at time t
$N_D(0)$ = total number of disperse coliform bacteria prior to UV light application (at time t = 0)
k = inactivation rate coefficient, cm^2/mW.s
I = average intensity of UV light in bulk solution, mW/cm^2
t = exposure time, s

The amount of UV radiation reaching disperse coliform is significantly different from the amount of UV radiation reaching particles associated coliform in the same system. While Equation 4-15 is applicable to disperse organisms, the expression shown in Equation 4-16 is applicable to modeling the inactivation of both disperse and particle associated coliform bacteria when the applied intensity to bulk liquid medium is known (Metcalf and Eddy, 2003).

$$N(t) = N_D(0)e^{-kd} + \frac{N_p(0)}{kd}(1 - e^{-kd}) \qquad [4\text{-}16]$$

Where: $N(t)$ = total number of surviving coliform bacteria at time t
$N_D(0)$ = total number of disperse coliform bacteria prior to application of disinfectant at time t = 0

$N_P(0)$ = total number of particles containing at least one coliform bacterium at time t = 0
k = inactivation rate coefficient, cm^2/mJ
d = UV dose, mJ/cm^2

The sun is an abundant source of both heat and ultraviolet light. In developing countries, drinking water disinfection has been accomplished by filling partially translucent bottles with water and leaving the bottles out in the sun (Rainey and Harding, 2002). An analogous application in stormwater management would be the use of translucent conduits to convey stormwater to and from TSCs. In theory, translucent conduits conveying stormwater that has been pretreated to remove majority of the solids could benefit from the disinfection properties of the sun. However, due to the paucity of data pertaining to the effectiveness of solar disinfection in stormwater applications, solar disinfection is only recommended in conjunction with the use of other unit processes. For example, shallow detention ponds allow heating and penetration of sunlight to the pond bottom, which creates a less friendly environment for pathogens.

4.3.5.2 Applicability

Projects that have identified pathogens as constituents may want to select either chemical or physical agent disinfection. Chemical agent disinfection (discussed in Section 4.5.3) is currently relatively cheaper; however this may change in the future with improvements in technology.

High turbidity and TSS in the influent may render the UV disinfection ineffective (U.S. EPA, 1999c). Pretreatment may be required to lower influent solids. The costs of fine solids removal pretreatment must be considered earlier in the selection stage. UV disinfection may be more expensive than other disinfection alternatives however advances in technology, and increases in the number of UV facilities continue to lower costs (U.S. EPA, 1999c).

Inactivated organisms may sometimes recover, reverse the effects of UV disinfection through a process know as photo reactivation. In the absence of light, inactivated organisms may also be able repair themselves through a mechanism know as dark repair (U.S. EPA, 1999c).

4.3.5.3 Favorable Conditions and Factors That Enhance Process

Physical disinfection is suitable for applications where the influent has low turbidity. Suspended solids provide places for pathogens to hide and also prevent the penetration of light into the influent. Physical disinfection should be chosen over chemical disinfection (specifically chlorine injection) if the influent could potentially have a high organic content, because toxic chlorination byproducts could form. For facilities that may need to discharge into sensitive receiving waters, physical agent disinfection may be more suitable because physical agents leave no residuals in the effluent.

4.4 Biological Processes

Conventional wastewater biological treatment has been used since the early 1900s to remove organic compounds to prevent depletion of dissolved oxygen levels, remove colloidal and suspended solids, transform or remove nutrients, and reduce pathogen concentrations (Metcalf and Eddy, 2003). Conventional wastewater biological processes include suspended growth and attached growth systems, and microorganisms are the primary removers of pollutants in these systems. The high energy and labor costs of conventional wastewater treatment lead to increased use of constructed wetlands in the 1980s. There is a broader array of biological processes used in wastewater treatment compared to stormwater treatment. However principles of conventional biological wastewater treatment can be applied to stormwater treatment systems, and experience with treatment wetlands is also applicable. A significant difference between stormwater and wastewater treatment systems is that wastewater systems generally have longer residence times (weeks as opposed to hours or days), which influences the biological processes that occur and the extent to which they occur. Generally the effectiveness of biological treatment processes (and nearly all other processes for that matter) can be enhanced by increasing the residence time. Pollutant influent concentrations also differ between wastewater and stormwater runoff, which affects biological treatment processes.

Biological unit processes for stormwater treatment involve the use living organisms (e.g., plants, algae, and microbes) to transform or remove organic and inorganic constituents from water and soil. They include microbially mediated transformations and uptake and storage processes.

4.4.1 Microbially Mediated Transformations

Microbially mediated transformations are chemical transformations promoted by bacteria, algae, and fungi that exist in the water column, soil, root zone of plants, and on wetted surfaces, such as leaves (Kadlec and Knight, 1996; Karthikeyan R., and Kulakow, 2003; Minton, 2002). Also refer to Section 5.5.2 for additional information.

4.4.1.1 Metabolism

Microbially mediated transformations occur as a result of respiration, which is a redox process. Redox reactions are chemical transformations involving the transfer of electrons or change in oxidation number of a species. Terminal electron acceptors are oxidizers, and electron donors are reducers. Respiration is the process that releases energy and nutrients from food sources so they can be assimilated and used by organisms. The process occurs in both aerobic (e.g., well aerated terrestrial soil) and anaerobic (e.g., wetland sediment) environments. Oxygen is used as the electron acceptor during aerobic respiration, while other chemicals (e.g., nitrate, sulfate) function as electron acceptors during anaerobic respiration. Facultative microbes undergo both aerobic and anaerobic respiration. Consequently, microbial transformations that occur are largely influenced by the oxidation-reduction (redox) potential of the system.

All microorganisms require carbon for metabolism, which can be utilized in two different ways. Carbon may be used as a source of energy to make adenosine triphosphate (ATP) (the major energy source within the cells of all living organisms that drives a number of biological processes; ATP captures chemical energy obtained from the breakdown of food molecules and releases it to fuel other cellular processes), or as the raw material from which cells are constructed. Organisms can be classified in terms of their metabolic needs. Chemotrophs are organisms that derive energy from electron-donating compounds such as glucose, rather than light. Photoautotrophs derive energy from light. Chemoheterotrophs obtain carbon and energy from organic compounds. Chemoautotrophs derive nutritive carbon from carbon dioxide, but obtain energy from inorganic electron donors rather than organic matter; specific groups can oxidize ammonium, nitrate, sulfur, iron, and manganese. Most bacteria are chemoheterotrophs, while only some specialized bacteria are chemoautotrophs. Algae are photoautotrpohs, and derive energy from light and carbon from carbon dioxide.

4.4.1.2 Simple Organic Compound Decomposition and Mineralization

When microbes aerobically oxidize simple organic compounds, the process releases, or mineralizes, organically bound elements. Mineralization refers to the release of elements from organic matter to produce inorganic (mineral) forms. Most of the inorganic elements released by mineralization are in forms more available as nutrients to higher plants and microbes. Once released through mineralization, elements can be further transformed by specific microbes. Or elements may be sequestered by binding to other inorganic constituents, or by sorbing to nondegradable organic matter (humus). Less desirable products, such as methane, may form during anaerobic decomposition. Mineralization is an important source of nitrogen, sulfur, phosphorus, and other nutrients for plants and microbes. Rates of organic compound decomposition and mineralization depend on various chemical factors that influence microorganisms such as pH, moisture, temperature, oxygen supply, and nutrients (Richards, 1987; Tate, 1995).

4.4.1.3 The Nitrogen Cycle

Nitrogen transformations facilitated by microorganisms include ammonification, nitrification, denitrification, and fixation. A simplified nitrogen cycle that would occur in a wetland is shown in Figure 4-3.

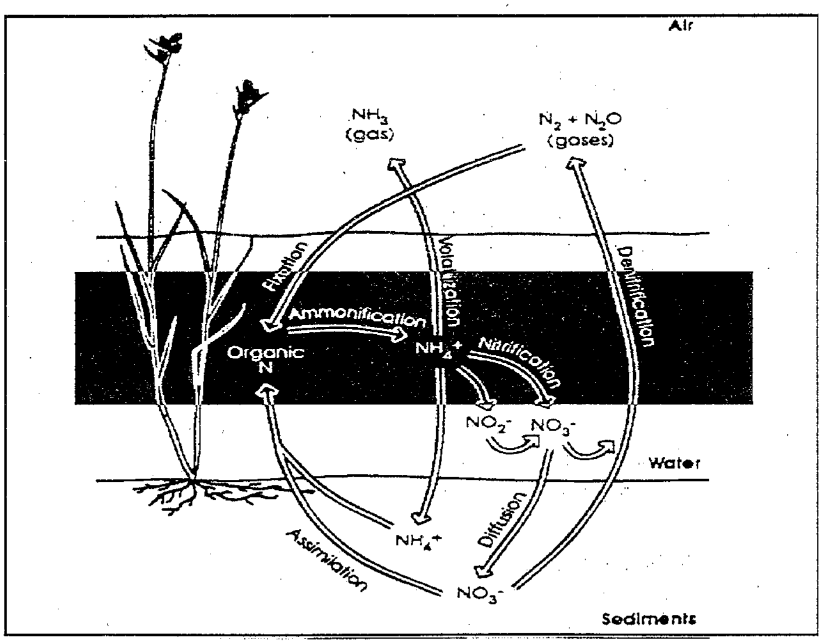

Figure 4-3. Simplified Nitrogen Cycle in a Wetland
Source: Interstate Technology and Regulatory Council (ITRC, 2003).

Ammonification is the mineralization of organic nitrogen to ammonium by chemoheterotrophic bacteria, and is the major process supplying nitrogen to wetland plants. Only about 1.5-3.5% of the organic nitrogen in soil mineralizes annually (Brady and Weil, 2000). Ammonification may occur aerobically or anaerobically. In wetland soils, the rate is typically highest in aerobic zones, and decreases with depth, due to the reduced efficiency of decomposition in anaerobic environments. However, since wetland soils have mostly anaerobic microbes, the overall mass of ammonium generated is greater in anaerobic conditions. Therefore, ammonification in wetlands is significantly reduced under nonflooded conditions (Kadlec and Knight, 1996; Vymazal, 1995). Generally as the carbon to nitrogen (C:N) ratio of the of the environment decreases, the ammonification rate increases; a C:N ratio of 30:1 or greater may result in immobilization of nitrate instead of mineralization (Richards, 1987).

Nitrification is the oxidation of ammonium to nitrate by a small number of chemoautotrophic bacteria in aerobic environments (e.g., water column, well-drained soils or aerobic layer of flooded soils, plant root zone). It is a two-stage reaction, in which ammonium is oxidized to nitrite in the first stage (by *Nitrosomonas* primarily), and nitrite is oxidized to nitrate in the second stage (by *Nitrobacter* primarily). Typically the second stage occurs quickly enough to prevent accumulation of nitrite. The reactions can be expressed as:

$$2NH_4^+ + 3O_2 \xrightarrow{\text{Nitrosomonas bacteria}} 2NO_2^- + 4H^+ + 2H_2O + \text{Energy}$$

$$2NO_2^- + O_2 \xrightarrow{\text{Nitrobacter bacteria}} 2NO_3^- + \text{Energy}$$

Denitrification is the reduction of nitrate to gaseous forms of nitrogen (nitric oxide, nitrous oxide and dinitrogen gas) in anaerobic environments such as wetland soils and anaerobic pockets in terrestrial soils. Seventeen genera of bacteria are capable of denitrification, including Pseudomonas, Bacillus, Micrococcus, and Achromobacter, and Thiobacillus denitrificans (Vymazal, 1995). Different genera dominate in water and soil (Richards, 1987; Vymazal, 1995). Mechanisms for denitrification vary depending on the conditions and organisms involved. A simplified reaction can be expressed as:

$$2NO_3^- \rightarrow 2NO_2^- \rightarrow 2NO \rightarrow N_2O \rightarrow N_2$$

Generally, when oxygen concentrations are very low, the end product is dinitrogen gas. However, nitric oxide and nitrous oxide are often formed under fluctuating oxygen levels. The amount formed of each gas depends on pH, temperature, degree of oxygen depletion, type of bacteria involved, and the concentrations of nitrate and nitrite (Richards, 1987). Low pH (< 5.0) inhibits rapid denitrification and favors formation of nitrous oxide. Nitrous oxide is a greenhouse gas and contributes to the depletion of the ozone layer.

Nitrogen fixation is the process by which nitrogen gas in the atmosphere (or nitrogen gas generated during denitrification) is reduced to ammonia by bacteria, algae and higher plants. Some bacteria such as *Rhizobium* and cyanobacteria (blue-green algae), as well a certain fungi, are capable of nitrogen fixation. The chemical reaction can be expressed as:

$$N_2 + 3H_2 = 2NH_3$$

Nitrogen-fixing organisms form symbiotic relationships with certain plants, forming nodules in the roots. Plants provide the organisms with carbohydrates for energy and a stable environment for growth, the organisms give plants usable nitrogen and other essential nutrients. Plants capable of nitrogen fixation due to their associations with microbes can be used as green manures in nitrogen-deficient soils (Ashman and Puri, 2002). Non-symbiotic fixation can also occur by some bacteria and algae.

Nitrogen can also be lost to the system as it volatilizes as ammonia gas at alkaline pH. Volatilization from flooded soils occurs frequently in wetlands. Volatilization is a physical process summarized in Section 4.3.4.2.

4.4.1.4 Other Inorganic Transformations

Certain microbes can enzymatically oxidize or reduce metals during respiration, affecting metal solubility and reactivity. Many of these inorganic transformations are the basis of bioremediation of metals. Example reactions are provided below. Refer to Section 5.5.2 for more information on specific microbes that mediate these reactions.

- Oxidation of ferrous (Fe^{2+}) to ferric (Fe^{3+}) iron precipitates ferric hydroxides or phosphates.
- Oxidation of sulfur may produce sulfuric acid which lowers pH and can increase soluble metal concentrations.
- Reduction of sulfate to sulfide causes formation of insoluble metal sulfides (e.g., pyrite, mercuric sulfide). Hydrogen sulfide may form when the sulfide concentration is significantly greater than metals concentrations.
- Reduction of hexavalent (Cr^{6+}) to trivalent (Cr^{3+}) chromium precipitates chromium oxides, sulfides, or phosphates.
- Reduction of Mn^{4+} to Mn^{2+} releases soluble cations.

Methylation of Hg^{2+} is an example of an undesirable microbially mediated process, which transforms an inorganic species to an organometallic form. The process occurs under anaerobic conditions (primarily in sediment) and is mediated primarily by sulfate-reducing bacteria (e.g., *Desulfovibrio*) as a byproduct of respiration. Methylmercury (CH_3Hg) is a neurotoxin, and a form of mercury easily bioaccumulated in living organisms. Methylmercury can be reduced by certain bacteria to Hg^0, a volatile element that poses less environmental risk.

4.4.1.5 Degradation of Xenobiotic Compounds

In addition to simple organics, various microbes (primarily heterotrophic bacteria) are able to use more complex organics (such as xenobiotic compounds) as energy sources during metabolism, often resulting in microbial decomposition of those compounds to less toxic forms. Also, under certain conditions, some microbes can transform xenobiotic compounds even when the compound cannot serve as the primary energy source (cometabolism). Cometabolism is important for the breakdown of chlorinated solvents, polychlorinated biphenyls, and many PAHs. Such principles are the basis of bioremediation of organic contaminants. Large concentrations of microbes live in association with plant roots; degradation that occurs in the plant root zone is referred to as rhizodegradation.

A xenobiotic compound may be degraded aerobically, anaerobically, or under both conditions, although both processes occur relatively slowly (thus requiring long residence times). Significant degradation is possible for phenols, phthalate esters, naphthalenes, chlorinated benzenes, and nitroaromatics in aerobic conditions. Some compounds degrade more rapidly in anaerobic conditions, including carbon tetrachloride, chloroform, lindane, phenol, and methylene chloride (Minton, 2002). Complete degradation of some constituents requires alternating aerobic and anaerobic conditions (Knapp and Bromley-Challenor, 2002).

In some cases, xenobiotic compounds undergo incomplete degradation, and the products may be as or more toxic than the parent compound. For example, trichloroethylene (TCE) is degraded to vinyl chloride rather easily. However, subsequent degradation of vinyl chloride, a carcinogen, usually occurs slowly.

4.4.1.6 Applicability Of Process

Microbially mediated transformations can be used to remove or convert dissolved nitrogen species (e.g., nitrate), metals, and simple and complex organic compounds. Transformations occur relatively slowly and require long residence times, on the order of days (and some transformations may require weeks to occur). Because of their moisture and temperature requirements, microbial processes have limited applications in arid climates, regions with long dry seasons 9unless supplemental moisture is supplied), and cold climates. Nitrification may result in leaching of nitrate from the system, which is of particular concern in areas with water quality impairment due to nutrient enrichment.

4.4.1.7 Favorable Conditions and Factors That Enhance Process

Most stormwater treatment systems will have a diverse microbial population. Therefore, it may be difficult to optimize conditions for all species. However, many reactions of interest only occur in the presence of specific microbes, thus optimization for these microbes should be the priority. Basic habitat requirements for all microbes include a substrate to colonize (e.g., soil, plant roots, leaf surfaces), appropriate nutrients including carbon sources, absence of toxics, and sufficient moisture. The pH also affects which microbes flourish. Most bacteria are very sensitive to acidic conditions, while fungi may thrive under both acidic and basic conditions. Many microbes form symbiotic relationships with certain plants; therefore, increasing the vegetation density (and using the right plants) may increase microbial populations. Amending the soil with organic matter can also increase populations. Oxygen requirements are another important factor. Depending on the microbe, it may require oxygen (aerobic) or other substances (facultative and anaerobic) for metabolism. Various factors determine available oxygen, including soil characteristics and inundation patterns. In ponds, water level management may increase surface microbial activity by allowing the soil to become aerated during dry periods.

Temperature affects microbial growth and transformation rates, and the effects follow an Arrhenius relationship. That is, increasing the temperature increases growth and transformation kinetics. The optimum temperature range for much microbial activity is between 15 and 45°C (Tate, 1995).

Nitrifying bacteria are more sensitive to environmental conditions than the bacteria that mineralize ammonium. Nitrifying bacteria require a supply of ammonium, but excess ammonium (as may accumulate under alkaline conditions) is toxic to *Nitrobacter*. The optimum temperature range for nitrification is 25-40°C, and rates are significantly reduced below 5°C, unless bacterial density is high (Kadlec and Knight, 1996; Subba, 1999; Tate, 1995; Vymazal, 1995). The optimum pH range is 6.6-8.0 (Tate, 1995). The rate of oxygen diffusion also affects the nitrification rate.

The primary factors that affect denitrification are nitrate concentration, aeration, moisture status, pH, temperature, and the nature and amount of organic matter available as energy sources (Tate, 1995). Denitrification may be limited by available carbon in mineral soils. Therefore, it may be necessary to add an available carbon source in the form of soil amendments to sustain bacteria until the treatment system builds up its own litter. Bachand and Horne (2000) evaluated the effect of plant species on denitrification in various types (i.e., stormwater, wastewater, agricultural) constructed wetlands. The type of vegetation present affects denitrification because decayed vegetation is a carbon source for microbes. Factors that influence the available carbon include plant production rates, plant physical structure, waterfowl grazing pressures, disturbance, the C:N ratio of the detritus, and plant fiber content. A laboratory-scale study found copper, cadmium and zinc concentrations in sediment of 500 mg/Kg inhibit denitrification due to microbe toxicity (Sakadevan et al., 1999). The overall order of inhibition was Cd > Zn > Cu (due in part to metal bioavailability).

Complete nitrogen removal from a treatment system as a gaseous product favors conditions where coupled nitrification-denitrification occurs. This condition is most favored where nitrogen species can diffuse across interfaces between aerobic and anaerobic environments. Therefore, favorable conditions include interfaces between aerobic and anaerobic zones in flooded soils, or in the plant root zone, where nitrate can diffuse from the oxygenated root zone to an adjacent anaerobic zone in the soil. Sea grasses and other benthic plants and algae may enhance coupled nitrification-denitrification because they oxygenate the upper sediment layers. However saturating the upper sediment layers with oxygen can also have the reverse effect, and lower denitrification rates during daylight hours. Moreover, if water column nitrogen concentrations are low, benthic algae may inhibit nitrification and denitrification because they compete for nitrate (Radke et al., 2003). To enhance denitrification, portions of aerobic systems can be made anaerobic by adding a deep layer of flooded gravel, or by increasing water levels or inundation periods. Aeration can be used to create aerobic conditions.

Nitrogen fixation can occur in aerobic and anaerobic environments, but the rate is faster in anaerobic conditions. Fixation is an adaptive process that provides nitrogen to organisms existing in otherwise nitrogen-depleted environments; therefore it is only significant in the absence of other forms of nitrogen (Minton, 2002). Nitrogen fixation in the root zone of wetland plants is only possible if N_2 gas is present (Vymazal, 1995). The presence of ammonium inhibits fixation (Kadlec and Knight, 1996). Nitrogen-fixing organisms have high nutrient requirements for molybdenum, iron, phosphorus, and sulfur (Brady and Weil, 2000). Their optimal pH range is between 5.0 and 8.0 (Vymazal, 1995). Data from treatment wetlands indicate that nitrogen fixation is not well quantified in these systems (Kadlec and Knight, 1996).

Some factors affecting degradation of xenobiotic compounds by microbes are summarized below (Knapp and Bromley-Challenor, 2002; National Research Council, 1993; Scragg, 1999):

- The specific microbe with the enzymatic capability to degrade the molecule must be present. Xenobiotics are not found in nature, therefore the concentration of degrading organisms may be low.
- Aliphatic and monocyclic aromatics are readily degradable. More complex structures such as PAHs are more resistant. The number of halogen molecules, their position within the structure, and type of halogen is also a factor (and affects toxicity). Chemicals with

either carbon-chlorine or carbon-fluorine bonds are typically metabolized slowly and some are highly resistant to aerobic degradation (e.g., polychlorinated biphenyls, and organochlorine pesticides). Conversely, in anaerobic degradation of chlorinated compounds, particularly aromatics, it often appears that reductive dechlorination is easier with the more highly chlorinated compounds.

- Concentrations that are too low inhibit degradation, however a compound may become toxic to the microbe at high concentrations. The degree and mechanisms of toxicity vary with the specific toxicants, their concentration, and type of microbes.
- Chemicals that are highly soluble degrade faster than less soluble compounds. Generally, solubility decreases with increasing molecular weight. Compounds with low solubility have high hydrophobicity (measured by the octanol-water coefficient, K_{ow}). A high K_{ow} is indicative of low aqueous solubility.
- The presence of multiple contaminants may result in selective degradation of compounds that are easiest to metabolize, or provide the most energy.
- How the compound is bound to the soil affects its availability for degradation. Binding depends on soil structure, porosity, and composition. Some xenobiotic compounds can be sorbed to clays, humic compounds, and amorphous metal oxides, thus rendering them more resistant to degradation.

4.4.2 Uptake and Storage

Uptake and storage processes refer to the assimilation of organic and inorganic constituents by plants and microbes. The organisms may assimilate essential nutrients for metabolism and growth, in addition to nonessential constituents.

4.4.2.1 Description of Process

Plants and microbes require essential nutrients to sustain growth, which may be assimilated from the water column or from soil solution. Nutrient uptake is a metabolic process however some mechanisms of uptake and storage are not well understood. In wetlands, free-floating plants uptake nutrients from the water column; emergent plants uptake nutrients from soil pore water; and submerged plants may obtain nutrients from both the water column and soil pore water (Guntenspergen et al., 1989). Macronutrients and micronutrients required by plants and microbes are summarized in Table 4-2. Other essential nutrients include carbon, hydrogen, and oxygen, which are supplied by the air, water, or organic compounds in water or soil. The specific forms in which nutrients exist are determined by factors such as pH and redox potential. Micronutrient cations are most available for uptake under acidic conditions. The presence of constituents, such as silicate clays and organic matter also affects nutrient speciation (Miller and Gardiner, 1998). Organic matter along with organic residues excreted by plant roots and microbes may react with cationic micronutrients to form organometallic complexes (chelates). Metal chelates are often more available for plant uptake than nonchelated metals because the metal cation remains in the aqueous phase. The strength of metal chelate formation is approximately on the order (Miller and Gardiner, 1998; Sparks, 2003):

$$Fe^{3+} > Al^{3+} > Cu^{2+} > Ni^{2+} > Co^{2+} > Pb^{2+} > Zn^{2+} > Fe^{2+} > Mn^{2+} > Ca^{2+} = Mg^{2+}$$

Phosphorus uptake by plants and microbes may improve the capacity of the soil to sorb other constituents. Uptake of macronutrients such as phosphorus and nitrogen in vegetated ponds can be significant until storage pools become full (Minton, 2002; Reddy et al., 1999). Studies of mature pilot wetlands show plants accounting for only about 2-5% of phosphorus removal and 2-8% of nitrogen removal (Minton, 2002). Increased performance may require harvesting and replacement of vegetation, which is typically not cost effective.

In addition to uptake for nutrition, various algae, and wetland and terrestrial plants accumulate organic and inorganic constituents in excess of their immediate needs (bioaccumulation). Bioaccumulation is an evolutionary response to scarcity in the natural environment, and is a basis of phytoremediation. The term hyperaccumulator applies to plants that can accumulate metals at concentrations 100-fold greater than concentrations found in the tissue of nonhyperaccumulators. For example, hyperaccumulators can concentrate more than 10 ppm mercury; 100 ppm cadmium; 1,000 ppm cobalt chromium, copper, and lead; and 10,000 ppm nickel and zinc. Metal tolerance is the primary characteristic of these plants. The plants are also capable of translocating metals from the root to plant stems and leaves. There are about 400 plants capable of hyperaccumulation in at least 45 plant families (Lasat, 2002). Some common families of terrestrial plants include Brassicaceae, Euphorbiaceae, Asteraceae, Fabaceae, Lamiaceae, and Scrophulariaceae (U.S. EPA, 2000a). In addition, various constructed wetland plants, such as duckweed (*Lemma minor*) and water hyacinth (*Eichhornia crassipes*) can hyperaccumulate metals (Qian et al., 1999; Zayed et al., 1998; Zhu et al., 1999; Williams, 2002).

Table 4-2. Characteristics of Essential Nutrients for Plants and Microbes.

Primary Nutrients	Chemical Species Assimilated	Function
Nitrogen	NO_3^-, NH_4^+, N_2	Constituent of amino acids, proteins, enzymes, and chlorophyll. Important in photosynthesis, metabolism, and protoplasm reactions. Component of DNA. Important for many growth and development processes. Stimulates uptake of other nutrients. Ammonium uptake is favored over nitrate.
Phosphorus	$H_2PO_4^-$, HPO_4^{2-}, PO_4^{3-}, organic phosphorus	Constituent of proteins, phospholipids, enzyme systems, and nucleic acids. Essential component of ATP, which drives most energy-requiring biochemical processes, including nutrient uptake. Stimulates early growth and root formation. Important in photosynthesis. *Comments:* Organic phosphorus is a major nutrient source. Phosphorus concentrations in soil water are typically low because phosphorus tends to form insoluble compounds in soil.
Potassium	K^+	Principal inorganic cation in cells. Cofactor of some enzymes. Affects cell division, formation of carbohydrates, translocation of sugars, various enzyme actions, disease resistance, stomata opening/closing, cell membrane permeability, and H^+ relationships. *Comments:* Abundant in soils, but often bound to soil minerals, making it unavailable for assimilation.
Secondary Nutrients	**Chemical Species Assimilated**	**Function**
Calcium	Ca^{2+}	Cofactor of enzymes. Regulates membrane permeability, cell integrity, and acidity. Essential component of plant cell walls and membranes.
Magnesium	Mg^{2+}	Cofactor of many enzymes (for reactions such as denitrification and sulfate reduction). Present in cell walls, membranes, and phosphate esters. Constituent of chlorophyll. Aids mobility and efficiency of phosphorus.
Sulfur	SO_4^{2-}, HS^-, S^0, $S_2O_3^{2-}$ Sulfur oxidizing bacteria use FeS and FeS_2	Essential for production of protein, constituent in amino acids. Promotes activity and development of enzymes and vitamins. Helps in chlorophyll formation. Improves root growth. *Comments:* Organic sulfur is a major nutrient source.
Micronutrients	**Chemical Species Assimilated**	**Function**
Boron	BO_3^{3-}, $B_4O_7^{2-}$	Required by higher plants, and some microbes for growth of new cells.
Chlorine	Most likely Cl^-	Coenzyme for photosynthesis. Influences cell membrane permeability. Prevents desiccation. Required by halophillic bacteria (which also need sodium).
Copper	Cu^+, Cu^{2+}	Important in photosynthesis and vitamin A synthesis, protein and carbohydrate metabolism, and probably nitrogen fixation (cofactor for several enzymes).
Iron	Fe^{2+}, Fe^{3+}	Essential for chlorophyll synthesis. Catalyst in respiration. Important in cell division. Important for nitrogen fixation.
Manganese	Mn^{2+}	Enzyme cofactor in many metabolic reactions. Catalyst with iron in chlorophyll synthesis. Role in chloroplast structure. Promotes pigment and Vitamin C synthesis.
Molybdenum	MoO_4^{2-}	Required for nitrogen use. Needed for conversion of nitrate into amino acids and for nitrogen fixation. Role in plant hormones.
Nickel	Most likely Ni^{2+}	Enzyme component. Important in nitrogen metabolism. Required for growth of some bacteria.
Selenium	SeO_3^{2-}	Present in some proteins. May be more important for microbes than plants.
Zinc	Zn^{2+}	Enzyme component, including enzymes involved in zinc synthesis of hormones that regulate growth and development. Role in chlorophyll synthesis.

Adapted from Miller and Gardiner (1998); Pittenger (2002), and Portier and Palmer (1989).

Other plants sequester metals in the root zone, and excrete matter that causes metal precipitation. This is a defensive strategy to prevent toxicity by inhibiting translocation from the roots to other parts of the plant, and is referred to as phytostabilization in the phytoremediation field. Phytostabilizing plants exhibit low levels of metal accumulation in their shoots. Plants with this characteristic are also effective for erosion control because of their extensive, deep root systems.

The ability to remove chlorinated solvents, petroleum hydrocarbons, herbicides, insecticides, explosives, and phenolic compounds has been investigated for wetland and terrestrial plants. Plants may sorb organics, and the compounds can remain in root tissue, become assimilated into the cell wall, become metabolized in the root, or translocate to plant leaves and volatilize. These processes have also been recognized to occur in constructed wetlands for wastewater treatment. Volatile organic compounds such as benzene and trichloroethene can be volatilized, as can selenium, arsenic, and mercury. In the field of phytoremediation, these processes are known as phytodegradation and phytovolatilization. Mechanisms of organic compound degradation by plants are not well understood (Scragg, 1999), but it is believed degradation by plants is assisted by microbes, particularly in the root zone (Karthikeyan and Kulakow, 2003; Salt et al., 1998; U.S. EPA, 2000a).

4.4.2.2 Applicability of Process

Uptake and storage can be used to remove dissolved metals, nutrients (phosphorus and nitrogen), and organic compounds from water and soil pore water. The processes may occur where soil properties and water quality are adequate to support vegetative and microbial growth, and residence times are adequate. The efficiency of uptake processes may be reduced in cold or arid climates because such conditions limit growth of organisms. Land requirements are equivalent to those needed for ponds, biofilters, and bioretention systems. Pollutant concentrations in stormwater treatment systems may not be high enough for significant uptake to occur. Due to lower generally influent concentrations for many constituents (such as nutrients), uptake and storage is probably less significant in stormwater ponds that has been demonstrated in wastewater treatment; and performance is likely to be more erratic (Minton, 2002). Ultimately, nutrient storage by plants and microbes is temporary. A portion of nutrients is released through tissue sloughing, plant senescence, and dormancy.

4.4.2.3 Favorable Conditions and Factors That Enhance Process

Uptake process can vary by season, latitude, and species. Uptake processes only occur during the growing season. Establishment and growth of plants and microbes is affected by various soil characteristics including texture, pH, nutrient levels, salinity and toxicity, soil moisture, and drainage (oxygen). Various soil amendments can be used to make the substrate more suitable for plant and microbial growth. Plants should be suitable for the climate and hydrologic regime, be tolerant of concentrations in stormwater, and have appropriate growth characteristics. Uptake processes are enhanced in warm climates due to the extended growing season. Increasing the density of vegetation will improve uptake, as will increasing residence times. Symbiotic microbes also enhance nutrient uptake by plants.

Plant uptake of organics is a function of the organic compound's solubility, hydrophobicity (K_{ow}), and polarity. Generally, moderately hydrophobic compounds with log K_{ow} between 0.5 and 3.0 are most readily taken up by and translocated within plants. More hydrophobic compounds may be sorbed by roots, but not translocated (U.S. EPA, 2000).

Nonpolar molecules with molecular weights of less than 500 will sorb to root surfaces, while polar molecules will enter the root and be translocated. Soil conditions (e.g., pH, acid ionization constant (pKa), organic and moisture content, texture) affect the solubility of the organic compound. Plant physiology also influences uptake of organics (Salt et al., 1998). Plant transpiration rates are important because they regulate the movement of organics through the plant. Seasonal and diurnal shifts in transpiration rates are relevant. In order for uptake mechanisms to occur, plants with appropriate characteristics must be selected. Differences in uptake of organics among plant species are well recognized (Salt et al., 1998).

Hyperaccumulating plants accumulate metals at levels 100-fold greater than nonaccumulator plants. Such plants have affinities for specific metals, and metal affinity may vary within different species of the same genus. Consequently, uptake of metals by plants beyond their specific metabolic needs (which are relatively minor) will not occur unless the appropriate species are selected. Table 4-3 summarizes the number of plant species that hyperaccumulate specific metals. The significant challenge with such uptake is management of plant material. Management of accumulated pollutants such as metals or phosphorus can be challenging when using biological materials for sorption, accumulation, or uptake due to fluctuating redox conditions that may occur during periodic stormwater flows and natural biological growth and decay cycles.

Table 4-3. Number of Hyperaccumulating Plant Species.

Metal	Number of Hyperaccumulating Plant Species
Nickel	> 300
Cobalt	26
Copper	24
Zinc	18
Manganese	8
Lead	5
Cadmium	1

Source: U.S. EPA, 2000a

Uptake of metals depends on metal bioavailability. Low bioavailability may explain why there are so few hyperaccumulators of lead, as lead tends to form insoluble precipitates. Organic matter excreted by roots can increase metal bioavailability by lowering the pH, or by forming metal chelates.

4.5 Chemical Processes

As discussed in Section 3.3, the treatability of stormwater is largely a function of hydrologic (including hydrodynamic), physical and chemical characteristics. Chemical characteristics, such as pH, alkalinity, hardness, redox conditions, organic carbon, and ionic concentrations, dictate dissolved solids partitioning and speciation of stormwater pollutants, which in turn controls the type of UOPs necessary to treat those pollutants. Three common chemical UOPs applied in the field of stormwater treatment include sorption, coagulation/flocculation, and chemical agent disinfection.

4.5.1 Sorption Processes

Urban stormwater runoff mobilizes and transports significant loads of metal and phosphorus species. Promulgation of NPDES Phase II regulations and state-specific regulations, have in part, spurred development of unit operations and processes for control of chemical species such as metals or phosphorus. Many traditionally-utilized filters using natural materials such as sand, gravel and perlite have relative minor capacity for sorption of phosphorus or metals. Such materials have relatively small surface areas or hydrodynamic characteristics that are not conducive to flow-through sorption treatment such as sorptive-filtration or ion exchange. Recently, unit operation and process (UOP) designs have started to combine surface reactions (such as sorption) and filtration using materials and systems engineered with hydrodynamic considerations. Examples of such media include manganese oxide, iron, aluminum and silicious oxide media, ion exchange media, media coatings, and media substrates (Sansalone et al., 2004; Sansalone and Teng, 2004; Liu et al., 2005a). Many filtration systems not engineered for sorption have shown some capacity for metals and phosphorus. In many cases this is due to the filtration or separation of biogenic materials such as leaves or organic debris or anthropogenic particulate matter found in stormwater. However biogenic materials are degradable, and while anthropogenic particles can have favorable sorption behavior as compared to sand or gravel, their capacity is significantly less than engineered media. While infrastructure also materials also have some degree of sorption capacity, many such materials are oxidized or abraded and mobilized in the urban environment. Compared to typical domestic wastewater and receiving water discharge criteria, metal species concentration in urban stormwater can exhibit elevated levels on an event basis as shown in Table 4-4 (Sansalone, 1997; Drapper et al., 2000; Barrett et al., 1995, 1993; Driscoll et al., 1990; Pitt et al., 2004).

Table 4-4. Comparison of Metal Concentrations in Stormwater and Domestic Wastewater.

Parameter	Units	Domestic wastewater	Urban land use stormwater	Urban transportation land use runoff	Discharge criteria[3]
		Metcalf and Eddy, (1991) Mean (Range)	Pitt et al. (2004)[1] Median (Range)	Sansalone et al. (1997)[2] Median (Range)	
TSS	mg/L	720 (350-120)	58 (8-448)	750 (150-22000)	
Total Zn	µg/L	75 (40-120)	116 (25-616)	628 (336-15244)	120.0
Diss. Zn	µg/L	---	52 (11-988)	1322 (209-14786)	110.0
Total Cu	µg/L	35 (20-45)	16 (4-99)	88 (43-325)	18.0
Diss. Cu	µg/L	---	8 (1-195)	44 (13-279)	17.0
Total Pb	µg/L	10 (2-15)	16 (2-160)	88 (31-1457)	82.0
Diss. Pb	µg/L	---	3 (0.9-43)	16 (13-21)	65.0
Total Cd	µg/L	1 (N/D-3)	1 (0.2-10)	8 (5-32)	5.6
Diss. Cd	µg/L	---	0.5 (0.2-3)	3 (2-9)	3.7

[1] A very extensive database of specific land use categories from open-space to transportation land use (highway or freeway) was summarized by Pitt et al., 2004 (National Stormwater Quality Database). The values shown in the table are the overall medians and ranges (defined by 5th and 95th percentiles) for all land use categories combined.
[2] The concentration is event mean concentration (EMC)
[3] The total metal discharge criteria are State EPA criteria for discharge to modified warm water surface water, and the dissolve metal discharge criteria are U.S. EPA criteria for discharge to modified warm water surface water

4.5.1.1 A Sorption Spectrum for Solutes

Sorptive unit operations and processes are a spectrum of specific mechanisms that range from surface complexation to precipitation and such processes are generally designed for solute mass transfer onto high surface area materials, generally engineered media. In stormwater, solutes with contemporary interest include phosphorus and metals. In combination with these sorptive processes, unit operations such as filtration can represent viable runoff control for dissolved and particulate-bound metal and phosphorus species. Mass transfer of dissolved species can occur through either engineered media or through mass transfer to runoff particles (partitioning) and then be separated as particulate-bound constituents through filtration. Mass transfer for different solutes occurs through different mechanisms and rates in stormwater runoff. For example, phosphorus mass transfer to particles is generally through a combination of sorption and precipitation depending on pH, and the rate of reaction can be very rapid; on the order of minutes to several hours. In contrast, mass transfer for different metals occurs differently and also has differing kinetics. For example, mechanisms of Pb mass transfer to particles (depending on the solid phase and pH) generally range from precipitation to surface complexation with relatively rapid kinetics, while Zn mass transfer generally range from surface complexation to hydrolysis with relatively slow kinetics. However, it must be recognized that the sorption phenomena rates are dependent on the sorbent, hydrodynamics and water chemistry and such phenomena are reversible. In other words, desorption from such materials can occur without consideration of the chemistry. In addition, leaching of metal or phosphorus from such materials is possible. Designs that allow drawdown of stormwater from a filter media within several hours can help prevent leaching and other issues such as biological growth and therefore reduction of hydraulic conductivity. Media can be engineered such that the chemistry of the media promotes chemical processes that result in more permanent chemical bonds between media and adsorbed solute (Liu et al., 2005b).

Mass transfer phenomena play an important role with respect to the fate and transport of metal species. In the general category of sorption, there exist specific mechanisms including surface complexation, ion exchange, differential precipitation, diffusion into solid and hydrolysis. Metal species sorption from stormwater runoff is an important category of mass transfer that has received extensive attention in assessing the fate and transport of metal species in the presence of sorbents (whether engineered media or natural/anthropogenic particles).

For a basic analysis of media parameters required for design and analysis, the engineering behavior of any media or substrate utilized for sorption requires knowledge of the equilibrium capacity of the media (how much pollutant will the media retain at equilibrium) and how rapidly the pollutant can be transferred and retained by the media. The equilibrium capacity is simply how much pollutant the media will hold when the rate of adsorption equals the rate of desorption and is know as an equilibrium isotherm. This capacity is equivalent to the storage volume of a basin when inflow is equal to outflow. The rate of adsorption of the media is analogous to rate of inflow into a basin and the rate of desorption from the media is analogous to the rate of outflow from the basin. By analogy, basin designs do not occur without information on inflow rates, outflow rates and storage; neither should sorptive filter designs. A review of media, isotherms and kinetics can be found elsewhere (Liu et al., 2005a; Sansalone and Teng, 2004; Teng and Sansalone, 2004; Liu et al., 2001a; Liu et al., 2001a; Sansalone, 1999).

Equilibrium isotherms are an important tool to describe the equilibrium between aqueous and solid (media) phases for a known combination and concentration of solute(s), media, water chemistry, media/solution ratio, experimental geometry and hydrodynamics. Isotherm analysis can provide engineering parameters as well as a qualitative indication of more fundamental mechanisms. Isotherms indicate the adsorption capacity of a media or particulate solid under a prescribed or given set of conditions. Isotherms generated for a given set of conditions can provide a quantitative indication of media capacity for individual solutes (i.e. mass of solute adsorbed per dry mass of media) even under the competitive conditions (multiple competing solutes) of stormwater. It cannot be overemphasized that an isotherm is a specific relationship for adsorption capacity under a specific set of conditions. Isotherms should be generated for the specific conditions of the media application and range consistent with the variability anticipated..

This section illustrates the use of a Freundlich isotherm model for a specific set of water chemistry conditions across a range of concentrations. The Freundlich isotherm is simple, robust and general model illustrated because the power law form of the model has both a physical and theoretical basis across a range of concentrations. The mathematical form of the model requires the determination of model parameters (exponent and coefficient) across specific concentration ranges for a fixed set of aqueous and adsorbent conditions. Illustrations of these results are presented. The results presented illustrate that changes in stormwater runoff conditions, for example media-solution ratio or pH, can lead to significant changes in equilibrium adsorption capacity (as measured by the isotherm). Specific isotherms for a given urban runoff application would be developed for those specific conditions and the specific application.

While isotherms are an effective tool to describe solute species (for example aqueous metals, aqueous phosphorus) interaction and media capacity as a function of equilibrium conditions and concentration of solid and aqueous phases, isotherms will yield only indirect information on the role of water chemistry and adsorbent characteristics. In addition to isotherms there are additional tools to model complex and variable natural or engineered systems. These tools are particularly important when the species of interest are minor or trace ionic species and the solid phase substrate exhibits a pH-dependent (amphoteric) surface charge. It is important to recognize that most stormwater particles exhibit amphoteric behavior and engineered media are generally amphoteric; in many cases by design.

In contrast to isotherm models (e.g., Freundlich) surface complexation (SC) models based on double-layer theory, belongs to another group of models that take a mechanistic and molecular-scale approach to surface interaction. As a result, surface complexation models are versatile and have a fundamental physical-chemical basis for predicting metal species surface interaction phenomena over a wide range of experimental and natural conditions. Therefore SC models represent an additional tool to examine the complexity of sorption interactions. Such models are becoming more common in routine environmental chemistry applications and are starting to see an emergence as a stormwater tool (Dean et al., 2005).

4.5.1.2 Sorptive Materials and Media

Engineered media such as oxide coated filter media with high surface area and amphoteric surface charge can be utilized to carry out the combined unit operations of filtration and processes of surface complexation for a range of treatment configurations for in-situ, decentralized treatment or centralized runoff treatment. Such treatment can be designed as a passive and integral part of existing urban infrastructure, for example urban and transportation infrastructure, or can be designed as a centralized treatment component. For process design, control and optimization, it is important to know the quantitative metal species adsorption properties of the engineered media. Experimental studies and modeling of media metal species adsorption properties are required for a quantitative evaluation of storm water media. One particular combined UOP for in-situ treatment for metal and phosphorus species removal in stormwater is an upflow sorptive buoyant media clarifier (SBMC). SBMCs are particularly well-suited for stormwater discharges from elevated urban infrastructure such as elevated roadway over water where both solutes and particles in runoff are a concern. There are many examples of in-situ treatments that combine sorptive processes and filtration operations; whether intentionally by design or inadvertently.

4.5.1.3 Background for Materials and Media

Amphoteric materials are used for metal species adsorption because of their relatively high surface area and their surface charge characteristics. Metal species adsorption behavior for specific media, such as silica sand, soils, granular activated carbon, and iron oxide, have been studied extensively in the past (Langmuir, 1997; Stumm and Morgan, 1996; Stumm, 1992). Applications of such adsorption behavior for selected engineering process treatment have proved successful for use in engineering design with specific engineered media. The pH at which there is an equal amount of positive and negative surface charge on an amphoteric media or particle is known as the point of zero charge (PZC). The PZC does not indicate the media has no charge, it indicates the pH at which there is a balance between positive and negative charges. Therefore the further the water pH is from the pH at the PZC (pH-PZC) the greater the dominant positive or negative charge. Therefore since the pH of most stormwater is in the range of 6 to 8, a PZC above 8 will result in a net positive media or particle charge and a PZC below 6 will result in a net negative media or particle charge. This should not suggest that adsorption does not occur near the PZC. When the pH of stormwater is near the PZC of the media or particles such adsorption can be chemically-specific. Most media, biogenic/anthropogenic particles or soil particles are amphoteric. For example, depending on the clay mineral, surface charge behavior is a combination of amphoteric charge and permanent charge. Many clay minerals are found in suspended stormwater solids or adsorbed on other stormwater particles. For example, clay minerals such as Na-bentonite are dominated by a large negative surface charge and therefore the amphoteric behavior in stormwater is small. In contrast, kaolinite, another clay mineral found in stormwater runoff has an amphoteric behavior that is relatively strong compared to the permanent charge. Generally, there is a net negative charge for suspended solids in stormwater although the behavior is amphoteric and dependent on mineral or organic content. Silica sand, a common filter media has a PZC-pH in the pH range of 2 to 3 resulting in a high net negative charge. However the surface area of silica sand is very low (approximately 0.05 m^2/g) so the result is a filter media that with low adsorption capacity. Stahl and James (1991) found their manganese oxide coated sands generated a larger surface area and significantly increased adsorption capability with increasing pH as compared to uncoated silica sand.

4.5.1.4 Examples of Adsorption Equilibria and Freundlich Isotherms

Figure 4-4 illustrates examples of adsorption isotherms for manganese oxide polymeric media (MOPM) obtained for the solution at initial pH values of 5, 6, and 7 and initial Pb(II) concentration of 5-mg/L (2.41×10^{-5} M). It is critical to emphasize that isotherms should be developed for the water chemistry conditions expected and that isotherms developed for other physical, chemical or hydrodynamic conditions or other media properties cannot be transferred or generalized to other media or other conditions. For example, the results in Figure 4-4 illustrate the role of water chemistry, specifically the impact of pH on isotherm results at a fixed concentration of Pb(II) as a single solute concentration of 2.4 x 10-5 M. While it is common to use gravimetric concentrations, i.e. mg/L, it is more appropriate to use chemical concentrations in moles. Figure 4-4 illustrates mg/L for familiarity. Results indicate an increase in media capacity was observed as the initial solution pH was increased. There is a slight increase in media capacity from pH 5 to 6, while at pH 7 the capacity was several times greater than at a pH of 6. Since the Freundlich isotherm has a theoretical basis for modeling solids (i.e. TSS or SSC) or engineered media with heterogeneous surface properties (Stumm, 1992), the Freundlich equation was able to model adsorption of MOPM well, given the heterogeneous surface properties of the media of which the surface characterization were described elsewhere (Liu et al., 2001a). In the Freundlich isotherm equation, the coefficient K_F is an indication of adsorption capacity while n reflects the steepness of the curve whether plotted on an arithmetic or logarithmic scale. The isotherm and adsorptive behavior for particulate solid or engineered media is a function of the concentration range, water chemistry, and the type of engineered media or solids for which the isotherm was developed. The isotherm and behavior should be developed, tested, and examined for the entire range of concentrations, competitive conditions, media or particulate solids loadings and chemistry. The Freundlich isotherm as a continuous function with the form of a power law model allows a mathematical description of equilibrium capacity for a solute or group of competitive solutes. Such a model allows a quantitative description of equilibrium capacity across a wide range of concentrations for a given set of water chemistry, solids or media type and hydrodynamic conditions. It is very important to recognize that resulting isotherms and behavior are unique and a specific isotherm should ONLY be applied for specific conditions under which the isotherm is applicable and assuming equilibrium conditions. To reiterate, isotherms are only valid for equilibrium conditions and for a specific media or solids gradation and water chemistry conditions.

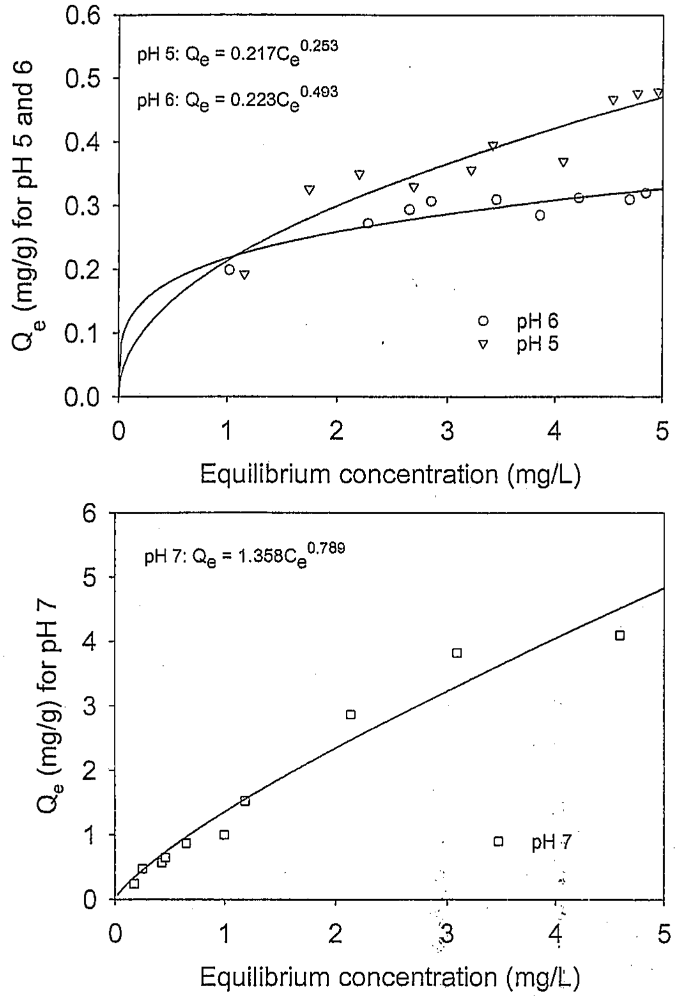

Figure 4-4. Adsorption Isotherm for Pb(II) on Manganese Oxide Coated Polymeric Media.
Lines are Freundlich model curve. Sorbent dosages range from 0.1-g/l to 20-g/l. Initial concentration is 5-mg/l (2.41×10-5 m). Reprinted with permission from Liu et al. ASCE Journal of Environmental Engineering (April, 2004).

In this example, the Freundlich model fit the data well as shown in Figure 4-4, and the Freundlich isotherm constants and their standard error for the representative equilibrium studies are summarized in Table 4-5. The Freundlich curve patterns are very different for each of the three solute pH levels examined. The adsorption capacity of Pb(II) at pH 7 is 6 times larger than that at pH 6, and the higher the solute pH, the steeper the curve.

Table 4-5. Freundlich Model Isotherm Coefficients for Manganese Oxide Coated Polymeric Media.

pHi	pHe[a]	Experimental matrix	Me^{2+} Metal	I[d] (mol/L)	C_0 (mg/L)	K_F[e]	StdErr[f]	n[e]	StdErr	r^2
7	6.63-5.71	[b]Single Me^{2+}	Pb	0.01	5	1.358	0.126	0.789	0.076	0.959
6	5.81-5.36	Single Me^{2+}	Pb	0.01	5	0.223	0.022	0.493	0.077	0.878
5	5.07-4.96	Single Me^{2+}	Pb	0.01	5	0.217	0.013	0.253	0.049	0.835
7	6.87-6.15	Single Me^{2+}	Zn	0.01	5	0.276	0.013	0.351	0.036	0.956
7	6.74-6.03	Single Me^{2+}	Cu	0.01	5	0.419	0.023	0.444	0.045	0.892
7	6.60-6.14	[c]Mixed Me^{2+}	Pb	0.01	1	1.266	0.228	0.964	0.176	0.860
7	6.60-6.14	Mixed Me^{2+}	Cu	0.01	1	0.748	0.056	1.022	0.094	0.965
7	6.60-6.14	Mixed Me^{2+}	Cd	0.01	1	0.157	0.008	0.488	0.067	0.926
7	6.60-6.14	Mixed Me^{2+}	Zn	0.01	1	0.077	0.005	0.978	0.022	0.819
6	6.13-5.46	Mixed Me^{2+}	Pb	0.01	1	0.273	0.020	0.766	0.131	0.875
6	6.13-5.46	Mixed Me^{2+}	Cu	0.01	1	0.119	0.024	4.254	1.414	0.689

a pH range of samples at equilibrium (0.1-20g/L dose range)
b only one testing metal in experimental solution
c the solution containing 1-mg/L Pb2+, Cu2+, Cd2+ and Zn2+.
d Ionic strength of background solution using NaNO3.
e Based on the Freundlich model where Qe is in mg/g and Ce is mg/L.
f Standard error for estimated parameter.
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4.5.2 Coagulation/Flocculation

Coagulation and flocculation are commonly recognized as a two-step serial process in which the destabilization of suspended particles is known as coagulation while aggregation of destabilized particles is known as flocculation. It is also common to find references to inorganics such as alum or ferric chloride as coagulants and polymeric materials that create flocs as flocculants. Suspended particles stay in the water column because they are small (therefore a relativity small gravitation force as compared to other forces); they are kept in suspension by Brownian motion, mixing velocity gradients and their similar charges make them repulse other suspended particles with which they collide. Mechanisms of destabilization (making single stable particles less stable so that they collide, "stick together" and form large flocs that settle more rapidly), include: double layer compression by different electrolytes; charge neutralization by specifically adsorbed charged species; enmeshment in a precipitate (formation of sweep floc); and adsorption and inter-particle bridging. There are three mechanisms for particle attachment (flocculation). First mechanism is perikinetic (or Brownian) flocculation, which is due to particle diffusion and only significant for particles less than 1-µm. A second mechanism is orthokinetic flocculation under which particle contacts are caused by differences in fluid velocity. The third mechanism is differential settling under which particles with different settling velocities collide. This mechanism is significant for suspensions with larger particles (>50-µm).

While coagulation-flocculation (C/F) has not been frequently applied to stormwater treatment in the past, that situation is beginning to change. Runoff control presents unique challenges for effective treatment due to the heterogeneous physical and chemical nature of constituents and the variable nature of constituent-producing processes in the environment. Increasing understanding of these unique challenges is, in part, responsible for increasing consideration of (C/F) as a unit operation/process (UOP) for stormwater runoff. These challenges include the site-specificity and variability of parameters such as urban activities (loadings such as traffic), hydrology, watershed geometry, infrastructure materials, and weather patterns create variable levels of metals, particulate and dissolved matter, and inorganic and organic constituents in stormwater runoff (Glenn et al., 2001; Novotny and Olem, 1994). In comparison to other commonly treated aqueous waste streams, such as typical wastewater and drinking water, urban runoff present very non-uniform particle gradations that vary from colloidal-size to gravel-size material with runoff residence times that are relatively short compared to other waters (Sansalone et al., 1998). For example, source area watersheds, such as urban transportation land uses with relatively short residence times (less than 30 minutes) that are designed for rapid conveyance are capable of transporting a much wider gradation of particles than larger, hydraulically less efficient urban watersheds. As this gradation is transported downstream in a larger urban watershed, larger particles are selectively removed in the flow path resulting in a selectively finer gradation as flow moves through the urban watershed. Whereas natural waters have residence times of days to weeks and wastewaters on the order of hours to day, stormwater may interact and entrain particles for only minutes before reaching the catchment outlet (Sansalone and Buchberger, 1997). Such conditions promote non-equilibrium geo-chemical and granulometric conditions, both of which complicate treatment. Despite the complications inherent in treating stormwater, recent developments in the study of the pollutant impact of surface water in the U.S. culminating with the Passage of the 1999 Stormwater Phase II Rule of the National Pollution Discharge Elimination System (NPDES) have accelerated interest in increasingly sophisticated runoff treatment unit operations and processes (UOPs) including coagulation-flocculation.

Stormwater runoff is a heterogeneous discharge composed of entrained particles commonly generated by urban activities, detritus, and dissolved/complexed inorganic/organic constituents generated from the interaction of typically acidic rainfall with various urban and infrastructure surfaces and residual detritus. Entrained solids exert an oxygen demand on receiving waters and account for the majority of mass in the storm sewer system. More significantly, however, these solid constituents are sorptive sites for solutes such as phosphorus and metals in the waste stream, comprising a solid-phase surface to which these solutes partition (Thompson et al., 1997). While metals sorbed onto runoff solid residuals are not necessarily an acute bioavailability threat, they comprise a solid waste that is often characterized as hazardous and must be stabilized to avoid further re-introduction of metal ions into the aqueous, and thus bioavailable, phase (Field and O'Shea, 1994). Therefore, it becomes imperative for any runoff treatment design (including C/F) to account for the nature of the particle size gradation and promote separation of stormwater solids from the aqueous matrix.

Application of C/F is generally considered when gravitational settling, or one of the many forms of particle separation (clarification, hydrodynamic separation, etc.) are unable to remove the colloidal and suspended particles and constituents with low settling velocity (Gromaire-Mertz et al., 1999). Colloidal and suspended particles (< 25-μm) tend to stay in the suspension and require either low surface loading rates for clarification or long clarification times. Both requirements are difficult and potentially uneconomical for many urban runoff conditions. While the settleable and sediment-size fractions of particles have been shown to transport the predominance of adsorbed constitute mass, the suspended fraction of particles cause turbidity of the receiving water body, reduce levels of dissolved oxygen, and pose toxicity threat to aquatic life (Sansalone et al., 1998).

In view of the above issues, alternative technologies or enhanced sedimentation are required to address urban rainfall runoff treatment. Beyond primary treatment, secondary or "advanced" UOPs such as C/F are seen as one possible enhancement. C/F processes have generated interest in urban runoff treatment for several reasons. First, C/F processes remove phosphorus, suspended solids, organic matter as well as the fractions of metals bound to suspended and colloidal particles. Secondly, C/F processes may be able to accommodate variations both in stormwater flow and composition as has been demonstrated for urban wastewater treatment (Passino and Ramadori, 1999). Depending on the process details, when sedimentation is followed by a C/F process or combined with a C/F process, particles down to 1-μm or less may be separated.

C/F is also a possible solution to reduce the impact of combined sewer overflows (CSO) on surface water quality (De Cock et al., 1999). Anderson et al. (1992) proposed application of C/F to stormwater overflow treatment, claiming that it could achieve sedimentation rates up to 20-m/h (5.55-mm/s) and solids removal efficiencies of greater than 90% on a mass basis. A prototype stormwater alum treatment system was introduced in a lake restoration project on Lake Ella in Tallahassee, Florida in, 1986, based on the flow-weighted injection of liquid aluminum sulfate (alum, $Al_2(SO_4)_3 \cdot 18\ H_2O$) into the runoff flows inside storm sewer lines before discharging to the lake (ERD, 1999). Alum treatment of stormwater has been shown to consistently reduce concentrations of orthophosphorus and total phosphorus by 85-95%, heavy metals by 80-90%, suspended solids by 95%, total nitrogen by 50-80%, and coliform bacteria by more than 99%. Six more alum stormwater treatment systems have been constructed since Lake Ella. These systems typically require little acquisition or basin construction, thus greatly reducing the capital cost of stormwater retrofit projects.

4.5.2.1 Unique Characteristics of Stormwater Runoff

In stormwater runoff at the upper end of the urban watershed, the colloidal and suspended fractions are mixed with the settleable and sediment fractions in a relatively shallow water column (mm to cm). With residence times of these particles generally less than several hours and with unsteady flow, equilibrium and steady-state floc development has not occurred in stormwater runoff by the time such flows are treated in-situ or regionally for an urban catchment. This makes urban runoff unique from natural waters and wastewaters. Natural C/F and floc-breakup are still active processes at the location of many in-situ treatments.

Particulates are important in understanding the impact of the pollution from urban runoff and have been studied extensively (Yu et al., 1994; Characklis and Wiesner, 1997; Sansalone et al., 1998; Drapper et al., 2000). While researchers have found that the higher metal concentrations (by definition) are associated with fine particles (<50-μm) (Xanthopoulos and Augustin, 1992; Sansalone and Buchberger, 1996), the greatest amount of metal mass has been found relating to the median-size to coarse particles (Sansalone, 1998). Nature and size distribution of the particles play an important role in determining their transport and fate, as well as any associated contaminants. These particles generally have a net negative charge in stormwater runoff. Large solids in runoff may settle into sewers and urban waterways, however, these particles and contaminants can be mobilized by subsequent storms or pose a chronic threat to aquatic life. Smaller, colloidal particles remain in suspension and can be transported much greater distances, while still pose a chronic threat to aquatic life. Therefore, granulometric-based distribution of particles in urban runoff results in both spatial and temporal variations in particle transport and contaminant fate (Characklis, 1997).

Removal of only the gross solids (greater than 6-mm) from combined sewer overflows would do little to reduce the impact of sewer overflows on receiving waters, other than to remove some of the more visible pollution (Xanthopoulos et al., 1993). Separation of fine particulate and colloidal solids is necessary in order to reduce the pollutant load from sewer overflows to levels acceptable for discharge to receiving waters (Booker et al., 1996). In general, stormwater runoff is of low hardness with a low acid combining capacity. While the colloids and the suspended particles have a negative charge in stormwater, the concentration of salt is generally low (Heinzmann, 1994). In water of low hardness, colloids are very stable, because the operational range of the electrostatic repulsion is higher than in hard water. Odegaard et al. (1990) have shown that at equal colloid and particle concentrations, soft water contains more colloids and particles with a diameter of < 1-μm and fewer particles with a diameter of > 1-μm than hard water. Therefore, the coagulant dose for destabilization is lower in water of high hardness than in water of low hardness.

4.5.2.2 Coagulants and Flocculants

Inorganic coagulants can be electrolytes or polyelectrolytes and are typically based on iron (ferric), aluminum, calcium, or magnesium. When these coagulants are dissolved in water, they generate highly charged cationic ions for destabilizing dispersed solid particles. When these cationic ions are introduced into a system with negative charged particles, they interfere with the repulsive stabilization by charge neutralization and allow the particles to come into close contact. This initiates the coagulation process. Large aggregates formed from destabilized particles are separated from the stream through clarification. Al^{3+} or Fe^{3+} ions can also be hydrated to form aquometal complexes of $[Al(H_2O)_6]^{3+}$ or $[Fe(H_2O)_6]^{3+}$. These positively charged species could cause destabilization of negatively charged colloids by adsorption and charge neutralization. Precipitation of amorphous metal hydroxide is necessary for sweep-floc coagulation. Inorganic coagulants usually offer a low unit price, therefore are widely available. They are quite effective in removing most suspended solids, and also capable of removing a portion of the organic precursors which may combine with chlorine to form disinfection by-products. The large volumes of floc they produced can entrap bacteria during the process of settling. Application of inorganic coagulants such as alum or ferric will consume alkalinity resulting in the alteration of pH in the water. For this reason, alum and iron salts generate demand for lime and soda ash. They also require corrosion-resistant storage and feed equipment. The large volumes of settled floc need to be disposed of in an environmentally acceptable manner. Issues of residual coagulant and flocculent concentration in both the effluent and in the residual materials require consideration when there are potential questions regarding toxicity.

Synthetic flocculants have been used in water treatment since 1960s. Linear and branched polymers are the most frequently encountered types. Molecular weights for polymers range from a few hundred thousand to tens of millions. A polymer is referred as a polyelectrolyte if its monomers contain ionizable groups. Nonionic polymers contain no charge-bearing groups and anionic polymers are usually copolymers of acrylamide and acrylic acid, sodium acrylate or another anionic monomer. Anionic polymers acquire a negative charge upon ionization. They are ineffective for negatively charged particles when used alone in coagulation. Cationic polymers can be copolymers of acrylamide with a cationic monomer, cationically modified acrylamide or a polyamine. The cationic charge in these polymers is derived from nitrogen in the form of a secondary, tertiary or quaternary amine group. Those containing secondary or tertiary amines are sensitive to pH. The charge on these polymers drops off quickly as the pH rises above 6. Cationic polymers become positively charged when dissolved. Cationic polymers are effective for negatively charged particles during coagulation process. Attachment of polymer to particle is via electrostatic attraction or ion exchange. Inter-particle bridges are formed during the process of flocculation.

Flocculation requires adsorption of polymer segment onto the particle surface. This adsorption is made possible through hydrogen bonding and hydrophobic interaction in which a polymer with significant hydrophobic character is "squeezed" out of the aqueous solvent to adsorb onto the particulate surface (Hecker, 1998). Charged polyelectrolytes interact with a particle surface through ionic mechanisms: electrostatic interactions between oppositely charged polymer and particulate surface; or polyvalent ion bridging between similarly charged polymer and particle surface. Polymers are efficient flocculants at low concentrations.

The most common flocculants are polyacrylamide that is a non-ionic polymer and its derivatives. They bring about agglomeration of the particles by inter-particle bridging. Polyacrylamides can be given an anionic charge by co-polymerizing acrylamide with acrylic acid. Cationic polymers are prepared by co-polymerizing acrylamide with a cationic monomer. The polyacrylamides are usually less pH sensitive.

4.5.2.3 Optimum Dosage of a Coagulant or Flocculant: Jar Testing

The objective of jar test is to determine the most effective coagulant and the optimal dosage. The parameters in jar test include particle concentration, water chemistry, mixing characteristics and dosage of coagulants and flocculants. Temperature, pH, alkalinity, ionic strength, mixing intensity, velocity gradients, mixing time and flocculation time are the controlling experimental parameters. Turbidity, suspended sediments (generally as TSS) and particle size distribution (PSD) of samples are measured to evaluate the effectiveness of various C/F processes.

Jar testers employed in the USA are similar to models produced by Phipps & Bird (i.e. a PB-900) that employ a 2-L jar with designed settling distance of 100-mm. Agitator paddle speed is linearly related to the velocity gradient (G, s^{-1}). Samples for turbidity, solids and PSD measurement are taken at the same depth without disturbing the settling solution in the jar. A common jar test procedure is ASTM D 2035-80. Generally the procedure involves recording the initial well-mixed raw water pH, temperature, turbidity, alkalinity, ionic strength and particle size distribution. A standard test is outlined as follows. The jar tester is started at a rapid mix of 120 rpm for 1 minute. The mixing speed is then reduced to 20 rpm after that and the slow mixing for the remained 20 minutes. 15-minute clarification settling follows to allow the flocs to settle. All parameters are measured immediately at the end of the test. Analyses of the data and variation of the dosage and testing are carried out until a desired water quality outcome and C/F process are reached.

4.5.2.4 Particle Agglomeration

A conceptual schematic of the mechanisms involved in particle coagulation is given in Figure 4-5. First, some characteristic of the aqueous matrix, typically pH, ionic strength of solution or a chemical additive, act to destabilize particles allowing Van der Waals attractive forces to dominate. Next, particles are brought into contact with each other due to various particle collision mechanisms, typically aided by complete mixing of the system to form aggregates. These aggregates undergo further agglomeration and disaggregation until a steady state particle size distribution is reached (Pontius, 1990). In terms of natural particle agglomeration, understanding the degree of influence of the pH of solution and average velocity gradients in terms of their impact on particle destabilization and particle collision is paramount.

Once particles are brought into contact, the collision process can occur and stable particle aggregates are formed. Most particle agglomeration models include three well-understood particle collision mechanisms: Brownian diffusion, fluid shear, and differential sedimentation. The driving forces for these mechanisms are the temperature gradient, velocity gradient, and particle density, respectively (Lick and Lick, 1988). The collision mechanisms are generally considered to be independent and their frequency functions (Table 4-6) are additive (Han and Lawler, 1992).

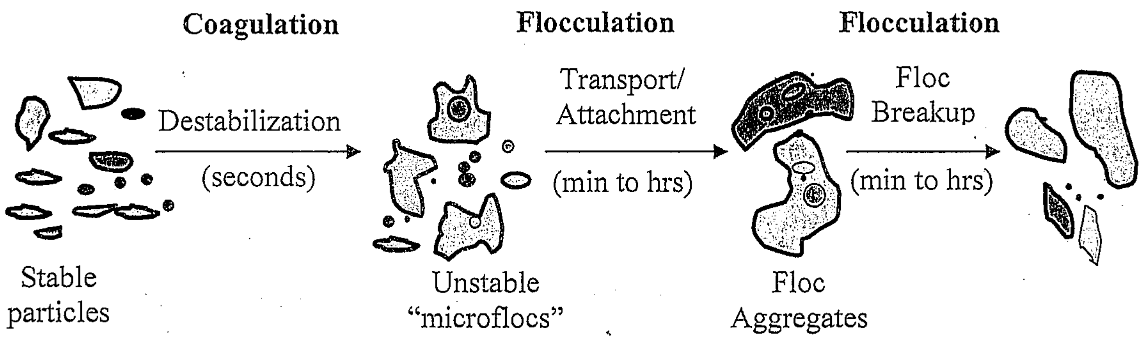


Figure 4-5. Subprocesses Controlling the Rate of Particulate Aggregation. Adapted from Montgomery (1985).

Table 4-6. Particle Collision Mechanisms Relevant to Coagulation/Flocculation.

Brownian Diffusion	Collisions of colloidal sized particles (< 1.0-μm) with some other particle of significantly different size	$\beta_{Br}(i,j) = \frac{2\kappa T}{3\mu}\left(\frac{1}{d_i} + \frac{1}{d_j}\right)(d_i + d_j)$
Fluid shear	Collisions of suspended solids (~1.0 to 50.0-μm) with particles of similar size	$\beta_{Sh}(i,j) = \frac{1}{6.18}(d_i + d_j)^3 G$
Differential Sedimentation	Collisions of settleable solids (> 50.0-μm) with particles of significantly different size.	$\beta_{DS}(i,j) = \frac{\pi g}{72\mu}(\rho_p - \rho_l)(d_i + d_j)^3 \lvert d_i + d$

d_i, d_j = diameter of particles i and j; κ is the Boltzmann's constant ($\kappa = 1.3805 \times 10^{-23}$ J/K); T is the absolute temperature of the aqueous suspension (K); μ is the dynamic viscosity (N-s/cm^2); G is the mean velocity gradient (sec^{-1}); g is the gravitational constant (9.81 m/s^2), and ρ_p and ρ_l refer to particle density and aqueous density, respectively (g/m^3).

Smulochowski's classic equation is given as Equation 4-17, presented with the particle collision mechanisms combined [$\beta(i,j) = \beta_{Br}(i,j) + \beta_{Sh}(i,j) + \beta_{DS}(i,j)$].

$$\frac{dN_k}{dt} = \frac{1}{2}\sum_{i+j=k}\beta(i,j)N_iN_j - N_k\sum_i\beta(i,k)N_i \quad [4\text{-}17]$$

In Equation 4-17, i, j, and k are subscripts referring to discrete particles sizes, $\beta(i,j)$ and $\beta(i, k)$ are collision frequency functions ($cm^3\ s^{-1}$) that describe particle collision frequency between two particles, here i and j and i and k, respectively. N_i, N_j, and N_k refer to the number concentration of particles (cm^{-3}) for size classes i, j, and k. The first term on the right side of Equation 4-17 describes the increase of particles of size k (cm) by the collision and attachment of particles of size i and j. The condition under the summation, i + j = k, indicates $v(i) + v(j) = v(k)$ where v represents spherical particle volume with diameter of size i, j, or k (Han and Lawler, 1992). The second term on the right side of Equation 4-17 describes the decrease in particles of size k due to the formation of flocs with diameters larger than k through the collision of a k-sized particle with that of an i-sized particle.

While this model demonstrates idealized particle aggregation behavior, i.e. all particle collisions result in a stable aggregate, equation 1 is typically presented with collision efficiency factors that range from 0 to 1 (given as δ in Equation 4-18). For the purposes of this research, collision efficiency functions are determined from Han and Lawler (1992).

$$\gamma(i,j) = \delta_{BR}\beta_{BR} + \delta_{FS}\beta_{FS} + \delta_{DS}\beta_{DS} \quad [4\text{-}18]$$

4.5.2.5 Natural C/F in Stormwater Runoff

While the study of particle agglomeration with engineered solutions (i.e. engineered C/F in wastewater and drinking water systems) has been a focus for the past decade in the areas of standard wastewater and drinking water, there is a lack of experimental investigation into the characteristics of heterodisperse particle agglomeration for other aqueous matrices, such as stormwater or snowmelt. As treatment schemes for stormwater solids become increasingly elaborate and modern, beyond simple gravitational settling, a detailed account of aggregate formation in the particle size distribution for a well-mixed system is imperative to viability. Even without the addition of coagulants or flocculants, natural C/F can occur in stormwater within hours, significantly altering the number and mass gradations of particles. These changes have significant implications for treatment decisions that may be based on gradations that represent a gradation different that what is actually loading a treatment system. This next section examines the role of selected parameters on natural C/F (without chemical additions) for heterodisperse stormwater particles. The influences of time, pH and velocity gradients, as prominent parameters of particle agglomeration, are all significant. However the following paragraphs only examine the role of time for brevity. Measured particle gradations from an urban Baton Rouge site (time of concentration less than 30 minutes) are applied to the Smulochowski binary collision equation with curvilinear particle efficiency corrections in order to evaluate the applicability of this model to the evolution of stormwater gradations.

Samples collected for particle agglomeration experiments were collected at an experimental site located in Baton Rouge, Louisiana, at City Park Lake near Louisiana State University. This site is typical of source area urban sites with residence times less than 30 minutes. These results examine the influence of specific parameters, pH, residence time, and mixing on natural flocculation. As a result, this site is representative of an urban source area site contributing particles to a larger urban watershed. Five liters runoff samples were collected at the inlet mouth of the debris separator (grit chamber) in a 10-liter polypropylene sample container chosen to capture the entire cross-sectional area of flow. Upon arrival to the lab, a well-mixed volume of the collected stormwater sample was appropriately diluted based on turbidity for laser-diffraction particle analysis. Typical sample dilution factors for particle analysis for runoff retrieved from the Baton Rouge site range from 5-15. While pH may not significantly change (<1 s.u.) during a rainfall-runoff event, pH control as well as control of hydrodynamics was required to examine agglomeration. Therefore if necessary, the diluted sample pH was manually controlled at a fixed pH by drop-wise addition of 0.02% trace-metal HNO_3 since coagulation parametric influences should be examined at a fixed pH. Sample mixing speeds were controlled using a stir-plate and stir-bar specifically chosen to maintain turbulent flow regime mixing conditions (constant hydrodynamics) throughout the experiment. After manual pH adjustment and particle analysis dilution, PSDs were recorded via particle analyzer every 15-minutes for a period of 12-hours. The laser diffracting particle analyzer measures the particle gradation by projecting a diode laser through a 160-mL well-mixed sample chamber. As the diode laser is projected through the entrained suspension of particles, these particles are illuminated. The degree of refraction of the laser from the surface of these particles is intercepted in the receiving lens of the reactor. Refraction of the laser is detected by a specially constructed detector consisting of 32 rings. These 32 rings correspond to 32 logarithmically-spaced particle size increments ranging from 1.0 to 250-μm. Thus, the particle analyzer is capable of conveying the particle gradation for stormwater solids in the suspended fraction (~1.0 to 50-μm), the settleable fraction (those particles which settle out of suspension after one hour of quiescent settling, ~ 50 to 100-μm), and a very small portion of the fine sediment fraction. Since it is difficult to keep 100 μm and larger particles suspended, or sampled representatively unless the full cross-section of flow is taken and analyzed, results are generally most representative below 100 μm and other analysis techniques utilized for larger particles.

4.5.2.6 Changes in the Particle Size Distribution

Due to the manner in which the particle analyzer measures the particle size distributions (PSD), specifically the assumption of spherical particle geometry, temporal PSD indicate both an increase in the total volume concentration and a shift in the maximum measured volume concentration when agglomeration occurs. Figure 4-6 shows the changes in the volumetric distribution of the stormwater sample collected on January 19, 2002, maintained at a pH of 6.5. Several PSDs are given over time for the storm event, with a break from graph A to graph B of 300-min. As is apparent from the inserted total volume concentration (TVC), d_{90n}, and d_{50n} curves, as well as the magnitude of the PSD peaks, agglomeration accelerates at 300-min and continues until the last PSD observed at 609-min from sample collection. As flocs are forming during the agglomeration process void spaces are created in between primary particles. The particle analyzer interprets this heterogeneous mass as one larger spherical particle. Thus, an increase in the TVC over time indicates a shift in the sample gradation from a predominance of smaller-sized particles to the coarser fraction (> 75-μm) due to floc formation.

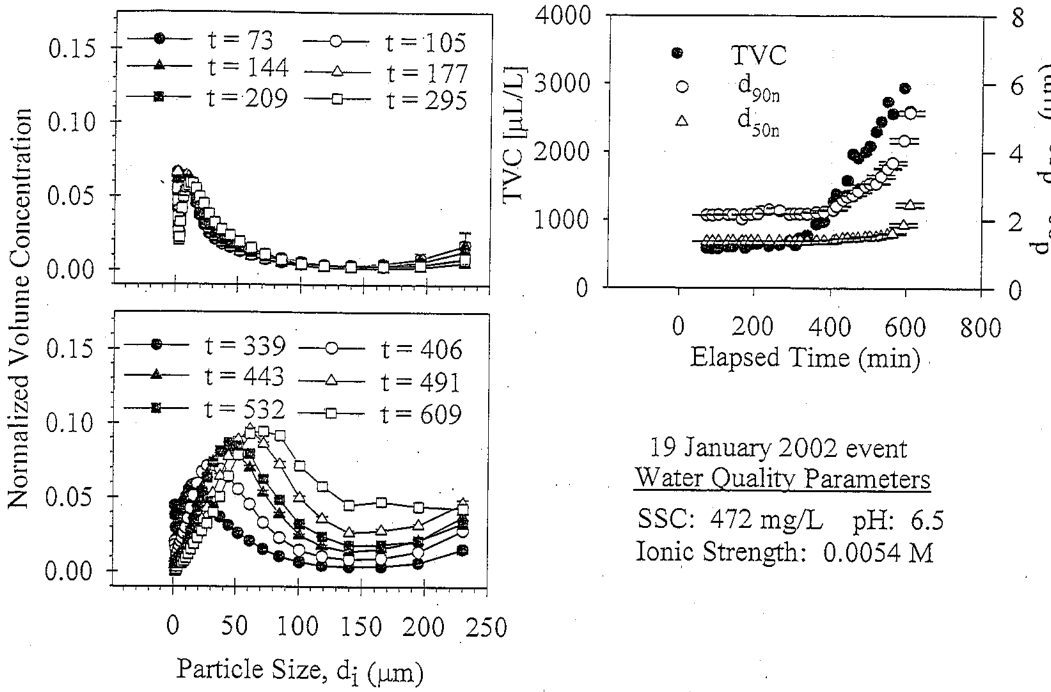


Figure 4-6. Evolution of the Runoff Particle Size Distribution.
Collected on January 19, 2002. Time zero is defined as the time at which runoff was observed at the catchment outlet. The first particle size measurement was done at time = 73-min from time zero. Each volume concentration is normalized to the total volume concentration (TVC) recorded at the time of PSD measurement. Symbols represent triplicate measurements; error bars represent standard deviations. D_{50n}: median representative particle diameter based on particle number (µm), d_{90n}: representative particle diameter for 90% of the particle gradation based on particle number (µm).

Several observations can be made from the figure. It is apparent during the first portion of the experiment that very little agglomeration occurs. This can be concluded by the fact that neither the peak of the volume distribution shifts in terms of particle size nor does the magnitude of the volume concentration peak increase. After 300 min (graph B) we see the occurrence of particle agglomeration in both the shift of the volume concentration peak to a larger particle size increment (from 15 µm at 339 min to 60 µm at 609 min) as well as an increase in the magnitude of the peak volume concentrations.

4.5.3 Chemical Agent Disinfection

Chemical agent disinfection refers to the use of chemical agents to partially destroy or immobilize pathogens. Disinfection must not be confused with sterilization which refers to a complete destruction of pathogens. Chemical agents used in wastewater treatment for chemical disinfection include: 1) chlorine and chlorine compounds, 2) bromine, 3) iodine, 4) ozone, 5) phenol and phenolic compounds, 6) alcohol, 7) heavy metals and related compounds, 8) dyes, 9) soaps and synthetic detergents, 10) quaternary ammonium compounds, 11) hydrogen peroxide, 12) peracetic acid, 13) various alkalis, and 14) various acids (Metcalf and Eddy, 2003). Chemical disinfection of stormwater is less common and the range of chemicals used in the few available studies is less extensive. Chemicals commonly used in stormwater disinfection include chlorine, chlorine compounds, and ozone.

4.5.3.1 Description

Oxidation compounds such as ozone and chlorine compounds immobilize pathogens through a variety of mechanisms including destruction of cell walls, which results in death. Other mechanisms include protein precipitation, modification of cell wall permeability, hydrolysis and mechanical disruption. The effectiveness of the disinfection process depends on contact time, concentration of the disinfectant, the type of organisms being targeted, and the nature of the influent (Metcalf and Eddy, 2003).

The main reactions in water when chlorine is added in the form of Cl_2 gas are hydrolysis and chlorination. Hydrolysis refers to the combination of chlorine gas with water to form hypochlorous acid (HOCl):

$$Cl_2 + H_2O \leftrightarrow HOCl + H^+ + Cl^-$$

A subsequent reaction is the disassociation of hypochlorous acid to hypochlorite ion (OCl^-):

$$HOCl \leftrightarrow H^+ + OCl^-$$

HOCl and OCl^- together represent the "free available" chorine in the system..The disinfection effectiveness of HOCl is about 40-80 times that of OCL^-. Therefore from a treatment perspective, the relative proportions of HOCL and OCl^- in a system is important.

Equation 4-19 describes the percent actual chlorine which can be used to evaluate the effectiveness of compounds containing chlorine.

$$(Cl_2)_{actual}, \% = \frac{(weight\ of\ chlorine\ in\ compound)}{(molecular\ weight\ of\ compound)} \ x\ 100 \qquad [4\text{-}19]$$

Available chlorine, which is a measure of the oxidizing power of chlorine compounds, is another criterion that can be used to evaluate the effectiveness of chlorine compounds in the disinfection process.

$$(Cl_2)_{available} = (Cl\ equivalent)[(Cl_2)_{actual}\ , \%] \qquad [4\text{-}20]$$

Where: Cl_2 actual = the actual percentage of chlorine as computed with Equation 4-19
Cl equivalent = the electron change in the associated half reaction

Ozone disinfection is similarly accomplished by introducing ozone into the influent. The reactions of ozone in water are shown in the reaction equations below. The free radicals produced as a result of these reactions possess strong oxidizing power and are thought to be the active forms in the disinfection process (Metcalf and Eddy, 2003).

$$O_3 + H_2O \rightarrow HO_3^+ + OH^-$$
$$HO_3^+ + OH^- \rightarrow 2HO_2$$
$$O_3 + HO_2 \rightarrow HO + 2O_2$$
$$HO + HO_2 \rightarrow H_2O + O_2$$

The expressions that were initially developed to model chlorine disinfection have been modified for the ozone disinfection process as shown in Equations 4-21 and 4-22.

$$\frac{N}{N_o} = 1 \quad \text{for } U < q \qquad [4\text{-}21]$$

$$\frac{N}{N_o} = \left[\frac{(U)}{q}\right]^{-n} \quad \text{for } U > q \qquad [4\text{-}22]$$

Where: N = number of organisms remaining after disinfection
N_o = number of organisms present before disinfection
U = utilized (or transferred) ozone dose, mg/L
n = slope of dose response curve
q = value of x intercept when $N/N_o = 1$ or $\log N/N_o = 0$ (assumed to be equal to the initial ozone demand).

The required ozone dosage depends on the initial ozone demand, and the required ozone dose. The quantities can be evaluated using Equation 4-23. Initial ozone demand depends on the constituents of the influent, in most cases pilot scale studies may be need to estimate the required dosage ranges (Metcalf and Eddy, 2003).

$$D = U\left(\frac{100}{TE}\right) \qquad [4\text{-}23]$$

Where: D = total required ozone dosage, mg/L
U = utilized (or transferred) ozone dose, mg/L
TE = ozone transfer efficiency, %

Both ozone disinfection and chlorine disinfection may produce undesirable byproducts depending on the composition of the influent. In the presence of organic and selected inorganic products byproducts such as pyruvic acid, aldehydes such as formaldehyde and acetaldehyde, acids such as acetic acids and formic acid may be formed. The amounts and type of byproducts formed for a particular ozonation operation will depend on the nature of the compounds that are present in the influent.

4.5.3.2 Applicability

Chemical disinfection is mainly used to remove pathogens from stormwater. In situations where pathogens are found to be a problem, chemical disinfection may be a viable alternative, site constraints and receiving water regulations permitting. Chemical disinfection should be selected as a unit process if and only if pathogens are included as a primary pollutant of concern.

Contact time is an important parameter that can influence the performance of a disinfection system. If high flow rates are expected, upstream detention may be needed to shave off high peak flows or disinfection plants must be sized to accommodate peak flows which could significantly increase costs.

Chlorine disinfection may leave a residual in the effluent. If nitrogen is present in the influent causing chloramines to form, the residual will be more resistant to degradation than free chlorine residual. In situations where receiving water regulations require dechlorination, ozone disinfection or UV disinfection may be more suitable alternatives.

The performance of chemical disinfection may be impacted by high organic and/or sediment content in the influent. In situations where high organics and sediment content are anticipated, pretreatment may be required which may result in higher cost. UV disinfection may be a viable alternative for high organic content applications but UV disinfection will also be adversely affected by the presence of sediment.

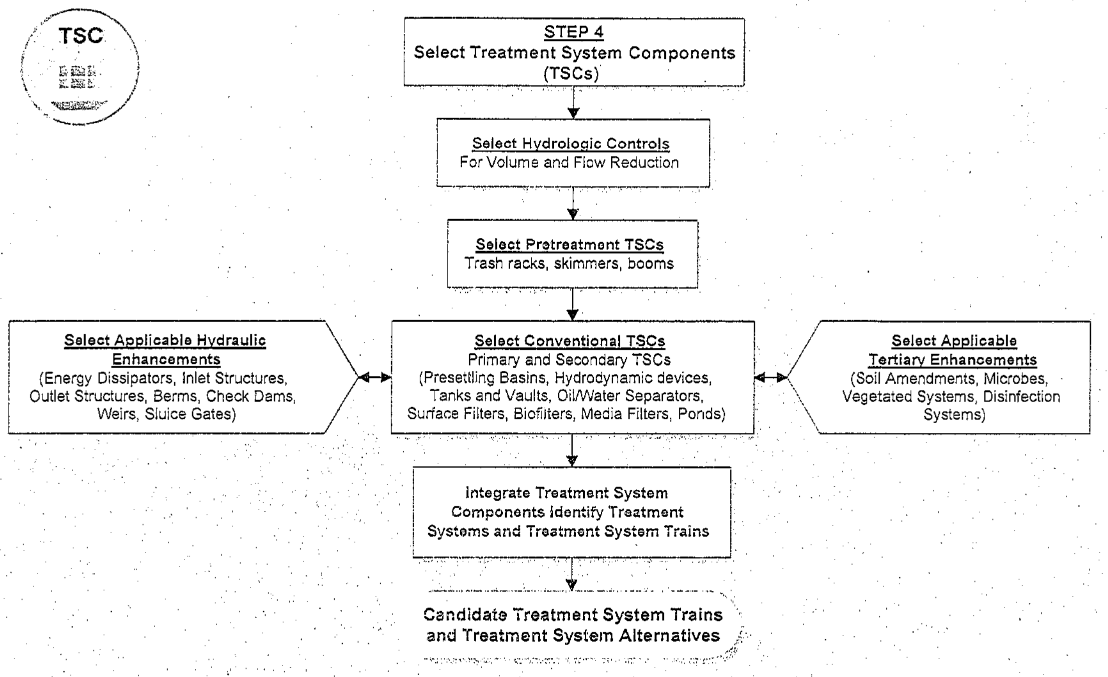
Chemical disinfection may require transportation and storage of toxic chemicals with the associated risks and liability. Other forms of disinfection such as UV disinfection may be viable alternatives in situations where safety and liability concerns are high on the list of goals and/or constraints.

4.5.3.3 Favorable Conditions and Factors That Enhance Process

Chemical disinfection is suited in applications where the influent to the physical disinfection system has low turbidity. Suspended solids provide places for pathogens to hide and shield pathogens from microbes. Chemical disinfection (specifically chlorine injection) may produce unwanted byproducts if the influent has a high organic content. For facilities that may need to discharge into sensitive receiving waters, physical agent disinfection may be more suitable because physical agents leave no residuals in the effluent.

CHAPTER 5.0

SELECT TREATMENT SYSTEM COMPONENTS



Key Concepts:

- How should the treatment train approach be used in system design?
- What hydrologic controls are available?
- What pretreatment options are applicable?
- What conventional treatment system components can be used for the core design?
- What tertiary enhancements can be incorporated?

5.1 Introduction

After potential UOPs for meeting water quality and/or quantity objectives have been identified, the appropriate treatment system components (TSCs) that provide those UOPs should be selected. TSCs comprise the fundamental elements of a stormwater treatment system. At least one UOP occurs in each TSC, but several may occur simultaneously. For example, both sedimentation and detention occur in a dry detention basin. Several TSCs involve multiple UOPs, and some processes may occur more effectively than others. As such, the placement or order of TSCs within a treatment system should be carefully considered to maximize the effectiveness of the design. The recommended approach herein is to use the concept of the treatment train, which bases the sequence of TSCs according to the following:

1. Minimize flow rates and/or volume of runoff from the urbanized drainage area (hydrological control).
2. Remove bulk solids (pretreatment: > 5mm)
3. Remove settleable solids and liquid floatables (coarse primary conventional treatment: >75 µm; fine primary conventional treatment TSCs: >10 µm)
4. Remove suspended and colloidal solids (secondary conventional treatment: > 0.1-25 µm)
5. Remove colloidal, dissolved, volatile, and pathogenic constituents (enhanced treatment)

Figure 5-1 illustrates the treatment train approach for stormwater pollutants of concern after hydrologic source controls have been implemented.

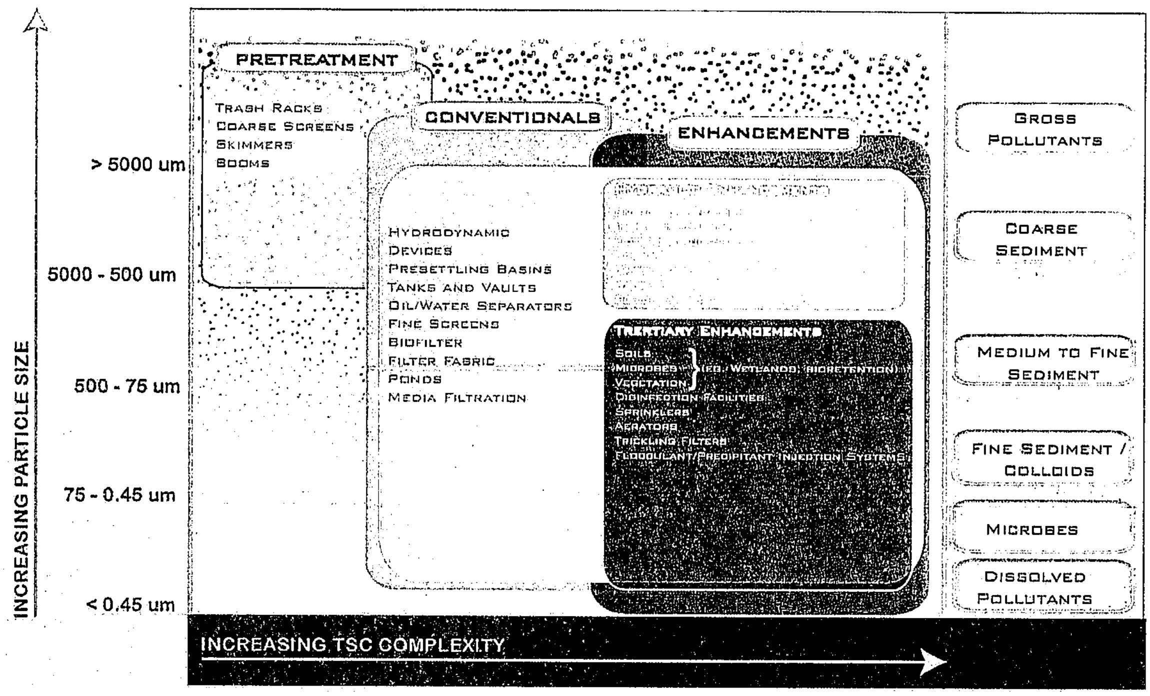


Figure 5-1. Conceptual Framework for Selecting TSCs Based on Particle Size.

The stormwater treatment train approach combines primary and secondary treatment (as defined in the wastewater field) into "conventional treatment", because some stormwater TSCs may be used as either primary and/or secondary components. Tertiary treatment of stormwater refers to modifications made to conventional TSCs to provide a higher level of treatment; such modifications are referred to in this chapter as tertiary enhancements and hydraulic controls. It should be emphasized that tertiary TSCs *enhance* the UOPs occurring in other TSCs, and are not stand-alone features of the system.

5.2 Hydrologic Control TSCs

Hydrologic source control includes components of low impact development (LID) and stormwater reuse. LID emphasizes distributed and onsite reduction and retardation of volumes and flows through distributed storage, infiltration, and ET. Such controls upstream in the catchment serve both to reduce peak flows and more importantly, to reduce the volume of runoff that must be treated and/or controlled with downstream TSCs. Stormwater reuse measures include capture of and use of stormwater runoff (in cisterns or rain barrels for example) for other uses such as irrigation. In hydrologic source control systems, components of the hydrologic cycle are exploited to remove water from the runoff before it is released downstream to receiving water bodies. The principal methods for runoff volume reduction are infiltration and evapotranspiration, although local storage and later reuse, through cisterns, is another option that is becoming more widespread.

The emphasis of this document is on downstream structural TSCs; hence, LID concepts are discussed only briefly. However, relevant design guidance for LID measures is available, including guidance by Prince George's County (2000) and Puget Sound Action Team (2003). It is important to note that in urban retrofit situations, distributed BMP and other LID practices may be the only feasible option due to space limitations.

5.2.1 Infiltration/Exfiltration Trenches and Basins

These TSCs can occur either at the beginning or at the end of a stormwater treatment system. Infiltration/exfiltration trenches and basins utilize infiltration to "dispose" of stormwater (e.g., remove stormwater from surface discharges). Stored stormwater infiltrates into the surrounding soil at a rate dependent upon the hydraulic properties of the local or engineered soil, and in some cases, the depth to groundwater. Recommendations for the minimum depth from the bottom of the infiltration basin to the seasonal high groundwater table vary between about 1.5 and 15 feet (Horner et al., 1994; Minton, 2002; Novotny, 1995; Urbonas and Stahre, 1998; WEF and ASCE, 1998). Local regulations and site-specific factors, such as the percolation rate and design volume, soil type and properties, hydraulic conductivity, soil and soil-water chemistry, soil filtering/adsorption/transformation ability, aquifer sensitivity, distance to drinking water supplies, and expected pollutant type, species and loading rates, should be used to determine if the groundwater table is at an acceptable depth for a particular infiltration practice. Besides not having backflow into infiltration systems, a more important factor for protecting groundwater is the amount of filtration or adsorption that would occur in the depth to the high groundwater table. For example, one could have a 20-foot depth to the high groundwater table with cobbles and it is likely that little filtration/adsorption would occur while as little as one or two feet of infiltration through some types of soil strata with high organic content would be very adequate for most pollutants. Sansalone and Teng provide a well-documented example of an engineered infiltration/exfiltration trench loaded directly by urban pavement runoff that combines permeable pavement for pretreatment and adsorptive media for filtration or adsorption (Sansalone and Teng, 2004; Teng and Sansalone, 2004). Infiltration after other treatment system controls is another option when there is limited water quality control that would occur in sub-strata under infiltration systems.

Each basin requires excavation of soil to obtain the required stormwater runoff design volume. Excavations are generally backfilled with properly-graded coarse aggregate to alleviate scour effects and aid infiltration through the soil (Mays, 2001). Infiltration trenches (Figure 5-2) can be installed in a highly localized environment, such as around the perimeter of buildings, if soil and structural conditions are appropriate. The influence of disturbed urban soils on infiltration rates must be considered, as discussed later in Chapter 7.0.

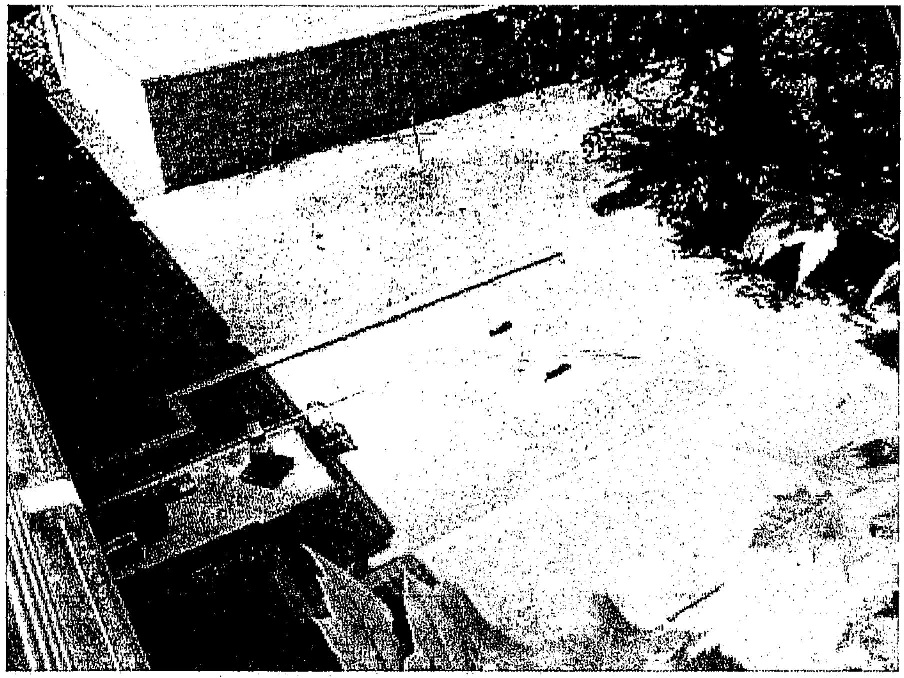


Figure 5-2. Infiltration Trench for Disposing Stormwater from a Parking Structure. Reprinted with permission from Villanova Urban Stormwater Partnership (2005).

5.2.2 Permeable Pavements

Permeable, or porous, pavement capitalize on either or both shallow or deep infiltration to minimize surface runoff. In some cases where native soils have limited infiltration capacity, porous pavement can be used with an engineered substrate to increase evapotranspiration losses with little deeper infiltration. While in cases where soils are favorable, deeper infiltration and increased runoff losses can occur (Li et al., 1999; Sansalone and Teng, 2004; Teng and Sansalone, 2004).

There are two general types of permeable pavement: monolithic and interlocking. Monolithic permeable pavement is constructed by leaving out the fine fraction of aggregate of the pavement mix, and is placed like regular pavement (Urbonas and Stahre, 1993). The pavement is generally placed on top of a thick granular porous layer that promotes infiltration and/or moisture retention and evapotranspiration Interlocking permeable pavement (Figure 5-3), also known as pavers, is made up of numerous interlocking pavement stones that\can have seams and/or holes in them to allow preferential drainage of water. The holes and seams in the interlocking pavers may be filled with sand, gravel or grass to assist high levels of infiltration (Huber et al., 2004) and/or evapotranspiration. The design of permeable pavement must recognize the elevation of groundwater and bedrock with respect to the porous pavement. If the groundwater and/or bedrock are located too close to the porous pavement the infiltration ability of the pavement could be drastically hindered (Urbonas and Stahre, 1993). Urban Drainage and Flood Control District's *Urban Storm Drainage Criteria Manual* (1999) and Ferguson (2005) provide useful guidance for porous pavement designs.

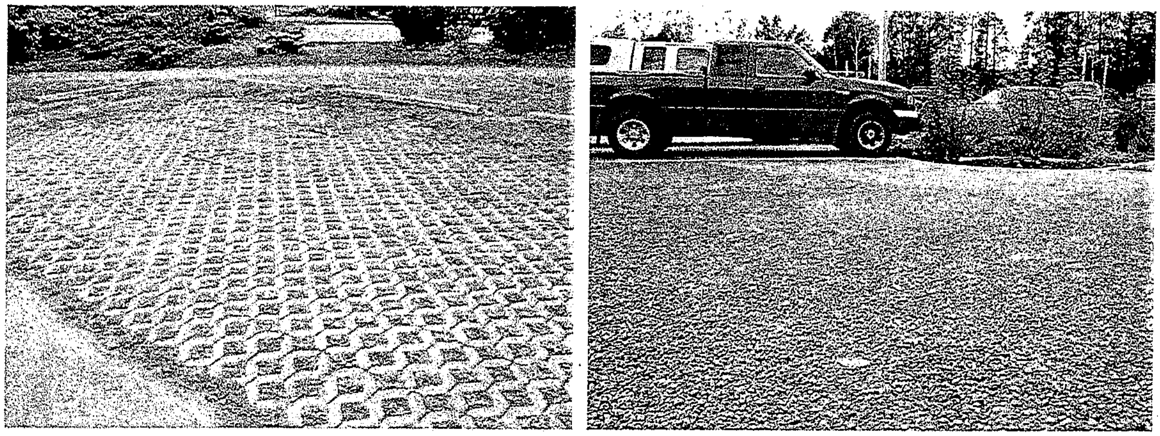


Figure 5-3. Two Types of Permeable Pavement: Interlocking Blocks (left) and Porous Asphalt (right).

Groundwater contamination issues must also be taken into account and include groundwater uses, risks due to industrial activities in the catchment, use and traffic levels on the porous pavement, and use of de-icing salts on the street (Pitt et al., 1996). Before the pavement is laid a native soil base is established, followed by a geotextile fabric separating the above thick layer of uniform graded rock base. Located above the rock base is a granular graded filter material. Porous pavement is then placed on top of the base material.

Porous pavement maintenance and longevity are concerns and many guidance documents suggest that porous pavement should only be constructed in low traffic areas of the urban watershed, such as parking lots, parking shoulders, etcetera. (UDFCD, 1999; VSC, 1999). Monolithic porous pavement has a higher tendency to clog within one to two years unless regular maintenance is performed, including vacuuming and pressure washing. Interlocking porous pavement does not generally experience as many clogging issues, depending on the hole size in the pavers (Field et al., 2000). However, interlocking pavers are more subject to vertical displacement. Maintenance practices to keep the pavement porous can be costly. In regions with severe winters, there have been few problems associated with porous pavement and the freeze thaw cycle (Pitt and Voorhees, 2000), including frost heave and clogging due to application of sanding materials.

5.2.3 Green Roofs and Other LID Elements

Green roofs are designed to, in effect, decrease impervious areas and lower runoff peaks by retaining water in the soil of these systems, while evapotranspiration occurs through the vegetation and runoff is slowed. There are two main types of green roofs: intensive and extensive. Intensive green roofs employ conventional lawn-like vegetation and may require a minimum soil depth of up to 1 foot (Scholz-Barth, 2001). Elaborate sprinkler and drainage systems are characteristic of intensive green roofs. Extensive green roofs (Figure 5-4) use native vegetation that is likely to be drought-resistant and consist of approximately 2-12 inches of soil; decreased soil depth obviously places lower load requirements on the structure (Scholz-Barth, 2001). While intensive green roofs can have other benefits, such as aesthetics, the extensive roof is more often used solely for environmental purposes. In some cases, the two are combined to achieve the desired results. For example roof top patio areas, where runoff is routed to a green roof can be combined with an extensive design.

Green roofs are primarily made up of three components: 1) the waterproof membrane, 2) soil and/or structure, and 3) vegetation. The waterproof membrane keeps the storm runoff out of the infrastructure, negating water damage issues. The soil provides a growth medium for the selected plants and grasses, and should usually have a high water retention capacity. In some cases a structure of plastic or other material is used to hold the soil and increase the strength of the green roof as well as protect the membrane. Structural design and safety are critical for green roofs. The vegetation that is grown on the green roof should be hardy and able to withstand high winds, extreme heat, and cold (per local conditions). Vegetation selection is highly variable and should be well thought out in order to serve both aesthetic and stormwater treatment purposes.

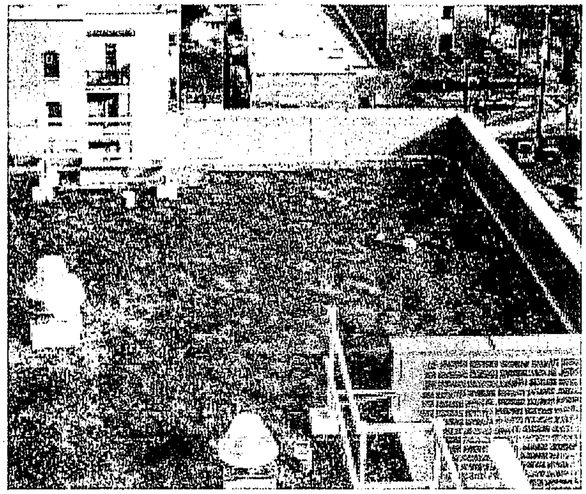


Figure 5-4. Example of an Extensive Green Roof.
Source: City of Portland (2005).

5.2.4 Other LID Elements

Other LID elements including swales, bioswales, buffer strips, filter strips and pocket wetlands utilize infiltration, evaporation and/or storage to decrease peak hydrographs and lower pollutant loads to receiving water bodies. Swales, buffer strips, and filter strips are all usually vegetated and function best in terms of infiltration when located on highly porous soil and filter solids most effectively when the vegetation is a dense, uniform growth of fine stemmed plants tolerant to local climatic conditions (Horner et al., 1994). Evapotranspiration is maximized when there are moisture adsorptive soils that temporarily detain water and allow soil soaking and drying to occur. These LID elements not only infiltrate water, thus reducing runoff volumes, but also treat stormwater by filtration, and adsorption. Swales are generally vegetated stormwater conveyance channels that slow stormwater runoff velocities, depending on length and slope of the swale (Field and Sullivan, 2003). Filter strips provide infiltration/evapotranspiration of stormwater, providing the overland flow is slow and shallow. Swales, buffer strips and filter strips infiltrate water depending on the soil infiltration properties and soil water content, which are driven by ET and storm interevent time. Under optimal conditions, these LID elements can remove a significant amount of the runoff volume.

5.3 Pretreatment TSCs

To reduce the potential for clogging or obstruction of downstream treatment system components, it is recommended to remove bulk pollutants such as litter, debris, and other large solids early in the treatment process. Screening or floatable trapping are generally the primary mechanisms to remove litter and debris. Screens have several configurations such as curb inlet grates, catch basin baskets and bar racks. Because these TSCs are relatively inexpensive and are a necessary component to maintain functionality and reduce the maintenance frequency of downstream (and likely more expensive) facilities, they should be considered for all potential treatment systems, particularly in the urban environment where litter is ubiquitous. Some devices that include screens also employ liquid-solid separation to increase the effectiveness and reduce clogging.

At sites where large quantities of floating liquids or debris are expected, devices that include skimmers, baffles, and inverted catch basin outlet designs (all of which are approaches for oil-water separation) may be used. If coarse solids are a problem, such as in areas where winter sanding activities occur, it may be desirable to install catch basin sumps or sedimentation manholes to minimize the maintenance requirements and/or clogging of downstream treatment facilities. Table 5-1 illustrates an effectiveness ranking of common pretreatment TSCs based on the UOPs they likely provide, which only includes hydrology/hydraulic and physical operations. The TSC rankings in this table are only relative to each other and are based on professional judgement and understanding of the UOPs that occur in the TSCs. A different ranking scheme is possible depending on the specific design of each TSC.

Table 5-1. Ranking of Pretreatment TSCs According to the UOP Effectiveness Level.

Fundamental Process Category	Unit Operations and Processes	Pretreatment TSCs			
		Bar Racks	Coarse Screens	Skimmers and Booms	Inlet Sumps
Hydrology / Hydraulics Operations	Flow attenuation	0	0	0	1
	Reduce total volume of runoff	0	0	0	0
Physical Operation	Screening	3	4	0	0
	Filtration	0	0	0	0
	Settling	0	0	0	3
	Flotation and Skimming	0	0	5	0
	Sorption processes (absorption)	0	0	4	0
	Volatilization / Aeration	1	1	0	0
	Physical agent disinfection (heat and ultra-violet radiation)	0	0	0	0

0 - TSC does not include unit process OR is not recommended for that process due to operations and maintenance issues (e.g., a filter should not be used to screen large debris)
1 - TSC includes unit process, but likely provides poor effectiveness
2 - TSC includes process, but likely provides marginal effectiveness
3 - TSC designed to include unit process, but other TSCs may be more effective
4 - TSC is specifically designed to include unit process, but design not optimal
5 - TSC is specifically designed to include unit process and is among the best alternatives available

5.3.1 Racks and Screening Devices

Screening devices may be used as pretreatment devices to remove gross solids from stormwater to facilitate treatment by downstream TSCs. Racks and screening devices separate solids primarily larger than the size openings. Screening devices are also sometimes used to protect other less robust drainage system components such as pump impellers and pipe inlets from being impacted by stormwater-borne solids. Table 5-2 summarizes properties of racks and screens.

Table 5-2. Practicability Considerations for Racks and Screening Devices.

PROPERTY	CONSIDERATION
Target Constituents	Gross Solids
Unit Operation	Screening
Hydraulics	Operational headloss and headloss increase due to clogging
Maintenance	Removal of captured debris can be difficult. Designs that are "self-cleaning" or allow for easy raking of material may be preferable. (Note bar racks are easier to rake than screens; expanded metal screens are very difficult to clean.)
Area Requirements	Small based upon areas for collected materials
Cost	Low for installation, potentially high for long-term maintenance
Aesthetics	Captured trash and debris may become unsightly and/or odorous

5.3.1.1 Associated UOPs and Potential Design Enhancements

Particle size separation is the primary unit process that occurs in racks and screens. If flows are impeded due to small opening sizes and/or clogging, water may be backed up behind the screen and sedimentation may occur. However, this is an undesirable process from a maintenance perspective unless an upstream storage area has been incorporated into the treatment system design. Racks and screening devices are very efficient at removing gross solids from stormwater. Target pollutants include constituents larger than screen sizes or spacing between bars. Materials that are up to ⅓ smaller than screen sizes may also be removed as build-up occurs at the screen interface. The mechanics of screening is discussed in Section 4.3.2.1. Headlosses due to clogging is discussed below.

5.3.1.2 Hydraulic Considerations

Racks and screening devices typically restrict the free flow of water by placing obstacles such as a screen or bars in the flow path. Obstacles in the flow path lead to energy losses must be accounted for. Overly restricted flow paths can lead to clogging and flooding with resulting damage to public property. Headlosses through bar racks can be estimated as follows (Metcalf and Eddy, 2003):

$$h_L = \frac{1}{C}\left(\frac{V^2 - v^2}{2g}\right) \qquad [5\text{-}1]$$

Where h_L = headloss, ft
C = an empirical discharge coefficient to account for turbulence and eddy losses (typically 0.7 for clean and 0.6 for clogged (Metcalf and Eddy, 2003))
V = velocity of flow through the openings of the bar rack, ft/s
v = approach velocity in the upstream channel, ft/s
g = acceleration due to gravity

As is evident in Equation 5-1 above, the headloss is a function of the approach velocity and the velocity through the bars. Note that the headloss calculated using this equation holds for clean bars; headlosses increase with clogging. To account for clogging, the velocity when the bars are clean can be divided by the percent reduction in flow area to estimate the clogged flow-through velocity.

For screens, the headloss can be calculated using the common orifice equation (Metcalf and Eddy, 2003):

$$h_L = \frac{1}{C(2g)}\left(\frac{Q}{A}\right)^2 \qquad [5\text{-}2]$$

Where h_L = headloss, ft
C = coefficient of discharge for the screen
Q = discharge through screen ft^3/s
A = effective open area of submerged screen ft^2
g = *acceleration due to gravity*

Values of C and A in Equation 5-2 are particularly dependent on the percent of open area of the screen. However, a typical value for C is 0.6. Headlosses during screen operation are most dependent on the size and quantity of solids in the water, the size of the screen openings, and the method and frequency of cleaning. (Metcalf and Eddy, 2003)

It is desirable to design rack and screening devices such that deposition does not occur in the upstream channel to minimize headloss. An approach velocity of about 1.6 ft/s (0.5 m/s) or greater at average flow is recommended to minimize deposition of materials (Tchobanoglous and Schroeder, 1985), unless the area upstream of the rack is to be used as a settling area.

5.3.1.3 Maintenance Considerations

Frequent cleaning is required to minimize headlosses and avoid clogging. Cleaning also lowers the likelihood of materials being forced through screens and bars. A number of the screening devices provide baskets and holding areas that simplify the task of cleaning. Other structures are "self-cleaning"; using the weight of captured materials in the influent or the effluent flows to move materials off screens and bars. Screenings are typically disposed of at a landfill.

5.3.1.4 Required Surface and Subsurface Area

In terms of space requirements, screens and racks are low profile TSCs often installed in the drainage path of stormwater conduits, and therefore require no additional surface or subsurface area (Figure 5-5). In situations where screens and rack installations are external or protrude out of stormwater conduits, the designer must check the dimensions of the installation to ensure that the design is feasible. End-of-pipe nets, screens and racks may require installation of an external frame for support. Therefore, adequate space at the end of the conduit is often necessary.

Figure 5-5. Trash Screen Along the Path of a Drainage Channel.
Reprinted with permission from Friends of Sligo Creek (2005).

5.3.1.5 Cost Considerations

Racks and screening devices are relatively economical compared to other TSCs. Proprietary devices that provide additional features to facilitate maintenance or minimize clogging are often more expensive than the basic screens and bar racks. Devices in this category tend to be durable, easy to operate, and require little or no maintenance of the structures themselves; this makes them an affordable choice as first line-of-defense components. However, in areas generating large quantities of trash and debris, the high frequency of clean-out required for basic screens and bar racks can make maintenance expensive. In these cases, the added cost of a more passive, proprietary device, such as a hydrodynamic separator or end-of-pipe trash net may be offset by the reduced frequency of maintenance.

5.3.1.6 Aesthetics

Screens and sacks are often less prominent than other above-ground treatment components and are less likely to impact the aesthetics of the entire treatment system if proper maintenance practices are implemented. However, the accumulation of trash and debris may become unsightly if the device is in full public view, and maintenance is limited. If captured materials decay, they can also cause odor issues.

5.3.2 Skimmers and Booms

Depending on other TSCs in the treatment system, skimmers and booms can be located in various locations in the treatment train, and therefore may target a variety of constituents. Inlet booms can be placed at curb inlets to capture coarse sediment and absorb oil and grease, while floating booms and skimmers can be placed on open water surfaces for the removal of floatable gross solids, floatable liquids, and particles brought to the surface via flotation mechanisms (see Section 4.3.3.3). Table 5-3 summarizes properties of skimmers and booms. Baffles and inverted outlet designs, while providing a skimming operation, are typically included as part of a tank, vault, hydrodynamic separator, or oil-water separator. These conventional TSCs are discussed individually in Section 5.4.

Mechanical skimmers are primarily used in wastewater treatment, industrial applications, decorative pond maintenance, or spill clean-up operations. They usually are floating devices that remove floating liquids and debris by mechanical suction into a storage tank, or by forward propulsion that causes the floating material to flow over a weir into an isolated chamber. While there may be increased need for mechanical skimmers for stormwater systems, passive skimmers are more common in stormwater treatment applications and are typically floating mats of absorbent material that can be placed directly on the water in areas such as catch basins, sumps, tanks, vaults, oil/water separators, or even within a sedimentation forebay of a pond. Figure 5-6 is an example of a passive skimmer used in stormwater treatment operations.

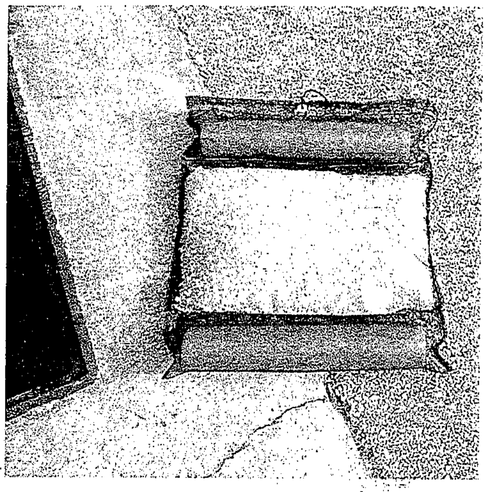
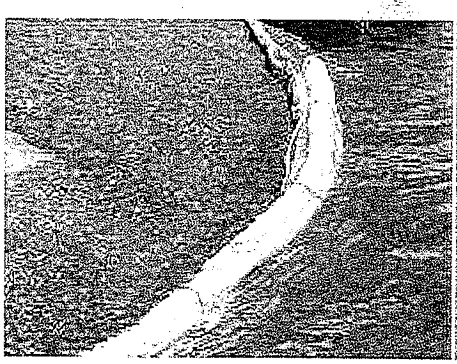


Figure 5-6. Ultra-Passive Skimmer for Stormwater Inlet Applications.
Reprinted with permission from Tri-State Environmental Technologies, Inc. (2005).

Passive skimmers have the similar characteristics to floating absorbent booms, with the primary difference being that floating booms can generally be applied over a larger area and can be designed to capture floating debris in addition to absorbing oil and grease. The terms skimmers and booms are often used interchangeably, however, and some manufacturers have used the term line skimmers to refer to floating absorbent booms (e.g., Abtech Industries) and inlet skimmers to refer to inlet booms (e.g., Suntree Technologies) (see Figure 5-7).



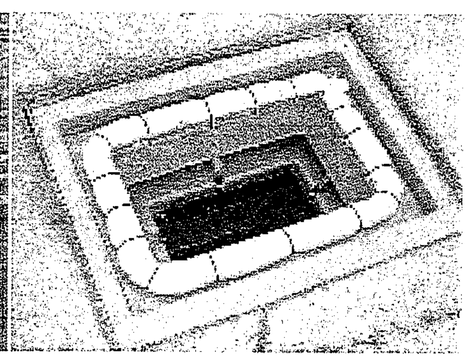


Figure 5-7. Examples of Passive Skimmers Used in Stormwater Treatment Applications.
Line Skimmer Reprinted with Permission from Abtech Industries (2005) (Left) and Inlet Skimmer Box Reprinted with Permission from Suntree Technologies (Right).

Both floating booms and passive skimmers are generally easy to use, have a low capital cost, and are suitable for retrofit situations. Less desirable attributes of floating booms include the need for constant monitoring and clean-out, decreased performance under high winds and high flow rates, and loss of trapped pollutants when a boom breaks or is overwhelmed with debris (VSC, 1999). Figure 5-8 shows a floating trash boom with a net skirt that is being overwhelmed with trash.

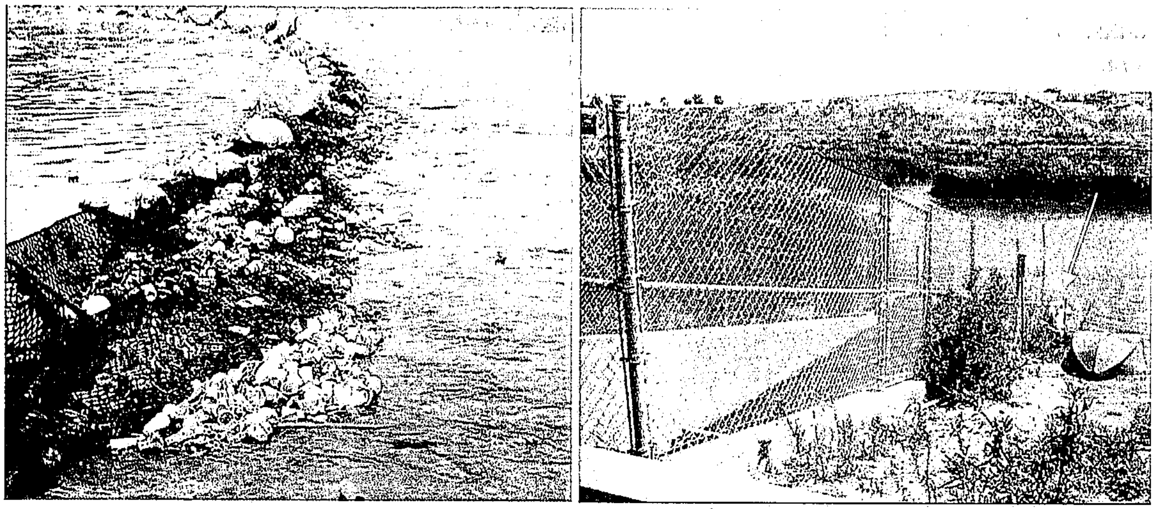


Figure 5-8. Example Trash Booms Used for Containing Trash and Debris from Water Surfaces. Source: California Regional Water Quality Control Board (Left), Geosyntec Consultants (Right).

Table 5-3. Skimmers and Booms Practicability Considerations.

PROPERTY	CONSIDERATIONS
Target Constituents	Floating liquids, trash, and debris
Unit Operation	Skimming, absorption, screening
Hydraulics	May impede flow (especially for inlet booms)
Maintenance	Frequent inspection for high trash-generating areas. Removal of captured debris for floating booms may require a boat. Absorbents may need frequent replacement to remain functional.
Area Requirements	Negligible to small around inlets
Cost	Low for initial installation. Maintenance costs may be high for high trash- and debris-generating areas.
Aesthetics	Captured floating trash and debris may become unsightly.

5.3.2.1 Associated UOPs and Potential Design Enhancements

The primary unit operations provided by the different types of skimmers and booms include absorption, skimming, and screening. Absorbent skimmers and booms including the storm drain inlet and floating varieties, may absorb hydrophobic liquids such as oil and grease and other petroleum products. Absorption rates can be improved by maximizing the contact area and contact time of the absorbent with the target liquid. Inlet absorbent booms and skimmers require shallow flow depths for the floating liquid to come in contact with the absorbent. Floating absorbent skimmers and booms are more effective in near quiescent conditions. Turbulence may cause the more homogenous oil and grease or other petroleum products to become emulsified, such that small individual oil droplets become surrounded by water particles; this effectively prevents contact with the hydrophobic absorption media.

The "skimming" action of floating booms removes floating debris or solids that have been floated to the surface (e.g., during another unit operation or process or in quiescent flows). Floating booms are best suited to slower moving waters, and removal of highly buoyant contaminants such as plastic bottles (VSC, 1999). The efficiency of booms is greatly reduced during high flows because trapped contaminants are more easily forced over or under the boom (VSC, 1999). In addition, the performance of a boom depends on the size of the target materials, the size of the boom, the float of the boom and the length of the skirt of the boom, if present. For street litter and debris a 10-inch boom with a 6-inch float and 12-inch skirt is appropriate (NCTCOG, 2004). A bigger boom such as an 18-inch boom with a 6 inch float and 12-inch skirt will contain larger items such as logs, but these are typically used within receiving waters and have little value for upper watershed water quality enhancement. Again the performance of booms and skimmers depends on their design and also on the frequency of removal of trapped or captured materials.

The overall performance of booms can be increased by angling the booms across the flow path to channel trash away from high flow areas in the drainage path (VSC, 1999). Frequent inspections and regular maintenance will also contribute to consistent performance. Carefully consider the manufacturer's recommendations.

5.3.2.2 Hydraulic Considerations

Skimmers and booms belong to a category of TSCs that either absorb or capture pollutants near inlets or outfalls, or float on top of the water being treated. Floating skimmers and booms do not affect overall storage volumes or limit the passing of flows. However, inlet booms (e.g., absorbents or filters) may impede flows and cause ponding upstream of the inlet, or cause flow to move around the inlet to the next inlet or other areas. The materials trapped by booms and skimmers, depending on the design and the amount of captured debris, can alter the hydraulics of the influent stream. Trapped material can potentially create dams across waterways, decreasing flow rates, and causing the water surface to rise, which could lead to upstream flooding. Well designed and maintained skimmers and booms are however, expected to have little impact on the hydraulics of the influent stream.

5.3.2.3 Required Surface and Subsurface Area

Most simple skimmers and booms float on the open water surface or are placed in front of or within a storm drain inlet. Thus there are typically no additional land surface or subsurface area requirements. Practitioners should refer to the manufacturer's specifications for space requirements of proprietary skimmers and booms. The area covered by the unwanted materials trapped by skimmers and booms can be reduced through regular maintenance.

5.3.2.4 Maintenance Considerations

Booms and skimmers are often made of tough, durable materials, and maintenance requirements are often minimal, except for adsorbent booms. Booms made of absorbents for trapping various liquids should be inspected and replaced per the manufacturer's requirements and/or based on inspections. Many types of booms may also be cleaned by pressure washing (outside of the waterbody).

The benefits gained from booms and skimmers can be nullified in the event of a breach where trapped materials are released. For many designs, breaches can be prevented by storing skimmed material in a way that precludes the waste from being released. However, some boom and skimmer designs do not separate pollutants from stormwater; they simply act as a barrier that allows stormwater to pass while preventing floatables from passing up to a maximum flow rate. The trapped materials remain in the water in most cases and should not be considered treated until "removed" and sent to a landfill. Wastes should be frequently removed from the site and properly disposed.

5.3.2.5 Cost Considerations

Capital costs for booms and skimmers are relatively low. Maintenance costs for the devices themselves can be nominal except in the cases where booms use absorbent media, which increases the cost some. However, the need for constant monitoring and removal and disposal of trapped pollutants in high generation areas, and/or the occurrence of frequent storm events requiring frequent removal of trapped materials, could however significantly increase costs depending on the application (VSC, 1999).

5.3.2.6 Aesthetics

Booms and skimmers are fairly visible and somewhat prominent devices that generally do not negatively impact the aesthetics of a treatment system, unless large amounts of trash and debris are allowed to accumulate behind these barriers, such as shown in Figure 5-8. In addition, excessive materials trapped by these devices may increase the possibility of the development of foul odors and provide breeding grounds for vectors and nuisance animals. In addition, decay of these trapped materials can reduce oxygen levels and/or release other pollutants. Periodically replacing absorbents and power washing floating booms and skimmers is recommended to keep the devices looking decent. In addition, regular removal of trapped materials makes booms seem less obtrusive and more acceptable.

5.4 Conventional TSCs

Conventional TSCs are the core components typically referred to as BMPs that provide the primary and/or secondary levels of stormwater treatment. The term BMP is avoided in this document. The recommended approach is to develop a *treatment train* that includes one or more *BMPs*, as well as other TSCs selected and designed to maximize the performance and robustness of the entire system.

As with primary wastewater treatment, primary stormwater treatment focuses mainly on the removal of coarse and settleable solids and liquid floatables, while secondary treatment focuses mainly on the removal of suspended and colloidal particles. Unlike conventional wastewater treatment, disinfection is considered tertiary treatment for stormwater because it is not typically used. Because many TSCs can be designed as either or both primary and secondary treatment components (e.g., vegetated swale), the term "conventional" is used here for TSCs that include both primary and secondary treatment. Table 5-4 provides a relative ranking of conventional TSCs according to the treatment effectiveness of the UOPs that occur. Note that these rankings are for illustrative purposes only since different rankings may be possible depending on the specific design of each TSC.

Any number of conventional TSCs can be used in a logical sequence depending on the target pollutants and associated UOPs required. Using the treatment train approach, the treatment system should be designed to remove successively finer and finer particulates, as well as dissolved constituents. Generally, the more UOPs and TSCs in place, the more effective the treatment train will be. It is recommended that the design engineer develop at least three different treatment system scenarios using conventional TSCs (e.g., 1) a sedimentation basin followed by a retention pond, 2) a hydrodynamic separator followed by a porous media filter, and 3) a bioswale followed by an infiltration basin). Then, selection of the final system from the candidates should be based on a practicability assessment, as described in Chapter 6.0.

Table 5-4. Ranking of Conventional TSCs According to the UOP Effectiveness Level.

Fundamental Process Category	Unit Operations or Processes	Conventional TSCs									
		Hydro-dynamic Devices	Settling Basins	Tanks and Vaults	Fine Mesh Screens	Filter Fabric	Biofilters	Media Filters	Extended Detention Ponds	Retention Ponds	Infiltration Basins
Typical Location in Treatment Train		P	P	P	P	P	P/S	P/S	S	S	S
Hydrology / Hydraulics	Flow attenuation (hydrograph matching)	0	2	3	0	0	1	0	5	4 to 5	3 to 5
	Reduce total volume of runoff	0	0	0	0	0	3 to 5	0	2 to 3	1	5
	Flow-duration control and design	0	1	3	0	0	1	0	4 to 5	4 to 5	4 to 5
Physical Operations	Screening	3 to 5	0	0	5	0	1 to 5	0 to 5	0	0	0
	Filtration	0	0	0	3	3	3 to 5	5	0	0	4
	Settling	2 to 3	3	3	0	0	3 to 5	0	3	5	2
	Flotation and Skimming	3 to 5	0	2	0	0	0	0	0	0	0
	Sorption processes (absorption)	0	0	0	0	2	3 to 5	4 to 5	0	0	2
	Volatilization / Aeration	1	0	0	0	0	1 to 3	0	3	3	0
	Physical agent disinfection (heat and ultra-violet radiation)	0	1	0	0	0	1	0	2	2	1
Biological Processes	Microbially-mediated transformations	0	0	0	0	0	0 to 2	2	3	4	2
	Uptake and storage	0	0	0	0	0	0 to 2	1	2	3	1
Chemical Processes	Sorption processes (adsorption)	0	0	0	0	2	3	4 to 5	1 to 2	2	4
	Flocculation / Precipitation	0	0	0	0	0	0	0	0 to 2	2	0
	Chemical agent disinfection (ozone, chlorine and chlorine compounds)	0	0	0	0	0	0	0	0	0	0

P - Primary treatment, S - Secondary treatment
0 - TSC does not include unit process OR is not recommended for that process due to operations and maintenance issues (e.g., a filter should not be used to screen)
1 - TSC includes unit process, but likely provides poor effectiveness
2 - TSC includes process, but likely provides marginal effectiveness
3 - TSC designed to include unit process, but other TSCs may be more effective
4 - TSC is specifically designed to include unit process, but design not optimal
5 - TSC is specifically designed to include unit process and is among the best alternatives available

5.4.1 Initial Settling Basins

A primary settling (sedimentation) basin, identified as an initial settling basin (ISB) herein, is used to remove settleable solids prior to treatment by other TSCs, or in the initial part of a TSC. Sediment forebays fully or partially isolated by a berm or baffle within larger detention/retention ponds are the most common type of ISB. ISBs "protect" sensitive and more expensive downstream TSCs, and decrease the downstream maintenance requirements by capturing sediment. ISBs may only be needed if treating large drainage areas or areas known to generate high sediment loadings. Table 5-5 summarizes properties of ISBs.

Table 5-5. Initial Settling Basins Practicability Considerations.

PROPERTY	CONSIDERATIONS
Target Constituents	Sediments, settleable solids, and heavy debris
Primary Unit Operations	Sedimentation
Hydraulics	Short-circuiting, detention time, turbulence, plug flow vs. continuously-stirred analysis
Maintenance	Sediment loading rate, floating trash and debris, anoxic behavior
Area Requirements	Effective length-to-width ratio (e.g., > 3:1), depth (3-8 feet), surface loading rate design
Cost	Low
Aesthetics	Floating trash, algae, nuisance and disease-transmitting organisms, animal control, vector control, odor, cleaning can be aesthetically disruptive and expensive

5.4.1.1 Associated UOPs and Potential Design Enhancements

As the name implies, ISBs depend primarily on gravitational force and a difference in density between solids and liquids for treatment. Therefore, designs that maximize the hydraulic residence time (minimize velocities and maximize flow length) of the captured volume are preferable. Figure 5-9 illustrates the unit processes occurring in an ISB.

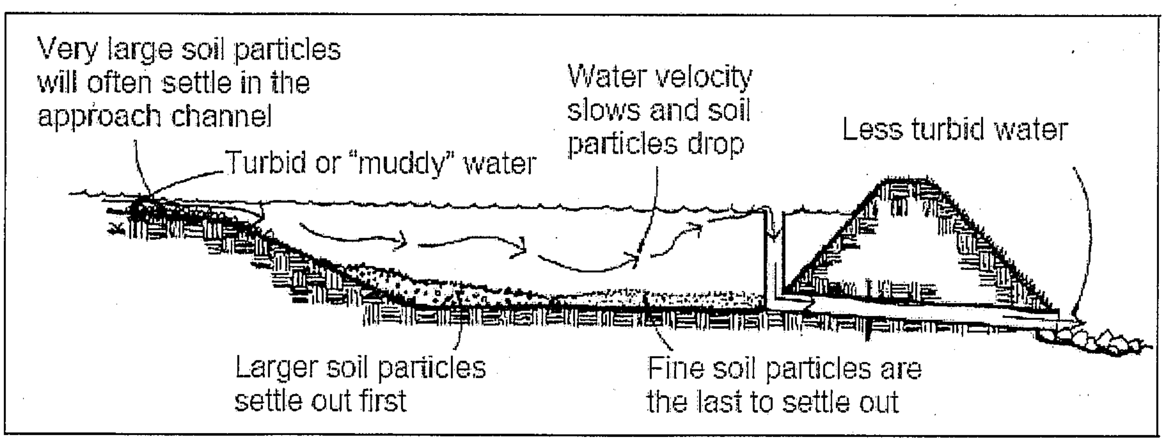


Figure 5-9. Unit Operations in an Initial Settling Basin (ISB).
Source: Michigan Department of Environmental Quality (MIDEQ, 2004).

The performance of an ISB depends on the design of the basin itself, the design of the inlet and outlet structures or berms, and the quality and flow characteristics of the influent. Since ISBs are meant to trap sediments and debris, an indicator of performance is how quickly downstream TSCs accumulate solids. Regular removal of trapped materials from ISBs will facilitate more consistent performance and decrease negative impacts to downstream TSCs. ISBs will only remove significant amounts coarse materials and associated pollutants. Further treatment of the effluent from ISBs generally must be provided, unless coarse sediment is the only targeted constituent.

If a particle gradation is known, the fraction of particles removed by an ISB may be calculated analytically using Hazen's formula as discussed in Section 4.3.3 and shown in Equation 4-4.

5.4.1.2 Recommended Pretreatment

If there is a constricted inlet structure and high trash or debris loads are expected, pretreatment may be necessary. Pretreatment for trash and debris may include catch basin inserts, inclined bar racks, hydrodynamic devices, floating booms, or trash nets.

5.4.1.3 Hydraulic Considerations

For wet pond applications, initial settling basins should be sized to provide 25-35% of the total volume of the pond. For infiltration facility applications, basins should be sized to be about 75% of the mean annual storm (King County, 1998). For extended detention pond applications, the forebay should be no less than about 5% of the total volume of the pond (UDFCD, 1999). As a general rule, ISBs should be designed to minimize short-circuiting and excessive turbulence during water quality design storm events (check with the local regulatory agency for exact sizing guidance), which can be achieved by increasing the length-to-width ratio of the basin and providing adequate energy dissipation at the inlet. (Note that for wet ponds, a submerged inlet may provide adequate energy dissipation.) The terminal settling velocity for a critical design particle under steady flow conditions can be calculated using Equation 4-2 in Section 4.3.3.

Oversizing an initial settling basin may lead to added cost with little benefit, and undersizing the ISB component of a pond system may cause siltation, increased maintenance, and reduced pollutant removal abilities of downstream system components. ISBs preceding flow-through facilities may be required to be offline. The outlet structures of ISBs must be designed to prevent trapped sediment from being flushed into downstream TSCs and the effluent flow rates must be such that the presettling basin does not become a bottle neck in the system (IDEQ, 2001).

5.4.1.4 Maintenance Considerations

Regular removal of trapped materials from ISBs is required. Maintenance frequencies will depend on site-specific conditions such as sediment loads, basin capacity, basin performance and the redox behavior of the sediment layer. The berms or impoundments of the ISBs should be inspected routinely and also inspected after large storms to remove any obstructions that may impact performance.

5.4.1.5 Required Surface and Subsurface Area

ISBs are typically above-ground TSCs and therefore require adequate open space. For detention-type applications, the width of the ISBs typically matches the width of the rest of the pond. The length of the ISB is selected to provide the desired treatment volume. The surface area required by the ISB is easily calculated in this case. For flow-through type applications, the size of the initial settling basin required is less obvious and depends on the flow rates and, quality of the influent, and other factors. Equation 4-3 in Section 4.3.3 can be used to estimate the required surface area given a critical design particle size (calculated from Equation 4-2) and influent design flow rate.

5.4.1.6 Cost Considerations

The cost of ISBs is comparable to the cost of ponds of the same size. If incorporated into a larger basin, the only cost is for separation (berm, etc.). The maintenance frequencies of ISBs can however be much higher than larger ponds. The benefits of properly designed and maintained ISBs outweigh the costs because they generally increase the longevity and effectiveness of the entire system and reduce maintenance of downstream TSCs.

5.4.1.7 Aesthetics

ISBs, like ponds, can be constructed to be aesthetically pleasing. Landscaping and regular vegetation maintenance can enhance the visual aesthetics of ISBs. Long-term maintenance activities, such as removal of algae mats and accumulated sediment, may prevent bad odors and mosquito breeding habitat. If there are no pretreatment TSCs, more frequent maintenance may be required to remove floating trash and debris.

5.4.2 Hydrodynamic Devices

Due to their ultra-urban[1] appeal, the use of hydrodynamic devices in stormwater applications is relatively common. Originally, these deflective, swirl and vortex separator devices were developed in Europe and Australia and have found much application in high-rate treatment of combined sewer overflows (CSOs) and stormwater runoff (Andoh and Saul, 2002). Today, there are several manufacturers of these devices for application in both combined and separate sewer systems (Field et. al., 1997). Table 5-6 summarizes properties of hydrodynamic devices. Figure 5-10 illustrates two popular hydrodynamic devices used in the U.S. Note that the CDS unit includes a screen that provides physical separation in addition to centrifugal settling.

Table 5-6. Hydrodynamic Devices Practicability Considerations.

PROPERTY	CONSIDERATION
Target Constituents	Floating liquids and solids, trash, heavy solids, and debris
Unit Operations	Sedimentation, screening
Hydraulics	Flow velocity, short-circuiting
Maintenance	Solids, trash/debris removal, vector control
Area Requirements	Underground, but may have utility conflicts
Cost	Medium to high
Aesthetics	Noise associated with frequent maintenance may be disruptive to residents. Units that store water may breed mosquitoes and generate bad odors.

1 Ultra-urban refers to urbanized areas with limited available space for BMPs (typically restricted to the right-of-way), high imperviousness, and high land costs (FHWA, 2000).

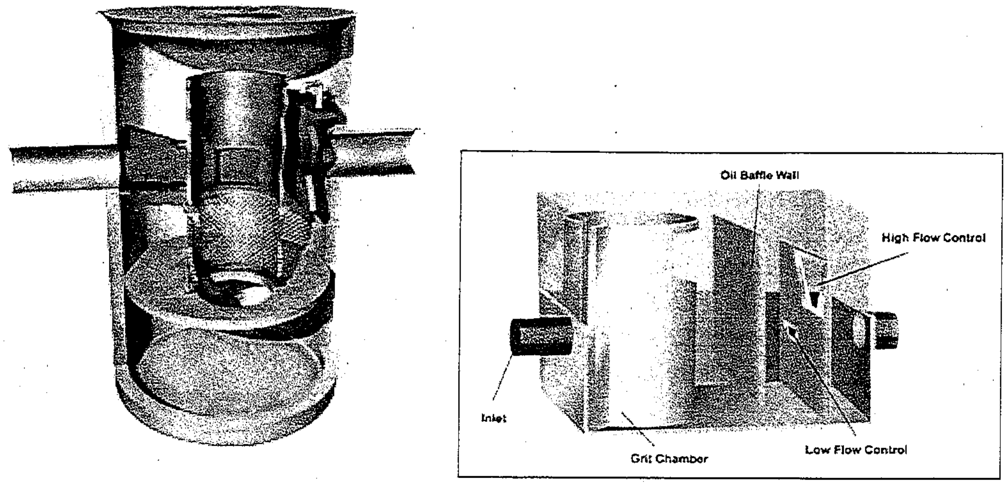


Figure 5-10. Example Hydrodynamic Separation Devices.
Reprinted with permission from CDS Technologies (2005) (Left) and Vortechnics (2005) (Right).

5.4.2.1 Associated UOPs and Potential Design Enhancements

The primary unit operations provided by hydrodynamic devices include density and particle size separation. In some designs they provide enhanced gravitational separation of floatable and settleable pollutants from stormwater. Separation is caused by the influent flowing in a swirling motion in a circular chamber, which creates velocity differentials that encourage pollutants to move toward the center of the vortex, while relatively clean water from the outer fringes of the vortex exits the system. In other designs, the direction of the outflow is reversed to enhance separation (e.g., CDS unit). Baffles are often included in the design to facilitate the removal of floatable solids, and oil and grease (Vortechnics, 2004).

While there are numerous proprietary hydrodynamic designs with a range of reported effectiveness values, all such devices can be assumed to be somewhat to very effective for separation of floatable material, trash and debris, and sediment sizes greater than about 75 µm. The appeal of hydrodynamic devices lies in their potential ability to provide solids removal at high flow rates. Primary target pollutants for hydrodynamic devices are solids and floatables. The addition of sorbent materials and other enhancements is needed for removal of dissolved constituents, floatable liquids and/or finer particulates.

5.4.2.2 Recommended Pretreatment

Hydrodynamic devices are either operated as stand-alone single primary treatment units or as pretreatment for downstream TSCs. Therefore, pretreatment is generally not needed for these devices.

5.4.2.3 Hydraulic Considerations

Hydrodynamic devices are flow-through facilities and are therefore sized to pass specified flows. Most proprietary devices may include various combinations of weirs, screens, orifices and baffles, which act as flow control structures. Sizing and selection can be accomplished by estimating the flow through the weir, orifice or baffle that acts as the flow control structure for the treatment chamber. Another important design consideration is the maximum flow capacity of the structure. If the device is used in an on-line configuration, a by-pass mechanism will typically be provided in the form of a weir to pass high flows. Off-line structures do not have to be designed to pass high flows and may not need extra flow controls to by-pass high flows.

For devices that utilize an orifice to pass the design flows the standard orifice equation can be used to calculate the design flow (see Equation 5-21 in Section 5.6.6). Manufacturers of commercial devices may provide the values of C_d (orifice contraction coefficient), A (orifice flow area), and h (design head) in Equation 5-21. Alternatively the manufacturer may provide software or tables to facilitate design and selection of structures. If parameter values are not provided by the manufacturer, A and h must be approximated and C_d can be looked up in a fluid mechanics or open-channel flow text book.

For devices that utilize a weir to pass design flows or bypass high flows, the standard weir equation can be used (see Equation 5-22, in Section 5.6.6). As with the orifice equation, manufacturers of proprietary devices sometimes provide values of C_d, h and L (design weir crest length) or even provide software, tables or other aids to facilitate design and selection of structures. If values for these parameters are not provided, they must be approximated or looked up in an applicable text book.

5.4.2.4 Maintenance Considerations

Manufacturers of proprietary hydrodynamic devices recommend frequent inspection, especially during the first year of installation (U.S. EPA, 1999d), and maintenance when a specified capacity is filled. The frequency of inspections depends on tributary watershed conditions and unit size. Areas with unstable soils or heavy winter sanding and/or large trash and debris generation may require more frequent maintenance (Vortechnics, 2004). Vacuum trucks are usually the most effective and convenient method of cleaning. Placing absorbent pads, or baffles or weirs inside the units is recommended for removal of oil and hydrocarbons because disposal of absorbent pads is usually cheaper than disposal of oil-water emulsions. Trash and debris can be removed with nets if it is desirable to separate the trash from the other pollutants (Vortechnics, 2004) and some hydrodynamic devices incorporate removable baskets (NCTCOG, 1999). Recommended maintenance frequencies range from once a year to four times a year (NCTCOG, 1999). Follow the manufacturer's recommendations for consistent results. Note that in areas with high trash loads, cleaning frequencies may need to be increased based upon observations.

Vector control may be an additional maintenance consideration due to water retention in the devices between storms. The combination of shallow depths, typically high nutrient concentrations (provided by the captured sediment), and the isolation from predators creates ideal mosquito breeding habitat, especially with long storm interevent times. Local vector control agencies should be consulted on acceptable mosquito abatement controls.

5.4.2.5 Required Surface and Subsurface Area

Hydrodynamic devices are primarily intended to be installed below ground. The only surface area needed for subsurface devices is access for maintenance. Subsurface space requirements for any particular hydrodynamic device can be obtained from the manufacturer once design flow rates are known. Hydrodynamic devices are designed for space-limited applications, therefore the space requirements for these devices as compared to other TSCs designed to treat comparable flow rates is low.

5.4.2.6 Cost Considerations

The costs of hydrodynamic devices typically range from about $2,000-8,000 per cfs for pre-cast units, depending on the size (U.S. EPA, 1999d). Installation costs are highly site-specific, but are generally between 25 and 100% of the cost of the unit (NCTCOG, 1999; FHWA, 2000). Maintenance costs are also site specific and may vary according to the number of devices being maintained in an area, but have been reported to range from about $300 to about $1,000 per unit per cleaning (U.S. EPA, 1999d; FHWA, 2000).

5.4.2.7 Aesthetics

Hydrodynamic devices are typically installed below ground with minimal aesthetic impacts compared to above-ground systems. In the unlikely event that an above ground installation is required, the hydrodynamic device can be painted and strategically placed to improve the aesthetics. The noise associated with maintenance (i.e., vactor trucks) may be of concern to neighboring residents and/or businesses.

5.4.3 Tanks and Vaults

Tanks and vaults are typically underground structures that are used to store and either slowly release (infiltrate) or reuse surface water. For the purposes of this document, tanks and vaults are used as generic terms for small volume plastic, concrete, or corrugated metal storage tanks, as well as oversized, low-gradient pipes (detention pipes) and similar structures. In some cases, some hydrodynamic devices are sized to behave more like a tanks or vaults. Properties of tanks and vaults are shown in Table 5-7.

Table 5-7. Tanks and Vaults Practicability Considerations.

PROPERTY	CONSIDERATIONS
Target Constituents	Coarse solids, floatables
Primary Unit Operations	Sedimentation, skimming
Hydraulics	High flow rates may re-suspend captured pollutants
Maintenance	Periodic cleaning with vactor truck or other suitable method
Area Requirements	Underground, therefore negligible
Cost	May be significant depending on drainage area
Aesthetics	Noise associated with frequent maintenance may be disruptive to residents. Units that store water may breed mosquitoes and result in odors. Generation of H2S and corrosive acids

There are several small volume storage tank and vault designs that can be used for stormwater treatment. Figure 5-11 shows an installation of an underground concrete detention tank. The use of underground detention chambers constructed out of large, low-gradient (and often perforated) pipes is also a popular storage treatment technique in areas where land availability and/or cost for surface detention is impractical. Underground storage may also be desirable in flat areas where it is difficult or costly to route stormwater to a surface facility. Underground detention pipes can be constructed out of a variety of materials. Table 5-8 compares the advantages and disadvantages of some common materials.

Table 5-8. Advantages and Disadvantages of Underground Detention Pipes.

Material	Advantages	Disadvantages
Corrugated HDPE Pipe	Lightweight Easy to install Economical (smaller diameters) Flexible	Susceptible to chemical attack Requires special bedding More difficult to customize
Concrete Pipe	Good corrosion resistance Widespread availability High strength Good load supporting capacity Easily customized	Requires careful installation Heavy Susceptible to attack by H_2S when uncoated
Corrugated Metal Pipe	Lightweight Easy to install Economical (large diameters) Flexible	Potential source of zinc Possibility of long-term corrosion Susceptible to deformation if improperly installed More difficult to customize Susceptible to attack by H_2S when uncoated

5.4.3.1 Associated UOPs and Potential Design Enhancements

Tanks and vaults are primarily sedimentation and to a more limited extent flow attenuation devices. As such they will typically only remove debris, sediment, and settleable and coarser suspended solids and the pollutants associated with these fractions. The performance of tanks and vaults depends on the design of the storage areas, the design of the inlet and outlet structures, residence time, redox conditions, and the quality and flow characteristics of the influent. Regular removal of trapped materials from tanks and vaults will improve consistency of performance and decrease the potential for sediment resuspension.

While tanks and vaults are well suited for space-limited applications, other storage-type TSCs such as detention ponds are often more desirable for stormwater quality treatment. Tanks only provide a limited level of water quality treatment due to the absence of vegetation and/or soils, which can provide additional treatment such as vegetative filtration, biological uptake, and sorption. To increase the number of unit processes provided by these simple structures, some innovative enhancements include placing filtration or oil-absorbent media within the vaults or incorporating baffles and inverted outlets into the design. In fact, there are several proprietary and nonproprietary vault-based devices available that include these design enhancements. These devices, also referred to as water quality inlets, oil-grit separators, or oil-water separators, consist of a series of chambers that promote settling of coarse sediment and separation of floating material (U.S. EPA, 1999e). Section 5.4.4 provides a more detailed discussion of oil-water separators; but it should be noted that these devices do not have well-proven water quality performance and some guidance has even suggested eliminating them from stormwater treatment (Schueler, 2000; Shepp, 1995), especially as "on-line" systems.

5.4.3.2 Recommended Pretreatment

To reduce the potential for clogging in the inlet and outlet structures of tanks and vaults, it is recommended that trash racks or large aperture screens be installed upstream. Floatable trash and oil can also be removed using surface skimmers or baffles. The addition of a sedimentation forebay is recommended if high loads of coarse sediment are expected. The forebay can be created by simply adding a baffle to isolate a section of the tank or vault. The inclusion of a forebay may centralize some of the more frequent maintenance activities and reduce the frequency of maintenance of the main chamber.

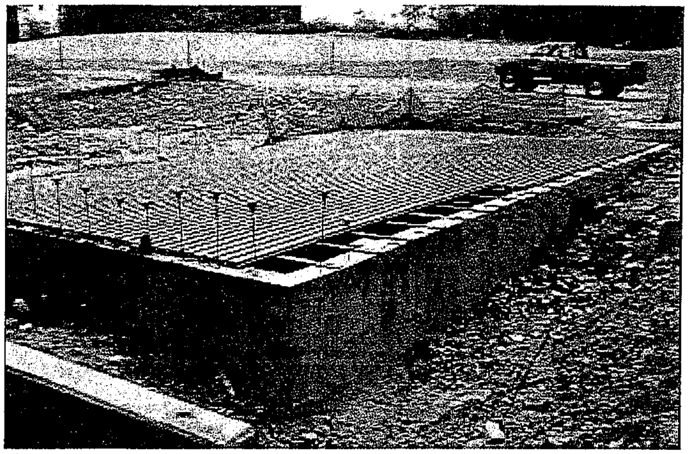


Figure 5-11. Example of Underground Concrete Vault for Stormwater Detention. Source: Atlanta Regional Commission (2001).

5.4.3.3 Hydraulic Considerations

Tanks and vaults are relatively simple to design in terms of hydraulics. The inlet and outlet structure should be selected and sized to minimize resuspension of captured materials and minimize short-circuiting. A flow-splitter is recommended to limit the portion of the stormwater runoff entering the unit to design flows and to bypass all flows above this. The tanks or vaults themselves should be sized to store the entire water quality design volume (depends on local regulations and the outlet structure must be sized as to provide the desired hydraulic retention times. Inlet structures must be designed to safely bypass flows that exceed the design volume.

5.4.3.4 Maintenance Considerations

Tanks and vaults must be regularly inspected to evaluate if cleaning is needed, so that vents, inlet structures and outlet structures remain unobstructed, and cracks that may cause water to enter or leave the tank are identified and fixed. Regular removal of accumulated material is needed to ensure consistent performance.

Corrugated metal tanks and pipes often hold water and silt in the corrugations, which after a period of time may cause corrosion. Frequent and complete removal of retained sediment and water will extend the life of metal tanks and pipes, but this increased maintenance burden and the risk for failure may actually offset the cost of a more expensive alternative.

In addition to general maintenance, tanks and vaults may require mosquito control if water is retained for greater than 72 hours (O'Meara, 1997). Regular removal of captured sediment and debris to allow complete drainage after a storm is probably the best mosquito control option (Deatrich and Brown, 2004). However, if the device intentionally holds water for greater than 72 hours, chemical or biochemical controls may be necessary. There are several larvacides and adulticides available for controlling mosquitoes, but state departments responsible for vector control, pesticide regulation, or human health services should be consulted prior to choosing any chemical or biochemical control. Water quality control agencies and departments of fish and wildlife may also have restrictions on the types of pesticides allowed in receiving waters.

5.4.3.5 Required Surface and Subsurface Area

The primary surface area required by subsurface tank installations is space for maintenance access, which is generally a manhole. Vaults are typically placed beneath parking lots or road surfaces for easy access to the manhole cover. The subsurface area required is proportional to the total volume of the tank or vault and the desired detention depth. Above-ground installations may take up a significant area which is again proportional to the design volume. Area requirements can be easily estimated by calculating the bottom area of the structure in question, or by consulting the manufacturer of the device.

5.4.3.6 Cost Considerations

Concrete vaults and plastic tanks can be expensive relative to corrugated metal pipe tanks. A preliminary cost estimate (FHWA, 2000) for concrete vaults can be obtained from the equation below:

$$C = 38.1(V / 0.02832)^{0.6816} \qquad [5\text{-}3]$$

Where: C = construction cost estimate (1995 dollars) and
V = volume of storage (cubic meters) for the maximum design event frequency.

Concrete vaults and plastic tanks are generally more durable than metal tanks because they will not corrode over time. However, plastic tanks require specially compacted bedding to ensure adequate structural support. Table 5-9 compares costs of various materials that could be used for underground storage facilities.

Table 5-9. Comparison of Underground Storage Facility Costs Per Cubic Foot.

Material	Diameter/ Capacity	Cost per linear foot*	Cost per ft³ storage*
Corrugated Steel Pipe	36" 48" 60"	\$60 \$82 \$111	\$8.49 \$6.53 \$5.66
Corrugated HDPE Pipe	36" 48" 60"	\$39 \$65 \$111	\$5.52 \$5.18 \$5.66
Concrete Pipe	36" 48" 60"	\$122 \$155 \$239	\$17.27 \$12.34 \$12.18
Fiberglass Underground Tank** (single wall)	10,000 G / 1337 ft³ 20,000 G / 2674 ft³ 30,000 G / 4010 ft³	NA NA NA	\$4.90 \$4.75 \$6.33
Steel Underground Tank	10,000 G / 1337 ft³ 20,000 G / 2674 ft³ 30,000 G / 4010 ft³	NA NA NA	\$6.86 \$5.98 \$6.48
Concrete Tanks	15,000 G / 2005 ft³ 25,000 G / 3342 ft³ 40,000 G / 5347 ft³	NA NA NA	\$7.78 \$9.58 \$7.57

**Costs provided are estimates only and do not include excavation and backfilling costs. Cost evaluation data provided from RSMeans (2002).*

**Tank costs do not include excavation, backfilling, inflow and outflow piping.

5.4.3.7 Aesthetics

Storage tanks and vaults are typically installed below ground and hence do not impact aesthetics as much as above-ground systems. For above-ground installations, storage tanks and vaults can be painted and strategically placed to improve aesthetics. Above-ground installations must incorporate all the necessary signage for public safety. Also above-ground vaults and tanks must have lids that should remain closed during normal operation. Noise considerations for maintenance should be considered when tanks are used in residential areas.

5.4.4 Oil-Water Separators

Oil-water or oil-grit separators (also referred to by others as water quality inlets (U.S. EPA, 1999e)) are designed to remove gross pollutants including petroleum hydrocarbons, grease, sand, and grit. Interception of solid particles through settling, and flotation and skimming of oils and other floatables are fundamental processes occurring within an oil-water separator. There are two common designs for oil-water separators: the American Petroleum Institute (API) separator and the Coalecing Plate Separator (CPS) (Figure 5-12). The API separator consists of three chambers divided by baffles and first chamber acts as an equalization chamber where grit and larger solids settle and turbulent flow slows before entering the main separation chamber. The CPS, which is generally smaller than the API, uses a single baffle and a series of oil-attracting coalecing plates in the main chamber. In both types of devices oil collects on the water surface, where it can be skimmed off, absorbed to a floating media pad, or removed mechanically. Solids settle to the bottom and oil rises to the top, according to Newton's or Stokes' law depending on the flow regime. Larger oil-water separators contain a sludge scraper which continually removes the captured settled solids into a sludge pit. The oil is also removed by an oil skimming operation on the water surface.

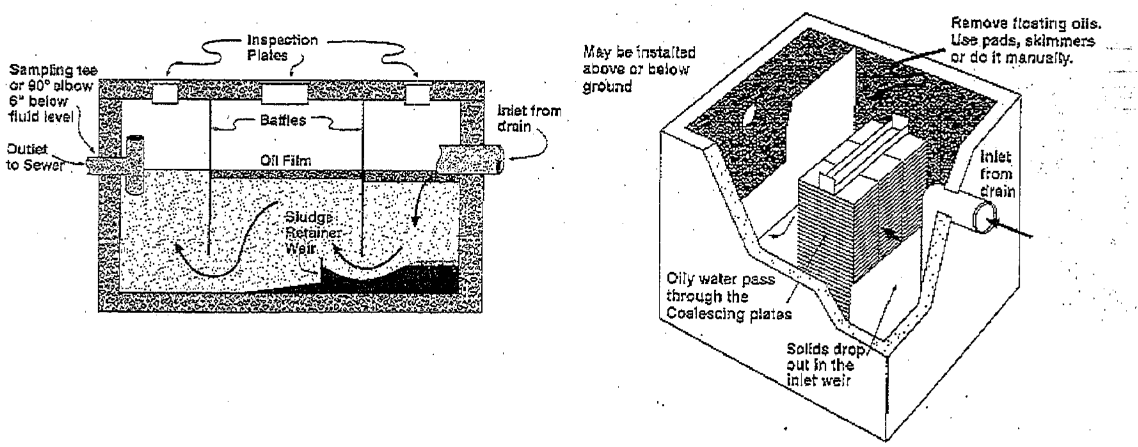


Figure 5-12. Common Oil-Water Separator Designs.
American Petroleum Institute (API) Oil/Water Separator (left) And Coalescing Plate Separator (CPS) (right).
Source: King County (2005), http://Dnr.Metrokc.Gov/Wlr/Indwaste/Oilfact.htm

The performance of oil/water separators in capturing and retaining oil and grease depends primarily upon pollutant loading rates and maintenance frequency. Low efficiencies are often associated with low influent concentrations and high efficiencies are often associated with higher influent concentrations; sometimes orders of magnitude higher than typical urban stormwater (Pitt, 2002a). An assessment of performance of these devices by Shepp (1995) found that the mean storm efficiency for several pollutants, including suspended sediment, total organic carbon, hydrocarbons, total phosphorus, organic nitrogen, total chromium, total cadmium, and total and dissolved copper, were zero to negative. More advanced structures, such as the multiple chamber treatment trains (MCTTs) have shown better performance than typical oil-grit separators (Schueler, 2000).

5.4.4.1 Associated UOPs and Potential Design Enhancements

Gravity separation that relies on the density differences between oil and water is the most basic type of unit operation used. Oil will rise to the water surface unless some other contributing factor such as a solvent or detergent interferes with the process. For gravity units, this density difference is the only mechanism by which separation occurs. Other technologies, such as dissolved air flotation, coalescing plates, and impingement coalescing filters, enhance the separation process by mechanical means. The addition of coalescing unit to the separator can dramatically increase the effectiveness and reduce the overall size of the unit.

5.4.4.2 Pretreatment Considerations

The use of a catch basin(s) or an interceptor tank as a pretreatment device would keep the coarser materials from entering the oil-water separation tank, but this may not be necessary if a multiple-chambered device is used.

5.4.4.3 Hydraulic Considerations

The oil-water separator design process is based on Newton's Law (simplified to Stoke's law for laminar particle settling regime) and includes the following steps:

1. Determine the droplet rise velocity (V_T) of the critical droplet size using Stokes' Law:

$$V_T = \frac{g}{18\mu} \cdot (\rho_w - \rho_o) \cdot d^2 \qquad [5\text{-}4]$$

Where: V_T = rising velocity (terminal velocity) of oil droplets (ft/s)
g = acceleration due to gravity (ft/s^2)
μ = absolute viscosity of water (lbm/ft·s)
ρ_w = density of water (lbm/ft^3)
ρ_o = density of oil (lbm/ft^3)
d = droplet diameter (ft)

2. Once the critical rise-rate (V_T) and maximum flow (Q) have been determined, the effective horizontal separation area is calculated from the equation:

$$A_H = \frac{Q}{V_T} \qquad [5\text{-}5]$$

This formula, based on a simple overflow rate concept, is commonly used in oil-water separator design. Often, large areas are required for effective separation. However, stacked coalescing plates can be used to create the necessary separator area in a limited space. The efficiency of a separator also depends upon the flow rate; as the flow increases, the separator performance decreases. Therefore, a separator must be designed to work at the maximum expected flow for a given rainfall event.

Selecting the critical (or design) density of oil is another relevant factor in the design. The heaviest oil presumed to be present is used to determine the critical rise velocity. In general, the specific gravity of oil ranges from 0.82-0.95. The separator will be most efficient for the lowest oil densities. Water temperature also affects performance. The viscosity and specific gravity of a liquid are direct functions of temperature. As temperature decreases the dynamic viscosity of the water increases, which increases the drag on rising oil droplets. Therefore, separation is more effective in warm water than it is in cold water and the lowest temperature routinely encountered should be used in the design. The solids content of the wastewater must also be considered for separator design. After the basic dimensions of the separator have been calculated, sufficient volume must be added for solids storage between cleanings.

5.4.4.4 Maintenance Considerations

The efficiency of oil-water separators in trapping and retaining solids and hydrocarbons depends largely upon how they are maintained. They must be designed for ease of maintenance and be frequently maintained. Accumulation of waste materials may hinder performance and result in scour during intermittent high flows (U.S. EPA, 1999e). When excess oil accumulates or when the device experiences high flows, the trapped oil may be forced around the retention baffle and into the discharge stream. Buildup of sludge will reduce the storage volume and the retention time so the oil does not have time to separate from the water before being discharged.

For MCTTs, the major maintenance issues include removal of sediment from the settling chamber when the accumulation exceeds 150 mm (6 in.) and removal and replacement of the filter media about every three years (Pitt, 2002b). It is recommended that maintenance of oil/water separators occur as frequently as twice per year, but should be inspected after every storm event after initial installation to evaluate the accumulation rate. Maintenance is typically accomplished with a vactor truck.

5.4.4.5 Cost Considerations

The construction costs for oil-water separators will vary greatly depending on their design size and depth, as well as site-specific conditions, but estimates of construction costs (adjusted to 2005 dollars) for cast-in-place oil-water separators have been reported to range from $6,600-21,200, with the average oil-water separator costing around $11,200 (Schueler et al., 1992). For the basic design and construction, the pre-manufactured units are generally less expensive than those that are cast-in-place (Berg, 1991). For more advanced units, such as the MCTT, construction costs range from about $10,000-20,000 per quarter acre (Schueler and Holland, 2000). For retrofit situations, the cost of MCTTs, as with most treatment systems, would be much higher. Pitt (2002b) reported total capital costs of $72,000 and $95,000 for retrofitting 0.25-acre and 2.5-acre parking lots, respectively, in Wisconsin with MCTTs. Maintenance costs will also vary greatly depending on the size of the drainage area, the amount of residuals collected, and the clean out and disposal methods available (Schueler et al., 1992). The cost of residuals removal, analysis, and disposal can be a major maintenance expense, particularly if the residuals are toxic and are not suitable for disposal in a conventional municipal landfill (i.e., classified as hazardous waste). Clearly if the captured material cannot be disposed of in a municipal landfill, it should not be discharged to receiving waters.

5.4.4.6 Aesthetics

Because oil-water separators are generally underground, aesthetics is usually not an issue. However, bad odors may be generated if maintenance is infrequent and the captured sediments become anoxic. Also, if the device contains standing water it can become a breeding ground for mosquitoes.

5.4.5 Surface Filters

In stormwater applications, the unit operations of particle size separation can be accomplished through the use of surface filters or media filters. Media filters provide filtration by directing the influent through layers of media such as sand, engineered media, peat, zeolite, compost, etcetera (see Section 5.4.6). Surface filters, on the other hand, consist of a membrane or a geotextile fabric that serves as a barrier to particulates that are larger than the pore openings in the filter. Most media filters use geotextiles to prevent other system components from clogging such as the filter bed, pipes and outlet structures. For example, geotextiles are used as pipe wraps in infiltration and media filtration facilities such as sand filters and infiltration/exfiltration trenches to prevent intrusion of the filter media into the outlet pipe system. In addition to being used as components of media filtration systems, geotextiles can be used as standalone filters. The use of geotextiles for erosion and sediment control, particularly as construction site BMPs such as silt fences (Figure 5-13) is probably the most common application. For design guidance and performance evaluation methodologies for silt fences see Stevens et al. (2004). In addition to silt fences, there are also several catch basin insert and water quality inlet designs that utilize geotextiles for coarse sediment filtration and absorption of hydrocarbons (Pitt and Clark, 1999).

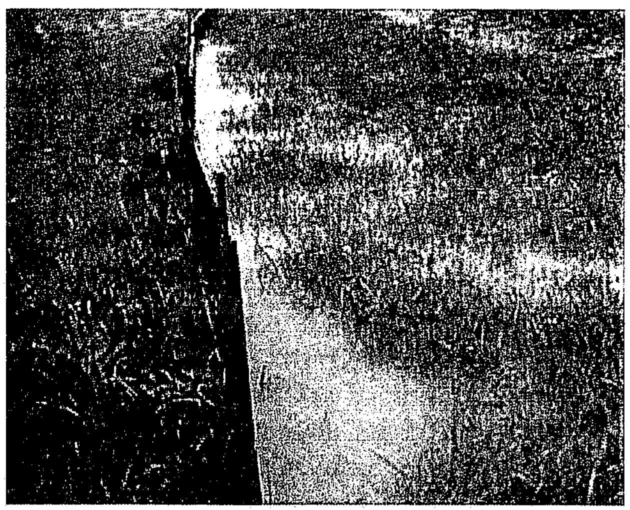


Figure 5-13. Example of a Geotextile Silt Fence Used to Control Construction Site Erosion. Source: Tennessee Department of Environment and Conservation (2002).

In general geotextiles require less space than media filters, but typically clog easier and are more difficult to maintain without total replacement. Geotextiles require a frame to provide external structural support because fabrics tend to have adequate tensile strength and negligible compressive strength. Geotextiles are made from various materials with a wide array of drainage properties. Commonly used geotextiles can be categorized based on manufacturing methods as either woven or nonwoven.

Nonwoven fabric can be either needle punched or spunbonded. Needle punched fabrics are typically designed to filter particulates from drainage systems and/or stabilize roadways, soils etcetera. The manufacturing process includes extruding continuous filaments of materials such as polypropylene, which are then cut, opened, laid into a web, needle punched, heat set and rolled into the finished product (ADS, 2004). Spunbonded fabrics are also made from continuous filaments of materials such as polypropylene spun uniformly over a flat surface to make a flat, mat-like fiber. The crossed filaments are thermally bonded together, rather than woven, into a tear-resistant material to create the filtration medium (ADS, 2004) that can be used in a variety of applications.

Woven fabrics are typically manufactured from extrude monofilaments of materials such as polypropylene, and interlaced to form a dimensionally stable fabric. The process results in a geotextile that is more resistant to soil and biological clogging than non-woven varieties (ADS, 2004).

5.4.5.1 Applications

Geotextiles have a broad range of stormwater applications that can be divided according to five main categories including filtration, subsurface drainage, erosion control, sediment control, and turbidity control. Filtration fabrics are used exclusively to filter sediment from stormwater, such as in catch basin inserts. Subsurface drainage fabrics are those used in underdrains or trench drains to minimize the migration of granular materials into the drainage system. Erosion control fabrics are used to protect cut slopes or open drainage systems from being eroded. Sediment control fabrics are used exclusively for silt fence applications. Turbidity control fabrics are used as silt curtains within waterbodies by impeding flow and promoting sedimentation. Other stormwater applications for geotextiles include:

- Keeping granular media out of perforated pipe systems in sand and other media filtration system,
- Providing drainage paths behind sheet piles, retaining walls and other subsurface barriers,
- Preventing clogging of outlet pipe systems in detention and retention ponds,
- Providing filtration in catch basin insert systems and end-of-pipe applications,
- Providing containment of turbid regions in water bodies (as turbidity curtains and silt screens),
- Retaining soils while allowing water to pass, and
- Stabilizing drainage courses and stream banks.

5.4.5.2 Associated UOPs and Potential Design Enhancements

Through filtration operations surface filters primarily target coarse solids and pollutants associated with them. Factors that impact the filtration efficiency in surface filters include:

- The effective filter area
- Size of filter fabric pores (apparent opening size)
- Percent open area of filter fabric
- Pressure drop across the filter
- Resistance of filter to fluid flow
- Swelling effect of influent on the filter
- Compressibility of the filter fabric under fluid pressure

- Size of suspended particles
- Tendency of particles to flocculate
- Rate of formation of filter cake
- Resistance of filter cake to fluid flow
- Incorporation of sorptive materials into the filter

If the filter is well maintained and its integrity is not compromised, the filter will at a minimum remove particles larger than the pore openings. Therefore, filter fabrics will generally only remove solids and particulate-bound constituents, and will provide limited removal of oils and greases if absorptive material is included. Surface filters are typically much thinner than media filters, which limits their pollutant sorption capacity. The ability of a surface filter to maintain its hydraulic capacity depends on the duration of the filtration operation and the size, shape and nature of the suspended solids relative to the filter's pore space (Pitt and Clark, 1999).

Direct sieving, cake filtration and standard blocking are three distinct modes of filtration that have been identified as components of the filtration mechanism. Direct sieving refers to the physical straining of particles through the aperture of the filter fabric, cake filtration refers to the blocking of particles by previously filtered materials, while standard blocking occurs when particles smaller than filter pores get trapped behind filter fibers at fluid flow stagnation points or get attached to filter fibers and other previously retained particles (English, 1997). A more detailed discussion of the filtration process is provided in Section 4.3.2.2.

5.4.5.3 Recommended Pretreatment

Surface filters may benefit from the use of coarse screens and trash racks as pretreatment controls. Screens and racks prevent sharp objects or large objects from causing structural damage to the filter. Floatables can potentially expedite filter clogging, therefore practices that prevent coarse solids and floatables from reaching the filter surface are recommended. For erosion control applications, filters may be used without pretreatment to protect other drainage structures; in these instances the filter fabric is the pretreatment. In soil stabilization and media filtration applications, the soil or the media serves as pretreatment by precluding large or sharp objects and floatables from reaching the filter surface. For some areas where high loadings of fine sediment are expected, more intensive pretreatment may be necessary or an alternative treatment system component, such as a sand filter, may be more appropriate.

5.4.5.4 Hydraulic Considerations

The primary purpose of filter fabrics is to separate soil or sediment particles to permit a relatively free flow of water. The apparent opening size (AOS) of a filter fabric controls its ability to retain particles, while the permittivity quantifies its ability to pass water through or across. To estimate the soil retention capacity of a filter fabric, the AOS must be known. To estimate the flow capacity, the permittivity, ψ, must be known. These properties are usually provided by the manufacturer or can be determined in a laboratory using the standard test methods ASTM D4751, "Standard Test Method for Determining Apparent Opening Size of a Geotextile" and ASTM D4491, "Standard Test Methods for Water Permeability of Geotextiles by Permittivity."

The selection of the AOS for a particular application depends on particle size distribution of the sediment or soil particles to be retained. The American Association of State Highway Officials' (AASHTO) specification M-288-96 recommends the following:

Table 5-10. Recommended Geotextile Apparent Opening Size by Application.

Percent In-Site Soil Passing 0.075 mm Sieve (%)	Application/Recommended AOS		
	Subsurface Drainage (mm)	Permanent Erosion Control (mm)	Separation (mm)
< 15	< 0.45	< 0.43	< 0.6
15 - 50	< 0.25	< 0.43	< 0.6
> 50	< 0.22	< 0.22	< 0.6

Source: AASHTO Spec M-288-96

The permittivity is expressed in units of reciprocal time (sec^{-1}) and is simply the permeability of the fabric divided by the thickness of the fabric. Given the permittivity, the headloss across the geotextile, and the area perpendicular to the direction of flow, the flow capacity of the fabric can be determined as follows:

$$q = 7.48 \cdot \psi \cdot \Delta h \cdot A \quad [5\text{-}6]$$

Where: q = volumetric rate of flow (gpm/s)
ψ = permittivity (sec^{-1})
Δh = change in head or headloss across the geotextile (ft)
A = cross-plane area of the filter fabric (ft^2)
7.48 = gallons per cubic foot

As is evident from Equation 5-6, the flow rate through a filter is directly proportional to the headloss across the filter and the area of the filter perpendicular to the direction of flow, essentially a Darcian flux. If a design flow is known, this equation can be used to estimate the necessary pore size of the filter fabric. The minimum permittivity selected depends on the specific application and the size distribution of the site soils, but for all subsurface applications, the fabric should have a higher permittivity than the site soils. The AASHTO specification M-288-96 recommends the following minimum permittivity:

Table 5-11. Recommended Geotextile Permittivity by Application.

Percent In-Site Soil Passing 0.075 mm Sieve (%)	Application / Recommended Permittivity		
	Subsurface Drainage (sec^{-1})	Permanent Erosion Control (sec^{-1})	Separation (sec^{-1})
< 15	0.5	0.7	0.02
15 - 50	0.2	0.2	0.02
> 50	0.1	0.1	0.02

Source: AASHTO Spec M-288-96

Equation 5-7 can be used as the criterion for determining acceptable water passage through a soil geotextile/filter system.

$$K_g > i_s K_s \quad [5\text{-}7]$$

Where: K_g = coefficient of permeability of the geotextile (permittivity times the thickness)
i = hydraulic gradient of the soil
K_s = coefficient of permeability of the soil

In summary, the performance of filter fabrics depends on the hydraulic conditions and the quality and characteristics of the influent. In terms of flow rates, throughput depends on the permeability of the surrounding media as well as the permeability of the filter fabric. To overcome decreasing flow rates due to clogging over time, filters must be maintained or replaced. Inadequately designed filters may clog, which may cause flooding and subsequent damage to property or excessive bypass of untreated flows.

5.4.5.5 Maintenance Considerations

In most stand-alone applications, the generally low cost of filter fabrics along with the difficulty in cleaning them makes frequent replacement more practical than cleaning and reuse. If the filter is used in a subsurface application, replacement can be difficult and costly, but maintenance via backwashing can in some cases be specifically accounted for in the system design. When used in conjunction with media filters, the filter fabric may be inaccessible and may only be maintained during complete system overhaul or during media replacement. Fabrics showing signs of wear or holes should be replaced to prevent catastrophic failure. Filter fabric failure may release media or accumulated contaminants downstream, which may cause clogging, damage to sensitive TSCs, and negative impacts to receiving waters. Besides cleaning, improper installation is the single biggest weakness of surface filters.

5.4.5.6 Required Surface and Subsurface Area

Space requirements include the space needed for influent containment and for the filter fabric supporting framework. A simple application may use filter fabric wrapped around a perforated outlet pipe in a tank or a vault. In this case, the tank provides influent containment while the pipe provides filter fabric support. Space requirements for the filter fabric itself are often minimal compared to the space requirements of the other system components.

5.4.5.7 Cost Considerations

Filter fabrics are relatively cheap and there is a wide range of products to choose from with new offerings being added. Tough, durable fabrics may be economical in some applications while some applications may require biodegradable fabrics, which are typically less expensive alternatives (English, 1994).

5.4.5.8 Aesthetics

Filter fabrics used as components of other TSCs are likely not obvious to the casual observer and therefore may not significantly impact the aesthetics of the system.

5.4.6 Media Filters

Media filtration is primarily intended to separate fine particulates and associated pollutants. In this process, stormwater is captured and directed either under gravity or pressure through media such as sand, engineered media, compost, zeolite, or combinations of media. Depending on the media type, media filtration may also be used for enhanced treatment to remove dissolved constituents such as metals and nutrients. Media such as activated carbon, peat, zeolites, activated alumina, polymers, engineered media, and synthetic resins have been widely used for years in water and wastewater treatment to remove dissolved metals and organics. Sand filtration (Figure 5-14) is widely used in stormwater treatment, and designs such as the Austin sand filter have been used throughout the U.S. for a number of years. Other media such as zeolite, peat moss, compost and various sorbent materials are also used for supplemental stormwater treatment in devices such as catch basin inserts, oil-water separators, and some proprietary devices (Media Filtration System, StormFilter™, AquaFilter™, etc.).

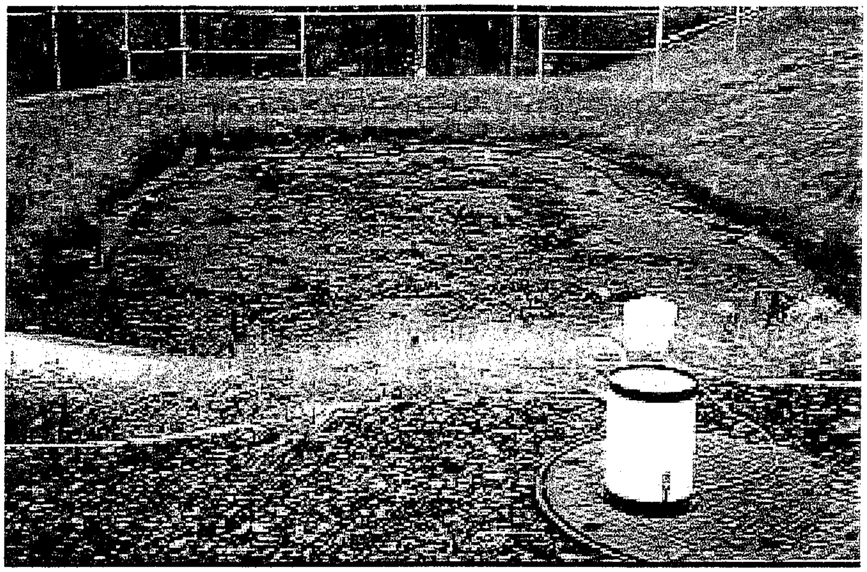


Figure 5-14. Sand Filter for Treating Stormwater.
Source: Atlanta Regional Council (2001), http://www.georgiastormwater.com/vol2/3-4-3.pdf

The choice of filter media is obviously an important design variable. Sand is used extensively for filtration because of many factors including cost, availability, handling, and maintenance. Sand filters are normally inert media filters (nonreactive and not organically enriched). They remove solids well and are somewhat effective in removing organics and dissolved constituents. There are now many options available for engineered media on natural and manufactured substrates. In both wastewater and stormwater treatment, effective dissolved metals removal has been achieved using iron- and manganese-coated sand (Benjamin et al., 1996; Sansalone, 1999a) and various engineered surface complexation and precipitation media (Liu et al., 2005a; Liu et al., 2005b). Aluminum oxide-coated sand and engineered media have been very effective in removing dissolved phosphorus (Ayoub et al., 2001; Ma et al., 2005).

In water and wastewater treatment, slow sand filtration has been shown to be extremely effective in removing suspended particles, bacteria, protozoa, and some viruses. Beneficial microbes on the filter surface provide an important treatment pathway for many biologically oxidizable pollutants. Surface bacteria and algae utilize nutrients for their life functions, removing them from the wastewater stream. However in stormwater, physical and chemical mechanisms of filtration dominate over biological conversion because microbes require regular organic loading and a wet environment to survive; these conditions are often not met because stormwater runoff is highly stochastic. In times of extreme dry periods, the microbes die off. This die-off could reduce the systems' ability to treat the next storm event, and depending on the life cycle of the organism, may result in the release of stored nutrients. These effects may be offset by the buildup of trapped organic matter in the filter. However in stormwater, trapped organic matter complexes metals, in particular copper, which may result in an inhibitory effect on the microbiology. (Copper compounds, such as copper sulfate, are often used to control microorganisms).

Compost filters that are made of yard waste, primarily leaves, have been found to be effective in removing oils, greases, organic pollutants, and nutrients due to their high humic content and sorption capacity. However many of these organic media leach constituents such as phosphorus or metals and degrade over time. The potential use of wood and nonwood-based fibers known for their significant sorption capacity for metals has been investigated as filtration media for stormwater by the USDA Forest Service Forest Products Laboratory, Madison, WI (Han et al., 1999).

5.4.6.1 Associated UOPs and Potential Design Enhancements

Treatment of stormwater by media filtration primarily involves the processes of 1) surficial sedimentation, entrapment, straining of solids by the media, 2) surface complexation, sorption, precipitation, and ion exchange of pollutants depending on the media type and pollutant, 3) microbial degradation of readily-oxidizable organic pollutants, and 4) surficial sedimentation for bed filters with surcharge capacity above the bed.

These and other relevant physical, chemical, and biological mechanisms that assist treatment by filtration are discussed in detail in Sections 4.3, 4.4, and 4.5. Absorption of pollutants is limited by the physical and chemical properties of the medium, surface area per unit volume and, most importantly, by the fraction of available bonding sites, which is a function of the age of the filter media. When pollutants are removed by reactive mechanisms such as ion exchange, precipitation, chelation, adsorption, etcetera, it should be understood that these reactions have limits such as sorption capacity of the media and reaction kinetics. For example, the equilibrium sorption capacity of the media is given as X mg/kg of the media. Given the mass of the media, the potential mass of pollutant removal can be calculated and compared with the influent pollutant loads over some time period. Reaction kinetics (for example first or second order rates) would also cause a slowing of the pollutant removal rates as pollutant saturation is approached and/or the pollutant concentration decreases (Liu et al., 2001a; Liu et al., 2001b). The media should be periodically replenished to maintain the performance effectiveness of the media.

For media that include ion exchange processes such as activated carbon, compost, and zeolite, when ions are removed from runoff, different ions are released into solution. While most of these exchangeable ions are not a problem in receiving waters, the designer should be aware of these potential sources of effluent constituents when using ion exchange media. Pitt and Clark (1999) noted that the exchangeable ion for activated carbon is mostly sulfate, for compost is usually potassium, and for zeolite is primarily sodium and some divalent cations (which increases hardness).

5.4.6.2 Recommended Pretreatment

With all media filters some form of pretreatment is generally recommended to avoid premature clogging (Clark and Pitt, 1999). However pretreatment requirements are highly dependent on the influent sediment size distribution, trash and debris loading rates, and the filter design. Ultimately, the decision to include pretreatment should be based on an assessment of runoff characteristics and the UOPs selected for target pollutant removal. Also, filters should be designed with a provision for overflow or bypass for extreme storm events to prevent damage and flooding if the device is blocked.

Sand filters may not necessarily need pretreatment to remain functional, but pretreatment of coarse sediments, trash, and debris is generally cheap, and it will centralize some of the more frequent maintenance activities by depositing the majority of these pollutants in the pretreatment device. Also, trash and debris can become unsightly if distributed across the surface of a sand filter. An upstream sedimentation tank or detention basin is often located immediately upstream of the sand filter to remove coarse sediment and to meter flows. Hydrodynamic devices are also suitable for removing coarse sediment, trash and debris, but do not provide flow attenuation.

5.4.6.3 Hydraulic Considerations

Since media filters are typically sized according to a design flow rate, they can be considered flow-based treatment systems. Filters should ideally operate under streamline flow. Poiseille's law modified by Kozeny and Carmen can be used to model liquid flow through porous media:

$$q = \left[e^3 \frac{e^3}{kS^2{}_v(1-e)^2} \right] [A \Delta Pg / \mu l] \qquad [5\text{-}8]$$

Where: q = Volumetric rate of flow
A = Cross sectional area of porous bed
P = Pressure drop across filter
l = Thickness of bed
e = Void fraction of porosity, dimensionless
S_v = Specific surface of solid particles on a volume basis
k = Dimensionless constant (ranges from 3-6 for most materials)
u = Viscosity of the fluid
g = Gravitational constant

As is evident from Equation 5-8, the rate of flow through a filter is directly proportional to the pressure drop across the filter and the area of the filter perpendicular to the direction of flow. The permeability coefficient for a filter system can be modeled by the Kozeny-Carmen relation presented in Equation 5-9. This equation accurately predicts the flow of liquids in simple systems but is limited for highly variable materials (English, 1997).

$$K = \left[\frac{e^3}{kS_v^2(1-e)^2} \right] \qquad [5\text{-}9]$$

Where: K = permeability coefficient
e = Void fraction of porosity, dimensionless
S_v = Specific surface of solid particles on a volume basis
k = Dimensionless constant (ranges from 3–6 for most materials)

Equations 5-10 and 5-11 represent two relations that can be used to model the variation of pressure drop across the filter during the filtration process (English, 1997). Equation 5-10 assumes internal surfaces are uniformly coated by small particles while Equation 5-11 assumes gradual clogging of the filter by large particles.

$$\frac{\Delta P}{\Delta P_m} = \frac{1}{(1 - jR)^m} \qquad [5\text{-}10]$$

Where: P = Piezometric pressure
R = Retention (volume of deposited particles / unit filter volume)

j, m = Empirically determined constants

$$\frac{\Delta P}{\Delta P_m} - \left[\frac{1}{(BR/E)^2}\right] \qquad [5\text{-}11]$$

Where: P = Piezometric pressure
R = Retention (volume of deposited particles / unit filter volume)
B = Inverse compaction factor of the retained particles.

Sizing and designing a media filter typically involves determining the water quality volume of the pretreatment unit and the surface area of the filter. The filter area for sand and organic filters should be sized based on the principles of Darcy's Law. The equation for the required filter bed area is computed based on the City of Austin (1996) design manual:

$$A_f = \frac{WQ_v \cdot d_f}{k \cdot \left(h_f + d_f\right) \cdot t_f} \qquad [5\text{-}12]$$

Where: A_f = Surface area of filter bed (ft^2)
WQ_v = Water quality design volume (ft^3)
d_f = filter bed depth (ft)
k = saturated hydraulic conductivity of filter media (ft/day)
h_f = average height of water above filter bed (ft)
t_f = design filter bed drain time (days)
(1.67 days or 40 hours is recommended maximum for sand filters, 48 hours for bioretention facilities)

Equation 5-12 is appropriate for a filter operating under clean-bed conditions, but does not adequately account for the reduction in the hydraulic capacity caused by clogging of the filter media over time. As a filter begins to clog, the flow-through rate begins to be governed more by the amount of sediment and organic materials accumulated on the filter surface and within the media than by the hydraulic head (Urbonas, 1999). Therefore, the use of Equation 5-12 may result in an undersized filter unless the influent sediment concentrations are expected to be low and frequent maintenance is planned. An alternative method for sizing a filter that accounts for the reduction in the hydraulic capacity is to estimate the sediment accumulation rate and then use an empirically derived exponential decay function to estimate the maximum reduction in flow between maintenance periods (Urbonas, 1999).

To evaluate if the peak design flow can be conveyed, the engineer should perform a backwater calculation accounting for media losses and pipe losses from the point of downstream control. The velocity of the pipe discharge onto the filter bed is important as it should not scour or dislodge the filter media.

The total flow rate Q through the media is given by:

$$Q = qA \qquad [5\text{-}13]$$

Where: q = specific flow rate for the medium (gpm/ft^2)
A = area of the filter bed (ft^2)

The specific flow rate of the media should match the design flow rate for the system to function effectively. The thickness of the media along with the specific flow rate determines the amount of residence time the water has to be treated. The longer the residence time the more effective the pollutant removal will be, especially for dissolved constituents treated by the reactive media.

Sand filters require a significant amount of hydraulic head (about 3-4 feet) to allow flow through the system. However, a perimeter sand filter would require only about 2 ft. Hydraulic conductivity (k) values used in Equation 5-12 depend on the media, porosity, temperature, media surface characteristics and flow conditions used. Typical k values are 3.5 ft/day for sand, 2.75 ft/day for a peat/sand mixture, and 8.7 for compost leaves (Claytor and Schueler, 1996). It is important to note that saturated hydraulic conductivity as measured in the lab using conventional permeability equipment results in typically much smaller values than would be observed in the field. Therefore, it is recommended that saturated hydraulic conductivity be determined using actual filter columns.

Media filtration units are designed with overflow structures and flow spreaders to prevent damage under high flow conditions. Filtration units are often slow working and require a large head to drive water through the media. While microorganisms may assist pollutant removal processes, they may also clog the filter media. Also, for many stormwater filters with any appreciable metal loading, specifically copper, the adsorption media may inhibit microbial growth (due to toxicity). Media should be protected from negative redox conditions as such conditions will solubilize many pollutants trapped on the media surface. For the Austin sand filter design, the underdrain piping should consist of a main collector pipe and two or more lateral branch pipes, each with a minimum diameter of 4 inches. The pipes should have a minimum slope of 1% (1/8 in/ft) and the laterals should be spaced at intervals of no more than 10 feet (City of Austin, 1996).

5.4.6.4 Maintenance Considerations

Long-term effectiveness of media filtration units requires regular maintenance to avoid piping and bypass. Replacement of the entire media bed may sometimes be necessary. Depending on the filter lifetime and the pollutant loading rate of the drainage area, the spent media may be classified as a hazardous waste and require appropriate handling and disposal.

Sand filters need to be monitored on a regular basis and after every significant storm event for:

- Ponding, clogging and blockage of the filter media
- Depth of sediment in the settling tank/pretreatment device
- Blockage of the outlet from the settling tank/pretreatment device to the filter

Regular maintenance activities may include: 1) removing sediment and litter from the pretreatment device, 2) regularly raking the filter surface to remove sediment and break up any crusts (scarifying) to improve flow rates through the media, and 3) periodically replacing the top layer of the filter media to maintain performance (UDFCD, 1999). If the filter is not cleaned frequently, the entire filter media may need to be replaced due to migration of sand within the media. Therefore, more frequent maintenance can be more cost effective in the long-term. Contaminated sand and other material removed from the filter or the sedimentation chamber (if applicable) can be removed to landfill.

5.4.6.5 Cost Considerations

The cost of a filtration device constructed in-situ may be significantly higher than a pre-fabricated device. Most large installations will be constructed in-situ. Maintenance costs are often high due to the amount of work required to rejuvenate a filter surface, and because a lot of work occurs in confined spaces (which requires special training). U.S. EPA (1999) indicates a construction cost for an Austin sand filter at $18,500 for a 0.4-hectare (1-acre) drainage area. However, the same design implemented at various locations by the California Department of Transportation, cost between $150,000 and $200,000 per hectare (Barrett, 2003). The large discrepancy in cost may be a function of site-specific conditions, particular design/size requirements by different regulatory agencies, or whether the costs include the costs of stormwater conveyance structures that would have been needed regardless of the sand filter.

5.4.6.6 Aesthetics

Aesthetics are generally not an issue for underground structures. However, if the filter media becomes anoxic due to poor drainage for example, foul odors may be emitted due to the reduction of sulfate to hydrogen sulfide. For above-ground facilities, aesthetics may be an issue and in some cases would require frequent trash and debris removal. The facilities themselves may also have aesthetic issues if designed as rectangular concrete structures.

5.4.7 Biofilters

In stormwater treatment, biofilters have a completely different connotation than in wastewater treatment. Biofiltration in wastewater treatment operations typically refers to a microbial biofilm, such as those that form in trickling filters for the removal of oxygen-demanding substances, or packed-bed filters for the removal of odorous gases. However, trickling filters are not easily adapted for stormwater treatment due to the stochastic nature of stormwater runoff, metals concentrations, which may be toxic to microbes, and the relatively low concentration of soluble organics compared to wastewater. Also, odors are generally not enough of a concern in stormwater treatment systems to necessitate separate components for odor control. Nonetheless, odors should be a design consideration for systems where oxygen may become limited and production of hydrogen sulfide is a concern.

Biofilters for stormwater treatment refer to the use of herbaceous plants and grasses planted within a trapezoidal or U-shaped channel to promote shallow, channelized flow (vegetated swale), or on a broad, mildly sloped area to promote sheet flow (filter strip) are recommended. Microorganisms likely exist in these systems, but they are not the primary remover of pollutants. Due to the simplistic and flexible design, limited area requirements, ease of maintenance, and demonstrated performance, biofilters are one of the most common stormwater TSCs being utilized in both urban and rural settings. Biofilters can be used as either primary or secondary TSCs depending on the target constituents. Biofilters offer several options for design enhancements. For example, swales can be designed as wet systems with a liner and wetland-type vegetation or as dry systems with an underdrain and/or infiltration component (Figure 5-15). To provide additional or enhanced UOPs, other possible modifications include appropriately selected vegetation, engineered underlying soils, check dams and berms, and custom inlet and outlet structures. For example, the underlying soils could be amended to improve their cation exchange capacity (CEC) and sodium adsorption ratio (SAR) (see Section 5.5.1, Soils and Soil Amendments).

Figure 5-15. Biofilter Treating Runoff from a Parking Lot.
Reprinted with permission from the Villanova Urban Stormwater Partnership (2005).

5.4.7.1 Associated UOPs and Potential Design Enhancements

The primary unit process provided by biofilters is filtration and biological oxidation. However, they also provide sorption, sedimentation, and, to a limited degree biological treatment, (i.e. microbial transformation and plant uptake) volume reduction (Strecker et al., 2003), and possibly aeration and volatilization when the flow is turbulent. Depending on the type of vegetation and underlying soils, swales may provide volume reduction via infiltration and evapotranspiration.

Filtration may occur in both the vegetated layer and the soil layer. Thus, it is often recommended to maintain flows at 2-3 inches below the height of the ground cover vegetation (Horner et al., 1994). Filtration can be improved by having increasing the density of vegetation. Well-drained soils that are ideal for infiltration will typically only support drought-tolerant vegetation without regular irrigation. An underdrain could be installed and the topsoil layer amended with moisture and/or pollutant adsorptive media, such as organic matter, to improve sorption, filtration, and infiltration. To improve microbial transformations of dissolved metals or organics, the topsoil layer may be amended with a nutrient-rich medium like organic matter. However addition of organic matter for any purpose may be counter-productive if nutrients are constituents of concern.

The hydraulic residence times within biofilters are usually too short for significant plant uptake of target constituents to occur, other than uptake from held moisture. However by increasing the contact time uptake processes (as well as sedimentation) may be improved. For example, indoor swale experiments conducted by Johnson et al. (2004) found that soluble metals (Cu, Cr, Pb, Zn, and Cd) were taken up by all three of the species of grass studied (Centipede, Kentucky Bluegrass, and Zoysia) after 24 hours of contact time. Ranges of repored performance are provided below.

Table 5-12. Ranges of Soluble Metals Retained by Three Different Grass Species. Reprinted with permission from Johnson et al. (2003).

	% Metals Retained
Copper	39.8 - 40.3
Chromium	13.8 - 36.8
Lead	57.1 - 64.8
Zinc	13.3 - 26.1
Cadmium	21.1 - 25.2

Potential design enhancements provided by soil amendments, microbes, and vegetation are discussed in Section 5.5. Various types of hydraulic controls that can be employed in biofiltration systems are discussed in Section 5.6.

5.4.7.2 Recommended Pretreatment

Biofilters typically require minimal pretreatment to remain functional. However, high loadings of coarse solids, trash, and debris may flatten grasses and reduce their ability to filter particles. Thus, trash racks and coarse sediment traps upstream of swales are generally recommended in areas with concentrated inflows. Biofilters are typically efficient at removing oil and grease, but high loadings may coat and kill vegetation. Therefore, if very high oil and grease loading are expected, such as from gas stations or high-volume roads, placing an oil-grit separator, skimmers or booms, or soils upstream of the biofilter is recommended.

5.4.7.3 Hydraulic Considerations

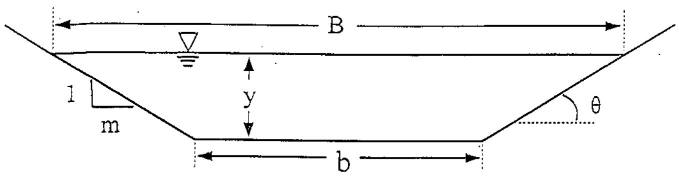
Biofilters should not have flow velocities greater than 1-3 feet per second. Depths should be maintained below the height of the vegetation (typically 2-4 inches for swales and 0.5-1 inch for filter strips). The hydraulic residence time should be no less than 5-9 minutes (Horner et al., 1994; King County, 1998). However, these are guidelines for a particular geographic location and the actual design should be dictated by UOP selected for treatment of the target constituents. Manning's equation for open-channel flow is the primary design equation used for estimating flow conditions and evaluating design parameters:

$$Q = \frac{k}{n} \cdot A \cdot R^{2/3} \cdot S^{1/2} \qquad [5\text{-}14]$$

Where: Q is the design flow rate, ft^3/s
k is 1.486 for English units, 1 for metric
n is Manning's roughness coefficient, unitless
A is the cross-sectional area, ft^2
R is the hydraulic radius (A/P, where P is the wetted perimeter), ft
S is the longitudinal slope of the channel bottom, ft/ft

Manning's equation is valid for both channelized and sheet flow calculations, and can be used to estimate the design parameters of swales and filter strips. The roughness coefficient, n, for swales and filter strips generally ranges from 0.2-0.4 depending primarily on the flow rate, grass height, and blade density (Khan et al., 1992; King County, 1995).

The illustration and formulas shown in Figure 5-16 are helpful in making Manning's equation calculations and estimating design parameters.



Useful Geometric Relationships

$A = by + my^2$

$A = By$ (sheet flow)

$B = b + 2my$

$P = b + 2y(m^2 + 1)^{0.5}$

$P = B$ (sheet flow)

$m = \cot(\theta)$

Notation: B = top width, b = bottom width, 1/m = side slope, θ = side slope angle, y = flow depth, A = cross-sectional area, P = wetted perimeter

Figure 5-16. Dimensions of Trapezoidal Channels and Relevant Formulae.

For large drainage areas, vegetated swales may have to be off-line facilities to minimize flooding and/or resuspension of deposited sediments during large storms. Off-line facilities require inlet controls, such as flow splitters and energy dissipaters.

5.4.7.4 Maintenance Considerations

The primary maintenance activities for biofilters are periodic mowing, and litter, debris, and sediment removal. Control of noxious weeds may also be necessary. Grass clippings should be removed from the site so nutrients are not released upon decay. The optimal grass height is 4-9 inches (King County, 1998). For swales with underdrains, periodic inspection during wet weather may be necessary to determine if clogging is occurring. If the biofilter begins to show signs of scour, immediate remedial actions should be taken. This may include installation of straw, coconut fiber or geotextile rolls, or other erosion control fabric and possibly reseeding. During vegetation establishment and possibly during the dry season, irrigation and reseeding may also be necessary. The use of fertilizers or pesticides should be avoided.

5.4.7.5 Required Surface and Subsurface Area

Manning's equation should be used to estimate the top width of the channel using the design flow rate and the recommended flow depth. It is recommended that side slopes do not exceed 3H:1V (Horner et al., 1994). However, side slopes reinforced with erosion control matting or riprap may be acceptable. If the bottom width must be greater than about 10 feet to maintain the maximum depth and velocity, a swale divider is recommended. The length is based primarily on the recommended minimum residence time for biofilters of 5-9 minutes, but swales should generally not be less than 100 feet and filter strips should not be less than 4 feet (King County, 1995).

The subsurface area requirements are only a consideration if an underdrain will be installed.

5.4.7.6 Cost Considerations

Unless constructed in an existing channel or ditch, the construction of gassed swales typically requires excavation or regrading to form the swale cross-section. Construction of filter strips may not require excavation and regrading. Therefore vegetated swales tend to be more expensive than filter strips. However, both vegetated swales and filter strips can be easily incorporated into landscaping elements such as open spaces and parking lot stall dividers, and require little additional capital invest. In addition, swales that are "on-line" can reduce or eliminate the need for underground piping, which can lower costs (Liptan, 1995). The maintenance and upkeep of biofilters can also be included in general grounds maintenance activities and typically is about the same cost. There are insufficient data to determine differences in cost among the various grass swale and filter strip designs. Capital costs for swales including design and contingency costs have been estimated at approximately \$0.50 per ft^2 (U.S. EPA, 2002b). Compared to other TSCs, biofilters are one of the cheapest treatment practices, and annual costs are considered to be low.

5.4.7.7 Aesthetics

Biofilters are maybe the least obtrusive types of TSCs. In general, vegetated TSCs tend to look more natural and are more easily camouflaged than nonvegetated systems. Filter strips can be designed and constructed to be indistinguishable from a lawn or other landscaped area. Vegetated swales are a little harder to disguise because they typically incorporate a linear channel or depression. Even so, swales and filter strips are considered to have very little negative impact on aesthetics compared to other TSCs. Although lack of regular maintenance, ill-suited vegetation, inadequate pretreatment, and heavy trash and sediment loads can nullify all the aesthetic benefits of biofilters.

5.4.8 Ponds

Ponds are one of the most commonly used TSCs (U.S. EPA, 2002). In this document, the term "pond" is used to describe an open natural basin that acts as the detention component in detention ponds (extended detention ponds) or the retention component in retention ponds (wet ponds), as well as wetlands.[2] Ponds do not include sediment forebays or inlet and outlet structures, which are normally considered as integral parts of a detention basin or a retention pond. ISBs and inlet and outlet structures are discussed in Sections 5.4.1 and 5.6.6, respectively.

The primary UOPs that occur in ponds sedimentation and volume reduction. The popularity of ponds stems from their demonstrated ability to provide both water quality improvement, and flood control benefits by regulating discharges of collected water. Ponds can be located in parks and other recreational areas and provide multiple uses. They can be transformed into stormwater treatment wetlands in most cases with little additional cost (VSC, 1999).

5.4.8.1 Associated UOPs and Potential Design Enhancements

The main pollutant removal mechanism in ponds is sedimentation. A discussion of sedimentation is presented in Section 4.3.3.2, Sedimentation (Gravitational Separation). The extent of sedimentation that occurs depends on the residence time, particle size distribution, hydrodynamics and particle density. Typical residence times for detention ponds are 24, 48, and 72 hours with variable or constant draw down rates. The addition of extended detention/retention pools can increase overall treatment by providing increased detention time for low flows. A similar effect is achieved by using variable drawdown times which cause the bottom half of a pond to be detained longer than the top half.

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[2] *Note that wetlands are considered to be retention ponds that have been enhanced with vegetation, soils, and microbes. These TSCs are discussed in Chapter 5.5.*

The efficiency of sedimentation processes depend on the flow properties of stormwater through the pond. Short circuiting and resuspension of previously captured sediments can lower the overall efficiency and can be prevented with adequate design. Under ideal conditions, the flow through a pond would be plug flow, where slugs of water move through the pond in an orderly manner with little or no mixing. Plug flow ensures approximately equal detention for all volumes of water moving through the pond. However, plug flow rarely occurs in a pond; usually ponds even with long residence times behave as well-mixed reactors. Tracer studies are required to identify these hydrodynamics, and the pond should be designed according to analytical models such as Hazen's model or computational fluid dynamics models. Short circuiting results when there are "dead zones" in the pond and water pockets get trapped in quiescent areas, causing other volumes to take shorter paths through the pond. Selection of pond length-to-width ratios of greater that 2 minimize the incidence of short circuiting (U.S. EPA, 1999f). Resuspension of sediment is more likely to occur in dry ponds and ponds that are less frequently maintained. Frequent maintenance, careful inlet and outlet structure design including positioning of inlets and outlets above the pond bottom to provide space for captured sediment will minimize resuspension.

Other UOPs that occur in ponds include coagulation and flocculation as discussed in Section 4.5.2, and various biological processes as discussed in Section 4.4. While both detention and retention ponds are often vegetated, retention ponds usually have more biological activity due to the permanent pool and wetland vegetation around the pond perimeter and littoral zone.

Ponds also serve as excellent hydrologic or hydraulic control components by providing flow attenuation and/or flow control through detention storage, infiltration, and evaporation. Both evaporation and infiltration provide volume reduction. Infiltration has the additional benefit of reducing mass loading of dissolved pollutants. Infiltration and evaporation are discussed further in the Section 4.2.2, Volume Reduction/Minimization of Volume Increases.

Infiltration is more likely to occur in dry ponds, particularly if the pond is constructed on a permeable bed. In some locations, treatment prior to infiltration may be required for ponds with a significant infiltration component. The amount of volume loss through evaporation mainly depends on the surface area of the pond, wind speed, and relative humidity. In addition, evaporation in dry ponds is affected by the capacity of moisture-holding soils, which can dry out between events. In general, ponds with larger surface areas, including both wet surface area as well as temporarily inundated areas, will evaporate more water. The surface area of a pond can be increased by making the pond shallower while providing the same volume. Evaporation can also be enhanced by adding sprinklers or fountains or other such devices that increase air-to-water contact. Amending soils in dry ponds so they will hold more moisture will also increase evapotranspiration.

5.4.8.2 Recommended Pretreatment

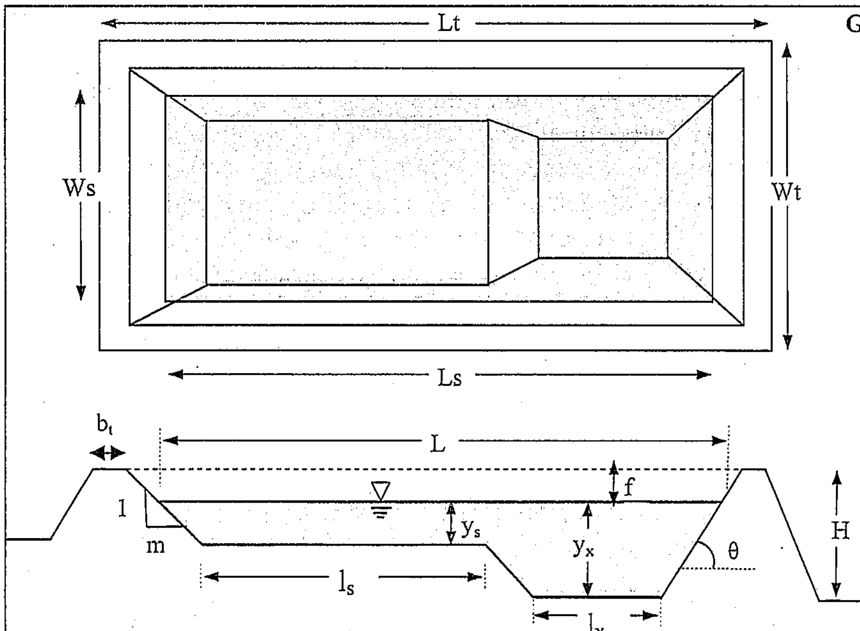
ISBs or sediment forebays are the most commonly used pretreatment TSCs for ponds. This form of pretreatment is so prevalent that the sediment forebay and the retention or detention pond are often considered as a unit. The sediment forebay serves multiple purposes. The primary purpose is to trap large solids and coarse sediment entering the system. The sediment bay attenuates the turbulence and the energy of the influent flow, and provides a uniform more streamlined flow profile. Other storage TSCs can be used as substitutes for the sediment forebay. Tanks and vaults will typically provide the same function as the sediment forebay but at a potentially higher cost. Biofilters can also be used as pretreatment for ponds for relatively low flows. Trash racks and screens can be incorporated into other pretreatment components, but should not be used as standalone devices. Large materials can damage inlet and outlet structures and cause resuspension of captured sediment. Larger objects that settle in the pond can also create aesthetic concerns.

5.4.8.3 Hydraulic Considerations

Short-circuiting is a fundamental design concern for stormwater ponds. It is caused by both the configuration of the pond and the density differences between the incoming water and previously contained water (Minton, 2002). Under ideal plug flow conditions, water is completely mixed in the direction perpendicular to flow and the hydraulic residence time is simply the volume of the pond divided by the flow rate through the pond. However in practice ideal plug flow conditions are rare and the actual residence time can be much less (Martin, 1988). Internal berms can be installed to achieve desired length to width ratios where the actual pond shape and/or inlet/outlet locations are restricted.

Embankments must be structurally sound to withstand hydrodynamic pressures at bank full depths. The high seasonal groundwater level must be below the pond bottom for dry ponds, otherwise the effects of buoyancy must be considered in the overall pond design. Overflow structures and spillways must be designed according to applicable design requirements (typically required to safely pass the 100-year flows) to protect against embankment breaching (King County, 1998; UDFCD, 1999).

Geometric design parameters are shown in Figure 5-17. Most jurisdictions have freeboard requirements of about 1-2 feet. Freeboard provides an extra safety margin during large events and is recommended.



Geometric Design Parameters

Lt = Total length of pond
Wt = total width of pond
Ws = top width at water surface
Ls = top length at water surface
H = outside berm height
l_s = length of storage pool
y_s = depth of storage pool
l_x = length of extended pool
y_x = depth of extended pool
b_t = berm thickness
m = side slopes
θ = side slope angle
f = freeboard

Figure 5-17. Important Geometric Design Attributes for Ponds.

5.4.8.4 Maintenance Considerations

The primary maintenance activities for ponds include removal of inlet and outlet obstructions after runoff events, maintenance of vegetation, periodic removal of accumulated sediment, periodic repair of pond berms, maintenance of access roads, and repair of spillways and inlet/outlet structures. Regular inspections and inspections after large storms are recommended. The importance of maintenance cannot be over emphasized as it can affect hydraulic performance as well as aesthetics.

5.4.8.5 Required Surface and Subsurface Area

At a minimum, ponds must be sized to meet the requirements of the governing authority. Most jurisdictions have rules for evaluating the "design volume" (e.g., the water quality volume requiring treatment). Using the design volume, a maximum depth, and an acceptable length to width ratio the required surface area can be easily calculated using geometric relations that are applicable to the cross sectional shape of the pond. The most common cross section shape assumed in the design of ponds is a trapezoidal cross section. Some of the frequently used geometric relations pertinent to trapezoidal cross-sections are shown in Figure 5-17.

5.4.8.6 Cost Considerations

The capital costs for ponds range from medium to high with retention pond costs typically being higher than detention ponds. For retention and detention ponds, the addition of multi-stage outlet structures for variable draw down times, spill ways, maintenance access ramps, multiple interior berms and extended detention/retention pools, can significantly increase construction and maintenance costs. The addition of impermeable liners in retention ponds and buoyancy prevention in detention ponds can also increase capital costs.

5.4.8.7 Aesthetics

Well designed and maintained ponds can enhance aesthetics. The aesthetic appeal of open water areas is a well known and water features are often used in landscape architecture. However, poorly designed and maintained ponds can develop unpleasant odors, breed vectors and/or lower neighboring property values.

Opportunities abound for improving pond aesthetics. Pond berms or embankments can be planted with grasses and shrubs with aesthetic value. Wet ponds can support various species of aquatic plants. Fountains and sprinklers, which increase evaporation, can be installed in ponds. The same elements can be incorporated into pond pretreatment TSCs. An aesthetically pleasing natural-shaped design combined with public safety elements, such as unobtrusive fences and signage, increases public acceptance. Fences can limit access, protect the public (small children), and reduce vandalism. In some jurisdictions, dry detention areas are used as parks or play fields with appropriate warning signs regarding their use during storms. Regular inspections and removal of accumulated sediment can mitigate odors and vectors.

5.5 Tertiary Enhancement TSCs

Tertiary enhancement treatment system components are features of a treatment system that enhance pollutant removals or hydrologic/hydraulic characteristics of the system by providing additional or more effective unit operations and processes; beyond or in addition to primary or secondary treatment. These TSCs should be considered if a level of performance higher than typically achieved by conventional treatment system components is desired, such as removing dissolved constituents and/or pathogenic organisms. Table 5-13 provides a list of tertiary enhancement TSCs and a relative effectiveness ranking of the unit operations and processes they may provide.

Table 5-13. Ranking of Tertiary Enhancments According to the UOP Effectiveness Level.

Category	Unit Operations and Processes	Tertiary Enhancements						
		Soils / Soil Amendments	Microbial Communities	Vegetation	Disinfection System	Sprinklers	Aerators	Flocculant / Precipitant Injection Sys.
Hydrology / Hydraulics Operations	Flow attenuation (hydrograph matching)	0	0	1	0	0	0	0
	Reduce total volume of runoff	5	0	2	0	1	1	0
Physical Operations	Screening	0	0	3	0	0	0	0
	Filtration	5	0	4	0	0	0	0
	Settling	0	0	0	0	0	0	5
	Flotation and Skimming	0	0	0	0	0	0	1
	Sorption processes (absorption)	4	0	2	0	0	0	0
	Volatilization / Aeration	1	0	2	0	5	5	0
	Physical agent disinfection (heat and ultra-violet radiation)	0	0	0	5	0	0	0
Biological Process	Microbially-mediated transformations	5	5	3	0	0	0	0
	Uptake and storage	3	4	2 to 5	0	0	0	0
Chemical Processes	Sorption processes (adsorption)	4 to 5	0	3 to 4	0	0	0	0
	Flocculation / Precipitation	0	0	0	0	0	0	5
	Chemical agent disinfection (ozone, chlorine and chlorine compounds)	0	0	0	5	0	0	0

0 - TSC does not include UOP or is not recommended due to operations and maintenance issues (e.g., a filter should not be used to screen)
1 - TSC includes UOP, but likely provides poor effectiveness
2 - TSC includes UOP, but likely provides marginal effectiveness
3 - TSC designed to include UOP, but other TSCs may be more effective
4 - TSC is specifically designed to include UOP, but design not optimal
5 - TSC is specifically designed to include UOP and is among the best alternatives available

5.5.1 Soils and Soil Amendments

Soils in terrestrial and wetland environments have multiple pollutant removal and hydrologic functions. These functions include sorption or precipitation of metals, phosphorus and organics; serving as a substrate and nutrient supplier for microorganisms; supply of growth factors for plants; infiltration; moisture retention; and evapotranspiration. Amendments are substances added to "poor" soils as design enhancements to improve one or more physical or chemical properties. This section summarizes factors that affect the use and performance of soil in stormwater treatment systems and discusses ways to improve soils through the use of soil amendments. Also refer to Section 3.2.2, Soil Characteristics.

5.5.1.1 Formation and Classification

Soil formation is influenced by factors such as climate, parent materials, biota, topography, and time. Downward movement of mineral and organic material creates a soil profile with layers of distinct physical, chemical, and biological properties, known as horizons. Horizons provide important clues about major inputs, transformations, movements and losses from the soil (Ashman and Puri, 2002). The six genetic Master soil horizons are designated using capital letters, and are summarized in order of decreasing depth in the soil profile in Table 5-14.

Table 5-14. Master Soil Horizons Used to Classify Soil Formation.

O	Dominated by organic material. Some soils are saturated with water for long periods or were once saturated but are now artificially drained; others have never been saturated. Some O layers consist of undecomposed or partially decomposed litter, such as leaves, needles, twigs, moss, and lichens, that has been deposited on the surface; they may be on top of either mineral or organic soils. Other O layers, are organic materials that were deposited under saturated conditions and have decomposed to varying stages.
A	Topmost mineral horizon. Characterized by a mixture of humic and mineral material; created by either an accumulation of organic matter that has moved down from the O horizon, or is generated within the horizon by root decay. Horizon exhibits obliteration of all or much of the original rock structure. Soils are typically darkened by the organics. Often coarse in texture as finer particles are lost due to translocation to lower horizons or erosion. The majority of biological activity occurs in this horizon, including being the location of the most roots of grasses and shrubs.
E	Mineral horizon. The main feature is loss of silicate clay, iron, aluminum, leaving a concentration of sand and silt particles. Horizon exhibits obliteration of all or much of the original rock structure. Usually lighter in color than A or B horizon. Residual material is resistant to degradation (e.g., quartz). Common in soils developed under forests but rare in grasslands.
B	Zone of accumulation from horizons closer to surface. In humid regions, maximum concentrations of silicate clays, and iron and aluminum oxides. In arid and semi-arid regions, calcium carbonate (limestone), calcium sulfate (gypsum) and related salts accumulate.
C	Unconsolidated parent material. May have been created by disintegration of rock in the R horizon below, or transported to the site. Generally but not always is the source of inorganic material for the upper layers through weathering and decay. Relatively little biological activity occurs.
R	Consolidated parent material with little evidence of weathering (bedrock). Granite, basalt, quartzite and indurated limestone or sandstone are examples of bedrock. Layers are cemented making excavation difficult. Bedrock that may contain cracks that may be coated or filled with clay or other material.

Adapted from Brady and Weil (2000), Minton (2002) and Soil Survey Division Staff (1993).

Individual soil horizons may vary from a fraction of an inch to many feet in depth (Pittenger, 2002). A typical natural soil profile (not all horizons necessarily present) will extend to a depth of about 3-6 feet (0.9-1.8 m). Soil profiles in arid and semi-arid climates are typically less developed than soils in more humid climates because less water percolates through them. For example, western surface horizons contain more calcium, potassium, phosphate and other nutrient elements than do soils in more humid climates because these nutrients have not been leached through the profile.

Due to prior activities in developed areas, soil horizons may not be pristine. Stormwater treatment facilities are frequently placed in B Horizons because the development of facilities typically removes A and/or O Horizons. The soils may therefore lack organic material, which is important for sorption processes and biological processes (Minton, 2002).

The type and location of horizons can be used to further classify soils. The U.S. soil classification system separates soils into 12 orders based on the physical, chemical, and biological properties of the soil. Taxonomic characteristics relevant for stormwater treatment include (Brady and Weil, 2000):

- soil moisture and temperature status throughout the year
- texture and structure
- pH
- concentration of organic matter, clays, and iron and aluminum oxides, and
- cation exchange capacity.

Soil orders are summarized in Table 5-15 and a map showing their distribution in the U.S. can be accessed at http://soils.usda.gov/technical/classification/taxonomy.

Table 5-15. Description and Distribution of United States Soil Orders.

Order	Description	% of U.S.
Andisols	Formed on volcanic ash and cinders. Typically young soil, not weathered. Tend to have large amounts of humus (7% to 12% organic carbon). Andisols must have andic soil properties in a cumulative thickness of 35 cm or more within the top 60 cm of soil. Andic properties include: 1) low bulk density, 2) potential for wind erosion, 3) amorphous iron and aluminum clays, 4) high macroporosity with rapid drainage, and 5) low soil strength when mechanically disturbed. Amorphous clays have a high cation exchange capacity. Andisol soils rapidly sorb or precipitate phosphorus due to high concentrations of iron and aluminum clays.	1.7
Alfisols	Usually form under forests and brush cover in cool to warm humid areas. Characterized by an accumulated layer of silicate clay from the A horizon. High cation exchange capacity and fertility. Medium to high concentrations of calcium and magnesium. Good water retention capacity.	13.9
Aridisols	Formed in arid climates. May have calcium carbonate (lime) layers, salt or calcium sulfate (gypsum) accumulation, and low organic matter. Deficiencies of zinc and iron, and to as lesser extent, manganese and copper are common.	8.3
Entisols	Extremely diverse group, but all show little evidence of mature soil formation. Absence of distinct soil horizons (e.g., young soils, parent material resistant to weathering). Soils range from deep sand to stratified river deposited clays, and from recent volcanic ash deposits (or erosion exposed surfaces) to dry, arid lake beds.	12.3
Gelisols	Present in areas of high altitude and permafrost (layer of material that remains at temperatures below 0°C for more than two consecutive years). Young soils with little profile development due to cold temperatures. Often found in wet environments. High in organic content. Found in Alaska only	8.7
Histosols	Organic soils formed in wetland environments (anaerobic). Most prevalent in cold climates up to the limit of permafrost. Organic soils have high cation exchange capacity, high water-holding capacity on a mass basis, and low bulk density, compared to mineral soils. Organic soils typically have a lower stock of some plant nutrients (e.g., potassium, copper) than mineral soils.	1.6
Inceptisols	Weakly developed (beginning of B horizon), but more weathered than Entisols. Soils are variable and may develop in almost any climate.	9.7
Mollisols	Dark-colored soils of grasslands and some hardwood forests. Deep, dark-colored A horizon, dominated by base cations (particularly calcium). High organic matter. Fertile soils.	21.5
Oxisols	Most extensively weathered soils. Typically found in hot and humid, tropical or subtropical climates, usually under hardwood forests. Hydrous metal oxide and kaolinite clays dominate. Low cation exchange capacity. Resistant to compaction. Easily binds phosphorus due to high concentration of iron and aluminum oxides.	< 0.1
Spodosols	Found under acidic forest vegetation. Sandy soils. Occur in moist to wet areas, commonly in cold or temperate climates, but also form in some tropical and subtropical areas such as Florida. Mineral soils with subsurface accumulation of organic matter, and accumulation of aluminum oxides, with or without iron oxides. Low cation exchange capacity due to acid leaching.	3.5
Ultisols	Formed in warm, humid climates. Form under forest vegetation, but may also form under savanna or wetland vegetation. Intensive weathering leaches base cations, and accumulates clay (kaolinite dominates) in B horizon.	9.2
Vertisols	Soils with 30% or more clay that develop from limestone, basalt or other calcium and magnesium rich parent materials. Found mostly in subhumid to semiarid environments in warm regions (generally occur where the climate features dry periods of several months). Native vegetation is grassland. The clays shrink and swell depending on moisture conditions, making cultivation difficult. Soils are often characterized as being either too wet or too dry. High cation exchange capacity and good organic matter content.	2.0

Adapted from Brady and Weil (2000), Miller and Gardiner (1998), Minton (2002), Soil Survey Staff (1999).

5.5.1.2 Soil Texture And Structure

Soil texture refers to the proportion of sand, silt, and clay mineral particles in soil. Sand, silt, and clay particles are defined by USDA based on particle size as shown in Table 5-16.

Table 5-16. USDA Soil Particle Size Texture Classes.

Soil Type	Particle Size (mm)
Sand	> 0.05-2.0
Silt	0.002-0.05
Clay	< 0.002

Soil texture affects nutrient and water-holding capacities, infiltration rates, and degree of soil aeration. In general, coarse-textured soils hold relatively little water, drain rapidly, and are low in fertility. Fine-textured soils hold relatively large amounts of water, may be poorly drained or well drained depending on their structure, and can be high or low in fertility depending on the types of clays present. Finer textured soils can be more difficult to manage because their pore sizes can be too small for suitable water percolation and aeration (Pittenger, 2002).

Soils are usually a mixture of sand, silt, and clay (as well as organic material). USDA uses textural classes that are based on the relative amounts of each size fraction. The textural triangle is a graphical representation of the twelve soil textural classes, as shown in Figure 5-18. The area occupied by clays dominates the textural triangle, reflecting the degree to which clay influences soil properties. Organic matter is not included in the textural triangle. Typical infiltration rates for the different textural classes are provided in Table 5-17. Infiltration rates may be used to size infiltration systems.

A sandy loam, loamy sand or loam texture is best for bioretention and other infiltration facilities. Loamy soils have good plant growth characteristics because of adequate nutrient holding capacity, and higher hydraulic conductivity and gaseous diffusion rates. Clays and silts are important for sorption of dissolved pollutants, but can reduce infiltration rates in high amounts. Clay soils may function as aquitards in wetlands, increasing the length of time wetland substrates are capable of supplying water to plants during seasonal drawdowns (USACE, 2000). For plant growth and microbial activity, soil temperatures warm up more quickly in spring with coarser soils, as warming air can circulate better through these soils.

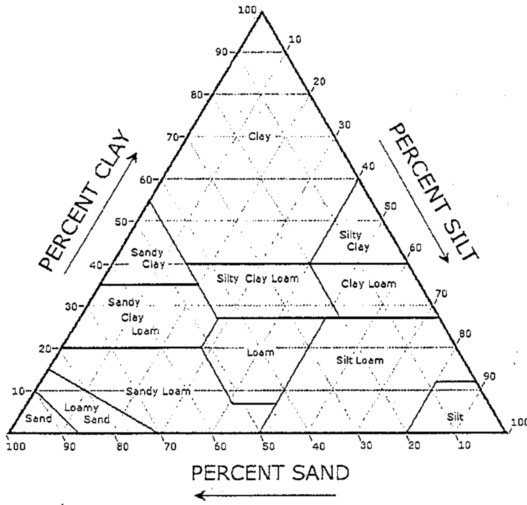


Figure 5-18. Soil Textural Triangle.
Source: U.S. Department of Agriculture (USDA, 2003).

Table 5-17. Typical Infiltration Rates for Soil Textural Classes.
Reprinted with permission (WEF and ASCE, 1998).

Soil Textural Class	Infiltration Rate	
	mm/h	in./hr
Sand	200	8.0
Loamy Sand	50	2.0
Sandy Loam	25	1.0
Loam	12.7	0.5
Silt Loam	6.3	0.25
Sandy Clay Loam	3.8	0.15
Clay Loam and Silty Clay Loam	< 2.3	< 0.09
Clay	< 1.3	< 0.05

Soil particles combine into aggregates formed by wetting and drying, root penetration and freezing, and are stabilized by binding forces of clays and organic matter. Soil structure refers to the size and form of aggregation. Structure affects movement of water, air, and plant roots within soils. Formation of aggregates modifies the basic textural characteristics of a soil. Soil structure types include: platy (thin, horizontal), prismatic (long vertical faces), columnar (like prismatic but rounded tops), blocky (polyhedrals, angular or subangular), granular (small spheres or polyhedral units, with faces that are not casts of adjoining peds), and structureless (massive or single grain). The type, size, and definition of aggregates found in a particular soil varies with texture, composition, depth, management and mode of formation.

The combined effects of soil texture and structure determine the range of soil pore sizes. Bulk density is a measure of the total mass (soil plus air) of a unit volume of dry soil. Usually as particle size decreases, bulk density decreases. Therefore, fine-textured soils such as silt loams, clays, and clay loams generally have lower bulk densities than sandy soils. Organic soils have lower bulk densities than mineral soils. Deeper in the soil profile, bulk densities are generally higher, as a result of lower organic matter, less aggregation, fewer roots and soil compaction (Brady and Weil, 2000). Soils with higher bulk densities have less pore space. High bulk densities result in poor soil aeration, slow movement of nutrients and water, and buildup of toxic gases and root exudates.

Soil porosity is related to bulk density as follows:

$$\text{Porosity }\% = \left[1 - \left(\frac{\text{Bulk density}}{\text{Particle density}}\right)\right] \times 100$$

Porosity is important because it determines how much water can exist in a saturated soil column. Macropores (larger than about 0.05 mm) allow for ready movement of air, and water drainage. They are also large enough to accommodate plant roots and microorganisms. Micropores (smaller than about 0.05 mm) are usually filled with water, and water movement is slow (much of the water retained in these pores is not available to plants). Micropores are also too small to permit much air movement. Fine textured soils, especially those without a stable granular structure, may have a preponderance of micropores, thus allowing relatively slow gas and water movement, despite the relatively large volume of total pore space. Aeration may also be inadequate for root development and for sustaining aerobic microorganisms (Brady and Weil, 2000). The optimum condition for plant growth and microorganisms is for soil to have a combination of micropores and macropores.

5.5.1.3 Chemical Composition

Soil is composed of mineral and organic matter fractions. Organic soils, or Histosols, are defined by the U.S. Soil Conservation Service as soils that are saturated with water and have greater than 18% organic matter (if mineral fraction is greater than 60% clay), greater than 12% organic carbon (with no clay in the mineral fraction), or 12-18% organic carbon (0-60% clay in the mineral fraction); or soils that are never saturated for more than a few days at a time and have more than 20% organic carbon (e.g., terrestrial soils that may form in tropical areas). All other soils are defined as mineral (Brady and Weil, 2000; Kadlec and Knight, 1996; Miller and Gardiner, 1998).

Primary minerals persist with little change in composition from formation, and include quartz, micas and feldspars; they are prominent in the sand and silt fractions. Secondary minerals are formed by weathering of less resistant minerals, and include silicate clays, and iron oxides; these minerals dominate in clay, and in some cases, silt fractions (Brady and Weil, 2000). The most reactive minerals are clays, and oxides of iron, manganese, and aluminum; both inorganic and organic pollutants readily sorb to these clay minerals (Minton, 2002).

Organic matter consists of biomass (living organisms), carbonaceous remains of organisms that once lived in the soil, and organic compounds produced by current and past metabolism in the soil. The organic content varies regionally across the U.S., generally increasing with increasing annual rainfall and decreasing temperature (Minton, 2002). Organic matter in soil consists mainly of carbon (50-55%) and nitrogen (7-8%). Typical well-drained mineral soils contain 1-6% organic matter by weight (Brady and Weil, 2000; Pittenger, 2002).

The benefits of organic matter in the soil are numerous (Miller and Gardiner, 1998; Brady and Weil, 2000). It is the source of 90-95% of the nitrogen in unfertilized soils. Organic matter can be the major source of both available phosphorus and sulfur when humus is present at 2%. Amendments of organic material also improve soil structure by stabilizing mineral aggregates (directly or indirectly through microbial action). Humus has colloidal properties and negatively charged carboxylic (-COOH) and phenolic (-OH) surface functional groups that participate in ion exchange or chelation of cations, and sorption of complex organic compounds. Humus buffers the soil against rapid changes in acidity, alkalinity, salinity, and degradation by pesticides and heavy metals. It also increases the available water content in sandy soils, increases both air and water flow rates through fine-textured soils, and supplies carbon to soil microorganisms. Surface organic matter can insulate the soil, retarding heat flow between the air and soil. In hot climates or on hot days, this benefits plant roots, but in cool climates, surface organic matter slows soil warming in the spring.

The carbon to nitrogen (C:N) ratio of organic matter is important because high C:N ratios may cause temporary shortages of nitrogen available for plants in soil. The high concentration of carbon added initially increases the microbial population. However, nitrogen quickly becomes limited, and microorganisms must compete with plants for available nitrogen. Thus the C:N ratio of organic mater helps estimate the rate of decay and the rate at which nitrogen can be made available to plants. The C:N ratio of organic matter in surface soils generally ranges from 8:1 to 15:1 The ratio is typically lower in subsurface soils (Brady and Weil, 2000). Ratios of 20:1 or less have sufficient nitrogen to supply microorganisms and also release nitrogen for plants. C:N ratios in the range 20:1 to 30:1 supply sufficient nitrogen for microorganisms but not enough to release much nitrogen for plants in the first few weeks after incorporation. Increased decomposition of the organic matter will decrease the C:N ratio. The incorporation of organic amendments such as undecomposed leaf litter, straw, or sawdust should be avoided due to their high C:N ratio. If materials with a high C:N ratio are incorporated into soils, an inorganic nitrogen fertilizer may also be incorporated to compensate for this effect. Adding materials with a high C:N ratio to the surface as mulch generally does not result in a nitrogen deficiency (Pittenger, 2002).

A fertile soil contains macronutrients (primary and secondary nutrients) and micronutrients that are necessary for plant and microbial nutrition. Primary nutrients are nitrogen, phosphorus and potassium. Nitrogen is most often the limiting nutrient in plant growth. Secondary nutrients are calcium, magnesium, and sulfur. Macronutrients vary for plants and microorganisms, but typically include boron, chlorine, cobalt, copper, iron, manganese, molybdenum, nickel and zinc. Organic matter supplies nitrogen, phosphorus, sulfur, boron and molybdenum. Correlations between soil organic matter and concentrations copper, molybdenum, and zinc have also been noted (Brady and Weil, 2000). Chlorine is added to soil in considerable quantities each year through rainfall. Refer to Section 4.4.2, Uptake and Storage, for additional information.

5.5.1.4 Factors Affecting Phosphorus Solubility and Fixation

Depending on the desired function and goals of the stormwater treatment system, it may be advantageous to stabilize phosphorus through soil sorption, or solubilize phosphorus, making it available for plant growth and microbial metabolism. Phosphorus is essential for photo-synthesis, nitrogen fixation, early growth and root formation (among other functions), and is also a component of andenosine triphosphate (ATP) (the molecule that drives metabolism) and DNA. Phosphorus availability is very dependent on the concentrations of certain cations and clay minerals in soil, as well as pH and redox potential.

Plant-available (i.e., phosphate) phosphorus is generally low in soils (about 0.01% of total phosphorus), particularly in many sandy, low-humus soils. Phosphorus may be bound to organics, iron, aluminum, or calcium. Organic phosphorus is generally more soluble than inorganic phosphorus, and is the major source of plant-available phosphorus in most soils. In acid soils, phosphate sorbs to the surfaces of insoluble hydrous oxides of iron, aluminum and manganese, and to 1:1-type silicate clays. Calcium phosphate compounds form in alkaline soils. Generally phosphate availability is highest at a pH of 6.0-7.0, and is decreased at more acidic or alkaline pH values. Highly weathered, acid mineral soils such as Ultisols and Oxisols are composed of 1:1 clay minerals like kaolinite, and aluminum and iron oxide. These soils have a higher capacity to fix phosphorus than less weathered mineral soils that develop in more temperate climates (Mollisols and Vertisols), which are dominated by 2:1 clay minerals.

Redox potential also affects the solubility of phosphorus. Under prolonged anaerobic conditions, iron phosphate compounds may become more soluble as iron is reduced from ferric to ferrous forms. This effect may occur in wet ponds, for example, where a shift to anaerobic conditions from higher than normal water levels can result in the export of phosphorus from the system.

5.5.1.5 Salt

Saline soils, which develop in arid climates, contain excessive soluble salts (e.g., chlorides, sulfates, and nitrates) and a high pH. High salt concentrations may also occur in cold climates from the use of deicing agents. Water tends to diffuse from plant cells into saline soils, causing plant dehydration and wilt. Therefore, salt-tolerant plants should be used where saline soils occur. Saline soils may need to be overirrigated with good quality water to leach excess salts from the root zone if less salt-tolerant plants are being grown.

Sodic soils typically have a pH between 8.5 and 10.0 due to hydrolysis of sodium carbonate. High concentrations of sodium are toxic to most plants and microorganisms. Sodic soils also have poor physical characteristics and low permeability. The electrical conductivity provides an estimate of soluble salts. A saline soil has an EC of 4.0 dS/m and a sodium adsorption ratio (SAR) less than 13. The SAR measures the exchangeable sodium percentage in soil. Sodic soils have a SAR equal to or greater than 13, but a low salt content (Miller and Gardiner, 1998).

5.5.1.6 pH

Soil pH determines the fate of many pollutants, including their decomposition, chemical speciation, and migration from soil to surface water or groundwater. Soil pH determines the speciation of metals and phosphorus, which affects the bioavailability of nutrients and toxics to plants and animals, and can influence microbial activity. Redox potential is also affected by pH, and tends to decrease as pH increases. Other pH dependent factors are discussed elsewhere in this chapter.

The pH of organic soils tends to be lower than mineral soils, due to the release of acidic compounds by soil microorganisms, and the higher number of cation exchange sites. Also, clays have the potential for developing into highly buffered acidic soils, due to the large number of cation exchange sites, compared to sand and silt. Acidity dominates in humid areas, and alkalinity is more prevalent in arid and semi-arid regions. This is because there is less leaching of base-forming cations (calcium, magnesium, etc.) in areas with low rainfall. Soils have a natural tendency to become more acidic over time, even under natural conditions. Human influences such as acid rain, tillage, fertilization, and irrigation practices have lowered soil pH values.

The effect of pH on nutrient availability is shown in Figure 5-19. Moderately to very acidic soils may contain inadequate levels of plant-available N, P, K, S, Ca, Mg, and Mo, but may also contain toxic levels of Al and Mn. Very alkaline soils are deficient in plant-available N, P, Fe, Cu, Zn, and Mn but also contain excessive concentrations of soluble salts or sodium, which are toxic to plants. Bacterial activity is significantly reduced at low pH, while fungi can flourish in both acidic and alkaline conditions. A soil pH in the range of 5.5 to 7.5 provides the most satisfactory level of nutrients for most plants (Pittenger, 2002).

Acid soils can also be regarded as aluminum soils. Aluminum ions are soluble at low pH, and concentrations of aluminum that are toxic to plants and microbes may result. Manganese may also reach toxic concentrations in acid soils.

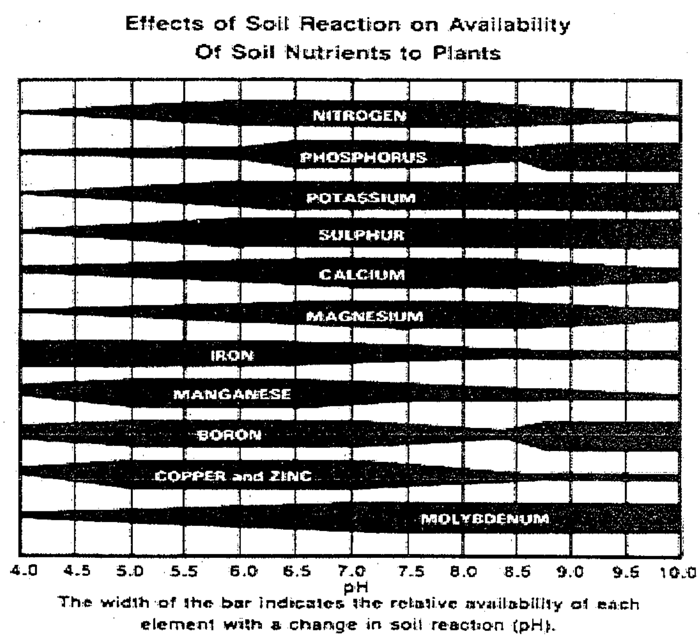


Figure 5-19. Nutrient Availability as a Function of pH.
Reprinted with permission from the Cornell Cooperative Extension (2005),
Http://Www.Cce.Cornell.Edu/Suffolk/Grownet/Home-Gardening-General/Lime.Gif

5.5.1.7 Redox Reactions

Redox reactions are chemical transformations involving the transfer of electrons. Terminal electron acceptors are oxidizers, and electron donors are reducers. The combined effect of redox potential and pH governs speciation and bioavailability of nutrients and toxics to a large degree. Respiration by plants and soil microorganisms is also a redox process. All plants and most soil organisms require oxygen for respiration. Aerobic respiration uses oxygen as the terminal electron acceptor during the oxidation of carbon to obtain energy for metabolism. Aerobic respiration occurs in terrestrial soils and in the upper few centimeters of wetland soils. When soils are flooded, anaerobic conditions may develop below the soil surface, and redox potential may decrease with soil depth. Anaerobic pockets may also occur in terrestrial soils, if microbes consume all of the oxygen during consumption of organic matter. As the redox potential decreases, some microbes can replace oxygen with other constituents during respiration. These constituents include nitrate, manganese, iron, sulfur, and methane. Certain bacteria mediate some of these redox reactions to obtain energy. Reactions of interest that occur under various redox conditions in soil (and aerobic surface water) are summarized in Table 5-18.

Table 5-18. Examples of Redox Reactions of Interest.

Matrix	Redox Condition	Dissolved Oxygen [mg/L]	Redox Potential [mV]	Representative Processes
Water	Aerobic	> 3	> 300	Precipitation of calcium carbonate and calcium phosphate (pH > 8.5) Precipitation of aluminum and iron phosphates Nitrification Oxidation of ferrous iron and Mn (II) Oxidation of organic compounds (carbon) and mineralization
Soil	Aerobic	1to 3	> 300	Nitrification Precipitation of calcium, aluminum and iron phosphates Bacterial degradation of organics
	Facultative	< 1	-100 to 300	Denitrification Reduction of ferric to ferrous iron (with loss of phosphorus) Reduction of Mn (IV) to Mn (II) Oxidation of sulfide to sulfate Bacterial degradation of organics
	Anaerobic	0	< -200 to -100	Reduction of sulfate to sulfide Precipitation of metal sulfides, hydrogen sulfide formation Bacterial degradation of organics Methanogenesis Reduction of nitrogen gas to ammonium Formation of methylmercury

Adapted from Minton (2002) and Stumm and Morgan (1996).

5.5.1.8 Colloidal Surface Charge and Cation Exchange Capacity

Various clay-sized particles (clay minerals, hydrous oxides of iron and aluminum, and amorphous minerals) and organic matter (humic compounds) are colloids. The presence of colloidal particles largely controls the storage and release of chemicals such as plant nutrients and metal toxins in soil. Colloidal particles have positively or negatively charged surface functional groups that attract ions to their surfaces. In most soils of temperate regions, soils have a predominately negative surface charge that attracts cations and repels anions, such as nitrate. Cation exchange may occur in response to concentration changes in soil pore water. The relative strength of attraction of cations to colloidal surfaces depends on the following factors (Ashman and Puri, 2002; Miller and Gardiner, 1998):

- Cation charge—affinity increases with charge.
- Concentration and pH—affinity increases with concentration. Hydrogen and aluminum ions dominate in acid soils and calcium and magnesium dominate in neutral to moderately alkaline soils. In humid regions, calcium, aluminum, and hydrogen dominate and in arid regions, calcium, magnesium, and potassium dominate. Metal cations dominate in mineral soils, while hydrogen dominates in organic soils.
- Hydration state/size—the less hydrated the cation is, the greater the chance it will be sorbed. Hydrogen, due to its small size, is exchanged much more strongly than would occur if based on cation charge alone.

Therefore, the strength of attraction of common cations in soil is:

$$\xrightarrow{H^+ = Al^{3+} > Ca^{2+} > Mg^{2+} > K^+ = NH_4^+ > Na^+}$$

Decreasing strength of attraction

Loosely held cations are more readily available for uptake by plants.

The Cation Exchange Capacity (CEC) measures the quantity of exchangeable cations sites per unit weight of dry soil (typically expressed as milliequivalents per 100 grams of soil or moles per kilogram). The CEC is important because it evaluates the soil's ability to store and supply plants with dissolved nutrients and to sorb metal pollutants. The CEC can be determined by standard analytical methods, or estimated if soil type is known.

The CEC of soil depends on the organic matter (humic compounds) content, and the amount and type of clay present. CEC as a function of soil texture and colloid type (i.e., chemical composition) is summarized in Table 5-19.

Table 5-19. Cation Exchange Capacity (CEC) and Surface Charge of Various Soil Types.

Soil Texture	CEC (centimoles/Kg)		
Sand	1-5		
Fine sandy loam	5-10		
Loams and silt loam	5-15		
Clay loam	15-30		
Clay	> 30		
Colloid Type	**CEC (centimoles/Kg)**	**Permanent Charge (%)**	**Variable Charge (%)**
Humus	100-300	10	90
Vermiculite	80-150	95	5
Smectite	60-100	95	5
Illite (Fined grained mica)	15-25	80	20
Kaolinite	2-8	5	95
Sesquioxides (Metal oxides and hydrous oxides)	0-3	0	100

Adapted from Miller and Gardiner (1998) and Brady and Weil (2000).

The CEC of organic colloids is pH dependent. The pH dependence of CEC for clays is affected by the source of the surface charge. Depending on the type of colloid, it may have both a permanent and variable charge, or mainly a variable charge. Generally, 2:1 clays (silicate with a mineral structure of two layers of silica to one layer of aluminum hydroxide) have both a permanent and variable charge. Hydrous oxides of aluminum and iron, 1:1 clay minerals (mineral structure of one layer of silica to one layer of aluminum hydroxide), and humus have mainly variable charge. Permanent surface charge is not affected by pH, and is almost always negative. Variable charge can be positive, negative, or zero, depending on soil pH (positive charges occur at low pH values) (Ashman and Puri, 2002). As pH increases, pH-dependent CEC also increases. Generally this effect occurs above pH of 6; the CEC is generally constant below this pH due to the effect of the permanent charge.

The correlation between CEC and capacity of soil to remove dissolved metals in stormwater treatment systems is not well defined. Stronger correlations have been found with the content of organic matter and clay in soil. The lack of correlation with the CEC may be due to variation in the metal concentration of the soil prior to exposure to stormwater and also in part to the different measurement methods used for CEC (Minton, 2002).

5.5.1.9 Hydraulic Considerations

Factors such as hydraulic conductivity, porosity, and field capacity are discussed in Section 3.2.2, Soil Characteristics. Other hydraulic considerations are discussed in this chapter under Soil Texture and Structure.

5.5.1.10 Soil Amendments

Prior to adding amendments, soils should be sampled and tested to evaluate the amendments needed and the appropriate amounts required. Amendments appropriate for stormwater treatment systems are summarized in Table 5-20.

Table 5-20. Functions of Various Soil Amendments.

Amendment	Functions
Compost	Improves soil structure and permeability Provides nutrients in a slow release form to vegetation and microorganisms Lowers pH Improves water-holding capacity Provides sorption sites for dissolved pollutants
Fertilizers	Provides nutrients needed by plants such as N, P, K, S, and Fe (slow release fertilizers are best). Test soils first to ascertain need
Lime (calcium carbonate, calcium hydroxide, calcium oxide, or dolomite)	Increases pH Adds calcium and magnesium Makes phosphorus in acidic soils more available to plants Reduces soluble iron and aluminum
Gypsum	Adds calcium and sulfur without modifying pH Improves infiltration capacity of sodic soils
Elemental sulfur	Lowers pH Reclaims sodic soils

The addition of compost from an appropriate source can significantly improve several chemical and physical soil properties. Compost specifications are summarized in Table 5-21.

One limitation of compost use is that leaching may occur initially after the addition, resulting in export of nutrients such as nitrogen and phosphorus, as found in one study (U.S. EPA, 1999g). However, the amount of leaching was shown to decrease over time.

Table 5-21. Specifications for Compost.

Parameter	Range	Parameter	Range
pH	5.0-8.5	<u>Metals</u>	
Soluble Salt Concentration	< 10 dS/m	Arsenic	< 41ppm
Moisture	30-60%	Cadmium	< 39 ppm
Organic Matter	30-65% dry weight basis	Copper	< 1,500 ppm
Particle Size	98% pass through ¾" screen or smaller	Lead	< 300 ppm
Stability (carbon dioxide evolution rate)	> 80% relative to positive control	Mercury	< 17 ppm
Maturity (seed emergence and seedling vigor)	> 80% relative to positive control	Molybdenum	< 75 ppm
Physical contaminants	< 1% dry weight basis	Nickel	< 420 ppm
<u>Pathogens</u>		Selenium	< 100 ppm
Fecal coliform	< 1,000 MPN per gram, dry weight basis	Zinc	< 2,800 ppm
Salmonella	< 3 MPN per 4 grams, dry weight basis		

Source: Low Impact Development Center Soil Amendment, Compost Specification (http://www.lowimpactdevelopment.org/epa03/soilamend.htm)

5.5.2 Microbes (Bacteria, Algae, Fungi)

Beneficial microbes in stormwater treatment systems include primarily bacteria, fungi, and algae. These beneficial microbes are not to be confused with pathogenic organisms, which are pollutants targeted for removal. Beneficial microbes are involved in uptake and storage processes, and also mediate a number of chemical transformations that affect the removal of dissolved metals, nitrogen species (e.g., ammonia, nitrate), and organic compounds. Some microbes of interest are summarized in Table 5-22. The largest concentrations of microbes are found in the aerated zones of soils, such as the top layers (0.3 m) and the root zone. This typically corresponds to the A and O soil Horizons.

Bacteria are unicellular organisms with cells without a distinct nucleus. Their numbers tend to be high in soil, as well as their diversity. Algae are microscopic organisms that carry on photosynthesis. Algae are typically found near the surface of terrestrial ecosystems. In aquatic environments, algae attach to various surfaces, such as vegetation or stones, or form mats on the water surface (free living species). Fungi are organisms without the ability to use the sun for energy. Rather, they live on dead or living plant and animal tissue. Common fungi include yeasts, molds, mildews, smuts, rusts, and mushrooms. Fungi are vigorous decomposers of organic matter.

Table 5-22. Some Microbes of Interest in Stormwater Treatment Systems

Microbe Function	Oxygen Needs and Energy Sources	Representative Genera
Oxidation of simple organic compounds	Aerobic heterotrophic	Numerous bacteria, fungi, and actinomycetes
Degradation of xenobiotic compounds	Aerobic or anaerobic heterotrophic	Specific microorganisms are required for different xenobiotic compounds. Refer to the PHYTOPET database.
Nitrification	Aerobic autotrophic, heterotrophic	Ammonium oxidizing bacteria: *Nitrosomonas, Nitrosospira, Nitrosococcus, Nitrosolobus, Nitrosovibrio* Nitrite oxidizing bacteria: *Nitrobacter, Nitrosococcus*
Denitrification	Facultative heterotrophic, autotrophic	Bacteria including *Achromobacter, Acinetobacter, Agrobacterium, Alcaligenes, Arthrobacter, Bacillus, Micrococcus, Rhizobium, Pseudomonas, Thiobacillus, Vibrio*
Nitrogen Fixation (symbiotic and non-symbiotic with plants)	Bacteria are aerobic, facultative, or anaerobic (depends on organism) heterotrophic or photoautotrophic; cyanobacteria are aerobic photoautotrophic (and obtain energy from photosynthesis)	Cyanobacteria (some) such as *Anabaena, Anabaenopsis, Collema;* bacteria such as *Rhizobia, Bradyrhizobia, Frankia, Azospirillum, Desulfovibrio, Azotobacter, Derxia, Beijerinckia, Rhodospirillum, Pseudomonas*
Iron Oxidation	Aerobic, facultative autotrophic and heterotrophic	Bacteria including *Thiobacillus ferrooxidans, Ferrobacillus ferroxidans, Leptothrix*
Iron Reduction	Anaerobic heterotrophic	Bacteria including *Geobacter, Desulfurmonas, Pelobacter*
Sulfur Oxidation	Aerobic or anaerobic autotrophic or heterotrophic	Bacteria including *Thiobacillus, Thiomicrospira, Sulfolobus.* Fungi and actinomycetes including *Aspergillus, Penicillium, Microsporeum, Mucor*
Sulfate Reduction	Anaerobic heterotrophic	Bacteria including *Desulfovibrio* and *Desulfotomaculum*
Methanogenesis	Anaerobic heterotrophic	Bacteria including *Methanobacterium, Methanococcus, Methanoplanus*
Mercury Methylation	Anaerobic heterotrophic	Process is mediated by sulfate reducing bacteria
Mycorrhizal (Root Zone) Associations	Aerobic heterotrophic; obligate symbionts	Arbuscular mycorrhiza fungi including *Acaulospora, Entrophospora, Gigaspora, Glomus, Sclerocystis* and *Scutellospora* Bacteria including *Rhizobium, Pseudomonas, Bacillus*

Adapted from Environment Canada PHYTOPET database http://www.phytopet.usask.ca/mainpg.php; Subba, 1999; Tate, 1995; Vymazal, 1995.

5.5.2.1 Symbiotic Associations between Microbes and Plants

Certain microbes, which include mycorrhizal fungi and rhizobacteria, are capable of forming symbiotic associations with plants. More than 75% of all terrestrial plants support mycorrhizae (Pittenger, 2002). Mycorrhizae in wetland environments are less common but do occur (Turner et al., 2000). Mycorrhizae, derived from Latin, means "fungus root."

Fungal mycorrhizae receive various nutrients and water directly from plant root systems. In return, plants have enhanced water uptake and drought resistance, additional nutrient sources (particularly enhanced uptake of phosphorus), and protection from potential pathogens and various anthropogenic contaminants (Tsao, 2003). Rhizobacteria can synthesize plant hormones and have positive effects on plant growth and development (some mycorrhizae also perform these functions). These include nitrogen-fixing bacteria such as *Rhizobium* and cyanobacteria (blue-green algae).

Fugal mycorrhizae include ectomycorrhiza, which sheath the host root but penetrate only the outer cell layers, and endomycorrhiza, which actually penetrate into host cells. The most important members of the latter group are arbuscular mycorrhizae (AM fungi) (formerly referred to as vesicular-arbuscular [VAM fungi]). AM fungi are the mycorrhizae of most agricultural crops and native plant species. AM fungi are present in almost all natural soils, but are consistently lacking in graded or eroded soil, and on sites that have supported weeds. Nursery plants grown in sterilized or soilless media are also deficient in AM fungi. The primary function of AM fungi is to enhance uptake of phosphate.

It may be necessary to introduce mycorrhizae and other beneficial microbes after severe disturbance or a long fallow. Ample numbers are usually provided by adding organic matter, however, soils can also be inoculated. Mycorrhizal inoculants are readily available commercially and are relatively inexpensive (e.g., $350/acre).

5.5.2.2 Optimum Conditions for Microbial Activity

Microbes are very diverse, making it difficult to optimize conditions for all communities. Basic habitat requirements are summarized below.

Nutrient Requirements. All microbes require carbon. Organic amendments added to the soil may increase microbial activity. Carbon can also be supplied by plant litter. Macronutrients and micronutrients are summarized in Section 4.4.2. Microbes have high nutrient needs, especially for nitrogen, phosphorus, sulfur, and calcium. High exchangeable levels of calcium in the soil increase microbial populations. Microbes also require growth factors (organic compounds needed in small amounts) for biosynthesis, such as amino acids and vitamins.

Temperature. Temperate affects the rates of microbial growth and mediated transformations, and generally follows an Arrhenius relationship. Generally, increasing the temperature (to the tolerance limit of the microbe) increases microbial growth. Microbial activity is greatest between 15 and 45°C (Tate, 1995). Although, the greatest resistance to temperature extremes among living entities is found in the microbial community.

pH. Most microbes prefer a neutral pH of 6.0 to 8.0. However, fungi are more tolerant of acidic conditions than other microbes. Many fungi survive in forested and organic soils with a pH as low as 3.0.

Moisture. In soils, moisture content near or just greater than the field capacity is near optimum. The field capacity is the amount of water remaining in a soil after the soil layer has been saturated and the free water has been allowed to drain away (usually a day or two). This converts to a moisture potential of -10 to -70 kPa. Dryness can either kill microbes or cause dormancy. Some anaerobic microbes grow best under saturated conditions.

Oxygen. Oxygen may serve as the terminal electron acceptor in redox reactions. Microbes require either aerobic (most), or anaerobic conditions for metabolism. Facultative microbes undergo metabolism under either condition.

Absence of Toxics. Constituents, particularly metals, may be present in concentrations and/or forms that are toxic to microbes. Toxicity may cause die-off or altered cell morphology. Generally, heavy metal toxicity is determined by the degree of attraction to natural binding sites on and within the cell (Portier and Palmer, 1989). In addition, microorganisms in non-marine environments face similar problems to plants in saline soils.

5.5.2.3 Required Surface and Subsurface Area

Because microbes are generally associated with soils and vegetation, surface and subsurface area requirements are equivalent to land requirements required by ponds and biofilters. Microbes may also colonize on the surface of media filters.

5.5.2.4 Maintenance

It may be necessary to add additional organic matter to the soil to provide a source of carbon and other nutrients. Other maintenance requirements are associated with control of nuisance algae.

5.5.2.5 Aesthetics

There are generally few aesthetic concerns associated with the use of beneficial microbes for treatment. However, blooms of nuisance algae may occur under high nutrient loading. Emission of foul odors may occur, and there may be human health hazards associated with the release of toxins by certain nuisance algae.

5.5.3 Vegetated Systems

Vegetation can be used to uptake organic and inorganic pollutants from water and soil solution. In addition, root exudates (organic excretions) assist in chelation or precipitation of metals. Vegetation also has indirect treatment functions including:

- Reduction of flow rates allowing for filtering and settling of particulates, and more time for microbial contact with pollutants
- Transpiration
- Erosion control
- Support of the microbial community by supplying a substrate, aerating the root zone, forming symbiotic associations, and providing organic litter.
- Improved infiltration into the shallow soils promoted by stem and root intrusion

It is important to select plants with characteristics that support these functions. Always consult a qualified botanist, landscape designer, or landscape architect before installing a vegetated system. Useful characteristics of vegetation used in stormwater treatment systems are summarized in Table 5-23 and general design considerations are provided in Table 5-24.

Table 5-23. Useful Characteristics of Vegetation Used for Stormwater Treatment.

Tolerant of site-specific and climatic conditions (temperature ranges, averages; total precipitation and duration of precipitation events and inundation, flow velocities, and humidity).
Not invasive or noxious.
Tolerant of typical stormwater pollutant concentrations. Evaluating plants used in constructed wetlands for wastewater treatment (as well as established stormwater treatment systems) provides information about pollutant tolerance.
Can uptake, store, or otherwise remove pollutants.
Easy to establish and resilient to stress.
Low maintenance requirements (e.g., disease resistant, low fertilization and mowing). Note, high growth rates may increase maintenance requirements.
High growth rates, large surface area of roots, stems and leaves, and deep rooted
Salt-tolerant in areas with high concentrations of soluble salts (arid regions), or cold climates where deicing agents are used.
Aesthetically pleasing (e.g., attracts birds, provides visual interest).
Supports symbiotic associations with microbes (e.g., mycorrhizal fungi or rhizobacteria).
Plants are readily available.

Table 5-24. General Design Considerations for Vegetated Systems.

Preserve existing natural vegetation whenever possible.
Diversify plant species to improve wildlife habitat and minimize ecological succession.
Situate plants to allow access for structure maintenance.
Avoid plants with deep taproots where appropriate, as they may compromise the integrity of filter fabric, and earth dam or subsurface drainage facilities. Note, many native plants may have taproot systems.
Avoid plants that may overpopulate or become too dense such that vector issues arise (e.g., vegetation too dense for mosquito fish, etc.).
Use seed mixes with fast germination rates under local conditions. Plant vegetation and seeds at appropriate times of the year.
Temporarily divert flows from seeded areas until vegetation is established.
Stabilize water outflows with plants that can withstand strong current flows.
Shade inflow and outflow channels, and southern exposures of ponds to reduce thermal warming.
Plant stream and water buffers with trees, shrubs, bunch grasses, and herbaceous vegetation when possible, to stabilize banks and provide shade.

Native plants should be used whenever possible. Natives are typically better suited to the local climate, and are easier to establish than exotics. Natives also provide the highest benefit to the local ecosystem. Where available, use local guidance on plant selection. Exotic species can also be considered based upon local guidance and desired attributes. Various municipal stormwater design manuals provide recommendations on plant species suitable for the region, including natives. Local conservation groups may also provide information. Nonlocal information should be used with caution. For example, lists of plants commonly used in stormwater treatment systems often contain species that would be considered invasive in other areas. Knowledge of species that exist locally in natural upland and wetland areas is also useful for selecting native plants. Many native plants have local specificity, which is relevant if a vegetated treatment system is located near open space; in this case, local plant varieties should be used whenever possible to prevent genetic mixing and decline of local plant communities.

Some general internet resources for native plants include:

- Lady Bird Johnson Wildflower Center Native Plant Information Network, http://www.wildflower2.org

- U.S. EPA Green Landscaping Resources, http://www.epa.gov/greenacres/resources.html#Natural%20Landscaping
- FHWA Roadside Use of Native Plants, http://www.fhwa.dot.gov/environment/rdsduse/index.htm
- USDA PLANTS Database, http://plants.usda.gov

Some general internet resources for invasive plants include:

- National Park Service Plant Conservation Alliance. Fact Sheets: Alien Plant Invaders of Natural Areas, http://www.nps.gov/plants/alien/factmain.htm#pllists
- National Invasive Aquatic Plant Outreach and Research Initiative, Non-Native Invasive Aquatic and Wetland Plants in the United States, http://aquat1.ifas.ufl.edu/seagrant/aquinv.html

Resources for removal of organic and inorganic compounds by plants include Environment Canada's two phytoremediation databases: PHYTOPET (for petroleum hydrocarbons and related organics such as PAHs and VOCs) and PHYTOMET (for 19 metals). PHYTOPET can be accessed on the Web at http://www.phytopet.usask.ca/mainpg.php, and PHYTOMET is available on CD-ROM. The databases are searchable by plant, pollutant, phytoremediation mechanism, and phytoremediation potential. The databases include over 775 terrestrial and aquatic plants.

5.5.3.1 Site-Specific Considerations

Site characteristics such as soil type, inundation patterns, topography, sun exposure, and ecological succession affect the plants that can be used at a site, the planting methods that should be used to improve plant establishment, and long-term establishment of plants.

Soil characteristics. Soil texture, degree of compaction, hydraulic conductivity, pH, nutrient levels, minerals (such as chelated iron, lime), salinity and toxicity affect plant establishment and growth. Refer to Section 5.5.1, Soils and Soil Amendments, for additional information. Whenever possible, topsoil should be spread to a depth of four inches (two inch minimum) over the entire area to be planted. This provides organic matter and nutrients for the plant material. Organic matter also allows the stabilizing materials to become established faster, while the roots are able to penetrate deeper and stabilize the soil, making it less likely that the plants will wash out during a heavy storm. If topsoil has been stockpiled in deep mounds for a long period of time, it is desirable to test the soil for pH as well as microbial activity. An example of soil characteristics appropriate for bioretention systems is shown in Table 5-25.

Table 5-25. Optimal Soil Characteristics for Bioretention.
Reprinted with permission from Claytor and Schueler (1996).

Parameter	Value
pH	5.2 to 7.0
Organic matter	1.5-4.0%
Magnesium	35 pounds/acre, minimum
Phosphorus	75 pounds/acre, minimum
Potassium	85 pounds/acre, minimum
Soluble salts	500 ppm
Clay	10-25%
Silt	30-55%
Sand	35-60%

Inundation. Soil moisture and system inundation patterns affect the plant species that can survive at a site. For this reason, it is useful to classify plants in terms of their wetland indicator status. The indicator status shows the estimated probability of a species occurring in wetland versus non-wetland environments. The categories are defined in Table 5-26.

Table 5-26. Wetland Plant Categories.

Wetland Indicator Status	Description
Obligate Wetland (OBL)	Nearly always occur in wetlands under natural conditions (more than 99% of the time)
Facultative Wetland (FACW)	Usually occur in wetlands (67- 99% of the time), but occasionally found in nonwetlands
Facultative (FAC)	Equally likely to occur in wetlands and nonwetlands and are found in wetlands 34-66% of the time
Facultative Upland (FACU)	Usually occur in non wetlands (67-99% of the time), but are occasionally found in wetlands (1-33% of the time)
Upland (UPL)	Almost always occur in nonwetlands under natural conditions (more than 99% of the time)

U.S. Fish and Wildlife Service has compiled a list of vascular plant species that occur in wetlands, which includes wetland indicator status. An electronic copy of the 1996 National List is available at http://wetlands.fws.gov/bha. The wetland indicator status alone does not indicate the depth or duration of flooding that a plant will tolerate. Hydrologic zones, as shown in Table 5-27, describe the degree to which an area is inundated by water. Plant tolerance levels to inundation have been divided into six zones (Georgia Stormwater Management Manual, 2001). Hydrologic conditions in a stormwater treatment system may fluctuate in unpredictable ways; thus the use of plants capable of tolerating variable hydrologic conditions greatly increases the rate of success. Conversely, plants suited for specific hydrologic conditions may perish when hydrologic conditions fluctuate, expose the soil, and increase the chance for erosion. Figure 5-20 is an example of vegetation in the different hydrologic zones of an extended detention basin.

Table 5-27. Wetland Zones and Hydrologic Conditions.

Zone #	Zone Description	Hydrologic Conditions
Zone 1	Deep water pool	1-6 foot deep permanent pool
Zone 2	Shallow water bench (low marsh)	6 inches to 1 foot deep and regularly inundated
Zone 3	Shoreline fringe (high marsh)	Regularly inundated
Zone 4	Riparian fringe	Periodically inundated
Zone 5	Floodplain terrace	Infrequently inundated
Zone 6	Upland slopes	Seldom or never inundated

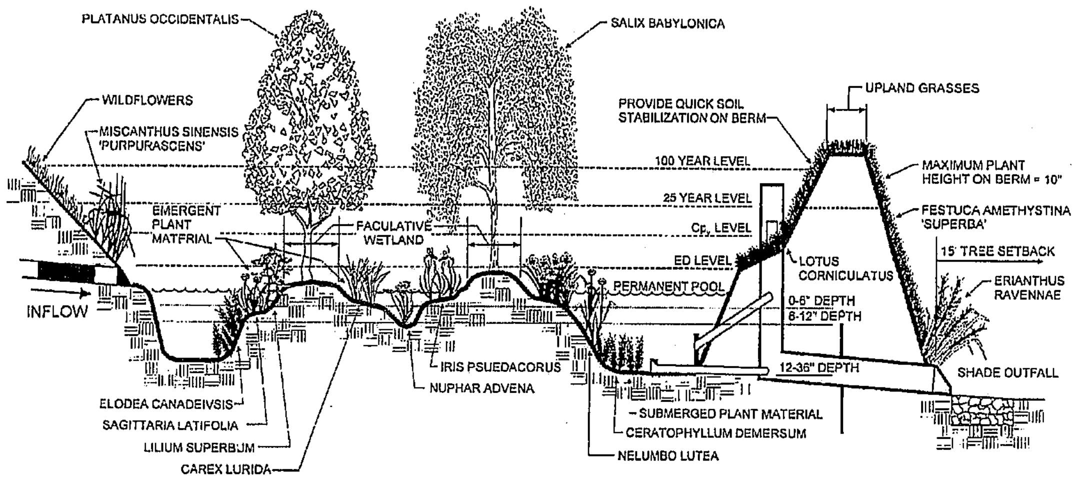


Figure 5-20. Configuration of an Extended Detention Wetland with Various Wetland Zones. Source: Atlanta Regional Council (2001).

Topography. Plant establishment and growth requires stable substrates for anchoring root systems and preserving seeds. Establishing plants directly on or below eroding slopes is not possible for most species. In such instances, plant species capable of spreading rapidly and anchoring soils should be selected, or bioengineering or other stabilization techniques should be used to aid the establishment of a vegetative cover. In addition, soils on steep slopes generally drain more rapidly than those on gradual slopes. This means that the soils may remain saturated longer on gradual slopes. If soils on gradual slopes are classified as poorly drained, care should be taken to select plants tolerant of increased saturation.

Site topography also influences species diversity. Small irregularities in the ground surface (e.g., depressions) are common in natural systems. More species are found in areas with many microtopographic features than in areas without such features. Raised sites are particularly important in wetlands because they allow plants that would otherwise die while flooded to escape inundation.

A given change in water levels will expose a relatively small area on a steep slope in comparison to a larger area exposed on a gradual or flat slope. Narrow planting zones will be delineated on steep slopes for species tolerant of specific hydrologic conditions, whereas gradual slopes enable the use of wider planting zones.

Sun Exposure. Sun exposure should be considered for its effect on plants. A southern exposure receives more sun and is warmer and drier than a northern exposure. Eastern and western facing slopes are intermediate, receiving morning and afternoon sun, respectively. Western exposures tend to be more windy than other exposures.

Ecological Succession. Ecological succession refers to the transition in plant species over time as a result of changes in site conditions. Some degree of succession is likely to occur, and new plant communities may or may not meet treatment objectives. Factors such as species diversity (and competition among plant species), soil fertility, and hydrology influence the rate and direction of ecological succession (USACE, 2000). Long-term vegetation management may be needed to manage succession and maintain desired plant populations.

5.5.3.2 Plant Hardiness Zones

Plants differ in their ability to withstand very cold winters. Plant hardiness zones have been established by the USDA and are based on historical annual minimum temperatures recorded in a region. Hardiness zones do not provide information about maximum temperature tolerance, which is also relevant. An electronic version of the 1990 USDA Plant Zone Hardiness Map can be assessed at http://www.usna.usda.gov/Hardzone/index.html. Cold hardiness ratings for selected woody plants are also provided on this website.

5.5.3.3 Factors Regarding Metal Accumulating and Stabilizing Plants

The term hyperaccumulator applies to plants that can accumulate metals at concentrations 100-fold greater than concentrations found in the tissue of non-hyperaccumulators. Thus, hyperaccumulators can concentrate more than 10 ppm mercury, 100 ppm cadmium, 1,000 ppm cobalt, chromium, copper, and lead, and 10,000 ppm nickel and zinc. Metal tolerance is the primary characteristic of these plants. Generally, hyperaccumulators are slow-growing, with a small biomass and shallow root systems. These characteristics are generally not desirable for stormwater treatment. Some common families of hyperaccumulating plants include Brassicaceae, Euphorbiaceae, Asteraceae, Fabaceae, Lamiaceae, and Scrophulariaceae, as well as the wetland plants duckweed (*Lemma minor*) and water hyacinth (*Eichhornia crassipes*). Hybrid poplar trees have also been identified as hyperaccumulating plants. Environment Canada's PHYTOMET database, which is available on CD-ROM, is a good resource for metal accumulating and hyperaccumulating plants.

Metal stabilizing plants limit the mobility and bioavailability of metals in soil by sorption, precipitation, complexation, or reduction of metal valences. The ability of these plants to sequester metals in the root zone is a defense strategy to prevent uptake of toxics into above ground biomass. However, plants need to be able to tolerate high concentrations of metals in the roots. Metal stabilizing plants have extensive roots systems that grow rapidly. This characteristic is found in many herbaceous species, grasses, trees, and some wetland plants. The efficiency of root adsorption can be measured using a Root Concentration Factor (RCF), which is defined as the ratio of the contaminant in or on the roots to the concentration dissolved in soil water. Suitable metal stabilizing plants have RCFs approaching unity.

5.5.3.4 Expected Performance

Vegetation can be expected to remove dissolved metals and organics through direct uptake and storage. In addition, excretions from plant roots assist in metal chelation and precipitation. Vegetation decreases flow rates allowing particulates to be removed by sedimentation. Vegetation increases microbial populations (by providing surface area, carbon, and oxygen transfer in the root zone), which transform and/or remove a variety of organic and inorganic constituents. Plant detritus provides sorption sites for various organics and metals.

In cold climates, plants have a shorter growing season and may go dormant in the winter. Uptake of nutrients into plant materials only occurs during the active growing season, and nutrient concentrations in vegetation are highest early in the growing season; seasonal changes in plant tissue concentrations tend to vary by nutrient and by plant species (Vymazal, 1995). Therefore, in cold climates, one would intuitively expect plants to exhibit seasonal effects, with reduced efficiency in winter versus summer. Also, release of nutrients from decaying vegetation would be expected to increase in winter.

There are not a lot of seasonal performance data for stormwater treatment systems, so the evaluation has been expanded to wastewater data. Cold climate data showing seasonal effects for stormwater and wastewater wetlands show inconsistent results. Constituents typically evaluated include BOD, phosphorus and nitrogen species, and TSS. Some studies showed no seasonal effects; and other studies show seasonal effects for some, but not other constituents, and the constituents exhibiting seasonal effects were not consistent (Newman et al., 2000; Oberts, 2000; Kadlec, 1999; Reuter et al., 1992; WERF, 1999). Studies specifically addressing effects of plant dormancy on treatment performance are lacking, and the discrete effects of plant dormancy could not be readily ascertained from these data. (However, increased winter exports of TKN and ammonia, when observed, were often attributed to release from dormant vegetation.) This is because decreased winter temperatures also reduce microbial activity, and can lead to the formation of thick ice layers which reduce the available treatment volume and efficiency of snowmelt treatment. Increased flows from snowmelt may cause scouring and resuspension of bottom sediments and detritus and associated pollutants.

Wastewater wetland microcosm study data from Montana State University suggests the following (Hook et al., 2003):

- Seasonal variation in COD removal was modified strongly by specific plant species. Vegetated cells removed more COD than the unvegetated control cell overall, and the presence of vegetation either attenuated or eliminated altogether the decrease in performance at low temperatures.
- Two species (*Scirpus acutus, Carex rostrata*) showed no significant seasonal effects, while the performance of the third species (*Typha latifolia*) differed significantly between warm and cold seasons (as did the unplanted cell). The difference in seasonal performance is attributed to differences in root zone oxidation. The amount of below-ground biomass may be a factor in oxygen export from the root zone. For example, *Typha* is known to have a shallower root system than *Scirpus*.
- The effects of the three plant species on performance were greatest during the coldest periods, implying that plant species selection may be more important to cold season than to warm season performance.

As such, the variable data on seasonal performance may be indicative of effect of plant specificity. Oxygen transfer through the root zone may be an important indirect removal mechanism for some constituents during periods of plant dormancy, provided the appropriate plants are used. For example, oxygen leakage to the root zone is important in subsurface flow wetlands for aerobic degradation of oxygen-consuming substances and nitrification (Brix, 1994). Reduced internal oxygen consumption due to cold temperatures and dormancy may allow greater oxygen leakage from roots during the cold season than the warm season (Callaway and King, 1996). With the right plants, increased oxygen transfer in the root zone may counteract, to some degree, the effects of reduced nutrient uptake in winter, thus dampening seasonal effects.

5.5.3.5 Required Surface and Subsurface Area

Area requirements for vegetation are generally equivalent to requirements for ponds, biofilters and bioretention areas.

5.5.3.6 Maintenance

Activities associated with the establishment and maintenance of vegetation may include:

- Irrigating, particularly after initial installation of plants. Some plants may require dry season irrigation.
- Monitoring changes in site conditions that affect vegetation and status of vegetation (a minimum of annual inspections should be conducted).
- Controlling weeds, diseases and insects (use of most pesticides is not encouraged). Integrated pest management (IPM) approaches are highly recommended. State cooperative extensions often provide good resources for IPM, such as the University of California Statewide IPM program, http://www.ipm.ucdavis.edu/.
- Mulching at least annually to suppress weeds, increase moisture retention, and replenish organic matter.
- Removing and replacing dead and diseased vegetation.
- Removing species as needed to prevent undesirable ecological succession.
- Pruning woody vegetation as needed to avoid conflicts with overhead utilities, or hazards with adjacent people and property.
- Removing plant stakes after the first growing season.
- Removing litter and debris for water pollution control, and to reduce favorable environments for harmful insects and pathogens.
- Applying fertilizers and soil amendments.

5.5.3.7 Cost Considerations

Costs are associated with planting, monitoring and maintenance (USACE, 2000). Planting costs may include labor, seed, contract-grown materials, nursery materials, equipment rentals (e.g., bulldozer, rototiller), and soil amendments. Costs of actual plant materials are highly variable, and are affected by several factors. Seeds are much less expensive than transplants. Containerized/balled and burlapped stock is more expensive than bareroot stock. Topsoil seedbank materials are less costly than transplants. Species that are difficult to propagate, in short supply, in short demand, or require specialized handling techniques are often very expensive. In general, large or mature planting stock is more expensive than small or young planting stock. Mechanized planting typically costs less than manual planting, particularly on large sites, and planting under water is much more expensive than planting on upland sites.

Maintenance costs may include soil amendments, irrigation, replacement or supplemental plants, and control of undesirable vegetation, insects, and diseases. Use of natives may reduce replacement costs because natives have a higher survival rate than exotic plants.

5.5.3.8 Aesthetics

Through the use of vegetation, the aesthetics of a stormwater treatment system can be greatly enhanced. A good landscape design can enhance adjacent property values. Aesthetic considerations for vegetated systems include:

- Morphology (e.g., size, shape, and growth habit) and color of foliage, flowers, fruit, stems and bark
- Seasonal characteristics (e.g., deciduous or evergreen)
- Ability to attract birds, butterflies, and beneficial insects
- Desired landscaping levels are obtained upon completion of construction or shortly thereafter

5.5.4 Disinfection Systems

Disinfection systems are used to destroy or inactivate pathogens. The primary types of disinfection systems for managing pathogens in stormwater use ozone or ultraviolet (UV) light (Dycus, 2004, O'Shea and Field, 1992). Despite the effectiveness of chlorine compounds, stormwater disinfection using chlorine and chlorine compounds is not as common due to the risks of chemical storage and the potential for formation of disinfection byproducts. However, because chlorination is the most commonly used disinfection process in wastewater, it is included in this discussion for comparison purposes. Unlike other disinfection technologies, chlorine disinfection typically leaves a residual which can prevent reinfection of the effluent. However, the chlorine residual, while temporary, can at elevated levels be very toxic to other aquatic organisms, therefore dechlorination may be required to protect sensitive receiving waters.

5.5.4.1 Associated UOPs and Potential Design Enhancements

The main unit process associated with disinfection TSCs is the inactivation of pathogenic organisms. All disinfection processes are oxidation processes unless there are additional physical operations that cause mortality, such as the use of acoustics to cause physical destruction of an organism. The effectiveness of any disinfection operation depends on the disinfection technology, the quality of the influent and the effectiveness of maintenance practices. Effective pretreatment and regular maintenance are the surest ways to enhance and maintain disinfection TSC performance. Table 5-28 summarizes the effect of various influent constituents on the disinfection process.

For all three disinfection technologies, increasing the contact time between the disinfection agent and the target organisms typically results in bacteria die-off. The effect of contact time is shown in Equation 5-15.

$$\frac{dN_t}{dt} = -kNt \qquad [5\text{-}15]$$

(Metcalf and Eddy, 2003)

Where: dN_t/dt = rate of change in the concentration of organisms with time
k = inactivation rate constant, T^{-1}
N_t = number of organisms at time t
t = time

For chlorine compounds and ozone, the disinfecting agent concentration is related to the die-off rate of the target organisms as shown in Equation 5-16. Because no chemicals are added during UV disinfection, the intensity of UV radiation is similarly related to the die-off rate of the target organisms (see Equations 4-14 and 4-15 in Section 4.3.5, Physical Agent Disinfection). While die-off is commonly assumed to be a first order processes, the rate constant can actually vary significantly and other reaction orders are common. Rate constants are either taken from the literature for similar conditions or measured experimentally.

$$k = k'C^n \qquad [5\text{-}16]$$

(Metcalf and Eddy, 2003)

Where: k = inactivation rate constant
k' = die-off constant
C = concentration of disinfectant
n = coefficient of dilution

5.5.4.2 Recommended Pretreatment

Some form of pretreatment such as detention or media filtration should be provided upstream of disinfection systems to remove solids and other stormwater constituents, such as organics, that interfere with disinfection process. Table 5-28 shows the impacts of various constituents of influent streams on various disinfection processes. The presence of solids affects all three processes, especially UV disinfection. Solids less than 10 µm, at low concentration, provide little shielding for pathogens. However particles greater than 10 µm, and high concentrations of particles smaller than 10 µm reduce transmissivity and provide effectively shield the microbes from disinfection (Metcalf and Eddy, 2003). Suspended solids are usually removed by media filtration, sedimentation, and filtration prior to disinfection as pretreatment for UV disinfection.

Table 5-28. Effects of Wastewater Constituents on Disinfection.
From Metcalf and Eddy, Wastwater Engineering. (2003). Reprinted with permission of the McGraw-Hill Companies.

Constituent	Chlorine	Ozone	Ultraviolet
COD, TOC etc.	Organic compounds that comprise the COD (or a COD surrogate such as BOD) can exert a chlorine demand. The degree of interference depends on their functional groups and their chemical structure	Organic compounds that comprise COD (or a COD surrogate such as BOD) can exert an ozone demand. The degree of interference depends on their functional groups and their chemical structure	No, or minor effect, unless humic materials comprise a large portion of the COD
Humic Materials	Reduce effectiveness of chlorine by forming chlorinated organic compounds that are measured as chlorine residual but are not effective for disinfection	Affects the rate of ozone decomposition and the ozone demand	Strong absorbers of UV radiation
Oil and Grease	Can exert a chlorine demand	Can exert an ozone demand	Can accumulate on quartz sleeves of UV lamps, can absorb UV radiation
TSS	Shielding of embedded bacteria	Increase ozone demand and shielding of embedded bacteria	Absorption of UV radiation, can shield embedded bacteria
Alkalinity	No or minor effect	No or minor effect	Can impact scaling potential. Also affects solubility of metals that may absorb UV light

Constituent	Chlorine	Ozone	Ultraviolet
Hardness	No or minor effect	No or minor effect	Calcium, magnesium, and other salts can form mineral deposits on quartz tubes, especially at elevated temperatures
Ammonia	Combines with chlorine to form chloramines	No or minor effect, can react at high pH	No, or minor effect
Nitrite	Oxidized by chlorine, formation of N-nitrosodimethylamine (NDMA)	Oxidized by ozone	No, or minor effect
Nitrate	Needed chlorine dose is reduced because chloramines are not formed. Complete nitrification may lead to the formation of NDMA due to the presence of free chlorine. Partial nitrification may lead to difficulties in establishing the proper chlorine dose	Can reduce effectiveness of ozone	No, or minor effect
Iron	Oxidized by chlorine, so larger dose may be needed.	Oxidized by ozone, so larger dose may be needed.	Strong absorber of UV radiation, can precipitate on quartz tubes, can adsorb on suspended solids and shield bacteria by adsorption
Manganese	Oxidized by chlorine, so larger dose may be needed.	Oxidized by ozone, so larger dose may be needed.	Strong adsorber of UV radiation
pH	Affects distribution between hypochlorous acid and hypochlorite ion	Affects the rate of ozone decomposition	Can affect solubility of metals and carbonates

Chlorine and ozone disinfection processes are also affected by solids but to a lesser degree than UV disinfection. This is because chlorine and ozone are much stronger oxidizers than UV. Both ozone and chlorine may react stormwater constituents to produce unwanted byproducts such as trihalomethanes, haloacetic acids and aldehydes. The recommended pretreatment for chlorine and ozone disinfection is media filtration, sedimentation, or filtration. If the influent is expected to have a high concentration of organics, UV disinfection may be a better option than chlorine or ozone disinfection.

5.5.4.3 Hydraulic Considerations

Disinfection facilities are more complex than most TSCs. Facilities can be designed to accommodate a wide range of flow rates, but in general, higher flow rates require more costly equipment. For processes that utilize contact basins, the headlosses that occur in the contact basins may be approximated using Equation 5-17.

$$h = \frac{1}{2g}\left(\frac{Q}{Cna}\right)^2 \qquad [5\text{-}17]$$

Where: h = headloss, m
g = acceleration due to gravity
Q = discharge through contact basin channel
C = discharge coefficient, unitless (typically about 0.8)
n = number of openings
a = area of individual openings

5.5.4.4 Required Surface and Subsurface Area

Disinfection systems need specialized equipment, which is usually housed in a shelter. The size of the equipment depends on the target flow rates and the quality of the components selected for the disinfection process. Space requirements for disinfection systems are highly variable and depend on the selected technology, design, and layout of the system. Both UV and ozone disinfection typically require less space than chlorine disinfection.

5.5.4.5 Maintenance

Disinfection systems require continuous maintenance for consistent performance. Follow the manufacturer's instructions for maintenance. For chlorine disinfection, maintenance activities typically include periodically disassembling and cleaning the various components of the system such as meters and floats, removing iron and manganese deposits, maintaining booster pumps, and testing and calibration equipment per the manufacturer's recommendations (U.S. EPA, 1999a). Maintenance frequencies will depend on site conditions, such as plant operation hours and influent quality.

For ozone disinfection plants maintenance activities include the calibration of monitoring equipment, refurbishment of air preparation equipment and ozone generator, and inspection and cleaning of the ozonator, air supply and dielectric assemblies. It is also important to constantly monitor and maintain ambient ozone levels below limits of applicable regulations (U.S. EPA, 1999b).

For UV disinfection plants, all surfaces between UV lamps and target organisms must be clean; the quartz tubes on the UV lamps must be constantly cleaned to reduce the effects of fouling. Fouling of the tubes minimizes light penetration into the influent and can greatly impact system performance. Automated cleaning systems are typically built-in. The formation of biofilms on the exposed surfaces of the UV reactor can negatively impact performance since biofilms can shield bacteria. Covered UV channels are less susceptible to biofilm formation. Occasionally cleaning channels with hypochlorite, paracetic acid or other suitable agents will remove biofilms (Metcalf and Eddy, 2003). Effective pretreatment combined with regular cleaning will maintain the transmissivity within the influent and keep lamp performance at optimum levels.

5.5.4.6 Cost Considerations

The cost of the three disinfection alternatives vary according to site conditions, influent quality and the designs selected. However, ozone disinfection tends to me more expensive than the other alternatives (U.S. EPA, 1999b). Improvements in technology continue to lower the cost of all three disinfection alternatives; however the greatest reductions in costs are likely for UV disinfection. UV disinfection costs are comparable to chlorine disinfection costs if the cost of dechlorination is included (U.S. EPA, 1999c). The addition of dechlorination could increase chlorination costs by as much as 30-50% (U.S. EPA, 1999a).

In general, higher flow rates require more costly equipment. However, to minimize costs, disinfection operations may benefit from upstream flow attenuation TSCs that typically lower flow rates, resulting in smaller disinfection facilities at reduced capital, operation and maintenance costs.

5.5.4.7 Aesthetics

As a safety feature, disinfection systems will likely be contained indoors or underground in some kind of structure. Containment structures can be designed and built to be as aesthetically pleasing as the budget allows. Therefore, the aesthetic impact of disinfection systems is considered to be minimal.

5.5.5 Flocculant/Precipitant Injection Systems

Conventional treatment systems such as detention and retention ponds are inherently limited in their effectiveness to remove fine particulates and associated constituents (e.g., metals and nutrients) from stormwater runoff by gravity settling and natural coagulation-flocculation mechanisms. Because of their small size and lower settling velocities, fine particulates are only partially removed by detention or retention. An increase in capture efficiency of fine particulates and associated constituents can be achieved by modifying the basin size and operating conditions. However they are less likely to be cost effective in cases where physical constraints such as space availability are limiting. Physical- and chemical-assisted precipitation or flocculation can provide effective treatment of fine particulates and associated constituents.

5.5.5.1 Associated UOPs and Potential Design Enhancements

Chemical-assisted precipitation/flocculation involves, as the name implies, the addition of a chemical to bring about a number of floc growth mechanisms including precipitation (Section 4.5.2). Precipitation is the process by which dissolved or suspended constituents in water settle out as solid precipitates that can be filtered, centrifuged or otherwise separated from water. In coagulation/flocculation a chemical coagulant causes destabilization of smaller particles through reduction of particle-to-particle repulsive forces, which results in aggregate formation. Coagulation/flocculation is most effective for colloidal and suspended size particles that would otherwise remain suspended in the water column. The most common types of coagulants used in stormwater treatment are alum, liquid organic polymer, calcium sulfate, and ferric chloride (Section 4.5.2).

5.5.5.2 Hydraulic Considerations

Coagulant mixing is the first operation to occur when the coagulant is injected to destabilize the particles in a rapid mixing unit. According to Camp and Stein (1943), the mean velocity gradient, G, defines the degree of mixing as shown in Equation 5-18:

$$G=\left(\frac{P}{\mu \cdot V_o}\right)^{0.5} \qquad [5\text{-}18]$$

Where: G= mean velocity gradient
P = power into the mixing chamber
μ = absolute viscosity of water
V_o = volume of the mixing chamber

The optimum G varies depending on the type of mixing device and coagulant. For iron salts and alum, G typically ranges from 1,000 to 5,000, and the mixing time would normally be short, on the order of less than 1-30 seconds. However, for polymers, less vigorous mixing occurs and with G ranges from 400 to 800, and longer mixing times on the order of 30-60 seconds would suffice.

Mixing in the flocculation unit may be done using paddles, baffled channels, and sometimes air injection. Flocculants can sometimes be introduced into a turbulent flow stream. For more detailed hydraulic design of these systems, wastewater engineering handbooks or guidance documents, such as Fair et al. (1968) and Ives (1990), may be consulted.

As headloss is the primary energy source that occurs with immediate change in the direction of flow, the headloss is given by the following equation Fair et al. (1968):

$$H_L = \frac{N \cdot V^2}{2g} \quad [5\text{-}19]$$

Where: V = velocity through the baffle opening
N = number of baffles
g = gravitational constant

The volume V_0 of the mixing unit is estimated from the following equation:

$$V_o = \frac{N \cdot Q^3}{2g \cdot G^2 \cdot \mu \cdot A^2} \quad [5\text{-}20]$$

Where: Q = flow rate
A = area of the baffle opening
All other parameters previously defined

According to Fair et al. (1968), the flocculation chambers with baffled channels would have flow velocities of 0.5-1.5 ft/s, hydraulic residence times of 10-60 minutes, and headlosses of 0.5-2 ft.

5.5.5.3 Pretreatment Considerations

Due to the variability in the stormwater characteristics, precipitation may require pretreatment steps including flow equalization, oil removal, and neutralization. Flow equalization will prevent wide fluctuations in flow rate, temperature and contaminant concentrations. Oil and grease may affect the settling of precipitates by creating emulsions. Pretreatment with an oil-water separator or skimmers may be necessary.

5.5.5.4 Maintenance Considerations

Precipitation/flocculation systems require routine maintenance. As they are most often automated chemical feed systems consisting of storage tanks, feed tanks, injection quills, overflow basins, mixers aging tanks, pipes, fittings, and valves, all manufacturer's maintenance schedules and procedures have to followed. Safe storage and handling instructions for chemicals along with Material Safety Data Sheets (MSDS) should be provided to the workers. Managing and regularly disposing of large quantities of sludge is a consideration.

5.5.5.5 Cost Considerations

The cost of constructing alum treatment units for stormwater is about $250,000, regardless of the basin size. Maintenance costs are approximately $25,000-50,000 per year. Chemical precipitation costs depend on many variables, including the characteristics of the influent quality, chemical dosage, volume of water to be treated, and level of the effluent quality.

Chemical costs vary widely depending on the form and quantity of material, and prices fluctuate throughout the country. Lime is generally the least expensive chemical agent (U.S. EPA, 2000b). Chemicals provided in bags or measured batches are more expensive than bulk chemicals. However, treatment costs cannot be estimated solely based on the price of the chemicals. For example, ferrous sulfate is one of the least expensive chemical coagulants available, but the large volume of sludge generated with its use makes it one of the most expensive to use in operation (U.S. EPA, 2000b).

5.5.5.6 Aesthetics

In general, aesthetics may not be a concern if sludge management is performed according to schedule. However, the presence of flocs in a stormwater pond may appear to the public as unsightly.

5.5.6 Sprinklers and Aerators

The processes of oxidation and volatilization may be enhanced by using sprinklers or aerators. Shallow treatment systems may not require mechanical aeration, as the surface area to volume ratio should allow sufficient wind-driving aeration. As treatment sites become deeper, oxygen depletion can become an issue. The principal aeration devices in water supply and wastewater systems may be classified as waterfall aerators, diffused-air (or pure oxygen) aeration systems, and mechanical aerators (Tchobanoglous and Schroeder, 1985). Examples of waterfall aerators include spray aerators, cascade aerators, and multiple-tray aerators. For moderately deep treatment systems, spray aerators such as surface splashers, sprinklers, and fountains, or diffused-air aeration systems that operate by introducing air by bubbles into the water column, can be used to enhance aeration. Paddle wheel aeration is also a common technique used for large ponds. Smaller fountains and paddle wheels may not sufficiently aerate the entire water column, due to the volume of they draw. Larger fountains can potentially remedy this problem by using intake piping that draws water from near the bottom of the treatment system. Davis (1996) found a 50% reduction in BOD when surface splashing aeration was replaced with aspirating (deep injection) aeration. Similarly, underwater aeration systems can be placed along the bottom of very deep treatment systems such as wet ponds and permanent pools.

Typical designs for aeration systems in water supply and wastewater applications incorporate electric motors to drive the system. For stormwater applications, a more passive approach may be more desirable. This can be accomplished by enhancing aeration during transport to or away from the treatment site using waterfall aerators or baffles to cause turbulence in an inflow or outflow pipe or channel. A waterfall over a low-flow weir is another example of aeration taking place near the outfall of a site.

For sites where treating the volume of runoff is the main concern and water quality is generally not an issue, some methods of stormwater reuse can be quite effective at aerating water and volatilizing some constituents. Stored runoff can be conveyed through a sprinkler or irrigation system to water fields, yards, and gardens. By passing through the sprinkler system, the water is greatly aerated, enhancing its quality.

5.5.6.1 Associated UOPs and Potential Design Enhancements

Knowing the influent and effluent dissolved oxygen concentrations can help in the decision to incorporate aeration into a treatment site. A high dissolved oxygen concentration is one indicator of good water quality. Aeration also enhances water quality by 1) reducing or eliminating thermal stratification, 2) lowering iron levels through oxidation of Fe^{2+} to Fe^{3+}, which creates ferric phosphate precipitates (Zaw and Chiswell, 1999), 3) increasing the volatilization rate of volatile stormwater pollutants, such as ammonia, and 4) reducing algae growth due to reduced availability of nitrogen and phosphorus. For sites with high concentrations of influent nitrogen and phosphorus, aeration could also reduce effluent nutrient by increasing populations of aerobic bacteria, which require nutrients.

Recently artificial aeration has been proposed to increase dissolved oxygen concentrations and improve water quality in the Shing Mun River in Hong Kong (Li et al., 2000). In a deep dam reservoir experiencing eutrophication, researchers installed two aeration systems consisting of a circulating flow control facility and a deep layer dissolved oxygen improvement facility (Terakawa and Fukuwatari, 1998). They were successful in creating a system in which the influent was introduced into the bottom layers of the reservoir, injecting oxygen rich water to the depleted areas. At two lakes in Ontario, Canada, researchers recorded significant reductions in phosphorus and iron, complete removal of hydrogen sulfide, and lack of blue-green algal blooms due to artificial injection of oxygen in the hypolimnetic zone (Gemza, 1997).

5.5.6.2 Hydraulic Considerations

Systems with high flow rates and water velocities probably do not require aeration, because high velocities should create sufficient aeration through mixing. If influent flow rates and velocities are low, aeration and mixing could provide hydraulic benefits by reducing temperature gradients and the propensity for thermal stratification-induced short circuiting. A baffle system that highly aerates the water will also reduce flow velocity; thus increasing the hydraulic retention time. Systems with long residence times and deep permanent pools will often need some sort of mixing or aeration keeps the systems aerobic.

5.5.6.3 Maintenance Considerations

Aeration devices are generally self-sufficient once installed. Fountains and underwater aerators required electricity, and the power supplies need to be maintained. It may be possible to use solar or wind energy, and potentially even microhydroelectric turbines to continuously power aeration devices. Structural modifications such as baffles will need to be inspected regularly to maintain functionality and clear clogs or impediments.

5.5.6.4 Cost Considerations

On a small scale, baffles are relatively inexpensive to incorporate into a treatment system. Fountains, especially those not powered by renewable resources, can be costly to operate. For water supply and wastewater applications, aeration is often the most energy intensive treatment operation (Tchobanoglous and Schroeder, 1985). Underwater aeration systems are costly to install and difficult to maintain, due to their inaccessibility. However, these systems are highly effective in improving the quality of water high in BOD.

5.6 Tertiary Hydraulic Controls

Hydraulic controls are devices or structures that control the direction, flow rate, depth, and/or velocity of a flow stream. For stormwater treatment, hydraulic controls are typically passive devices that require sufficient elevation drop (head) to function properly. Common hydraulic controls include energy dissipaters, check dams, flow splitters, berms, and inlet and outlet structures.

5.6.1 Hydraulic Potential (Head) Considerations

Any hydraulic component must include consideration of available hydraulic head, the vertical distance between water at the inflow and outflow of the hydraulic structure. Head requirements for individual TSCs must be noted; some devices simply will not conform to available head.

5.6.2 Energy Dissipators

Energy dissipators are engineered devices placed at drainage system outlets to minimize erosion and scour, at the transition of a channel to a pond, or at the impoundment at the end of a channel segment. (Energy dissipation along channels is discussed in the next section.) Artificial conveyance systems typically deliver flows at velocities that may cause erosion in receiving waters. Energy dissipators allow conveyance systems to operate at high velocities without causing erosion (ARC, 2001).

Energy dissipator designs generally use rock, riprap, or concrete materials to absorb the impact of the incoming high energy flows. Some examples of energy dissipator designs are riprap aprons (Figure 5-21), riprap outlet basins (Figure 5-22), and baffled outlets (ARC, 2001). A detailed design of energy dissipators has been omitted in this discussion. For design information, refer to the local flood control agency for guidance, or publications such as WEF and ASCE (1992) and UDFCD (1999). Some factors to be considered in the selection and design of energy dissipation structures include (FHWA, 1983):

- the design discharge
- outlet flow conditions (velocity and depth)
- outlet slope
- operational characteristics and performance curve
- standard culvert outlet design (e.g., projection, wingwalls, headwalls and aprons)

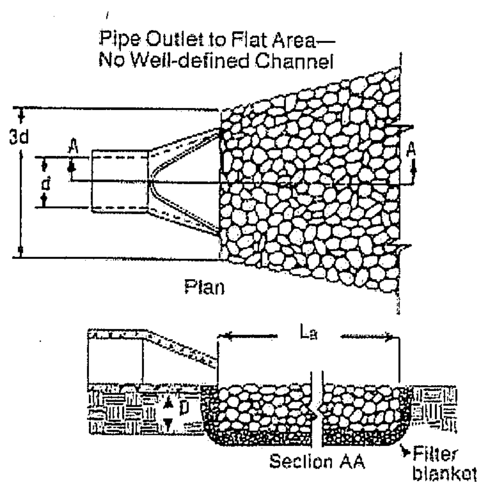


Figure 5-21. Example Riprap Apron Design.
Source: Atlanta Regional Council (ARC, 2001).

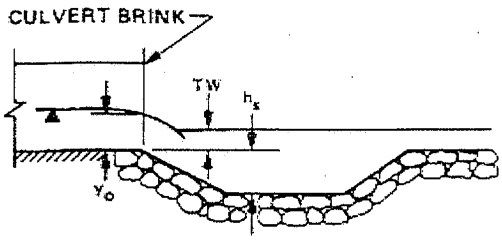


Figure 5-22. Example Riprap Basin Design.
Source: Atlanta Regional Council (ARC, 2001).

Well designed and constructed energy dissipators are durable structures requiring little maintenance. For early detection of structural problems and other maintenance needs, routine inspections and inspections after large events are recommended. Energy dissipators provide protection against scour and erosion at a low cost, with minimal impact to aesthetics. The cost of energy dissipators is considered to be low compared to the cost of other TSCs.

5.6.3 Check Dams

Check dams (Figure 5-23) are small barriers typically constructed of rock, gravel bags, sandbags, fiber rolls, or reusable products, and are placed across the drainage paths of stormwater controls, or used for erosion control (CSQTF, 1993). Check dams are usually considered in the context of erosion control. However check dams can also be used to enhance open channel TSCs, such as biofilters, particularly in situations with higher ground slopes. Check dams have also found applications in the field of stream restoration, the subject of which is beyond the scope of this document. If fish passage is an issue in a channel, the check dams must be designed with a small weir or pipe, and possibly with baffles, to permit upstream passage.

Check dams can reduce flow velocities in vegetated swales by obstructing the flow path. The pools that typically form on the upstream side of check dams can enhance sedimentation and infiltration into shallow soils. The check dam itself serves as a barrier to trapped sediment and other solids that would otherwise pass through to the drainage system outlet, although in some cases scour during an event may limit that benefit.

For consistent performance, check dams should be routinely inspected, and the captured sediment removed. Inspections after large storm events are recommended to detect structural damage that can lead to resuspension of captured sediment and release into the drainage system. Although check dams can trap sediment, they must not be used as a standalone TSCs for solids removal.

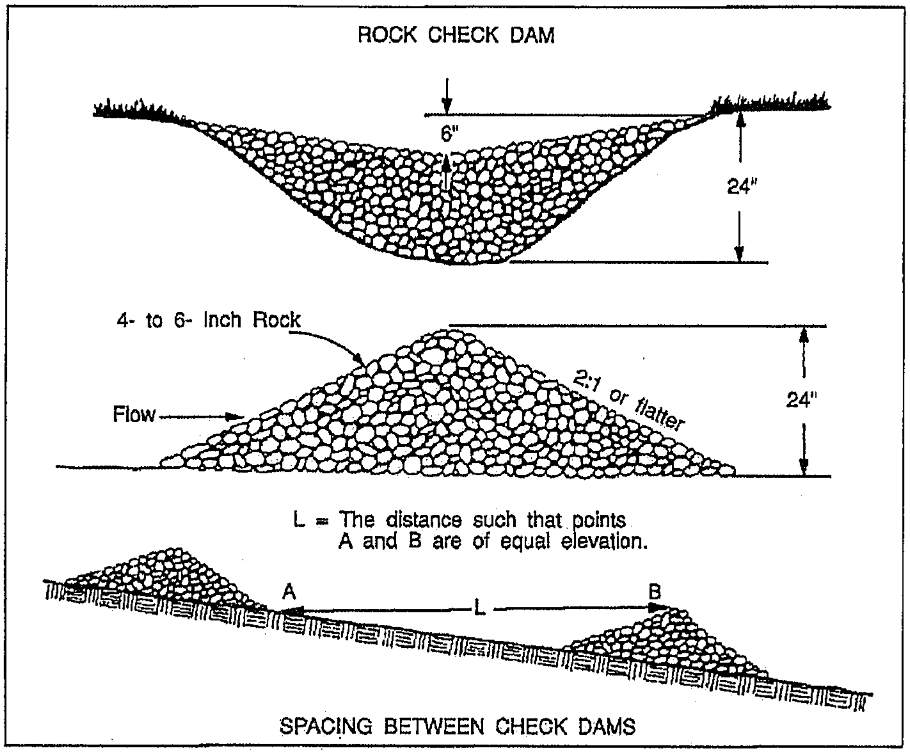


Figure 5-23. Check Dam Schematic
Source: Urban Drainage and Flood Control District (UDFCD, 1999).

5.6.4 Flow Splitters

A TSC often has a limiting hydraulic (flow) or storage capacity, and provision must be made for bypass. The bypass is conveyed into a constrained device via a weir, orifice or combination, an example of which is illustrated in Figure 5-24. The concept is not dissimilar from a regulator that diverts a specified flow into an interceptor sewer upstream of a combined sewer overflow location. A rating curve must be developed for the weir and/or orifice control such that the inflow into the TSC is appropriately limited. Flow splitters are also available commercially and are sometimes included as a component of proprietary devices.

Other considerations include adequate hydraulic head and maintenance to prevent clogging by debris. Flow splitters are discussed in WEF and ASCE (1992) and other stormwater control manuals. Flow splitting for sampling purposes can be quite complex.

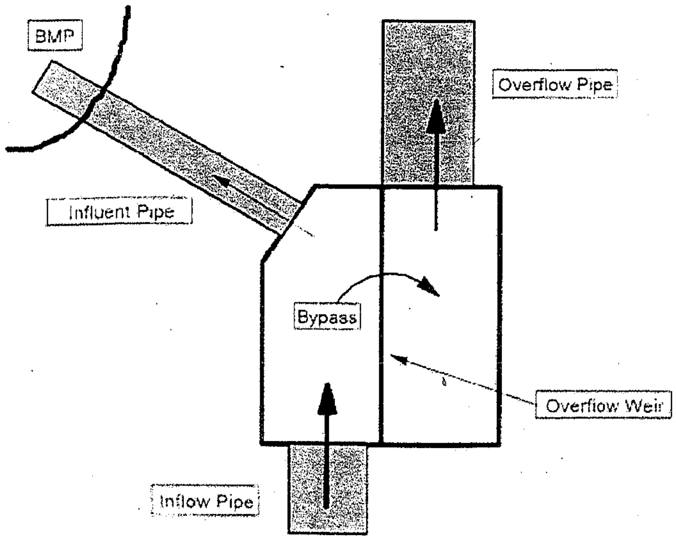


Figure 5-24. Schematic of a Generic Flow Splitter.
Source: Metropolitan Council (2001).

5.6.5 Berms

Berms are embankments (often built with earthen material) that provide containment for stormwater, either by partitioning a larger impoundment (Figure 5-25) or as part of the embankment for the entire impoundment. Most volume-based TSCs employ earthen berms because other materials such as plastic or concrete walls are expensive. TSCs that employ or benefit from berms include ponds, biofilters, and media filters. Berms create storage volume for water quality treatment flows and also flood control storage volumes in cases where there are multiple uses of a basin, for example. Berms can be built with sandbags, earth, and construction waste materials. Structural (hydraulic, geotechnical) considerations for embankments may be found in UDFCD (1999) and other publications, such as Bureau of Reclamation (1987). Such considerations are as important as the depth of storage behind the embankment increases and/or the consequences of downstream flooding due to failure are significant.

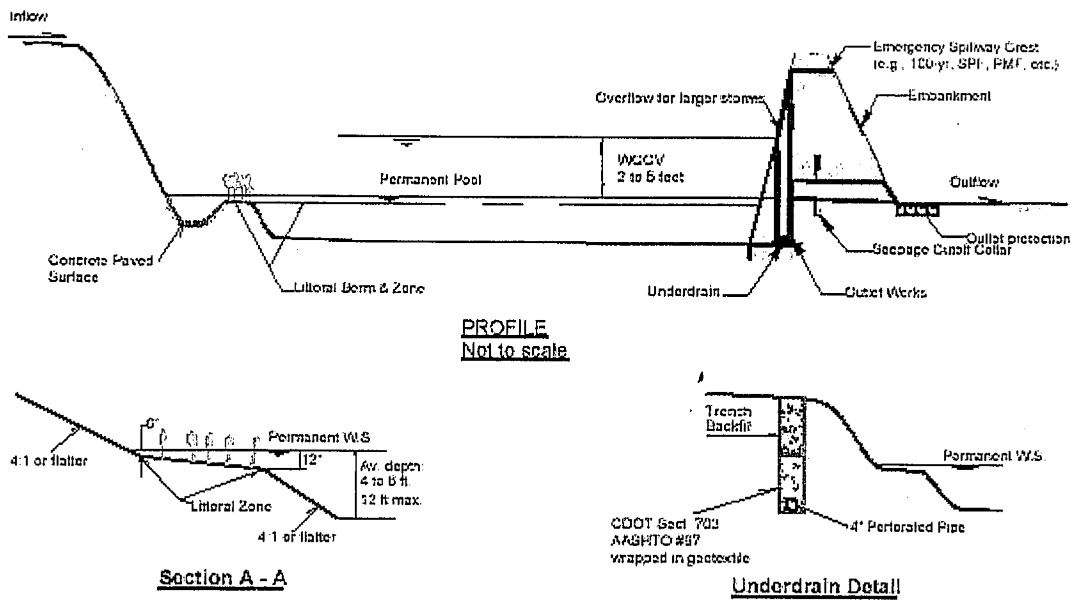


Figure 5-25 Berm as Part of Component of Retention Pond.
Source: Urban Drainage and Flood Control District (UDFCD, 1999).

Small berms require little maintenance; however, periodic inspections are recommended to keep berms structurally sound. Due to the potential flooding that may result from berm breaches, inspections should be conducted after every large event, including checking for piping and slope failure. Vegetated berms may need to be mowed and occasionally reseeded to maintain vegetation. For ease of maintenance and safety when traversing, larger embankment side slopes should not be steeper than 4 horizontal to 1 vertical (WEF and ASCE, 1992).

5.6.6 Inlet and Outlet Structures

Inflow to detention facilities is usually through a culvert or pipe and less commonly via a small spillway or open channel. In all cases, it is necessary to protect against erosion and possible structural damage, as discussed in Section 5.6.2. The potential for upstream backwater effects should also be investigated. Inlet and outlet structures for detention basins should be separated as much as possible to avoid short-circuiting. The UDFCD (1999) recommends a gradual expansion away from the inlet and contraction towards the outlet, with a basin length to width ratio of between 2:1 and 3:1. A trash rack is sometimes placed at the basin entrance to collect large and unsightly debris and gross pollutants.

Arguably the most sophisticated hydraulic designs in stormwater treatment systems are for outlet structures of detention basins. Design considerations include:

- detention of possible flood control volume (FCV), for a typical multi-purpose basin;
- detention of the water quality control volume (WQCV);
- development of a rating curve for release of both the flood control volume and the WQCV;
- selection of outlet structure design from many possible hydraulic components, including orifices, weirs, risers, gravel filters, underdrains, etcetera;

- structural integrity of the outlet structure;
- maintenance, including protection against clogging, removal of trash, etcetera;
- safety, where it would be possible for humans or animals to access the structures.

The desired outlet rating curve (flow versus depth) is constructed based on desired detention times for the FCV (larger volume from less frequent storms) and WQCV (smaller volume from frequent storms), as discussed in more detail in Section 7.1. The goal is to design an outlet such that the smaller WQCV has sufficient detention to provide sedimentation and water quality benefits before passing through a larger capacity outlet that releases larger volumes of flood storage. As one example, in Denver, CO, the WQCV is to be released "...over a 40-hour period, with no more than 50 percent of the top of the WQCV being released in 12 hours." (UDFCD, 1999, Volume 3, page S-38). Release of the FCV (e.g., from storage of a design 10-year or 100-year storm event) in Denver is based on the capacity of the upstream catchment to infiltrate additional rainfall (slower release allowed for sandy soils in the catchment). While other localities might specify drawdown of the FCV in a specified time, such as 72 hours, to empty the facility for the next event. This necessarily results in a combination of small orifices, infiltration channels, or small pipes to release the WQCV, and larger drop inlets, weirs, or spillways (at higher elevations in the detention basin) to release the FCV (see Section 7.1.1.1).

Outlet structures can consist of elements such as:

- infiltration into buried tile drain or perforated collector pipe (i.e., underdrains)
- small or larger pipes or culverts on the bottom or sides of a basin
- vertical risers, sometimes constructed from a culvert segment, often perforated and protected against clogging by gravel around the perimeter
- orifice plates on side of vertical riser
- drop inlets to a drainage pipe
- spillways

A typical combination of elements is shown in Figure 5-26, in which low flows are released slowly through the orifice plate, and higher flows are released over the drop shaft or spillway. (See also Figure 5-25, and figure in Figure 7-2 in Section 7.1) A huge variety of combinations are available to the engineer, from which a rating curve may be constructed by adding the flow rates through each outlet at a given head. Whether or not an outlet will behave exactly like an orifice (Equation 5-21), or a broad or sharp-crested weir (Equation 5-22, Equation 5-23) depends among other things, on the geometry of the device and possible tailwater influences. V-notch weirs (Equation 5-23) are often a better choice for water quality treatment than rectagular weirs because they provide larger detention at low flows while providing flood protection at high flows.

$$Q_{orf} = C_d * A * (2gh)^{0.5} \quad [5\text{-}21]$$

Where: Q_{orf} = Flow through orifice
C_d = Orifice contraction coefficient
A = Orifice flow area, ft^2
h = design head, ft (equal to the inlet pipe diameter)
g = acceleration due to gravity

$$Q_{weir} = C_d * L * (h)^{1.5}$$ [5-22]

Where Q_{weir} = Flow through weir
C_d = weir coefficient
h = available head, ft (height of weir)
L = design weir crest length, ft

For a v-notch weir, the weir equation becomes (all parameters previously defined):

$$Q_{v-notch} = \frac{8}{15} \cdot \tan\left(\frac{\theta}{2}\right) \cdot \sqrt{2g} \cdot h^{5/2}$$ [5-23]

Equation 5-22 applies to a fully submerged orifice. For example, a pipe often behaves as an orifice when completely submerged, but behaves as an open channel or culvert when only partially submerged. Discharge coefficients may need to be determined for odd shapes through hydraulic model studies; traditional (e.g., Davis, 1952) and newer (e.g., French, 1985; Mays, 2001) hydraulic references may be consulted for coefficient values for common shapes. Clogging or structural damage can also alter the hydraulic characteristics of the structure; a conservative design that will meet maximum outflow constraints is encouraged. Should it be necessary to protect against backflow, flap gates may be provided.

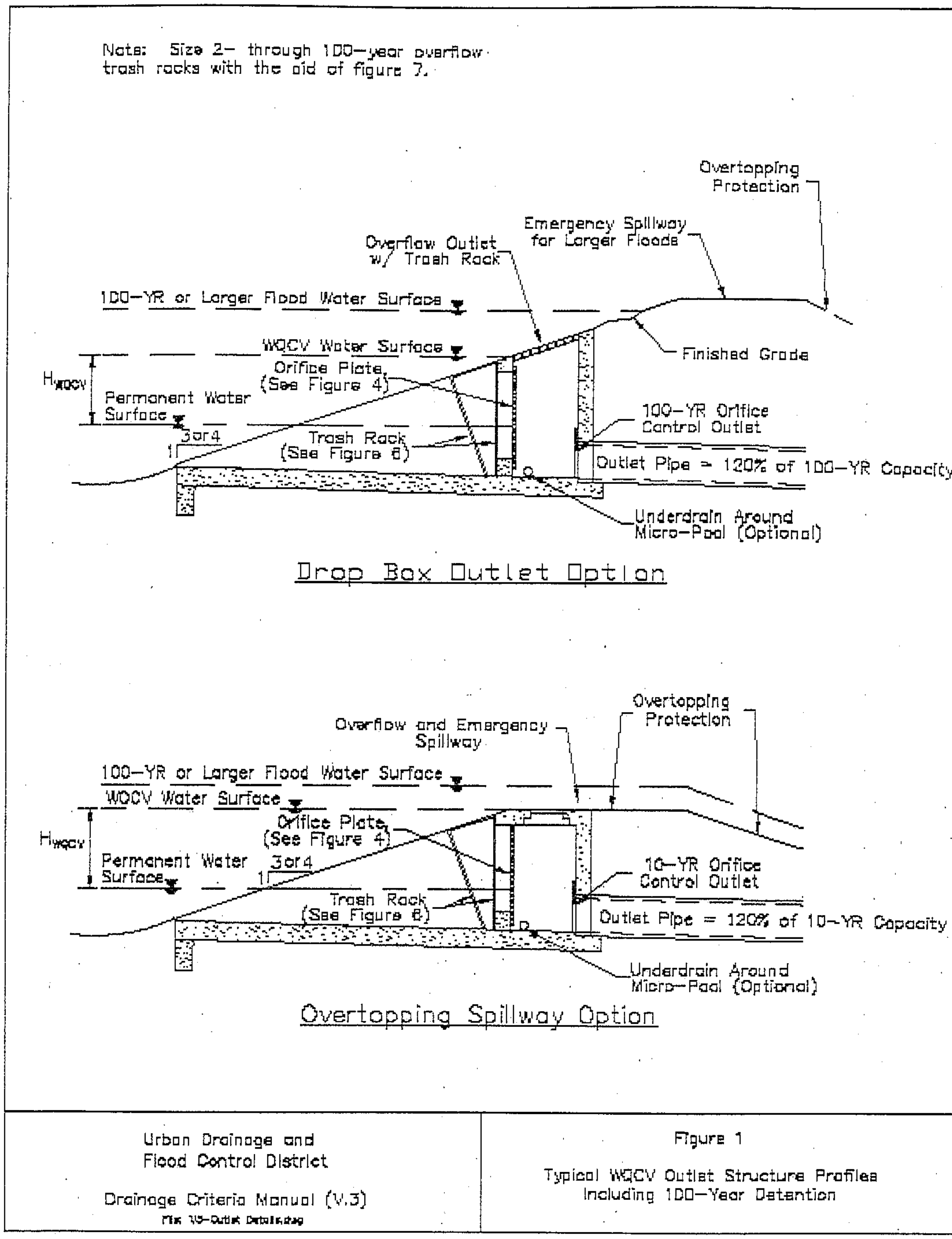
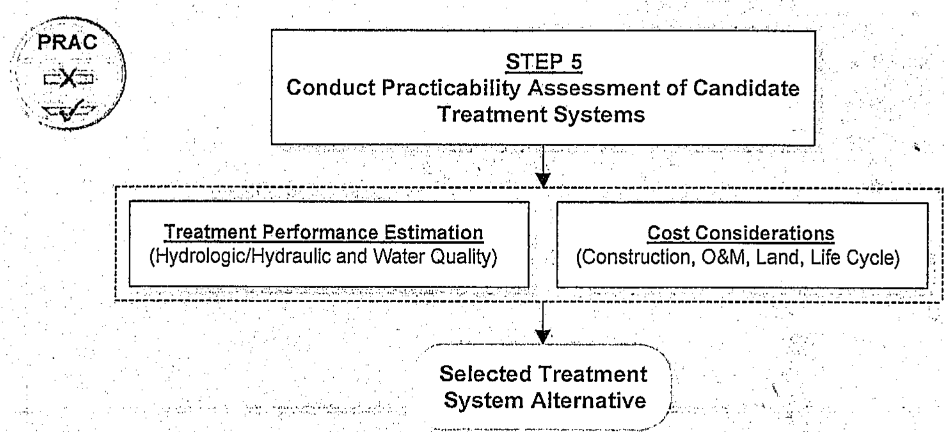


Figure 5-26. Typical Configuration of a Combination Outlet. The water quality control volume is released through an orifice plate and the flood volume discharges through the drop inlet or spillway. Source: Urban Drainage and Flood Control District (UDFCD, 1999).

CHAPTER 6.0

PRACTICABILITY ASSESSMENT OF CANDIDATE TREATMENT SYSTEMS



Key Concepts:

- How can you identify the best treatment system option based on hydrologic and hydraulic performance?
- What resources are available to help select the best treatment option from the candidate TSCs based on treatability data and water quality performance?

6.1 Introduction

Evaluating the practicability of candidate TSCs requires consideration of several site-specific factors including expected performance for target pollutants, hydrology and hydraulics, surface and subsurface space availability, maintenance, costs, and aesthetics. Other factors include safety, regional constraints, and downstream impacts. Many of these factors are discussed in Chapters 3.0 and 5.0. This chapter addresses in detail two of the most important practicability factors: 1) treatment performance in terms of meeting hydrologic, hydraulic and water quality goals, and 2) costs associated with implementation, operation, and maintenance. The last section in this chapter summarizes other common practicability factors that should be considered when assessing alternative treatment system designs and components. As many practicability factors are highly site-specific, all potentially relevant factors could not be included in this document. The design engineer should use the information presented in previous chapters to account for site-specific conditions as much as possible, but additional sources of information may be required. For instance, snowmelt hydrology was briefly discussed in Section 3.2.5, Seasonality and Long-term Variation, but additional information may be required for a particular site due to the complexity of snowmelt processes. If snowmelt is expected to be a significant contributor to annual runoff at a site, the design engineer should review Novotny et al. (1999) for additional information on snowmelt characteristics and treatment options. Also see Caraco and Claytor (1997) and Metropolitan Council (2001) for guidance on the selection and design of stormwater treatment systems in cold climates.

6.2 Treatment Performance Estimation

Estimating the treatment performance of a TSC requires an evaluation of 1) runoff volume reductions, 2) long-term, volumetric capture efficiency and 3) expected effluent quality for target constituents.

6.2.1 Volume Reduction

There is certainly a basis for factoring in volume and resulting pollutant load reductions into performance estimates, particularly when there are TMDLs. The infiltration capacity of the soils in a TSC primarily influences the volume reduction through infiltration to subsurface and, combined with vegetation, ET. Soils with a high fraction of clays will prevent significant stormwater volume reductions due to their poor infiltration capacity. If stormwater volume reductions are a goal for a detention basin, soils can be amended to improve the capacity for infiltration. Higher infiltration rates will result in larger volumes entering the soils for immediate infiltration, as well as after storm ET losses. The ET rates are also important, as they affect whether soils dry out in time to infiltrate stormwater from the next event.

It is expected that wet ponds and wetland basins or channels might not significantly decrease the volume of runoff because soils suitable for placement of a wet pond or wetland basin will typically exhibit low infiltration capabilities. Otherwise a liner will be necessary to maintain the water quality pool during the wet season. Due to the need to maintain a permanent wet pool for optimal pollutant removal in a constructed wetland, little volume reduction can be expected due to infiltration losses. However, volume reductions would be expected in biofilters due to drier, more permeable soils and complete vegetative cover.

Based on the limited study data available, dry detention basins and biofilters show an average volume reduction of about 30% and 38%, respectively, while wet ponds and wetland basins show an average volume reduction of about 7% and 5%, respectively (Table 6-1) (Strecker et al., 2004). Based on this analysis, detention basins (dry ponds) and biofilters (vegetated swales, overland flow, etc.) appear to contribute significantly to volume reductions, even though they are not likely designed specifically for this purpose. Assuming a capture efficiency (discussed in the next section) of 80%, a dry detention basin could be expected to reduce stormwater runoff volumes by about 25% on average. The actual volume reduction depends on the infiltration characteristics of the soils and local ET rates. Therefore, a long-term water balance simulation using a continuous hydrologic model may be necessary to accurately estimate annual average volume reductions.

Table 6-1. Average Volume Losses in Treatment System Components.

TSC (BMP) Type	Mean Monitored Outflow/Mean Monitored Inflow for Events Where Inflow is Greater Than or Equal to 0.2 Watershed Inches
Detention Basins	0.70
Biofilters	0.62
Media Filters	1.00
Hydrodynamic Devices	1.00
Wetland Basins	0.95
Retention Ponds	0.93
Wetland Channels	1.00

(Source: International Stormwater BMP Database; all units in mg/L; values in parenthesis are the 95% confidence intervals about the median).

6.2.2 Capture Efficiency

The capture efficiency (percent of stormwater runoff volume treated) of an on-line volume-based TSC (e.g., detention facility) is primarily a function of the volume of the facility and the hydraulic design of the outlet structure (e.g., brimfull or half brimfull emptying time of the detention facility). A properly designed storage-based TSC should generally result in capture efficiencies satisfying regulations (e.g. on the order of ≥ 70-90% of the long-term flows from the watershed). Untreated stormwater runoff volumes that bypass the detention facility will therefore generally be less than 30% of the annual average runoff volume, ideally on the order of 10-20%.

For volume-based TSCs, the bypassed, untreated flows occur most often from the tail end of large storms. Depending on the pollutant and the runoff characteristics of the watershed, these bypasses will frequently have lower pollutant concentrations because the majority of particulate-bound pollutants are washed off of impervious surfaces and discharged earlier in the storm. This higher pollutant loading at the beginning of a storm event is referred to as the "first flush" effect (Section 3.3.4). However, for many pollutants and under the varied rainfall conditions found seasonally and geographically around the U.S., a first flush effect may not exist. First flush is frequently oversimplified for the complex phenomena of pollutant source loading to runoff.

For flow-based TSCs, flow bypass occurs whenever the flow rate exceeds the design capacity of the device. This generally occurs near the peak of the runoff hydrograph. If the facility is off-line, a flow splitter, valve, or weir typically regulates the bypass. However, if the TSC is an on-line facility (e.g., swale as part of the primary stormwater conveyance system) ~~then~~ flows are not physically bypassed, but treatment levels generally decrease as the flow rate exceeds the water quality design flow rate. The annual average volumetric capture efficiency can be estimated by integrating under the historic hydrograph or the long-term flow-duration curve. The integration at a particular flow rate yields the average runoff volume to be treated. By integrating at a range of flow rates, the flow-based system can be sized for the flow rate that would capture the desired runoff volume percentage to be treated (e.g. 80%). As with volume-based treatment systems, flow-based systems are evaluated in Appendix E for thirty locations in the U.S.

Design Volume: In simplified sizing approaches, the design volume (often expressed in watershed inches) is the depth of runoff that results in a runoff volume equivalent to the storage design volume of a detention basin. The runoff volume for the tributary area is a function of the watershed size and runoff coefficient; the runoff coefficient is a function of the impervious fraction and soil type(s) in the tributary area. Larger design depths result in a larger percentage of the stormwater runoff captured by the basin. However, as design depths become excessively large, only relatively marginal improvements are gained. Given that drain time criteria remain constant, very large design depths are undesirable because the smaller, more frequent storms will pass quickly through the basin without receiving sufficient detention time for sedimentation to occur. A proper design depth provides nearly complete treatment of smaller, more frequent storms, and captures significant portions of larger storms. Continuous simulation screening results are provided in Appendix E that show percent capture versus design depths for thirty locations in the U.S.

Drawdown Rate: The drawdown rate is the outflow rate (cfs) at which a detention facility is emptied. Often the upper third of the detention basin is emptied in half of the detention time (from full pool), while the lower two-thirds is emptied in the remaining detention time (WEF and ASCE, 1998). This scenario creates storage capacity quickly for the next storm event if the next storm occurs before the basin is completely empty (i.e. storm interevent times typically less than 24-72 hours). Slower drawdown of the lower half of the pool promotes effective treatment for smaller storm events that would not completely fill the detention basin. Typical detention times range from 24 to 72 hours to achieve sedimentation and removal of associated pollutants. Short detention times (e.g. 24 hours) create storage volume more quickly, resulting in a higher capture efficiency, but do not allow as much time for sedimentation. An appropriate detention time should be based on the expected particle size distribution in stormwater runoff, and typical storm interevent times. Longer detention times are appropriate to treat runoff with a large fraction of fine particles. Shorter detention times are more appropriate for stormwater runoff with fewer fines, or in areas with storms that occur in series with short interevent times. A drain time of 36-48 hours from a brimfull condition is often an appropriate compromise between the removal efficiency of particles and capture efficiency of stormwater runoff volumes.

6.2.3 Pollutant Removal

Median influent and effluent concentrations for various TSCs and common target constituents are shown in Table 6-2. The data are from the International Stormwater BMP Database (www.bmpdatabase.org) as of October 2004. Data summaries by typical stormwater pollutants are also provided in the Pollutant Fact Sheets (Appendix A). The degree of pollutant removal depends on the pollutant species/form and the level of treatment provided by the TSCs. As discussed in Chapter 5.0, design features such as pond surface area, length-to-width ratio, vegetation and soil types, and the use of a forebay or other enhancements may affect the type and level of treatment provided. Since the data presented in Table 6-2 represent typically designed TSCs, treatment systems specifically designed to provide specific UOPs may perform better than the median values shown. The design engineer must decide if his/her system should be assigned an effluent quality value lower than the median, such as the lower 95% confidence interval, when making performance estimates. Alternatively, some of the theoretical/empirical equations presented in Chapter 4.0 could be used to estimate performance. However, since these equations are based on simplified representations of complex unit operations and processes, over-reliance on these equations without supportive performance data should be avoided if possible.

Table 6-2. Median of Average Influent and Effluent Concentrations of Treatment System Components.

Constituents	Point of Discharge	Detention Pond	Wet Pond	Wetland Basin	Biofilter	Media Filter	Hydrodynamic Devices
Suspended Solids (mg/L)	Influent	87.73 (48.4-159.1)	88.38 (48.9-159.7)	82.12 (65.7-102.7)	51.95 (22-123)	61.14 (45.4-82.4)	110.74 (51.1-240.1)
	Effuent	41.35 (30.8-55.5)	19 (12.9-28.0)	19.68 (16.6-23.4)	24.6 (15.0-40.3)	25.47 (14.7-44.3)	40.34 (18.4-88.7)
Total Cadmium (µg/L)	Influent	2.3 (1.9-2.9)	0.55 (0.1-2.6)	xx	0.58 (0.3-1)	0.4 (0.2-0.8)	1.69 (1.4-2.1)
	Effuent	1.3 (0.8-2.2)	0.31 (0.05-2.0)	xx	0.25 (0.21-0.34)	0.31 (0.16-0.59)	1.65 (1.05-2.6)
Dissolved Cadmium (µg/L)	Influent	xx	xx	xx	0.26 (0.1-0.9)	0.29 (0.2-0.4)	0.72 (0.4-1.3)
	Effuent	0.41 (0.22-0.76)	xx	xx	0.22 (0.11-0.43)	0.24 (0.18-0.33)	0.93 (0.27-3.2)
Total Copper (µg/L)	Influent	32.28 (22.7-46)	17.89 (7.4-43)	xx	21.8 (11.6-40.9)	15.29 (12.4-18.8)	21.43 (14.7-31.2)
	Effuent	18.9 (16.6-21.5)	6.92 (4.7-10.3)	xx	10.01 (5.6-17.9)	9.81 (8.1-11.8)	14.13 (11.1-18.1)
Dissolved Copper (µg/L)	Influent	12.11 (8-18.3)	8.87 (5.4-14.6)	xx	12.32 (6.5-23.4)	8.83 (6.7-11.6)	12.07 (3.7-39.5)
	Effuent	14.72 (10.4-20.9)	5.09 (3.1-8.3)	xx	7.66 (4.7-12.5)	7.95 (6.6-9.7)	8.63 (3.3-22.9)
Total Chromium (µg/L)	Influent	9.45 (9.5-9.5)	7.31 (2.7-19.6)	xx	2.46 (1.1-5.5)	2.78 (1.8-4.3)	xx
	Effuent	2.85 (1.7-4.8)	1.78 (0.5-6.7)	xx	2.18 (1.2-4.0)	1.46 (0.9-2.3)	xx
Total Lead (µg/L)	Influent	69.2 (33.6-142.5)	33.34 (10.2-109.3)	12.63 (3.8-42)	19.56 (7.4-51.6)	15.61 (9.3-26.1)	21.96 (10.6-45.7)
	Effuent	15.02 (9.5-23.8)	6.68 (2.9-15.6)	3.25 (1.9-5.6)	6.95 (4.2-11.7)	5.5 (3.5-8.6)	12.98 (4.2-40.2)
Dissolved Lead (µg/L)	Influent	3.4 (2-5.8)	9.48 (0.9-101.4)	xx	2.5 (0.9-6.9)	2.18 (1.6-3.1)	1.87 (1.1-3.1)
	Effuent	2.33 (1.7-3.3)	4.16 (2.0-8.9)	xx	1.35 (0.5-3.6)	1.42 (1.0-1.9)	2 (0.6-6.5)
Total Zinc (µg/L)	Influent	273.84 (177.7-421.9)	75.29 (44-128.9)	164.27 (54.6-494.1)	129.17 (57.3-291.3)	121.8 (72.6-204.3)	167.1 (123.1-226.8)
	Effuent	85.26 (50.6-143.7)	28.63 (21.4-38.3)	118.73 (32.8-429.5)	39.44 (28.2-55.2)	64.96 (45.3-93.2)	89.66 (74.4-108.1)
Dissolved Zinc (µg/L)	Influent	48.79 (22.7-104.8)	57.36 (20.1-163.4)	xx	67.39 (33.8-134.4)	71.66 (41.3-124.4)	48.56 (28-84.3)
	Effuent	43.99 (20.0-96.6)	16.89 (2.6-109)	xx	31.96 (26.7-38.3)	57.14 (37.7-86.6)	45.17 (29.6-68.9)
Total Phosphorus (mg/L)	Influent	0.4 (0.3-0.5)	0.53 (0.3-0.9)	2.91 (1.9-4.6)	0.19 (0.1-0.4)	0.25 (0.2-0.4)	0.79 (0.3-2.2)
	Effuent	0.3 (0.2-0.44)	0.16 (0.12-0.21)	0.15 (0.07-0.33)	0.32 (0.24-0.43)	0.14 (0.11-0.17)	0.19 (0.07-0.51)
Dissolved Phosphorus (mg/L)	Influent	xx	0.2 (0.1-0.4)	0.06 (0-0.1)	xx	xx	xx
	Effuent	xx	0.07 (0.04-0.13)	0.07 (0.03-0.18)	xx	xx	xx
Total Nitrogen (mg/L)	Influent	xx	1.49 (0.6-3.6)	2.56 (1.6-4)	0.58 (0.3-1)	xx	xx
	Effuent	xx	1.17 (0.77-1.78)	2.42 (1.46-4.0)	0.69 (0.37-1.29)	xx	xx
Nitrate-Nitrogen (mg/L)	Influent	0.89 (0.5-1.6)	1.15 (0.3-5.1)	0.63 (0.4-1.1)	0.31 (0.2-0.6)	0.55 (0.4-0.8)	xx
	Effuent	0.64 (0.37-1.09)	0.48 (0.11-2.05)	0.46 (0.16-1.28)	0.5 (0.36-0.68)	0.82 (0.68-0.97)	xx
TKN (mg/L)	Influent	1.99 (1.6-2.5)	1.06 (0.8-1.4)	1.23 (1-1.6)	2.27 (1.8-2.9)	2.2 (1.7-2.9)	6.37 (2.3-17.3)
	Effuent	1.87 (1.46-2.39)	0.84 (0.68-1.04)	1.33 (0.84-2.11)	1.6 (1.42-1.8)	1.79 (1.45-2.2)	4.68 (1.97-11.12)

Notes: xx - Lack of sufficient data to report median and confidence interval. All units in mg/L; values in parenthesis are the 95% confidence intervals about the median. See Appendix A for more detailed summary of BMP performance data.
Source: International Stormwater BMP Database October 15, 2004 (www.bmpdatabase.org).

6.2.3.1 Suspended Solids

Larger suspended solids can be removed effectively by gravitational sedimentation, screening or surficial straining. For most well-designed TSCs that incorporate these UOPs, the median effluent concentrations range from 20 to 40 mg/L, provided the concentration and characteristics (e.g., particle size distributions) of influent suspended solids do not significantly deviate from "typical" stormwater. Well designed treatment systems that incorporate wet pools and wetland vegetation typically exhibit good effluent quality for suspended solids. Based on currently available data, these TSCs can typically achieve effluent concentrations of around 20 mg/L. Well designed biofilters and media filters also perform well in achieving low effluent suspended solids concentrations (~25 mg/L).

The presence of a permanent wet pool is a feature of a wet pond/wetland system. Incorporating even a small permanent wet pool can significantly improve the sediment removal performance of a TSC by providing long periods of retention during smaller storms. Long retention times during small events allow for appreciable sediment removal compared to dry facilities that typically have very limited detention times during small events. Generally, settleable solids comprised of inorganic particles in the 25-75 μm range are effectively removed by quiescent gravitational sedimentation (Section 4.3.3).

For biofilters and media filters, filtration and to a limited degree gravity settling, are the primary removal mechanisms for suspended sediments. Direct filtration can usually be effectively accomplished at concentrations less than 50 mg/L, and generally requires some level of pretreatment in urban runoff, where solids concentrations are frequently above 100 mg/L and can exceed 1,000 mg/L depending on the site, loading, and hydrology. Generally, the removal of suspended inorganic particles less than 25 μm require some natural or enhanced coagulation/flocculation followed by sedimentation and/or filtration.

Based on the available data, the central tendency of TSS effluent concentrations is significantly higher (i.e., poorer effluent quality) for dry detention basins (which drain after each event and generally lack a significant littoral zone) and hydrodynamic TSCs (flow-through systems that rely on centrifugal forces and screening to provide treatment). However as noted above, dry detention basins have been shown to provide considerable reduction in effluent volume (up to about 30%), which may translate to lower total mass loading of TSS downstream.

6.2.3.2 Trace Metals

The important forms of trace metals from a treatability and regulatory perspective are total, dissolved, and particulate-bound metals. If bound to organic or inorganic particulates, viable unit operations include sedimentation and filtration either as separate unit operations or in combination with coagulation/flocculation as pretreatment to these operations. If present as a dissolved complex, precipitation could be effective. If present as a dissolved ionic species such as Cu^{2+}, Pb^{2+}, or Zn^{2+}, surface complexation (including adsorption) could be effective. Based on effluent quality, well designed wet ponds, biofilters, and media filters can provide better effluent quality compared with detention pond and hydrodynamic devices (Table 6-2). TSCs that are effective in removing trace metals also are typically good at removing fine particulates.

6.2.3.3 Nutrients

Treatability for phosphorus is a function of whether phosphorus is present in particulate or dissolved form. In dissolved form, phosphorus may readily undergo surface complexation reactions, sorption, or precipitation (Section 3.3). Uptake by vegetation and microbes is another mode by which dissolved phosphorus is effectively removed. Media or soils containing iron, aluminum or hydrated Portland cement can be very effective at removing dissolved phosphorus species through surface complexation or precipitation. If bound to organic or inorganic particles, viable UOPs include sedimentation and filtration either alone, or in combination with pretreatment using coagulation/flocculation.

As shown in Table 6-2, media filters, wet ponds, and wetland basins report the lowest median effluent total phosphorus concentrations, although only wet ponds have a statistically significant difference between median influent and effluent values (i.e., the TSC affected total phosphorus concentrations). While median effluent levels for dissolved phosphorus are the lowest for wetland basins, the available data are insufficient to reliably differentiate the performance of various TSCs.

Nitrogen compounds exist in dissolved form and as particulate-bound species. Treatability success for nitrogen species, as with other constituents in stormwater, is highly dependent on the form and species of nitrogen present. Treatability for nitrogen also depends on the presence of specific bacteria that mediate nitrogen transformations. Physical operations such as sedimentation have played an insignificant role with respect to treatment of nitrogen as compared to microbially mediated transformations. Microbial decomposition of organic matter mineralizes nitrogen as ammonia, which can be oxidized to nitrite and nitrate. Nitrate can be reduced to nitrogen gas by anaerobic bacteria, for complete removal from the system. Median effluent quality of total nitrogen, total Kjeldahl nitrogen (TKN), and nitrate-nitrogen are summarized in Table 6-2. However, available data on removal of nitrogen species are insufficient to draw definitive conclusions about TSC performance based on averaged effluent concentrations.

Filters, ditches, and dry ponds typically exhibit poor nitrate removal, and in many cases have been shown to export nitrate. In these TSCs, organic nitrogen is converted to nitrate in the mineralization and nitrification processes, however the aerobic conditions are not favorable for denitrification. Thus, theses TSCs may export more nitrate than is present in the influent. Conversely, in wet ponds and wetland basins, plants, algae and other microorganisms take up nitrate as an essential nutrient. However, nitrogen is also released back into the system upon death or decay of the organisms.

6.3 Cost Considerations

Estimating the costs of stormwater treatment systems, including annual operations and maintenance costs, is one of the more challenging aspects of stormwater planning and management. The following subsections present some simplified methodolgies for estimating these costs.

6.3.1 Life Cycle Costs

Life cycle costs should be evaluated for candidate TSCs. The present value of the life cycle cost for a treatment system is equal to the sum of the following costs: 1) initial construction, 2) land, 3) the present worth of the total annual operating and maintenance, and 4) the present worth of the salvage value of the system. Annual life cycle costs can be calculated as the sum of the following costs: 1) the amortized value of initial construction, 2) amortized land value, 3) average annual operating and maintenance, and 4) the amortized salvage value.

Equations 6-1, 6-2, 6-3 can be found in any text on engineering economics, and can be used to calculate the present worth of annual operation and maintenance costs, present worth of the salvage value, and an equivalent annual value of the present worth, respectively. The service life (n) of the system and an associated interest rate (i) must be estimated to calculate costs.

Present worth (P) of Annual O&M costs (A)

$$P = A\left(\frac{(1+i)^n - 1}{i(1+i)^n}\right) \quad [6\text{-}1]$$

Present worth (P) of the salvage value (F)

$$P = \frac{F}{(1+i)^n} \quad [6\text{-}2]$$

Equivalent annual value (A) of a present worth (P).

$$A = P\left(\frac{i(1+i)^n}{(1+i)^n - 1}\right) \quad [6\text{-}3]$$

Note that i is the interest rate per compounding time period (A) over the service life of the system (n). For instance, if interest rates were compounded monthly, then i is the annual interest rate divided by 12, and n is equal to $12 \cdot x$ years. The costs provided in this chapter are converted to July 2004 dollars using the consumer price index (CPI) shown in Table 6-3. The CPI is used because it is in the public domain and provides a good composite index across construction, operation and maintenance, and land value changes. The Engineering News Record construction cost index is another popular index. It is available for a small charge from the Engineering News Record (http://enr.construction.com/features/conEco/subs/default-city.asp?referid=1850).

Table 6-3. Consumer Price Index (CPI) for 1994 to 2004.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL
2004	185.2	186.2	187.4	188	189.1	189.7	189.4
2003	181.7	183.1	184.2	183.8	183.5	183.7	183.9
2002	177.1	177.8	178.8	179.8	179.8	179.9	180.1
2001	175.1	175.8	176.2	176.9	177.7	178	177.5
2000	168.8	169.8	171.2	171.3	171.5	172.4	172.8
1999	164.3	164.5	165	166.2	166.2	166.2	166.7
1998	161.6	161.9	162.2	162.5	162.8	163	163.2
1997	159.1	159.6	160	160.2	160.1	160.3	160.5
1996	154.4	154.9	155.7	156.3	156.6	156.7	157
1995	150.3	150.9	151.4	151.9	152.2	152.5	152.5
1994	146.2	146.7	147.2	147.4	147.5	148	148.4
	AUG	SEP	OCT	NOV	DEC	AVE	
2004	189.5	189.9	190.9	191	190.3	188.9	
2003	184.6	185.2	185	184.5	184.3	183.96	
2002	180.7	181	181.3	181.3	180.9	179.88	
2001	177.5	178.3	177.7	177.4	176.7	177.1	
2000	172.8	173.7	174	174.1	174	172.2	
1999	167.1	167.9	168.2	168.3	168.3	166.6	
1998	163.4	163.6	164	164	163.9	163	
1997	160.8	161.2	161.6	161.5	161.3	160.5	
1996	157.3	157.8	158.3	158.6	158.6	156.9	
1995	152.9	153.2	153.7	153.6	153.5	152.4	
1994	149	149.4	149.5	149.7	149.7	148.2	

Source: http://inflationdata.com/inflation/Consumer_Price_Index/HistoricalCPI.aspx
Note: historical CPI data back to 1913 are available at this web site.

6.3.2 Previous Cost Studies

The results of numerous studies of TSC control costs during the past 30 years have been summarized in recent reports. Heaney et al. (1999) developed wet-weather control costs as part of a larger study on BMP cost-effectiveness for U.S. EPA. Results of this study are summarized in Sample et al. (2003). These documents include summaries of the cost information presented by Young et al. (1996) who summarized earlier cost data with emphasis on highway costs. Numerous earlier cost studies were summarized by U.S. EPA (1999h). A report for Caltrans (2001) compares the costs of 39 BMPs built as test projects for them with other studies including significant efforts by the Southeastern Wisconsin Regional Planning Council (1991) and Brown and Schueler (1997). The Caltrans BMP costs were much higher than other reported costs. The primary reason seems to be that these BMPs were single purpose water quality retrofits in highly developed expressways. Thus, the Caltrans data are considered to be atypical and are not included in this analysis. The cost data presented herein are taken from the following sources:

1. City of Austin, TX (Caltrans 2001)
2. City of Portland, OR (Caltrans 2001)
3. Delaware DOT (Caltrans 2001)
4. Florida Department of Environmental Protection (Caltrans 2001)
5. King County, WA (Caltrans 2001)
6. Maryland State Highway Administration (Caltrans 2001)

7. Oregon DOT (Caltrans 2001)
8. Prince George's County, MD (Caltrans 2001)
9. Snohomish County, WA (Caltrans 2001)
10. Virginia DOT (Caltrans 2001)
11. Washington State DOT (Caltrans 2001)
12. Wossink and Hunt (2003)
13. Minton (2002)

These cost data were compiled into a single spreadsheet database for the analysis.

6.3.3 Construction Costs

Construction costs are normally estimated using one of two methods:

1. Cross-sectional analysis of comparable projects.
2. Process analysis of designs of various sizes by a design team. RSMeans® data (http://www.rsmeans.com) are based on this approach with some calibration against recently constructed projects.

The process analysis approach should be more reliable since it is performed under more carefully controlled conditions wherein all parameters but one are held constant (e.g., the cost of a house as a function of square footage). The process approach is highly recommended and should be used once candidate TSCs have been identified. The results of both approaches will be presented in this section.

6.3.3.1 Cross-Sectional Analysis of Comparable Projects

The traditional way to summarize cost estimating data is to approximate the total cost using a single variable power function as shown in Equation 6-4. This power function is linear in the log-transform. The two parameters can be estimated from a log-log graph or found using linear regression on the log-transformed data, or using nonlinear regression on the untransformed data. Finding the two parameters for the power function is easily accomplished using built in trend line functions available in standard spreadsheet software.

$$C = \alpha_0 x^{\alpha_1} \qquad [6\text{-}4]$$

where: C = total cost, \$,
x = independent variable that is a measure of size,
α_0 = coefficient, and
α_1 = exponent.

The exponent, α_1, represents the economies of scale, which in general terms, are factors that cause the average cost of production to decrease with increased output. If $\alpha_1 < 1.0$, then unit costs decrease as size increases. A generic economies of scale factor that has been used for years is $\alpha_1 = 0.6$ (Peters and Timmerhaus, 1980). When $\alpha_1 = 1$, the power function simplifies to a linear relationship and no economies of scale are present. If $\alpha_1 > 1$, then diseconomies of scale exist.

The power function approximation offers a way to replace a cost database with a single equation. It also satisfies the condition that total cost is zero if size is zero. However, this simple approximation may be inaccurate. Also, total cost is seldom a function of only one explanatory variable. For multiple variables, the estimated cost can be expressed in a general form as:

$$C = f(x_1, x_2, \ldots x_i, \ldots x_n) \qquad [6\text{-}5]$$

where: C = total cost, and
x_i = i^{th} independent variable

If a database of total costs as a function of n explanatory variables is available, an approximating equation can be developed using several multiple regression approaches. The drawback to this approach is that the relationship of total cost to explanatory variables is seldom this simple. For stormwater treatment systems, virtually all cost data are presented as a function of one of the following measures of size:

1. Contributing drainage area
2. Volume of the TSC
3. Design flow rate into the TSC

A cost analysis by Heaney and Lee (2005) using data from the above sources is summarized in Table 6-4. This database consists of 106 BMPs. Most data are for systems that incorporate storage TSCs (70 sites), with wetlands comprising the single largest category (25 sites). The median drainage area for the sites is about 5 acres, but the drainage areas are highly variable. Facilities with storage as the primary TSC tend to drain much larger areas. Obviously, drainage area imperviousness has a major impact on the hydrology of a site, and therefore system sizing and performance. However, for this cost analysis, only information on total drainage area was available, not percent imperviousness. The runoff volume expressed in watershed inches reflects the variation in sizing for the facilities examined and in the information presented here, ranges from 0.22 to 1.24 inches with a median of 0.78 inches. The median is used as the measure of central tendency due to wide variability in the data. The estimated unit costs per acre treated vary from about $3,700 for extended detention ponds to over $90,000 for Delaware sand filters. A better measure of drainage area is DCIA because it is the primary cause of runoff from the more frequent storms (Lee and Heaney, 2003). Wossink and Hunt's (2003) results show the same wide variability. If the price per gallon ($/gal) of water stored is used as the metric of performance, then the rankings are similar. Unit costs, in $/gal, range from $0.08 for wetlands to nearly $3.00 for sand filters. An important reason why wetlands have the lowest unit cost is that they are the largest controls and reflect the expected economies of scale for larger control units. Analysis of the effect of size on total costs showed wide scatter in the data with little evidence of economies of scale. However, a more accurate way to explore economies of scale is to use process-based data as will be described in the next section.

Table 6-4. Construction Costs as a Function of Service Area and Design Volume.

Control	Samples	Median Drainage Area, ac.	Median Runoff in./acre	Caltrans Median $/acre treated	NC State Median $/acre treated	Caltrans Median $/gallon	Caltrans Median 1,000 gal.
Compost Filter	11	2.70	0.22	$ 10,000		$ 0.60	68.4
Detention Pond, Extended	23	16.50	0.94	$ 3,739		$ 0.12	273.0
Detention Pond, Wet	22	36.70	0.43	$ 7,366	$ 4,600	$ 0.32	717.0
Detention Pond, Wetland	25	47.40		$ 7,444	$ 666	$ 0.08	1787.7
Infiltration Trench	8	4.36	0.78	$ 12,476		$ 0.62	14.1
Sand Filter, Austin	9	6.01	0.62	$ 14,952	$ 39,600	$ 2.86	68.8
Sand Filter, Delaware	4	1.30	1.24	$ 90,725	$ 39,600	$ 2.87	45.8
Swale	4	3.53	0.86	$ 11,238		$ 0.36	50.7
Total	106						
Median	10	5.18	0.78	$ 10,619	$ 22,100	$ 0.48	69

**All costs are in July 2004 dollars.*

6.3.3.2 Process Analysis of Control Costs

Process analysis of costs is done by having a single group of professionals design a control with all parameters fixed except one measure of size. This approach should provide more accurate information because all of the assumptions are controlled. The limitation of this approach is that it is more expensive and has not been done for wet-weather water quality controls. A good indicator of stormwater treatment costs can be obtained by evaluating similar controls such as storage devices and wastewater treatment plants using published estimates from companies such as RS Means.

Construction costs for four categories of water storage tanks are shown in Table 6-5. These data can be closely approximated by power functions of the form:

Construction cost ($1,000) = Cost/Volume = a*Volume(1,000 gal.)^b [6-6]

The average cost per gallon is then:
Average cost ($/gallon) = a*(Volume (1,000 gal.)$^{b-1}$ [6-7]

For example, the average cost of a 100,000 gallon elevated storage tank is (Table 6-5):
Average cost = $19.394*100^{0.5329-1}$ = $2.26/gallon.

Strong economies of scale exist for storage tanks with a range of exponents from 0.48 to 0.68. As expected, elevated tanks cost more per gallon than ground level tanks.

Table 6-5. Construction Costs for Water Storage Tanks Based on 2003 RS Means Data.

Storage	Minimum 1,000 Gal.	Maximum 1,000 Gal.	Parameters* a	b	R^2	Capacity in 1,000 gal. 10 $/gal.	100 $/gal.	1000 $/gal.
Elevated	50	1000	19.394	0.5329	0.982		$2.26	$ 0.77
Ground, concrete	100	10000	8.189	0.6185	0.99	$ 3.40	$1.41	$ 0.59
Ground, steel	250	10000	3.38	0.6804	0.982	$ 1.62		$ 0.37
Underground, small	0.55	15	2.3	0.482	0.975	$ 0.70		

*Parameters in the equation Total Cost ($1,000) = a*Capacity in 1,000 gallons^b.

It is instructive to compare unit costs in Table 6-5 with the treatment system costs in Table 6-4. Sand filters are in the 50,000 gallon size range and have a unit cost of about $2.86/gallon. This estimate is similar to the unit cost of a ground level concrete storage tank. The economies of scale factor is also estimated for packaged wastewater treatment plants. The economies of scale factor is about 0.66.

6.3.3.3 Conclusions on Treatment System Construction Costs

A relatively high variability exists in the reported construction costs of stormwater treatment facilities. Key sources of this variability include:

1. Most of these designs are multipurpose and also provide flood control and drainage. Thus, only a portion of the cost is assignable to water quality control costs.
2. Large regional variability in precipitation and runoff patterns.
3. Large variability in the cross-sectional data on how the costs are calculated.

The following conclusions can be used for preliminary cost estimating purposes.

1. The economies of scale factor for these controls is in the range of 0.65-0.70.
2. The price per gallon is a more reliable measure of average costs than $/acre since the latter measure does not correct for how much of the drainage area is directly connected.
3. First approximations of unit costs can be made using the following estimates:
    a. Volume based TSCs: $0.10-$0.30/gallon.
    b. Infiltration TSCs and Swales: $0.30-$0.60/gallon.
    c. Filtration TSCs: $2.50-$3.00/gallon.

6.3.4 Land Costs

Land costs can have a major impact on stormwater treatment facility costs. They may be zero for subsurface controls, or where the land is free. Land is "free" when it is in a right of way, easement, or it is some type of public land such as a park. At the other end of the spectrum, land cost can be the market value based on alternative uses of the land if it is not used as a stormwater control. In between these two extremes are a myriad of assumptions that can be made as to how this land should be valued. Heaney et al. (1999) and Sample et al. (2003) discuss these questions. No simple answer exists. The question of land valuation is becoming even more relevant as interest in LID increases. A key component of LID is to locate TSCs onsite by integrating them into the existing landscape. Thus, one could argue that a significant portion of landscaping costs should be included in stormwater treatment system costs or that onsite treatment is very inexpensive since the landscaping is already provided.

The following first approximations for land costs can be used in the analysis of urban areas:

- Unimproved land: $25,000-50,000 per acre.
- Improved land with infrastructure for residential developmentt: $75,000-200,000 per acre.
- Improved land for commercial development: $100,000-300,000 per acre.
- High density urban land: $500,000-2,000,000 per acre.

These costs represent the purchase price of land. However, land can have a significant resale value after the life of the project. Thus, one could argue that the return on selling the land will offset the initial cost, and so land has no net cost. A perhaps more reasonable assumption is that the net cost for land is the return forgone while it is being used as part of a treatment facility. The annual operation cost is equal to the land purchase price times the annual interest rate.

Land costs affect how much land is used for the various treatment facilities. Claytor and Schueler (1996), Wossink and Hunt (2003), and Pack (2004) provide current information on land use of controls relative to the drainage area treated as shown in Table 6-6.

Table 6-6. Ratio of Control Area to Drainage Area for TSCs.

BMP	Control area/drainage area		Source
	Min. %	Max. %	
Wet pond	1	5	Wossink & Hunt 2003
Infiltration basin	2	3	Claytor & Schueler 1996
Stormwater wetland	1.5	6.5	Wossink & Hunt 2004
Sand filter	0	3	Claytor & Schueler 1996
Bioretention	2	7	Wossink & Hunt 2005
Grass Swale	10	20	Claytor & Schueler 1996
Filter Strips	25	100	Pack 2004

These ratios are derived from data on in-place TSCs and simulations of the expected design ranges for filter strips.

The design depth of the treatment system also affects land costs. Table 6-7 shows an example of the expected impact of land costs on a wet detention system with an average depth of 4 feet versus a wetland with an average depth of 1.5 feet. Land costs are assumed to be $100,000/acre in both cases. The wetland has a lower construction cost per gallon than a detention basin. However, it is only able to store water to a depth of 1.5 feet instead of 4.0 feet for the detention basin. Thus, it requires more land to store the same volume of water. In this case, the land cost doubles the unit cost of the wetland making it only slightly less expensive than the detention basin.

Table 6-7. Effect of Land Costs on Total TSC Costs.

Item	Detention Basin	Wetland
Volume, gallons	100,000	100,000
Volume, ft^3	13,369	13,369
Assumed depth, ft.	4	1.5
Area, acres, =	0.077	0.205
Extra area, %	20%	20%
Area, acres, =	0.092	0.246
Construction $/gallon	$ 0.50	$ 0.25
Total construction cost, $	50,000	25,000
Land cost, $/acre	$ 100,000	$ 100,000
Land cost, $	$ 9,207	$ 24,553
Added cost for land, %	18.4%	98.2%
Total cost,construction + land, $	59,207	49,553
Total $/gallon	$ 0.59	$ 0.50

6.3.5 Operation and Maintenance Costs

Wossink and Hunt (2003) summarize basic operation and maintenance activities based on data collected in the Mid-Atlantic States. The results are listed below.

- Wet Pond: Mowing banks (monthly, seasonal). Outlet/inlet inspection (after large events). Removing vegetation from outlet (varies). Forebay dredging (0-3 times over life of pond).
- Stormwater Wetland: Harvest and replanting of wetland vegetation (0-1 times over life of wetland). Outlet/inlet inspection (after large events). Removing vegetation from outlet (varies). Forebay dredging (0-3 times over life of pond).
- Bioretention Area: Pruning shrubs and trees (0-2 times per year). Mowing (monthly, seasonal). Weeding (monthly, seasonal). Re-mulching (1-2 times per year). Replanting shrubs (0-1 times over life of bio-retention area). Removing sediment accumulation (1-2 times over initial life of practice). Underdrain inspection (1 time per year).
- Sand Filter: Dredging sedimentation chamber (1 time annually to 1 time every three years). Removing built up debris from sand chamber (2-3 times per year initially, 1 time per year thereafter). Outlet inspection (1 time per year). Underdrain inspection (1 time per year).

O&M costs are often expressed as a percentage of construction costs. U.S. EPA (1999h) summarizes available estimates of annual O&M costs as a function of initial construction costs as shown in Table 6-8. Review of the more recent literature does not indicate that better estimates are available.

Table 6-8. TSC O&M Costs as a Percentage of Construction Costs.
Source: U.S. EPA, 1999h.

Type	% of Construction $
Detention basins	<1
Retention basins	3 to 6
Constructed wetland	3 to 6
Infiltration trench	5 to 20
Infiltration basin	1 to 10
Sand filter	11 to 13
Bioretention	5 to 7
Grass swale	5 to 7
Filter strip	320/acre maintained

6.3.6 Salvage Values at End of Project

Salvage value can be negative (e.g., the system has to be removed) when the accumulated sediment is deemed to be hazardous and must be removed at great cost). It can also be positive, e.g., the land value appreciates significantly during the project. It is very difficult to estimate these future events. Thus, salvage values are assumed to be zero for evaluating life cycle costs.

6.3.7 Total life cycle cost

The equivalent uniform annual cost of the construction cost plus land cost plus O&M costs will be determined in this section based on the data presented above. All systems are assumed to last for 20 years and an interest rate of 5% per year is used. The results for the indicated scenario are shown in Table 6-9.

The data from the previous sections on construction, O&M, and land costs were used to estimate the life cycle costs (LCC) for a scenario of a control with a storage capacity of 100,000 gallons. Construction costs are based on the median $/gallon for each category. The present value of annual O&M costs can be determined by multiplying the annual O&M as a percentage of construction costs by the Present Worth Factor for a Uniform Series at an interest rate of 5% and a 20-year service life (Equation 6-1). This factor is 12.46. Thus, for compost filters with an annual percentage of 10, the present worth of these annual O&M costs is 1.246 times the construction costs. The storage depth for each BMP is used to estimate the land area. The cost of the land is assumed to be the opportunity foregone during this 20-year period or $5,000 per year. The present worth of 20-years of equal payments of $5,000 per year is $62,311. Then, the total costs are the sum of construction costs, O&M costs and land costs. Lastly, the full life cycle cost (LCC) per gallon is shown.

6.4 Other Practicability Factors

Worksheet 2 in Appendix C summarizes various practicability factors (e.g., system reliability, safety concerns, property values, aesthetics, projected removed pollutants, projected runoff volume reduction, regional constraints, relative and land cost, and maintenance requirements) that should be considered when selecting the final treatment system from candidate TSCs. System design parameters such as reliability and design confidence, and UOPs, are also included in Worksheet 2. The design engineer may need to develop a preliminary design for each candidate TSC to thoroughly assess which system is most practicable.

After all practicability factors have been carefully assessed for each candidate TSC, there still may be more than one feasible option for the site. In this case, candidate TSCs should be reevaluated in terms of meeting project goals and objectives (Appendix C).

Table 6-9. Life Cycle Cost for Eight BMPs with a Storage Capacity of 100,000 Gallons.

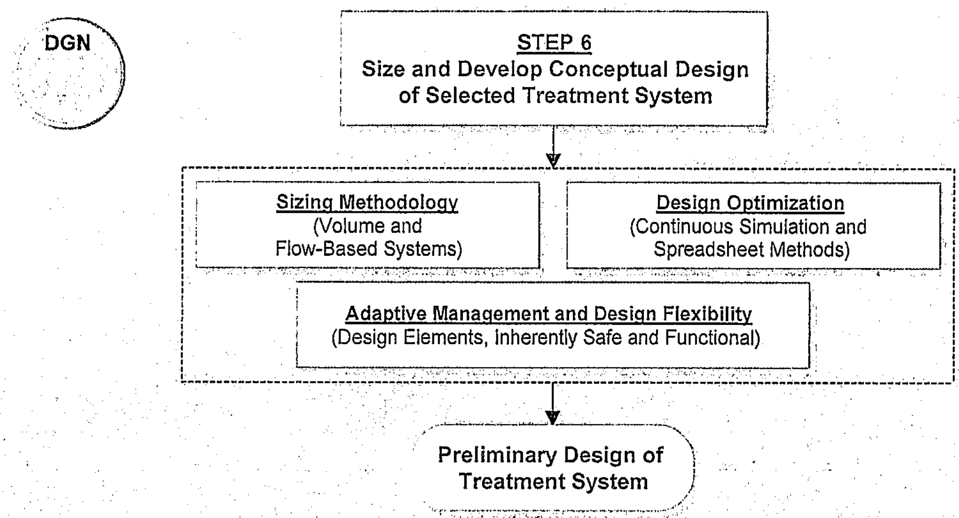
N, years =	20
Interest, i/yr. =	0.05
Present worth factor uniform series =	12.4622
Assumed size, gallons =	100,000
Net land cost, $/acre =	$ 62,311

Control	Const. Cost $/gallon	Total Const. Cost, $	O&M % of Const. $/year	PW of O&M as % of Const. $	Storage Depth, ft.	Extra Land, %	Land Acres	Net Land Cost, $
Compost Filter	$ 0.60	$ 60,000	10%	124.6%	1	0.1	0.338	$ 21,061
Detention, Extended	$ 0.12	$ 12,000	3%	37.4%	4	0.2	0.092	$ 5,733
Detention, Wet	$ 0.32	$ 32,000	3%	37.4%	4	0.2	0.092	$ 5,733
Detention, Wetland	$ 0.08	$ 8,000	5%	62.3%	1.5	0.2	0.246	$ 15,329
Infiltration Trench	$ 0.62	$ 62,000	6%	74.8%	1	0.1	0.338	$ 21,061
Sand Filter, Austin	$ 2.86	$ 286,000	12%	149.5%	8	0.1	0.042	$ 2,617
Sand Filter, Delaware	$ 2.87	$ 287,000	12%	149.5%	1	0.1	0.338	$ 21,061
Swale	$ 0.36	$ 36,000	6%	74.8%	1	0.1	0.338	$ 21,061

Control	Total Present Worth of LCC				LCC Total $/gallon
	Const.$	Land $	O&M $	Total $	
Compost Filter	$ 60,000	$ 21,061	$ 74,773	$ 155,834	$ 1.56
Detention, Extended	$ 12,000	$ 5,733	$ 4,486	$ 22,219	$ 0.22
Detention, Wet	$ 32,000	$ 5,733	$ 11,964	$ 49,696	$ 0.50
Detention, Wetland	$ 8,000	$ 15,329	$ 4,985	$ 28,313	$ 0.28
Infiltration Trench	$ 62,000	$ 21,061	$ 46,359	$ 129,421	$ 1.29
Sand Filter, Austin	$ 286,000	$ 2,617	$ 427,703	$ 716,320	$ 7.16
Sand Filter, Delaware	$ 287,000	$ 21,061	$ 429,198	$ 737,259	$ 7.37
Swale	$ 36,000	$ 21,061	$ 26,918	$ 83,979	$ 0.84

CHAPTER 7.0

DESIGN SELECTED TREATMENT SYSTEM



Key Concepts:

- What level of analysis is needed to adequately size and conceptually design treatment system options?
- How do you optimize the design and verify that project goals will be met?

7.1 Sizing Methodology

Stormwater treatment system design involves both the *mechanism* for hydrologic and hydraulic controls as well as the *design criteria* for determining the runoff volume and/or flow rate for which to design. Hydrologic and hydraulic design guidelines of various detail are included in references such as the following:

- Water Environment Research Federation and American Society of Civil Engineers (1992)
- Debo and Reese (2003)
- King County (1998)
- Mays (2001)
- Minton (2002)
- Urban Drainage and Flood Control District (1999)
- Urbonas and Stahre (1993)
- Washington State Department of Ecology (2001)
- Water Environment Federation and American Society of Civil Engineers (1998)

- U.S. Environmental Protection Agency (2004)

Several of these references are based in part on one of the original guidelines produced for the Washington, D.C. Council of Governments by Schueler (1987). In addition to the above references, many cities and other public agencies provide good, localized design guidelines, such as the City of Portland, Oregon's Bureau of Environmental Services (2002), to list just one.

7.1.1 Sizing Hydrologic/Hydraulic Controls

Several methods can be employed for sizing hydrologic and hydraulic controls including flow attenuation, volume reduction, and flow-duration. Flow attenuation is primarily a flood control objective where runoff is retained just long enough to shave the peaks, but from a water quality perspective flow attenuation is also used to maximize hydraulic retention time in stormwater treatment systems. Flow attenuation combined with volume reduction is often necessary to match pre-development water balance and flow regimes, which is the objective of flow-duration design. The following discusses methods for sizing treatment systems and hydromodification controls designed to meet commonly encountered hydrologic and hydraulic objectives.

7.1.1.1 Flow Attenuation Design

Many stormwater regulations require post-development hydrograph peaks to be no greater than pre-development peaks, as indicated in Figure 7-1. At the downstream end of the catchment or subarea, this "peak shaving" reduction is almost always accomplished simply through storage with a controlled release. The combination of storage and hydraulic outlet configuration may be adjusted through simple storage routing (storage-indication, or modified-Puls routing works well and is easily performed on a spreadsheet) to achieve the desired peak reduction. The greater the available storage volume, the greater the peak reduction that is possible. If the outlet capacity is too large, the hydrograph for events with peak flows under the capacity are simply passed through the storage volume with minimal reduction.

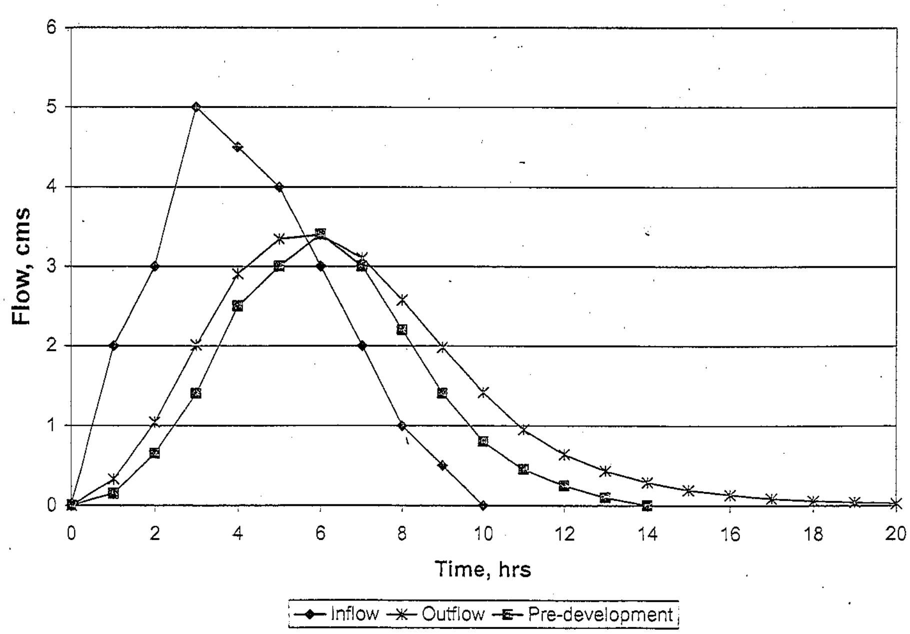


Figure 7-1. Typical Peak Flow Reduction ("Peak Shaving") Resulting From Storage.

If a storage basin is configured to detain large storms, with large outlet capacity, then if there are no other modifications, small storms will essentially pass through unmodified. However, control of small storms is one of the cornerstones of water quality control. Hence, extended-detention ("dry") basins can be configured with multiple outlets, as indicated in Figure 7-2. The smallest and lowest volume is designed to contain and hold for an extended period frequent "small" storms (i.e., depths less than a few tenths of an inch) that make up 80-90% of most rainfall events at most locations in the U.S. (WEF and ASCE, 1998). The low-flow outlet is often a small-diameter pipe (with protection against clogging), perforated riser, or filter drain and is used to drain this detention volume over, typically, a 24-72 hour period, as a goal. (If detention is too long, the basin might not be empty for the next storm event.) A somewhat larger outlet may be installed at an intermediate depth (labeled "1-yr storm outlet" in Figure 7-2) to reduce peak flows of larger events. Finally, an outlet for larger storms (potential for flooding) is provided (labeled "100-yr storm outlet" in Figure 7-2) in the form of a weir or emergency spillway (or large pipe). Of course, all outlets contribute to drainage of the facility during very large events. But if the 100-yr outlet is placed at the bottom of the structure, small events will pass through unmodified, with little water quality benefit. Typical outlet structures for these purposes are illustrated in Figure 7-3. An outlet rating curve (outflow versus depth) is constructed as the sum of the outflows from the various hydraulic outlet components, which is then used in the storage-routing procedure for design.

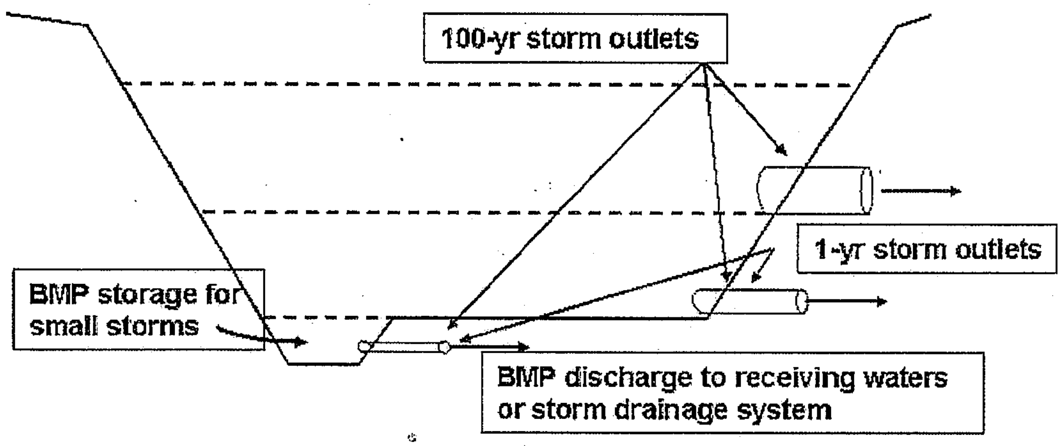


Figure 7-2. Outlet Configuration for Multiple-Objective Stormwater Control. Reprinted with permission from L.A. Roesner.

Peak flow reduction may also be accomplished upstream in the watershed through "hydrologic source control" mechanisms (including components of LID) that reduce the volume of the runoff hydrograph and delay the peak through distributed storage. However, this document focuses on downstream, structural treatment systems. Of these, beside infiltration systems, both bioretention areas as well as extended detention basins have been shown to reduce runoff volumes. Regarding storage volume, the volume of storage in the collection network (pipes, channels) should be included in estimates of peak flow attenuation from the whole catchment. This is usually accomplished through flow routing down the drainage network.

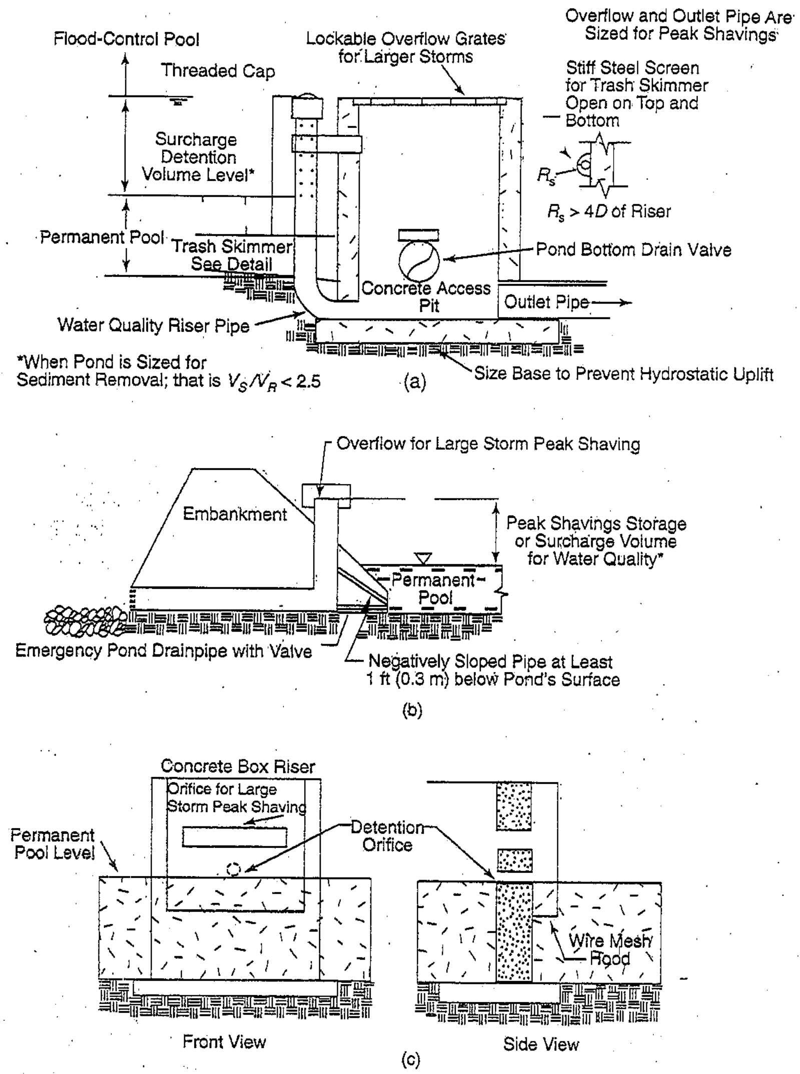


Figure 7-3. Typical Outlet Structures Used in Detention Basins. Reprinted with permission from WEF and ASCE (1998).

7.1.1.2 Volume Reduction Design

Volume reduction is possible in two ways: upstream reduction in runoff, for example, through hydrologic source control (i.e., LID) and TSCs that emphasize infiltration and ET. LID options are described in sources such as Prince George's County (2000), Puget Sound Action Team (2003), and Urban Drainage and Flood Control District (UDFCD, 1999), to name a few. The emphasis of this document is downstream, structural TSCs. Therefore, upstream hydrologic source control options that emphasize onsite storage, infiltration, and ET are not discussed explicitly apart from the brief discussion in Section 3.2.3.3 (Evapotranspiration) and Section 5.2 (Hydrologic Control).

Downstream TSCs reduce runoff volumes through the combined mechanisms of infiltration and ET. ET is facilitated through an ample free water surface and/or plants that transpire from the near-surface soil layers, or by soil soaking and drying. Wetlands and retention ponds obviously promote ET via a free water surface and transpiration. To a lesser extent, bioswales and controls that hold and store water at or near the surface will also promote ET via soil soaking and drying, including transpiration. Infiltration occurs through any permeable surface that is not saturated, or if saturated, is able to respond to an applied gradient, to the extent that it is not reduced by clogging due to sediment in the influent. Water that is retained in shallow soils after wetting can be evaporated between storm events. For this purpose, ponds, wetlands, and devices designed to promote infiltration are often part of a treatment train, with a sediment forebay or gross pollutant trap upstream of the primary facility. Issues of sediment accumulation and maintenance specific to infiltration devices are discussed Section 5.2.1

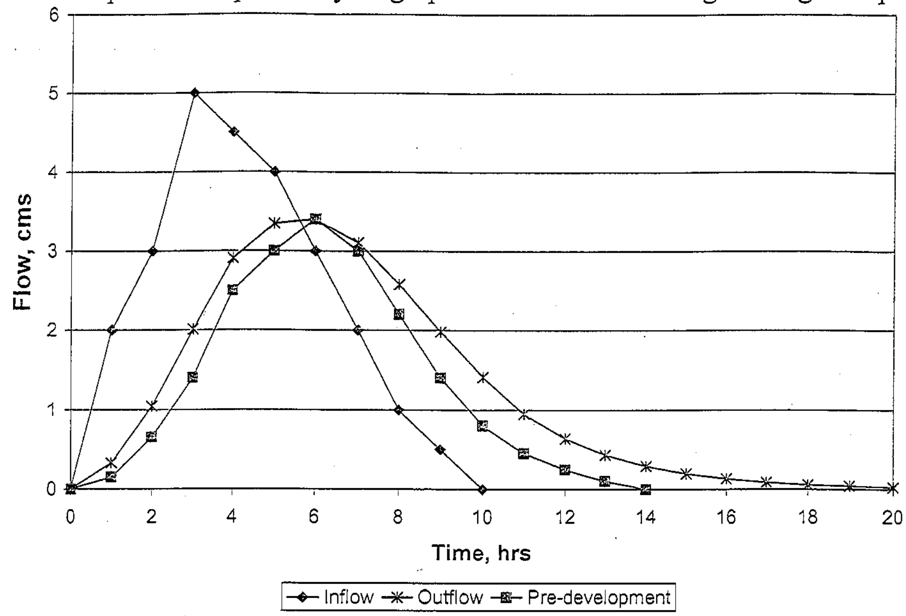
Data relevant to design for infiltration and ET are discussed in Section 3.2.3.3. Infiltration estimates based solely on native soils are the easiest to obtain but are subject to large variation in areas of disturbed soils, which include practically all urban areas and construction sites for TSCs. Hence, infiltration estimates should be made preferably on the basis of field infiltrometer tests of representative soils. Some recent studies illustrating the effect of compaction on infiltration rates include Pitt et al. (1999) and Pitt et al. (2001).

7.1.1.3 Flow-Duration Control

The flow-duration method seeks to minimize the difference in both the magnitude of flows discharged from the watershed and the cumulative time period each flow level persists between the pre- and post-development conditions. This approach incorporates principles from both flow attenuation (e.g., conveyance, detention) and volume reduction (e.g., infiltration, evapotranspiration), while taking into account the distribution of flows. Changes in flow-duration are most easily detected from comparison of the pre- and post-development flow-duration curves.

Comparing several different stormwater management strategies, including flow attenuation, volume reduction and flow-duration matching, Palhegyi and Bicknell (2004) suggest that, of the three, flow-duration offers the best means of limiting modification of downstream hydraulic conditions. While designing for flow attenuation over a range of design storm sizes accounts, in part, for potential impacts to downstream morphology from both large and small runoff events, it does not address the increased frequency of potentially erodible discharges. Volume reduction, in turn, fails to regulate the intensity of runoff from the watershed. By matching both the magnitude and frequency of flows under post-development conditions to those assumed for the pre-development watershed for potential erosive flow rates, flow-duration helps govern the overall amount of "work" done on the downstream channel.

As pre-development hydrographs are modified through storage for peak reduction



(Figure 7-1), the duration of moderate and low flows is extended over what would have occurred naturally because of the volume increase. With an increase in volume due to urbanization and development, there must be an increase in low flows to release the stored inflows. This means that the duration of low flows is increased both because of the redistribution of the hydrograph shape (higher flows converted to lower flows through storage) and because of the increase in low flows necessary to account for the higher volume of runoff. The extended duration of some of these low flows can be highly erosive, especially when these flows are near bank-full flows (often a 1-2 year storm).

Matching flow-duration for the full range of stormwater runoff events is thought to be the most effective method for protecting streams from increases in erosive flows with development (SCVURPPP, 2004). Another effective method is the stabilization of the stream. The steps involved in flow-duration control design include:

1. estimating stormwater runoff from the pre- and post-project sites using a long-term precipitation record;
2. generating flow-duration curves from the results; and
3. designing a storage-release system such that when the post-project runoff is routed through the system, the discharge matches the pre-project flow-duration characteristics.

Figure 7-4 illustrates the flow-duration design methodology. Rather than analyzing single storm events (either water quality size or smaller flood control size), flow-duration requires an analysis of the full probability distribution of runoff derived from a continuous hydrologic simulation. Flow-duration curves (or alternatively histograms) of pre- and post-development conditions are constructed to determine the reduction in flow rate for each flow-duration time interval to be achieved by a control facility for those flows considered to be potentially erosive. Figure 7-5 provides an example of flow-duration curves for a 716-acre catchment in California generated using a full range of storms in a 50-year continuous simulation. As illustrated, the continuous simulation approach closely reproduces the pre-project flow-duration curve for flows above potentially erosive flows.

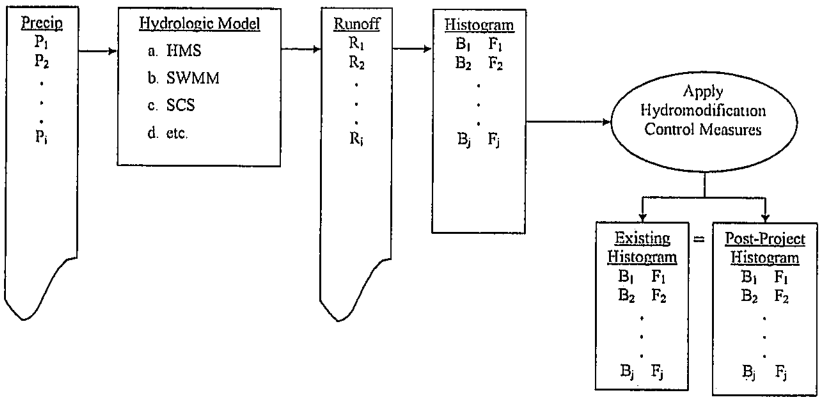


Figure 7-4. Illustration of the Flow-Duration Methodology.
Source: Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP, 2004).

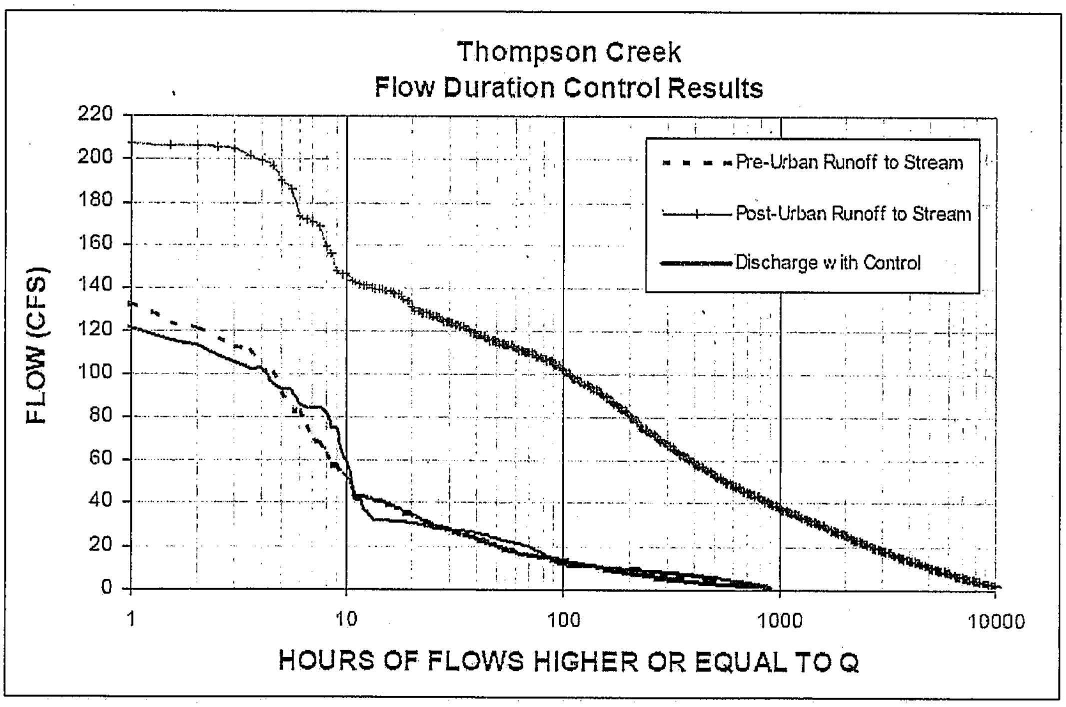


Figure 7-5. Example Comparison of Flow-Duration Control Design.
Source: Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP, 2004).

A similar example is provided by Nehrke and Roesner (2001). The approach is that post-development runoff may be controlled through design of storage and outlet controls such that excessive erosion is prevented. If the goal is maintenance of downstream flow-duration relationships within a certain frequency range, for example, to maintain geomorphologically significant flow relationships, say in the 1-2 year return period range, then outlets may be designed appropriately for that purpose. While not very common today, flow-duration design criteria are becoming more popular with regulatory agencies. For example, King County, WA has a flow control criterion requiring post-development to match pre-development flow-durations for 50% of the two-year through 50-year peaks (King County, 1998). Santa Clara County, CA is considering a similar criterion requiring flow-duration controls be designed so post-development discharge rates and durations match pre-development discharge rates and durations from 10% of the two-year peak up to the 10-year peak (SCVURPPP, 2004).

Another downstream criterion might be maintenance of stream power relationships for erosion control. Erosion Potential (Ep) is measured as an increase in the effective work index above the pre-developed conditions. Maintaining the in-stream erosion potential is similar to maintaining flow-duration in that maintaining flow-duration also maintains work and the erosion potential. However, maintaining the erosion potential can be accomplished in ways other than maintaining flow-duration. In other words, the shape of the flow histogram could change as long as the total effective work remains the same between pre- and post-development.

Erosion Potential can be calculated as follows:

$$Ep = \frac{W_{unstable}}{W_{stable}} \qquad [7\text{-}1]$$

Where: Ep = erosion potential

$W_{unstable}$ = work index for a stream section determined to be unstable

W_{stable} = work index for a stream section determined to be stable

$$W = \sum_{1}^{n} (\tau_i - \tau_c)^{1.5} \cdot \Delta t \qquad [7\text{-}2]$$

Where: W = index of total effective work done over the length of flow record

n = length of flow record

τ_c = critical shear stress that initiates bed mobility or shear erosion

τ_i = applied hydraulic shear stress, computed as ρgdS

Δt = duration of flows (hours)

d = depth of water

ρ = water density

g = gravitational acceleration

S = stream slope.

The critical shear stress is based on the least resistant boundary material observed. Critical values of shear stress and velocity for the stream bed and stream bank provide a measure of the stream's resistance to erosion. For different bed material sizes, critical values of shear stress and velocity for bed mobility can be estimated using two methods: Shield's equation and from permissible velocity tables published in ASCE Manual of Practice No. 77 (WEF and ASCE, 1992).

The success of flow-duration matching for erosive flows depends not only on detailed analyses, but also upon good design and construction of such facilities. There is still some question as to whether this can be successfully accomplished on a project-by-project basis, especially for smaller developments. For example, a small error in the final placement of a weir structure could mean that the facility will not be effective. Flow-duration may only be successful if applied on a regional scale by entities that can better ensure that proper design and construction takes place.

In watersheds that are already partially built-out and where stream erosion is already occurring, the most cost-effective approach to addressing stream erosion issues may be to install grade and bank stabilization projects in the stream. Controlling runoff from new development will not solve existing problems, and therefore the overall best use of funds may be to help the stream adjust to its new flow regime.

7.1.2 Sizing Flow-Based Treatment Systems

"Flow-based" controls contain very limited or no storage volumes and include sand filters, filter strips, swales, infiltration trenches, and some infiltration basins as well as some proprietary devices such as the StormFilter and Bay Saver that are better described by their ability to treat up to certain flow rates rather than up to a storm runoff volume. For proprietary devices, sand filters, and infiltration trenches, a bypass mechanism is sometimes provided, either external to the device or included in its design, so that high flows (higher than the design flow for treatment) are bypassed around the device. On the other hand, swales must usually pass the entire hydrograph—high flows as well as low flows—but will only function well as a pollutant removal device for low flows. An infiltration basin is often essentially a form of extended detention, which may be designed for a desired outflow into the soil (and atmosphere), but which is usually designed on the basis of volumetric considerations discussed in the next section.

The level of sophistication for sizing both flow-based and volume-based devices varies considerably. In many municipalities, a "water quality event" or "BMP volume" may be defined by the local Department of Public Works. For instance, on the basis of continuous simulation or a simple frequency analysis of rainfall totals, a depth of, say, 0.9 in. in 24 hours may be chosen as the "water quality design event." The rainfall would be converted to a design storm through application of a Natural Resources Conservation Service (NRCS) dimensionless hyetograph, such as a Type II distribution for the U.S. Southeast, or a Type I-A for the U.S. Pacific Northwest (Bedient and Huber, 2002; King County, 1998). The design storm may be converted to a design hydrograph by a variety of standard hydrological techniques, such as a unit hydrograph, SCS methods, Santa Barbara Unit Hydrograph, time-area method, and so forth. Or the hyetograph may be input to a model. (All of these methods are inferior to the continuous simulation approach, discussed subsequently.) The resulting runoff hydrograph is then used to determine a peak flow for sizing of the flow-based device. The peak will necessarily be quite low compared to flood runoff events; that is, the flow-based device will control the frequent "small" events, as discussed earlier. However, assigning a "treat at the peak" of a flood-design hydrograph has almost no technical basis in terms of targeting appropriate treatment sizes.

Given the required flow for the device, it is then sized according to infiltration rates and other criteria to accept such a flow (WEF and ASCE, 1998). Devices that rely on infiltration must be diligently maintained to prevent clogging.

In the absence of a pre-specified water quality rainfall event, regression relationships developed by Guo and Urbonas (1995) and documented by WEF and ASCE (1998) may be used to obtain a design storm depth for locations in the U.S. (The relationship for volumetric runoff coefficient is given earlier as Equation 3-3). For purposes of flow-based systems, the depth must be assigned a duration to distribute it in time, after which standard hydrologic techniques again may be used to estimate a runoff hydrograph. The distribution in time is not necessarily straightforward, since "real" storms do not have convenient durations such as 24 hours. However, if daily rainfall totals are used, frequency diagrams of the type shown in Figure 7-6 may be used to obtain a 24-hour (midnight to midnight or sometimes 8:00 a.m. to 8:00 a.m.) rainfall total corresponding to a specified percent exceedance. Again, this is a somewhat arbitrary method for determining treatment flow rates.

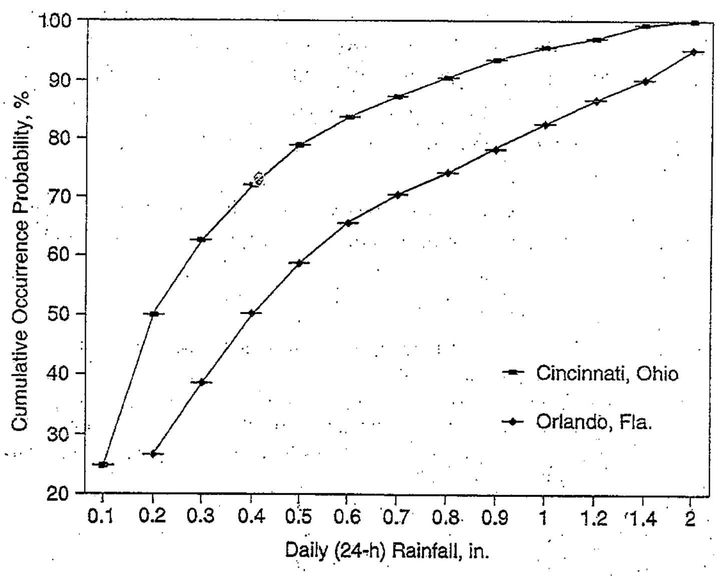


Figure 7-6. Cumulative Frequency Distribution of Daily Precipitation for Two U.S. Cities. Reprinted with permission from WEF and ASCE (1998).

Another approach to setting a design storm size is to conduct a frequency analysis of the actual rainfall data by separating the hourly values into events using a minimum interevent time (MIT) criterion. The duration of such events is the "real" duration and not necessarily 24 hours. The separation criterion varies, but 6 hours is often employed. That is, rainfall occurrences separated by six hours or more are considered separate events (see Bedient and Huber (2002) for explanation). Example plots for Salem, OR (1948–2003 rainfall) are shown in Figure 7-7 for depths and Figure 7-8 for maximum event intensities. Depths and intensities corresponding to specified frequencies may be obtained from such graphs and used in standard hydrologic techniques described earlier. And the actual events may be extracted from the historic record for use as design hyetographs of a specified frequency.

Guo and Urbonas (2002) suggest that the exponential distribution may be used to fit cumulative probabilities such as those in Figure 7-6 and Figure 7-7:

$$F(d) = \text{prob}(d \le D) = 1 - e^{-D/D_m} \quad [7\text{-}3]$$

where: d = storm event depth,

D = particular event depth of interest, and
D_m = mean storm event depth = reciprocal of exponential distribution parameter.

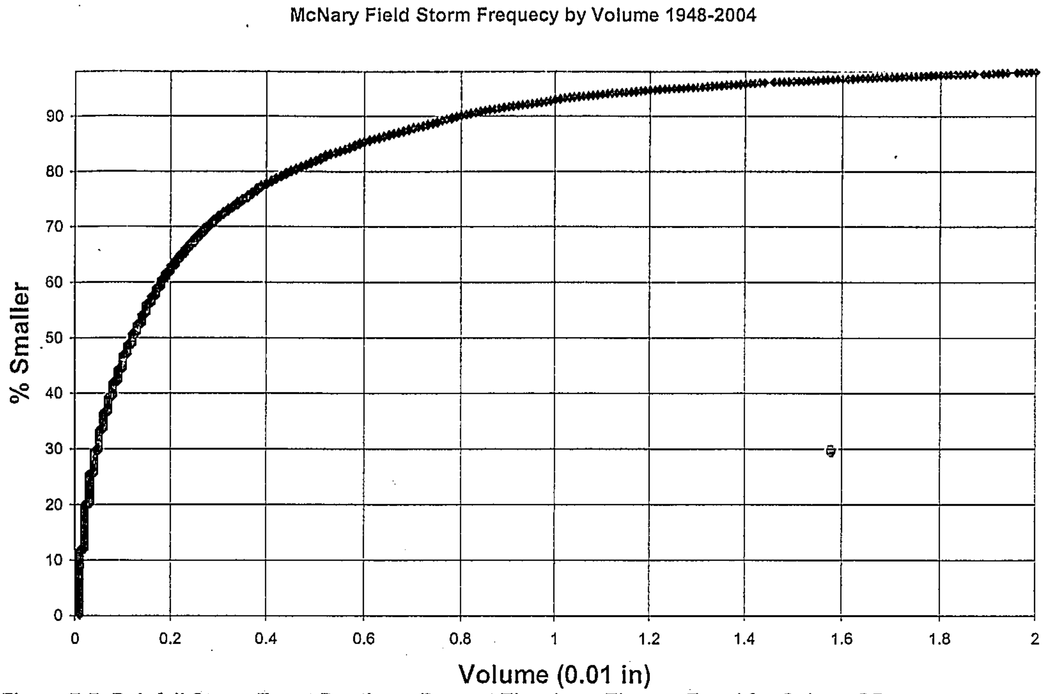


Figure 7-7. Rainfall Storm Event Depth vs. Percent Time Less Than or Equal for Salem, OR. Minimum Interevent Time Separation = 6 Hrs.

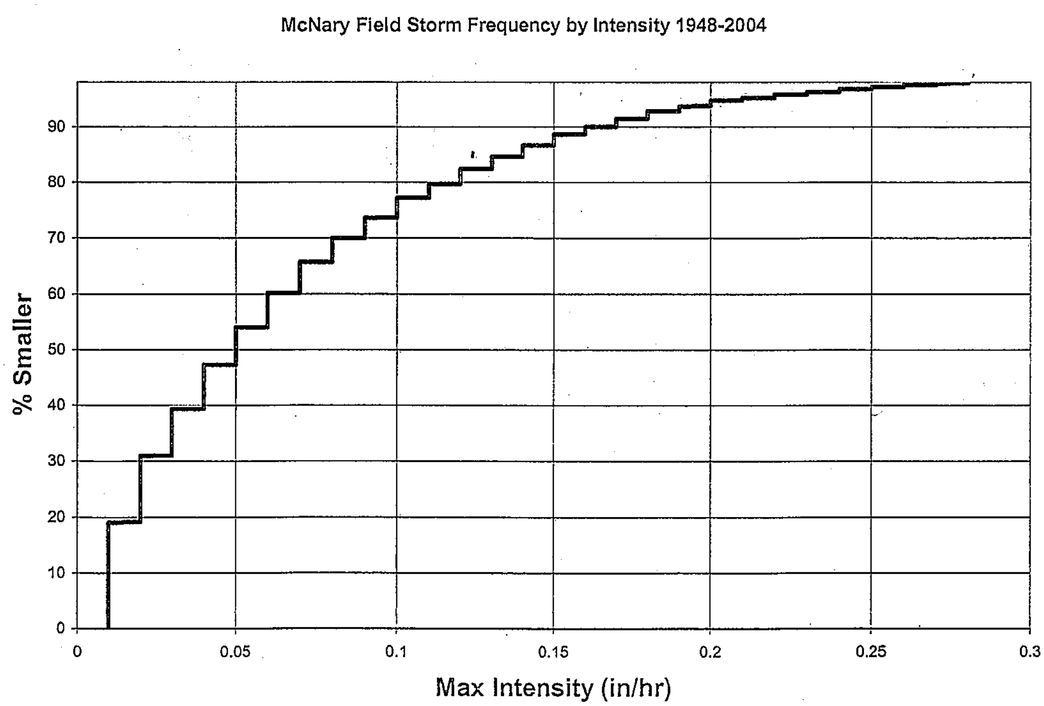


Figure 7-8. Maximum Event Rainfall Intensity vs. Percent Time Less Than or Equal For Salem, OR. Minimum Interevent Time Separation = 6 Hrs.

The vexing problem of how to assign a duration leads to the most sophisticated procedure discussed herein: continuous simulation for selection of design events. The idea of continuous simulation is to run a calibrated model for the period of record of historic rainfall, and perform a statistical analysis of the resulting hydrographs (and sometimes, on the resulting pollutographs if quality is simulated). Hourly rainfall data are available in the U.S. at most first-order weather stations beginning about 1948. Fifteen-minute data, better suited for urban analyses, are available at a smaller number of stations beginning about 1972. Such data may be obtained from the National Climatic Data Center (or NCDC), at http://www.ncdc.noaa.gov/oa/ncdc.html.

Unfortunately, the one-hundredth of an inch resolution data are typically only available for a few years out of the period of record due to a change in instrumentation at most stations in the 1980s. Among other difficulties, it is much harder to define the starting and stopping times for low intensity rainfall when a tipping bucket gages tips only at every tenth of an inch. However, on the basis of trial simulations, the difference between the hundredth of an inch and tenth of an inch resolution data appear to make little difference in the final runoff frequency curves derived.

Although calibration is clearly desirable, it is seldom possible. Fortunately, in the urban environment, the imperviousness of catchments usually means that more credible simulations may be performed even without calibration. Simulations performed by competent modelers are generally no less credible than reliance on heuristic parameter estimation, such as the time of concentration, required for simpler techniques. Continuous simulation methods are discussed in Section 7.2.

The most common way to present continuous simulation results is through a plot of magnitude versus percent time less than or equal to (or the complement: percent time exceeded). Oregon State University et al. (2003) performed continuous simulations for the Moyewood Pond urban catchments in Greenville, NC (200 acres) (Stanley, 1994; Stanley, 1996) and the Walnut Creek highway catchment in Austin, TX (26 acres) (M. Barrett, personal communication, 2003; Walsh et al., 1997) using calibrated SWMM models. Continuous simulation results for the Greenville site for storm event runoff depth and storm event maximum flow are shown in Figure 7-9 and Figure 7-10, respectively. Simulations were based on 15-min rainfall data, and a 6-hr MIT was used for defining individual storm events. For example, the 90% runoff depth and normalized maximum flow for the actual 33% imperviousness of the site is about 0.4-in and 0.3 in/hr, respectively. The magnitudes obviously increase with imperviousness.

Total runoff depths and peak flows are compared for the two catchments in Figure 7-11 and Figure 7-12, respectively. Event depths and peak flows increase with increasing MIT, as expected. Magnitudes are clearly higher for the Austin, TX site than for the Greenville, NC site, an outcome that might not be intuitive. Additional detail on the Greenville, NC and Austin, TX simulations is provided by Brown (2003) and Brown and Huber (2004).

Once again, an exponential fit may be obtained to the curves in Figure 7-9 to Figure 7-12, as suggested by Guo and Urbonas (2002). The curves may be made dimensionless by dividing by the mean runoff event depth or mean runoff event peak flow.

The results of Figure 7-9 to Figure 7-12 offer ways to select design peaks and volumes on the basis of allowable frequency, if local regulations permit such an approach. In all cases, somewhere in the vicinity of the "knee of the curve" is an attractive choice, since it becomes difficult to capture the peaks and volumes for extreme events at that point. Guo and Urbonas (1996) offer a criterion for selection of an optimum point on the knee of the curve, which is to use the location at which incremental change in dimensionless capture ratio equals the incremental change in dimensionless runoff volume or peak. "Capture ratio" may be in the form of either number of events captured, or cumulative volume captured. However, the volume basis is likely a more robust method. Runoff volume or peak is made dimensionless by dividing by the mean storm event magnitude. The concept is illustrated in Figure 7-15 for the former criterion.

Use of different models and simulation options lead to similar results presented in different ways. For example, Hydrologic Engineering Center STORM model simulations for six cities are summarized in Figure 7-13 (WEF and ASCE, 1998), from which storage volumes necessary to detain runoff for 24 hours were determined by continuous simulation. Additional details are given in WEF and ASCE (1998). Another way to present STORM model results is given by Heaney et al. (1977, 1979), in which control effectiveness of combinations of storage and treatment are provided; results for San Francisco, CA are shown in Figure 7-14, from which further cost optimization may be performed. "Level of control" means percentage of generated BOD that is removed by the treatment unit.

Driscoll et al. (1986) presented a method for sizing flow-based treatment systems that have a maximum flow capacity where all flows above the capacity are bypassed, such as infiltration systems and hydrodynamic devices. The method determines the long-term volumetric capture of a device that captures all inflows up to a rate, Q_T, for situations where storm flows are gamma distributed. Figure 7-16 illustrates the effect of normalized treatment capacity (treatment capacity, Q_T, divided by mean runoff flow rate, Q_R) and the coefficient of variation of runoff flow rates (CV_q) on long-term capture efficiency (Driscoll et al., 1986).

For ease of application by the practitioner, results of continuous simulations are provided in Appendix E for 30 locations in 15 hydrologic regions throughout the U.S. The simulations were computed for 4-acre and 20-acre impervious catchments in a manner similar to the development of Figure 7-9 to Figure 7-12. A complete explanation of the results is presented in Appendix D, but the figures may be used for *screening purposes* for sizing flow-based TSCs within the 15 different hydrologic regions. Results for four locations are compared in Figure 7-17. Flow magnitudes may be scaled up (or down) linearly on the basis of impervious area. Differences in the frequency relationships are apparent for the four locations. Results for infiltration-based controls, i.e., a filter strip, are also provided in Appendix E for the 30 locations as a function of infiltration rate and slope of the filter strip. A comparison of five locations is shown in Figure 7-18 for one infiltration rate and slope; again, regional differences are very apparent.

This subsection has summarized various ways in which frequency results for rainfall intensity (Figure 7-8), peak flow magnitude (Figure 7-10, Figure 7-12) and combinations (Figure 7-14) may all be used to size flow-based controls. Detailed screening results are provided in Appendix E. Volume-based controls use similar information and are discussed in the next section.

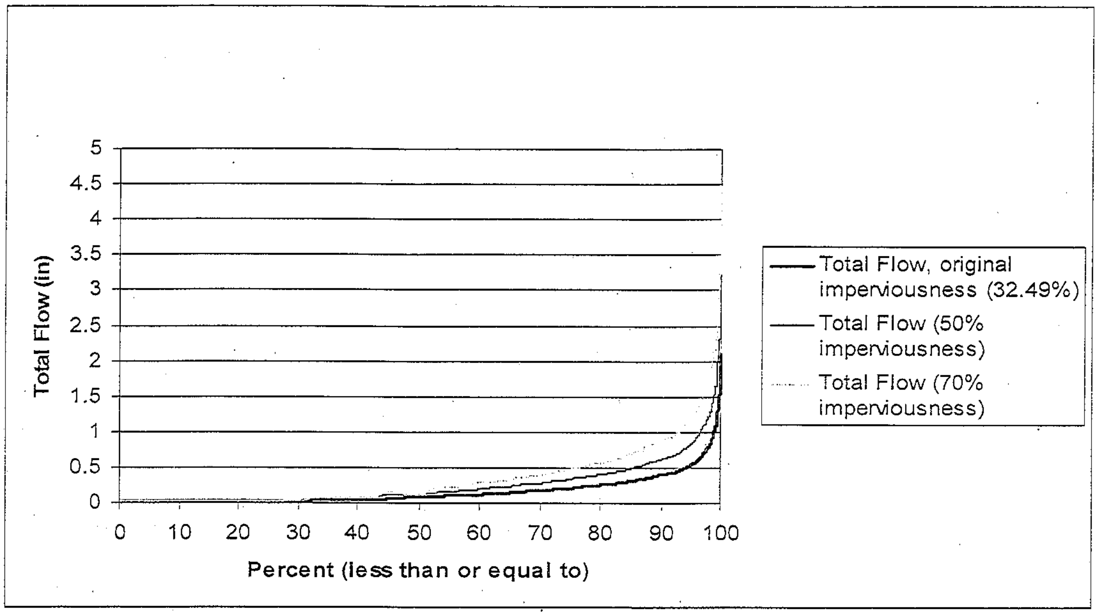


Figure 7-9. Runoff Depth Frequency Relationship for Moyewood Pond Catchment, Greenville, NC. Minimum Interevent Time = 6 Hrs (OSU et al., 2003).

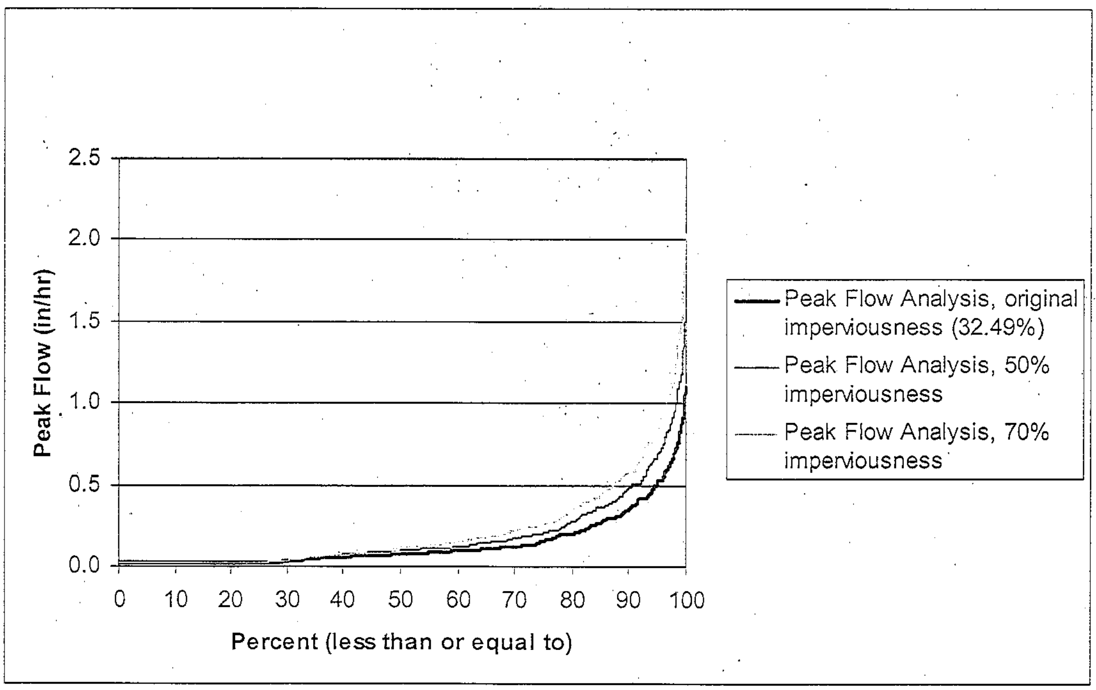
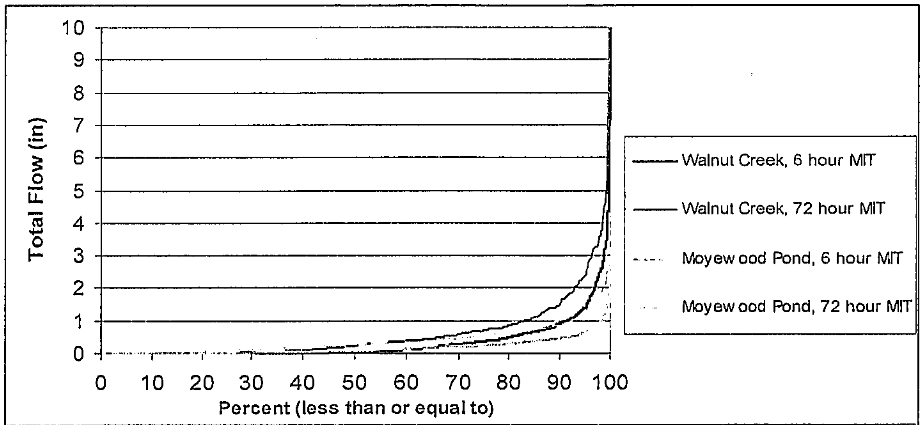


Figure 7-10. Runoff Peak Flow Frequency Relationship for Moyewood Pond Catchment. Greenville, NC. Minimum Interevent Time = 6 Hrs (OSU et al., 2003).



Continuous Simulation Characteristics	Moyewood Pond 38% Impervious	Walnut Creek 38% Impervious
Precipitation- total (in)	911.25	751.70
Average yearly (in/yr)	28.48	30.09
Infiltration- total (in)	560.49	346.21
Average yearly (in/yr)	17.52	13.85
Evaporation- total (in)	50.98	70.09
Average yearly (in/yr)	1.59	2.80
Runoff- total (in)	310.88	342.28
Average yearly (in/yr)	9.72	13.69

Figure 7-11. Total Runoff Depth Comparisons Between Regions and MIT Values.
Based upon Walnut Creek andMmoyewood (Greenville) Pond site simulations at constant 38% imperviousness (OSU et al., 2003). Note: average values are low because of missing data in the 15-min rainfall records used to drive the model. Evaporation is low because of runoff from pavement and predominant infiltration into sandy soils. Moyewood pond simulation period: 5/13/71 – 1/1/03. Walnut Creek simulation period: 12/1/75 – 12/1/00.

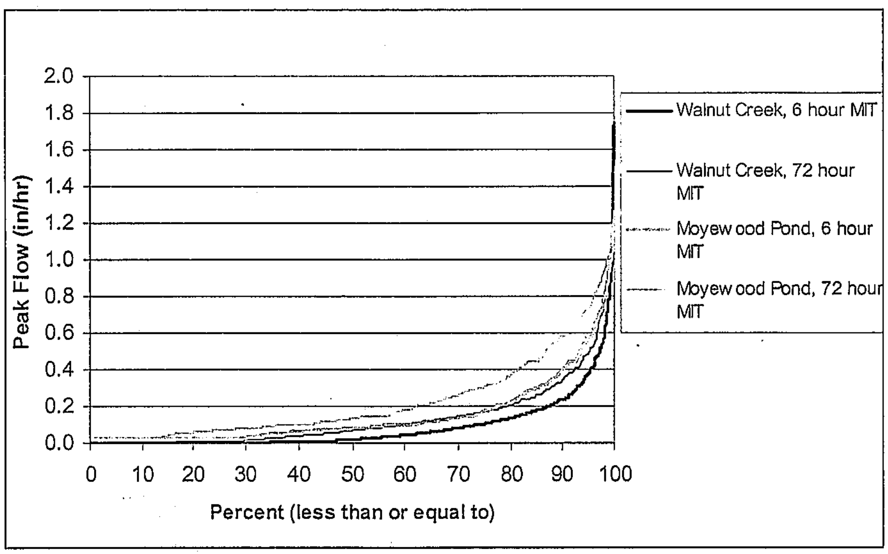


Figure 7-12. Peak Flow Comparison Between Regions and MIT.
Based upon Walnut Creek and Moyewood Pond site simulations at constant 38% imperviousness. Peak flow frequencies also provide insight about downstream impacts. (OSU et al., 2003)

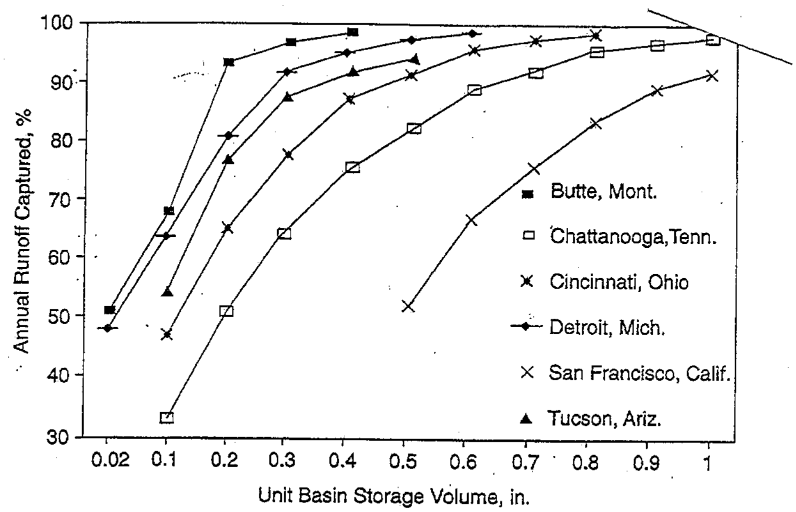


Figure 7-13. Runoff Capture Rates vs. Unit Storage Volumes at Six Study Sites. Reprinted with permission from WEF and ASCE (1998).

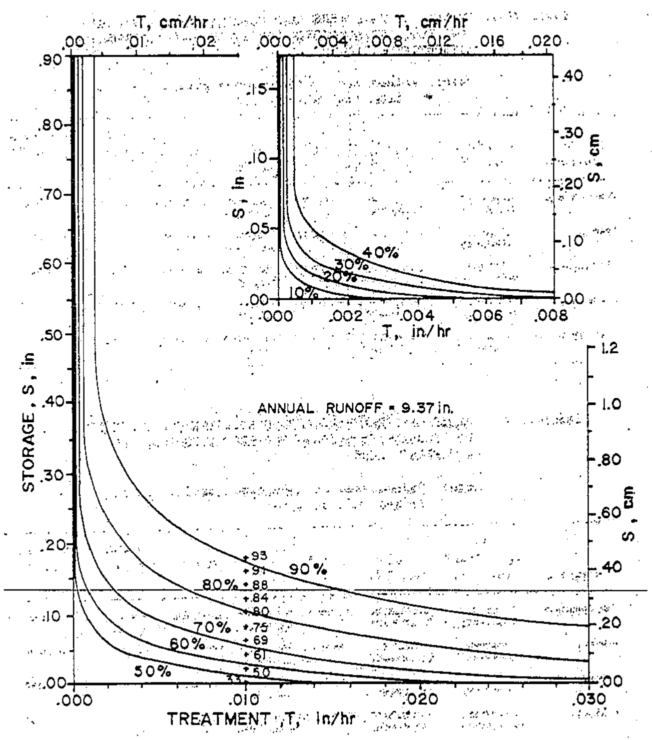


Figure 7-14. Storage-Treatment Combinations for Given Levels of Control for BOD Removal. STORM Model First-Flush Pollutant Generation for San Francisco (Heaney et al., 1977).

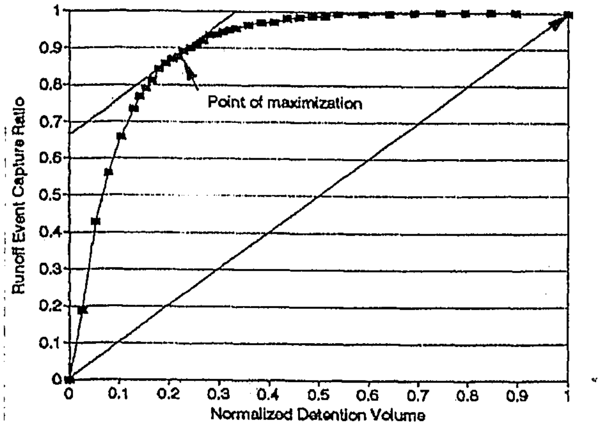


Figure 7-15. One Criterion for Design Detention Volume Selection.
Based on equating slopes of normalized detention to runoff event capture ratio.
Reprinted with permissin from Guo and Urbonas (1996).

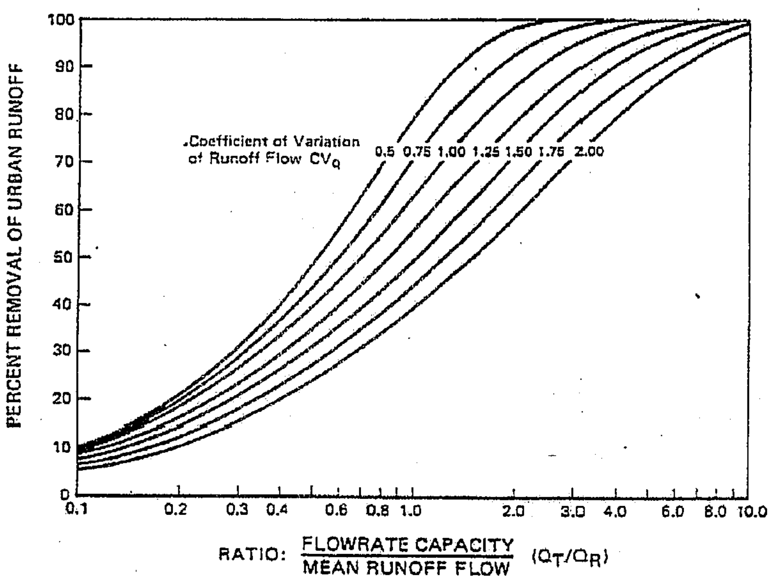


Figure 7-16. Average Long-Term Performance for a Flow-Capture Device.
Source: U.S. EPA publication (Driscoll et al., 1986).

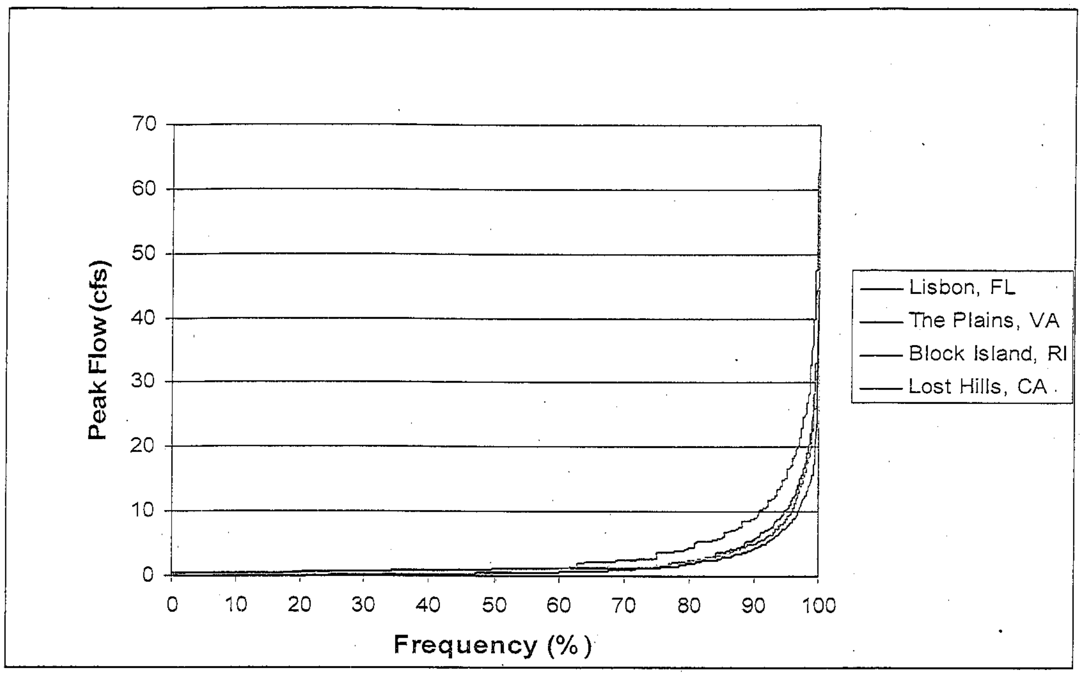


Figure 7-17. Peak Flow Frequency Analysis Comparing Four Locations Around the U.S.
"Frequency" means percent of entire runoff period for which peak flow is less than or equal to indicated value.

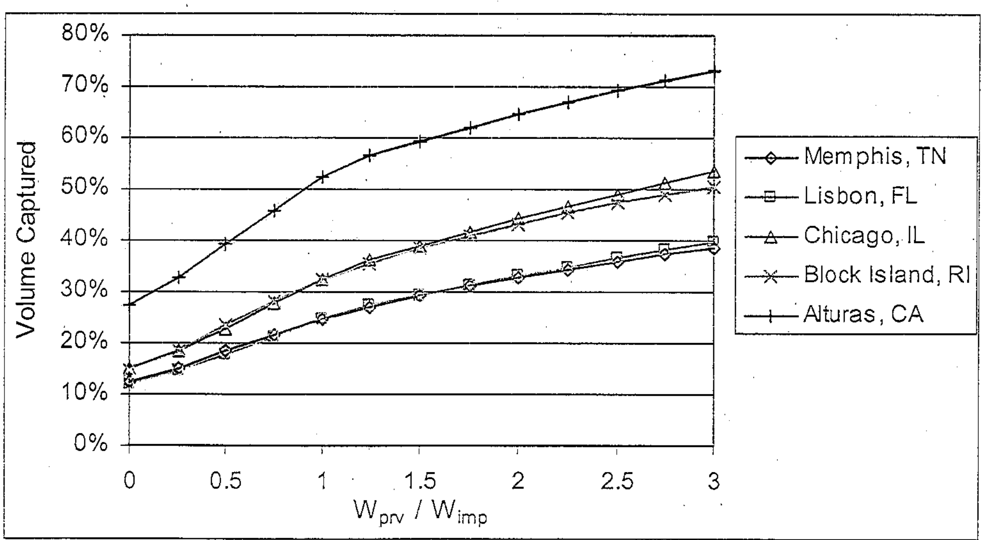


Figure 7-18. Filter-Strip Effectiveness Comparison for Five Locations Around the U.S.
Constant infiltration rate of 0.2 in./hr and filter strip slope of 0.1. The abscissa is the ratio of the width (flow path length) of the pervious filter strip to the width of the tributary impervious catchment.

7.1.3 Sizing Volume-Based Treatment Systems

Volume-based systems are somewhat simpler to size than flow-based systems from a hydrologic point of view because only a total runoff volume (or equivalent depth over the catchment) is needed to determine the required storage volume. For example, from a frequency analysis of rainfall events at many locations, Driscoll et al. (1989) produced contours of storm event depths (with MIT = 6 hr) for the U.S. (Figure 7-19). Such a map summarizes information obtained by many simulations of the type shown for just one site in Figure 7-7. The application of WEF and ASCE (1998) runoff estimation techniques that rely in part upon Equation 3-3 for runoff volume estimates is provided in that reference. Obviously, better, site-specific information on volume-frequency relationships may be obtained both by analysis of local rainfall records (to improve upon Figure 7-19) or best, by analysis of simulated runoff to produce site-specific runoff volume-frequency relationships of the nature of Figure 7-9, Figure 7-12, Figure 7-13, and Figure 7-14.

Similar to the sizing methodology for flow-based systems, Driscoll et al. (1986) provide a method for sizing off-line volume-based systems where storm volumes are gamma distributed. Figure 7-20 illustrates the effect of normalized treatment volume (treatment volume, V_E, divided by mean runoff volume, V_R) and the coefficient of variation of runoff volumes (CV_{VR}) on long-term volumetric capture efficiency (Driscoll et al., 1986).

The USGS has produced regression relationships for runoff flows and volumes at many locations in the U.S. Examples include Laenen (1983) for urban areas in western Oregon, and Franklin and Losey (1984) for Tallahassee, FL. Relationships for the U.S. are summarized by Sauer et al. (1983). These regression relationships provide good peak flow and runoff volume estimates for ungaged watersheds, but unfortunately, the lowest return period for estimates is 2-year, which is much too high for most stormwater quality designs. However, these regression relationships may be used to check sizing for flood control.

Continuous simulations provide more than just a depth or flow rate that corresponds to a certain frequency. The output (hydrographs and pollutographs) may be analyzed for the parameter of interest, including runoff event depth, average flow, maximum flow, duration, interevent time, pollutant load, pollutant EMC, pollutant maximum concentration, and so forth. Events corresponding to return periods or frequencies of interest may be selected as design events for modeling or for hyetograph input into simpler hydrologic procedures (Bedient and Huber, 2002). Although continuous modeling generally involves the most effort, continuous models are getting easier to use, and spreadsheet procedures are also available, as will be discussed in the next section. Models also have the ability to simulate series-parallel arrangements of TSCs. They are most appropriate for evaluating the hydrologic and hydraulic performance of a treatment system. Water quality simulations must be used with caution so that simulation of downstream controls reflects the removal of heavier particles by upstream controls. Hence, treatment train configurations may be analyzed by continuous simulations if careful attention is paid to the impacts of controls in series.

To summarize, both flow-based and volume-based sizing may be performed based on a hierarchy of procedures beginning with 24-hour rainfall depths, for example, specified by a local agency, to which standard hydrologic techniques may be applied, moving up to frequency analysis of rainfall to obtain design depths and intensities, and culminating with continuous simulation modeling for hydrograph and pollutograph-based analyses.

Screening results for the U.S. for evaluation of volume-based controls are presented in Appendix E. As described earlier for flow-limited controls, continuous simulations were performed for a standard impervious catchment (described in the appendix). Volume-based controls were simulated as off-line storage, for which the annual percent capture of the off-line device is presented regionally, and on-line storage, for which effectiveness in TSS removal is a function of detention time. Evaluation of the latter involves simulation of particle removal within the device, as explained in Appendix D.

Example regional comparisons for off-line controls are shown in Figure 7-21 and for on-line controls in Figure 7-22. Generally, a given basin size captures a greater percent annual runoff volume in a drier area, such as Alturas, CA than in a humid area, such as Lisbon, FL, as shown in the Figure 7-21. Similarly, it can be seen in Figure 7-22 that for the same unit basin size, on-line detention is more effective (for TSS removal) in Alturas, CA than in Lisbon, FL. Screening results for 30 locations in the U.S. are provided in Appendix E.

With respect to sizing of treatment systems, site-specific analysis is always best (to be preferred over general screening results). Application of continuous simulation for this purpose is discussed in the next section, with detailed examples provided in Appendix D.

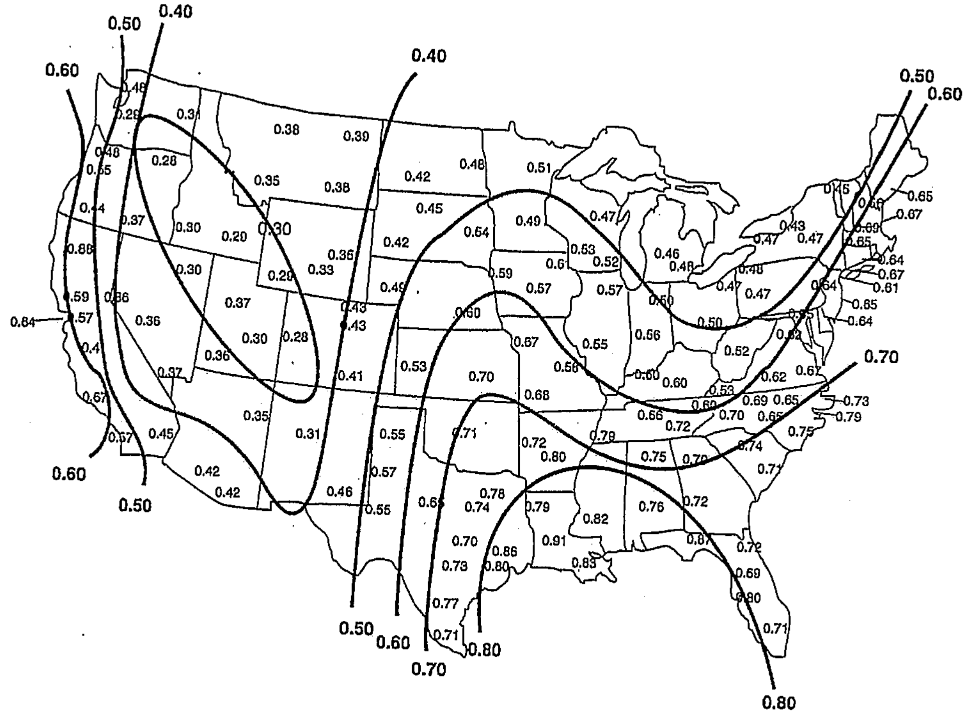


Figure 7-19. Mean Storm Precipitation Over the U.S. Based on 6-Hr Minimum Interevent Time.
Source: U.S. EPA publication (Driscoll et al., 1986).

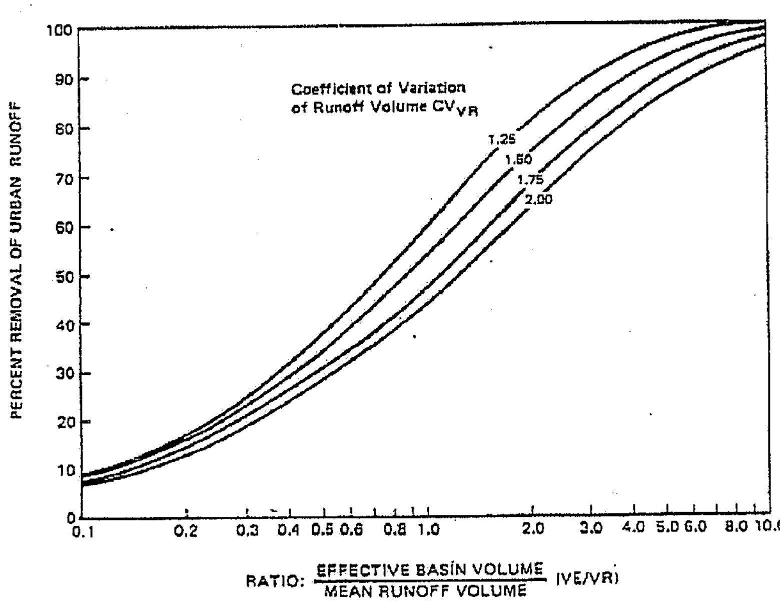


Figure 7-20. Average Long-Term for Detention Systems.
Source: U.S. EPA publication (Driscoll et al., 1986).

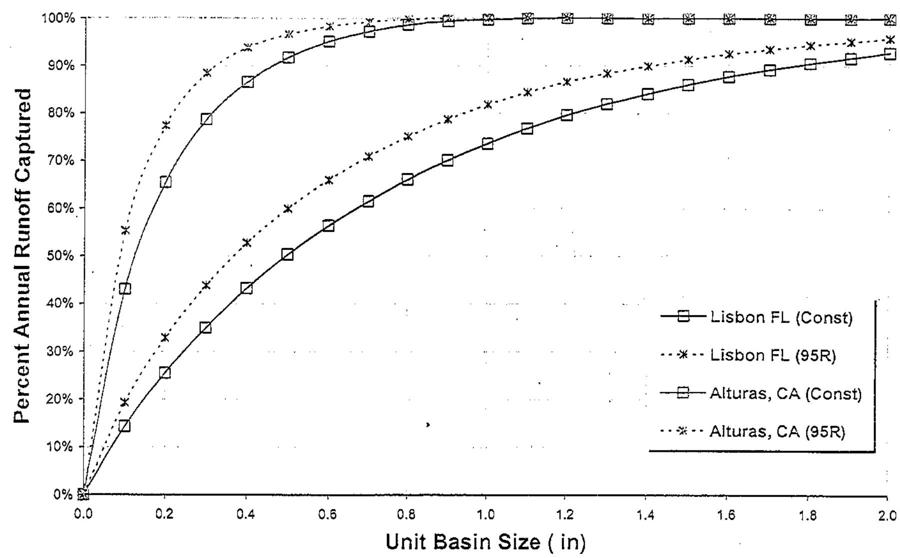


Figure 7-21. Percent Annual Runoff Volume Capture as a Function of Unit Basin Size.
For off-line storage at two different locations and two 72-hour drawdown time outlet structures (constant and 95% exponential). Unit basin size is in terms of inches over the catchment area.

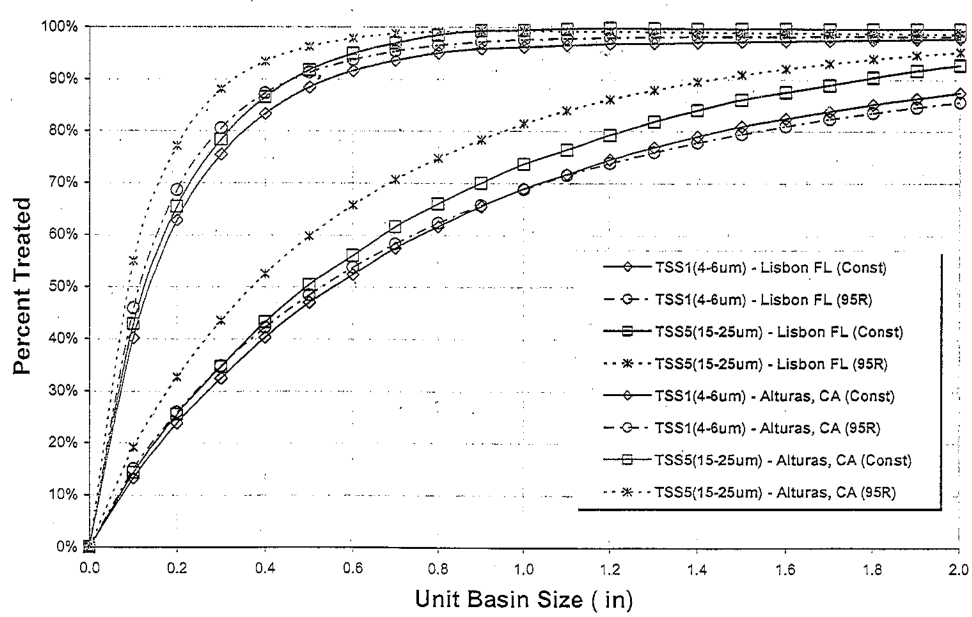


Figure 7-22. Percent TSS Removed as a Function of Unit Basin Size.
For on-line storage at two different locations and two 72-hour drawdown time outlet structures (constant and 95% exponential). Unit basin size is defined as inches over the catchment area. Particle sizes ranges are defined in Appendix D, with "TSS5" being largest and "TSS1" being smallest.

7.2 Performance Verification and Design Optimization

After a stormwater treatment system is properly sized, it may be desirable to analyze the hydrologic performance to ensure it will meet the runoff management goals. Depending on the level of detail and the methods used for sizing, much of this analysis may have already been done. However in most cases, detailed continuous simulations coupled with cost-benefit analyses would not have been completed during preliminary design stages. The following subsections describe some of the methods for verifying the performance of a treatment system and optimizing its design.

7.2.1 Modeling and Models

Hydrologic methods for evaluation of regional hydrologic impacts on treatment system performance have been discussed in the previous section. These often begin with "classical single-event methods," such as the rational method for peak flows, unit hydrographs, SCS (now NRCS) methods for losses and hydrographs, Santa Barbara Unit Hydrograph method, and so forth. In almost all cases, the resulting hydrographs are driven not by actual monitored rainfall, but by synthetic design storms, typically SCS dimensionless hyetographs (e.g., Type I-A for the Pacific Northwest, Type II for the southeast). As discussed earlier, a 24-hr duration is usually assigned, out of tradition, not out of any hydrologic considerations. Although event methods could certainly be applied to other design hyetographs derived from monitored rainfall, they rarely are. In addition to the issue of the rainfall driver, the question of initial conditions also arises, since event methods are sensitive to antecedent moisture conditions that affect infiltration and depression storage. These may be handled in a consistent way when applying the SCS method (i.e., through choice of AMC I, II, or III), but more often than not are ignored—or worst case (saturated) conditions are assumed, leading to an overly conservative design. Event hydrographs may then be passed through trial layouts of a treatment system for hydraulic design. Of course, such methods cannot account for water storage in the system between events. These methods are embedded in several versions of commercial software and are routinely accepted by the profession in spite of issues just mentioned.

The alternative to event methods is continuous simulation, using any of several models. Included among software for this purpose are federally-supported models such as (Singh, 1995):

- EPA Storm Water Management Model (http://www.epa.gov/ednnrmrl/swmm/index.htm)
- HEC-HMS (http://www.hec.usace.army.mil/)
- HSPF (http://water.usgs.gov/software/surface_water.html)

Continuous simulation may also be performed by several other models, even in a spreadsheet format, such as shown by Heaney and Lee (2005). Continuous models (which may also be used to simulate single storm events) are driven by a period-of-record precipitation file and should provide for soil moisture accounting, ET, regeneration of depression storage, and infiltration capacity, etcetera.

Apart from a better estimate of the overall water budget for the catchment, continuous models also permit the user to simulate the interaction of storage capacity and storm runoff volumes and/or pollutant loads, such that estimates can be made about how often the device will still contain water when the next event arrives. Results may be presented in a frequency format, as illustrated in the previous section (and in Appendix D), so that the percentage of annual runoff and/or pollutant load captured (or passed through) a control device may be determined as a function of device capacity. This information can then be used to develop sizing requirements so that continuous simulations would not need to be performed for each TSC.

Depending on the model, several forms of output may be analyzed statistically, such as runoff peaks, volumes, and durations as well as water quality parameters such as loads, EMCs, peak concentrations, etcetera. That is, the analysis may be performed on the parameter of interest, not just one or two hydrologic parameters. Because large events are inherently included in the simulation, safety factors for flood control or other device purposes also fall out of the evaluation. Finally, it is well established that the frequency of a runoff parameter, such as peak flow, will be different than the frequency of the rainfall event that caused it (primarily because of variable antecedent conditions as well as precipitation durations and intensities). Hence, frequency analysis can be separated from analysis of rainfall frequencies, in the form of an IDF curve, or even in the more sophisticated analysis of rainfall event parameter frequencies, of the type described in Section 7.1.3.

Finally, continuous modeling permits optimization for design on the basis of minimum cost, minimum downstream discharge, minimum downstream pollutant load, and a variety of other possibilities. This may be done heuristically with models such as SWMM or in a more integrated fashion with the spreadsheet models of Heaney and Lee (2005). Regarding costs, continuous modeling also allows for an estimate of the number of hours ("wet hours") a control is in use and the amount of sediment removed, for computation of operation and maintenance costs, as well as expected maintenance needs. Estimates of residuals or solids removed by a device will also be useful for operation and maintenance evaluations.

While continuous modeling affords several technical advantages, there are disadvantages as well. Continuous modeling generally requires more effort in assembling the necessary long-term precipitation input, from the NCDC, as well as in statistical interpretation of the multi-year hydrographs (and sometimes the corresponding pollutographs). Additional training may be required for use of the necessary models. Event modeling with synthetic design storms is easily reviewed by agencies, since much of it involves relatively prescribed parameter selection. Event models are available from many public and commercial software suppliers, and descriptions of the incorporated hydrologic techniques, such as the SCS method, may be found in any hydrology text. Commercial software also often includes reservoir routing and simple storage design options. Oversight agencies often strongly suggest, if not absolutely require, certain event modeling techniques, which can make the leap to continuous simulation more difficult. On the other hand, such local guidance (e.g., Urban Drainage and Flood Control District, 1999; Washington State Department of Ecology, 2001) often provides invaluable information on local parameters, suitable design conditions, and methods adapted to that particular region.

Again, continuous simulations can be performed to develop general sizing and design criteria on a sub-regional basis and the results used for simpler design requirements, which could then employ event models. For example, an agency could look at the results of treatment system sizing using event-based methods to design via continuous simulation to ascertain what the actual results would be and adjust the event-based storm size (or release hydrograph) accordingly.

7.2.2 Modeling Data Requirements

Data requirements for modeling include required input for the model itself as well as calibration and verification data (monitored hydrographs and pollutographs). Unfortunately, the latter are routinely unavailable, especially for an undeveloped site. In this typical situation, the modeler should still compare results with the nearest or most appropriate site for which data are available, including monitoring conducted by the USGS, numerous agencies in response to NPDES requirements, state and department of transportation agencies (e.g., Caltrans), universities, and so forth. Sensitivity analysis should also be performed on the model to help determine the most important parameter needs and to help evaluate uncertainty in the output.

Model input data include the following:

Rainfall input. For continuous modeling of urban areas, 15-min precipitation records (TD 3260) from the NCDC should be used unless shorter time increment data are available locally. If neither is available, then hourly data should be used. The NCDC 15-min data typically begin at about 1972, while hourly data can start as early as 1948. ET data are needed to compute the vertical water balance; one source is Farnsworth and Thompson (1982). If the additional complication of snowmelt is simulated, appropriate meteorological data are need to compute melt.

Catchment data. These include area, directly connected and other imperviousness, depression storage, slope, roughness, infiltration values or other loss parameters (such as SCS curve numbers), shape factors (such as time of concentration), etcetera. Additional soil properties may be needed to model soil moisture levels.

Data for flow routing, if simulated. These include channel/pipe connectivity, shape, dimensions, slope, roughness, invert and ground elevations, etc. If hydraulic structures are simulated, their hydraulic characteristics must obviously be provided. For small catchments (up to several acres), it may not be necessary to simulate flow routing, but for larger urban watersheds, the storage, delay, and attenuation provided by the drainage system should be accounted for.

Data for simulation of controls. These include stage-area-volume-discharge information for storage devices, infiltration properties for swales and filter strips, ET, hydraulic considerations, etcetera. If water quality in controls is simulated, additional information may include UOPs, outlet EMC frequency distribution, treatability data (distribution of sizes and/or settling velocities), sorptive properties, and so forth, depending strongly on the model used.

Good maps and drainage plans are an essential part of the data preparation effort. If spatially oriented data are included in a GIS for a locality, this effort will be greatly facilitated. Soil survey maps and reports are always useful.

The importance of site-specific data cannot be overemphasized. For example, infiltration into soils is notoriously variable in space, with infiltrometer measurements that may differ even for closely spaced samples. Urban soils are likely to have been compacted and not reflect infiltration characteristics for nearby undisturbed sand, silt, clay, etc. (Pitt et al., 1999; Pitt et al., 2001). Because infiltration is a key parameter for the evaluation of effectiveness of such common devices as swales, site-specific infiltrometer data are essential and are not that costly.

Similarly, the effectiveness of any stormwater control is a function of the "treatability" of the stormwater. Obviously, the larger and heavier the particles, the easier it is for any device to remove them. Therefore it is important to have settling velocity or particle size data on the expected influent. Finally, an analysis of a treatment train must account for the fact that upstream devices will remove the "easiest" (largest) material first, and performance of downstream devices will be affected accordingly. For example, in watersheds that are effectively swept regularly, the runoff may be expected to be cleaner prior to input into a treatment system. Likewise if a bioswale discharges to a wetland treatment system, the wetland would not receive as high input loads as it would if the bioswale were not there.

The developers of the International BMP Database (Strecker et. al., 2004) have recommended that stormwater treatment system performance be accounted for by: 1) how much runoff is prevented, 2) how much runoff is treated (and not), and 3) what is the resulting effluent quality of treated runoff. Using these descriptors will help one evaluate "performance" through several possible measures, and not overestimate treatment system performance on the basis of a single estimate.

7.2.3 Recommended Process Modeling Methodologies

The previous sections emphasize the approach of this guidance, which provides a recommended hierarchy for modeling in the following preferential order:

1. Continuous simulation, using a model suited to the task, such as the ones discussed in Section 7.2.1. Depending upon the objective, it may not be necessary to simulate water quality as well as water quantity, since water quality simulation is much more difficult and uncertain. However, if water quality is not included, then the results for storage effectiveness are less accurate since the tradeoff between maximizing volume captured and maximizing load captured is not explicitly included. The volume captured can be maximized by shortening the detention time but water quality control will be improved if detention time is increased. Continuous simulation models can be used to simulate the effects of use of simpler methods for sizing treatment systems. For example, continuous simulations can be conducted on potential event-based model sizing methods to ascertain the capabilities of the event-based models and establish sizing requirements to which the event-based models are applied.
2. Event models of "classical" hydrology, using site-specific data. These models should only be used when verified with a continuous simulation approach to determine what the potential results of wet weather controls may be over the entire spectrum of runoff hydrographs. This is especially critical for design of systems for reducing downstream erosion.
3. Generalized regional guidelines, of the type discussed in Section 7.1. These can include simplified methods provided by WEF and ASCE (1998) and the extensive regional, but general, continuous simulation results provided with this document (Appendix E). These regional guidelines might also provide a starting point for event and continuous models.

Guidance with regard to the generalized results has been provided in Section 7.1. No attempt will be made to provide a description of "standard" hydrologic procedures documented in dozens of texts and stormwater manuals (and option 2 above). Nor will descriptions of screening methods already provided by WEF and ASCE (1998) and similar sources because these sources are readily available and no improvement can be made on the presentation made in the originals. However, much has been implied herein about the advantages of continuous simulation for analysis of wet weather controls, and documentation of this recommended approach is provided by the two examples presented in Appendix B.

7.2.4 Optimization Methodologies

Heaney and Lee (2005) and Lee et al. (2005) summarize how spreadsheet based process simulations can be linked with cost data, performance standards, and optimization software to find the actual "best" management practice(s). Pack (2004) develops these methods for infiltration systems while Rapp (2004) develops them for storage/release systems. The results of process simulation where performance is measured in terms of percent pollution control as a function of the size of the storage and release rate are illustrated in Figure 7-23 (Lee et al., 2005). Each point on the figure represents a simulation run. The percent pollutant control for selected runs is also included. The isoquants in Figure 7-23 show the various combinations of storage and release rate that yield a given percent pollution control over the simulated period. For example, the 85% isoquant shows that storage can be reduced significantly if the release rate is increased from 0.010 to 0.015 mm/hr. However, further increases in the release rate (decreasing the detention time) require more storage. Thus, the portion of this isoquant for which release rates exceed 0.015 mm/hr. is technically inefficient. The least cost combination for 85% control is the one that minimizes the life cycle cost for storage plus release rate. The optimal solution can be determined graphically (for two variables) or using the Solver optimization software in Excel.

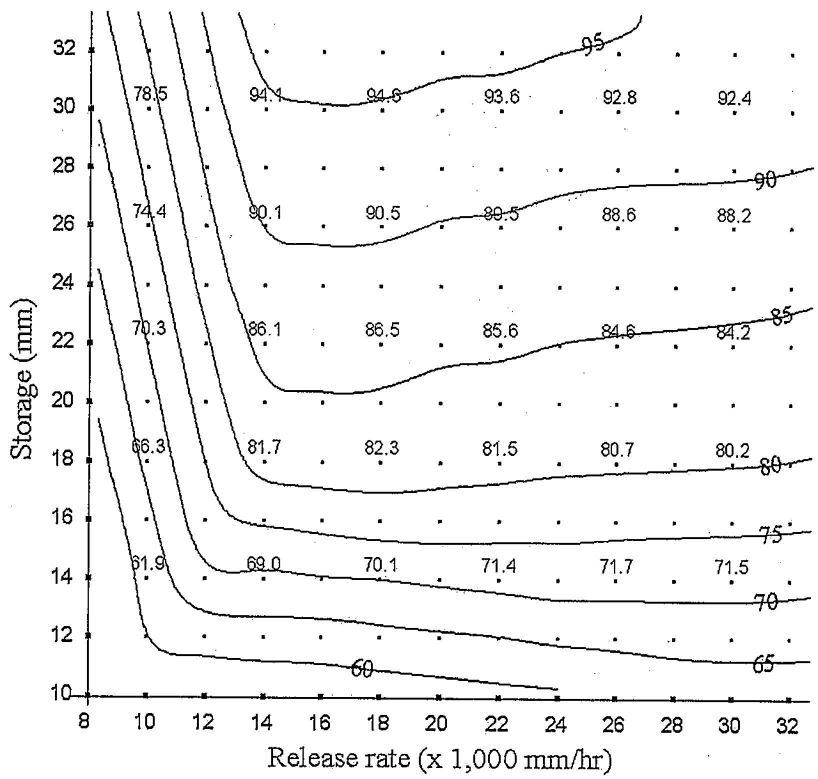


Figure 7-23. Pollutant Control as a Function of the Assumed Storage Volume and Release Rate.

A schematic of the flow of information between the simulator and the optimizer is shown in Figure 7-24. This process can be repeated for all performance levels to derive the final cost-effectiveness curve that shows total costs as a function of the percent pollution control are illustrated in Figure 7-25 (Rapp, 2004). This performance curve is typical. Incremental costs of control typically increase rapidly beyond about 80% pollutant control. A detailed example of this simulation/optimization is provided in Appendix B.

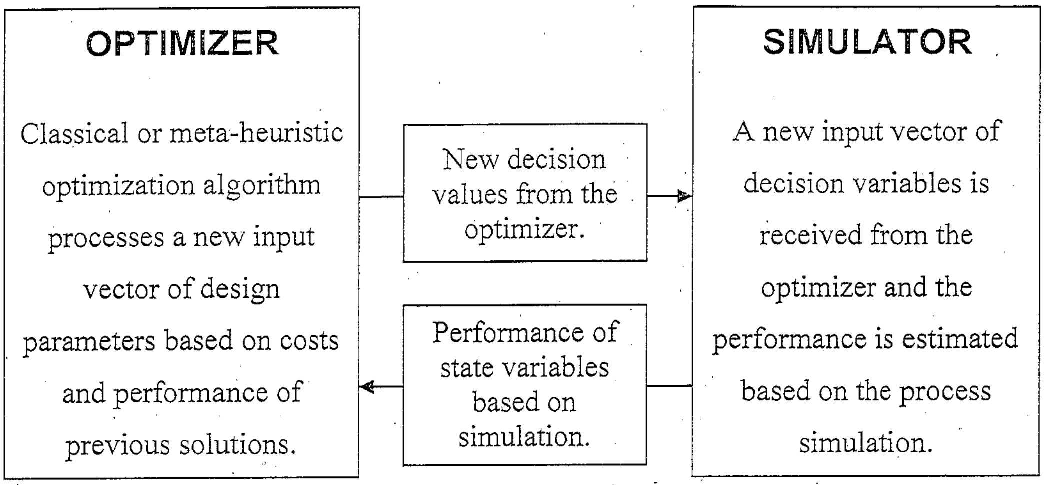


Figure 7-24. Linkage Between the Simulator and the Optimizer.

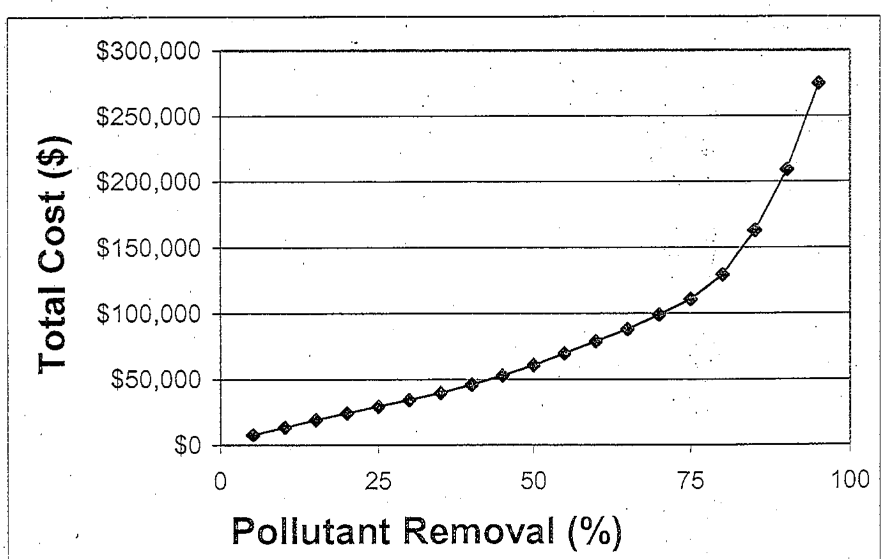


Figure 7-25. Illustrative Performance Curve for a Storage/Release Treatment System.

7.3 Flexible Design/Adaptive Management

The design methodologies described in this document focus attention on selection of specific treatment train designs that are anticipated to perform within specified constraints and to achieve established project goals. However, these estimates need to be refined based on the results of actual operation. The concepts of flexible design and adaptive control and management are important and effective components of implementation and should not be overlooked. These concepts can be quite powerful in situations where effluent quality and downstream hydraulic performance are direct measures of project success, and they allow for changes to be made in system function well after implementation. Continuous simulation of various designs requires the specification of how the system will be operated. It also provides valuable estimates of system behavior across the entire spectrum of flow conditions. Often these approaches only minimally increase capital costs for a project and can frequently significantly increase the likelihood of achieving project goals.

Flexible design is defined here as having UOPs that can be readily adjusted or modified following construction or installation to achieve variations in system function and performance. Adaptive management is a means for managing these flexible design elements to allow for changes in implementation to be made based on information obtained from monitoring of the effectiveness and performance of a treatment system. Although it is not always possible, ideally adaptive management and flexible design go hand-in-hand and are integral and intentional components of the physical design of a treatment system.

7.3.1 Design Elements

Many UOPs lend themselves to a flexible design approach. The obvious examples include hydraulic controls that can be adjusted to:

- Achieve longer or shorter residence times or to match complex water quality performance goals.
- Match predevelopment flow-duration curves in the receiving water.
- Adjust, split, divert, or redirect flows between downstream processes or TSCs.
- Adjust the physical outlet configuration to permit fish passage.
- Increase or decrease peak discharge flow rates.
- Increase or decrease the quantity of water diverted for infiltration.
- Increase or decrease the drainage area flowing to specific facilities through simple modifications such as additional swales, curb-cuts, gutters, and so forth.

Flexible hydraulic designs frequently include the use of controls such as adjustable stop-log structures, adjustable weir plates, valves and gates, and interchangeable orifice and weir plates.

Many other UOPs and TSCs can be designed to allow for adaptive management of the system through the incorporation of flexible design including:

- Allowance for additional storage volume. For example, designing additional storage that may not be used unless expected performance is not achieved or for flexibility in the use of flood storage for water quality treatment.

- Setting aside additional site area for future treatment processes should they be needed at a later date.
- Increasing or decreasing the quantity of vegetation in system as well as variations in vegetation management strategies, such as altering vegetation type or species to achieve water quality benefits. For example, different plant species have varying pollutant removal capacities and tolerances. Adjusting plant composition and density within the treatment site can maximize plant cover and pollutant uptake.
- Outlet adjustments that allow water level to be maintained during drought conditions. For example, having an adjustable low flow control is particularly important during times of drought and low baseflow in vegetated and wetland systems.
- Changing filter media or loading rates to treat specific pollutant needs.
- Increasing or decreasing maintenance to preserve treatment effectiveness.

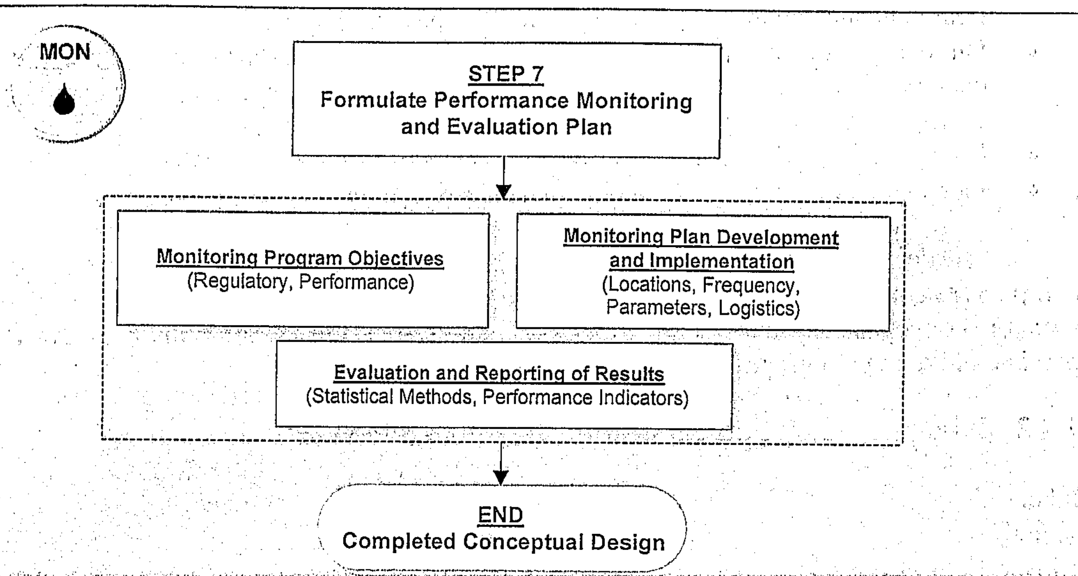
The design engineer needs to pay particular attention to making all of the other design components compatible with flexible design elements. For example, the capacity of outlet structure conveyance systems downstream of an adjustable stop-log structure must allow for safe passage of the maximum possible flow independent of the setting.

7.3.2 Inherently Safe and Inherently Functional Design

Flexible design requires the use of inherently safe and inherently functional designs. Inherently safe designs do not allow the flexible or adjustable component of the system to be set such that the setting results in an unsafe condition. Likewise inherently functional designs do not allow a flexible control element to be set such that the element results in a condition that compromises the functionality of the system either from a water quality or operational perspective. For example, the concept of inherently functional design could be used to limit the size of a pipe leading from an adjustable flow splitter to an off-line wetland system based on the maximum flow rate that the wetland system might tolerate without incurring damage to vegetation, or that could result in the export of accumulated sediments. This approach sets an upper limit on the flow rate to be diverted to the wetland system.

CHAPTER 8.0

PERFORMANCE MONITORING AND EVALUATION



Key Concepts:

- What monitoring is needed or required to demonstrate long-term project success
- How will the monitoring program be implemented?

8.1 Introduction

Treatment system performance monitoring is conducted by researchers, public entities, and private companies to meet both regulatory and nonregulatory needs. Evaluating the performance of installed stormwater treatment systems can be an in depth and costly process. However, the importance of performance monitoring, particularly for treatment systems installed in critical pollutant source areas or upstream of sensitive receiving waters, cannot be overstated.

Several environmental laws exist that mandate implementation of stormwater monitoring programs including:

- The Clean Water Act (CWA) of 1972
- The Endangered Species Act (ESA) of 1973
- Coastal Zone Act Reauthorization Amendments (CZARA) of 1990

Performance monitoring allows for the evaluation of the actual effectiveness of the treatment system, and if carefully designed, allows for the modification of various TSCs to improve performance by adaptive management (see Section 7.3). Monitoring of a stormwater treatment system involves 1) determining the scope and objectives, 2) developing a monitoring plan to meet monitoring objectives, 3) implementing the monitoring program, and 4) evaluating and reporting the results. In depth descriptions of EPA-approved methods for all phases of monitoring, from sampling to data collection, can be found in multiple sources such as the ASCE and EPA Urban Stormwater Monitoring Guidance Manual (2002), Caltrans Stormwater Monitoring Protocol Guidance Manual (2000), WEF Manual of Practice No. 23 (1998), and EPA Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls (1997). Additional resources relevant to treatment system performance monitoring and evaluation are included in Section 8.5.

8.2 Monitoring Program Objectives

A successful monitoring program begins, with a clear identification of monitoring objectives and potential constraints. Stormwater treatment system monitoring is initiated to address a broad array of programmatic, management, regulatory, and research goals. Monitoring goals are often focused on achieving water quality objectives (including hydrology/hydraulics and water quality) downstream of the facility. It is important in the planning stage of a monitoring project to quantify the methods that will be used evaluate attainment of the monitoring goals and objectives.

Before beginning a performance monitoring program, it is important to clearly identify and understand the specific hydrologic and stormwater quality objectives at a particular site, which should have occurred early in the conceptual design phase. This information is useful for determining necessary or potential monitoring and analysis methods. For example, a treatment system with well-defined inlets and outlets, such as a detention pond, would have more monitoring options than a treatment system without well-defined inlets and outlets, such as a bioretention area. Furthermore, a site would require significantly different sampling methods if the pollutants of concern are pathogens or oil and grease, as opposed to heavy metals or nutrients.

8.3 Monitoring Plan Development and Implementation

To support the monitoring objectives, appropriate technologies and current stormwater monitoring knowledge should be incorporated into the monitoring plan where possible. Developing a monitoring program requires selection of monitoring locations, monitoring frequency, parameters, sampling (e.g., grab or composite, manual or automated) and analytical methods, as well as storm criteria such as size, duration and season. A quality assurance and quality control (QA/QC) plan, which describes the data quality objectives of the monitoring program, and a health and safety plan, should also be developed as part of the monitoring program.

For nonregulatory efforts, or for treatment systems designed to reduce runoff volume or rate, the monitoring plan may consist of simple flow monitoring; or even visual inspection during runoff events may be sufficient to evaluate performance. Downstream channel or streambank conditions can be visually inspected to assess if erosion, scour, or cut-out has been reduced. To determine the effectiveness of an infiltration system, it may be necessary to monitor influent flow rates, and compare these with overflow data from the system. If there is no flow meter, a weir and pressure transducer combination can be used to monitor flow rates and volumes. Monitoring for infiltration rate requires at a minimum some form of water level detection, such as ultrasonic or pressure related detection.

A fundamental requirement of every successful water quality monitoring program is effective and representative sampling of runoff events at the site. Stormwater sampling is very challenging and is subject to unforeseen circumstances, which may include equipment malfunctions, safety issues, discrepancies between the actual event and forecasts, seasonal runoff variations, and other circumstances. One objective of developing a monitoring plan is to minimize these effects through the use of sound monitoring protocols and strategies during the implementation stage.

Various methods, all with different cost and time structures, can be used for sampling. Grab samples at a specific point in time, are most often collected manually and can be labor intensive due to the broad time scale of runoff events. If samples need to be collected at different times, and over extended time periods, automated samplers could be a more cost-effective option (provided the constituent, due to its nature, does not require collection by grab sampling). To set up an effective automated monitoring program, however, initial equipment setup may be costly. To accurately sample a storm event, automated samplers require a flow measurement device, a flow sensor, and a rain gage. Samples must be collected in appropriate containers (e.g., Teflon® or polyethylene for metals, treated glass for other constituents) using clean sampling techniques. Sampler tubing must be an U.S. EPA-approved material.

Once sampling equipment has been installed, two types of sample programming methods can be employed. The most common and cost-effective is flow-weighted composite sampling. This method uses flow data to collect larger sample amounts during high flows, allowing for a more accurate representation of an entire runoff event. A more costly, but more accurate method is discrete, or grab sampling, which consists of collecting samples from discrete time intervals for individual analysis. Analysis of discrete samples provide a more accurate description of the pollution dynamics throughout a storm event. Grab sampling is also required for constituents that transform rapidly, require special preservation, or adhere to bottles (Caltrans, 2000).

The major cost in a monitoring program is the chemical analyses of samples. A comprehensive analytical suite can be costly, especially if several locations are being sampled. For most stormwater treatment system monitoring, composite sampling greatly reduces analytical costs compared to analysis of discrete samples. However, depending on the specific monitoring goals, such as collection of first flush data, detailed intraevent sampling data may be needed. For projects in which monitoring is of limited scope and time, manual grab sampling may be more cost effective because less equipment is needed to implement the program.

8.4 Evaluation and Reporting Results

Reporting of the monitoring results should include information on sampling and analytical methods, in addition to the water quality data and analysis (including an evaluation of data quality). For each site, sample name, sample time and date, rainfall event including any flow rate measurements taken, when the rain started and stopped, rainfall intensity and the total amount of rainfall should be included.

The data should obviously be evaluated and discussed in terms of meeting monitoring objectives. For example, if the primary objective is to assess stormwater quality, a straightforward comparison of pollutant concentrations in stormwater with regulatory criteria may satisfy the reporting requirements. For long-term trend analysis and comparison, a detailed reporting approach should be developed as data become available and trends become apparent.

8.5 Resources for Treatment System Performance Monitoring

A short list of additional resources relevant to performance monitoring and evaluation are given below:

- WERF (2004). Post-Project Monitoring of BMPs/SUDS to Determine Performance and Whole-Life Costs.
- ASCE and U.S. EPA (2002). *Urban Stormwater BMP Performance Monitoring – A Guidance Manual for Meeting the National Stormwater BMP Database Requirements*. Prepared by GeoSyntec Consultants and Urban Drainage and Flood Control District [Online] http://www.bmpdatabase.org/docs.html
- Caraco, D. and Claytor, R. (1997). *Stormwater BMP Design Supplement for Cold Climates*. Prepared by the Center for Watershed Protection for the U.S. EPA, http://www.cwp.org/cold-climates.htm.
- Federal Highway Administration (FHWA) (2000). *Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring*. Prepared by Tetra-Tech, Inc. and Hagler Bailly Services, Inc. FHWA-EP-00-002, Washington, D.C.
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CHAPTER 9.0

FUTURE RESEARCH RECOMMENDATIONS

The selection of UOPs and associated TSCs for treating specific target constituents in stormwater should be based on past experience, research, and sound scientific and engineering principles. However, to meet ever more stringent water quality management goals and objectives, stormwater treatment is becoming progressively more complex. Significant data gaps exist for the more advanced treatment mechanisms, such as coagulation/flocculation, sustainable filtration, adsorption, ion exchange, precipitation, biological uptake, microbial transformations, and management of residual materials. Pilot studies are needed to start bridging the knowledge gap between UOP theory and field observations of treatment system performance. Results of pilot studies are also needed for parameter estimation and calibration of fate and transport models. The following research topics have been identified to fill some of the gaps in current stormwater treatment knowledge:

- Development of techniques for accurately measuring and analyzing individual unit operations and processes within TSCs.
- Evaluation of design variables that are related to biochemical and geochemical treatment mechanisms.
- Evaluation of the effectiveness of combination of sedimentation, filtration, and chemical addition for controlling suspended sediment transport.
- Identification and evaluation of accurate and applicable methods for monitoring particle size distribution of suspended sediment concentrations.
- Correlation of heavy metals concentrations to suspended sediment in urban and highway runoff.
- Evaluation of design and performance with respect to particle size distribution in stormwater runoff and associated metals.
- Evaluation of metals speciation under anaerobic and anoxic conditions.
- Evaluation of seasonal effects of plant species on pollutant removal.
- Evaluation of pollutant removal capabilities of native plants.
- Evaluation of the characteristics and effects of short-circuiting, bypass, and overflow.
- Evaluation of the correlation between hydraulic residence time and performance.
- Development of methods or models for estimating the true hydraulic residence time in stormwater ponds.
- Development of alternative methods to optimize detention basin design to maximize treatment.
- Assessment of retrofit options for flood control basins and systems that maximize water quality control while maintaining adequate flood control protection.
- Development of methods for improving/maintaining hydraulic conductivity of infiltration-based TSCs.
- Development of unit treatment models that incorporate advanced treatment mechanisms, such as sorption, ion exchange, biological uptake, and microbial transformations.

- Development of models for simulation of treatment train hydraulics and pollutant removal.

Just as not all pollutants and UOPs have been presented in this document, there are undoubtedly many more relevant research topics that would benefit the stormwater community. Design engineers will inevitably need to consult other sources of information and conduct independent research relevant to their particular site conditions, water quality objectives, and personal interests. As the state-of-the-practice advances with additional research and knowledge to varying degrees and complexities, stormwater treatment professionals will increasingly migrate from treatment system designs based on "black box" estimates of performance to designs that focus on achieving pollutant-specific goals through integration of UOPs and TSCs in treatment trains. With this migration, the stormwater engineering community will continue to progress toward sustainable stormwater management solutions.

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Montgomery Water Works & Sanitary Sewer Board

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Anchorage Water & Wastewater Utility

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Fairfield-Suisun Sewer District
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Inland Empire Utilities Agency
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Lodi, City of
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Los Angeles County, Sanitation Districts of
Napa Sanitation District
Orange County Sanitation District
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Sacramento Regional County Sanitation District
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San Francisco, City & County of
San Jose, City of
Santa Barbara, City of
Santa Cruz, City of
Santa Rosa, City of
South Bayside System Authority
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South Orange County Wastewater Authority
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Sunnyvale, City of
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Meeting the Challenges of Stormwater Management *and* Vector Control

Integrating stormwater management and vector control in a Phase II city

By Kenneth E. Banks

Managing stormwater in Denton, TX, took a new direction on August 6, 2002, when a mosquito—captured as part of a local University of North Texas research project—tested positive for West Nile virus (WNV). Based on the cases of WNV being found in surrounding states, as well as in other areas of Texas, city officials suspected that it would be only a matter of time before the disease reached Denton. After August 2002, however, Denton's mosquito control philosophy shifted from being associated mainly with nuisance controls to potentially having major public health implications. The city needed a unified, coordinated approach to mosquito management that ensured the protection of both public and environmental health. This article outlines the rationale behind Denton's mosquito control program and describes how the city has attempted to meet the multiple—and sometimes conflicting—challenges of stormwater management, integrated pest management, and public health protection.

One of the immediate issues for the mosquito control program involved determining which control methods were most appropriate. Before WNV arrived in Texas, several groups of citizens had worked with the City of Denton to decrease the number of pesticides and herbicides applied in parks and other public places. The city has worked with these groups to adopt an integrated pest management approach to controlling both animal and plant pests within city properties. The approach for mosquito control was no different, and city staff members desired to put together a program based on preventative—rather than reactive—controls. The overriding goal of the program was to instigate scientific and appropriate responses for mosquito control, based on data about mosquito habitats, breeding seasons, and control measures and on the overall risk to public health. Staff also realized, however, that this type of program could not be administered solely by the City of Denton. Citizen involvement and guidance were needed, as was technical support.

Public health is an overriding goal in any municipal environment. In addition, relatively recent National Pollutant Discharge Elimination System (NPDES) regulations have challenged small to medium-sized (Phase II) cities to adopt measures to improve stormwater runoff quality by using myriad best management practices (BMPs). Although improving stormwater quality is the goal of the Phase II program, the public health implications of some stormwater improvements are often ill understood and in some instances might not be considered at all. This situation might become particularly pronounced in smaller cities that are struggling to meet the regulatory compliance deadlines of the Phase II program without the benefits of additional staff and resources. As resources become increasingly taxed and compliance deadlines approach, meeting the immediate stormwater-quantity and -quality requirements might become the only programmatic goal of stormwater management.

Stormwater Best Management Practices and Mosquitoes

Managing stormwater has traditionally involved activities related to the quantity and quality of stormwater runoff; recent concerns about disease vectors that might be associated with structural stormwater BMPs, however, have caused many stormwater professionals to begin to consider the potential public health impacts of certain structural BMPs. Those involved in BMP design, implementation, operation, and regulations are finding that the responsibilities of stormwater management go beyond simple compliance with urban runoff regulations. The challenge now has become an issue of maintaining compliance with state and federal stormwater regulations while simultaneously minimizing the potential impacts to public health. Many Phase II municipalities just becoming involved with a new and somewhat bewildering array of stormwater regulations, requirements, and BMPs might be unprepared to deal with the additional complicating factor of public health.

Most of the recent public health concerns about disease vectors have centered around mosquito control. On a global basis, there is no doubt diseases transmitted by mosquitoes are among the most significant causes of human illness and death, with millions of people being affected by mosquito-borne illnesses every year. These problems might be exacerbated in urban areas, which tend to have numerous human-made and natural mosquito-producing habitats. Habitats might include, but are certainly not restricted to, certain stormwater BMPs, particularly those that retain water for a designated period of time. Such systems might be designed to have relatively still water and/or densely vegetated areas to settle contaminants and provide areas where biological activity can mitigate pollutants. Unfortunately the same conditions can also provide optimum conditions for some mosquito life cycle stages.

A mosquito's life cycle consists of four stages—egg, larvae, pupa, and adult—and eggs must be laid in stagnant water or on damp soils likely to be flooded with water. Eggs typically hatch in 24–48 hours, and the resulting larval and pupal stages will typically last five to 18 days before producing an adult mosquito (Floore, 2002). The amount of time spent in any given life stage depends on environmental conditions, particularly temperature. Anything done to disrupt the cycle from the egg to the adult phase, however, can effectively prevent mosquitoes from being able to transmit diseases.

In some instances, the intensive media coverage concerning mosquitoes and their relation to human health produces the perception that any type of standing water is a breeding ground for large numbers of disease-infected mosquitoes. This perception might lead citizens or public officials to suggest that all sites having standing water should be filled, drained, sprayed, or otherwise managed to completely eliminate all mosquitoes. These concerns are not unfounded; some recent studies conducted in California have demonstrated that many common BMP designs are capable of providing breeding habitats for mosquitoes, some of which are capable of transmitting human diseases (Metzger et al., 2002). Studies have also shown, however, that proper design, construction, and maintenance of BMPs can dramatically reduce the suitability of these structures for producing mosquitoes (Kluh et al., 2002).

The relatively recent and rapid proliferation of WNV and the resulting impacts on public health have many municipal separate storm sewer system permittees concerned about the potential impact of stormwater BMPs on disease transmission. Although the newness of this illness has garnered a lot of media attention and created a general concern among many people, according to the national Centers for Disease Control and Prevention (CDC), the risk to any one person is extremely low.

WNV first appeared in the eastern United States in 1999 and rapidly spread westward, becoming isolated in birds, humans, and mosquitoes in 44 states and Washington, DC, by the end of 2002. The number of humans affected by the virus increased dramatically during 2002 and 2003 (see Table 1). Typical symptoms of WNV in humans are flulike, characterized by mild fever, headache, body ache, swollen lymph glands, and occasional development of a rash. According to the CDC, about 13% of those infected develop West Nile fever, with headaches and flulike symptoms from which they eventually recover. Some individuals who become infected with WNV (thought to be less than 1% of the total number of people infected) will develop meningitis, an infection of the membranes of the brain or spinal cord, or encephalitis, an infection of the brain. Both conditions can cause death or permanent injury, and advanced age seems to be an important risk factor for developing a life-threatening form of the disease. The fatality rate is approximately 3–15% among those who contract meningitis or encephalitis.

Table 1. Incidence of WNV in Humans in the US, January 1999–September 2003

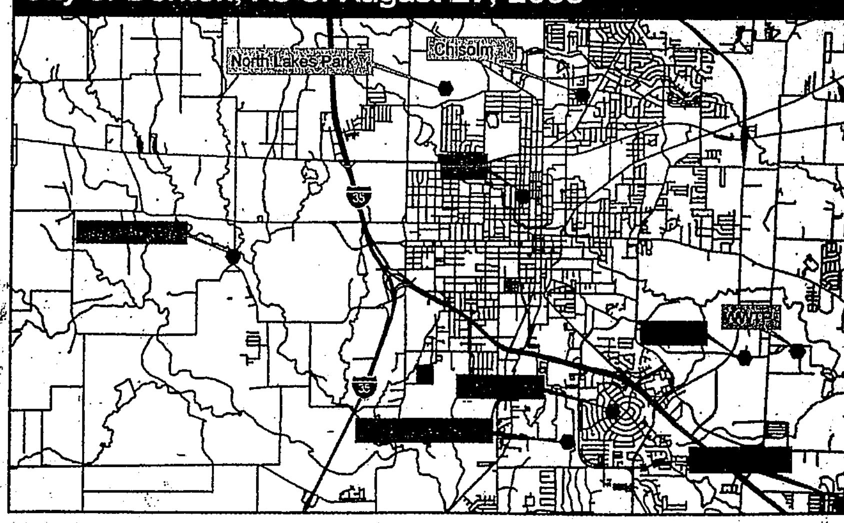
[redacted]

Based on mosquito biology, any standing water has the potential to promote mosquito growth. Because some stormwater management practices use standing water to promote water-quality improvements—or because they have a possibility of creating standing water if not properly maintained—there is a chance stormwater management practices will contribute to mosquito problems. Stormwater BMPs, however, are essential to minimizing the adverse water-quality impacts caused by development and thus are a vital component of urban surface-water conveyance systems. The challenge facing the City of Denton was to provide water-quality improvements through stormwater management without jeopardizing public health.

Denton Setting

The city of Denton occupies an approximately 64-mi.² area in north-central Texas, about 30 mi. north of Dallas. Three major watersheds drain from Denton, and there are many ponds, wetland areas, streams, and stormwater conveyances within these watersheds. The city also has numerous parks and a large number of protected greenbelts

Figure 1. Map of WNV-Positive Samples Within the City of Denton, As of August 27, 2003



Green labels indicate a single positive sample. Yellow labels indicate two samples have tested positive from the same location.

and environmentally sensitive areas along riparian corridors. Denton is located in close proximity to Lake Lewisville, a large (45-mi.[2]) multipurpose reservoir. Many of these areas have the potential to provide a mosquito habitat.

Soon after the discovery of the first WNV-positive mosquito sample, the City of Denton developed and implemented the Mosquito Surveillance and Response Plan. The plan is designed to establish the programmatic assessment of mosquito populations within the city and to guide the use of various control measures. City staff recognized that the magnitude of the mosquito control program required the cooperation and coordination of many different departments within the city, county, and state public health agencies and of the citizens of Denton. The city also decided that employing a proactive, targeted approach to mosquito management was much more desirable than merely responding to an outbreak once it occurred.

Mosquito Response Plan

City staff recognized early in the process of developing the mosquito response plan that there was a potential for overlap between mosquito control and stormwater management. Because there is a real potential for vector production in stormwater BMPs, the City of Denton's Watershed Protection Department, which administers both the city's watershed monitoring program and its stormwater program, was chosen as the lead department for mosquito control issues. The Watershed Protection Department, acting as a general coordinator, works closely with the city's Drainage, Engineering, Animal Control, and Code Enforcement Departments and the Public Information Office concerning various aspects of control. The city staff also maintains close contacts with the Denton County Health Department. Cooperation among the various city and county departments has been crucial to providing the city with the best possible means of achieving clean-water goals without sacrificing public health.

Mosquito Surveillance

During the fall of 2002, the City of Denton entered into an agreement with the University of North Texas to begin an active adult mosquito monitoring program. Beginning in April 2003, several adult mosquito traps were deployed throughout the city. Two main types of traps are used: a CDC light trap baited with carbon dioxide and a gravid trap designed to collect ovipositing female mosquitoes. Light traps rely on a carbon dioxide attractant to lure mosquitoes into an area where a fan conveys the mosquitoes into a capture net. Gravid traps contain a pungent liquid mixture of water, hay, and other organic material that lures female mosquitoes ready to lay eggs. Currently almost all of the mosquitoes that have tested positive for WNV within Denton have been captured using gravid traps.

After capture, adult mosquitoes are transferred from the traps to specially designed transport boxes and then are sent to the Texas Department of Health for identification of species level and testing for the presence of viruses. If viral infections are detected, further testing is conducted to determine if the virus is West Nile or some other mosquito-

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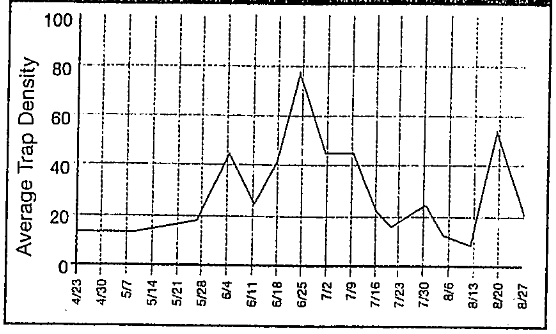
Figure 2. Average Number of Trapped Mosquitoes per Sampling Event, April–August 2003



borne virus, such as Saint Louis encephalitis or eastern equine encephalitis. Trapping is conducted approximately once a week using four fixed locations, four locations randomly chosen within four large geographic areas in the city, and two completely random locations. Some limited trapping has also been based on additional information, such as the number of complaint calls or observations of dead birds.

Mosquito Trap Informatio

To date, 28 different mosquito sp have been identified within Denton, and more than 7,000 mosquitoes have been submitted for testing. As of September 9, 2003, 12 samples tested positive for WNV. All of the information collected by the trapping network is used to create maps showing sampling locations where WNV-positive samples were collected (see Figure 1). Sites where multiple samples were collected are color-coded so citizens can quickly tell where the disease appears to be more prevalent. Maps are posted on the City of Denton Web page as soon as the information is obtained.

Information concerning the dynamics of mosquito densities (see Figure 2) and the overall incidence of WNV (see Figure 3) can be produced quickly from trap results. This information gives city officials and citizens a better understanding of mosquito population densities within the City of Denton and a sense of the relative risk of WNV transmission to humans. Citizens are quickly informed about the appropriate city risk level and are provided with infor- mation concerning the most appr ate protection activities. The inform tion is also used to direct city staff to areas that have consistently high mosquito population densities, to determine if target mosquito species appear to be associated with stormwater infrastructures or homeowner management practices, and to help determine the appropriate larviciding approach.

Trapping information, along with information on animal or human cases of WNV, is used to establish risk levels for the city. Each risk level is triggered by data concerning the likely public health risk and coincides with a particular series of activities. Control activities become more pronounced as the threat to public health increases. An outline of triggers, associated risk levels, and resulting activities of the city's Mosquito Surveillance and Response Plan can be viewed by going to the Water Utilities Department page at www.cityofdenton.com.

Adult Mosquito Control: To Spray or Not To Spray

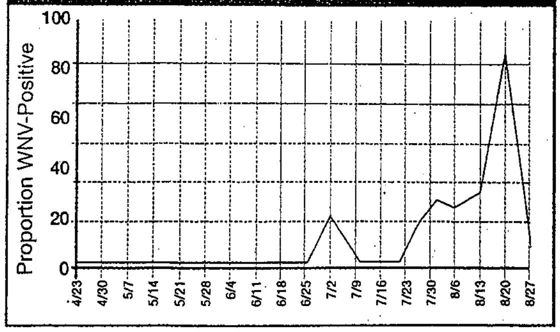
The most important maintenance cy from a public health standpoint involves humans and mosquitoes in urban and suburban environments. The principal vector of WNV in Denton, *Culex quinquefasciatus*, is a highly domesticated species that uses the transient waters common to the urban environment as larval habitat. Other mosquito species might be involved in suburban or rural maintenance cycles, but in Denton they do not seem to be a major contributor to the transmission of WNV.

Traditional mosquito control often uses insecticides as space sprays to kill adult mosquitoes. One of the most popular approaches to the application of these sprays in urban and suburban environments has been ultralow-volume (ULV) applications of either organophosphates—for example, Malathion—or synthetic pyrethroid products. Some research, however, suggests that ULV applications—either by ground or by aerial equipment—have had little lasting effect on certain mosquito species (Hudson, 1986; Gubler, 1989).

One of the greatest concerns raised during the development of the mosquito response plan was that adulticiding operations—if used—would create a false sense of security among residents. Although minimal data exist concerning the efficacy of ULV applications in an urban environment under real field conditions, control that is anywhere near 100% is unlikely because of several factors: (1) the nature of the insecticide (the droplets produced by the ULV machinery must contact the mosquito to kill), (2) the large number of obstructions to ULV applications in an urban setting, and (3) the number of places a mosquito can hide in a typical urban environment. Citizens who are used to the relatively high level of insect control obtained by insecticide applications in home or yard settings, however, might not understand that the entire mosquito population will not be killed by broad-scale ULV spraying. The fast breeding cycle of mosquitoes during certain times of the year also makes it likely that a new generation of biting adults will appear soon after ULV applications.

Because of the many concerns about chemically based adult mosquito control, emphasis was placed on community-focused, integrated approaches. The rationale was that the best control could be achieved through source reduction and, in some cases, larviciding activities conducted by both community members and city staff. Through this approach, community members have a role in and a responsibility for program implementation and maintenance. It is important to realize, however, that the Mosquito Surveillance and Response Plan is not a no-spray program. At higher risk levels, limited spraying is considered a management option based on the flight range and densities of target mosquitoes, the

Figure 3. Proportion of Traps Testing Positive for WNV, April–August 2003



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prevalence of virus-positive mosquito pools, the perceived risk to the human population, and the time of the current weather patterns. If spraying is conducted, ULV applications with synthetic pyrethroid products are performed within areas of highest risk.

Although certainly the sustainability of disease control programs of this magnitude can benefit from a sense of community ownership, community members must find neighboring mosquito habitats unacceptable and must be convinced their best interest is to control mosquitoes both in their own backyards and in their neighborhoods. This requires education and continued reinforcement, and it might take some time for a substantial number of community members to become involved in actions that have traditionally been perceived to be a government responsibility. Denton's approach is somewhat top-down; citizens are provided with information on how to best accomplish source reduction and larval control. To date, this approach appears to be successful.

Larviciding: Stop Mosquitoes Before They Can Bite

Over the past few years, major advances have been made in the ar biological mosquito control. Biolc control strategies involve natural predators, including *Gambusia affinis* (mosquito fish), fungi, protozoans, round worms, flat worms, and such bacterial agents as *Bacillus thuringiensis israelensis* (Bti). Each biological control agent has certain benefits and restrictions. To use a biological control agent successfully, the applicator must have a basic knowledge of its biology. Some biological control mechanisms, for example, are limited by salinity, temperature, or organic pollution, and some mosquito species are much more susceptible to specific types of biological control agents. All of these factors must be considered when choosing and applying biological control agents.

The perfect pesticide is easily applied, reasonably inexpensive, and nontoxic to nontarget organisms and eliminates the pest quickly before it becomes a threat. Although no single pesticide combines all of these factors, certain types of *Bacillus* bacteria have been developed into pesticides that are very close to the perfect model Bti, for example, is a naturally oc ring soil bacterium that produces a poison capable of killing mosquito larvae. Bti is considered ideal for mosquito management because of its specificity to mosquito larvae and because of its lack of toxicity to nontarget organisms.

Under adverse conditions, Bti bacteria form asexual reproductive cells, called *endospores*, which enable the cells to survive. The endospores of Bti also contain crystals of delta endotoxin, an insecticidal protein toxin. When eaten by a mosquito larva, the crystals dissolve in the larva's intestine and perforate the cells of its gut, disrupting its normal digestion and preventing it from feeding. When the larva stops feeding, its gut pH is lowered by equilibration with its blood pH. This lowered pH enables the bacterial spores to germinate, and the bacteria then invade the host, causing a lethal infection. Death typically occurs a few hours after digestion. Based on laboratory studies, the United States Environmental Protection Agency concluded that the toxicity and infectivity r to nontarget animals are minimal to nonexistent (USEPA, 1998). Currently Bti is commercially available in powder, liquid, granular, capsule, and briquette formulations.

The City of Denton decided that biological control agents would be the main tools for mosquito control. Bti and the closely related bacterium *Bacillus sphaericus* (Bs) were considered the most environmentally acceptable and commercially available biological control agents because of their relative specificity for mosquitoes and their negligible toxicity to vertebrates (Rishikesh et al., 1983). Limited applications of larvivorous fish (*Gambusia affinis*) also were considered to be a valuable component of an integrated control program, either alone or together with other control agents (Walton et al., 1990; Walton and Mulla, 1991; Reed et al., 1995). It is very important, however, to consider the ecological implications of releasing mosquito fish into certain areas. Some states also might require permits for the release of these organisms.

Mosquito Control and the Construction Review Process

Cooperation and collaboration among various city and county departments are crucial in minimizing vector production from BMPs. By reviewing BMPs before implementation and by monitoring them after installation, the risk to public health from vectors can be decreased. Because the Watershed Protection Department staff is familiar with issues of vector control, members can request stormwater design modifications that will minimize the potential for producing vector breeding habitats.

The Watershed Protection Department staff also is involved in the acceptance of stormwater pollution prevention plans (SWPPPs) for projects within the city. Although the general permit to discharge stormwater within the state of Texas does not address the issue of mosquito control, the Texas Health and Safety Code specifically states that a collection of water in which mosquitoes are breeding in the limits of a municipality is not allowed (§341.011). Other states have similar codes. For Denton, the Texas Health and Safety Code is reinforced at the local level through ordinances and is used as justification for requiring mosquito control within the SWPPP review process. If a city believes mosquito control is an issue on a particular project, it can request the permittee to add mosquito control measures to the SWPPP. In these situations, most of the requested SWPPP activities involve source reduction.

Public Education and Citizen Involvement Efforts

A common misperception among citizens is that distant water bodies are contributing to local mosquito densities. Although some species of mosquitoes are strong fliers capable of many-mile flights, most mosquito species collected in Denton's trapping operations are considered weak fliers. For Denton, as for many areas of the southern US, the mosquito species that represents the greatest risk for WNV transmission is the Southern house mosquito, *Culex quinquefasciatus*. Because this mosquito has an average flight range of approximately 0.5 mi. from its breeding habitat, it is crucial to inform the public of the importance of eliminating local mosquito habitats and treating local, private sources of water for larval control.

The City of Denton encourages

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active citizen participation in localized control and provides Bti materials free of charge to all citizens aiding in local private-property larviciding activities. This program has been a great success and has fostered a sense of partnership among citizens and city staff. Citizen phone calls have also proven to be a very useful source of information for Denton staff. Although the number of calls can become overwhelming during the peak of the mosquito season, they provide useful information regarding the density of localized mosquito populations, the presence of dead birds, and the notification of potential mosquito breeding habitats.

Public information distributed by the city directs citizens to the Watershed Protection Program staff for mosquito-related issues. Because the program staff is familiar with the city's stormwater infrastructure and mosquito surveillance plan, this process has been very efficient in determining the relationship between the mosquito problem and stormwater systems. If the problem seems to be related to a component of the stormwater infrastructure, city staff will conduct a site visit and perform source reduction, vegetation maintenance, or larviciding activities. If the problem does not seem to be related to the stormwater system, the staff will provide information on how citizens can minimize mosquito populations around the home. If many complaints are received from a single area, workshops on mosquito control may be conducted through neighborhood organizations. The city's Public Information Office distributes additional information, including fliers, newspaper ads, notices in public buildings, and public service announcements on local cable channels. This approach has proven to be an efficient way to convey information to a large number of citizens.

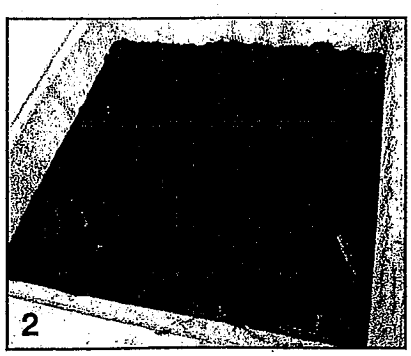
Maintenance of City Stormwater Facilities

For the most part, wet facilities within the city do not appear to create significant mosquito habitats, as long as the quantity and quality of water is sufficient to maintain sufficient mosquito predators. If inspections reveal the presence of mosquito larvae or a large number of adults, limited treatments of these facilities may be warranted, particularly when excessive plant growth creates isolated areas where mosquitoes can proliferate. In these situations, treatment with granular forms of Bti might be more effective than using briquettes.

For permanent bodies of water, the city takes an active role in vegetation management and might introduce mosquito fish. The goal is to manage emergent vegetation so it does not reach density levels that prevent predators from being able to effectively locate mosquito larvae. In situations where mosquito larvae are present and vegetation removal is impractical or undesirable, granular Bti might be used.

Drainage swales and structures that maintain standing water in sumps or basins have proven to be some of the more problematic areas for mosquito control. Often swales will have some undercutting associated with poorly designed or eroded culverts, which can retain water long after the rest of the swale is dry (see Photo 1). Underground stormwater conveyances that retain water can also produce similar habitats (see Photo 2). The resulting pockets of water usually are still and highly organic and have minimal mosquito predators. The city's Drainage Department monitors and treats these areas as a part of normal stormwater infrastructure maintenance. Drainage staff are trained to recognize potential breeding sites and mosquito larvae and to appropriately treat these areas. Treatment usually involves either repair of system malfunction or treatment with Bti or Bs. Maps and records concerning which locations were treated are maintained to make the process more efficient. Table 2 summarizes some of the common mosquito species in Denton, their respective stormwater habitats, and control measures used for particular types of stormwater controls.

Poorly designed culvert and eroded area with standing water likely to produce large amounts of mosquitoes



Poorly designed underground stormwater junction where hundreds of mosquito larvae were found after a large storm

Regulatory Requirements of Larvicide Applications

Stormwater managers not only must face the regulatory requirements of NPDES, but if they become involved with mosquito control they also need to understand the regulatory requirements for vector control agents. Although Bti and Bs are both bacterial agents, they are listed by EPA as registered pesticides. From a regulatory standpoint, therefore, most states treat them no differently than chemical agents. Typically, municipal pesticide applicators have to obtain a noncommercial applicator's license in vector control from the appropriate state agency to legally apply mosquito pesticides. The licensed applicator then can provide a relatively extensive training program for nonlicensed individuals to work under the applicator's license.

Some states do not require extensive training for the application of certain types of pesticides. The Illinois State Department of Agriculture, for example, enacted an emergency rule-making provision on August 16, 2002, to allow individuals who have been trained for at least one hour by a licensed mosquito applicator to apply Bti and Altosid products (products containing the insect-growth regulator methoprene) during certain times of the year. The training must cover pesticide labels, use restrictions, application rates, application methods, and any other information the trainer feels is appropriate for the safe and effective use of insecticides.

Critical Review of the Program

Mosquito control programs realistically cannot eliminate mosquitoes entirely rather, they serve to reduce numbers and thus the risk of disease transmission. For situations that warrant control

Table 2. Mosquito Species Commonly Found in Denton and Control Measures Associated With Stormwater Infrastructure Types

Permanent Water		
Wetlands		
Temporary or Floodwater		
Artificial Containers and Tree Holes		

measures, it is more efficient to control mosquitoes where they are produced as larva than to attempt to control adult populations through spraying programs. It also is important to realize that public perception is a critical part of both stormwater control and mosquito management. Public education efforts should strive to demonstrate how a properly maintained and treated stormwater BMP can actually work to reduce mosquito populations. Areas that appear to be good larval habitats will attract laying adults, which will deposit their eggs in the area. If proper

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maintenance and/or treatment activities are performed, however, the chance of the eggs developing into biting adults is greatly reduced. This is not the case in habitats where there are no predators and where no treatments or other management activities are performed.

West Nile virus usually becomes a more pronounced human health issue in late summer or early fall, when mosquito populations are larger and the number of infected mosquitoes increases (see Figures 2 and 3). The best time to prevent problems, however, is earlier in the season, when source reduction and larviciding can be effectively employed. If your community is at risk for WNV, start these programs early and maintain a consistent effort throughout the mosquito season. Coordinated source reduction and larviciding efforts involving cooperation among stormwater managers, municipal staff, county agents, citizens, and businesses are likely the best approach in an urban setting. As with many municipal issues, vector control is a problem shared by many different entities and will likely require a concerted effort to reach an acceptable resolution. Through cooperation among multiple city departments and public health agencies, the City of Denton has made substantial progress toward accomplishing the dual goal of protecting water quality and human health.

Addressing the threat of an emerging infectious disease like WNV depends on sustained and coordinated efforts of many parties. Undoubtedly the control of WNV depends on establishing and maintaining effective integrated pest management control systems; however, collaboration among state and local health departments, academic centers, city staff, and citizens is also crucial for program success. A strong and flexible plan involving all of these partners is the best defense against WNV outbreak or other vector-borne illnesses that might result from stormwater BMPs.

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Urban Integrated Pest Management

Mosquitoes

Dawn H. Gouge, Kirk A. Smith, Carl Olson, & Paul Baker

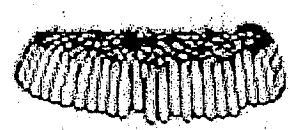
Introduction

Mosquitoes are one of the most important insect pests that affect the health and well being of humans and domestic animals worldwide. If environmental conditions are favorable vast populations can occur, anywhere in the U.S., and even the dry Southwest. Female mosquitoes require a blood meal for egg production, and they produce a painful bite as they feed. While feeding, they can transmit a number of disease-causing organisms to humans and animals. The diseases these organisms cause includes: encephalitis, dengue fever, filariasis, yellow fever, and malaria. Both encephalitis and dengue (caused by different mosquito born viruses) are potential threats in Arizona.

Mosquito Biology

Mosquitoes are flies with slender bodies, delicate legs, and scaled wings. The mosquito life cycle is an example of complete metamorphosis. There are four distinct stages in the life of a mosquito; egg, larva, pupa and adult.

A few days after acquiring a blood meal the female mosquito lays eggs. Depending on the species the eggs can be laid singly or in rafts, on the surface of the water, on the sides of containers, or on damp soil.



Culex eggs

After the eggs hatch, the larvae or "wrigglers", swim in the water and feed on microorganisms or decaying matter. There are four growth phases in the larva's life, called instars. The larvae must come to the surface of the water to breath (with the exception of a few specialized mosquitoes).

Mosquito larvae have a siphon at the tail end of the body. The siphon permits larvae to breath by penetrating the surface of the water to access air directly.

After the fourth larval instar, the pupa forms. Pupae, often called "tumblers", do not feed. Mosquito pupae breath by using their respiratory "trumpets" to draw air directly from the atmosphere. Larvae and pupae can be killed by cutting off their access to air with oils or monomolecular films.

After a few days, the adult mosquito emerges from the pupal skin and flies away. Only female mosquitoes take blood meals, and the blood is used to produce eggs. Male and female mosquitoes also feed on flower nectar. Male mosquitoes look similar to females but can be identified by having feathery antennae. The long hairs on their antennae help them to locate flying females.

Mosquitoes in Arizona

There are over 40 different species of mosquitoes in Arizona. Most are nuisance pests only and do not transmit disease, while other species exist without impacting humans in anyway.

Western Encephalitis Mosquito - *Culex tarsalis*

This mosquito is widely distributed in the western United States. It is a vector of several types of encephalitis causing viruses. This mosquito breeds in nearly every freshwater source except tree holes. It is common in areas using flood irrigation. The adults hide in vegetation, burrows, barns and culverts. They feed on birds and mammals including humans.

Yellow Fever Mosquito - *Aedes aegypti*

The yellow fever mosquito is not native to Arizona and can transmit viruses that cause yellow fever, dengue fever and dog heartworm. This mosquito breeds in man-made containers and natural containers such as tree holes. Small amounts of water are preferred sites for egg laying. Old tires, clogged gutters, pet dishes, and birdbaths are just some of the many sites where this mosquito will lay its eggs.

The yellow fever mosquito is a highly domestic, tropical species, and has been identified in the towns of Douglas, Naco, Benson, Sahuarita Heights, Nogales and Tucson. Currently the species is moving northward in Arizona and has been found established in Southern Pinal County. Moreover, mosquito surveillance indicates that yellow fever mosquito populations are established throughout Tucson.

Malaria Mosquito - *Anopheles freeborni*

Larvae of this species prefer clear, fresh seepage water in sunlit or partially shaded pools. Roadside ditches and grassy fields provide overwintering sites for adults. The malaria mosquito feeds on rabbits, cattle, horses, dogs and will aggressively bite humans as well. Anopheles freebori is the most important vector of malaria in Arizona and California. The mosquito also transmits avian malaria to bird species and the Myxomatosis virus to rabbits. The species transmitted malaria in the state of Arizona until the early 1900's.

Southern House Mosquito - *Culex quinquefasciatus*

The southern house mosquito is found throughout the southern half of the United States. Its Latin name refers to five lines that can be seen on the length of the body. This mosquito prefers to lay eggs in small pools of water, and can utilize water that is polluted with organic material. This mosquito enters houses readily, hence its common name. It can be an annoying pest at night, not only because of its bite but also because of its high-pitched buzz. The southern house mosquito can transmit nematodes which cause dog heartworm and viruses causing encephalitis.

Diseases

Encephalitis

Encephalitis is an inflammation of the brain and the causal virus is primarily transmitted by the mosquito, *Culex tarsalis*. The mosquito transmits the virus to birds, horses, mules and occasionally people. Birds serve as the most important host reservoir for the virus in the disease cycle. During the mosquito season public health officials routinely trap and test mosquitoes for viruses, and undertake sentinel chicken flock testing. The chickens are bled once or twice a month and tested for antigens indicating the presence of viruses. Health officials may also survey local and migrating bird populations to determine the incidence of virus and the potential for transmission. However, this is only usually done under special circumstances such as during severe floods.

Western equine encephalitis (WEE), is known to occur in Arizona. Arizona state livestock officials periodically warn horse owners to make sure their horse vaccinations are up to date for the potentially fatal equine sleeping sickness or Western equine encephalitis. The Arizona Department of Health commonly finds mosquitoes carrying the virus that causes WEE.

Mosquitoes carrying WEE are most common during the summer and early fall months. Symptoms of WEE in horses include neurological signs such as depression and lack of coordination. A sick horse may also go down and not be able stand back up. The illness is fatal in 20-50% of horses that are stricken with the disease. Human symptoms include high fever, convulsions, delirium and other characteristic central nervous system dysfunctions. Medical assistance should be obtained quickly if symptoms occur.

Saint Louis encephalitis (SLE) is a second viral disease transmitted by Culex tarsalis in Arizona. Birds are again the most important hosts, but humans can also be infected. Unlike WEE, horses are not involved with the SLE disease cycle. Infected mosquitoes are commonly found in Phoenix, Tucson, Yuma and other sites. fatal human cases are uncommon and occur sporadically. SLE is a much more serious threat to humans than WEE. Children and the elderly are most susceptible to fatal infections.

Dengue

Dengue is a disease caused by a complex of viruses transmitted between humans by Aedes aegypti. No other animals are involved in the disease cycle. This disease is currently endemic (naturally transmitted) in Mexico and sporadically occurs in southern Texas. It is not endemic in Arizona, but this situation is likely to change given the presence of this mosquito throughout southern Arizona. The disease has three forms. Dengue fever is characterized by a high fever, severe joint pain, vomiting and a rash. Recovery normally occurs in a few weeks. Dengue hemorrhagic fever and/or dengue shock syndrome are much more serious forms of the disease that occur in people that have had dengue previously. Both hemorrhagic dengue and dengue shock syndrome can be fatal and children and the elderly are most susceptible.

Heartworm

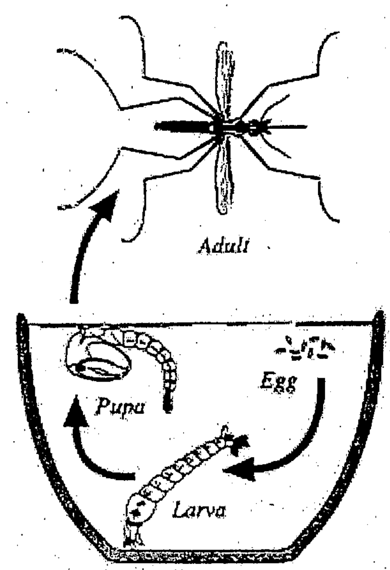
Mosquitoes also transmit heartworm in dogs. Heartworm can cause severe circulatory problems and produce symptoms such as coughing, labored breathing and general loss of vitality in advanced stages. Because of the impracticality of protecting dogs from mosquito feeding, the most effective means of controlling heartworm is to prevent worms from reaching the adult stage inside the dog. Veterinarians can prescribe excellent drug treatment to protect pets from heartworm.

Mosquitoes have not been implicated in the transmission of the AIDS virus.

Non-Chemical Control Measures

Mosquito Control

Since mosquitoes need water to complete their life cycle, a mosquito problem can develop just about anywhere that water collects. Municipal and farm animal waste lagoons may become breeding sites. Farm ponds and lakes are typically not major mosquito breeding areas if they contain fish and are free of weeds, algae or floating debris in which mosquito larvae hide. Permanent natural bodies of water, such as swamps, may contain a wide variety of predatory insects and fish that keep mosquitoes from reaching severe nuisance levels, although storms and floods may disrupt this system and allow mosquito populations to rise rapidly. Unfortunately it is important to recognize that some natural environments also generate large mosquito populations.



Generalized Mosquito Life Cycle

In residential areas, human activities often create mosquito-breeding sites or increase the production of mosquitoes in natural bodies of water. For example, road building and maintenance often impede the drainage of rain runoff, creating a mosquito-breeding site. Clogged drainage ditches along roads can also become breeding sites.

Logging and construction activities often leave tire ruts in the soil. These depressions are ideal breeding sites for "floodwater" mosquito species.

Around the home, objects such as bird baths, boats, canoes, discarded tires, soda and tin cans, plant pots and similar objects collect water and allow mosquitoes to breed literally right in our own backyard. The stagnant water in unused swimming pools becomes an ideal breeding site. However, mosquitoes will not breed in a maintained swimming pool. You can help reduce mosquito populations by eliminating or properly maintaining these problem spots. Do not store open containers, tires, etc. on your property where they can collect water. Discard them as soon as possible.

What You Can Do

1. Check flower pots and other containers for excess water.
2. Flush out the water in bird-baths and fountains every few days.
3. Store boats, canoes and other objects so that they do not collect rainwater.
4. Remove water that collects in depressions in tarpaulins covering boats and other equipment or objects. Rinse off water collecting on back yard trampolines and other items.
5. Keep rain gutters free of leaves and other debris that prevent water from draining.
6. Correct drainage problems in yards and playing fields to prevent rain and irrigation water from pooling for prolonged periods.
7. Fill holes or depressions in trees with sand or mortar.
8. Repair leaky pipes and outside faucets, and connect open waste-water drains to a sewage system or construct separate sump or leach lines.
9. Empty water containers for pets and check livestock watering troughs and tanks.

10. Correct or report drainage problems in ditches along public or private roadways.

Because some mosquito species can fly quite a long way from breeding sites a community-wide effort may be needed to reduce mosquitoes to tolerable levels. This requires the formation of a local mosquito control program to organize community-wide "clean up" efforts and to determine the need to eliminate breeding sites or to apply insecticidal sprays to control the insects. Local pest abatement districts can be set up using property tax dollars to employ a local pest control operator to coordinate management strategies.

- Discard containers that may collect water.
- Flush out birdbaths periodically.
- Keep roadside ditches and drainage areas clear of debris so that storm water drains off easily.
- Avoid prolonged flooding of playing fields. Organic acids can be used to improve turf drainage.
  Repellents

Some personal protection from mosquitoes can be achieved through the use of insect repellents. Many of these products contain DEET (N,N-diethyl-m-toluamide). Select the desired formulation (e.g. lotion, aerosol spray or cream) and apply it to exposed skin. Repeated use of repellents over a short period of time (several days) is not recommended, especially for pregnant women and children. Some individuals may be sensitive to DEET, discontinue skin application if irritation occurs.

Certain insect repellants contain insecticides and are only suitable for application to clothing and not to the skin. Please read directions carefully.

The consumption of certain natural substances including garlic and the vitamin B complex is reputed to reduce the number of bites. But as yet there is no scientific evidence to confirm their effectiveness.

Things To Try

Installing and maintaining tight fitting window and door screens will help keep mosquitoes out of the home. Candles containing oil of citronella are often used outdoors to repel mosquitoes from around decks and picnic tables. These products work best when there is relatively little air movement to disperse the chemical too quickly. Avoid splashing water on lit citronella candles, as they can flair. In some restricted areas of Arizona bats and birds, may consume mosquitoes as part of their diet. Putting up nesting boxes around your property will attract these natural predators to the area. However, the feeding activity of insect-eating bats and birds will not be sufficiently selective to cause significant reductions in mosquito populations. Please monitor bird and bat boxes regularly as bees can invade the boxes and develop hives.

What Doesn't Work?

Electrocution traps ("bug zappers") placed out-of-doors are not effective in reducing or eliminating mosquito populations. Recent studies have shown that less than 1% of the insects "zapped" in such devices were actually biting insects. The majority of the insects killed in electrocution traps are actually beneficial or harmless.

Electronic mosquito repellants that emit high frequency sound to "repel" mosquitoes have not been shown to be effective. Claims that certain plants placed around a porch or the deck will repel mosquitoes are not supported by scientifically based studies as yet.

Outdoor chemical foggers will keep mosquitoes away for several hours, but once the chemical dissipates, the mosquitoes return. Insecticides are available for controlling larvae, but their application in either large bodies of water or small artificial breeding sites can be difficult, expensive or illegal, particularly for an individual homeowner. Control programs targeting mosquito larvae are best left to trained individuals in county or local government agencies.

Many Mosquito populations have developed resistance to insecticides. Modifying or eliminating breeding sites is the only long-term solution to severe mosquito problems.

Management Products

Homeowners wishing to treat small areas, such as birdbaths, garden ponds, etc, can use a bacterial insecticide available at many hardware and garden centers. There are a variety of products containing a bacterium known as Bacillus thuringiensis israelensis or Bti. This bacterium kills mosquitoes, but will not harm fish, birds or other wildlife. Most products containing Bti will control mosquito larvae for about 7 days during mosquito season. The product is effectively used in breeding sites (usually 1 Bti briquette per 100 sq. ft. or less). Simply treating all areas of standing water with Bti without knowing if these areas are actually sources of the problem is a waste of time and money. Look to see if you have mosquitoes breeding in the water source before treating. It can be difficult to see the eggs but it is easy to see the larvae and pupae if you remove some water using a white cup or saucepan.

Toxicology and Chemical Control

Effective mosquito control is often a complex, expensive task, frequently requiring the cooperative efforts of communities as well as such groups as industry, agriculture, state and local governments. Many people are concerned about harmful effects of pesticides on the environment, their animals and plants, and themselves. Pesticide toxicity and pesticide hazard is not the same thing. "Toxicity" is the "killing power" under experimental conditions, whereas "hazard" is the risk of poisoning when a product is normally used. Hazard includes both the chemical toxicity and the chance of exposure to the product.

The dosage used and the type of chemical compound determines the hazard level of the pesticide. For example, if an individual were to consume an oral dose of 400 milligrams of table salt per kilogram of body weight the person would become violently ill. In fact every year about 60 people die from aspirin overdose. At lower doses both aspirin and salt are not hazardous. Thus, it is important that the dosage levels recommended on pesticide labels be followed very carefully.

Adulticides

Adulticides are pesticides used to kill adult mosquitoes. Mosquito control districts in the U.S. commonly use adulticides such as permethrin, malathion and naled. Applications of methoxychlor spray to vegetation, tree trunks and walls of buildings and catch basins will control certain adult mosquito species but not others.

Larvicides

Larvicides are products that are used to control mosquitoes in their larval stage and include the following:

Bacillus thuringiensis israelensis

Bacillus thuringiensis israelensis, or Bti, is a naturally occurring soil bacterium. The bacterium produces proteins in a crystalline form. When the mosquito larvae eat these crystals, the proteins attack their gut wall, killing the larvae. Bti has a highly specific mode of action, and is of minimal environmental concern. Bti is quickly biodegraded and leaves no residue. Always store Bti products under cool conditions prior to use.

Bacillus sphaericus

Bacillus sphaericus (Bs) is a common soil-inhabiting bacterium. The bacterium produces a protein toxin that may be used to control mosquito larvae. Bs is commonly used to control mosquito larvae in highly polluted water, such as sewage treatment plants. Bs is nontoxic to non-target organisms. Some natural recycling of this organism is likely and products usually last for about 21 days.

Chemicals

Methoprene is a synthetic pesticide that mimics the insect juvenile hormone. When methoprene is present, the development of the mosquito larvae is disrupted, and they do not develop to the adult stage. Mosquito control districts use methoprene in situations like cisterns and abandoned swimming pools. The breeding site needs to be treated periodically depending upon the formulation of the product used. Thirty day and 150-day briquettes are available as well as granular formulations (lasting a few days). The compound is not destroyed by heat. Methoprene is toxic to some other insects but is safe for use around humans.

Temephos is an organic phosphate compound that is used occasionally in temporary pools that contain mosquito larvae but do not support non-target organisms.

Alternatives to Pesticides

Oils and monomolecular surface films are used to control pupae and late-fourth instar larvae by interfering with their ability to breath. These products are usually used when an adult emergence will occur without treatment (at this point it is usually too late to utilize the other options). However, oils and monomolecular films will control all immature stages.

Gambusia

Gambusia are mosquito-eating fish. Some mosquito control districts raise the fish and use them to stock man-made water bodies. These fish will reproduce and continue to eat mosquito larvae. Gambusia should never be released into natural watercourses as they out compete native fish species. The Gila top minnow is now a protected fish. In many areas where Gambusia have been released the Gila top minnow no longer exists. Most small minnow fish (such as guppies, flathead minnow and shad) are good at reducing mosquito larvae populations and are suitable for release into garden ponds.

Fishermen using minnows as bait should avoid releasing live fish into water systems. Often the species of the bait minnow is not suitable for release into the fishing environment and in time such action may result in the collapse of the natural ecosystem and destruction of game fish populations.

Organized Mosquito Control

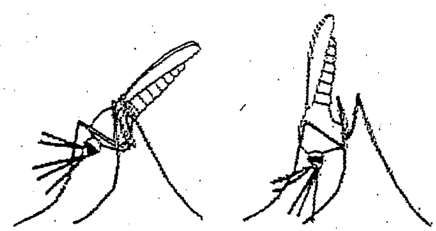
Because of the complexity of controlling mosquito populations, technical assistance may be required. Mosquito control personnel may be necessary on a permanent basis and communities may wish to investigate the desirability of an area-wide approach.

In summary: the most important element in mosquito control is you. By reducing mosquito-breeding habitats on your property you can significantly reduce populations with no side effects to the environment.

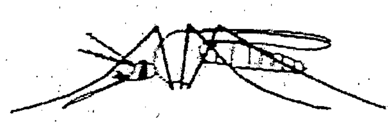
Tips for Professionals

The adults of the three most common genera of mosquitoes can be distinguished as follows:

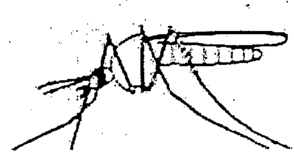
1. Anopheles has palps about as long as the proboscis. The insect rests with the body and proboscis in one axis at an angle to the surface.
2. Aedes has palps much shorter than the proboscis. The insect rests with the body and proboscis in 2 different planes at an obtuse angle to each other. The tip of the abdomen is pointed.
3. Culex has palps much shorter than the proboscis. The insect rests with the body and proboscis in 2 different planes; the body rests off but parallel to the surface. The end of the abdomen is rounded.



Anopheles adults resting



Aedes adult resting



Culex resting

Mosquitoes are often confused with:

- Midges (Chironomidae) - wings lack scales, front tarsi usually lengthened, with short proboscis.
- Dixid midges (Dixidae) - wings lack scales and body is bare.
- Crane flies (Tipulidae) - wings lack scales, body is bare, and legs are very long. Usually Tipulids are much larger (3/8-11/2 inch) and emerge in spring.

Some Final Facts

- There are 150 different species of mosquitoes occurring in the United States and over 40 species in Arizona.
- A single female can lay hundreds of eggs over her lifetime. Aedes aegypti eggs can survive

for more than five years under certain conditions.
- All mosquitoes need water to complete their life cycle.
- Not all species bite humans; some prefer birds, others prefer horses, and some will even bi frogs, turtles and reptiles.
- Only females take a blood meal; both males and females feed on plant nectar.
- Some mosquito species fly considerable distances, 20 miles or more. Some species tend to remain close to their larval habitats.
- Adult females can survive several weeks.
- Mosquitoes are responsible for more human mortality around the world than any other living creature.

The authors would like to thank Dr. Craig Levy (Vector Borne Diseases, Arizona Health Services), Dr. Henry Hagedorn (Department of Entomology, University of Arizona) and Dr. Diana Wheeler (Department of Entomology, University of Arizona), and Dr. Tony Porti (Aquaculture, Maricopa Agricultural Center) for critical review of this publication.

Issued in furtherance of Cooperative Extension work, acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, James A. Christenson. Director. Cooperative Extension, College of Agriculture, The University of Arizona.

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Wisconsin Department of Natural Resources

West Nile Virus and Storm Water Management

Storm water detention pond in Edgerton, WI.

Is a wet detention pond a breeding area for mosquitoes that carry the West Nile Virus (WNV)?

Wet detention ponds are typically designed to have a 3-foot pool of water which is not the preferred breeding area for the type of mosquitoes that carry West Nile Virus (genus Culex), referred to as container mosquitoes.

Why are wet detention ponds being developed?

Wet ponds are important for both flood control and water quality protection. Wet ponds temporarily hold water and release it slowly allowing sediment and other pollutants to settle to the bottom of the pond instead of being carried into lakes and streams. A DNR-recommended wet detention pond design standard can be accessed from the Storm Water Publications page.

What are the primary breeding areas for mosquitoes that carry WNV?

Stagnant pockets or shallow (typically less than 3-feet deep) pools of water that exist for 7 days or more. These primary breeding areas include: discarded tires, bird feeders, clogged gutters, buckets, and other areas with shallow stagnant water.

Should we eliminate all possible sources of mosquito breeding habitat?

It is not possible. We need to realize that mosquitoes are a part of the ecosystem. Trying to fully eradicate them would cause adverse environmental consequences, however, we can take steps to limit the habitat of the breed of mosquitoes that carry West Nile Virus. People can take steps to reduce their risk of exposure. See *Wisconsin Division of Public Health: http://www.dhfs.state.wi.us/dph_bcd/westnilevirus/* (Exit DNR)

Are there alternative designs or treatments for stormwater instead of relying on wet detention ponds?

Yes. The problem is that areas developed into parking lots, roads and rooftops (impervious areas) lead to more runoff with less water infiltrating into the ground. This can be offset by trying to minimize the amount of impervious areas and, where feasible, direct runoff to vegetated areas that are designed to infiltrate water into the ground within a 24-hour period.

Can wet detention ponds become prone to mosquito breeding?

A wet detention pond is designed to fill up with sediment and other pollutants. When the permanent pool becomes too shallow, generally less than 3-feet, the property owner or other responsible party (sometimes the municipality) needs to dredge the sediment that has accumulated in the pond. If a wet detention pond becomes noticeably shallow, or develops stagnant areas, then dredging should be done as the pond can then become mosquito-breeding habitat.

For more information on WNV and mosquito management, see these links.

Runoff Management | Watershed Bureau | Water Division

Last Revised: Thursday January 15 2004

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Oregon Department of State Lands

West Nile Virus Wetlands & Waterways

Recent concerns over the spread of West Nile Virus have brought considerable attention to mosquitoes and their habitats. This page provides information about WNV and mosquitoes in relation to wetlands and waterways.

Photograph by
Jo-Ann Ordano
©California Academy of Sciences

Background on West Nile Virus

WNV is a mosquito-borne virus that first appeared in the U.S. in 1999. Based on the rate of spread across the U.S., it is likely that the first human infections in Oregon will occur sometime in 2003.

Most people who become infected with WNV will have either no symptoms or mild flu-like symptoms. Even in areas where the virus is circulating, very few mosquitoes are infected with the virus, according to the Centers for Disease Control. Even if the mosquito is infected, less than 1% of people who get bitten and become infected will get severely ill. The chances you will become severely ill from any one mosquito bite are extremely small. WNV can be contracted by anyone of any age, but it is more likely to develop into a serious condition in older people.

From 1999 through early 2003, the Centers for Disease Control reported about 250 deaths nationwide from WNV. When compared to other causes of death, the risk of death from WNV infection is relatively low. For example, there are approximately 2,600 deaths per year due to talking on a cell phone while driving, 20,000 deaths per year due to influenza, and 40,000 deaths per year from cancer.

Not all mosquitoes carry WNV, not all mosquitoes feed on humans, and the mosquito-breeding habitat varies for each mosquito species. Multnomah County Vector and Nuisance Control has used mosquito sampling data from across the U.S. to prepare a chart showing some of these differences between mosquito species.

Where mosquitoes breed

According to the State of Oregon Mosquito-borne Disease Response Plan, mosquito control "programs are not intended to eliminate mosquitoes entirely, but rather to reduce their numbers and therefore reduce the risk of disease transmission." Mosquitoes are an important part of the food chain providing a food source for many birds, bats, amphibians, and fish species. However, we can take steps to minimize mosquito population booms in urban areas and to minimize our exposure to mosquitoes.

Most natural wetland areas are typically far from urban centers, therefore, eliminating the mosquito habitat in your backyard is the first place to begin minimizing mosquito population booms.

Exposure in wetlands

Mosquito exposure in natural wetlands is limited and selective to those engaging in wetland-dependent activities such as wildlife watching or fishing and hunting. Prudent mosquito avoidance measures such as covering up, limiting your activity in these areas at dawn and dusk, and judicious use of an insect repellant following product recommendations are recommended as the primary preventive measure.

Draining natural wetlands is not a viable control measure for mosquitoes or controlling WNV. Such action may require both state permits and federal permits.

Even after "draining," a wetland may hold water from flooding, rainfall or snowmelt. These low spots may produce more mosquitoes than healthy wetlands. In addition, filling these wetlands may force water to flow elsewhere, creating flooding or additional wetlands.

In addition, reduction of standing water during the winter (November-March) is not likely to reduce mosquito populations because during this time of year, the conditions are too cool for most species of mosquitoes to breed.

Degraded wetlands and artificial wetlands

Storm water runoff and incompatible surrounding land use practices adversely impact natural wetlands. This includes storm water runoff from urban and newly urbanizing areas and sedimentation from both agriculture and construction activities. Therefore, altered or degraded wetlands often have stagnant water, increased nutrient levels and fewer natural mosquito predators. These conditions may result in mosquito production habitats near residential areas. Integrative pest management practices that combine ongoing surveillance activities with larval and adult mosquito control measures have been implemented by the State of Oregon and local government agencies to target these and other mosquito production areas.

Research from North Dakota found that there were many more mosquitoes in degraded wetlands than in higher quality wetlands.[1] The authors conclude that maintaining the natural functions of wetlands (i.e., minimize disturbance) would be a good start to potentially reducing mosquito habitat. The preservation of healthy wetlands, unpolluted by excessive urban storm water runoff and/or sedimentation should therefore be of vital concern to the public and to mosquito control agencies throughout the state.

Irrigation waters

Flood irrigation, drainage ditches, and irrigation tail water also provide mosquito breeding habitat because these areas typically contain standing stagnant water with high nutrient levels. Unlike natural wetlands, these areas do not have mosquito predator populations to naturally control mosquito populations. Minimizing time spent in these areas during dusk and dawn when mosquitoes are most active and taking other mosquito protection measures is advised.

Protection measures

One aspect of WNV that scares people is that they feel like they have no control over their risk as compared to making lifestyle choices such as not smoking to reduce the risk of cancer or not talking on their cell phone while driving.

This is not true. Self-protection is still the best way to reduce your risk of contracting WNV. There are many ways you can prevent getting bitten by mosquitoes and reduce mosquito-breeding areas around your home.

Any water that stands for more than a week is sufficient to breed mosquitoes. To reduce mosquito habitat in your back yard, dump rain barrels, change standing water such as bird baths, animal water, and wading pools weekly, and get rid of spare tires.

If you have a self-contained pond on your property with no connection to natural waterways, you might consider stocking it with mosquito fish.

However, you must take precautions to prevent these fish from entering any natural waterway. Introduction of these nonnative predator fish can be harmful to native species. An Oregon Department of Fish and Wildlife fact sheet provides more information.

You may also consider stocking ponds with rainbow trout, but they are not able to survive in warm water conditions that occur in some ponds during the summer and should not be introduced in some areas. Consult with an ODFW fish biologist at a local department field office to determine what fish may be most appropriate for your pond and location.

A poster developed by the Oregon Department of Human Services Center for Disease Control and Prevention gives tips on reducing mosquito breeding areas around your home.

The Centers for Disease Control has developed a list of self-protection measures.

Take prudent precautions, but remember that your chance of becoming seriously ill from West Nile Virus is very slim.

For more information

By Telephone

Oregon Department of Human Services
Toll-free telephone information line, (866) 703-4636
or (866) 703-INFO.

Recorded topics include disease facts, symptoms, how to reduce the risk of infection and, for physicians, clinical information for diagnosing, treating and reporting a West Nile case.

The messages are recorded in English and Spanish.

Multnomah County residents also can call (503) 988-6453 or (503) 988-

NILE for information. Callers can choose from various recorded West Nile topic areas and, if they need still more information, can opt out for a live operator.

Other Web Resources

- Oregon Department of Health and Human Services
- Centers for Disease Control
- American Mosquito Control Association
- Fight the Bite!
- The Montana Department of Public Health and Human Services
- The USDA Regional Pest Management Centers National Pest Alert brochure on WNV

References

[1]Chipps, S., D. Hubbard, K. Werlin, N. Haugerud, K. Powell. December 2002. Development and Application of Biomonitoring Indicators For Floodplain Wetlands of the Upper Missouri river Basin, North Dakota. South Dakota State University.

Information adapted from material supplied by Montana Dept. of Environmental Quality.

Information compiled by Jennifer Goodridge, Wetland Specialist

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03/20/03

The Journal for Surface Water Quality Professionals
Stormwater

Letters to the Editor

Surface Hydrocarbons vs. Mosquito Breeding

Editor:
Stormwater BMPs as a source for vectors is not a new issue (March/April 2002 Stormwater, "The Dark Side of Stormwater Runoff Management: Disease Vectors Associated With Structural BMPs" and "Stormwater, BMPs, and Vectors"). It has been suggested that because of the accumulation of hydrocarbons (e.g., motor oil, ethylene glycol, gasoline) in BMPs, standing water would be rendered unsuitable for larvae. The hydrocarbon film would prevent the larvae from being able to breath through specialized mouth parts. Is this true? How much oil is adequate? Was this observed during your survey of any of the BMPs?

Walter K. Caldwell
Environmental Specialist
Environmental Health Administration, Watershed Protection Division
Washington, DC

Two of the coauthors of the articles respond:
As a general rule, the accumulation of hydrocarbons on the surface of standing water in BMPs does not provide reliable mosquito prevention. However, to best answer this question, we first need to review some basic mosquito biology.

The life cycle of mosquitoes involves a process known as complete metamorphosis. This describes a process of dramatic change from egg to immature (larvae and pupae) to adult, where the immature stages do not even remotely resemble the adult stage. Perhaps the most well-known complete metamorphosis occurs in butterflies and moths when they change from eggs to caterpillars to winged adults. A pupal stage occurs between the larval and adult stages during which changes in physiology and morphology take place. When complete, adults emerge from the pupal skin and carry on life as sexually mature insects.

Although best known for the females' need to feed on blood, mosquitoes spend most of their life as wingless immatures. Adult female mosquitoes lay their eggs in carefully selected locations either on the surface of standing water or in areas subject to flooding. After they hatch, the immature stages (larvae and pupae) are completely reliant on water. Larvae feed on microorganisms and organic material in the water and eventually develop into pupae, which are also aquatic but do not feed. Adults then emerge from the pupal skin onto the water surface from where they take flight, mate, and start the cycle over again. There are currently 176 recognized species of mosquitoes in the United States. Each has a preferred or specific habitat type.

Aquatic stages of nearly all species of mosquitoes breathe atmospheric air through specialized body structures called "siphons" in larvae and "trumpets" in pupae. These breathing structures function much like a diver's snorkel: They are essentially hollow tubes that work by breaking the surface tension of the water and allowing air to enter the body. This is one of the main reasons mosquitoes require relatively tranquil standing-water habitats. Wave action, turbulence, or significant currents prevent mosquitoes from maintaining a connection with the water surface to breathe. This critical water-to-air connection needed by immature mosquitoes was recognized early on by mosquito control experts as a vulnerability that could be used in integrated control efforts. Hydrocarbon surface films, such as kerosene, were found to interfere with the immature mosquitoes' ability to connect with the water surface, causing them to drown. There are several commercially available materials used today for professional mosquito control that work on this basic principle; one is a petroleum oil-based material and the other is classified as a monomolecular film.

However, oils that accumulate in sumps, catch basins, and vaults of BMP devices do not provide reliable mosquito prevention. Oily sheens present on the water surface are rarely uniform and usually contain a multitude of "breaks" through which mosquito larvae can access surface air. The La Brea Tar Pits, in western Los Angeles County, form natural ponds that produce mosquitoes despite the fact that crude oils seep into them from belowground sources. Likewise, oil-contaminated wastewater sumps in oil fields are often major mosquito breeding sources. Manmade habitats in storm sewer systems including catch basins and, more recently, in stormwater BMPs also frequently provide usable habitat for certain mosquito species despite the presence of oils. Unfortunately, the mosquitoes most likely to utilize "dirty water" are in the genus Culex and are both public nuisances and competent vectors of viruses, including St. Louis encephalitis and West Nile virus.

It should be concluded, then, that although "runoff-derived" hydrocarbon accumulations in stormwater BMPs, sumps, and other structures might occasionally inhibit or even prevent mosquito breeding from taking place, the efficacy of such accumulations in preventing breeding cannot be relied upon with any degree of confidence. Our research studies in southern California clearly support this, as mosquitoes are detected regularly in BMP devices that hold oil-contaminated urban water runoff. We are not aware of any public health or vector control agencies that rely upon these kinds of accumulations to inhibit mosquito production.

Stormwater BMPs, especially those that hold permanent sources of standing water by design, pose a difficult challenge for public health officials and vector control agencies. We feel very strongly that the best solution to the problem of mosquito breeding in stormwater structures lies in fostering cooperation between BMP designers, municipal planners, public health officials, and vector control agencies. It is essential that new stormwater BMP designs incorporate features that suppress or prevent vector breeding and harborage. Through creative engineering we might be able to eliminate or deny access to the habitat that mosquitoes and other vectors need from BMPs: standing water. The state or local public health/vector control agency can discuss specific vector issues in your area and provide input and consultation into siting, design, and maintenance of proposed BMPs.

Marco E. Metzger
Public Health Biologist
California Department of Health Services, Vector-Borne Disease Section
Ontario, CA
Susanne Kluh
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Greater Los Angeles County Vector Control District
Santa Fe Springs, CA

SW - January/February 2003

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Dennis Dickerson - *REMINDER* West Nile Virus and Stormwater Treatment Workshop

From: "Kelly Middleton" <kmiddleton@sgvmosquito.org>
To: "Kelly Middleton" <kmiddleton@sgvmosquito.org>
Date: 1/19/04 3:49 PM
Subject: *REMINDER* West Nile Virus and Stormwater Treatment Workshop

REMINDER!

The Greater Los Angeles County & San Gabriel Valley Mosquito & Vector Control Districts are hosting the **"Impact of Stormwater Treatment Devices (BMPs) on Mosquito Production and Public Health"** Workshop in Santa Fe Springs on January 28, 2004. The Agenda is attached. This program will provide valuable information to help cities, planners, developers, and consultants comply with NPDES requirements while protecting public health.

Please register before January 26th by calling the Greater LA Co. Vector Control District at (562) 944-9656.

Questions? Comments? Please contact me personally at: kmiddleton@sgvmosquito.org

Kelly Middleton
Public Information Officer
San Gabriel Valley Mosquito & Vector Control District
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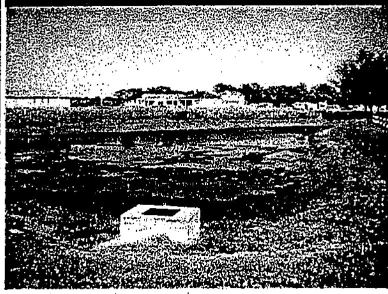
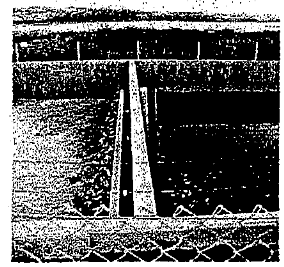
SGVmosquito.org

West Nile Virus and Stormwater Treatment:
How to Comply Without Breaking the Law

IMPACT OF STORMWATER TREATMENT DEVICES (BMPs) ON MOSQUITO PRODUCTION AND PUBLIC HEALTH WORKSHOP



January 28, 2004
8:15 am -12:00 noon



Workshop location:

Greater Los Angeles County Vector Control District
12545 Florence Ave.
Santa Fe Springs, CA 90670
(562) 944-9656
Co-hosted by San Gabriel Valley Mosquito and Vector Control District
RSVP by January 26, 2004
Please carpool if possible

Agenda

8:15-8:30	**Sign-in** (coffee and pastries provided)
8:30-8:45	**Know Your Enemy: Mosquito Biology, West Nile Virus and Other Arboviral Diseases in Urban Southern California** Susanne Kluh, M.S., Vector Ecologist Greater Los Angeles County Vector Control District
8:45-9:15	**The Federal Clean Water Act and NPDES Permits: Unintended Consequences for Vector Control and Liabilities for Cities** Marco Metzger, Ph.D., Associate Public Health Biologist California Department of Health Services, Vector-Borne Disease Section
9:15-9:30	**BREAK** (refreshments provided)
9:30-10:15	**Managing Mosquitoes in Stormwater Treatment Devices** Marco Metzger, Ph.D., Associate Public Health Biologist California Department of Health Services, Vector-Borne Disease Section
10:15-11:00	**Managing Mosquitoes in Surface-Flow Constructed Treatment Wetlands** William E. Walton, Ph.D., Associate Professor and Entomologist, Dept. of Entomology, University of California Riverside
11:00-11:15	**Working with Your Local District: Public Nuisance as Defined in the California State Health and Safety Code** Jack Hazelrigg, Ph.D., District Manager Greater Los Angeles County Vector Control District
11:15-noon	**Open Discussion**

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Managing Mosquitoes in Stormwater Treatment Devices

MARCO E. METZGER, Vector-Borne Disease Section, California Department of Health Services

The federal Clean Water Act, as amended in 1987, requires states to develop and implement nonpoint source pollution management programs (see Copeland 1999, 2003). These mandated programs require that certain measures be taken to abate pollutants carried by rainwater and urban (i.e., dry weather) runoff, herein collectively referred to as stormwater runoff. A principal component of stormwater programs is the implementation of Best Management Practices (BMPs), a term first adopted in the 1970s to represent actions and practices used to reduce the flow rates and the constituent concentrations in runoff (WEF and ASCE 1998).

The regulatory pressure to achieve increasingly higher levels of pollution abatement gave birth to a burgeoning industry that specializes in developing stormwater treatment devices based on the latest available technologies. These "treatment" BMPs are engineered to maximize the capture and removal of target pollutants from stormwater, often with the added benefit of reducing excessive downstream flows. Hundreds of designs have been developed across the United States, including many proprietary devices, and in some cases existing structures such as flood-control basins and constructed wetlands may be modified to function as treatment BMPs to satisfy local needs. Unfortunately, although "best" for managing runoff, these devices often provide aquatic habitats suitable for mosquitoes and other vector species as an unintended consequence of their implementation (see CH2M Hill 1999; Chanda and Shisler 1980; Dorothy and Staker 1990; Florida Coordinating Council on Mosquito Control 1998; Kluh et al. 2002; McLean 2000; Metzger et al. 2002, 2003; O'Carroll 1978; Santana et al. 1994; Schimmenti 1979; Schmidt 1980; Smith and Shisler 1981). In this publication, "treatment BMP" and "treatment device" are used interchangeably.

Public health and safety is a major component of all stormwater management programs. Flood control and the reduction of waterborne pathogens are high priorities, yet mosquito management is often overlooked. Mosquito management is essential to prevent disease transmission and maintain quality of life and must be integrated into every stormwater program. This publication provides basic guidelines for mosquito management that are relevant to the location, design, and operation of proprietary and nonproprietary stormwater treatment devices. Unfortunately, the rapid growth and evolution of stormwater programs and BMP designs combined with the tremendous number of local factors that may influence mosquito production at any given site preclude any "cure-all" recommendations or solutions. Careful implementation of these guidelines will help suppress mosquito breeding while reducing health risks and discomfort, lowering costs associated with mosquito abatement, and lessening legal liability.

MOSQUITOES AND MOSQUITO CONTROL

Mosquitoes are regarded as undesirable in both rural and urban areas throughout most of the United States. Not only is their biting activity a nuisance, mosquitoes also vector (transmit) pathogens that cause human and animal diseases. The recent threat of West Nile virus compounds concerns and reinforces the need for effective mosquito control.

MOSQUITO AND VECTOR CONTROL ASSOCIATION of CALIFORNIA
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There are approximately 3,000 species of mosquitoes worldwide (about 200 in the United States) and all require water to complete their life cycle (fig. 1). Mosquito control is most effective when directed at immature stages in standing water rather than at adults and is best conducted using a combination of techniques including biological, physical, chemical, and in states such as California, legal control (California Health & Safety Code [H&S Code], §§2060-2067, 100170, 100175). Biological control uses or enhances natural enemies of mosquitoes such as fish; physical control makes habitats less suitable for mosquito production; chemical control uses insecticides that target immatures or adults; and legal control can force uncooperative parties to eliminate breeding habitats on their property or face financial penalties.

Despite advances in mosquito management, the importance and need for careful preventative design and maintenance plans is paramount. This becomes apparent especially when faced with the limitations imposed by certain treatment BMPs as a result of their design, location, or accessibility. For example, underground treatment devices that hold permanent sources of water and produce mosquitoes are unlikely to support commonly used biological control agents, and physical controls such as exclusion

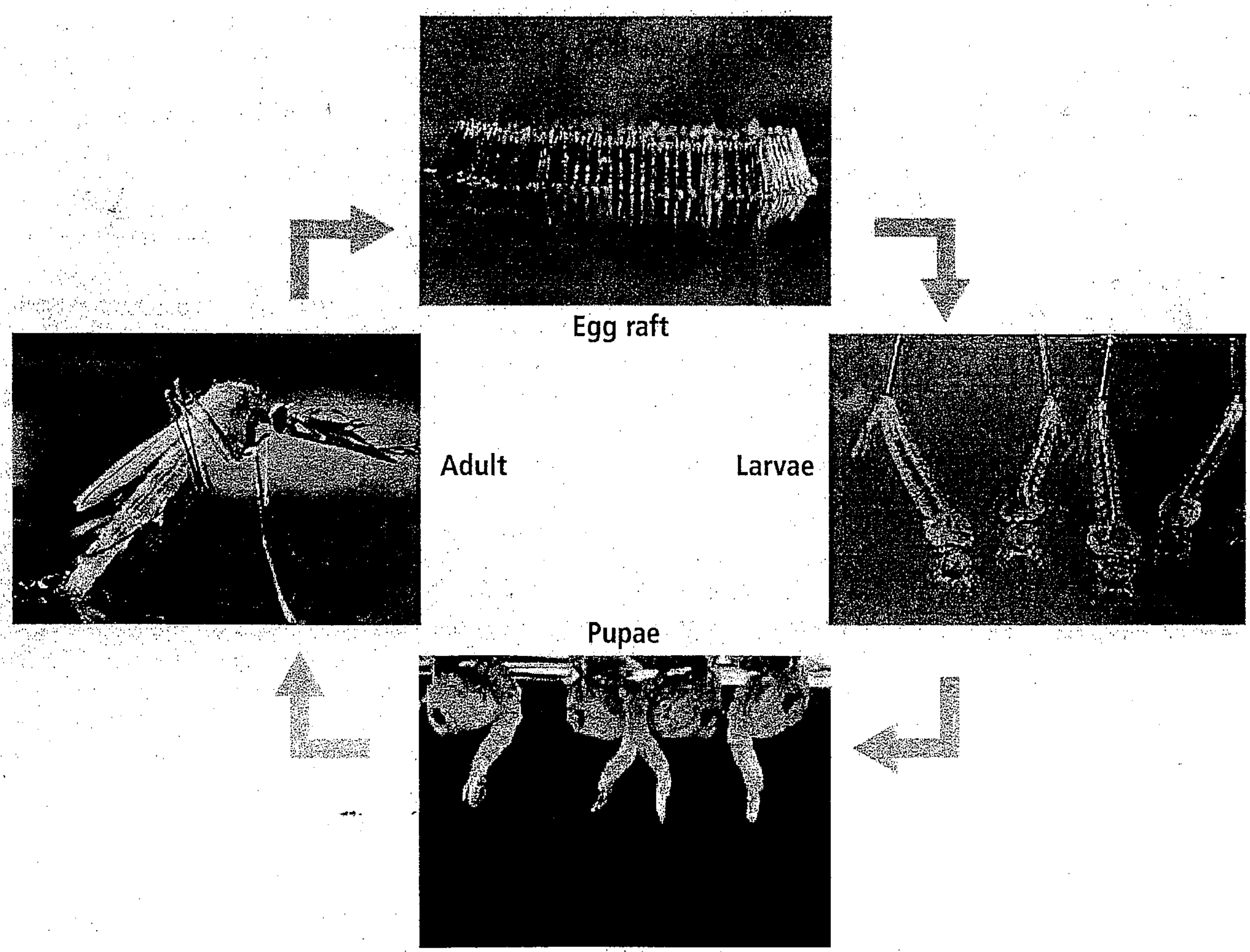

Figure 1. The mosquito life cycle consists of four stages: egg, larva, pupa, and adult. Female mosquitoes lay eggs on or near water. Eggs hatch into aquatic larvae that feed on organic material and grow through four stages before becoming pupae. Winged adults emerge from pupae, mate, and begin the cycle again. Only female mosquitoes feed on blood, which provides the nutrients needed for the development of eggs. Males are more short-lived and feed on plant juices. *Photos courtesy of Marin/Sonoma Mosquito and Vector Control District.*

(e.g., valves and covers) can be difficult to implement without affecting the devices' intended function. In these situations, chemical treatment, and legal abatement in some states, are the only remaining options. Note that in this publication, "chemical treatment" refers to the use of registered pesticides to control the aquatic stages of mosquitoes (larvicides), including bacteria, hormone mimics, and oils.

LARVICIDING VERSUS PREVENTATIVE ENGINEERING

As more and more stormwater programs recognize the importance of integrating mosquito control into their lists of public health priorities, the dilemma of how to effectively manage mosquitoes in designs that favor mosquito breeding becomes obvious. Larvicide treatments are increasingly considered as long-term solutions for mosquito control in lieu of costly retrofits, replacements, or redesigns. However, sole reliance on larvicides is *not* a long-term solution for preventing mosquito production. Every possible effort should be made to "design the bugs out" during preconstruction planning or via postconstruction retrofits to avoid creating a possible public health hazard. When all else fails, registered pesticides should be applied only by certified professionals due to the risk of establishing pesticide resistance in target organisms, as well as potential liability issues from misuse.

TYPE AND LOCATION OF TREATMENT BMPS

When selecting and installing stormwater treatment devices, agencies consider factors such as the projected runoff for a given area, the available or allocated space, cost, and local pollutants of concern. Structural designs can range from simple to elaborate and appear to be limited only by funding and the imagination of engineers. The most common processes used for pollution management in treatment BMPs that may be used singly or in combination include trash capture, settling and sedimentation, media filtration, and infiltration. Typical urban and suburban treatment devices include vegetated channels (swales), dry detention basins, wet retention ponds or constructed wetlands, media filtration devices, and belowground sumps, vaults, and basins. Of concern to public health officials is that an alarming number of these devices hold nutrient-rich stagnant water that provides breeding places for mosquitoes (fig. 2).

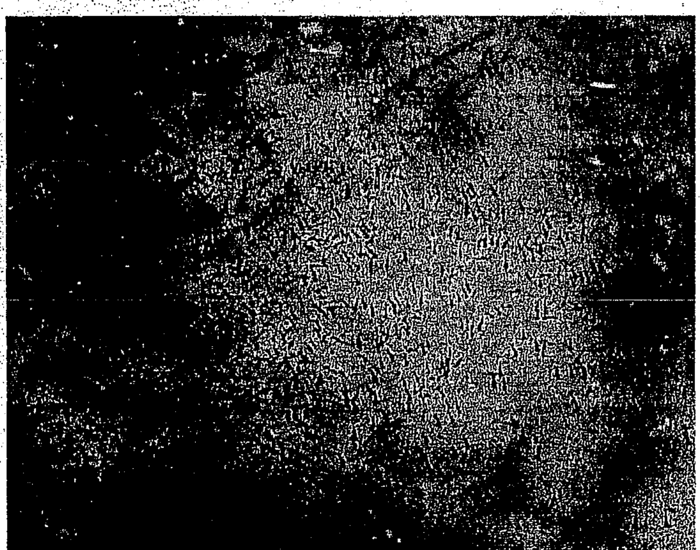

Figure 2. Waters rich in accumulations of organic materials created by some treatment BMPs provide ideal larval habitats for many species of mosquitoes, including those that can transmit human diseases. The standing water in this small roadside stormwater basin harbored hundreds of mosquito larvae and illustrates the reproductive potential of mosquitoes when provided with suitable habitat. *Photo: Marco Metzger.*

Location can greatly affect whether a treatment BMP becomes a significant source of mosquitoes. For example, identical structures in different locations may vary widely in potential mosquito production due to the number of mosquitoes present in the area, the species composition, and the duration of breeding activity. Elements that may influence the mosquito breeding potential in any given location may include a variety of environmental, construction, and local factors operating singly or in combination (table 1). Because of their propensity to breed mosquitoes, *all* treatment BMPs, regardless of their design, should be monitored periodically by vector control professionals with knowledge of the biology and ecology of local mosquito species. A more proactive approach would be to include vector

Table 1. Factors that may influence mosquito production potential in treatment BMPs.

Elevation
Installation above or below ground
Local climate
Local fauna (i.e., potential predators)
Nonstormwater runoff quantity, quality, and event frequency (e.g., residential and commercial)
Proximity to existing mosquito sources
Stormwater runoff quantity, quality, and event frequency
Surrounding host animals (wild and domestic) potentially available for female mosquitoes to feed upon
Surrounding land use, both present and future
Surrounding structural refuges for adult mosquitoes (e.g., trees, shrubs, storm sewers)
Surrounding vegetation, both native and exotic

Note: This list is incomplete. Other local factors may also be conducive to mosquito production.

control professionals in preconstruction planning. This type of collaborative effort could help prevent costly future retrofits or replacements necessary to meet mosquito management goals.

MOSQUITO SUPPRESSION THROUGH DESIGN AND MAINTENANCE

The majority of treatment BMPs operate as "passive" systems, meaning that they do not require active operational control or adjustment beyond routine maintenance. As a result, most installations remain unsupervised for extended periods, and if conditions are favorable, mosquito breeding could occur unobserved and uncontrolled. Conscientious planning that emphasizes mosquito habitat reduction or elimination in both design and maintenance plans can prevent these problems (Metzger et al. 2002; O'Carroll 1978; Schimmenti 1979). Minimizing the mosquito production potential of treatment BMPs requires that standing water not be available for sufficient time to permit emergence of adult mosquitoes. This can be achieved in one of three ways:

- Rapid discharge of all captured water.
- Denying mosquitoes access to standing water (e.g., tight-fitting covers).
- Making the habitat less suitable for breeding (e.g., vegetation management, mosquitofish).

Mosquito development from egg to adult varies by species and is influenced primarily by temperature and food availability. Certain species can complete the aquatic stages of development and emerge as adults in less than 1 week under ideal conditions. Because of this, a 72-hour maximum residence time for captured water in treatment BMPs is recommended in California and elsewhere as a conservative safeguard to prevent emergence of adult mosquitoes (Florida Coordinating Council on Mosquito Control 1998; Metzger et al. 2003; Santana et al. 1994). In reality, many treatment BMPs hold water for over 72 hours, sometimes due to their outdated designs, and more recently in order to meet stringent effluent water quality requirements. To ensure that public health and safety is maintained, the following suggestions should be considered for any structure that holds water for over 72 hours.

- Select or design an alternative (or modified) device that provides adequate constituent removal and complete drainage in 72 hours. *This is the most reliable and cost-effective choice.*
- Contact state or local public health or vector control agencies to determine whether local mosquito species and local factors (e.g., high elevation) may preclude rapid mosquito emergence, thus safely allowing water residence times to exceed 72 hours. In some areas this may require a detailed study that should be funded by the soliciting party.
- Provide adequate funds necessary to support routine mosquito monitoring and control.

Possibly the most overlooked aspect of treatment BMP implementation is the long-term commitment of funds necessary for proper maintenance of structures. Routine and timely maintenance is critical for suppressing mosquito breeding as well as for meeting local water quality goals. If maintenance is neglected or inappropriate for a given site, even structures designed to be the least "mosquito friendly" may become significant breeding sites. Table 2 lists conditions that may increase the probability of breeding mosquitoes over time in various treatment BMPs. Maintenance guidelines for individual BMPs are often site-specific and are beyond the scope of this publication.

Table 2. Postconstruction conditions that may increase the probability of mosquito production in treatment BMPs.

Clogging (e.g., effluent pipes, media filters, infiltration basins)
Establishment of invasive or exotic vegetation
Groundwater fluctuations
Nonstormwater runoff (i.e., increases in runoff frequency, residence time, and/or volume)
Scouring and erosion
Structural damage (e.g., shifting or settling, roots)
Trash and sediment accumulation (e.g., formation of pools, clogging, redirected water flows)
Vandalism
Vegetation overgrowth

Note: This list may be incomplete. Other conditions favorable to mosquito production may become apparent as structures age.

BASIC GUIDELINES FOR MOSQUITO MANAGEMENT

Dry Systems

This category includes all stormwater treatment devices that are designed to drain completely following a storm event and remain dry. Examples include extended detention (dry detention) basins, vegetated swales, infiltration devices, and media filters.

- Design structures so they do not hold standing water for more than 72 hours. Special attention to groundwater depth is essential.
- Incorporate features that prevent or reduce the possibility of clogged discharge orifices (e.g., debris screens). The use of weep holes is not recommended due to rapid clogging.
- Use the hydraulic grade line of the site to select a treatment BMP that allows water to flow by gravity through the structure. Pumps are not recommended because they are subject to failure and often require sumps that hold water.
- Design distribution piping and containment basins with adequate slopes to drain fully and prevent standing water. The design slope should take into consideration buildup of sediment between maintenance periods. Compaction during grading may also be needed to avoid slumping and settling.
- Avoid the use of loose riprap or concrete depressions that may hold standing water (fig. 3).
- Avoid barriers, diversions, or flow spreaders that may retain standing water.

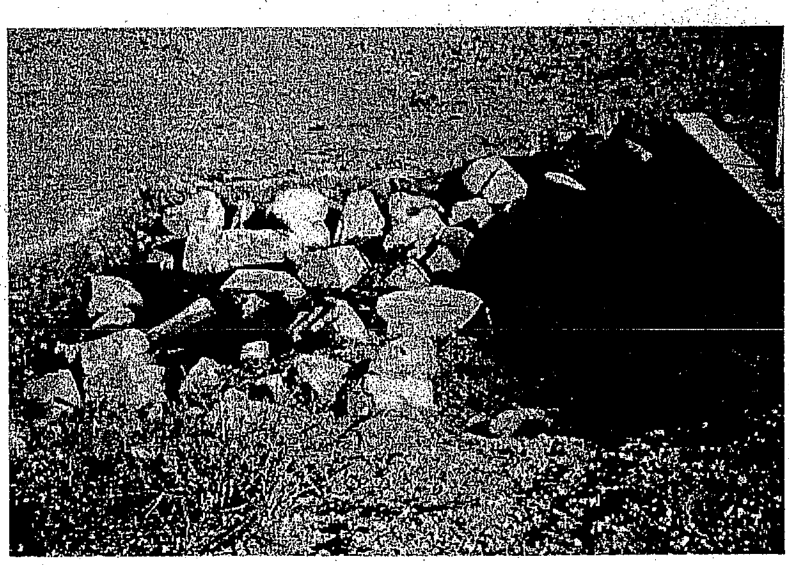

Figure 3. The use of loose rocks (riprap) to dissipate the energy of incoming runoff encourages mosquito production. Inevitably, standing water collects between the rocks, providing habitat for mosquitoes and making monitoring and control very difficult. A low-maintenance sloped concrete slab with imbedded rocks or concrete blocks is recommended as an alternative. *Photo: Marco Metzger.*

Systems with Sumps, Vaults, or Basins

This category includes all stormwater treatment devices, except ponds and wetlands, that incorporate features that hold permanent or semipermanent standing water. Sumps, vaults, and basins may be located both above and below ground, but they are particularly common features of belowground proprietary and nonproprietary treatment devices that tie into existing storm sewers. Examples include above- and belowground media filters, oil-water separators, vortex separators, and vault-type devices (fig. 4).

- Completely seal structures that retain water permanently or longer than 72 hours to prevent entry of adult mosquitoes. Adult female mosquitoes may

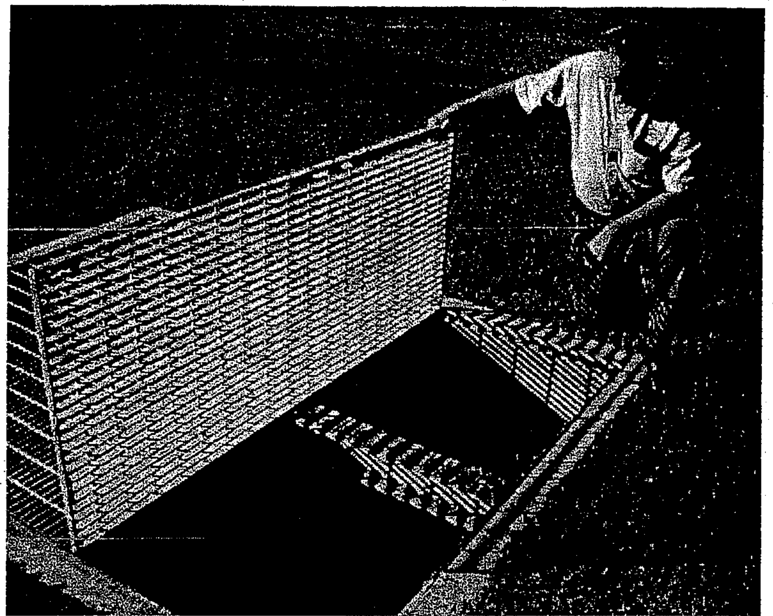

Figure 4. Stormwater treatment BMPs that hold permanent sources of standing water, especially belowground devices, pose a difficult challenge to mosquito exclusion efforts. A cooperative effort between stormwater professionals, municipal planners, public health officials, vector control agencies, and others is crucial to developing novel techniques that eliminate or deny mosquitoes access to standing water. Contact the state or local public health or vector control agency to discuss local vector issues and provide input and consultation on siting, design, and maintenance of proposed treatment BMPs. *Photo: Marco Metzger.*

Figure 5. Mosquitoes can access underground sources of water in treatment BMPs from many places, including inlet and outlet pipes, loose-fitting covers, and vent holes. As a general rule, any gap 1⁄16 inch (2 mm) or greater is large enough to allow egg-laying females to enter. The hole in this manhole cover is more than large enough to allow mosquito entry. *Photo: Marco Metzger.*

penetrate openings as small as 1⁄16 inch (2 mm) to gain access to water for egg laying (fig. 5). Screening can exclude mosquitoes, but it is subject to damage and is not a method of choice.

- If using covers, they should be tight fitting with maximum allowable gaps or holes of 1⁄16 inch (2 mm) to exclude entry of adult mosquitoes. The use of gaskets can provide a much more effective barrier when used properly.
- If the sump, vault, or basin is sealed against mosquitoes, with the exception of the inlet and outlet, submerge the inlet and outlet completely to reduce the available surface area of water for mosquito egg-laying (female mosquitoes can fly through pipes). Alternatively, creative use of flapper or pinch valves, collapsible tubes (Mulligan and Schaefer 1982), and "brush curtains" might be effective for mosquito exclusion in certain designs.
- Design structures with the appropriate pumping, piping, valves, or other necessary equipment to allow for easy dewatering of the unit if necessary.

Stormwater Ponds and Wetlands

Stormwater ponds and constructed, modified, or restored wetlands that receive runoff and provide stormwater treatment pose a difficult challenge for mosquito control because nearly all produce mosquitoes to some degree (fig. 6). Over time, emergent and shoreline vegetation create habitats conducive to mosquito breeding that may be difficult or even hazardous for mosquito control professionals to access. Hazards increase significantly if proper access (see below) is not provided. If these kinds of structures must be built, it is crucial that appropriate and adequate funds be allocated to support long-term site maintenance as well as routine monitoring and management of mosquitoes by a qualified agency. The long-term costs, jurisdictional and maintenance conflicts associated with establishment of protected species (United States Fish and Wildlife Service 1999), and legal liability (e.g., H&S Code) associated with

Figure 6. Stormwater treatment ponds and constructed wetlands form complex biological systems in which mosquitoes can be difficult to control. Effective mosquito management in these habitats requires careful planning before, during, and after construction. Mosquito suppression in this stormwater pond was achieved by following guidelines provided in this publication, i.e., weekly larval monitoring, annual removal of emergent vegetation, and maintenance of a healthy mosquitofish population. Additional guidelines for managing mosquitoes in surface-flow constructed wetlands are available and should be consulted (see Walton 2003). *Photo: Marco Metzger.*

these kinds of projects must be evaluated; if any doubt exists, consider alternate treatment devices. For example, feasibility studies of subsurface flow treatment wetlands are currently under investigation and may provide excellent mosquito-free alternatives (see Anonymous 2002).

Long-term management of mosquitoes in stormwater ponds and wetlands should integrate biological control, vegetation management and other physical practices, and chemical control as appropriate. Also, a provision for regular inspection of sites for detection of developing mosquito populations should be included. Some general guidelines are listed below. Local factors may influence the overall effectiveness of certain approaches for mosquito reduction. Additional information and guidelines are available for surface-flow constructed treatment wetlands and should be consulted (Walton 2003) to ensure that mosquito populations are minimized.

Mosquito Predators and Biological Control

- Stormwater ponds and wetlands should maintain water quality sufficient to support surface-feeding fish such as mosquitofish *(Gambusia affinis)*, which feed on immature mosquitoes and can aid significantly in mosquito control.
- If large predatory fish are present (e.g., perch and bass), mosquitofish populations may be negatively impacted or eradicated. In this case, careful vegetation management remains the only nonchemical mosquito control measure.
- Where mosquitofish are not allowed, careful vegetation management remains the only nonchemical mosquito control measure.
- Other opportunistic predators such as dragonflies, diving beetles, birds, and bats feed on mosquitoes when available, but their effects are generally not sufficient to preclude chemical treatment. Despite popular beliefs, control of adult mosquitoes by birds (e.g., purple martins) and bats cannot be relied on in lieu of habitat maintenance and chemical control (Kale 1968; Tuttle 2000).

Vegetation

- Emergent vegetation provides mosquito larvae with refuge from predators, protection from surface disturbances, and increased nutrient availability while interfering with monitoring and control efforts.
- Perform routine maintenance to reduce emergent plant densities to facilitate the ability of mosquito predators (i.e., fish) to move throughout vegetated areas.
- Whenever possible, maintain stormwater ponds and wetlands at depths in excess of 4 feet (1.2 m) to limit the spread of invasive emergent vegetation such as cattails (*Typha* spp.). Deep, open areas of exposed water are typically unsuitable for mosquito immatures due to surface disturbances and predation. Deep zones also provide refuge areas for fish and beneficial macroinvertebrates should the densely vegetated emergent zones be drained.

- Build shoreline perimeters as steep and uniform as practicable to discourage dense plant growth.
- Use concrete or liners in shallow areas to discourage unwanted plant growth where vegetation is not necessary.
- Eliminate floating vegetation conducive to mosquito production (i.e., water hyacinth [*Eichhornia* spp.], duckweed [*Lemna* and *Spirodela* spp.], and filamentous algal mats).

Miscellaneous

- Make shorelines accessible to maintenance and vector control crews for periodic maintenance, control, and removal of emergent vegetation, as well as for routine mosquito monitoring and abatement procedures, if necessary.
- Design and obtain necessary approvals for all stormwater ponds and wetlands to allow for complete draining when needed.

General Access Requirements

Providing adequate and safe access for maintenance activities and for mosquito monitoring and management in stormwater treatment devices cannot be over emphasized (fig. 7). An alarmingly high number of treatment BMPs already exist that were constructed with little or no regard to reasonable access and safety. Examples include basins with 1:1 perimeter slopes, devices with deep sumps or vaults, and covered devices with heavy lids or grates.

- All stormwater treatment devices should be easily and safely accessible without the need for special requirements (e.g., OSHA requirements for "confined space"). This allows vector control personnel to effectively monitor and, if necessary, abate vectors.
- If utilizing covers, the design should include spring-loaded or lightweight access hatches that can be opened easily for inspection.
- Mosquito larvicides are applied with handheld equipment at small sites and with backpack or truck-mounted high-pressure sprayers at large sites. The effective swath width of most backpack or truck-mounted larvicide sprayers is approximately 20 feet (6 m) on a windless day. Because of these equipment limitations, all-weather road access (with provisions for turning a full-size work vehicle) should be provided along at least one side of large aboveground structures that are less than 25 feet (7.5 m) wide. Structures that have shoreline-to-shoreline distances in excess of 25 feet should have a perimeter road for access to all sides.

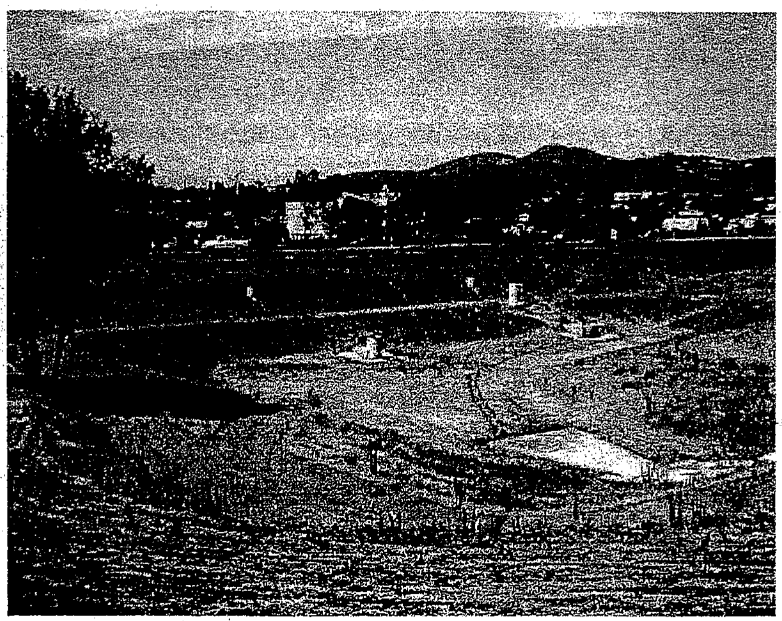

Figure 7. An example of a well-designed perimeter road and access ramp to the basin floor. Adequate access in and around BMP devices such as this large extended detention basin are critical for maintenance activities and vector control. *Photo: Marco Metzger.*

- Access roads should be built as close to the shoreline as possible. Vegetation or other obstacles should not be permitted between the access road and the stormwater treatment device that might obstruct the path of larvicides to the water.
- Vegetation should be controlled (by removal, thinning, or mowing) periodically to prevent barriers to access.

CONCLUSION

Stormwater treatment devices, especially those that hold permanent sources of standing water by design, create a difficult challenge for public health officials and vector control agencies and may pose a legal liability in states such as California (H&S Code). The best solution to managing mosquito populations in stormwater structures lies in fostering interdisciplinary cooperation among stormwater professionals, municipal planners, public health officials, vector control agencies, and others. Existing and future treatment BMPs must incorporate features and follow guidelines to minimize or eliminate mosquitoes. Contact state or local public health or vector control agencies to discuss local vector issues and provide input and consultation into siting, design, and maintenance of proposed treatment BMPs. Ultimately, a proactive rather than reactive approach saves money, time, effort, and most importantly, ensures the public's health.

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FOR MORE INFORMATION

You'll find more information on mosquito control in the following ANR Communication Services publications

Aquatic Pest Control, Publication 3337, 2001.

Managing Mosquitoes in Surface-Flow Constructed Treatment Wetlands, Publication 8117, 2003, available for free downloading at http://anrcatalog.ucdavis.edu/pdf/8117.pdf

Mosquitoes: Pest Notes for Home and Landscape, Publication 7451, 1998.

Mosquitoes of California, 3rd edition, Publication 4084, 1978.

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STORMWATER BEST MANAGEMENT PRACTICES, MOSQUITOES, AND WEST NILE VIRUS

Monte Deatrich and Warren S. Brown, P.E.
Tri-County Health Department

West Nile Virus

West Nile Virus is a mosquito borne disease, a flavivirus commonly found in Africa, West Asia, and the Middle East. Prior to 1999 the virus was predominately found in the eastern hemisphere. In the fall of 1999 an unusually high number of birds were reported dying in the New York City area. The death of the birds was later attributed to the West Nile Virus (WNV).

The virus traveled south along the coast to Florida; it rapidly traveled westerly across the United States to the Midwest. The virus was first identified in Colorado during the late summer of 2002, identified first in horses and birds. By winter it was identified in birds, horses and mosquito pools all along the eastern portions of the South Platte River and Arkansas River Drainages. In 2003 Colorado saw a significant increase in WNV activity, leading the nation in human cases. In that year, Colorado had a total of 2947 human WNV cases with 61 deaths reported (as of 3/31/04). There were a total of 9858 human cases in the U.S. in 2003 with 264 deaths (as of 3/31/04).

It is estimated that 20% of the people who become infected will develop West Nile fever. Symptoms include fever, neck stiffness, headache, body aches, occasional skin rash on the trunk of the body, swollen lymph gland, muscle weakness and paralysis. It is estimated that 1 in 150 persons (<1%) infected with West Nile Virus will develop a more severe form of the disease. More severe infections known as West Nile meningitis and West Nile encephalitis include headache, high fever, neck stiffness, stupor, disorientation, coma, tremors, and convulsions. West Nile infections primarily occur in the human population in late summer and early fall.

The most common exposure route of human infection with West Nile Virus is through the bite of an infected mosquito. Recent investigations have identified blood transfusion and transplanted organs as a source of infection. There is one case of transplacental transmission of West Nile Virus in a human case, and based on a recent case in Michigan, it appears that WNV can be transmitted through breast milk.

Birds are the reservoir host of West Nile Virus; mosquitoes are the vectors for the virus. A mosquito becomes infected when it takes a blood meal from a bird infected with West Nile. The mosquito then becomes infected and may feed on an uninfected bird essentially affecting the bird with the virus. This cycle will take place throughout the summer building up the virus in the bird and mosquito population. Eventually a mosquito will feed on a human incidental host. It only takes one bite from an infected mosquito to transmit the virus to a human. A mosquito cannot become infected from biting an infected incidental host.

It is only the female mosquito that transmits the disease (male mosquitoes feed primarily on plant serums). Female mosquitoes require a high protein meal for reproduction purposes, so they depend on a blood meal to reproduce eggs.

Not all mosquitoes are capable of transmitting WNV; *Culex* species are most responsible for the spread of virus. *Culex pipiens* is a key species in the eastern part of United States, this particular species predominately feeds on birds. In the western part of the United States the *Culex tarsalis* is most responsible for spreading the disease. The *Culex tarsalis* feeds primarily on mammals and is much more efficient transmitter of the virus. Colorado has both *Culex pipiens* and *Culex tarsalis* species of mosquitoes.

Surveillance programs are key in identifying the presence of West Nile. In 2003, the Tri-County Health Department surveillance program consisted of; mosquito, bird, horse, sentinel chicken, and human surveillance. West Nile Virus was identified in 58 mosquito pools, 109 birds, 62 horses, and 409 humans. It identified the presence of the virus in early July. The virus movement was tracked and identified throughout the summer and into the early fall.

It is widely recommended that the best programs for controlling West Nile Virus is through integrated mosquito management, removal of breeding places, and public education. An integrated mosquito management program focuses on interrupting the mosquito life cycle. The best approach is interrupting the mosquito life cycle at the early stages of development of the mosquito larva. This can be most effectively done through water management or use of biological controls. Fish and frogs can play a key role in naturally controlling mosquito larva by feeding on them. *Bacillus thuringiensis* (Bti) is the naturally occurring bacterium that is most widely used for mosquito control. It is commonly found in soil and water. Mosquito larva is attracted to Bti as one of their major food sources. The Bti attacks the mosquito gut causing it to bleed to death.

Another method of control is through the use of growth regulators that prevent the development of the larva onto the adult stage. Growth regulators are chemical products.

Mosquitoes have four stages of their life cycle. The first three stages are egg, larva and pupa of which all are aquatic. The final stage is the adult stage, it is here where transmission of the virus begins. So it is easy to see that control of the virus is key at the larval stage.

Mosquitoes depend on standing water for reproduction purposes. Fluctuating shallow water with vegetation is preferred. Fluctuating water levels affect plant growth by killing some plants. The decomposition of plants promotes bacterial growth of which the mosquito larva depends on as its primary food source. Mosquito larva can complete its aquatic life cycle in as short as 4 days depending on the water temperatures and food supply available to them.

Stormwater Best Management Practices and Mosquitoes

To determine the extent to which stormwater best management practices (BMPs) contribute to the breeding or production of mosquitoes, Tri-County Health Department (TCHD) reviewed the literature and the mosquito control efforts conducted by Adams, Arapahoe, and Douglas County mosquito control personnel in 2003. TCHD also visited several of the BMPs that required treatment during the 2003 season, to investigate why they may have produced mosquitoes.

NATIONAL EXPERIENCE

In 1998, the California Department of Health Service's Vector-Borne Disease Section (VBDS) conducted a two-year study of vector production associated with 37 operational stormwater best management practices (BMP) structures in Southern California. (1) The VBDS surveyed 150 agencies in 289 states. The results of the investigation left no question that a variety of vector species, particularly mosquitoes, utilize the habitats created by stormwater BMP structures throughout the US (1). Of 72 agencies that completed the VBDS questionnaire, 86% reported mosquito production associated with local BMPs. BMPs that maintained permanent sources of standing water provided excellent habitat for mosquitoes and frequently supported large populations. Conversely, BMPs designed to drain rapidly provided less suitable habitats and rarely harbored mosquitoes. (1)

The VBDS study concluded that two factors contribute to mosquito production in BMPs

- Improper design
- Lack of maintenance

The study states that designs that allow water to stand in the BMP for more than 72 hours will allow mosquitoes to breed. Lack of maintenance allows the accumulation of vegetation, silt, and debris that contribute to standing water that remains in the BMP long enough to produce mosquitoes.

LOCAL EXPERIENCE

Arapahoe County

In 2003, Arapahoe County treated 23 BMPs for mosquitoes. This effort required 790 pounds of larvicide and 254 person hours to complete the task. It is estimated that there are a total of 335 to 365 total private stormwater BMPs. On this basis, approximately 6-7% of the BMPs have been found to be problems for mosquito production.

Adams County

In Adams County, it is estimated that 10,000 BMPs were inspected for mosquito production from 1999 to 2003. Of those, 2050 BMPs were treated for mosquitoes. On this basis, approximately 20.5% of BMPs were discovered to be problems for mosquito production in Adams County.

Douglas County

Douglas County treated 168 sites associated with engineered storm drain systems in 2003. The data provided did not make a distinction between stormwater retention facilities and storm drain systems.

Field Investigation of BMPs Associated with Mosquito Breeding

To attempt to determine what aspects of stormwater BMPs may have contributed to mosquito production during the 2003 season, Tri-County Health Department visited several BMPs that Arapahoe County treated for mosquitoes in 2003. Tri-County Health Department was not able to obtain design drawings for the facilities, to determine the exact type of BMP that was initially designed and constructed.

Site 1 was a large BMP, with substantial amounts of wetland type vegetation throughout the entire basin. Standing water was also noted throughout the basin. Concrete culverts at the north and south ends of the basin were surcharged with water nearly to the crown of the pipe. No outlet structure was apparent in the basin. Considering that there was no outlet structure and that significant wetland vegetation was present, it is possible that the facility could have originally been designed as a wetland BMP. The Arapahoe County inspector did mention that a concrete "trickle channel" was on the bottom of the basin.

The presence of the trickle channel would suggest that this BMP was not intended to be a constructed wetland BMP. The presence of standing water in the inlet or outlet culverts indicates that the pipes are completely surcharged with water, providing additional mosquito habitat. In addition, the inundation of the culverts and the trickle channel indicate that this BMP is holding significantly more water than the designers intended.

Figure 1 below illustrates the standing water and lush wetland type vegetation. Figure 2 shows the culvert pipe surcharged with water.

Figure 1: Wetland Vegetation and Standing Water

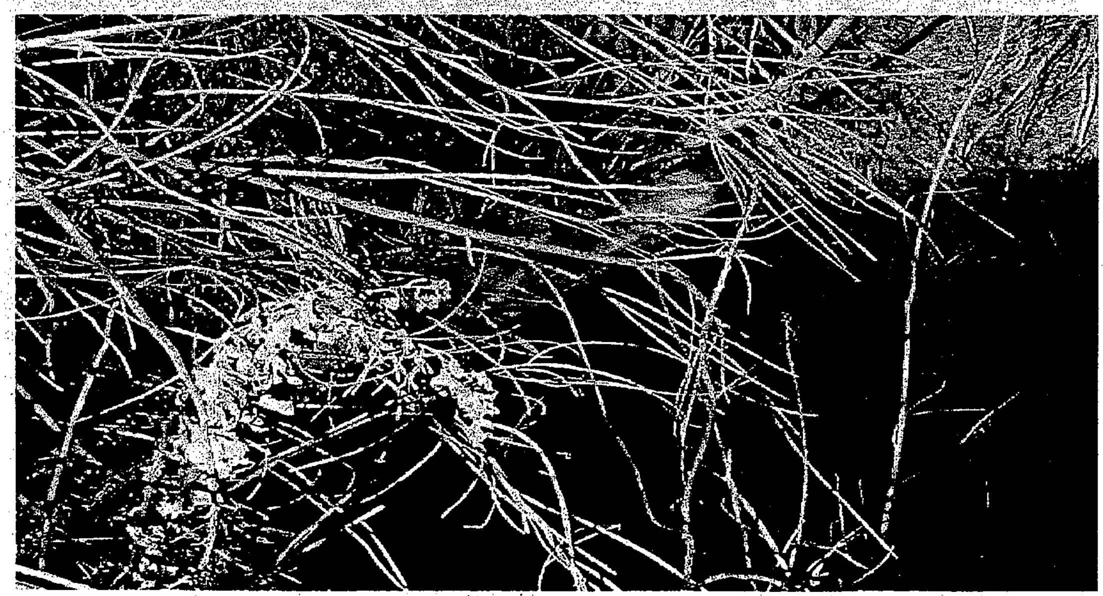

Figure 2: Concrete Culvert-Nearly Full of Water

Site 2 was an extended detention basin (EDB) that was full of water during the 2003 mosquito season. As indicated in Figure 3 below, the EDB was dry when the photo was taken on March 11, 2004. The photo shows a very short distance between the inlet culvert and the release structure. It is not clear whether this EDB was designed with a micropool, or if the micropool area had silted in. The lack of a clearly defined micropool with steep banks can contribute to mosquito production during periods of runoff. In addition, the rock around the outlet may have silted in, preventing the pond from draining between storm events.

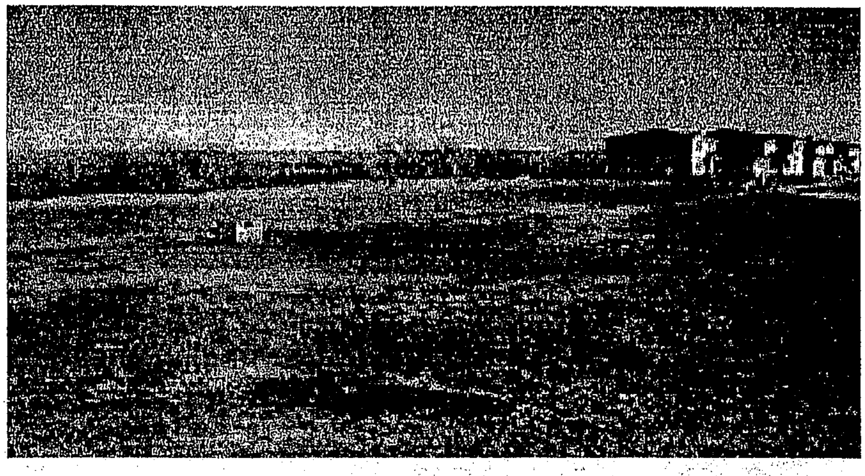

Figure 3: Extended Detention Basin

Site 3, in Figure 4 below, was another Extended Detention Basin. The inlet is shown on the left at the rip-rap. Standing water is noted near the inlet, and the continuous presence of water has created a lush vegetative growth conducive to mosquito production.

Figure 4: Estended Detention Basin, with "Permanent Water" and Wetland Vegetation

Site 4 was another EDB. As shown in Figure 5, the area where the "micropool" would be expected was possibly too "silted in" to allow the micropool to form.

This BMP was equipped with an access road to make it accessible to maintain by periodically removing silt accumulation near the outlet structure. This BMP also had rock around the outlet pipe, that may tend to clog with silt. The possible "silting in" of the micropool, combined with clogging that may result from the rock at the outlet results in shallow standing water from storm events that remains long enough to allow mosquitoes to breed.

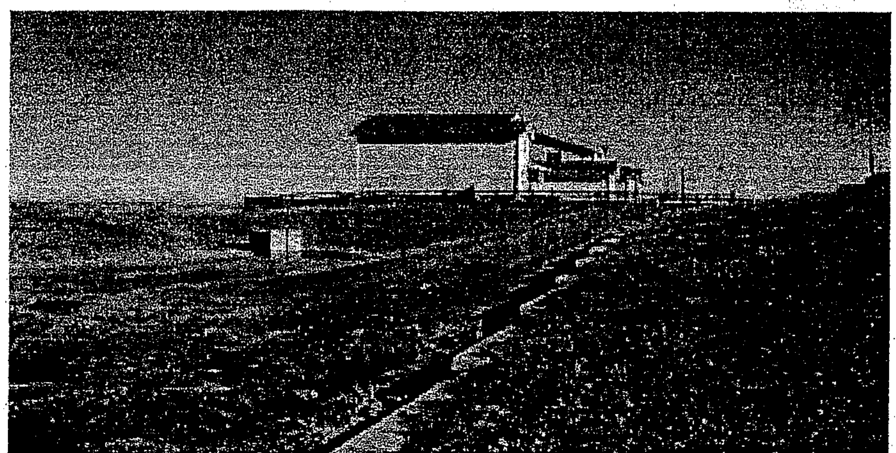

Figure 5: EDB with Access Road and Rock Around Outlet Structure

The outlet structure at Site 5 is shown in Figure 6 below. The photo illustrates significant clogging of the outlet structure that can lead to mosquito production. The micropool no longer exists as it was designed and shallow standing water remains long enough for mosquitoes to breed.

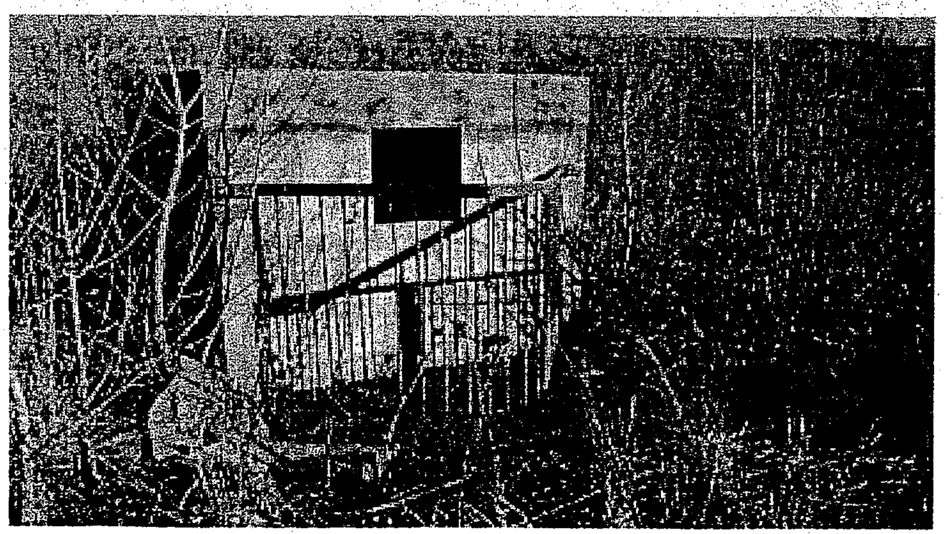

Figure 6: Outlet structure with heavy siltation, preventing drainage

Site 6 is shown in Figure 7 below. This micropool. appears sufficiently shallow and has sufficient stagnant water with organic matter to produce mosquitoes. The rock at the outlet is prone to clogging.

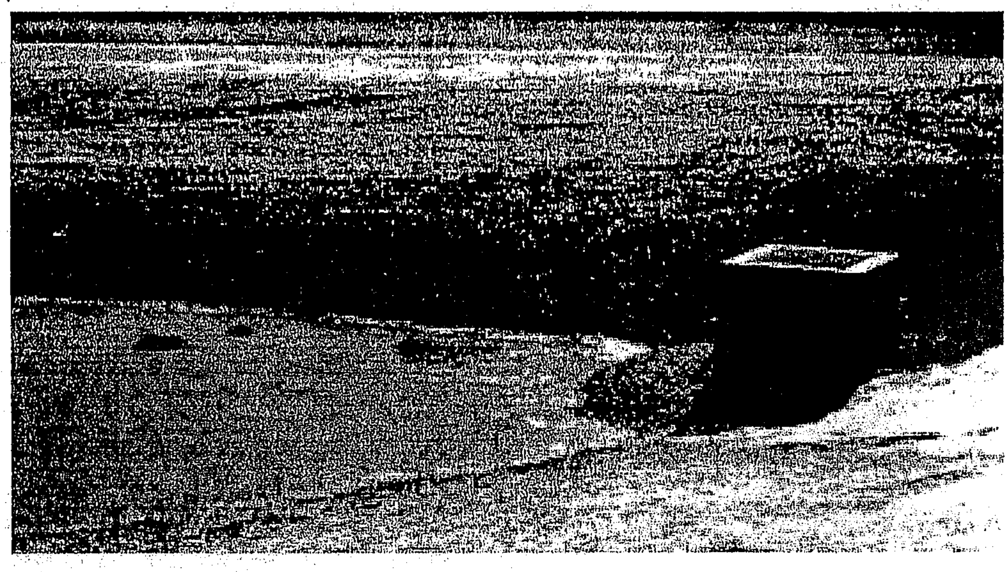

Figure 7: EDB with Micropool & Rock Outlet

Figures 8 and 9 below are from Site 7. Figure 8 indicates two primary conditions for mosquito breeding: 1) permanent, stagnant, standing water; and 2) heavy vegetation that produces organic matter.

Figure 8: EDB? With Permanent Standing Water and Wetland Vegetation

Figure 9 shows an outlet structure at Site 7. It is apparent that the outlet structure does not release sufficient water to have prevented this BMP from becoming a large wetland. This site has produced large numbers of mosquitoes for many years.

Figure 9: Outlet Structure of Perforated CMP Culvert

Figure 10 below is from Site 8. It is unclear whether the standing water shown in Figure 10 was intended to be a micropool or a forebay. The inundation of the culvert does not appear to be intended. Although this BMP was implicated in the production of mosquitoes in 2003, it does appear that it has the potential to produce mosquitoes.

Figure 10: EDB-Not a mosquito site in 2003, but has potential!

Conclusions

Based on a review of literature, data from Adams, Arapahoe and Douglas Counties, and a field tour of known mosquito breeding sites, Tri-County Health Department has drawn some preliminary conclusions. It is established that stormwater BMPs can and do breed mosquitoes. Poor design and performance of outlet structures, appears to be a significant factor causing water to stand in the BMPs for long periods of time. Outlet structures designed with rock around the outlet pipes are prone to clogging with silt. From observation of EDB's, it appears as if the silt first clogs the rock outlet structure. As additional silt enters the BMP, it begins to fill into the micropool basin. The micropool basin becomes shallow, making it favorable for mosquito production. Additional water entering the BMP then "spreads out" beyond the micropool, creating additional mosquito breeding habitat.

It also does not appear that all micropools create habitat for mosquitoes. Micropools designed and maintained with steep sides and deeper pools without vegetation do not appear to breed mosquitoes. These only appear to become a problem when the "rock type" outlet structure plugs from silt and the micropool "silts in".

It has been suggested that many BMPs are initially constructed as construction BMPs, and then are converted to permanent BMPs after completing of grading. During construction, sites are highly devegetated, creating large amounts of silt during storm events that is transported into the BMPs. This silt is often not removed prior to conversion to a permanent BMP, creating a BMP that may hold water well beyond the micropool area for long periods of time. These BMPs may later become "wetlands", due to significant vegetative growth. These factors result in a BMP that can breed mosquitoes, due to shallow, stagnant water that remains for long periods of time and produces vegetation. The vegetation decays, producing organic matter that is conducive to mosquito production.

Recommendations

BMPs should be designed and maintained to drain completely with 72 hours (1). However, it is recognized that many extended detention basins (EDB's) are designed with micropools, i.e. are intended to have permanent standing water. These micropools do not necessarily lead to the production of mosquitoes, if they are properly designed and maintained.

EDBs with micropools can be designed to minimize mosquito production by:

1. Avoiding shallow depths in the pools. Depths should be sufficient to prevent the growth of wetland vegetation.
2. Provide steep slopes to micropool banks
3. Consider mechanical aeration of permanent pools
4. Make the micropool accessible to remove silt, vegetation, and maintain the outlet structure

5. Make the micropool accessible to treat with larvicide
6. Avoid rock at the outlet structures

All BMPs should be inspected during construction to assure compliance with the design. Small design details that are critical to the performance and function of the BMP may be overlooked by the contractor.

BMPs need to be regularly inspected and maintained. Maintenance consists of the removal of silt, and accumulated vegetation, and the outlet structure itself.

Questions for Further Study

During preparation of the presentation and this paper, several questions came up, that require further consideration and study.

1. Is treatment, i.e. larvaciding, less expensive or more cost effective that maintenance?
2. Can counties continue to bear the expense of treating private facilities?
3. If counties cannot afford treatment, can private entities do the job?
4. Are BMPs that become wetlands, subject to Army Corps of Engineers 404 Permits?

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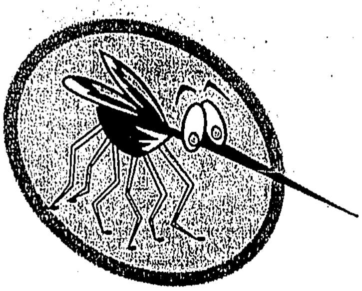
West Nile Virus A FACT SHEET ON MOSQUITO HABITAT



The spread of West Nile Virus (WNv) in Ontario has attracted the attention of public health officials, the media and Ontario residents. At this time, the human health risk of West Nile Virus remains minimal compared to other human health risks. However, knowledge of the scope and severity of illness is growing as this newly emerging virus extends across North America.

West Nile Virus is a public health issue. The Ontario Ministry of Health and Long-Term Care, in association with local health units and municipalities across the province, has the primary responsibility for research and public education about West Nile Virus. As with other public health issues, these agencies have requested the assistance of the people of Ontario and other institutions, such as Conservation Authorities, to help deal with the virus.

WHAT IS WEST NILE VIRUS?

Human Illness from West Nile Virus

Human illness from the West Nile Virus (WNv) is still rare, even in areas where the virus has been reported. According to the Centers for Disease Control (CDC), the chance that any one person will become seriously ill from an infected mosquito bite is low. Many people who have contracted WNv do not even know it. About 20% of those infected will have a mild illness with flu-like symptoms (mild fever, headache, muscle aches, stiff neck, swollen glands, skin rash) within 3 to 15 days following the bite of an infected mosquito. Less than 1% of those infected will develop encephalitis (swelling of the brain) and may experience prolonged muscle and neurological problems. Personal preventative measures are the most effective way of protecting yourself against WNv. Once you have WNv and recover, it is believed that you are immune for life.

Mosquitoes and West Nile Virus

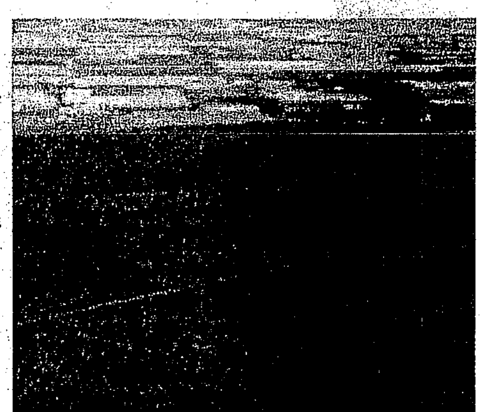
West Nile Virus is usually spread to people through the bite of infected mosquitoes. Mosquitoes acquire the virus when feeding on infected birds. The virus is stored in the salivary glands of the mosquito and transmitted to humans and animals when the mosquito takes a blood meal. The virus as a single dose is not powerful; several mosquitoes infected with the virus must bite before the virus will infect a human.

According to the CDC, very few mosquitoes are infected with the virus, even in areas where the virus is circulating. There are approximately 50 species of mosquitoes in Southern Ontario. Approximately 18 species can carry the virus but not all mosquito species are capable of transmitting it. At present, the mosquito species of most concern in the transmission of the West Nile virus to humans are the Culex species or catch basin mosquito. They are active from May to August. They prefer stagnant waters with lots of nutrients for breeding (i.e. water in ditches, eaves troughs, bird baths and roadside catch basins) and are more common in urban rather than rural areas. These species tend to be more active throughout the night between dusk and dawn. The other species of concern are the Aedes species. These species prefer temporary wet areas such as flood plains for breeding and feed throughout the day or night. Both species are relatively weak fliers, so they will not travel far from their birth place. Therefore, the primary method for reducing mosquito populations is to eliminate mosquito habitat in backyards.

WEST NILE VIRUS AND MOSQUITO HABITAT

One misconception is that any type of standing water, such as wetlands and waterways, may produce large numbers of virus-infected mosquitoes and that all potential sites should be drained, filled, sprayed or managed to eliminate the possibility of WNv transmission. However, not only is it impossible to eradicate all mosquitoes, but not all water bodies are home to the mosquito species that propagate WNv. Instead, mosquito-producing habitats vary depending on the mosquito species. Since not all mosquito species that feed on humans transmit WNv, control measures for West Nile Virus will vary depending on the habitat.

In general, activities that encourage the presence of natural mosquito predators and reduce the amount of artificial or disturbed habitat will assist in reducing the mosquito species that carry West Nile Virus.



Healthy wetlands are not the preferred habitat of mosquito species that are primarily responsible for transmitting WNv.

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Natural Environments

Wetlands

Mosquitoes are common in natural wetlands. However, results from monitoring studies conducted in southwestern Ontario (Essex and Perth County) in the summer of 2002 found that the mosquito species primarily responsible for transmitting West Nile Virus (i.e. the Culex species) is not commonly found in natural wetlands.

Healthy wetlands have features that reduce the number of mosquitoes. Mosquitoes are an important part of the food chain and healthy wetlands are home to hundreds of mosquito-eating aquatic insects (beetles, back swimmers, water striders, dragonflies, etc.), birds, frogs, fish, turtles and bats. This balanced predator-prey relationship provides natural mosquito control. In addition, water levels naturally fluctuate in wetlands or are stirred by the wind, which helps reduce the number of mosquitoes.

Recognizing the valuable role of wetlands in water purification, reducing the severity of flood and erosion events and providing habitat for wildlife and recreation, their preservation is extremely important. If a wetland is disturbed by humans or if other life forms are eliminated through the incorrect use of pesticides, it is possible that the number of mosquitoes in a wetland may actually increase. Therefore, it is important to preserve the natural balance in a wetland. Wetland restoration and preservation decreases the mosquito population by providing habitat for the natural enemies of mosquitoes and by reducing or preventing flooding in areas that aren't normally wet (i.e. areas that will support mosquitoes but not their predators).

Flood Plains

Culex mosquito species are not common in natural flood plains but Aedes species are. Flood plains are also home to a variety of other species that prey on mosquitoes, and altering these areas to eliminate mosquitoes will also affect these species as well as increase sedimentation, erosion, etc., downstream. Altering fish habitat is strictly regulated under the Federal Fisheries Act. Since Culex and Aedes are relatively weak fliers, the best preventative measure is to avoid these areas.

Floodplains are home to many species that prey on mosquitoes.

Note: Before undertaking any activity within wetlands or flood plains, consult with your local municipality and Conservation Authority.

Man-Made Environment

Storm Water Management Ponds

Storm water management ponds are designed to hold and treat runoff (i.e. rain or melting snow) from nearby land. In some cases, they filter the water (runoff may be contaminated with soil, salt, oil and other residues) and lockup some of the harmful substances carried in runoff. In the storm water management pond, pollutants are treated by settling and biological processes. If left untreated, pollutants in the runoff may be harmful to the receiving environment. Storm water management ponds are often constructed in subdivisions and help to keep sediments and contaminants out of rivers and streams as well as reducing erosion and flooding during storm events. Thus, they provide a great number of benefits to the community as a whole.

Storm water management ponds are generally not breeding areas for the virus-transmitting mosquito species. In fact, the chance of finding a significant number of Culex species in a storm water pond is much, much smaller than of finding them in artificial containers in your backyard. There are several reasons for this:

- Wet Ponds are constructed to hold large volumes of water to improve water quality. These types of ponds are designed to contain water most of the time. Current studies have shown that very few wet ponds are significant mosquito breeding sites. One reason is that the Culex species primarily breed in shallow areas. Wet ponds tend to be deep and some are designed with steep banks along the sides. Another reason is that Culex species will not lay eggs in areas exposed to wind, since the wind will destroy their egg rafts. Wet ponds tend to have a large surface areas and are regularly cleaned out, which effectively disrupts the life cycle of the Culex mosquito.

Wet storm water ponds are not normally habitat for WNv mosquitoes because of their depth and exposure to wind.

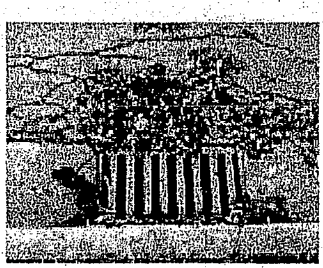
• Dry Ponds are designed to help reduce flooding during wet periods but otherwise lack ponded water. These areas usually have channels that water flows through during a storm (Culex will not breed in moving water), but then slowly dries up. These types of ponds should not hold water for more than 48 hours as the potential for mosquitoes using them will increase. Some of these areas are more naturalized with vegetation that may attract mosquitoes (as well as their predators).

Dry storm ponds are not normally habitat for WNv mosquitoes because they regularly dry up.

Storm water management ponds that are perceived to be mosquito breeding areas should be monitored for the mosquito species responsible for transmitting West Nile Virus. If the local Medical Officer of Health decides that a storm water management pond has raised the risk of West Nile Virus spreading, the pond may be treated to control mosquito larvae. It is also recommended that the pond design should be reviewed to ensure it is functioning as intended.

Catch Basins

Catch basins are one of the main breeding sites for Culex species. The depth of the catch basin does not appear to affect mosquito population numbers, but organic material is very important (i.e. putting grass clippings, leaves and other plant material into sewers will increase the number of mosquitoes). Catch basins in newer subdivisions have fewer Culex species because of the lack of vegetative material, while older neighbourhoods have higher numbers of these mosquitoes.



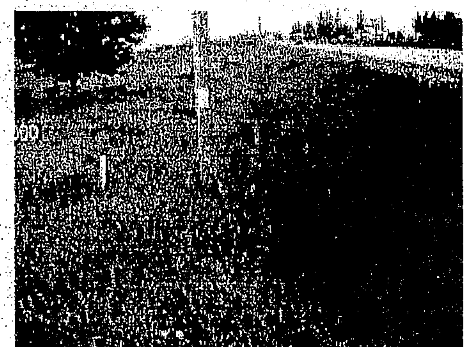
Catchbasins with lots of vegetative material are prime breeding sites for WNv mosquitoes.

Catch basins in older neighbourhoods with dense population and/ or retirement homes nearby should be monitored for the mosquito species responsible for transmitting West Nile Virus. Municipalities are reviewing local situations and some, including London, have already intiated a program to apply larvacide in catch basins.

Irrigation and Drainage Ditches, Municipal Drains and Small Private Ponds

Drainage ditches provide prime mosquito producing habitat because these areas typically contain warm, standing water that is loaded with nutrients. Sites can be made unsuitable for mosquitoes to lay eggs in by:

- running a narrower and deeper ditch through centres of broader ditches,
- designing steep slopes and gravelled shore lines,
- manipulating water levels,
- controlling emergent vegetation,
- improving drainage,
- infilling small wet pockets.

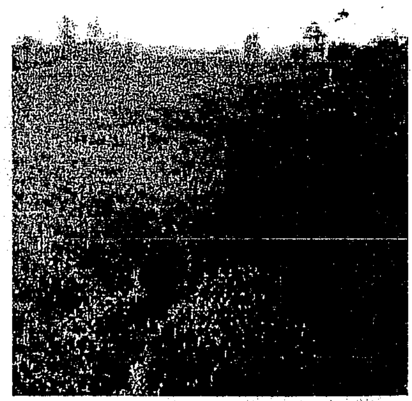


Warm, stagnant water in drainage ditches can be prime WNv mosquito breeding habitat.

Developers and home bulders are aware of the possibility that mosquito larva could be located in construction swales and ditches and are implementing programs to monitor these situations. Some firms have already applied larvacide in construction swales.

Golf Courses and Gravel Pits

In semi-natural environments (such as golf courses and gravel pits), there may be a mixture of natural and artificial water features. Each area should be examined separately for its potential to breed mosquitoes. The primary defence measure is to encourage personal protection measures (i.e. long sleeved shirts, DEET on skin or clothing, avoiding dawn and dusk) for people using the area to reduce the risk of exposure to West Nile Virus.



There are several options for reducing mosquito breeding habitat in semi-natural environments.

Secondarily, mosquito populations can be reduced or discouraged from laying eggs by:

- stocking ponds with fish,
- adding a fountain or aeration unit to create surface (wave) movement,
- redesigning ponds to discourage Culex species (i.e. steep banks, deep water, mow vegetation to the edge of the water feature),
- regularly skimming the surface along the edges (where water tends to be stagnant) to remove mosquito larvae,
- using larvicide in ponds where there is no drainage off the site.

Personal protection measures are a key factor in reducing your risk of contacting WNv.

TAKE ACTION TO PROTECT YOURSELF!

Monitor the Spread of West Nile Virus

Crows, blue jays and ravens usually die as a result of having contracted West Nile Virus:

- Report all sightings of dead crows and any large numbers (i.e five or more) of bird deaths to your local health unit

Personal Protection

Mosquitoes prefer dark places rather than direct sun, so dawn, dusk and early evening are peak mosquito-biting times:

- Limit your outdoor activity during dawn and dusk
- Wear long sleeved, light colored clothing and long pants
- Use insect repellent containing DEET on skin or clothes

Reduce the Spread of West Nile Virus

Mosquitoes prefer stagnant, nutrient rich water and temporary wet areas for breeding:

- Empty all standing water from small containers at least once a week (e.g. flower pots, buckets, plastic containers, discarded tires, etc.)
- Clear eaves troughs and down spouts
- Add an aerator to fish ponds
- Screen windows and doors
- Store wheelbarrows, etc. upside down
- Clear out dense shrubbery where mosquitoes breed and rest
- Fill in small low spots on your property so water cannot collect
- Refer to the Health Unit pamphlet for other tips

Note: Vitamin B, vegetable oil and ultrasonic bug-zapping devices are NOT effective in preventing mosquito bites or reducing mosquito populations. In fact, they may harm the environment or discourage the presence of natural mosquito predators.

FOR MORE INFORMATION:

Middlesex London Health Unit
Tel: 519-663-5317
Web: www.healthunit.com/diseaseprevention.htm

Oxford County of Health
Tel: 519-539-9800
Web: www.county.oxford.on.ca/publichealth

Perth District Health Unit
Tel: 519-271-7600
Web: www.pdhu.on.ca

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UPPER THAMES RIVER
CONSERVATION AUTHORITY

Financial Assistance by:

LDI

LONDON HOME BUILDERS' ASSOCIATION

The information provided in this fact sheet is current as of July 2003 and every effort has been made to ensure accuracy. However, as the West Nile Virus is new to North America and subject to a variety of environmental influences you should always check with current sources of information.

May 8, 2003

$56,400 Grant Supports Study on How Storm Water Affects Mosquitos

Dr. John Wallace, assistant professor of biology at Millersville University, recently received a $56,400 Maryland State Highway Administration (MDSHA) Research Grant to conduct a study on the role of storm water management techniques in mosquito diversity, abundance and arbovirus presence, such as West Nile, St. Louis and Eastern Equine Encephalitis. The study will be conducted during 2003-04 in Maryland's Howard and Montgomery counties.

According to Wallace, the two-year study's objectives include determining the diversity and abundance of mosquito fauna in these aquatic systems, assaying or testing adult mosquitoes for West Nile virus, and developing a control program for MDSHA personnel to maintain after the study has been completed.

To better understand the role of storm water management facilities as habitats for mosquitoes, as well as their impact on the presence of West Nile virus, mosquito diversity and abundance, Wallace says collections of larval and adult mosquitoes will be monitored on a biweekly basis from May through October of 2003-04. In addition, Wallace, Dr. Jay Moné, of MU's biology department, and Millersville University student Caroline Ehlenbeck, will test adult mosquitoes for West Nile virus in MU's lab.

By this August, explains Wallace, the project will enter into the control phase in which he will train MDSHA personnel to collect mosquito samples, both before and after biological insecticidal treatments, for identification, enumeration and testing the effectiveness of the new control program. Wallace will continue control efforts and reduced monitoring during 2004.

Because of extensive surveillance efforts conducted throughout the Commonwealth and in Lancaster County, Wallace reports that the State West Nile Virus program has shifted its prime directive to involve more control or abatement and less surveillance. Consequently, Dr. Wallace will not be coordinating surveillance efforts with MU students as in the past; however, he will continue to serve on Lancaster County's West Nile Task Force.

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An Evaluation of Mosquito Populations Near Storm Water Drainage Ponds, Versus Background Mosquito Populations in Non-Storm Water Pond Developments

A comparison based on total number of mosquitoes, and prevalence of West Nile Virus vector species.

Heather Bost
J. Scott Meschke
Research Proposal
ENVH 583
5/2003

Abstract

The spread of West Nile Virus across the United States over the past four years has lead to an increased awareness of the need for mosquito surveillance and abatement programs. The purpose of this study is to identify and compare the occurrence of vector-species of mosquitoes in neighborhoods with and without storm water drainage ponds. This will be accomplished by trapping adult and larval mosquitoes at selected areas in King County. The data generated by this project will be integrated in to the overall mosquito surveillance data for King County, and be used by the Seattle Crow Project in their wild bird monitoring studies. The information gathered in this project is important because storm water drainage ponds are often blamed for mosquito problems, even though vector mosquitoes such as the *Culex* species have been shown to breed in small containers such as birdbaths and discarded tires. Consequently, drainage ponds are frequently targeted for mosquito abatement efforts, which may result in unnecessary larviciding which is both expensive for the county, and harmful for the environment. This study will determine whether or not the population of mosquitoes, particularly West Nile Virus vector species, show a significant increase in prevalence with proximity to storm water drainage ponds.

Specific Aims

- Collect adult and larval mosquitoes from areas in King County with a range of proximities to storm water drainage ponds.

- Document both the total number of adult mosquitoes, and the species distribution (adult and larval) collected per site.

- Determine whether or not the total number of mosquitoes, or the number of West Nile Virus vector species, show a significant increase in prevalence with proximity to storm water drainage ponds.

Background

The spread of West Nile Virus across the United States over the past four years has lead to a revival of interest in mosquito surveillance and abatement programs. Washington State has a long history of mosquito borne disease, and mosquito borne disease surveillance. In the 1960's a state wide mosquito survey was conducted, and in some areas mosquito control districts were formed. In the 1970's sentinel chicken flocks were set up in Benton and Grant Counties to monitor for mosquito born diseases. In the 1990's the Washington State Department of Health (DOH) established its Zoonotic Disease program (1). From the 1930's through the 1970's human and horse cases of mosquito-borne encephalitis were a significant problem, particularly in the eastern part of the state. However, with improvements in abatement programs and vaccination capabilities, outbreaks became less frequent, and there have been no reported cases of mosquito-borne encephalitis since the 1980's. The lack of a perceived threat from mosquito born diseases resulted in little mosquito surveillance being done in recent years. The arrival of West Nile Virus in the United States in 1999, and in Washington State in 2002 has changed that perception, and in 2001 the DOH began a West Nile Virus surveillance program.

West Nile Virus is a flavivirus which normally infects wild bird species, and only incidentally infects humans, horses and other domestic animals. Humans, horses and other domestic animals are dead end hosts since they do not develop high enough viremic levels to transmit the virus to new vectors. The first recognized case of West Nile Virus occurred in Uganda in 1937. It has since been recognized as the cause of severe human meningoencephalitis in outbreaks around the world. Most people who are infected with the virus do not show clinical signs, and those who do usually develop only fever and other flu-like symptoms. However, West Nile virus can be deadly in older populations, and has been known to affect people of all ages, with severe cases sometimes resulting in long term health affects.

According to a recent review by Brinton (2),

> WNV has been isolated from *Culex, Aedes, Anopheles, Minomyia,* and *Mansonia* mosquitoes in Africa, Asia, and the United States, but *Culex* species are the most susceptible to infection with WNV [2.1, 2.2]. Also *Culex* mosquitoes feed on wild bird species that have high levels of viremia [2.3]. Natural vertical transmission of WNV in *Culex* mosquitoes in Africa has been reported and is expected to enhance virus maintenance in nature [2.4]. Mechanical transmission by ticks may also play a role in virus maintenance [2.1].

Several mosquito species have been identified as potential vectors based on detection of WNV or viral RNA in mosquito pools. This does not necessarily indicate that the species is capable of passing the virus on to humans or other hosts, rather it merely indicates they have fed on an infected host.. Further research is necessary to establish most of these as vector species. Nine of the potential West Nile Virus vector species are present within the State of Washington, including: *Culex pipiens, Culex tarsalis, Aedes vexans, Aedes cinereus, Anopheles punctipennis, Coquillettidia perturbans, Ochlerotatus japonicus, Ochlerotatus canadensis* and *Culiseta inornata* (3). Of these identified potential vectors the *Culex* species, particularly *Culex pipiens,* is of particular concern in Washington, both because they are known to transmit the virus between hosts and because they tend to live in urban areas. *Culex pipiens* are known to breed in a variety of environments from water collected in fallen logs, to storm water drainage ponds, to bird baths. The exact distance mosquitoes will fly from their birthplaces is unknown, but most of the species identified as potential vectors are believed to travel only ½ to 2 miles over their lifetimes(3). *Aedes vexans* may travel up to 20 miles, but they generally lay eggs on river flood plains, and have not previously been found in drainage ponds in King County (4).

Methods

Site Selection

- County maps showing locations of storm water drainage ponds will be used to identify eight locations that do not have these ponds within a ½ mile radius. Eight locations within a ½ mile radius of a storm water drainage pond, having similar habitat characteristics to the non-pond areas, will be chosen as controls.

- If possible, these areas will be chosen to correspond to areas where the Urban Crow Project is monitoring wild bird populations.

Mosquito Trapping

- Adult and larval mosquitoes will be trapped monthly during the mosquito breeding season (March – October) in each area. Collecting will be done according to DOH guidelines (appendix one), using carbon dioxide traps. Larval collection will be done using the "simple scoop" method (appendix two) in order to allow comparison of total numbers caught, as well as comparison of species caught at each location.

- Adult mosquitoes will be sent to the Washington State Department of Health (DOH) where they will be identified to species by visual inspection under a microscope.

- Mosquito larva will be reared to adults in the laboratory in growth chambers, then will be identified to species level similar to field trapped adult mosquitoes.

Data Analysis

- Data will be analyzed to determine whether or not the total number of mosquitoes, or the number of West Nile Virus vector species caught at each site, show a significant increase with site proximity to storm water drainage ponds. This will be done two ways. First the analysis will be done with sites grouped as those within ½ mile of a pond, and those not within ½ mile of a pond. Additionally, the data will be analyzed based on the total number of ponds within a 2 mile radius of each collection site, to see if there is a spatial "dose response" relationship.

Budget

Equipment

- Mosquito trapping and rearing equipment will be provided by the Washington State Department of Health.

Projected Costs

- Travel expenses incurred during collection of specimen: Gas + Vehicle expenses $0.13 / mile * 500 miles/ month = $65.00/month

- Mosquito identification: Provided by DOH

Timeline

- 5/03: Select Sites, Receive mosquito trapping equipment and training from DOH.
- 6/03 – 10/03: Trap mosquitoes

- 11/03 – 2/04: Begin preliminary data analysis
- 3/04 – 5/04: Resume trapping to generate data over a complete breeding season
- 5/04-6/04: Complete analysis and write up results

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3. Washington State DOH (2002) Washington State Mosquito-borne Disease Response Plan. www.doh.wa.gov/ehp/ts/zoo/wnv/wnv.html

4. Zych, Amanda (2003) Manuscript in process.

Centers for Disease Control and Prevention (2001) Epidemic/Epizootic West Nile Virus in the United States: Revised Guidelines for Surveillance, Prevention, and Control. http://www.cdc.gov/ncidod/dvbid/westnile/resources/wnv-guidelines-apr-2001.pdf

Appendix

1. EVS Carbon Dioxide Trap

2. Larval Surveillance Procedures

U.S. Environmental Protection Agency

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Do Stormwater Retention Ponds Contribute to Mosquito Problems?

Issue Number: 71
Chapter Name: Technical Notes
Date: 05/2003

Stormwater retention ponds have received much press of late regarding their potential as breeding grounds for mosquitoes. Concerned parties are raising questions about whether the benefits of these ponds are worth the potential risks associated with mosquitoes that rely on water for hatching grounds. The answer usually depends on the type of pond and how well it is managed.

Ponds represent one class of controls that are used to regulate stormwater runoff. Nationally, tens of thousands of these ponds exist, owned and operated primarily by local governments. For example, the City of Chesapeake, Virginia, operates and maintains 140 ponds in its community of 200,000 people; Portland, Oregon, operates and maintains 365. These ponds, depending on their design, serve three main purposes: to capture stormwater to prevent flooding, to detain and slow the rate of runoff to reduce stream channel erosion and habitat degradation; and to capture and hold sediment and other pollutants that are present in runoff. Many of these ponds are aesthetically-pleasing and boost nearby property values.

Are Stormwater Ponds Required by Law?

While EPA's stormwater permitting regulations are designed to control runoff from urban, industrial, and construction sources, these regulations do not require the use of ponds. Rather, EPA's program promotes the use of appropriate location-specific controls as selected, designed, operated, and maintained by the permittee. The National Pollutant Discharge Elimination System (NPDES) permittees, whether they are municipalities or industrial entities, are required to develop stormwater management programs or stormwater pollution prevention plans that identify the management practices that they elect to use to manage stormwater. Ponds may be among the practices that they select. While EPA does not mandate the use of ponds, some counties and municipalities have developed local ordinances as part of their stormwater management programs that require stormwater treatment ponds for certain types of developments within their jurisdiction. To provide assistance for stormwater management, EPA, states, and municipalities have developed numerous guidance manuals on proper design, inspection, operation, and maintenance of stormwater ponds. South Carolina Department of Health and Environmental Control distributes the *Citizen's Guide to Stormwater Pond Maintenance* both online and in hard copy. In Virginia, Fairfax County posts a *Quick Reference Guide for Stormwater Management Ponds* on its Web site at www.co.fairfax.va.us/gov/DPWES/environmental/SWM_QuickRef.htm.

Mosquito Control

Types of Ponds

Wet Ponds (Retention ponds)

Wet ponds are storm water control structures that provide both retention and treatment of contaminated storm water runoff. A wet pond consists of a permanent pool of water into which stormwater runoff is directed. Runoff from each rain event is detained and treated in the pond until it is displaced by runoff from the next storm. By capturing and retaining runoff during storm events, wet detention ponds control both storm water quantity and quality.

Dry Ponds (Detention ponds)

A dry pond is designed to capture and slowly release runoff water for a period of 72 hours or less after a precipitation event. Dry ponds do not treat the storm water and are typically constructed in areas where flood control is the greatest concern.

Discussion of mosquito control in guidance manuals written to date has been sparse, although that should not imply that mosquito control is not being addressed. Properly designed, operated, and maintained ponds are not conducive to standing water and as such should not be fertile breeding grounds for mosquitoes. To help control mosquitoes in their wet ponds, some localities introduce mosquito predators such as mosquito fish.

Mosquito breeding potential depends on the depth and location of the standing water. To prevent proliferation of mosquitoes in wet ponds, guidance manuals often contain recommendations for minimum pool depths and the establishment of habitats that promote colonization of the facility by mosquito predators both aquatic and terrestrial (e.g., dragonflies and mosquito fish). Improperly maintained dry ponds, however, may contribute to mosquito problems. In cases where the dry ponds are improperly designed or maintained and do not drain within 72 hours after a precipitation event, increased mosquito populations have been observed.

The Florida Cooperative Extension Service reported in *Mosquitoes Associated with Stormwater Detention/ Retention Areas*, one of a series of fact sheets by the University of Florida's Entomology and Nematology Department (http://edis.ifas.ufl.edu/mg338), that properly functioning, extended detention wet ponds are not a significant mosquito problem, but that dry pond systems holding standing water as a result of improper design, construction, or maintenance (or neglect) are a problem. As a result, Florida requires these dry ponds to be designed to drain within 72 hours to prevent the creation of mosquito habitat.

Relying on Pesticides

Pesticides, thought of by many as the best deterrent for mosquitoes, are often used as a last resort for insect control on these ponds. As a result of the recent West Nile Virus outbreaks, EPA is paying more attention to mosquito control and will continue to use its educational materials and research to promote proper design, operation, and maintenance of stormwater ponds and routine inspection of those ponds as a way to ensure adequate control. EPA hosts a Web site for citizens on pesticide use and provides several fact sheets on mosquito control at www.epa.gov/pesticides.

In the past, officials responsible for mosquito control programs made decisions on pesticide use based on evaluations of the nuisance level that communities would tolerate from a mosquito infestation. Increasingly, however, these decisions are being made based on the risks to the general public from diseases transmitted by mosquitoes. Based on surveillance and monitoring, mosquito control officials select specific pesticides and other control measures that best suit local conditions in order to achieve effective control of mosquitoes with the least impact on human health and the environment. It is especially important to conduct effective mosquito prevention programs by eliminating breeding habitats or applying pesticides to control the early life stages of the mosquito. Prevention programs, such as elimination of any standing water that could serve as a breeding site, help reduce the adult mosquito population and the need to apply other pesticides for adult mosquito control.

State and local agencies in charge of mosquito control typically employ a variety of techniques in an Integrated Pest Management (IPM) approach, which include surveillance, source reduction, larvicides, and adulticides to control mosquito populations. Since mosquitoes must have water to breed, reducing opportunities for breeding can be as simple as turning over trapped water in a container to large-scale engineering and management of marsh water. The use of larvicides involves the application of chemicals to habitats to kill pre-adult mosquitoes (see box). Larvicides can reduce overall pesticide usage in a control program by reducing or eliminating the need for ground or aerial application of chemicals to kill adult mosquitoes.

Using Larvicides

Larvicides include biological insecticides, such as the microbial larvicides Bacillus sphaericus and Bacillus thuringiensis israelensis. Larvicides also include other chemicals used for controlling mosquito larvae, such as temephos, methoprene, oils, and monomolecular films. Larvicide treatment of breeding habitats helps reduce the adult mosquito population in surrounding areas. For more information about mosquito control see the American Mosquito Control Association (AMCA) Web site at www.mosquito.org or your state health department (a listing of Web sites is available at www.cdc.gov).

Use Alternative Stormwater Controls When Practical

Reducing our reliance on stormwater ponds for runoff control is another way to reduce potential mosquito breeding habitat. More people are turning to alternative non-structural techniques, such as rain gardens, bioinfiltration, infiltration, and vegetative swales, that slow down water and help it infiltrate without extended periods of ponding. These techniques are successfully minimizing or eliminating the need for stormwater ponds or significantly reducing the pond size requirements. Care must be taken to ensure that these alternative controls drain all standing water as designed over the years.

Similarly, efforts to reduce the amount of impervious surface in communities can reduce the need for stormwater ponds. Narrower streets, sidewalk-less communities, and elimination of cul-de-sacs are just a few of the ways that communities are now reducing the need for stormwater controls. That is not to imply that stormwater ponds can be eliminated easily. Retention/detention ponds use less space than many other types of stormwater controls and are often found to be the best and cheapest way to control runoff--especially when flooding is a concern.

Mosquito proliferation in stormwater ponds is a concern, especially when so many wet and dry ponds are in place and continue to be installed across the country. Many ponds are not properly maintained, particularly in cases where they are installed in subdivisions and other developments where the entity responsible for long-term maintenance is not clearly defined once the construction is complete. However, if inspected regularly and maintained properly, ponds can effectively reduce flooding and remove pollutants without allowing proliferation of large mosquito populations.

TORONTO **Fact Sheet**

May 2003

West Nile Virus Larviciding Program

Toronto City Council adopted the West Nile Virus Larviciding Protocol at its April 2003 meeting to control mosquitoes and reduce the risk of illness from West Nile Virus (WNV). Pellets of the larvicide methoprene will be manually deposited in 175,000 storm water catch basins maintained by the City.

Toronto Public Health is following guidelines set by the provincial government and is consulting with other health units in southern Ontario who have plans to use methoprene in catch basins. This program is based on lessons learned in jurisdictions such as New York City and Chicago and uses an Integrated Pest Management approach with a public education campaign to inform residents of personal protection measures and the importance of eliminating stagnant water on private property.

Why is the City targeting storm water catch basins?
Storm water catch basins have been identified as concentrated breeding grounds of mosquitoes in many cities across North America. The mosquitoes most likely to carry WNV (Culex pipiens) breed in small, stagnant pools of water such as those in catch basins, and not in open bodies of water like rivers, swamps or lakes. A 2002 study confirmed the presence of these mosquito larvae in virtually all Toronto catch basins sampled. The use of methoprene is the most effective way to control mosquito larvae in catch basins.

When will larviciding begin?
Two applications of larvicide are planned, one in late June and one in late July, when Culex pipiens mosquitoes are at the peak of their reproduction cycle. The exact date for larviciding depends on larval surveillance and weather conditions. The public will be informed by newspaper advertisements 48 hours prior to each application of larvicide and the city's web site and information line will be updated daily with specific information on where larviciding will occur.

What is methoprene?
Methoprene is classified by the U.S. Environmental Protection Agency (EPA) as a "least toxic" insecticide. It works by interrupting the mosquito life cycle and preventing immature mosquitoes from developing into biting adults. Methoprene is one of the simplest and most effective methods of reducing mosquitoes. It is licensed for mosquito control in Canada and the U. S. and can only be applied by licensed applicators. It is not available for consumer use.

What is the human health impact of methoprene?
Methoprene is not harmful to humans when used to control mosquitoes in catch basins.

Will putting methoprene into catch basins harm the natural environment?
No. Methoprene, once dissolved, has a half-life of less than two days, which means half the concentration will disappear within two days, and the remaining half will be undetectable within ten days. It breaks down quickly in water and in the presence of sunlight. It does not remain in the ground or leach into groundwater, has low toxicity to fish and other aquatic organisms and poses virtually no risk to other species when used in the amounts required to kill mosquito larvae. While the application is not expected to reach rivers, ponds or Lake Ontario in any amount that would have a negative impact, an impact assessment of this year's program will be conducted.

Does a larvicide program this year mean there will be one every year?
No. This year's larviciding program will be fully evaluated before any recommendations are made to continue next year. The volume of human WNV cases, evidence from mosquito surveillance, consultation with the Ministry of Health and Long Term Care, and the experiences of other health units will all be taken into consideration when assessing options for 2004.

What is the difference between "larviciding" and "adulticiding" (spraying)?
Pellets of larvicide will be dropped manually into catch basins. Larvicide can be applied in small targeted amounts to reduce the number of immature or larval mosquitoes. Adulticides are sprayed into the air to kill adult mosquitoes and are more toxic to humans and the natural environment.

What other efforts are underway to reduce mosquito breeding sites?
Toronto Public Health is working with Works and Emergency Services to conduct a number of pilot projects using alternative methods to control mosquito populations. These may include the flushing, steaming or vacuuming of catch basins and possible trials of mechanical devices using sound waves to kill larvae. Stagnant water on public lands will be surveyed in 2003 to determine the presence of larvae and assess the need for control measures.

For more information, visit www.toronto.ca/health, or www.health.gov.on.ca. For general information, or to report a dead bird, call Toronto Public Health at 416-338-7600.

April 2003

West Nile Virus—Wetlands & Waterways

Public concern over the spread of West Nile Virus (WNV) in Montana in 2002 has brought attention to mosquitoes and their habitats. An attitude may prevail that any type of standing water, such as wetlands and waterways, may be producing large numbers of virus-infected mosquitoes and that all potential mosquito production sites should be drained, filled, sprayed or managed in such a way to eliminate the possibility of WNV transmission. This fact sheet was developed to provide information about WNV and mosquitoes in relation to wetlands and waterways and to provide information about effective measures that citizens and water managers can take to reduce mosquito production sites and protect themselves from WNV.

Background on West Nile Virus.[1]
WNV is a mosquito-borne virus that first appeared in the northeast U.S. in 1999. The virus, probably with the aid of migrating birds and mosquitoes, spread as far west as Montana in three years. The first case of equine WNV in Montana was reported in August 2002 and the first documented human infection occurred later the following month.

Most people who become infected with WNV will have either no symptoms or mild flu-like symptoms. Even in areas where the virus is circulating, very few mosquitoes are infected with the virus, according to the Centers for Disease Control. Even if the mosquito is infected, less than 1% of people who get bitten and become infected will get severely ill. The chances that you will become severely ill from any one mosquito bite are extremely small. WNV can be contracted by anyone of any age, but it is more likely to develop into a serious condition in older people with compromised immune systems.

From 1999 through early 2003, the Centers for Disease Control reported about 250 deaths nationwide from WNV. When compared to other causes of death, the risk of death from WNV infection is relatively low. For example, during that same time frame there were approximately 10,400 deaths due to talking on a cell phone while driving, 80,000 deaths due to influenza, and 160,000 deaths from cancer.

Not all mosquitoes are capable of transmitting WNV, not all mosquitoes feed on humans, and the mosquito- producing habitats vary for mosquito species. For example, species of *Aedes* and *Ochlerotatus* are produced in irrigation and flood waters in the spring and early summer. Species of *Culex*, oftentimes referred to as container mosquitoes, will deposit eggs in a variety of water holding containers like old tires, bird baths, buckets, wading pools, etc. *Culex pipiens*, the northern house mosquito, is a common household mosquito and the primary vector of WNV.[2] The Montana Department of Public Health and Human Services in conjunction with the Department of Entomology at Montana State University will be trapping and testing mosquitoes for WNV this spring. Because horses and birds are more susceptible to the virus than humans, the Montana Departments of Agriculture and Fish, Wildlife and Parks are also monitoring the disease.

Importance of Wetlands

In a 2002 survey of Montana residents, 84% and 83% of respondents agreed or strongly agreed with the statements "Wetlands and riparian areas are important resources in Montana" and "It's important to me that wetland and riparian areas in Montana are conserved and protected."[3] A recent national survey revealed very similar results across various demographic groups.[4] Wetlands are considered important because of the contributions to society they provide:

- Wetlands contribute to better water quality by physically, chemically and biologically cleansing water of pollutant and debris.
- Wetlands contribute to flood attenuation by retarding the flow of fast-moving water that can be erosive and destructive and by reducing sedimentation that contributes to the pollution of water bodies.
- Wetlands can store large volumes of water during spring runoff and during storms and release it slowly beck into the ground or the water channel.
- Wetlands often contribute to ground water recharge by allowing it to infiltrate into deeper ground layers.
- Wetlands can provide water and forage for livestock. Wet meadows can produce excellent hay crops.
- Wetlands are wildlife habitat for wetland-dependent species that include imperiled, threatened, endangered, increasing and stable species. Fish, amphibians, mammals and birds may use wetlands during part of all of their life cycles.
- Wetlands sustain biological diversity of plant and animal species and plant and animal communities wherever they are located in the landscape.
- Wetlands provide recreational opportunities including photography, wildlife watching, hunting, fishing and nature walks.
- Wetlands provide open space; therefore, protection of wetlands simultaneously protects open space and provides all the benefits derived from open space.
- Wetlands lend themselves to be studied and observed at many levels and provide tremendous informal educational opportunities and formal educational opportunities in the fields of biology, botany, zoology, ecology and chemistry.
- Wetlands provide economic value by providing all of the above and providing food, fish, and medicines. Some of the functions wetlands perform would otherwise cost society.

In Montana, because of our arid environment, wetlands are relatively rare features on the landscape, representing less than 1 percent of the land surface. This makes each wetland that much more valuable and important for the benefits listed above. Federal, tribal, state and local governments, consultants, non-profit organizations and private citizens are all working on wetland protection and wetland stewardship in Montana. A national "No Net Loss" of wetlands policy guides many of these wetland protection and stewardship actions.

Mosquitoes and Wetlands.

Mosquitoes are an important part of the food chain providing a food source for many birds, bats, amphibians, other aquatic insects and some fish species. In addition, healthy wetlands typically have a balanced predator prey relationship that provides natural mosquito control measures.

Research completed in neighboring North Dakota found that mosquito populations were about an order of magnitude higher in impaired wetlands than reference wetlands (several reference wetlands had no mosquitoes at all).[5] Impaired wetland also had lower invertebrate diversity and lower plant diversity than reference wetlands. Altered or degraded wetlands often have stagnant water, increased nutrient levels and fewer natural mosquito predators. Therefore, natural and well restored wetlands contribute to minimizing mosquito production by 1) preventing or reducing floods and pooled water in areas not normally wet which support mosquitoes but not their predators and 2) providing habitat for natural enemies of mosquitoes. Maintaining the natural functions of wetlands and restoring impaired wetlands to natural healthy fully functioning wetlands should be of vital concern to the public and mosquito control agencies.

A common misperception is that distant water bodies are contributing to local mosquito outbreaks. *Aedes* and *Ochlerotatus* (species that typically inhabit irrigation and floodwaters) have an average adult flight range of up to 2 miles from hatch sites. Individuals have been trapped at distances of up to 7 to 10 miles. *Culex* (container species) are generally weak fliers, but have been known to fly up to 2 miles from their hatch sites[6]. The short flight range of many mosquito species highlights the importance of eliminating mosquito habitat in backyards as the primary role in minimizing mosquito population booms. Any water that stands for more than a week is sufficient to breed mosquitoes. To reduce mosquito habitat in your backyard, dump rain barrels, change standing water such as bird baths, animal water, and wading pools weekly, and drill holes in or get rid of spare tires. More tips on reducing mosquito producing areas around your home can be found http://www.ncpmc.org/NewsAlerts/westnilevirus.html. As a final note, most wetlands are typically far from housing and urban centers, so the mosquitoes produced in wetlands tend to stay in wetland areas.

Mosquito exposure in wetlands is limited and selective to those engaging in wetland-dependent activities such as wildlife watching or fishing and hunting. Prudent mosquito avoidance measures such as covering up, limiting your activity in these areas at dawn and dusk, and judicious use of products containing DEET are recommended as the primary preventive measure.

Draining or filling wetlands is not a viable measure for controlling mosquitoes or WNV. Most wetlands are considered "water of the United States" and are protected by the Clean Water Act. Such action may require a federal permit http://www.nwo.usace.army.mil/html/od-rmt/mthome.htm and may be subject to the state water quality act. In addition, even after draining, a low spot may hold water and when flooded provides mosquito habitat. Mosquitoes have a very short life cycle (less than a week from eggs to adults) and eggs of some species can remain dormant for more than a year. Further more, reduction of standing water during the winter (November-March) is not likely to reduce mosquito populations because during this time of year, the conditions are too cool for most species of mosquitoes to breed.

Stormwater Runoff

Sediment Basins or Detention Ponds temporarily collect and treat storm water runoff. This method relies on the "settling out" of particulate matter to clean the water collected. These features provide a valuable service to protect natural waterways from excess sediment and polluted runoff. Sediment Basins/Detention Ponds should detain water for no more than 48 hours due to mosquito production potential. If detention time exceeds 48 hours, mosquito surveillance and control treatment, if necessary, should be considered. Retention Ponds often serve the duel purpose of collecting storm water runoff and functioning as a water supply for a construction project. Water is collected and used for a variety of purposes (e.g. dust control and wash plant operations). Mosquito control treatment should be considered for these types of ponds. Any type of mosquito control treatment must be included in the Storm Water Pollution Prevention Plan (SWPPP) which is a required element to obtain a Storm Water Permit. Additional permitting requirements may apply. Contact DEQ Storm Water Program at 444-3080 for Storm Water Permit information.

Irrigation Floodwaters.
Flood irrigation, drainage ditches, and irrigation tail water provide prime mosquito producing habitat because these areas typically contain standing water with high nutrient levels. Unlike wetlands, these areas do not have mosquito predator populations to naturally control mosquito populations. Minimizing time spent in these areas during dusk and dawn when mosquitoes are most active and taking other mosquito protection measures is advised.

Protection Measures.
Self-protection is still the best way to reduce your risk of contracting WNV[7]. The Centers for Disease Control has developed a list of self-protection measures which include:

- Apply insect repellent containing DEET (N,N-diethyl-meta-toluamide) when you're outdoors. For details on when and how to apply repellent, see Insect Repellent Use and Safety
- When possible, wear long-sleeved clothes and long pants treated with repellents containing permethrin or DEET since mosquitoes may bite through thin clothing. Do not apply repellents containing permethrin directly to exposed skin. If you spray your clothing, there is no need to spray repellent containing DEET on the skin under your clothing.
- Consider staying indoors at dawn, dusk, and in the early evening, which are peak mosquito biting times.
- Limit the number of places available for mosquitoes to lay their eggs by eliminating standing water sources from around your home. Learn more on the Prevention of West Nile Virus.
- Install or repair window and door screens so that mosquitoes cannot get indoors.

Mosquito Control.
Mosquito control programs are not intended to eliminate mosquitoes entirely, but rather to reduce their numbers below human annoyance thresholds and therefore reduce the risk of disease transmission. For situations in which mosquito surveillance warrants control measures, controlling mosquito where they are produced is more effective than attempting to control adult mosquito populations through aerial spray programs. Biological larvicides are made from the bacteria *Bacillus thuringiensis israelensis* (Bti) or *Bacillus sphaericus* (Bsph). These products are target species specific; meaning that beneficial insects, fish and other organisms that live in the water are virtually unaffected while mosquito larvae is destroyed. Certain larviciding oils that form a monomolecular film over the water surface prevents immature mosquitoes from breathing will biodegrade in 24 hours. Insect growth regulators are another effective option to control immature mosquitoes. Montana Department of Agriculture (406-444-5400) has a list of mosquito control products currently registered in the State of Montana.

Regulatory Considerations.

In addition to federal permits and state water quality act considerations necessary to alter wetlands, pesticide application requires a permit and other regulatory considerations. Commercial and government pesticide applicators need a license from the Montana Department of Agriculture. In order to apply pesticides to state waters, a 308 permit from Montana Department of Environmental Quality is required (406) 444-3080. State waters include "a body of water, irrigation system or drainage system, either surface or underground." State waters do not include a pond or lagoon used solely for treating, transporting or impounding pollutants or irrigation waters when waters are used up and not returned to state waters. Wastewater lagoon system operators need to ensure than any mosquito abatement efforts do not disturb beneficial microbes in the lagoon systems.

For more information

The Montana Department of Public Health and Human Services
http://www.dphhs.state.mt.us/news/west_nile_virus/west_nile_virus.htm

Centers for Disease Control http://www.cdc.gov/ncidod/dvbid/westnile/index.htm

American Mosquito Control Association: www.mosquito.org

The USDA Regional Pest Management Centers National Pest Alert brochure on WNV
http://www.ncpmc.org/NewsAlerts/westnilevirus.html.

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[6] AMCA 2002. American Mosquito Control Association. www.mosquito.org

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EFFECTIVENESS OF URBAN STORMWATER BMPs IN SEMI-ARID CLIMATES

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ABSTRACT

The phenomena of land-use changes, including urbanization, impacting the physical and biologic integrity of the receiving waters are discussed in this paper. The observed and reported impacts are tied to the types of structural stormwater best management practices (BMPs) that have the greatest potential in mitigating them in the semi-arid climates as experienced in Colorado and other states and regions that have similar climatic conditions. In addition, topics related to clogging of filtering and infiltrating systems, underground vs. above ground facilities, water quality capture volume vs. flow-through facilities, details of what makes extended detention basins function best and the basis for comparing "effectiveness" of BMPs are addressed in this paper.

INTRODUCTION

Virtually no one argues anymore that land use changes that increase site imperviousness or reduce rainfall-infiltration/interception capacity have an impact on receiving gulches, streams, rivers and lakes of the nation. The degree of these impacts appears to be related to the intensity of the land use change, local climate, site geology and the nature of the receiving water. When a tract of rangeland changes to a single-family residential land use, we estimate that the receiving waters in the Colorado's high plains region see the following changes:

Annual:	Before	After	Increase
Runoff Volume	0.52	3.61	700%
Number of Runoff Events	< 1.0	29+	>3000%
Load of TSS, & TP			>500%

What this table does not reveal is that most of the 29+ runoff events represent an increase from zero to some measurable values in peak and volume, namely an infinite ratio since the starting value is zero. The most obvious and immediate impacts that we visually observe are the geomorphic changes in the receiving gulches, streams and rivers (see Figure 1).

Figure 1. Channel degradation at Marcy Gulch.

At the August 2002 gathering of experts from around the world in Snowmass Village, Colorado the topic of "Linking Stormwater BMP Designs and Performance to Receiving Water Impact Mitigation" (Urbonas, 2002) was addressed and debated in much detail. The general themes (virtually a consensus) that emerged from this gathering support the above-stated observations for the Colorado's high plains region. The consensus is that land use changes that reduce rainfall abstractions and increase surface runoff increase the rates and volumes of storm runoff, increase the numbers of runoff events, increase the annual pollutant loads and modify the physical and biologic nature of the receiving waters. The physical changes that occur to our receiving waters also result in changes to aquatic and adjacent terrestrial habitat and in their biologic integrity (See Figure 2).

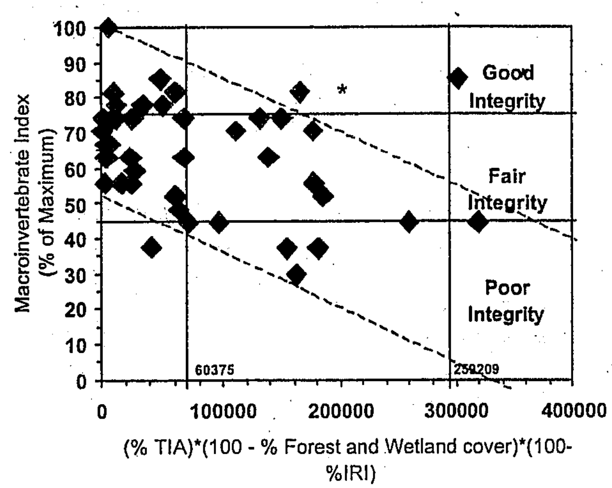

Figure 2. Changes in Macroinvertebrate Index in Austin, Texas with increasing degree of urbanization in a watershed. (Horner, 2001)

Of most interest to the professionals that manage our water resources and local waterways, were the following three observations that emerged from this conference:

1. Regardless of the location on earth, changes in biology and physical nature of receiving waters are virtually inevitable as land uses change.

2. Watershed-wide use of BMPs to control runoff rates and/or volumes <u>can reduce</u> the degree of these impacts. (See Figure 3)

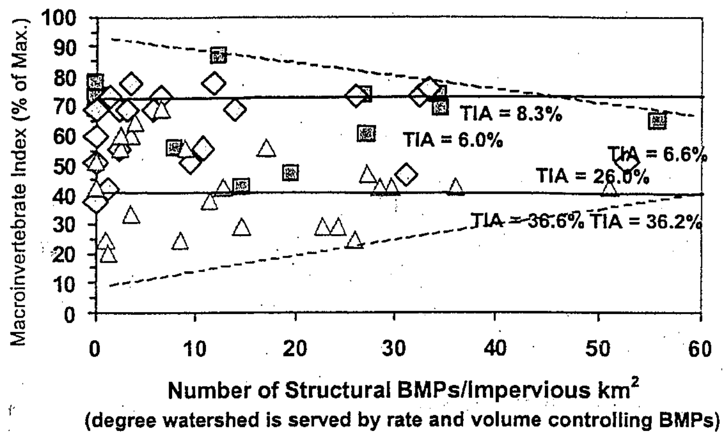

Figure 3. Biologic Index vs. Structural BMP Density. (Horner, 2001)

3. Stabilizing of receiving streams as lands begin to urbanize is essential in limiting stream bank and bed erosion and loss of aquatic habitat. (See Figure 4)

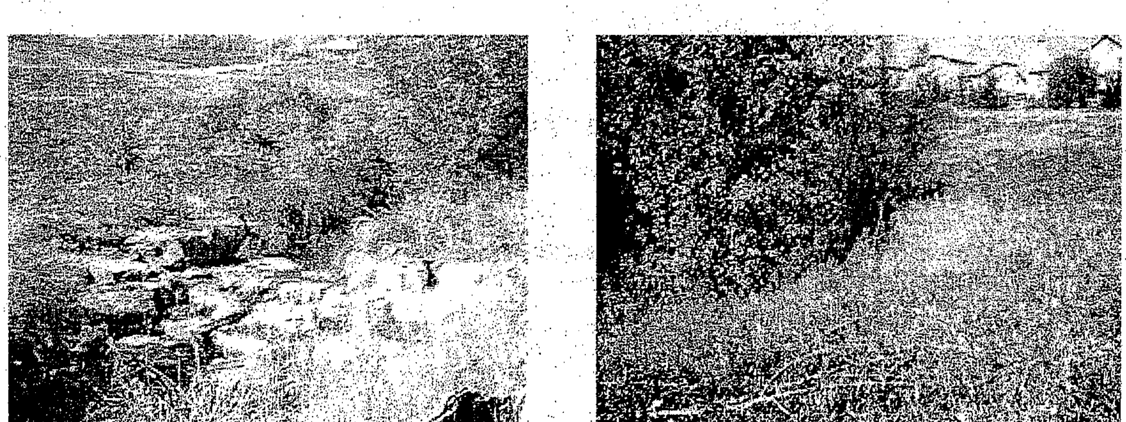
Figure 4. Grade control and soil-riprap stabilized bank - Rock Creek, Superior, Colorado.

WHAT SHOULD "EFFECTIVE" BMPs DO?

Assuming the reason we use BMPs is to help mitigate the impacts of urbanization on our receiving waters, the BMPs we select will need, as a minimum, to do the following:

1. Control rates of runoff from the large numbers of new, smaller runoff events seen in urban areas to very low rates of flow. This reduces, but does not eliminate, the erosive energies experience by the receiving streams and the erosion they cause.

2. Reduce runoff volumes from the new population of small runoff events, thus reducing the pollutant loads delivered by stormwater to receiving waters.

3. Remove from the water column, as much as practicable, Total Suspended Sediment (TSS) particles smaller than 60 µm found in the stormwater column.

4. Integrate structural BMPs into the fabric of the community by providing multi-use opportunities, minimizing nuisances associated with them (e.g., mosquitoes) and making sure they are readily maintainable when visual evidence indicates a need for such maintenance.

The criteria recommended in the Urban Drainage and Flood Control District's (District) *Volume 3 of the Urban Storm Drainage Criteria Manual* (*Manual*) (UDFCD, 1999) have been developed with all of these principles in mind. In addition, looking further down the road, should the Total Maximum Daily Load (TMDL) process mandate that numeric water quality limits be met, the BMPs recommended in the *Manual* will provide the space to modify these BMPs so as to address these mandates and, hopefully, meet them.

The various post-development BMPs recommended in the *Manual* are based on the following fundaments principles:

1. Reduce the accumulation of pollutants on the urban landscape through public education and other practices that encourage
    a. proper disposal of household waste and pollutants
    b. proper use of pesticides, herbicides, fertilizers, etc.
    c. control of pet waste
    d. aggressive erosion and sediment control during construction
2. Reduce surface runoff volumes as much as practicable
3. Fully capture and treat 80% of all stormwater runoff events (annual average) and the "first flush" of larger storms
4. Remove small TSS particles and associated pollutants from the stormwater column before discharging to the receiving waters
5. Appropriate industrial site management to keep rainfall and runoff from coming into contact with products and chemicals that may pollute the runoff
6. Be accessible and visible for easy inspection and maintenance.

Lets examine items 2, 3 and 4 further.

Reducing Stormwater Runoff Volume

The literature is full of terms such as "Smart Growth", "Low Impact Development", "Sustainable Development", etc. All of these terms refer to a family of stormwater management practices that promote the reduction of runoff volume from urban areas. The first step in stormwater quality management in the *Manual* recommends reducing runoff volumes through the use of "Minimized Directly Connected Impervious Areas" (MDCIA). This set of practices in nothing less than what is being recommended by the terms described above. The District's *Manual* has been advocating these practices since before 1994 and has specific design recommendations for the following runoff volume reducing BMPs:

1. Grass Swale (GS)
2. Grass Buffer (GB)
3. Modular Block Porous Pavement (MBP)
4. Porous Landscape Detention (PLD)
5. Porous Pavement Detention (PPD)
6. Sand Filter Basin (SFB)

The first three BMPs require that follow-up facility that has a Water Quality Capture Volume (WQCV) be provided downstream. They reduce runoff volumes, but do not eliminate runoff entirely from the smallest 80% of the runoff events. As a result, facilities that have a WQCV that is reduced in accordance with the recommendations given in the *Manual* need to be installed to capture and treat the residual runoff from these events.

The final three BMPs have their own WQCV and are actually designed to infiltrate water into the ground if the local geology permits. Even where the underlying soils have very low hydraulic conductivities, such as clays, some of the volume captured will not return to the receiving waters as surface runoff. It will return slowly as interflow or be evapotranspired, a similar manner as pre-developed soils and vegetation would do.

All of these can be integrated into the fabric of the development on site, very close to where the rainfall first reaches the ground. "Rain Gardens" (see Figure 5) used in the eastern United States are an example of what we call PLDs. They have the look of slightly depressed grass areas, flower gardens or shrub patches; yet can serve the needs of a commercial and residential sites very well. MBP or PPD can be made to be part of parking lots, private drives, roadside parking strips or shoulders, etc. GS and GB can be substituted for curb-and gutter in most developments, including residential and commercial areas as part of the often-required open space dedications for new developments (see Figure 6).

Figure 5. A "Rain Garden" in Prince George County, MD (same as a PLD in the *Manual*).

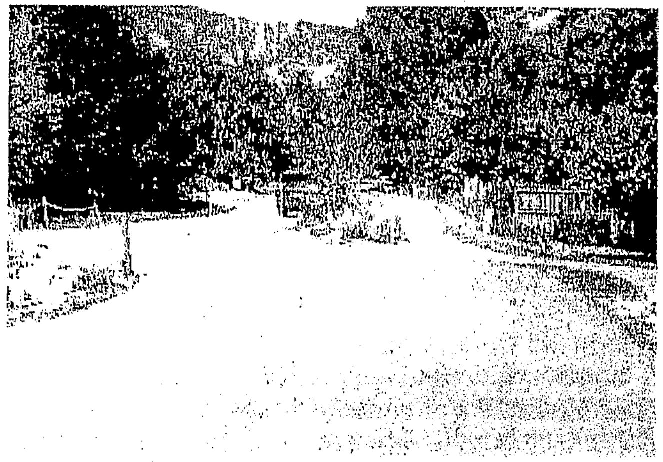

Figure 6. Use of GSs and GBs in a residential neighbourhood, Boulder, CO.

What does that mean in terms of runoff reduction benefits? We have not yet been able to complete data acquisition and analysis yet ourselves, but data collected in Scotland (Macdonald and Jefferies, 2002) show the following for the events when runoff actually occurred at the porous paved parking lot:

- Average Runoff Volume: 75% less than at asphalt paved parking lot.
- Lag time: Between 30 and 600 minutes at the porous paved parking lot, but almost instantaneous at the asphalt-paved lot.
- Average Peak Flow Rate: On the average reduced by 77%

In addition, these data also show that swales do produce a measurable benefit in reducing the runoff rates and volumes, but the result is not as dramatic as with porous pavement.

SUCCESSFUL ("EFFECTIVE") PERFORMANCE OF BMPs IS IN THE DETAILS

Like any technology, it is the details that make the difference between a product that works well and one that does not function well, requires undue amount of maintenance and operation, and is a general pain to own and to get to perform consistently. Let's examine some of the more common issues, problems and misconceptions that we encounter throughout the District and other locations in United States, namely:

1. Clogging potential of sand filters and infiltrating facilities
2. Extended Detention Basins – need for micro-pools and effective trash tacks.

Clogging Potential of Sand Filters and Infiltrations Facilities

There exists a perception that a SFB can impose a large maintenance burden on its owner. This concern is justified and has been addressed by the design parameters recommended in the *Manual*. The design criteria were developed to minimize maintenance and it is estimated that over an extended number of years an SFB should cost about the same to maintain as an EDB or a RP, and less than a Constructed Wetland Basin (CWB). This will not be the case if there is construction erosion occurring upstream that is washed down into the SFB. Regardless of this possibility, the removal of the accumulated sediment and the removal and replacement of the top two to three inches of the sand will return it to full operation. Under normal urban runoff conditions, it is estimated that a SFB will operate well, namely empty out the full WQCV within two days or less, for about five years. When the emptying time becomes longer than that, simple removal and replacement of the top 2- to 3-inch layer of sand will return it to full operation.

Similar, but less frequent maintenance costs are estimated for PPDs and PLDs. In the former, one must use a vacuum to remove the top 2- to 3-inches of sand from the annular spaces in the MBP blocks and replace it with fresh sand. For the latter, plant root activity will keep the top surface area open for a longer period of time than for bare soils, thus extending the period between maintenance.

It is important to recognize that all BMPs will require maintenance and some of them will be more difficult to maintain than others. For example, the micro-pool in an EDB will need to be drained, the bottom dried out and deposits removed. In addition, the forebay will need regular cleaning. The entire basin's bottom will eventually need to have a layer of deposits removed and revegetated, and the structural elements such as inflows, rundowns and outlets fixed as they deteriorate over time. A SFB does not have a forebay or an outlet (see Figure 7). Unless the underdrain pipes are crushed, something that can be avoided with the use of lighter tracked equipment, there are few structural elements to consider. In addition, the sediments on top of the sand media typically dry out quickly and can be removed at almost any time of the year.

Figure 7. Example of a SFB that functioned well for 10-years in Littleton, CO; was removed by RTD in 1999 to make way for park-and-ride lot expansion.

Extended Detention Basin

Two of the most important elements of an EDB that are often misunderstood and improperly implemented are:

1. Micro-pools
2. Trash racks.

<u>*Micro Pool.*</u> Despite that the fact that the latest version of the *Manual* has been in circulation since 1999, quite a few EDB facilities designed and constructed since then have outlets that work well and/or micro-pools. It appears that some designers and their clients continue to leave out micro-pools and do not use the details for the outlet recommended in the *Manual* in their designs. Much research and thought went into developing the recommended design details, especially in selecting the materials and the type of trash rack to be used at the outlet. When the recommended trash rack is used, its operation can be compromised if no micro-pool is installed. These two work in tandem to provide a well functioning EDB that will dry out the basin's bottom within a relatively short period of time, thus preventing ideal breeding conditions for mosquitoes. Yes, a micro-pool significantly reduces, and keeps in check, the mosquito populations associated with many BMPs. It does that by:

1. Providing an active surcharge storage volume for nuisance dry-weather flows and most frequently occurring runoff from very small storms
2. Having a relatively deep permanent pool with steep sideslopes that is poor habitat for mosquito breeding
3. Providing habitat for predator species (e.g., dragonfly) that eat mosquito larvae
4. Limiting the area where shallow waters will be present for extended periods of time
5. Providing a reservoir where mosquito larvae control agents (i.e., DIMP) can be added if the need arises.

Mosquitoes breed best in stagnant shallow waters. Without a micro-pool and the currently recommended details for EDB & RP outlets, the lowermost small orifices in the outlet plate, or riser if one is used, clog with sediment, along with the lower portions of the trash rack. When that happens, stormwater does not empty out fully, leaving behind large areas of the basin's bottom covered with a stagnant shallow layer of water and soggy soils that stay wet for weeks, a perfect mosquito breeding habitat. Typically, mosquito larvae need 72-hours to hatch, mature and emerge as the blood-sucking insects that we hate so much. When the EDB is constructed using the recommended details, the main body of the basin is emptied out in 40-hours or less, depending on the size of the storm, leaving only the 2.5-feet deep micro-pool area wet (see Figures 8 and 9).

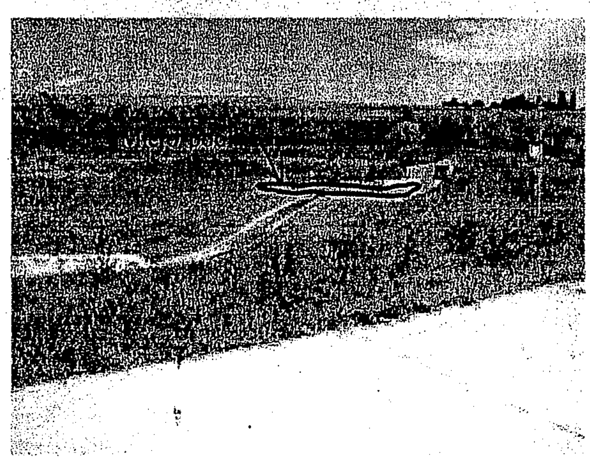

Figure 8. A properly designed EDB in Jefferson County, CO. Note the small wet area (micro-pool) at the outlet during in 2002.

Trash Rack. Many EDBs and PRs today have an ineffective trash rack at the outlet or none at all. Water quality outlets, by their nature, require very small openings. As a result, they are prone to clogging by floating and neutrally buoyant trash such as paper, plastic bags, sticks, leaves, grass clippings, etc. A properly sized and designed trash rack is the best defense against such clogging. In addition, trash racks at all detention basin outlets are an essential element for public safety to keep persons from being lodged against the outlet by hydraulic pressure as the basins fill. The details recommended in the *Manual* are the result of many observations throughout the United States and suggestions by the practitioners in the Denver area. They come as close as possible to being optimum in configuration and sizing using the knowledge we possess today. The only configuration for the removal of suspended solids that would perform better is a floating outlet that rises and falls with the water level, but the technology for its continued long-term performance has not yet been perfected.

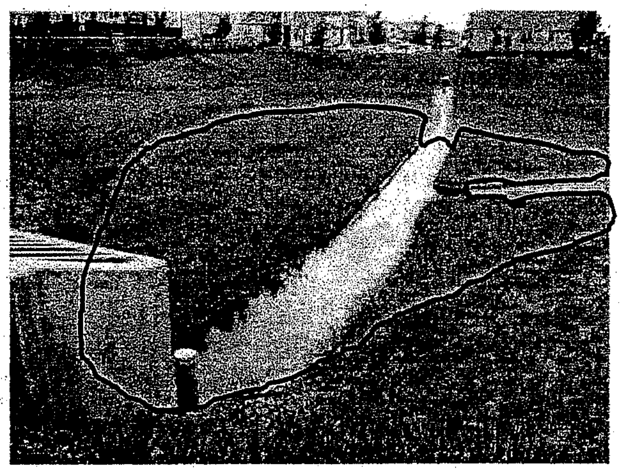

Figure 9. An EDB without a micro-pool. Note the large saturated wet area during a dry weather period in 2002, a drought year, that provides good habitat for mosquito breeding.

OTHER IMPORTANT BMP-RELATED ISSUES

Lets examine three other issues that are the topic of most questions we receive from practitioners, namely:

1. Use of BMPs with a WQCV vs. flow-through devices
2. Above-ground vs. underground BMPs
3. Basis for comparing BMP "effectiveness"

Use of BMPs with Water Quality Capture Volume vs. flow-through devices

Starting on page 3 of this paper we listed several points in answering the question of "What should effective BMPs do?" One of these is the ability of a BMP to control the rates of runoff from large numbers of smaller runoff events to very low rates of flow. This is needed to reduce the erosive energies experience by the receiving streams, thus also reducing the impacts of urbanization on aquatic habitat. Another was to remove the smallest TSS particles from stormwater (i.e., less than 60 μm) in order to reduce the deleterious effects of these particles on macroinvertebrates and fish in the receiving streams in Colorado.

The capture of the WQCV recommended in the *Manual* and its release over 12 to 40 hours, depending on the type of BMP used, goes a long way towards meeting those goals. It provides for complete capture and treatment, on an average annual basis, of 80% of all stormwater runoff events and of the "first flush" of the remaining 20%. In fact, doubling the capture volume increases the complete capture ratio by only 5%. When it comes to the removal of the small TSS particles, and associated pollutants, the release of the full WQCV over a 40-hour period by an EDB or 12-hour period by a RP provides the residence time needed to settle out these particles from the water column. The difference in the residence time is possible by the fact that the permanent pool of a RP provides a much more efficient treatment facility for the removal of TSS particles than an EDB without one. Another feature of the slow release of the WQCV is that it will retard even the smallest runoff events, thus not allowing them to short-circuit through the outlet without some treatment. For the smallest of these runoff events, the micro-pool provides a similar function to the permanent pool of the RP, extending TSS removal efficiency to runoff events not receiving much treatment without it.

Devices that do not have a WQCV, namely the flow-through devices, do not mitigate flow rates. As a result, the full energy of the large numbers of new runoff events in urban areas reach the receiving stream without any attenuation. In addition, the very short residence time, on the order of seconds, does not permit the removal of the smaller TSS particle. Some of these devices, however, can be effective in removing larger sediment, bed load and trash, namely, the "gross pollutants." For this reason the District has clarified its policy on their use in retrofit situations for small tributary areas (i.e.,, "not significant redevelopment"). When faced with the prospect of having one of these devices retrofitted into the existing urban landscape or not having any treatment, their use needs to be looked at on a case-by-case basis.

Aboveground vs. underground BMPs

Under most normal circumstances, there is no justifiable reason to use underground facilities in areas of new urban development or significant redevelopment. With the expectation of PLD and PPD which require about 4% of the total impervious area of the development, all of the above-ground BMPs recommended in the *Manual* require less than 2% of the total impervious area of the development to provide a WQCV. The surface area required by BMPs with a WQCV can further be reduced if PP, PPD, PLD, GS and/or GB are used. Since virtually all zoning ordinances require at least 5% of the total land area to be open and landscaped, BMPs can easily be integrated into the site landscape plan. All it takes is creativity and the services of a landscape architect to integrate the two functions, namely site landscaping and stormwater management.

Aboveground BMPs are visible to the owners and the public, while underground facilities are out-of-sight and, as a result, often become out-of-mind. As we discussed earlier, effective BMPs need to be accessible and visible for easy inspection and maintenance in order to keep operating as designed. An inspection program can be designed to visit each BMP site on a regular basis, open the access manholes, inspect its condition and to measure the floating debris and deposit layers on the bottom. It is also possible to schedule a regular maintenance cycle to clean them out. However, both approaches need a clear commitment on behalf of the original and subsequent owners, good record keeping and some form of institutional reporting to "assure" they are being maintained.

The author had an opportunity to inventory underground grease and oil traps at an industrial district. What became obvious is that despite the best of intentions and past agreements to maintain them, virtually all of the traps were not maintained for years and some had their manhole covers overlaid with asphalt paving sometime in the past. It took a jackhammer to break out the hardened grease in one of the traps that had its manholes under a 2-inch layer of asphalt and was not serviced for more than five years. This was a clear case of out-of-sight and out-of-mind.

A simple visual inspection, often not much more than a drive-by of aboveground facilities, will reveal significant problems. In addition, when the aboveground facility is not operating properly, becomes silted in, there is structural damage to the outlets, etc., the owner or the responsible municipality will see it and be compelled to take rehabilitative maintenance action to keep the site "clean" nuisance free and operating.

Basis for Comparing BMP "Effectiveness."

Two significant new thoughts have emerged in recent years about "effectiveness" of structural BMPs. First is the notion that a truly effective BMP will have an ability to mitigate many of the impacts of urbanization on receiving waters, including the modifications in hydrology that accompany land-use changes. The second is the questioning of the hypothesis that "percent removal" of pollutants is an appropriate metric in comparing the performance of different BMPs. The first one was already addressed earlier in this paper.

The Urban Water Resources Research Council (UWRRC) of the American Society of Civil Engineers (ASCE), under a grant from EPA, developed a BMP performance database based on scientific and engineering principles. At this time the database contains data from over 200 BMP field evaluation sites in United States, Canada and Europe.

After studying this data, it was concluded that there is no scientifically grounded basis for using "percent removal" of pollutants as the basis for comparing the performance of various structural BMPs (Clary, *et. al.*, 2001). Such comparisons may be valid if BMP performance were compared in a specific city to service similar land-use conditions. As the geography and land uses change, the runoff quality and quantity change as well. The result being that the "percent removed" numbers change as well.

What the investigative team found was that comparing the effluent quality vs. influent quality, and the volume of stormwater treated in relation to the average runoff volume in the area, provided more stable and scientifically sound basis for comparing performance or "effectiveness" of BMPs in their ability to affect the water quality reaching the receiving waters of the nation (for more information visit www.bmpdatabase.org web site). This is a very important finding if the performance data are to be used in TMDL studies and to make eventual commitments to the regulatory agencies. After all, the total maximum daily, seasonal or annual load will depend entirely on the effluent quality that leaves and bypassed the BMP and not on the percent removal of a constituent. The latter can show high percent removals when the concentrations in runoff are high and low removals when they are low, even when the runoff itself is very clean.

Figure 10 shows the results of a statistical analysis of several BMP types in terms of "percent removals" and effluent concentrations for TSS. The percent removal box and whisker plots show very wide bands of confidence that imply that almost all of the BMPs have similar performance when the 95% confidence test is applied. That is not the case when the effluent concentrations are compared. When interpreting this graph it is important to understand that most of these BMP groups (i.e., bioswales, hydrodynamic devices, retention basins and wetlands) have very few data sets and their results are prone to statistical anomalies and need to be viewed with some scepticism. Nevertheless, the trends so far show that, with the exception of hydrodynamic devices, all BMP groups reported here produce less than 30 mg/l TSS in the effluent, a concentration comparable to secondary treatment of wastewater.

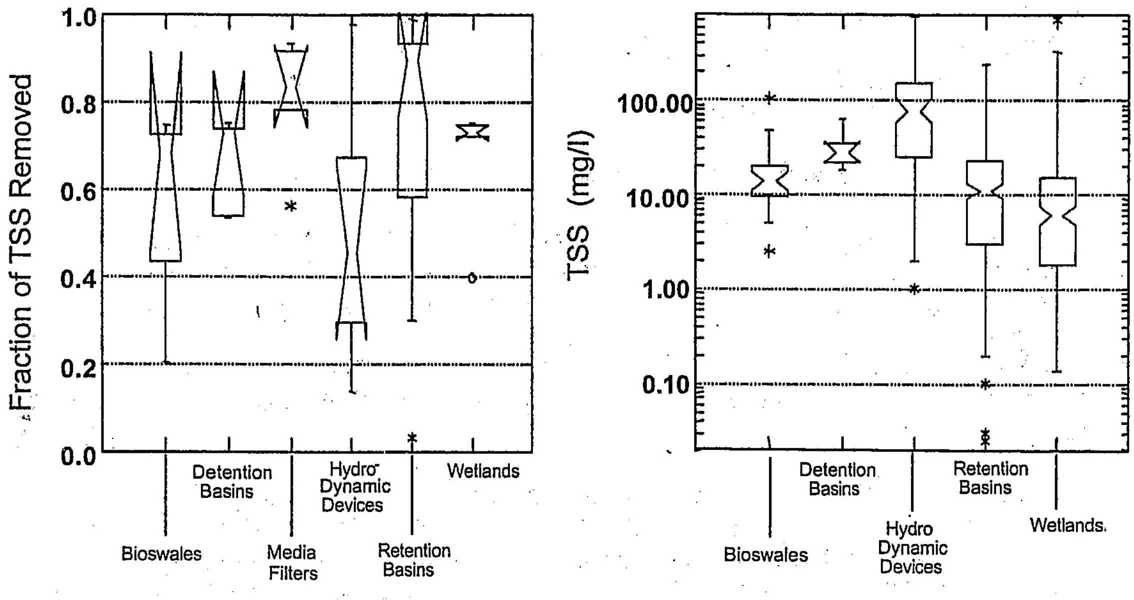

Figure 10. Box and Whisker Plot of influent and effluent *Event Mean Concentration* for TSS data for several BMPs in the National BMP Database (Ref.: www.bmpdatabase.org)

SUMMARY OF ISSUES DISCUSSED

The key issues discussed and points made in this paper can be summarized as follows:

- Urbanization and other land use changes can have a profound impact on the receiving waterways of Colorado's high plains that are driven by changes in hydrology, water quality and human activities.
- Watershed-wide use of BMPs that significantly reduce runoff rates and control runoff volumes from the majority of most frequently occurring smaller storms (i.e., 80% of runoff events) can reduce these impact on receiving waters and their biota.
- Effective BMPs, in addition to controlling runoff volumes and rates of runoff, need to remove TSS particles less than 60 μm in size from stormwater runoff to the maximum extent practicable, should be integrated into the urban landscape to the maximum extent possible and be readily accessible and visible for maintenance.

- The District's *Manual* provides good guidance for the selection, sizing and design of a number of BMPs, including those that can reduce runoff volumes.
- BMP effectiveness should be based on comparing their ability to mitigate the impacts of modified hydrology as well as the quality of the effluent they can produce. Use of "percent removals" for comparing BMP performance is not recommended by the National BMP Database project.
- Filter-type BMPs can clog quickly if not properly sized and maintained. The criteria in the *Manual* for sand filters take these issues into account.
- It is critical to provide a micro-pool and the trash rack details recommended in the *Manual* to have an extended detention basin that has fewest operational and mosquito problems.
- Aboveground facilities are recommended for all new development and significant redevelopment, reserving underground facilities for retrofit in dense urban areas.
- In order to mitigate hydrologic impacts of land use changes and to reduce small TSS particle concentrations in stormwater, BMPs with a water quality capture volume are needed.

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Best Management Practices for Mosquito Control

Washington State Department of Ecology
Water Quality Program

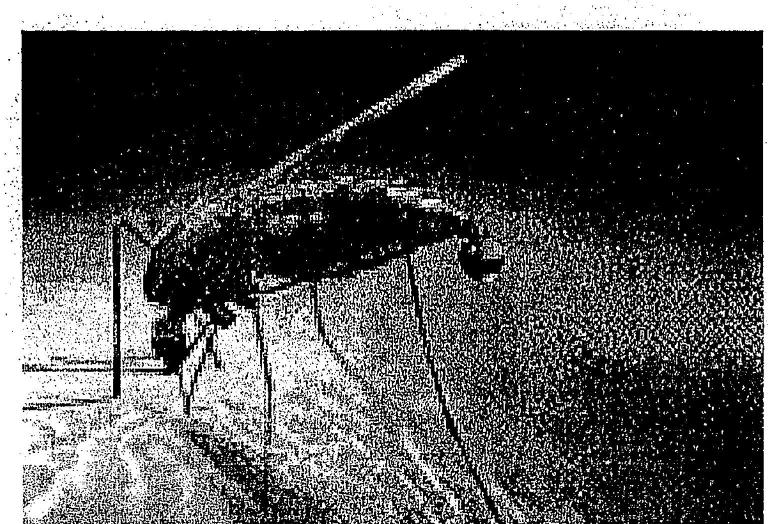

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Table of Contents

A mosquito control handbook will be provided for informational purposes only. The Handbook has no legal relevance to the NPDES General Permit or the BMPs.

Mosquito Handbook Table of Contents

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Introduction

On April 10, 2002, the Washington State Department of Ecology (Ecology) issued NPDES General Permit No. WAG-992000, covering mosquito control activities that discharge insecticides directly into surface waters of the state. Under the permit, the use of insecticides for mosquito control in water is allowed when the effects are temporary and confined to a specific location, though locations where insecticides are used may be widespread throughout the state. Applications of insecticides are subject to compliance with Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) labels, monitoring/reporting requirements, and approved best management practices (BMPs) that include integrated pest management options. When adopted by a mosquito control entity, these BMPs for Mosquito Control satisfy that NPDES Permit No. 992000, Condition S4 requirement.

These Best Management Practices for Mosquito Control were developed through a collaborative effort of representatives from Washington and Oregon based mosquito control districts, Washington State counties, Washington State University, mosquito control insecticide industry and the state departments of Health, Agriculture, Fish and Wildlife, Transportation and Ecology. Our appreciation goes out to the many mosquito control experts and others who took the time to review the draft and offer their expertise and suggestions.

Mosquito control entities in Washington State that wish to develop their own BMPS may do so, but they must be approved by Ecology. An approvable integrated pest management (IPM) program for mosquitoes must involve natural resource scientists when planning control measures that could harm delicate ecosystems and include all the features of IPM as defined in Washington State law RCW 17.15.010 (as adapted to mosquito management):

1) Minimize mosquito breeding and feeding sites.
2) Monitor mosquito populations and disease.
3) Establish the targeted densities of mosquito populations based on community factors of health, public safety, economic and aesthetic thresholds.
4) Treat mosquitoes to reduce populations below the targeted threshold using strategies that may include biological, cultural, mechanical, and chemical control methods and that consider human health, ecological impact, feasibility, and cost effectiveness.
5) Evaluate the effects and efficacy of pest treatments.

Best Management Practices for Mosquito Control

I. Minimize Mosquito Breeding and Feeding Sites

Risk Assessment: Probability of outbreak in humans: Remote
Action threshold: The presence or even the suspected presence of mosquitoes (any species) in an area identified for control efforts triggers minimization efforts in the early spring and summer. The mean development time from egg hatch to pupation takes 5 to 10 days at temperatures near 25° C (77° F) (Pratt and Moore, 1993). However, eggs of certain species can hatch in water as cold as 45° F (Lilja, 2002, p. 24). Minimization actions are most effective in the early spring and continued through fall on an as-needed basis.
Rationale: Minimizing man-made breeding sites in the targeted area of control and personal protection, especially for those with compromised immune systems, are the best defenses against getting bitten by mosquitoes, giving the best protection for the least cost.
Minimum BMP Response:

1. Provide information to those in the area of control on eliminating artificially-created mosquito breeding sites, use of biological controls, use of repellents and on protecting animals of concern. Local and state environmental health departments have a variety of informational brochures. See http://www.doh.wa.gov/ehp/ts/Zoo/WNV/WNV.html for links.
2. Take appropriate minimization actions.
3. If possible, obtain resources to enable effective responses.

Minimization Actions

Eliminate Artificial Breeding Sites around Homes and Offices

- Empty or turn over anything that holds standing water—old tires, buckets, wheelbarrows, plastic covers, and toys. Do not let water stagnate for more than seven days.
- Change water in birdbaths, fountains, wading pools, and animal troughs weekly.
- When practical, drill holes in the bottoms of containers that are left outdoors.
- Clean and chlorinate swimming pools that are not in use and be aware that mosquitoes can breed in the water that collects on swimming pool covers.
- Consider aerating ornamental pools and use landscaping to eliminate standing water; mosquitoes can potentially breed in any stagnant puddle that lasts more than four days.
- Recycle unused containers—bottles, cans, and buckets that may collect water.
- Make sure roof gutters drain properly, and clean clogged gutters in the spring and fall.
- Fix leaky outdoor faucets and sprinklers.
- Keep all ornamental shrubs and bushes trimmed and pruned to open them up to light and air flow. This will not only give mosquitoes fewer places to hide, but will promote growth and vigor in the plants.

Use Appropriate Bio-controls

- Stock water gardens *that have no surface inlet or outlet* with mosquito-eating fish (*i.e.,* goldfish, mud minnow, stickleback, and perch). Tadpoles, dragonfly larvae, diving beetles, back swimmers, and front swimmers also prey on mosquito larvae. For more information, see http://www.wa.gov/wdfw/factshts/westnilevirus.htm
- Native vegetation and nest boxes can help attract mosquito-eating birds and bats. However, property owners should avoid introducing non-native fish or wildlife in an attempt to control mosquitoes. While it is permissible to release some fish commonly available in pet stores into small, contained backyard pools and ponds, non-native fish should not be released into open or partially contained waters that may occasionally flood into natural water bodies. Some non-native species, including so-called mosquito fish, *Gambusia affinis*, can be major pests when introduced outside their natural range. *Gambusia* are aggressive and have been known to feed on eggs, larvae and juvenile native fish and amphibians. Because of these negative impacts on native species, Gambusia is a regulated species in Washington State, and may not be introduced without a fish stocking permit issued by WDFW.
- Under WDFW policy, transfer/stocking permits may only be issued to organized mosquito control districts, the U.S. Army Corps of Engineers, and local or state health departments; permits may not be issued to private individuals. To protect the Olympic mudminnow, a state sensitive species, *Gambusia* stocking is prohibited in Clallam, Jefferson, Kitsap, Grays Harbor, Mason and Thurston and portions of Lewis County that drain into the Chehalis river. For information on fish stocking permits contact the WDFW regional office in your area.

Eliminate Mosquito Feeding Sites

- Make sure window and door screens are "bug tight." Repair or replace if needed.
- Stay indoors at dawn and dusk when mosquitoes are the most active.
- Wear a long sleeve shirt, long pants and a hat when going into mosquito-infested areas such as wetlands or woods.
- Use mosquito repellant when necessary, and carefully follow directions on the label. For extensive repellent information from the Centers for Disease Control see Appendix B: Insect Repellent Use and Safety
- Areas frequented by the public, such as parks, zoos, outdoor concert areas, and wildlife reserves should consider making repellents available.

Protect Animals of Concern

- To protect your horses and other equines, talk to your veterinarian about the West Nile virus vaccine. The vaccine requires two doses three to six weeks apart, and immunity may not be achieved until up to six weeks after the second dose. An annual booster should be given a few weeks to a month prior to the start of the mosquito season in your area.
- Veterinarians should be consulted if you have concerns about your household pets or other animals. Repellents may be used in some instances.
- Thoroughly clean livestock watering troughs weekly.
- For more information see: http://www.aphis.usda.gov/lpa/issues/wnv/prv.html and/or http://www.cdc.gov/ncidod/dvbid/westnile/birds&mammals.htm

New Construction and Storm Drains

As new facilities are being designed, consideration should be given to reducing mosquito habitat as much as possible.

- When considering a drainage or water treatment facility for mosquito control, the first consideration should be whether the problem could be reduced by physical modification or repair without compromising the facility's function. Physical modifications should be designed by an engineer and reviewed by the local government to insure they meet applicable design requirements. A possible design modification may include scarifying the pond bottom where it is no longer infiltrating as originally designed, providing slope to the bottom of the drainage facility or enhancing infiltration by some other method. Eliminating low spots that collect small amounts of standing water and altering excessive overgrown vegetation may also be options. Alterations of slopes or repairs to a facility should not involve a reduction in the water retention or carrying capacity of the facility. As an example, soil should not be added to fill low spots. Instead, low spots should be graded flat such that the carrying capacity is not reduced.

Sprinklers and Irrigation Systems

Over-watering and poor irrigation practices are common producers of mosquitoes around the home, in parks, in irrigated fields, and on golf courses. Report standing water to appropriate maintenance personnel.

- Irrigated lands are among the highest producers of mosquito breeding sites in Washington State. High numbers of mosquitoes can develop in standing water as a result of flood irrigation. The actions below can help eliminate mosquito breeding sites by using physical controls (Colorado, 2002; Pratt and Moore 1993).

  1) Minimize standing water in fields so that it does not lie fallow for more than four days by improving drainage channels and grading.
  2) Tail waters should not be allowed to accumulate for more than four days at the end of the field.
  3) Keep excessive overgrown vegetation out of ditches to promote more rapid drainage, but retain ground cover to prevent soil loss.
  4) Have ditches repaired to reduce seepage to the extent practicable (elevated water tables can produce unintended standing water in fields). Modification or repairs to a ditch should not reduce the carrying capacity.
  5) Minimize flood and rill irrigation practices to the extent practicable.
  6) Avoid over-watering.

Foster Healthy Wetlands

Do NOT drain or fill wetlands. Wetlands perform at least three classes of functions: hydrologic functions (*i.e.*, flood peak reduction, shoreline stabilization, or groundwater exchange), water quality improvement (sediment accretion, filtration or nutrient uptake), and food-chain support (structural and species diversity components of habitat for plants and animals, including threatened endangered and sensitive species). Many wetlands recharge ground water critical for local drinking water supplies and prevent streams from drying up during the summer. Given the critical functions wetlands perform, Ecology does not condone draining wetlands as a method for mosquito control. Since most predation on mosquitoes occurs when they are larvae, the best mosquito control is often to target the larvae, either by fostering predators native to the area of control (amphibian larvae, aquatic salamanders, small fish) or by applying selective larvicides such as Bti. Wetland literature suggests that dragonflies are a significant predator on adult mosquitoes and it has been found that mosquito "outbreaks" most often occur in destabilized wetland and stream ecosystems that have been changed or tampered with so that the predators of the larvae are excluded. Draining wetlands and removing greenbelts will not eliminate mosquitoes. In fact, such actions could actually increase the mosquito population if their natural predators are destroyed because many mosquito species need only a small puddle or depression to breed. (Tom Hruby, Ecology Wetland Specialist, personal communication 2/26/03).

II. Monitor Mosquito Populations and Disease

Risk Assessment: Probability of outbreak in humans: Remote to low
Action threshold: The presence of vector or nuisance mosquitoes suspected or confirmed in the area.
Rationale: Base-line data on mosquito populations and mosquito-borne disease will help target educational efforts and are essential to control efforts, should they become necessary.
Minimum BMP Response: Obtain and track avian mortality, human encephalitis/meningitis, and equine surveillance in the area of control. Further quantify epizootic activity by inventorying mosquito habitats, and trapping and testing for vector mosquitoes. Consider targeted insecticide control if surveillance indicates high potential for human risk to increase.

Monitoring Strategies for landowners of private property and contracted licensed applicators

- Contact your local health department for information about birds, horses, and humans found to test positive for West Nile virus or other mosquito-borne diseases in your area of control.
- Accurately map and identify rearing areas for mosquitoes, by species if possible. These are those sites for mosquito rearing that cannot be eliminated by following preventative measures such as container emptying, proper pond maintenance, and eliminating excess standing water by using appropriate irrigation BMPs. This is important because appropriate treatment measures are contingent on the habitat (species) encountered. The following Northwest mosquito habitats and control issues have been identified in the Mosquito-borne Response Plan developed by the Department of Health (Lilja, 2002). Vectors in specific regions have not all been identified. Contact your local health department for the latest mosquito vector information.

Floodwater: *Aedes vexans* and *Ochlerotatus sticticus* develop in large numbers along the borders of the Columbia and other rivers and create important mosquito problems in this region. The larvae hatch in the spring or early summer when the streams overflow areas such as willow and cottonwood swales where the eggs have been laid. The eggs of these species are dormant when temperatures remain below 45-50° F. Partial dormancy of the eggs may continue until sometime in June so that only some of the eggs are hatched by floods occurring in April or May. In some seasons, the larger rivers may rise, recede, and rise again to cover the same egg beds and produce an additional hatch. In other seasons, two or three successive rises may occur, each of which is higher than the last. Females that emerge in the first hatch may lay eggs that will hatch in the second or third rises of the river. Most of the eggs are laid between the 10 and 20 foot levels, and some of the eggs that are not flooded during a series of low flood crest years remain viable for as long as four years.

Large *Aedes vexans* and *Ochlerotatus sticticus* breeding areas have been managed efficiently by controlling water levels above dams such as the Bonneville Dam. Dikes have prevented flooding in other areas. Clearing of brush has been of value in some locations. However, control of the major section of these types of breeding areas must often be accomplished with insecticide applications.

Irrigation Water: Breeding places for several mosquito species are provided by irrigation water. *Aedes dorsalis, A. vexans, Ochlerotatus melanimon*, and *Ochlerotatus nigromaculis* are among the most important species that may develop when water is applied and stands for a week or 10 days. Other species such as *Culex tarsalis, Culiseta inornata,* and *Anopheles freeborni* may be produced if water remains for a week or ten days. Tremendous numbers of mosquitoes breed in many areas where uncontrolled irrigation is practiced. Applications of insecticides are effective but are not substitutes for proper grading. Elimination of standing water is effective in preventing development of mosquitoes. Application of insecticides may be necessary for breeding places that cannot be drained. See Sprinklers and Irrigation Systems in Section I above.

Tidal Waters: *Aedes dorsalis* is the only species that can breed in large numbers in both fresh and salt water in the Northwest. The larvae develop in some coastal areas where potholes are filled by the higher tides or where water levels fluctuate in permanent or semi-permanent pools. Leveling, drainage, or similar practices are effective in preventing breeding, but such areas must be properly maintained. Insecticide control may be necessary where these methods are inadequate or ineffective. *Ochlerotatus togoi* has also been found in coastal areas including San Juan, Island, Skagit, Kitsap, and Mason counties. Larvae of this species have been found in pools of pure seawater along rocky shorelines.

Snow Water: In many high mountain meadows and also at lower levels, mosquitoes breed in pools caused by snow melt. Development may require several weeks at higher elevations. *Aedes communis,A. cinereus, Ochlerotatus hexodontus, O. fitchii*, and O. *increpitus* are the most common species found in these locations. Usually there is only one generation per year, but the large numbers that may be produced are a severe annoyance to those who are working or seeking recreation in these areas. Elimination of breeding areas by drainage or maintenance of constant water levels is practical in some situations. Insecticide applications might have to be made by hand or by plane because of inaccessibility to heavy ground equipment.

Permanent Waters, Ponds and Artificial Containers: The mosquitoes that lay their eggs on the water are usually found where water is present continuously during the season or at least for several days. Such locations include natural permanent ponds, including still waters along the borders of lakes and rivers sheltered from wave action and currents with some degree of vegetation, log ponds, tree holes, semi-permanent ponds and wetlands of various types, and artificial containers. *Culex tarsalis, C. pipiens, C. peus, Anopheles freeborni, A. punctipennis, Culiseta incidens,* and *C. inornata* are commonly found in such places. *C. tarsalis* and *C. pipiens* develop in large numbers in log ponds. *C. pipiens* also develops in large numbers in sewer drains, catch basins, and water left in artificial containers. *Coquillettidia perturbans* are found in permanent water in wetlands, swamps, and marshes that have emergent or floating vegetation. Insecticides are often used effectively to control most of these species, except those breeding in artificial containers that can be emptied. Larvae of *C. perturbans* are difficult to control because they are attached to the roots of plants. Insecticide granules are sometimes applied, but eliminating host plants may be the most useful procedure to control this species. Consult with your local WDFW office before removing plants on WDFW-managed lands or in ecologically sensitive areas.

Stormwater: In response to the anticipated arrival of West Nile virus in King County, King County Water and Land Resources developed recommendations for dealing with the mosquito control at County drainage facilities. The study (Whitworth, 2002) identified the four basic habitats preferred by mosquitoes, the types of mosquitoes associated with the habitat type, and the WNV vector mosquito species that prefers each habitat type. Table 1 summarizes this information.

Table 1. Disease Vector Mosquito Species Associated With Drainage Control Facilities

Habitat Type	Facility type	*Vector Species*
Permanent Water	Year round wet ponds Larger Regional Ponds Wet Bioswales	*Anopheles punctipennis*
Marshes & Wetlands	Wet Bioswales Some Regional Facilities	*Aedes cinereus* *Coquilletidia preturbans*
Temporary or Flood Water	Temporary Wet Ponds Dry Bioswales Retention/Detention Ponds Open Ditches	*Aedes vexans* *Culiseta inornata*
Artificial Containers / Tree Holes	Catch Basins Underground Tanks/Vaults Discarded containers & Tires	*Ochlerotatus japonicus* *Culex pipiens* *Culex tarsalis* *Culiseta inornata*

Table 2 summarizes biological information of vector mosquitoes found in Washington State.

Table 2. Potential Disease-Carrying Mosquitoes in Washington State

Mosquito Species	Day or Night Biter	Range	Generations per Year	Preferred Habitat	Breeding Comments
Aedes cinereus	Aggressive during day	Does not travel far from habitat	One-eggs hatch at different times	A woodland species: semi-permanent bogs & swamps, wetlands, wet bioswales & floodwaters	Hatches in the early spring. Larvae found among dense aquatic vegetation.
Aedes vexans	Day & Night	20+ miles	Many	Any temporary water body like ditches, puddles, containers, pools & floodwater.	Eggs may lie domant 3+ yrs, hatches in ditches, still water.
Anopheles punctipennis	Night	Stays near habitat.	One	Springs and creeks connected to stormwater ponds, bioswales and wetlands.	Prefers algae-laden, cool pools on edges of slow flowing rivers and streams. Has entirely dark palpi.
Coquilletidia preturbans	Night - often comes to lights	Strong fliers, enters homes and lit areas.	One, but hatchlings do not complete development until the following spring.	Permanent marshes, wetlands, temporary wet ponds, dry bioswales & open ditches.	Needs thick growth of aquatic vegetation. Remains below the water surface attached to roots and stems. Hatchlings emerge in spring.
Culex pipiens	Night	Usually migrates only short distances.	Many	Found around water with high organic content, as in catch basins & sewer effuent ponds, tree holes, artificial containers & manholes.	Proliferate in in artificial containers. Lays eggs in clusters of 50 to 400. Larval and pupal stages take 8 -10 days.
Culex tarsalis	Night	Enters buildings after dark.	Many	Any fresh water, artificial containers, & agricultural and irrigated areas	Larvae develop from spring to fall in waters w/ high organic material. Eggs laid in rafts of 100 - 150 & hatch w/in 48 hrs.
Culiseta inornata	Dawn & Dusk	Stays near habitat.	Many	Cold water - associated with glacial runoff and sunlit waters, does not like hot weather. Found at all elevations.	Breeds throughout spring and summer in cold water, females may appear during warm winter breaks. Usually feeds on livestock, not people.
Ochlerotatus japonicus	Day & Night	Not known	Many	Artificial containers, catch basins, undergound tanks and vaults & tree holes	Larvae are found in artifical containers.

*New information has come in on *Ochlerotatus canadensis* that adults live for several months in woodland pools by melting snow or rain. They feed on a large range of mammals, birds, and reptiles.

Additional Monitoring for Public and Specialty Targeted Areas of Control

- Conduct ongoing mosquito larvae surveillance, including studying habitats by air, aerial photographs and topographic maps, and evaluating larval populations.
- Monitor and track data from mosquito traps, biting counts, complaints, and reports from the public.
- Keep seasonal records concurrent with weather data to predict mosquito larval occurrence and adult flights.
- Consider using sentinel chicken flocks for surveillance (See Centers for Disease Control and Prevention, Epidemic/Epizootic West Nile Virus in the United States: Guidelines for Surveillance, Prevention and Control, page 10, http://www.cdc.gov/ncidod/dvbid/westnile/resources/wnv-guidelines-aug-2003.pdf)
- Accurately map and identify rearing areas for mosquitoes. These would be those sites that cannot be eliminated by preventative measures such as emptying containers, proper pond maintenance, and eliminating excess standing water by using appropriate irrigation BMPs. These habitats can be identified by aerial photo assessments, topographic maps, and satellite imagery where available. This is important because appropriate treatment measures are contingent on the particular species that live in specific habitats.
- Agricultural site maps should include hay, pasture, circle irrigation, orchards, and rill irrigated field crops. An important land use that has caused problems to mosquito control districts in the past is flood irrigated pastures where the water stays on more than five to seven days.

Note: Detailed information on mosquito surveillance is available from Washington State Department of Health, available online at www.doh.wa.gov/ehp/ts/Zoo/WNV/WAArboviralRespPlan.pdf and http://www.doh.wa.gov/ehp/ts/Zoo/WNV/WestNileVirusSurv.pdf

III. Establish Targeted Densities for Mosquito Populations

Risk Assessment: Probability of outbreak in humans: Remote to low
Action threshold: The presence (positive identification) of any vector mosquitoes in the area triggers activities to reduce their presence. Since people with compromised immune systems are likely to be the most vulnerable to mosquito-borne diseases, the areas of their exposure should be a priority.
Rationale: Once vector mosquitoes have been positively identified in an area, control treatments are warranted, especially around high risk populations. If the cost of treatments is prohibitive, every effort should be made to educate those at risk of exposure about minimizing habitat and personal protection measures.
BMP Minimum Response: Analyze disease activity data, i.e., avian mortality, human encephalitis/meningitis, equine encephalitis and mosquito surveillance information in the area of control. Set targeted densities with special consideration being given for segments of the population most vulnerable to mosquito-borne diseases such as the elderly. If needed, enhance human surveillance and activities to further quantify epizootic activity, such as mosquito trapping and testing.

Establish Targeted Mosquito Densities for all Areas of Control

To establish the targeted density of mosquito populations review information on incidences of avian mortality, human encephalitis/meningitis, and equine encephalitis for your area (the Department of Health or your local health department can provide this information). Conduct entomologic survey (inventory habitats and map mosquito populations). Using surveillance information and input from the people in the control area, establish the targeted density of mosquito populations based on the level of control desired by those in the area of control, public safety, and funding.

- Demarcate no-spray zones on maps. This may include areas such as schools, hospitals, fish farms, wildlife refuges, the homes of individuals who are on chemically sensitive registers, and crops grown under a certified organic program. Other crop sites that do not have a tolerance for the mosquito control products used should also be listed. If the control entity is not a mosquito control district organized under RCW 17.28, then individual residences where the occupants do not want to be treated should be identified as no-spray zones.
- Individual homeowners and businesses determine targeted mosquito populations densities based on the level of control desired and factors of risk and cost. Mosquito control agents must consult with their sponsors to determine targeted mosquito densities.
- Once the targeted density has been established, continue larvae surveys to find density response to habitat minimization efforts and need for larvicide treatments.

IV. Mosquito Control Treatments

Risk Assessment: Probability of outbreak in humans: Low to moderate
Action threshold: The positive identification of vector mosquitoes in the area may trigger activities to reduce their presence. Once minimization strategies have been taken, larvae surveys (*i.e.* dipping) can indicate the effectiveness of those efforts and the need for further action. General Permit Condition S4.2.C states that the targeted density of larvae is 1 per three dips to commence larviciding unless vector mosquitoes are in the area and the probable breeding sites are inaccessible. This level is a minimum; mosquito control agents may want to set the targeted density at a higher level due to cost and risk factors.
Rationale: Once vector mosquitoes have been positively identified in an area, control treatments are warranted. If the cost of treatments is prohibitive, every effort should be made to educate those at risk of exposure about minimizing breeding habitat and personal protection measures.
Minimum BMP Response: Treat mosquitoes to reduce populations below the targeted threshold using strategies that consider biological, cultural, mechanical, and chemical control methods. Evaluate methods for effectiveness of control, human health and ecological impacts, feasibility, and cost effectiveness.

Use an Integrated Pest Management (IPM) Approach for all Areas of Control

Ideally, an IPM program considers all available control actions, including no action, and evaluates the interaction among various control practices, cultural practices, weather, and habitat structure. An ecologically-based IPM strategy relies heavily on natural mortality factors and seeks out control tactics that are compatible with or disrupts these factors as little as possible. When biological or chemical treatment is needed, select treatments based on the species of mosquitoes found in larva pools, the age of larva, breeding habitat, density of larval populations and temperature.

Pesticide applications shall not commence unless surveillance of a potential application site indicates a larva/pupa count of greater than 1 per 3 dips and the need to apply insecticides to control mosquito populations, or unless dead birds, infected horses, or adult mosquito surveys indicate the presence of vector mosquitoes when larvae counts cannot be made due to their inaccessibility. In these cases beginning control methods such as larviciding may be desirable or even necessary without the larvae dips. However, just because a dead bird is found which tests positive for WNV in an area does not mean that the vector mosquitoes are breeding in the nearest storm drain. Those in the business of controlling mosquitoes will have to know the breeding sites and species of vectors in the area to perform effective mosquito control.

Fish and game specialists and natural resources biologists (WDFW) must be notified of planned control measures whenever delicate ecosystems could be harmed by mosquito control practices (i.e. aerial applications over wildlife refuges). Other resource management agencies (i.e., National Marine Fisheries

Service and U.S. Fish and Wildlife Service) may need to be consulted to determine when and where operations may harm delicate ecosystems, as well as appropriate treatments in these situations.

Biological Controls

Natural Waters WDFW has several concerns with stocking biological mosquito predators in natural waters. Along with the introduction of non-native fish, the transfer of fish diseases from one location to another, even among native populations, can cause disease outbreaks. That is why all movement and stocking of fish requires a permit from WDFW, whether the fish are native or not. Due to the inability to test live fish without killing them, the transportation of fish from one watershed to another requires disease testing (usually on the adults at spawning, or by sacrificing a number of young fish) and verification that the remaining fish are reared on disease-free water. In addition, any non-native fish stocking currently needs to go through SEPA review prior to approval. The laws in Washington State are designed specifically to prevent this type of "Johnny Apple-seeding" from occurring. For more information, please contact your nearest Regional Office of the Department of Fish and Wildlife.

Ponds or impoundments with no inlets or outlets Biological methods may include stocking species such as the Three-Spined Stickleback (*Gasterosterous aculeatus*) which is native to Washington State and known to be an effective predator of mosquitoes. Mud minnow, perch tadpoles, dragonfly larvae, diving beetles, back swimmers and front swimmers also prey on mosquito larvae. Guppies, goldfish, and other fish commonly sold in pet stores are exempt from permitting by Washington's Department of Fish and Wildlife (WDFW) and may be suitable for smaller ponds, horse troughs, and ornamental pools. However, before planting any of these exempt fish, consult with WDFW. Some of these fish, such as goldfish, may have severe ecological impacts on ponds and lakes.

Mosquito Fish (*Gambusia affinis*) have been used for mosquito control in virtually every state because of the adult's ability to consume large amounts of mosquito larvae. These warmwater fish rarely exceed 2.5 inches and prefer shallow water. They tend to flourish in almost any environment, including well discharges, cisterns, water tanks, potholes, rain barrels, and open septic tanks. *Gambusia* have been known to dramatically reduce and even eliminate mosquito larvae. WDFW suggests that the use of *Gambusia* be integrated into an overall mosquito control plan rather than used as an exclusive solution to mosquito abatement. Permits must be obtained from WDFW for use of *Gambusia* as a mosquito control measure.

Chemical Controls

Select chemical controls by comparing the species and targeted life stage of mosquitoes, the breeding habitat, density of larval populations and temperature with the efficacy of the products, nontarget impacts, resistance management, and costs. For example, while *Bacillus* products are effective on early instars they do not control older larva. Methoprene can be used on older larval stages and for situations where it is too late to use either *Bacillus* or methoprene (i.e., pupa), or a monomolecular film might be used. Some *Bacillus* products do not have residual characteristics when temperatures are high, and larval populations can grow at the rate of an instar a day. In this situation the larva may be in the late third to fourth instar stage before an application of *Bacillus* can be made. Always consult product labels for specific information on efficacy and use. Product Material Safety Data Sheets (MSDS) provide additional information such as protocols or measures to be taken for accidental releases and other pertinent product information.

The following is the approved list of insecticides that may be considered for mosquito control operations. Consult with Federal, State and local agencies as needed.

1. *Bacillus thuringiensis israelensis* (Bti)
2. *Bacillus sphaericus* (H-5a5b)

3. Methoprene Granular, Liquid, Pellet, or Briquet (Restricted on state listed species sites – see Appendix A).
4. Monomolecular Surface Films (Restricted on state listed species sites – see Appendix A).
5. Paraffinic white mineral oil. Paraffinic white mineral oil is restricted on state listed species sites – see Appendix A and shall not be used in waters of the state unless:
   a. The mosquito problem is declared a public health risk; or
   b. The other control agents would be or are known to be ineffective at a specific treatment site; and
   c. The waterbody is non-fish-bearing (when uncertain, consult Washington State Fish and Wildlife concerning fish and wildlife) and has no inlet or outlet.
6. Larvicides that contain malathion or temephos may not be used in lakes, streams, wetlands, the littoral zone of water bodies or on state listed species sites listed in Appendix A. These products are allowed for use where the treatment site has documented resistance to all less toxic control methods and where the active ingredient has no chance of entering surface waters and in accordance with S1of the general permit. Typical sites for use are manure fields or highly organic contained waters.
7. Terrestrially applied insecticides are NOT regulated under federal or state water pollution control laws and are not subject to NPDES permit conditions or requirements. However, in Washington State *applications of insecticides used for adult mosquito control, even if they are labeled for use over water, i.e., streams, wetlands, rivers, lakes, ditches, etc, must be permitted under a Clean Water Act (NPDES) permit.* A variety of adulticides are regulated for use in Washington State by WSDA. Table 4 lists some of these products. For a complete list see the WSDA website: http://www.kellysolutions.com/WA/showproductsbypest2.asp?Pest_ID=IOAMAAC04

Table 3. Permitted Insecticides Used For Mosquito Control

Typical Products	Active Ingredient	Label Use Rate and 2003 cost estimates	Application Method(s) Persistence and Comments	Human Health Restrictions	Environmental Impacts and Restrictions	Target Pests on Label
Aquabac, Bactimos, Vectobac and Teknar	(Bti) *Bacillus thuringiensis israelensis*	0.25 to 2 pints/acre or up to 10 lbs/acre @ $24/gal. Granules $1.65/lb	Hand sprayer, ground sprayer or sprinkler cans. Effective 1 - 30 days depending on formulation. Broad spectrum, except *Coquilletidia*	Not for potable water. Minimal non-dietary and dermal risk to infants and children.[1]	Non-toxic to most nontarget species.	Mosquito larvae
VectoLex WDG	*Bacillus sphaericus* (H-5a5b)	0.5 to 1.5 lbs/acre $4.65/lb	Granules are mixed with water and sprayed. Effective for 1-4 weeks, depending on the species of mosquito larvae, weather, water quality and exact form of the granules. Effective on *Culex spp.* Less effective against other species.	Not for potable water. Essentially nontoxic to humans[3]	No risks to wildlife, nontarget species or the environment[3]	Larval control in water with high organic content.
Altosid liquid	Methoprene: Active ingredient is a growth hormone mimic that does not allow the mosquito larvae to mature.	3 to 4 oz./acre $226/gal	Use hand and ground sprayers. Effective for a few days unless specially formulated for slow release. It is not persistent because it degrades rapidly in water. The briquettes are used in areas needed for longer term residual control such as ponded areas of standing water, areas where flood waters may make it impossible to use Bti. Rates increase with deeper water. Altosid XR-G is a sand formulation, good for pastures or marshes with thick vegetation.	Not for potable water. Does not pose risks to human health[3]	Minimal acute and chronic risk to freshwater fish, freshwater invertebrates and estuarine species.[4] Restricted on state listed specie sites – see Appendix A.	Horn fly, mosquito larvae, cigarette beetle, tobacco moth, sciarid fly, flea larvae, mealy bug and spider mite.
Altosid pellets	Methoprene	2.5-10 lbs/acre $24/lb				
Altosid XR	Methoprene	1 briquette 100-200 sq ft. $2.70 @				
Altosid briquet	Methoprene	1 briquette / 100 sq ft. $.90 @				
Altosid XR-G	Methoprene	5-20 lbs/ac $8.48/lb				

Typical Products	Active Ingredient	Label Use Rate and 2003 cost estimates	Application Method(s) Persistence and Comments	Human Health Restrictions	Environmental Impacts and Restrictions	Target Pests on Label
Agnique MMF Arosurf MSF	Monomolecular surface film *Poly(oxy-1,2-ethanediyl)Alpha-isooctadecyl-hydroxy*	0.2 to 0.5 gal/acre @ $30/gal.	Sprayed by hand or ground equipment. Film remains active for 10-14 days on floodwaters, brackish waters and ponds. It is susceptible to wind breaking the surface tension and could be rendered ineffective at winds above 10 mph and in very choppy water. Adult females are killed by entrapping and drowning when they contact the surface to lay their eggs.	Okay for potable water, livestock, backyard ponds, pool covers. No risk to human health[3]	Less environmental impact than oil-kills pupa stage. Films pose minimal risks to the environment[3] Arthropods may be harmed Restricted on state listed specie sites – see Appendix A.	Larval, pupal and midge control. Adult female mosquitoes.
Golden Bear Oil Bonide Oil	Petroleum distillate oils prevent the larvae from obtaining oxygen through the surface film	3 to 5 gal/acre $11/gal	Liquid formulations are sprayed by hand or ground equipment. Persists for 12 – 15 hours, then evaporates. Less expense--kills pupae stages	No risk to human health.[3]	May not be applied to fish-bearing waters or on state listed specie sites – see Appendix A. Misapplied oils may be toxic to fish and other aquatic organisms.	Larval and pupal control
Abate	temephos	0.5 to 1.5 oz/acre $2.00/oz	Sprayed liquid. Breaks down within a few days in standing water, shallow ponds, swamps, marshes, and intertidal zones. Temephos is applied most commonly by helicopter but can be applied by backpack sprayers, fixed-wing aircraft, and right-of-way sprayers in either liquid or granular form.	Not for potable water. Poses low risk to human health. High dosages, like other OPs*, can over-stimulate the nervous system, causing nausea, dizziness, and confusion. [3]	Poses severe risk to nontarget aquatic species and the aquatic ecosystem. Highly toxic to some aquatic invertebrates. Moderately toxic to very highly toxic to trout. [6] For use in areas with high organic content, such as puddles and ponding on fields where manure is present. May not be used in lakes, streams, wetands or the littoral zone of a water body. Restricted on state listed specie sites – see Appendix A.	Mosquito larvae, midge, punkie gnat, and sandfly larvae in non-potable water.

Typical Products	Active Ingredient	Label Use Rate and 2003 cost estimates	Application Method(s) Persistence and Comments	Human Health Restrictions	Environmental Impacts and Restrictions	Target Pests on Label
Malathion 8EC	malathion	8 oz/acre, cost NA	Labeled for use in intermittent flooded areas, stagnant water and temporary rain pools.	Harmful by swallowing, inhalation or skin contact.[8]	Toxic to fish, aquatic invertebrates, and aquatic life stages of amphibians. Highly toxic to bees and birds.[8] May not be used in lakes, streams, wetands or the littoral zone of a water body. Restricted on state listed specie sites – see Appendix A.	Aphids, leafhoppers, grasshoppers, spider mites, bugs, beetles, moths, worms, flies, mosquitoes and mosquito larvae

*OPs are organophophates

1. http://www.epa.gov/oppbppd1/biopesticides/factsheets/fs006476t.htm
2. http://www.epa.gov/pesticides/factsheets/larvicides4mosquitos.htm#microbial
3. http://www.epa.gov/pesticides/citizens/larvicides4mosquitos.htm#microbial
4. http://www.epa.gov/pesticides/biopesticides/ingredients/index.htm#M
5. http://www.epa.gov/pesticides/citizens/malathion4mosquitos.htm
6. http://www.epa.gov/oppsrrd1/REDs/factsheets/temephosfactsheet.pdf
7. http://www.epa.gov/oppsrrd1/op/malathion/summary.htm
8. http://www.epa.gov/oppsrrd1/op/malathion/summary.htm

When Adulticides Fit into a Mosquito Control Plan

Note: Terrestrially applied products are NOT regulated under federal or state water pollution control laws and are not subject to NPDES permit conditions or requirements when applied to terrestrial sites. In Washington State *applications of adulticides, even if they are labeled for use over water. i.e., streams, wetlands, rivers, lakes, ditches, etc, must be permitted under a Clean Water Act permit.*

Select triggers for the use of adulticide products: Some mosquito control districts recommend using light traps to monitor for mosquitoes. For example, Adams County MD recommends that counts of 8 to 12 mosquitoes caught in 12 hours or a 3 adult mosquito landing count per minute in a residential area triggers the need to adulticide (Thomas Haworth, personal communication, November 7, 2003). Some applicators recommend adulticiding residential areas and upland areas where mosquitoes are migrating only when there is evidence of mosquito-borne epizootic activity at a level suggesting high risk of human infection. The following are examples of this type of evidence: high dead bird densities; high mosquito infection rates; multiple positive mosquito species including bridge vectors; horse or mammal cases indicating escalating epizootic transmission, including bridge vectors, horse or mammal cases, or a human case with evidence of epizootic activity.

Reducing vector densities below transmission threshold usually requires multiple ULV applications. Therefore, triggers should take into account this latency effect so that human transmission is not proceeding prior to or during operations. This presupposes identifying increasing human risk at least 2 weeks before human cases might present. Trigger design and implementation should reflect this need for preemptive adulticiding.

BMPs for adulticides:

1) Meteorological conditions:
   - Check wind speed and direction before spraying and be observant of all changes in direction and speed during the application. Use appropriate wind indicators. Gauges are highly recommended for ground applications and smoke for aerial applications.
   - For aerial applications, check temperature at different elevations to decide if there is an inversion.
   - Spray only when wind is away from sensitive sites.
   - Dusk or dawn is the recommended time to spray when mosquitoes are out.

2) Minimum wind conditions and temperature inversions:
   - Air inversions can go from 50 feet to 600 feet.
   - Inversions can be used to force the droplets down.
   - Spray under the inversion and only when conditions will not allow the cloud to drift into the stream.
3) Maximum wind: Do not spray in winds over 10 mph.
4) Fish-bearing stream spray buffers: Follow label buffers.

The following is a table of ultra low volume (ULV) mosquito adulticides that may be used in terrestrial applications in Washington State.

Table 4. Insecticides Used for Adult Mosquito Control

Typical Products	Active Ingredient	Label Use Rate	Use	Cost	Residual Life	Comments
Biomist & Kontrol Permanone Aqua Reslin	Permethrin	ULV 4 oz/acre	Adult Control	$.24/oz	24 hours	Effective, 100 ft set-back from water.
MGK 5%, Pyrenone 25-5	Pyrethrin	ULV 1-4 oz/acre	Adult Control	$1.20/oz	1 hour	No set-backs to water. Approved for crop and pasture applications. Expensive
Scourge	Resmethin	ULV 4 oz/acre	Adult Control	$.58/oz	1-4 hours	Has not performed well in some areas. No setbacks to water.
Fyfanon ULV	Malathion	ULV rates vary	Adult Control	$.24/oz	24 hours	Very highly toxic to nontargets.
Anvil	Sumithrin	0.0012 lb – 0.0036 lbs ai per acre	Adult Control	$.40/oz	1-4 hours	Tested and used in the NW. No water precautions.
Dibrom, Trumpet	Naled	Not recommended for ground ULV use.	Adult control			No set-backs to water. Approved for crop and pasture applications.

What Constitutes an Emergency?

Health emergencies are declared by local health departments in consultation with Washington State Department of Health. If an emergency is declared and the following steps haven't already been taken, the responsible officials should immediately initiate an information and outreach program that emphasizes habitat minimization and personal protection; they should then begin conducting larval surveys and secure the funding, permits and licenses needed for applying insecticides.

Insecticides may be applied to waters in an emergency once an application has been submitted but before permit coverage is granted:

- As a result of consultation between the departments of Health and Ecology, in response to the development of a human health emergency as determined by the Washington State Department of Health.
- As a result of consultation between the departments of Agriculture and Ecology, and then only in response to the development of pesticide resistance within a population of mosquitoes. Monitoring of insecticide persistence and residuals shall be a condition of such approval.

For practical purposes, once an outbreak is underway, larval surveys/control and habitat minimization measures will have little immediate effect. At this point, personal protective measures and large-scale adulticiding may provide the only means to reduce human/vector contact and further spread of the disease beyond those already infected.

References Cited

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Appendix A.
State Listed Species Restricted Areas

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Basis of Restrictions

Ecology's Aquatic Mosquito Control National Pollutant Discharge Elimination System (NPDES) General Permit No. WAG-992000 Condition S4 3 states, "In developing the IPM plan, the Permittee shall consult with local governments and State and Federal agencies as needed."

Ecology took the lead developing an IPM plan to assist many local governments and others performing mosquito control operations who were suddenly in the business of mosquito control due to the spread of the West Nile virus. As the permit required, Ecology consulted with the Department of Fish and Wildlife (WDFW) in spring 2003 during this process. As a result the WDFW identified wildlife species that it considered most vulnerable to certain mosquito control larvacides, identified the primary areas occupied by these species, and requested that pesticide applications be restricted in these areas.

These areas, along with areas identified as habitat for federal and state listed fish species were compiled into a document called *Insert A* and listed as areas where larvicides containing monomolecular surface films, methoprene, petroleum distillates, malathion and temephos were not allowed for use. Larvicides containing *Bacillus thuringiensis israelensis* (Bti) and *Bacillus sphaericus* (BS) were allowed for use due to their extreme low toxicity to non-target species. Unfortunately, the recommendations for restrictions were given to Ecology after the mosquito spray season had begun and in the interest of having a permit pathway in place for applicators for the 2003 spray season Ecology listed the recommendations as *Insert A* and opened them for public review after the season was over.

The restrictions in Insert A have been considerably revised as a result of a more thorough review initiated the fall of 2003. Significantly, the restrictions on the use of methoprene in waters containing federal and state listed salmon have been lifted to allow monitoring for effects. The restrictions for state listed species that are still recommended by WDFW are listed here and a map of those areas is provided. Restrictions specific to larvicide active ingredients are also noted on *Table 3*.

Criteria Used for the Restrictions

The criteria WDFW used for denoting species as vulnerable were:
1) State species of concern (i.e. listed as state endangered, threatened, sensitive, or candidate),
2) Current range and distribution of the species was highly localized, and
3) The species inhabited freshwater wetlands during most of the mosquito control treatment period.

Six species initially met those criteria: northern leopard frog (*Rana pipiens*), Oregon spotted frog (*Rana pretiosa*), western toad (*Bufo boreas*), western pond turtle (*Clemmys marmorata*), American white pelican (*Pelecanus erythrorhynchos*), and one butterfly, the Yuma skipper (*Ochlodes yuma*).

WDFW identified areas occupied by the two extant populations of northern leopard frog; two, extant, western Washington populations of Oregon spotted frog; western toad breeding ponds (for western Washington only); the three remaining western pond turtle populations; the single American white pelican breeding colony; and the one known Washington Yuma skipper population.

Based on the review of published literature, expert advice, and the vulnerability of these rare and endangered animals and their freshwater invertebrate food resources WDFW requested that if mosquito control is deemed necessary in the areas WDFW described in April 2003, that it be restricted to the use of *Bacillus* products.

Aerial Applications

An exception to the WDFW request regarding the use of certain larvicides was made for the single American white pelican breeding colony. The colony resides on islands and along the shores of the Columbia River, south of the confluence of the Snake River, in Walla and Benton counties. While chemicals such as methoprene were not deemed toxic for the pelican breeding colony, the method of aerial application was believed to be unacceptably disturbing for their successful breeding. It was agreed that aerial applications would not be made on the pelican breeding areas, whereas less obtrusive methods of mosquito control were acceptable near these sites.

Discussions among several WDFW habitat biologist found that aerial applications of larvicides also disturbed work being done by biologists in a few wildlife refuge areas around the state. It was therefore agreed that operators making aerial applications over wildlife refuges would notify the appropriate regional WDFW office of their scheduled aerial applications at least 24 hours prior to spraying. The notification can be made by phone or fax.

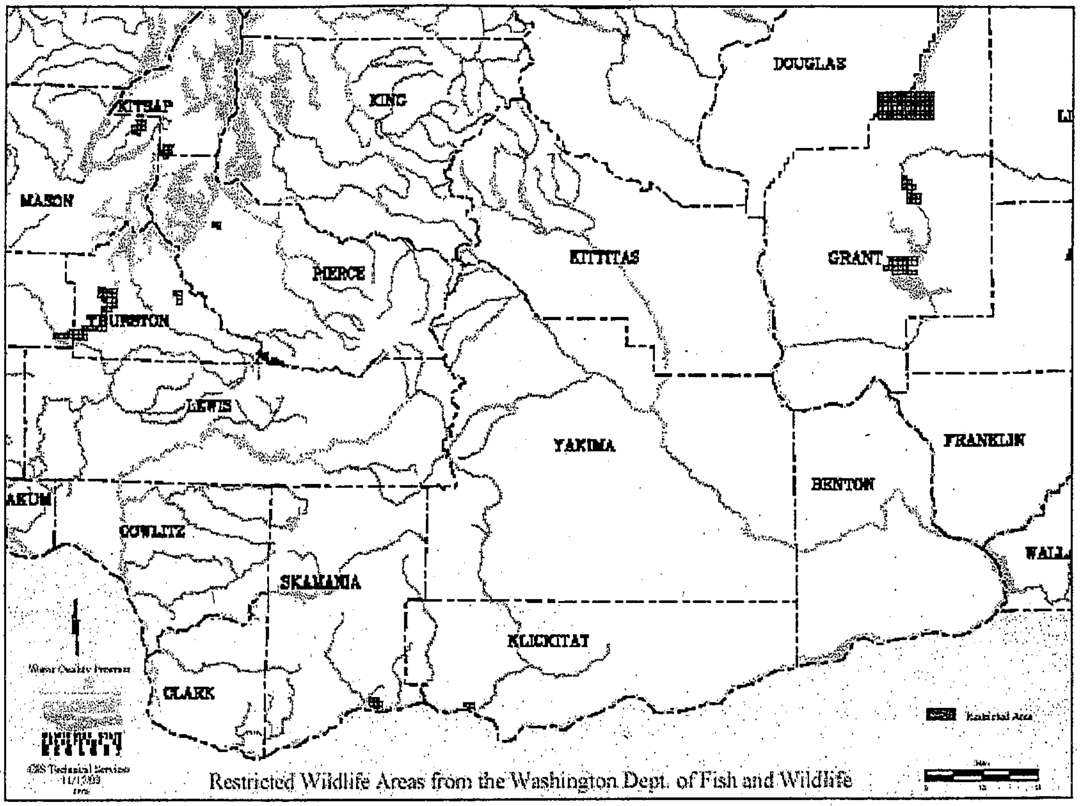
Area of Impact

Only a few populations of northern leopard frog, Oregon spotted frog, western toad, western pond turtle, and Yuma skipper remain in Washington. The total area occupied by these species in rivers, lakes, ponds, and wetlands is tiny, comprising of portions of 117 sections (<0.18% of Washington State). The areas identified for northern leopard frog (36 Sections) and western pond turtle (13 Sections) are owned or managed by WDFW. A prudent, risk-adverse approach is warranted with vulnerable threatened and endangered species.

The following areas are restricted to the use of *Bacillus thuringiensis israelensis* (Bti) and *Bacillus sphaericus* (H-5a5b) only.

1) Grant County, north of Moses Lake, within the Crab Creek watershed: T21N R27E Sections 1, 12, and 13; T21N R28E Sections 7, 17, 18, 19, 28, 29, 30, 31, 32, and 33.
2) Grant County, south and west of Moses Lake and south of Interstate-90, the northern portion of the Potholes: T19N R27E Sections 33, 34, 35, and 36; T19N R28E Sections 31 and 32; T18N R27E Sections 1, 2, 3, 4, 8, 9, 10, 11, 12, 13, 14, 15, and 16; T18N R28E Sections 5, 6, 17, and 18.
3) Grant County, area within and near the Sun Lakes – Dry Falls State Park wetlands: T24N R27E and 28E.
4) Kitsap County: lakes, ponds, and wetlands located in T22N R1W Sections 1, 2, 10, 11, and 12.
5) Klickitat County, west of the Klickitat River, all waters in T3N R12E Sections 28, 29, 32, and 33.
6) Mason County, on the Kitsap Peninsula: lakes, ponds, and wetlands located in T23N R2W Sections 11, 12, 13, 14, 15, 22, and 23.
7) Pierce and Kitsap counties, Carney Lake, located in T22N R1W.
8) Pierce, Thurston, and Lewis counties, within the Nisqually River watershed: Alder Lake (or Alder Lake Reservoir), located in townships: T15N R4E and 5E.
9) Pierce County, south of Tacoma, Chambers Creek and associated waters in T20N R2E Sections 26 and 27.
10) Skamania County, east of Carson, all waters in T3N R8E Sections 23, 24, 25, 26, and 36; T3N R9E Sections 30 and 31.
11) Thurston County, west of Yelm: lakes, ponds, and wetlands located in T17N R1E Sections 8, 9, 16, and 21.
12) Thurston County, south of Olympia and east of Interstate-5, within the Black River watershed, the Beaver Creek drainage, located in T16N R2W Sections 9, 10, 11, and 12; T16N R1W Section 7.
13) Thurston County, south of Olympia and west of Interstate-5, within the Black River watershed: Black River proper from south of Black Lake to the Chehalis River

confluence, and the following tributaries, Stony Creek, Dempsey Creek, Salmon Creek, and Blooms Ditch. Legal description as follows for these sensitive areas: T17N R3W Sections 10, 11, 12, 13, 14, 15, 23, 24, 25, 35, and 36; T17N R2W Sections 7, 18, 19, and 30; T16N R3W Sections 2, 11, 14, 19, 20, 21, 22, 23, 30, and 31; T16N R4W Sections 25, 26, 27, 31, 32, 33, 34, 35, and 36.



Restricted Wildlife Areas from the Washington Dept. of Fish and Wildlife

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Ecology's Aquatic Mosquito Control National Pollutant Discharge Elimination System (NPDES) General Permit No. WAG-992000 Condition S4 3 states, "In developing the IPM plan, the Permittee shall consult with local governments and State and Federal agencies as needed."

Ecology took the lead developing an IPM plan to assist many local governments and others performing mosquito control operations who were suddenly in the business of mosquito control due to the spread of the West Nile virus. As the permit required, Ecology consulted with the Department of Fish and Wildlife (WDFW) in spring 2003 during this process. As a result the WDFW identified wildlife species that it considered most vulnerable to certain mosquito control larvacides, identified the primary areas occupied by these species, and requested that pesticide applications be restricted in these areas.

These areas, along with areas identified as habitat for federal and state listed fish species were compiled into a document called *Insert A* and listed as areas where larvicides containing monomolecular surface films, methoprene, petroleum distillates, malathion and temephos were not allowed for use. Larvicides containing *Bacillus thuringiensis israelensis* (Bti) and *Bacillus sphaericus* (BS) were allowed for use due to their extreme low toxicity to non-target species. Unfortunately, the recommendations for restrictions were given to Ecology after the mosquito spray season had begun and in the interest of having a permit pathway in place for applicators for the 2003 spray season Ecology listed the recommendations as *Insert A* and opened them for public review after the season was over.

The restrictions in Insert A have been considerably revised as a result of a more thorough review initiated the fall of 2003. Significantly, the restrictions on the use of methoprene in waters containing federal and state listed salmon have been lifted to allow monitoring for effects. The restrictions for state listed species that are still recommended by WDFW are listed here and a map of those areas is provided. Restrictions specific to larvicide active ingredients are also noted on *Table 3*.

Criteria Used for the Restrictions

The criteria WDFW used for denoting species as vulnerable were:
1) State species of concern (i.e. listed as state endangered, threatened, sensitive, or candidate),
2) Current range and distribution of the species was highly localized, and
3) The species inhabited freshwater wetlands during most of the mosquito control treatment period.

Six species initially met those criteria: northern leopard frog (*Rana pipiens*), Oregon spotted frog (*Rana pretiosa*), western toad (*Bufo boreas*), western pond turtle (*Clemmys marmorata*), American white pelican (*Pelecanus erythrorhynchos*), and one butterfly, the Yuma skipper (*Ochlodes yuma*).

WDFW identified areas occupied by the two extant populations of northern leopard frog; two, extant, western Washington populations of Oregon spotted frog; western toad breeding ponds (for western Washington only); the three remaining western pond turtle populations; the single American white pelican breeding colony; and the one known Washington Yuma skipper population.

Based on the review of published literature, expert advice, and the vulnerability of these rare and endangered animals and their freshwater invertebrate food resources WDFW requested that if mosquito control is deemed necessary in the areas WDFW described in April 2003, that it be restricted to the use of *Bacillus* products.

Aerial Applications

An exception to the WDFW request regarding the use of certain larvicides was made for the single American white pelican breeding colony. The colony resides on islands and along the shores of the Columbia River, south of the confluence of the Snake River, in Walla and Benton counties. While chemicals such as methoprene were not deemed toxic for the pelican breeding colony, the method of aerial application was believed to be unacceptably disturbing for their successful breeding. It was agreed that aerial applications would not be made on the pelican breeding areas, whereas less obtrusive methods of mosquito control were acceptable near these sites.

Discussions among several WDFW habitat biologist found that aerial applications of larvicides also disturbed work being done by biologists in a few wildlife refuge areas around the state. It was therefore agreed that operators making aerial applications over wildlife refuges would notify the appropriate regional WDFW office of their scheduled aerial applications at least 24 hours prior to spraying. The notification can be made by phone or fax.

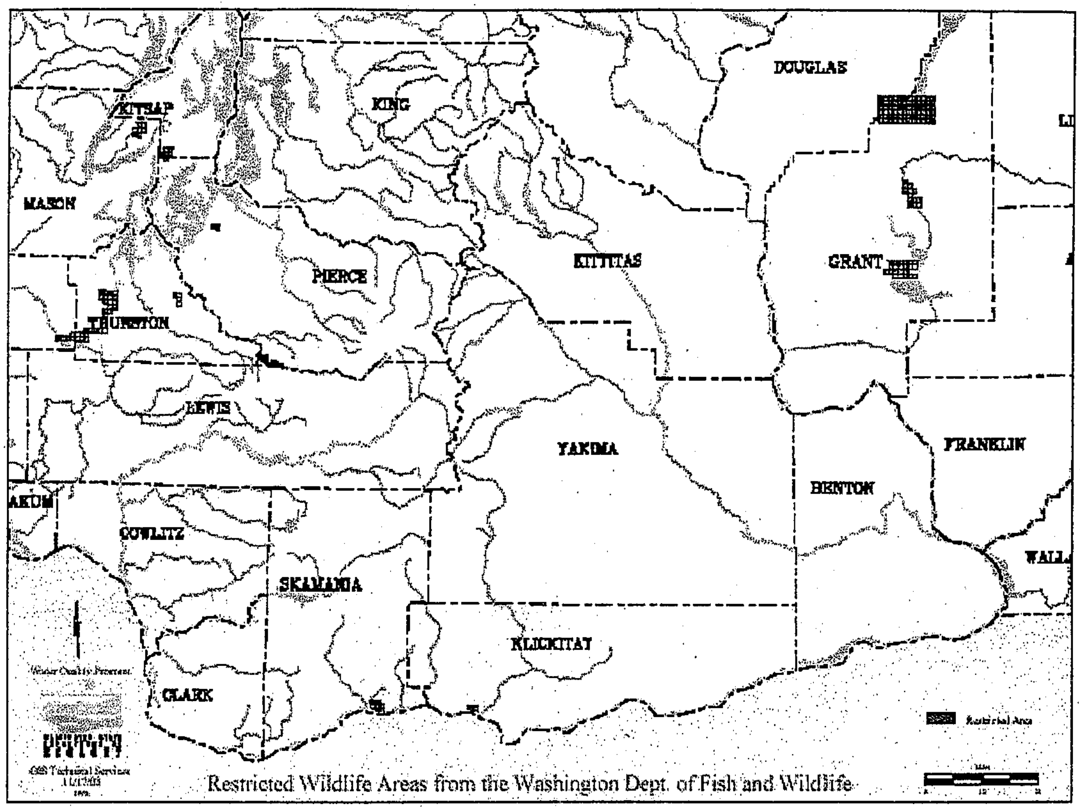
Area of Impact

Only a few populations of northern leopard frog, Oregon spotted frog, western toad, western pond turtle, and Yuma skipper remain in Washington. The total area occupied by these species in rivers, lakes, ponds, and wetlands is tiny, comprising of portions of 117 sections (<0.18% of Washington State). The areas identified for northern leopard frog (36 Sections) and western pond turtle (13 Sections) are owned or managed by WDFW. A prudent, risk-adverse approach is warranted with vulnerable threatened and endangered species.

The following areas are restricted to the use of *Bacillus thuringiensis israelensis* (Bti) and *Bacillus sphaericus* (H-5a5b) only.

1) Grant County, north of Moses Lake, within the Crab Creek watershed: T21N R27E Sections 1, 12, and 13; T21N R28E Sections 7, 17, 18, 19, 28, 29, 30, 31, 32, and 33.
2) Grant County, south and west of Moses Lake and south of Interstate-90, the northern portion of the Potholes: T19N R27E Sections 33, 34, 35, and 36; T19N R28E Sections 31 and 32; T18N R27E Sections 1, 2, 3, 4, 8, 9, 10, 11, 12, 13, 14, 15, and 16; T18N R28E Sections 5, 6, 17, and 18.
3) Grant County, area within and near the Sun Lakes – Dry Falls State Park wetlands: T24N R27E and 28E.
4) Kitsap County: lakes, ponds, and wetlands located in T22N R1W Sections 1, 2, 10, 11, and 12.
5) Klickitat County, west of the Klickitat River, all waters in T3N R12E Sections 28, 29, 32, and 33.
6) Mason County, on the Kitsap Peninsula: lakes, ponds, and wetlands located in T23N R2W Sections 11, 12, 13, 14, 15, 22, and 23.
7) Pierce and Kitsap counties, Carney Lake, located in T22N R1W.
8) Pierce, Thurston, and Lewis counties, within the Nisqually River watershed: Alder Lake (or Alder Lake Reservoir), located in townships: T15N R4E and 5E.
9) Pierce County, south of Tacoma, Chambers Creek and associated waters in T20N R2E Sections 26 and 27.
10) Skamania County, east of Carson, all waters in T3N R8E Sections 23, 24, 25, 26, and 36; T3N R9E Sections 30 and 31.
11) Thurston County, west of Yelm: lakes, ponds, and wetlands located in T17N R1E Sections 8, 9, 16, and 21.
12) Thurston County, south of Olympia and east of Interstate-5, within the Black River watershed, the Beaver Creek drainage, located in T16N R2W Sections 9, 10, 11, and 12; T16N R1W Section 7.
13) Thurston County, south of Olympia and west of Interstate-5, within the Black River watershed: Black River proper from south of Black Lake to the Chehalis River

confluence, and the following tributaries, Stony Creek, Dempsey Creek, Salmon Creek, and Blooms Ditch. Legal description as follows for these sensitive areas: T17N R3W Sections 10, 11, 12, 13, 14, 15, 23, 24, 25, 35, and 36; T17N R2W Sections 7, 18, 19, and 30; T16N R3W Sections 2, 11, 14, 19, 20, 21, 22, 23, 30, and 31; T16N R4W Sections 25, 26, 27, 31, 32, 33, 34, 35, and 36.



Restricted Wildlife Areas from the Washington Dept. of Fish and Wildlife

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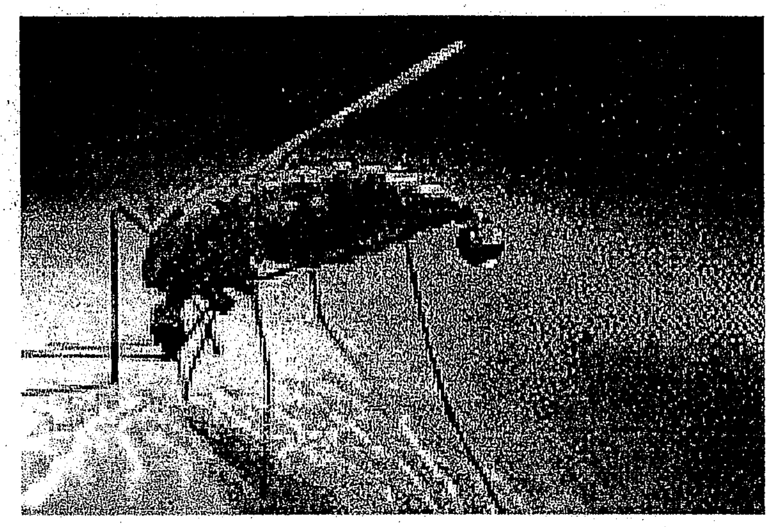
APPENDIX B

Insect Repellent Use and Safety

From the Center for Disease Control

Best Management Practices for Mosquito Control

Washington State Department of Ecology
Water Quality Program



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Best Management Practices for Mosquito Control

Washington State Department of Ecology
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Table of Contents

A mosquito control handbook will be provided for informational purposes only. The Handbook has no legal relevance to the NPDES General Permit or the BMPs.

Mosquito Handbook Table of Contents

Tables

Introduction

On April 10, 2002, the Washington State Department of Ecology (Ecology) issued NPDES General Permit No. WAG-992000, covering mosquito control activities that discharge insecticides directly into surface waters of the state. Under the permit, the use of insecticides for mosquito control in water is allowed when the effects are temporary and confined to a specific location, though locations where insecticides are used may be widespread throughout the state. Applications of insecticides are subject to compliance with Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) labels, monitoring/reporting requirements, and approved best management practices (BMPs) that include integrated pest management options. When adopted by a mosquito control entity, these BMPs for Mosquito Control satisfy that NPDES Permit No. 992000, Condition S4 requirement.

These Best Management Practices for Mosquito Control were developed through a collaborative effort of representatives from Washington and Oregon based mosquito control districts, Washington State counties, Washington State University, mosquito control insecticide industry and the state departments of Health, Agriculture, Fish and Wildlife, Transportation and Ecology. Our appreciation goes out to the many mosquito control experts and others who took the time to review the draft and offer their expertise and suggestions.

Mosquito control entities in Washington State that wish to develop their own BMPS may do so, but they must be approved by Ecology. An approvable integrated pest management (IPM) program for mosquitoes must involve natural resource scientists when planning control measures that could harm delicate ecosystems and include all the features of IPM as defined in Washington State law RCW 17.15.010 (as adapted to mosquito management):

1) Minimize mosquito breeding and feeding sites.
2) Monitor mosquito populations and disease.
3) Establish the targeted densities of mosquito populations based on community factors of health, public safety, economic and aesthetic thresholds.
4) Treat mosquitoes to reduce populations below the targeted threshold using strategies that may include biological, cultural, mechanical, and chemical control methods and that consider human health, ecological impact, feasibility, and cost effectiveness.
5) Evaluate the effects and efficacy of pest treatments.

Best Management Practices for Mosquito Control

I. Minimize Mosquito Breeding and Feeding Sites

Risk Assessment: Probability of outbreak in humans: Remote
Action threshold: The presence or even the suspected presence of mosquitoes (any species) in an area identified for control efforts triggers minimization efforts in the early spring and summer. The mean development time from egg hatch to pupation takes 5 to 10 days at temperatures near 25° C (77° F) (Pratt and Moore, 1993). However, eggs of certain species can hatch in water as cold as 45° F (Lilja, 2002, p. 24). Minimization actions are most effective in the early spring and continued through fall on an as-needed basis.
Rationale: Minimizing man-made breeding sites in the targeted area of control and personal protection, especially for those with compromised immune systems, are the best defenses against getting bitten by mosquitoes, giving the best protection for the least cost.
Minimum BMP Response:

1. Provide information to those in the area of control on eliminating artificially-created mosquito breeding sites, use of biological controls, use of repellents and on protecting animals of concern. Local and state environmental health departments have a variety of informational brochures. See http://www.doh.wa.gov/ehp/ts/Zoo/WNV/WNV.html for links.
2. Take appropriate minimization actions.
3. If possible, obtain resources to enable effective responses.

Minimization Actions

Eliminate Artificial Breeding Sites around Homes and Offices

- Empty or turn over anything that holds standing water—old tires, buckets, wheelbarrows, plastic covers, and toys. Do not let water stagnate for more than seven days.
- Change water in birdbaths, fountains, wading pools, and animal troughs weekly.
- When practical, drill holes in the bottoms of containers that are left outdoors.
- Clean and chlorinate swimming pools that are not in use and be aware that mosquitoes can breed in the water that collects on swimming pool covers.
- Consider aerating ornamental pools and use landscaping to eliminate standing water; mosquitoes can potentially breed in any stagnant puddle that lasts more than four days.
- Recycle unused containers—bottles, cans, and buckets that may collect water.
- Make sure roof gutters drain properly, and clean clogged gutters in the spring and fall.
- Fix leaky outdoor faucets and sprinklers.
- Keep all ornamental shrubs and bushes trimmed and pruned to open them up to light and air flow. This will not only give mosquitoes fewer places to hide, but will promote growth and vigor in the plants.

Use Appropriate Bio-controls

- Stock water gardens *that have no surface inlet or outlet* with mosquito-eating fish (*i.e.,* goldfish, mud minnow, stickleback, and perch). Tadpoles, dragonfly larvae, diving beetles, back swimmers, and front swimmers also prey on mosquito larvae. For more information, see http://www.wa.gov/wdfw/factshts/westnilevirus.htm

- Native vegetation and nest boxes can help attract mosquito-eating birds and bats. However, property owners should avoid introducing non-native fish or wildlife in an attempt to control mosquitoes. While it is permissible to release some fish commonly available in pet stores into small, contained backyard pools and ponds, non-native fish should not be released into open or partially contained waters that may occasionally flood into natural water bodies. Some non-native species, including so-called mosquito fish, *Gambusia affinis*, can be major pests when introduced outside their natural range. *Gambusia* are aggressive and have been known to feed on eggs, larvae and juvenile native fish and amphibians. Because of these negative impacts on native species, Gambusia is a regulated species in Washington State, and may not be introduced without a fish stocking permit issued by WDFW.

- Under WDFW policy, transfer/stocking permits may only be issued to organized mosquito control districts, the U.S. Army Corps of Engineers, and local or state health departments; permits may not be issued to private individuals. To protect the Olympic mudminnow, a state sensitive species, *Gambusia* stocking is prohibited in Clallam, Jefferson, Kitsap, Grays Harbor, Mason and Thurston and portions of Lewis County that drain into the Chehalis river. For information on fish stocking permits contact the WDFW regional office in your area.

Eliminate Mosquito Feeding Sites

- Make sure window and door screens are "bug tight." Repair or replace if needed.
- Stay indoors at dawn and dusk when mosquitoes are the most active.
- Wear a long sleeve shirt, long pants and a hat when going into mosquito-infested areas such as wetlands or woods.
- Use mosquito repellant when necessary, and carefully follow directions on the label. For extensive repellent information from the Centers for Disease Control see Appendix B: Insect Repellent Use and Safety
- Areas frequented by the public, such as parks, zoos, outdoor concert areas, and wildlife reserves should consider making repellents available.

Protect Animals of Concern

- To protect your horses and other equines, talk to your veterinarian about the West Nile virus vaccine. The vaccine requires two doses three to six weeks apart, and immunity may not be achieved until up to six weeks after the second dose. An annual booster should be given a few weeks to a month prior to the start of the mosquito season in your area.
- Veterinarians should be consulted if you have concerns about your household pets or other animals. Repellents may be used in some instances.
- Thoroughly clean livestock watering troughs weekly.
- For more information see: http://www.aphis.usda.gov/lpa/issues/wnv/prv.html and/or http://www.cdc.gov/ncidod/dvbid/westnile/birds&mammals.htm

New Construction and Storm Drains

As new facilities are being designed, consideration should be given to reducing mosquito habitat as much as possible.

- When considering a drainage or water treatment facility for mosquito control, the first consideration should be whether the problem could be reduced by physical modification or repair without compromising the facility's function. Physical modifications should be designed by an engineer and reviewed by the local government to insure they meet applicable design requirements. A possible design modification may include scarifying the pond bottom where it is no longer infiltrating as originally designed, providing slope to the bottom of the drainage facility or enhancing infiltration by some other method. Eliminating low spots that collect small amounts of standing water and altering excessive overgrown vegetation may also be options. Alterations of slopes or repairs to a facility should not involve a reduction in the water retention or carrying capacity of the facility. As an example, soil should not be added to fill low spots. Instead, low spots should be graded flat such that the carrying capacity is not reduced.

Sprinklers and Irrigation Systems

Over-watering and poor irrigation practices are common producers of mosquitoes around the home, in parks, in irrigated fields, and on golf courses. Report standing water to appropriate maintenance personnel.

- Irrigated lands are among the highest producers of mosquito breeding sites in Washington State. High numbers of mosquitoes can develop in standing water as a result of flood irrigation. The actions below can help eliminate mosquito breeding sites by using physical controls (Colorado, 2002; Pratt and Moore 1993).
    1) Minimize standing water in fields so that it does not lie fallow for more than four days by improving drainage channels and grading.
    2) Tail waters should not be allowed to accumulate for more than four days at the end of the field.
    3) Keep excessive overgrown vegetation out of ditches to promote more rapid drainage, but retain ground cover to prevent soil loss.
    4) Have ditches repaired to reduce seepage to the extent practicable (elevated water tables can produce unintended standing water in fields). Modification or repairs to a ditch should not reduce the carrying capacity.
    5) Minimize flood and rill irrigation practices to the extent practicable.
    6) Avoid over-watering.

Foster Healthy Wetlands

Do NOT drain or fill wetlands. Wetlands perform at least three classes of functions: hydrologic functions (*i.e.*, flood peak reduction, shoreline stabilization, or groundwater exchange), water quality improvement (sediment accretion, filtration or nutrient uptake), and food-chain support (structural and species diversity components of habitat for plants and animals, including threatened endangered and sensitive species). Many wetlands recharge ground water critical for local drinking water supplies and prevent streams from drying up during the summer. Given the critical functions wetlands perform, Ecology does not condone draining wetlands as a method for mosquito control. Since most predation on mosquitoes occurs when they are larvae, the best mosquito control is often to target the larvae, either by fostering predators native to the area of control (amphibian larvae, aquatic salamanders, small fish) or by applying selective larvicides such as Bti. Wetland literature suggests that dragonflies are a significant predator on adult mosquitoes and it has been found that mosquito "outbreaks" most often occur in destabilized wetland and stream ecosystems that have been changed or tampered with so that the predators of the larvae are excluded. Draining wetlands and removing greenbelts will not eliminate mosquitoes. In fact, such actions could actually increase the mosquito population if their natural predators are destroyed because many mosquito species need only a small puddle or depression to breed. (Tom Hruby, Ecology Wetland Specialist, personal communication 2/26/03).

II. Monitor Mosquito Populations and Disease

Risk Assessment: Probability of outbreak in humans: Remote to low
Action threshold: The presence of vector or nuisance mosquitoes suspected or confirmed in the area.
Rationale: Base-line data on mosquito populations and mosquito-borne disease will help target educational efforts and are essential to control efforts, should they become necessary.
Minimum BMP Response: Obtain and track avian mortality, human encephalitis/meningitis, and equine surveillance in the area of control. Further quantify epizootic activity by inventorying mosquito habitats, and trapping and testing for vector mosquitoes. Consider targeted insecticide control if surveillance indicates high potential for human risk to increase.

Monitoring Strategies for landowners of private property and contracted licensed applicators

- Contact your local health department for information about birds, horses, and humans found to test positive for West Nile virus or other mosquito-borne diseases in your area of control.
- Accurately map and identify rearing areas for mosquitoes, by species if possible. These are those sites for mosquito rearing that cannot be eliminated by following preventative measures such as container emptying, proper pond maintenance, and eliminating excess standing water by using appropriate irrigation BMPs. This is important because appropriate treatment measures are contingent on the habitat (species) encountered. The following Northwest mosquito habitats and control issues have been identified in the Mosquito-borne Response Plan developed by the Department of Health (Lilja, 2002). Vectors in specific regions have not all been identified. Contact your local health department for the latest mosquito vector information.

Floodwater: *Aedes vexans* and *Ochlerotatus sticticus* develop in large numbers along the borders of the Columbia and other rivers and create important mosquito problems in this region. The larvae hatch in the spring or early summer when the streams overflow areas such as willow and cottonwood swales where the eggs have been laid. The eggs of these species are dormant when temperatures remain below 45-50° F. Partial dormancy of the eggs may continue until sometime in June so that only some of the eggs are hatched by floods occurring in April or May. In some seasons, the larger rivers may rise, recede, and rise again to cover the same egg beds and produce an additional hatch. In other seasons, two or three successive rises may occur, each of which is higher than the last. Females that emerge in the first hatch may lay eggs that will hatch in the second or third rises of the river. Most of the eggs are laid between the 10 and 20 foot levels, and some of the eggs that are not flooded during a series of low flood crest years remain viable for as long as four years.

Large *Aedes vexans* and *Ochlerotatus sticticus* breeding areas have been managed efficiently by controlling water levels above dams such as the Bonneville Dam. Dikes have prevented flooding in other areas. Clearing of brush has been of value in some locations. However, control of the major section of these types of breeding areas must often be accomplished with insecticide applications.

Irrigation Water: Breeding places for several mosquito species are provided by irrigation water. *Aedes dorsalis, A. vexans, Ochlerotatus melanimon*, and *Ochlerotatus nigromaculis* are among the most important species that may develop when water is applied and stands for a week or 10 days. Other species such as *Culex tarsalis, Culiseta inornata*, and *Anopheles freeborni* may be produced if water remains for a week or ten days. Tremendous numbers of mosquitoes breed in many areas where uncontrolled irrigation is practiced. Applications of insecticides are effective but are not substitutes for proper grading. Elimination of standing water is effective in preventing development of mosquitoes. Application of insecticides may be necessary for breeding places that cannot be drained. See Sprinklers and Irrigation Systems in Section I above.

Tidal Waters: *Aedes dorsalis* is the only species that can breed in large numbers in both fresh and salt water in the Northwest. The larvae develop in some coastal areas where potholes are filled by the higher tides or where water levels fluctuate in permanent or semi-permanent pools. Leveling, drainage, or similar practices are effective in preventing breeding, but such areas must be properly maintained. Insecticide control may be necessary where these methods are inadequate or ineffective. *Ochlerotatus togoi* has also been found in coastal areas including San Juan, Island, Skagit, Kitsap, and Mason counties. Larvae of this species have been found in pools of pure seawater along rocky shorelines.

Snow Water: In many high mountain meadows and also at lower levels, mosquitoes breed in pools caused by snow melt. Development may require several weeks at higher elevations. *Aedes communis,A. cinereus, Ochlerotatus hexodontus, O. fitchii*, and O. *increpitus* are the most common species found in these locations. Usually there is only one generation per year, but the large numbers that may be produced are a severe annoyance to those who are working or seeking recreation in these areas. Elimination of breeding areas by drainage or maintenance of constant water levels is practical in some situations. Insecticide applications might have to be made by hand or by plane because of inaccessibility to heavy ground equipment.

Permanent Waters, Ponds and Artificial Containers: The mosquitoes that lay their eggs on the water are usually found where water is present continuously during the season or at least for several days. Such locations include natural permanent ponds, including still waters along the borders of lakes and rivers sheltered from wave action and currents with some degree of vegetation, log ponds, tree holes, semi-permanent ponds and wetlands of various types, and artificial containers. *Culex tarsalis, C. pipiens, C. peus, Anopheles freeborni, A. punctipennis, Culiseta incidens,* and *C. inornata* are commonly found in such places. *C. tarsalis* and *C. pipiens* develop in large numbers in log ponds. *C. pipiens* also develops in large numbers in sewer drains, catch basins, and water left in artificial containers. *Coquillettidia perturbans* are found in permanent water in wetlands, swamps, and marshes that have emergent or floating vegetation. Insecticides are often used effectively to control most of these species, except those breeding in artificial containers that can be emptied. Larvae of *C. perturbans* are difficult to control because they are attached to the roots of plants. Insecticide granules are sometimes applied, but eliminating host plants may be the most useful procedure to control this species. Consult with your local WDFW office before removing plants on WDFW-managed lands or in ecologically sensitive areas.

Stormwater: In response to the anticipated arrival of West Nile virus in King County, King County Water and Land Resources developed recommendations for dealing with the mosquito control at County drainage facilities. The study (Whitworth, 2002) identified the four basic habitats preferred by mosquitoes, the types of mosquitoes associated with the habitat type, and the WNV vector mosquito species that prefers each habitat type. Table 1 summarizes this information.

Table 1. Disease Vector Mosquito Species Associated With Drainage Control Facilities

Habitat Type	**Facility type**	***Vector Species***
Permanent Water	Year round wet ponds Larger Regional Ponds Wet Bioswales	*Anopheles punctipennis*
Marshes & Wetlands	Wet Bioswales Some Regional Facilities	*Aedes cinereus* *Coquilletidia preturbans*
Temporary or Flood Water	Temporary Wet Ponds Dry Bioswales Retention/Detention Ponds Open Ditches	*Aedes vexans* *Culiseta inornata*
Artificial Containers / Tree Holes	Catch Basins Underground Tanks/Vaults Discarded containers & Tires	*Ochlerotatus japonicus* *Culex pipiens* *Culex tarsalis* *Culiseta inornata*

Table 2 summarizes biological information of vector mosquitoes found in Washington State.

Table 2. Potential Disease-Carrying Mosquitoes in Washington State

Mosquito Species	Day or Night Biter	Range	Generations per Year	Preferred Habitat	Breeding Comments
Aedes cinereus	Aggressive during day	Does not travel far from habitat	One-eggs hatch at different times	A woodland species: semi-permanent bogs & swamps, wetlands, wet bioswales & floodwaters	Hatches in the early spring. Larvae found among dense aquatic vegetation.
Aedes vexans	Day & Night	20+ miles	Many	Any temporary water body like ditches, puddles, containers, pools & floodwater.	Eggs may lie domant 3+ yrs, hatches in ditches, still water.
Anopheles punctipennis	Night	Stays near habitat.	One	Springs and creeks connected to stormwater ponds, bioswales and wetlands.	Prefers algae-laden, cool pools on edges of slow flowing rivers and streams. Has entirely dark palpi.
Coquilletidia preturbans	Night - often comes to lights	Strong fliers, enters homes and lit areas.	One, but hatchlings do not complete development until the following spring.	Permanent marshes, wetlands, temporary wet ponds, dry bioswales & open ditches.	Needs thick growth of aquatic vegetation. Remains below the water surface attached to roots and stems. Hatchlings emerge in spring.
Culex pipiens	Night	Usually migrates only short distances.	Many	Found around water with high organic content, as in catch basins & sewer effuent ponds, tree holes, artificial containers & manholes.	Proliferate in in artificial containers. Lays eggs in clusters of 50 to 400. Larval and pupal stages take 8 -10 days.
Culex tarsalis	Night	Enters buildings after dark.	Many	Any fresh water, artificial containers, & agricultural and irrigated areas	Larvae develop from spring to fall in waters w/ high organic material. Eggs laid in rafts of 100 - 150 & hatch w/in 48 hrs.
Culiseta inornata	Dawn & Dusk	Stays near habitat.	Many	Cold water - associated with glacial runoff and sunlit waters, does not like hot weather. Found at all elevations.	Breeds throughout spring and summer in cold water, females may appear during warm winter breaks. Usually feeds on livestock, not people.
Ochlerotatus japonicus	Day & Night	Not known	Many	Artificial containers, catch basins, undergound tanks and vaults & tree holes	Larvae are found in artifical containers.

*New information has come in on *Ochlerotatus canadensis* that adults live for several months in woodland pools by melting snow or rain. They feed on a large range of mammals, birds, and reptiles.

Additional Monitoring for Public and Specialty Targeted Areas of Control

- Conduct ongoing mosquito larvae surveillance, including studying habitats by air, aerial photographs and topographic maps, and evaluating larval populations.
- Monitor and track data from mosquito traps, biting counts, complaints, and reports from the public.
- Keep seasonal records concurrent with weather data to predict mosquito larval occurrence and adult flights.
- Consider using sentinel chicken flocks for surveillance (See Centers for Disease Control and Prevention, Epidemic/Epizootic West Nile Virus in the United States: Guidelines for Surveillance, Prevention and Control, page 10, http://www.cdc.gov/ncidod/dvbid/westnile/resources/wnv-guidelines-aug-2003.pdf)
- Accurately map and identify rearing areas for mosquitoes. These would be those sites that cannot be eliminated by preventative measures such as emptying containers, proper pond maintenance, and eliminating excess standing water by using appropriate irrigation BMPs. These habitats can be identified by aerial photo assessments, topographic maps, and satellite imagery where available. This is important because appropriate treatment measures are contingent on the particular species that live in specific habitats.
- Agricultural site maps should include hay, pasture, circle irrigation, orchards, and rill irrigated field crops. An important land use that has caused problems to mosquito control districts in the past is flood irrigated pastures where the water stays on more than five to seven days.

Note: Detailed information on mosquito surveillance is available from Washington State Department of Health, available online at www.doh.wa.gov/ehp/ts/Zoo/WNV/WAArboviralRespPlan.pdf and http://www.doh.wa.gov/ehp/ts/Zoo/WNV/WestNileVirusSurv.pdf

III. Establish Targeted Densities for Mosquito Populations

Risk Assessment: Probability of outbreak in humans: Remote to low
Action threshold: The presence (positive identification) of any vector mosquitoes in the area triggers activities to reduce their presence. Since people with compromised immune systems are likely to be the most vulnerable to mosquito-borne diseases, the areas of their exposure should be a priority.
Rationale: Once vector mosquitoes have been positively identified in an area, control treatments are warranted, especially around high risk populations. If the cost of treatments is prohibitive, every effort should be made to educate those at risk of exposure about minimizing habitat and personal protection measures.
BMP Minimum Response: Analyze disease activity data, i.e., avian mortality, human encephalitis/meningitis, equine encephalitis and mosquito surveillance information in the area of control. Set targeted densities with special consideration being given for segments of the population most vulnerable to mosquito-borne diseases such as the elderly. If needed, enhance human surveillance and activities to further quantify epizootic activity, such as mosquito trapping and testing.

Establish Targeted Mosquito Densities for all Areas of Control

To establish the targeted density of mosquito populations review information on incidences of avian mortality, human encephalitis/meningitis, and equine encephalitis for your area (the Department of Health or your local health department can provide this information). Conduct entomologic survey (inventory habitats and map mosquito populations). Using surveillance information and input from the people in the control area, establish the targeted density of mosquito populations based on the level of control desired by those in the area of control, public safety, and funding.

- Demarcate no-spray zones on maps. This may include areas such as schools, hospitals, fish farms, wildlife refuges, the homes of individuals who are on chemically sensitive registers, and crops grown under a certified organic program. Other crop sites that do not have a tolerance for the mosquito control products used should also be listed. If the control entity is not a mosquito control district organized under RCW 17.28, then individual residences where the occupants do not want to be treated should be identified as no-spray zones.
- Individual homeowners and businesses determine targeted mosquito populations densities based on the level of control desired and factors of risk and cost. Mosquito control agents must consult with their sponsors to determine targeted mosquito densities.
- Once the targeted density has been established, continue larvae surveys to find density response to habitat minimization efforts and need for larvicide treatments.

IV. Mosquito Control Treatments

Risk Assessment: Probability of outbreak in humans: Low to moderate
Action threshold: The positive identification of vector mosquitoes in the area may trigger activities to reduce their presence. Once minimization strategies have been taken, larvae surveys (*i.e.* dipping) can indicate the effectiveness of those efforts and the need for further action. General Permit Condition S4.2.C states that the targeted density of larvae is 1 per three dips to commence larviciding unless vector mosquitoes are in the area and the probable breeding sites are inaccessible. This level is a minimum; mosquito control agents may want to set the targeted density at a higher level due to cost and risk factors.
Rationale: Once vector mosquitoes have been positively identified in an area, control treatments are warranted. If the cost of treatments is prohibitive, every effort should be made to educate those at risk of exposure about minimizing breeding habitat and personal protection measures.
Minimum BMP Response: Treat mosquitoes to reduce populations below the targeted threshold using strategies that consider biological, cultural, mechanical, and chemical control methods. Evaluate methods for effectiveness of control, human health and ecological impacts, feasibility, and cost effectiveness.

Use an Integrated Pest Management (IPM) Approach for all Areas of Control

Ideally, an IPM program considers all available control actions, including no action, and evaluates the interaction among various control practices, cultural practices, weather, and habitat structure. An ecologically-based IPM strategy relies heavily on natural mortality factors and seeks out control tactics that are compatible with or disrupts these factors as little as possible. When biological or chemical treatment is needed, select treatments based on the species of mosquitoes found in larva pools, the age of larva, breeding habitat, density of larval populations and temperature.

Pesticide applications shall not commence unless surveillance of a potential application site indicates a larva/pupa count of greater than 1 per 3 dips and the need to apply insecticides to control mosquito populations, or unless dead birds, infected horses, or adult mosquito surveys indicate the presence of vector mosquitoes when larvae counts cannot be made due to their inaccessibility. In these cases beginning control methods such as larviciding may be desirable or even necessary without the larvae dips. However, just because a dead bird is found which tests positive for WNV in an area does not mean that the vector mosquitoes are breeding in the nearest storm drain. Those in the business of controlling mosquitoes will have to know the breeding sites and species of vectors in the area to perform effective mosquito control.

Fish and game specialists and natural resources biologists (WDFW) must be notified of planned control measures whenever delicate ecosystems could be harmed by mosquito control practices (i.e. aerial applications over wildlife refuges). Other resource management agencies (i.e., National Marine Fisheries

Service and U.S. Fish and Wildlife Service) may need to be consulted to determine when and where operations may harm delicate ecosystems, as well as appropriate treatments in these situations.

Biological Controls

Natural Waters WDFW has several concerns with stocking biological mosquito predators in natural waters. Along with the introduction of non-native fish, the transfer of fish diseases from one location to another, even among native populations, can cause disease outbreaks. That is why all movement and stocking of fish requires a permit from WDFW, whether the fish are native or not. Due to the inability to test live fish without killing them, the transportation of fish from one watershed to another requires disease testing (usually on the adults at spawning, or by sacrificing a number of young fish) and verification that the remaining fish are reared on disease-free water. In addition, any non-native fish stocking currently needs to go through SEPA review prior to approval. The laws in Washington State are designed specifically to prevent this type of "Johnny Apple-seeding" from occurring. For more information, please contact your nearest Regional Office of the Department of Fish and Wildlife.

Ponds or impoundments with no inlets or outlets Biological methods may include stocking species such as the Three-Spined Stickleback (*Gasterosterous aculeatus*) which is native to Washington State and known to be an effective predator of mosquitoes. Mud minnow, perch tadpoles, dragonfly larvae, diving beetles, back swimmers and front swimmers also prey on mosquito larvae. Guppies, goldfish, and other fish commonly sold in pet stores are exempt from permitting by Washington's Department of Fish and Wildlife (WDFW) and may be suitable for smaller ponds, horse troughs, and ornamental pools. However, before planting any of these exempt fish, consult with WDFW. Some of these fish, such as goldfish, may have severe ecological impacts on ponds and lakes.

Mosquito Fish (*Gambusia affinis*) have been used for mosquito control in virtually every state because of the adult's ability to consume large amounts of mosquito larvae. These warmwater fish rarely exceed 2.5 inches and prefer shallow water. They tend to flourish in almost any environment, including well discharges, cisterns, water tanks, potholes, rain barrels, and open septic tanks. *Gambusia* have been known to dramatically reduce and even eliminate mosquito larvae. WDFW suggests that the use of *Gambusia* be integrated into an overall mosquito control plan rather than used as an exclusive solution to mosquito abatement. Permits must be obtained from WDFW for use of *Gambusia* as a mosquito control measure.

Chemical Controls

Select chemical controls by comparing the species and targeted life stage of mosquitoes, the breeding habitat, density of larval populations and temperature with the efficacy of the products, nontarget impacts, resistance management, and costs. For example, while *Bacillus* products are effective on early instars they do not control older larva. Methoprene can be used on older larval stages and for situations where it is too late to use either *Bacillus* or methoprene (i.e., pupa), or a monomolecular film might be used. Some *Bacillus* products do not have residual characteristics when temperatures are high, and larval populations can grow at the rate of an instar a day. In this situation the larva may be in the late third to fourth instar stage before an application of *Bacillus* can be made. Always consult product labels for specific information on efficacy and use. Product Material Safety Data Sheets (MSDS) provide additional information such as protocols or measures to be taken for accidental releases and other pertinent product information.

The following is the approved list of insecticides that may be considered for mosquito control operations. Consult with Federal, State and local agencies as needed.

1. *Bacillus thuringiensis israelensis* (Bti)
2. *Bacillus sphaericus* (H-5a5b)

3. Methoprene Granular, Liquid, Pellet, or Briquet (Restricted on state listed species sites – see Appendix A).
4. Monomolecular Surface Films (Restricted on state listed species sites – see Appendix A).
5. Paraffinic white mineral oil. Paraffinic white mineral oil is restricted on state listed species sites – see Appendix A and shall not be used in waters of the state unless:
   a. The mosquito problem is declared a public health risk; or
   b. The other control agents would be or are known to be ineffective at a specific treatment site; and
   c. The waterbody is non-fish-bearing (when uncertain, consult Washington State Fish and Wildlife concerning fish and wildlife) and has no inlet or outlet.
6. Larvicides that contain malathion or temephos may not be used in lakes, streams, wetlands, the littoral zone of water bodies or on state listed species sites listed in Appendix A. These products are allowed for use where the treatment site has documented resistance to all less toxic control methods and where the active ingredient has no chance of entering surface waters and in accordance with S1of the general permit. Typical sites for use are manure fields or highly organic contained waters.
7. Terrestrially applied insecticides are NOT regulated under federal or state water pollution control laws and are not subject to NPDES permit conditions or requirements. However, in Washington State *applications of insecticides used for adult mosquito control, even if they are labeled for use over water, i.e., streams, wetlands, rivers, lakes, ditches, etc, must be permitted under a Clean Water Act (NPDES) permit.* A variety of adulticides are regulated for use in Washington State by WSDA. Table 4 lists some of these products. For a complete list see the WSDA website: http://www.kellysolutions.com/WA/showproductsbypest2.asp?Pest_ID=IOAMAAC04

Table 3. Permitted Insecticides Used For Mosquito Control

Typical Products	**Active Ingredient**	**Label Use Rate and 2003 cost estimates**	**Application Method(s) Persistence and Comments**	**Human Health Restrictions**	**Environmental Impacts and Restrictions**	**Target Pests on Label**
Aquabac, Bactimos, Vectobac and Teknar	(Bti) *Bacillus thuringiensis israelensis*	0.25 to 2 pints/acre or up to 10 lbs/acre @ $24/gal. Granules $1.65/lb	Hand sprayer, ground sprayer or sprinkler cans. Effective 1 - 30 days depending on formulation. Broad spectrum, except *Coquilletidia*	Not for potable water. Minimal non-dietary and dermal risk to infants and children.[1]	Non-toxic to most nontarget species.	Mosquito larvae
VectoLex WDG	*Bacillus sphaericus* (H-5a5b)	0.5 to 1.5 lbs/acre $4.65/lb	Granules are mixed with water and sprayed. Effective for 1-4 weeks, depending on the species of mosquito larvae, weather, water quality and exact form of the granules. Effective on *Culex spp.* Less effective against other species.	Not for potable water. Essentially nontoxic to humans[3]	No risks to wildlife, nontarget species or the environment[3]	Larval control in water with high organic content.
Altosid liquid	Methoprene: Active ingredient is a growth hormone mimic that does not allow the mosquito larvae to mature.	3 to 4 oz./acre $226/gal	Use hand and ground sprayers. Effective for a few days unless specially formulated for slow release. It is not persistent because it degrades rapidly in water. The briquettes are used in areas needed for longer term residual control such as ponded areas of standing water, areas where flood waters may make it impossible to use Bti. Rates increase with deeper water. Altosid XR-G is a sand formulation, good for pastures or marshes with thick vegetation.	Not for potable water. Does not pose risks to human health[3]	Minimal acute and chronic risk to freshwater fish, freshwater invertebrates and estuarine species.[4] Restricted on state listed specie sites – see Appendix A.	Horn fly, mosquito larvae, cigarette beetle, tobacco moth, sciarid fly, flea larvae, mealy bug and spider mite.
Altosid pellets	Methoprene	2.5-10 lbs/acre $24/lb				
Altosid XR	Methoprene	1 briquette 100-200 sq ft. $2.70 @				
Altosid briquet	Methoprene	1 briquette / 100 sq ft. $.90 @				
Altosid XR-G	Methoprene	5-20 lbs/ac $8.48/lb				

Typical Products	Active Ingredient	Label Use Rate and 2003 cost estimates	Application Method(s) Persistence and Comments	Human Health Restrictions	Environmental Impacts and Restrictions	Target Pests on Label
Agnique MMF Arosurf MSF	Monomolecular surface film *Poly(oxy-1,2-ethanediyl)Alpha-isooctadecyl-hydroxy*	0.2 to 0.5 gal/acre @ $30/gal.	Sprayed by hand or ground equipment. Film remains active for 10-14 days on floodwaters, brackish waters and ponds. It is susceptible to wind breaking the surface tension and could be rendered ineffective at winds above 10 mph and in very choppy water. Adult females are killed by entrapping and drowning when they contact the surface to lay their eggs.	Okay for potable water, livestock, backyard ponds, pool covers. No risk to human health[3]	Less environmental impact than oil-kills pupa stage. Films pose minimal risks to the environment[3] Arthropods may be harmed Restricted on state listed specie sites – see Appendix A.	Larval, pupal and midge control. Adult female mosquitoes.
Golden Bear Oil Bonide Oil	Petroleum distillate oils prevent the larvae from obtaining oxygen through the surface film	3 to 5 gal/acre $11/gal	Liquid formulations are sprayed by hand or ground equipment. Persists for 12 – 15 hours, then evaporates. Less expense--kills pupae stages	No risk to human health.[3]	May not be applied to fish-bearing waters or on state listed specie sites – see Appendix A. Misapplied oils may be toxic to fish and other aquatic organisms.	Larval and pupal control
Abate	temephos	0.5 to 1.5 oz/acre $2.00/oz	Sprayed liquid. Breaks down within a few days in standing water, shallow ponds, swamps, marshes, and intertidal zones. Temephos is applied most commonly by helicopter but can be applied by backpack sprayers, fixed-wing aircraft, and right-of-way sprayers in either liquid or granular form.	Not for potable water. Poses low risk to human health. High dosages, like other OPs*, can over-stimulate the nervous system, causing nausea, dizziness, and confusion. [3]	Poses severe risk to nontarget aquatic species and the aquatic ecosystem. Highly toxic to some aquatic invertebrates. Moderately toxic to very highly toxic to trout. [6] For use in areas with high organic content, such as puddles and ponding on fields where manure is present. May not be used in lakes, streams, wetands or the littoral zone of a water body. Restricted on state listed specie sites – see Appendix A.	Mosquito larvae, midge, punkie gnat, and sandfly larvae in non-potable water.

Typical Products	Active Ingredient	Label Use Rate and 2003 cost estimates *	Application Method(s) Persistence and Comments	Human Health Restrictions	Environmental Impacts and Restrictions	Target Pests on Label
Malathion 8EC	malathion	8 oz/acre, cost NA	Labeled for use in intermittent flooded areas, stagnant water and temporary rain pools.	Harmful by swallowing, inhalation or skin contact.[8]	Toxic to fish, aquatic invertebrates, and aquatic life stages of amphibians. Highly toxic to bees and birds.[8] May not be used in lakes, streams, wetands or the littoral zone of a water body. Restricted on state listed specie sites – see Appendix A.	Aphids, leafhoppers, grasshoppers, spider mites, bugs, beetles, moths, worms, flies, mosquitoes and mosquito larvae

*OPs are organophophates

1. http://www.epa.gov/oppbppd1/biopesticides/factsheets/fs006476t.htm
2. http://www.epa.gov/pesticides/factsheets/larvicides4mosquitos.htm#microbial
3. http://www.epa.gov/pesticides/citizens/larvicides4mosquitos.htm#microbial
4. http://www.epa.gov/pesticides/biopesticides/ingredients/index.htm#M
5. http://www.epa.gov/pesticides/citizens/malathion4mosquitos.htm
6. http://www.epa.gov/oppsrrd1/REDs/factsheets/temephosfactsheet.pdf
7. http://www.epa.gov/oppsrrd1/op/malathion/summary.htm
8. http://www.epa.gov/oppsrrd1/op/malathion/summary.htm

When Adulticides Fit into a Mosquito Control Plan

Note: Terrestrially applied products are NOT regulated under federal or state water pollution control laws and are not subject to NPDES permit conditions or requirements when applied to terrestrial sites. In Washington State *applications of adulticides, even if they are labeled for use over water. i.e., streams, wetlands, rivers, lakes, ditches, etc, must be permitted under a Clean Water Act permit.*

Select triggers for the use of adulticide products: Some mosquito control districts recommend using light traps to monitor for mosquitoes. For example, Adams County MD recommends that counts of 8 to 12 mosquitoes caught in 12 hours or a 3 adult mosquito landing count per minute in a residential area triggers the need to adulticide (Thomas Haworth, personal communication, November 7, 2003). Some applicators recommend adulticiding residential areas and upland areas where mosquitoes are migrating only when there is evidence of mosquito-borne epizootic activity at a level suggesting high risk of human infection. The following are examples of this type of evidence: high dead bird densities; high mosquito infection rates; multiple positive mosquito species including bridge vectors; horse or mammal cases indicating escalating epizootic transmission, including bridge vectors, horse or mammal cases, or a human case with evidence of epizootic activity.

Reducing vector densities below transmission threshold usually requires multiple ULV applications. Therefore, triggers should take into account this latency effect so that human transmission is not proceeding prior to or during operations. This presupposes identifying increasing human risk at least 2 weeks before human cases might present. Trigger design and implementation should reflect this need for preemptive adulticiding.

BMPs for adulticides:

1) Meteorological conditions:
    - Check wind speed and direction before spraying and be observant of all changes in direction and speed during the application. Use appropriate wind indicators. Gauges are highly recommended for ground applications and smoke for aerial applications.
    - For aerial applications, check temperature at different elevations to decide if there is an inversion.
    - Spray only when wind is away from sensitive sites.
    - Dusk or dawn is the recommended time to spray when mosquitoes are out.

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An assessment of mosquito breeding and control in four surface flow wetlands in tropical-subtropical Australia

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Abstract In Queensland, Australia, the tropical-subtropical climate is ideal to promote macrophyte growth in surface flow wetlands; however, there have been concerns that constructed wetlands are potential breeding sites for disease-bearing mosquitoes. The aim of this study was to assess whether mosquitoes were breeding in these constructed wetlands, and if so, where they breed, and what parameters might influence breeding: e.g. water quality, vegetation, or macroinvertebrate communities. A study of four surface flow constructed wetlands located in different climatic regions was undertaken. Mosquito larvae were sampled using 240 ml dippers and macroinvertebrates using dip nets. The wetland with the greatest biodiversity of macrophytes and macroinvertebrates had the least number of mosquito larvae (< 1% of all dips). Samples with most mosquito larvae occurred amongst dense mats of *Paspalum* grass or dead *Typha*. Despite the presence of larvae in some parts of these wetlands very few late instars or pupae were found i.e. completion of the mosquito life cycle to adult mosquitoes was unsuccessful.

This study has shown that the presence of mosquito larvae can be minimised by increasing macroinvertebrate biodiversity, by planting a variety of macrophyte types and species, excluding aggressive plant species, and maintaining at least 30% open water. Macroinvertebrates are probably a crucial factor in the control of mosquito larvae ensuring that predation of the early instars prevents or limits the development of pupae and the emergence of adults.

Keywords Constructed wetlands; macroinvertebrates; macrophytes; mosquitoes; predation

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Introduction

An awareness of healthy waterways and water re-use has created the need to develop and implement wastewater management strategies which are economically and ecologically sustainable. Constructed wetlands are an excellent option for water quality improvement particularly where land is available. Constructed wetlands for wastewater treatment are designed as ecological systems. Water quality enhancement is achieved through a combination of physical, chemical and biological processes facilitated by the plants and micro-organisms. Freewater Surface Flow (FWS) constructed wetlands are similar to many natural wetlands with plants being the most conspicuous feature. As ecological systems they support a variety of living organisms: plants, algae, macroinvertebrates, vertebrates, and a plethora of micro-organisms. However, the plants and animals living in FWS wetlands must be adapted to permanent flooding and often eutrophic water quality.

In Australia surface flow constructed wetlands for the treatment of municipal wastewater and urban stormwater are multi-functional providing wildlife habitat, landscape enhancement, water storage and flood mitigation (Greenway and Simpson, 1996; Greenway, 2000). Despite these benefits to wildlife and humans, concerns have been raised by government authorities and the community that surface flow wetlands may be potential breeding sites for disease-bearing mosquitoes (NHMRC, 1998; QDNR, 2000). These limitations are also recognized by the USEPA 2000 "While a constructed wetland's attractiveness to wildlife may be regarded as a benefit to the human community, the potential for breeding mosquitoes can be an obstacle to permitting, funding, siting of a constructed wetland" p.17. This view is also shared by entomologists (Walton *et al.*, 1998; Walton, 2002; Russell, 1999). Medical entomologists have claimed that constructed wetlands are directly responsible for an increased risk of disease due to an increase in mosquito breeding habitat; however, not all species of mosquito are disease vectors or nuisances. Most mosquitoes are opportunistic breeders and if a suitable body of water is available they will deposit eggs. However, mosquito larvae are an integral component of aquatic food webs (US-EPA, 2000; Greenway and Simpson, 1996; Greenway, 2000). Thus, the critical and significant issue is whether the larvae survive and whether adult mosquitoes emerge from pupae. It is the authors' view that if constructed wetlands are designed to function as wetland ecosystems with a diversity of aquatic organisms, then it is likely that the predator/prey mix would control mosquito breeding. If health risks can be avoided, this will increase public acceptance of the value of constructed wetlands for the treatment of wastewater. This is of particular significance to the wastewater industry since in order to promote the concept of constructed wetlands they must also demonstrate that risks of mosquito-borne disease are minimal.

Observations by the first author indicated that mosquito breeding was not a problem in the nine pilot scale wetlands in Queensland (Greenway and Woolley, 1999), however this needed to be quantified. A study commenced in November 1999 to investigate whether mosquito breeding was occurring in four surface flow constructed wetlands. The aim of the study was to determine if these constructed wetlands provided a suitable habitat for successful larval development of mosquitoes, and to try and identify which factors either prevent or encourage larval development.

Methods

Site description – wetland design and water quality

Four surface flow constructed wetlands at different geographical locations with different climatic conditions were selected for this study. Cairns, coastal northern Queensland (tropical-wet); Blackall, inland central Queensland (arid); Cooroy (Noosa Shire), south east coastal Queensland (subtropical-wet); and Rosewood (Ipswich City Council) inland south east Queensland (subtropical-dry).

The Cairns Wetland was constructed in 1994 and was originally band planted with a diversity of species. *Typha* spread rapidly and now covers 60% of Channel 1, 100% of Channel 2 and 70% of Channel 3; the remainder is predominantly *Eleocharis*; water depth is 40–50 cm. It receives secondary effluent after passing through an oxidation ditch. Water quality is low in ammonia but high in phosphorus (Greenway and Woolley, 1999, 2001).

The Blackall Wetland was constructed in 1993 and planted with six local species. The original depth of the channels was 50 cm, however in 1999 the channels were deepened to 1.5 m with steep vertical banks (along one or both sides), except at the inlet and outlet sections. *Typha* and floating rafts of *Paspalum distichum* now dominate these shallow areas; however, 60–95% of the channels are open water. Channel 1 is 95% open water with a narrow band of *Typha* at the inlet and outlet section and along the perimeter on one side. Channel 2 is 75% open water with *Typha* at inlet and outlet sections and floating rafts of *Paspalum distichum* and *Persicaria attenutum*. Channel 3 is 60% open water; 30% is a dense raft of *Paspalum* and *Persicaria*, and 10% *Typha*. Channel 4 is 95% open water with small patches of *Typha* and isolated clumps of *Paspalum*. It receives secondary treated effluent (Greenway and Simpson, 1996; Greenway and Woolley, 1999).

The Cooroy Wetland near Noosa is the largest wetland. The first wetland was built 1995 and consists of three large cells linked by pipes. The second wetland of similar dimensions was built in 1999. Each cell is separated by septa into sections producing a sinusoidal flow path. Cell 1 is shallow (20–40 cm) throughout. Cell 2 and Cell 3 each have a deep pond

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(1–2 m) in the first section (30 m length), the remainder is shallow. The wetland supports a diversity of plants. The secondary effluent is treated by a trickling filter followed by alum dosing (to remove phosphate by precipitation), it then flows into an open water lagoon prior to release into the wetlands.

The Rosewood Wetland near Ipswich was built in 1995 and consists of 4 rectangular cells. Cell 1 is a deep open water lagoon (150 cm); Cells 2 and 3 are surface flow wetlands dominated by a wide band of *Typha* around the periphery, with a deeper open water pond in the centre; Cell 4 is a subsurface flow wetland planted with *Phragmites australis*. The wetland receives primary settled effluent which flows into Cell 1 where further settling takes place, before discharge into the vegetated cells.

Water depth, temperature and dissolved oxygen were recorded at each sampling station. Annual temperatures ranged from 15°C to 27° at Cooroy and from 22° to 30° at Cairns. Dissolved oxygen was highly variable – varying seasonally, diurnally, with depth and vegetation. Open water areas had the highest DO (up to 16 mg/L). Cairns recorded 13 mg/L amongst submerged pond weed (*Ceratophyllum*) and algae. DO decreases with depth to negligible values amongst or beneath dense or dead vegetation.

Field sampling

At each site a minimum of three sampling stations were established in each channel or cell. Where possible these were located where there was vegetation. At Blackall, Rosewood and Cooroy, open water sections and storage lagoons were also sampled. Vegetation in the wetlands was recorded according to species, type and percentage cover.

Mosquito larval distribution was assessed by taking 10 surface dips, using a 240 ml dipper, at each station. Mosquito larvae numbers were counted and for each dip categorised into: no larvae (0), 1–10 larvae, 11–40 larvae and greater than 40 larvae. In addition the developmental stage of the larval instars – 1st, 2nd, 3rd, 4th and pupae were noted. Where possible the larvae were identified to species. Dip nets were used to sample the aquatic biota by swoops conducted within a 2 m radius of each station. Water depth, temperature and dissolved oxygen were recorded.

Results

Macrophytes

A summary of the categories of macrophyte types and the overall percentage cover vegetation is given in Table 1. For details of plant species refer to Greenway *et al.* (2002).

Cooroy had the greatest species richness with a total of 38 species. Of the emergent macrophytes the most abundant species were the sedges *Baumea articulata, Baumea rubiginosa, Lepironia articulata, Schoenoplectus validus* and the flowering *Phylidrum lanuginosum*. The diversity of species can be attributed to direct planting, natural colonisation and active management to remove invasive weed species. The shallow depth 20 cm for most cells is optimal for the growth of these emergent species. The deep cells (1.5–2 m) were suitable for water lilies and submerged species.

Table 1 Macrophyte species richness in the four surface flow constructed wetlands

Macrophytes	Cooroy	Cairns	Blackall	Rosewood
Emergents	23	10	4	3
Attached with floating leaves	7	8	1	1
Free floating	4	6	3	3
Submerged	4	1	–	–
Total species	38	26	8	7
% cover	70%	95%	10%	95%

Cairns had 26 species; however, *Typha* was the dominant species forming dense mono-specific stands of live and dead shoots in all three channels. Only two channels had sections which had not been completely colonised by the spread of *Typha*. In Channel 3 these sections were dominated by *Eleocharis sphaceolata;* in Channel 1 there were sections of *Eleocharis, Schoenoplectus* and *Paspalum*. *Ceratophyllum* occurred beneath the *Schoenoplectus*.

Rosewood was also dominated by *Typha* which formed dense stands of live and dead shoots, isolated clumps of *Baumea articulata* extended into the deeper centre of Cell 2 and clumps of *Cyperus* sp occurred at the margins. The channels at the Blackall wetland were mostly free of vegetation except for the shallower inlet and outlet sections which contained *Typha*. Dense mats of water couch *Paspalum distichum* and knotweed *Persicaria attenuatum* had formed in sections of Channels 2 and 3.

Macroinvertebrates

A summary of the total number of macroinvertebrate taxa in the major classes is given in Table 2 – for a complete list of these taxa identified to family, genus and species refer to Greenway *et al.* (2002). Cooroy had the greatest species richness, in particular the larval stages of dragon flies (*Epiproctomorpha*), damsel flies (*Zygoptera*) and caddis flies (*Trichoptera*), and pond snails. Cooroy and Rosewood both had large numbers of water beetles. Macroinvertebrate sampling at Cairns was limited to three collections, hence species richness at Cairns is much lower than expected.

Mosquitoes

Ten species of mosquito larvae were identified: *Anopheles annulipes*, *Culex annulirostris*, *C. australicus*, *C. gelidus*, *C. halifaxii*, *C. squamosus*, *Culicinae* sp., *Uranotaenia* sp., *Verrallina carmenti* and *V. lineatus*. All species were found at Cairns. Only *C. annulirostris* is a known vector of Ross River virus. Larvae of this species and *C. annulipes* were found in all four wetlands.

A summary of the relative abundance of mosquito larvae based on the percentage number of dips containing either no larvae, less than 10 larvae, 11–40 larvae or more than 40 larvae is given in Table 3. At Cooroy less than 1% of dips in Cells 2 and 3 contained any larvae; 2% of dips in Cell 1 contained larvae and these were only found at the sampling station with dense *Phragmites* and overgrown mats of *Paspalum* grass. At Blackall all sampling stations in Channel 1 were open water and only 0.5% of dips contained larvae. In Channels 2 and 3 the mid station was open water but the other two stations contained either *Typha* or isolated *Paspalum* clumps; the dips with > 40 larvae were sampled from within the *Paspalum* clumps. Channel 3 had the greatest cover of vegetation (40%) – with

Table 2 Major macroinvertebrate taxa present in the four wetlands

Taxa	Cooroy	Cairns	Blackall	Rosewood
Gastropoda (snails)	8	2	1	
Annelida (worms/leeches)	3	1	5	2
Crustacea (copepods, ostrarods)	5	4	3	3
Ephemeroptera (May flies)	3	3	1	
Epiproctomorpha (dragonfly)	17	8	3	
Zygoptera (damsel fly)	8	4	2	1
Hemiptera (water bugs)	8	6	9	4
Diptera (flies/mosquitoes)	9	11	5	8
Coleoptera (water beetles)	19	4	8	18
Trichoptera (Caddisfly)	7		1	
Total taxa	87	43	38	36

Table 3 Relative abundance (% of dips) of mosquito larvae

	Location	# Dips	No larvae	< 10 larvae	11–40 larvae	> 40 larvae
Cooroy:	Cell 1	210	98%	2%	–	–
	Cell 2	210	99.5%	0.5%	–	–
	Cell 3	210	99%	1%	–	–
Cairns:	Channel 1	40	80%	17.5%	–	2.5%
	Channel 2	40	87.5%	12.5%	–	–
	Channel 3	40	80%	17.5%	2.5%	–
Blackall:	Channel 1	220	99.5%	0.5%	–	–
	Channel 2	210	95%	2%	–	3%
	Channel 3	190	84%	14%	2%	–
	Channel 4	200	96.5%	3.5%	–	–
Rosewood:	Cell1 pond	200	95%	5%	–	–
	Cell 2 Typha	170	68%	25%	6.5%	0.5%
	Cell 3 Typha	140	54%	40%	6%	–

dense stands of *Typha* and floating mats of *Paspalum* and *Persicaria*, 16% of dips contained larvae. All dips with larvae were sampled at the station with the floating mats of vegetation.

At Cairns 10–20% of the dips contained larvae. Only 1 dip contained 11–40 larvae and 1 dip contained > 40 larvae and these both occurred on the same sampling day. All samples were taken at stations with dense stands of live and dead *Typha*.

At Rosewood the open water settlement pond (Cell 1) recorded the least larvae (5% of dips), whereas the vegetated cells had the highest number of larvae: 32% of dips in Cell 2 and 46% of dips in Cell 3. Most of these larvae were concentrated in the dense stands of *Typha* with dead submerged stems and leaves, around the shallow edge of the cells. At each of the 4 wetlands 70–90% of the larvae found were early instars (1st and 2nd stages) and less than 1% were pupae.

Discussion

Macrophytes facilitate water treatment in constructed wetlands but they are also essential for ecosystem functioning. Sustainable populations of organisms are dependent upon habitats that provide the attributes for a species complete life history. Wetland plant diversity is important for determining macroinvertebrate associations (De Szalay and Resh 2000) and wildlife diversity (Knight *et al.*, 2001) because of the creation of habitats and food resources. Wetzel (2001) noted that the most effective wetland ecosystems "are those that possess maximum biodiversity of higher aquatic plants and periphyton associated with the living and dead plant tissue". In constructed wetlands macroinvertebrate biodiversity is also enhanced by good water quality – secondary or tertiary treated effluent, and aerobic conditions.

Our study of four surface flow constructed wetlands found that the Cooroy wetland with shallow marsh and deeper ponds had the greatest species richness of macrophytes (38 species) and macroinvertebrates (90 taxa) and the lowest occurrence of mosquito larvae (< 1% of dips). The Cairns and Rosewood wetlands dominated by dense monospecific stands of *Typha* had fewer macroinvertebrate taxa (47 and 38 respectively) and a higher proportion of mosquito larvae (20% of dips at Cairns and 40% of dips at Rosewood). The Blackall wetland was mostly open water with small stands of *Typha* and sections with floating mats of water couch (*Paspalum*) and 41 macroinvertebrate taxa were found. Less than 0.5% of dips in the open water channels contained mosquito larvae whereas 16% of dips from amongst the *Paspalum* had larvae. A marsh with a diversity of macrophytes appears optimal for macroinvertebrate biodiversity and the control of mosquito larvae by predation.

Dense stands of *Typha* with an accumulation of submerged dead stems and isolated pockets of water are suitable for mosquito breeding. Similarly dense floating mats of *Paspalum* grass and *Perscicaria* are also suitable for mosquito breeding but of limited habitat value for many macroinvertebrates due to the lack of swimming space and low dissolved oxygen. Mosquito larvae are surface breathers and can survive in anaerobic conditions, however many aquatic macroinvertebrate predators are also surface breathers, e.g. notonectid bugs, water beetles, or surface predators e.g. pond skaters. Predation is best avoided if the mosquito larvae can isolate themselves from predator access. Orr and Resh (1992) found that dense beds of *Myriophyllum aquaticum* were a primary habitat for *Anopheles* larvae where they survive in microhabitats. Walton (2002) noted that in the arid south western United States, constructed treatment wetlands can increase mosquito production if there is poor water quality and dense coverage of submerged dead vegetation. An abundance of notonectids in the settlement pond (Cell 1) at Rosewood probably accounted for low numbers of mosquito larvae.

Despite the presence of more mosquito larvae at Rosewood and Cairns the low numbers of 3rd/4th instars and pupae suggests predation. Walton and Workman (1998) attributed the lack of late instars in a Californian constructed wetland to invertebrate predators, mostly notonectid bugs.

There is limited published material on the ecological characteristics of constructed treatment wetlands, in particular with respect to aquatic invertebrates. Knight *et al.* (2001) summarised some of the key findings of the North American Treatment Wetland Database (NADB v 2.0) with respect to quantitative data on habitat, wildlife, human uses and ecological risks. Martin *et al.* (2001) conducted an ecological survey of a cypress-gum swamp forest in Florida that had been receiving secondary treated effluent since 1984. In addition to biological monitoring for vegetation, benthic macroinvertebrates and fish, they also monitored mosquito larvae and pupae in the summer months from stations that were 70% vegetation cover. Although direct quantitative comparisons cannot be made with the present study due to different methods of recording larval abundance they noted that "the number of immature mosquitoes collected at each station was typically low". Using twenty 450 mL dippers at each station they recorded an average number of larvae between 143–527/m^3, i.e. 0.64–2.4 larvae per dip. They also noted that macroinvertebrate density measured using Hester-Dendy samplers was also low. They attribute low dissolved oxygen as the most significant factor affecting macroinvertebrate populations. The wetland supported a diverse and abundant fish population which Martin *et al.* suggest "appears to provide a significant control on mosquito populations" p.323.

The exotic mosquito fish *Gambusia holbrooki* was found at Cooroy and Blackall where it was deliberately introduced to control mosquitoes. However the effectiveness of *Gambusia* in the control of mosquito larvae in Australian wetlands and waterways has not been scientifically proven with mosquitoes only making up a small part (< 10%) of their diet. "Several authors have observed that gambusia may actually encourage mosquito populations by preying on their invertebrate predators" (NSW-NPWS 2002). As with most introduced species *Gambusia* is competing with native species for food and habitat. The Cairns wetland supported a large tadpole (and frog) population probably due to the absence of *Gambusia*.

Walton and Workman (1998) conducted a comparative study of mosquito larvae and macroinvertebrates in two structurally different constructed wetland cells. Design 1 consisted of a shallow (0.5 m) densely vegetated marsh (*Schoenoplectus californicus*); design 2 had shallow inlet and outlet marshes separated by a section of deeper (1.2 m) open water. Larvae were sampled in the vegetated sections of both designs. Larvae abundance was higher in design 1 and contained proportionately more later (3rd/4th stage) larval instars.

Average larval numbers ranged from 10 per dip (400 ml) in early summer to less than 1 per dip in late summer in design 2, and from 40–60 per dip in early summer, to 2–5 per dip in later summer, in design 1. Predatory macroinvertebrates (notonectids, dragonfly nymphs, beetle larvae) were more abundant in early summer in design 2. Differences in larval abundance were attributed to larger populations of predators in design 2 facilitated by habitat preference for open water – particularly for notonectids.

Our study has also shown that maximum biodiversity of macrophytes and macroinvertebrates, and minimal mosquito larvae survival can be achieved by having a combination of shallow marsh vegetation (20–40 cm depth) with no more than 70% plant cover and deeper (1–1.5 m) open water ponds. Aggressive plant species such as *Typha* and *Phragmites* should not be planted unless they are managed to prevent spreading and the build-up of submerged layers of dead leaves and stems. Harvesting may be a management option. Plant species that produce thick floating mats such as *Paspalum distichum* (water couch) and *Persicaria* sp (knotweeds) should also be discouraged as they cause anaerobic conditions in the underlying water column, provide pockets of stagnant water for mosquitoes to breed and prevent predator access. Greenway (2003) has reviewed the suitability of macrophytes in surface flow wetlands in tropical-subtropical climates, with genera such as *Schoenoplectus, Lepironia, Baumea, Phylidrum* and *Bolboschoenus* providing alternatives to *Typha* and *Phragmites*.

The management of wastewater must be consistent with protection of risks to human and animal health from mosquito-borne disease. Constructed wetlands should be designed to optimise wastewater treatment and ecological benefits to wildlife while minimising the potential for nuisance conditions such as mosquito breeding. Invertebrate predation is an important method for mosquito control. The value of constructed wetlands as low cost alternatives to traditional wastewater treatment facilities has even greater significance in populated developing countries such as Africa and India where there is limited wastewater treatment. Constructed wetlands in these countries offer an economical solution to wastewater treatment providing they can be assured that other health risks such as mosquito-borne diseases are eliminated.

Conclusion

This study of four surface flow constructed wetlands in Queensland, Australia has shown that the Cooroy wetland has the greatest species richness of macrophytes and macroinvertebrates and the lowest occurrence of mosquito larvae, suggesting that vegetation diversity (type, species and cover) is a significant factor in the control of mosquito breeding in constructed wetlands. Both the Cairns and Rosewood wetlands were dominated by dense monospecific stands of *Typha* and had a large build-up of dead organic matter – stems and leaves, beneath the surface. These woven mats of leaves formed small isolated pockets of water suitable for mosquito larvae development. These isolated pockets make it harder for predator access as well as having low dissolved oxygen concentrations associated with microbial decomposition of dead organic matter. At Blackall mosquito larvae were of greatest occurrence amongst the dense mats of *Paspalum* grass – again the interwoven stems and roots restricting predator access, but very few larvae occurred in the open water sections.

Our study showed that although mosquitoes lay eggs in the wetlands and these hatch into larvae, very few larvae are likely to emerge as adults due to predation of the early instars. There needs to be wider recognition that mosquito larvae are an integral component of wetland ecosystems, and providing ecosystem functioning is maintained, then predator-prey relationships will ensure the control of mosquito breeding. Wetland design and maintenance is necessary to ensure wetland ecosystems support a diversity of macroinvertebrate predators. In Australia the introduction of the mosquito fish *Gambusia* is not recommended. Public acceptance that constructed wetlands are multi-functional systems providing benefits for human use, wildlife and downstream aquatic ecosystem health, will ensure that these treatment systems become an integral component of our urban landscape.

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Managing Mosquitoes in Surface-Flow Constructed Treatment Wetlands

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Constructed treatment wetlands can provide cost-effective water quality treatment and may provide other benefits such as wildlife conservation, wetland habitat enhancement, and sites for public education and recreation. However, man-made wetlands used to treat municipal or agricultural wastewater as well as storm water often produce mosquitoes, which are a public health concern. Design features that are thought to be necessary for water quality improvement, such as shallow water and dense emergent vegetation, can cause significant mosquito production. Because many bird species are reservoirs for viral pathogens that cause diseases in humans and domesticated animals, the attraction of large numbers of birds to constructed wetlands also increases the risk of transmission of mosquito-borne viral infections to susceptible bird populations living near human residences and to humans and companion animals. The potential for conflict between wetland operators or managers and agencies charged with protecting public health is typically highest near areas of residential development and in arid regions where mosquito populations are naturally low.

This publication discusses how the design and operation of surface-flow wetlands constructed primarily for water quality improvement can contribute to issues related to high populations of mosquitoes. Subsurface-flow wetlands, another type of constructed treatment wetland, are not discussed here. Surface-flow wetlands most often appear similar to a marsh containing emergent vegetation (fig. 1). Many of the recommendations discussed here also apply to man-made wetlands intended for uses other than water quality improvement. Incorporating design features to minimize mosquito production can significantly decrease mosquito abundance, lower the costs of mosquito control, and may lessen legal liability.

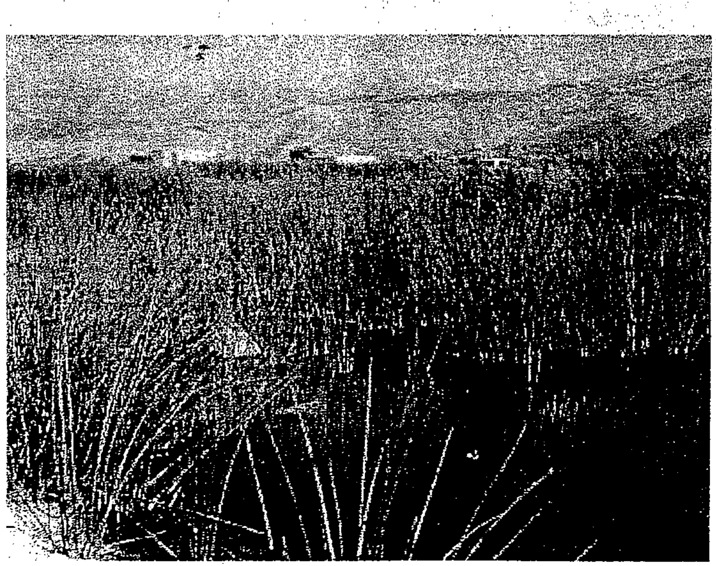

Figure 1. A constructed treatment wetland incorporating a mixture of emergent macrophytes in shallow marshes and deep-water zones. Photo: William E. Walton.

TREATMENT WETLAND SITING

Most treatment wetlands must be built near the wastewater source because conveyance of wastewater and storm water over long distances is expensive and impractical. Several excellent publications listed in the bibliography highlight the factors to be considered when siting a wetland and describe the engineering principles that should be considered in the design of a wetland for water quality improvement.

Surrounding land uses and the potential for mosquitoes to move from a wetland into residential and commercial zones must be considered when siting a wetland. A conflict will be created over time if suburban sprawl encroaches on treatment wetlands in rural areas. Also, the area circumscribed by a wetland underestimates the potential region affected by mosquitoes because adult mosquitoes effectively disperse up to several miles from their developmental sites.

Buffer zones between human developments and adjacent mosquito habitation sites have been recommended by public health officials outside the United States to extend 1 to 1¼ miles (1.5 to 2 km), but larger buffer zones of 3 miles (5 km) or more may be needed in situations where resident mosquito species disperse readily. Strong prevailing winds can move swarms of biting adult mosquitoes up to 10 miles (16 km). Active mosquito abatement is generally carried out within a 1-mile radius of a human residential area if active sites of mosquito production are nearby. There is currently no established criterion in California for determining the size of a buffer zone around a treatment wetland. Typical distances reached by 90 percent of the mosquitoes emerging from a freshwater treatment wetland might range from ½ to 3 miles (1 to 5 km), but a buffer zone of this size may not be sufficient to avoid legal abatement.

Figure 2. A technician samples mosquitoes in a constructed treatment wetland using a dipper. The dipper is similar to a ladle and holds 12 to 15 ounces (350 to 450 ml) of water. Dipping is a standard sampling technique for immature mosquitoes. This technician is using a head shield and DEET-based repellent on his shirt and arms to help avoid mosquito bites while sampling during a period of high mosquito production in the summer. Photo: William E. Walton.

PRETREATMENT TO MINIMIZE MOSQUITO PRODUCTION

Poor water quality tends to increase the production of mosquitoes. High levels of organic matter and nutrients, particularly reduced forms of nitrogen such as ammonia, are thought to provide nutrients for the bacteria and algae used as food by mosquito larvae. The decomposition of organic matter and conversion of ammonium to other forms of nitrogen in the nitrogen cycle require considerable amounts of oxygen, which can lead to low dissolved oxygen concentration and can create unsuitable conditions for aquatic mosquito predators such as predatory insects and fish.

Wastewater may require pretreatment before discharge into a treatment wetland, and the level of pretreatment is an important consideration in the size of a treatment wetland. Studies to date indicate that discharge of raw or primary-treated municipal wastewaters into a vegetated lagoon or shallow vegetated wetland can result in mosquito larval abundance from several hundred to over 1,000 larvae per 400-milliliter dip sample (fig. 2). Pretreatment to secondary standards may limit average densities to fewer than 200 mosquito larvae per sample (fig. 3), but these levels far exceed

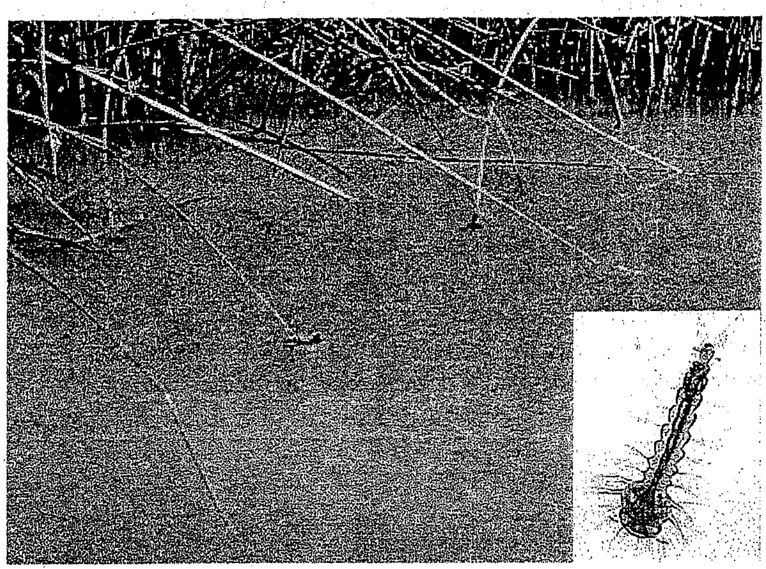

Figure 3. An aggregation of foul water mosquitoes *(Culex quinquefasciatus* and *Culex stigmatosoma)* near the outflow of secondary-treated sewage entering a constructed treatment wetland. The western encephalitis mosquito *(Culex tarsalis)* and tule mosquito *(Culex erythrothorax)* are prevalent within the vegetation. Insert: Close-up of a mosquito larva. Photos: William E. Walton.

acceptable mosquito abundance, particularly when humans live nearby. Where threshold values for intervention against mosquitoes are in place for seasonally flooded and treatment wetlands, they range from average densities as low as 0.2 to 0.5 mosquito larvae (*Culex* and other species) per dip sample to 5 mosquito larvae per dip sample. Although pretreatment before discharge into a treatment wetland may reduce mosquito production, it does not guarantee against mosquito presence.

TREATMENT WETLAND DESIGN AND OPERATION

Wetland Cell Layout

Compartmentalization of a wetland reduces mosquito abatement and wetland maintenance and management costs. By focusing mosquito abatement efforts on a comparatively small portion of the wetland and incorporating design features that facilitate effective mosquito control from the perimeter of the wetland (fig. 4), the cost of mosquito abatement decreases significantly as compared to mosquito abatement using fixed-wing aircraft or helicopters to dispense mosquito control agents across the entire wetland. In the southwestern United States, the cost in 1998 for applying mosquito control agents was $2,100 to $2,700 per acre per season for a 15- to 25-acre (6- to 10-ha) thickly vegetated, single-basin wetland receiving municipal wastewater that had undergone secondary treatment (Walton 2002). (These costs were based on contractual agreements for commercial pest control services; surveillance is not included.) Costs can be significantly reduced when aircraft are not needed and mosquito abatement can be focused in compartmentalized wetlands receiving high-quality municipal effluent. For example, the cost of mosquito

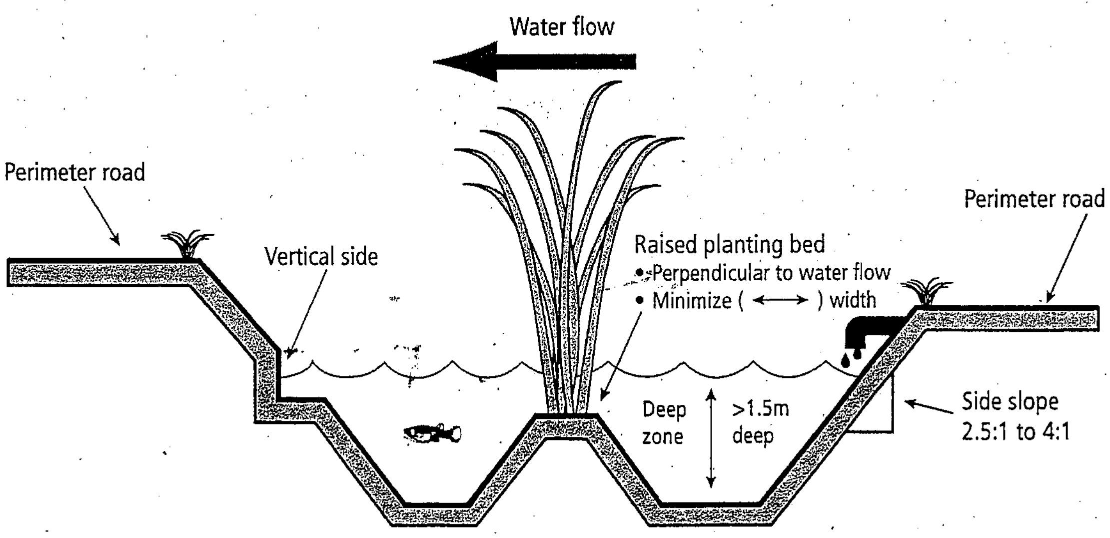

Figure 4. Cross-section of a constructed treatment wetland incorporating features that reduce mosquito production. Alternative designs for perimeter berms are illustrated. Note: drawing is not to scale.

abatement for a compartmentalized 490-acre (198-ha) treatment wetland in 2000 was approximately $25 per acre per season.

The maximum distance across the wetland cell surface should not exceed two times the effective distance of standard truck-mounted mosquito abatement equipment (about 20 feet [6 m]). Mosquito abatement for wetland cells that are larger than 40 feet (12 m) with roads on both sides may require special equipment and extra labor, which quickly increase the cost of mosquito control.

The costs of land, berm construction, water conveyance structures, and other features required to compartmentalize wetlands must be weighed against lower potential costs for maintenance and management as well as for mosquito abatement. A minimum of two parallel wetland cells is required to continue water treatment when one cell is removed from operation. Increased redundancy of water flow through a greater number of parallel-flow paths enhances operational flexibility but may also significantly increase land and construction costs. Wetland cells may also be arranged in series for tiered designs on hillsides or to ensure and enhance water treatment when high-quality outflow is required. Combinations of parallel and series flow regimes, as well as blending incoming water with water recycled from the wetland effluent, can enhance water treatment and improve the flexibility of the flow regime.

Water Depth and Flow Rate

Shallow water (less than 6 inches [15 cm] deep), thick vegetation, and poor water quality (e.g., high biological oxygen demand, high concentration of reduced forms of nitrogen) are virtually guaranteed to create mosquito problems. Water depths over 12 inches (30 cm) can reduce the health and growth of emergent plants in treatment wetlands and discourage mosquito production. However, based on limited experimental evidence, the deeper water also may be less effective in wetland treatment performance. Overall, water depths more than 3 to 4 feet (1 to 1.2 m) may be required to reduce the proliferation of emergent vegetation and create conditions that effectively limit mosquito production.

Water deeper than 5 feet (1.5 m) (see fig. 4) is often recommended for limited areas of treatment wetlands because deep water zones

- help maintain plug flow by mixing and redistributing water flowing from shallow emergent marsh areas where short-circuiting may occur
- enhance wind-driven oxygenation of water, which is important when treating poor-quality water with high oxygen demands
- limit the area in the wetland colonized by emergent vegetation
- provide a sump for particulate matter
- create conditions that are less conducive for mosquito production.

Waves and water disturbance in open water zones are not favorable to mosquito egg laying and can drown immature mosquitoes. Open water zones also enhance predation by fish and other fauna on mosquito larvae and pupae. Nevertheless, treatment wetlands containing nearly complete surface coverage by vegetation and shallow water are still being proposed despite ample evidence of greater mosquito control problems, generally poor water quality performance, and comparatively lower wildlife value as compared to wetlands with mixed water depths and 50 percent, or less, emergent vegetation coverage.

For water quality improvement, water depth is an important aspect of treatment wetland design because it affects plant growth, diffusion distance, and hydraulic residence time. Water depths over about 2 feet (60 cm) cause pond or shallow lagoon conditions, which are not favorable for some water treatment needs and do not provide all of the treatment benefits of emergent vegetation in wetlands. Shallow water depths may increase linear flow velocities and shorten diffusion gradients, which is important for atmospheric or sediment exchange of gaseous and dissolved pollutants as well as substances such as atmospheric oxygen, but these benefits are lessened in zones of thick vegetation. The dissolved oxygen concentration in thick vegetation is typically very low (approximately 0 mg/liter). Redox reactions favor mobilization of nutrients and other pollutants, and while low oxygen concentrations promote nutrient removal via denitrification they also promote mosquito production by reducing the effectiveness of mosquito predators. Moreover, shallow water (less than 6 inches [15 cm] deep) may cause incomplete flooding of wetland cells that have not been graded to precise elevation tolerances.

Whereas high flow velocities are known to reduce mosquito survival, a quantitative relationship between flow velocity and mosquito production does not currently exist. Mosquito production can occur from nearly any quiescent body of water, such as backwaters, more or less isolated pools, and marshy areas of streams and rivers.

Wetland Grading and Bottom Slopes

A bottom slope of 0.01 to 0.05 percent is recommended for wetlands if dewatering is needed for vegetation management and mosquito abatement. Bottom slopes must permit effective drainage yet not expose substrate to mosquito oviposition during operational fluctuations in water level or disrupt the maintenance of a consistent water depth. Constructed treatment wetland cells can be graded to small tolerances in elevation (variation as low as 1.2 inches [3 cm]) using laserleveling, whereas typical grading practices may provide variation within 6 inches (15 cm) of design specifications. Bottom slopes of 0.01 to 0.03 percent have been recommended for mosquito source reduction in irrigated agriculture. Bottom slopes in treatment wetlands typically range from 0 to about 0.5 percent.

Wetland Side Slopes

For mosquito control, steep embankments from 2.5:1 to 4:1 (horizontal:vertical; see fig. 4) adjacent to deep water are more effective than edges of shallow water containing extensive emergent vegetation. Steep slopes reduce the amount of emergent vegetation coverage, allow better access to immature mosquitoes by aquatic predators, and favor environmental factors such as wave action that decrease mosquito survival. Steep sides also limit the amount of wetted substrate favorable for oviposition by floodwater mosquitoes that is created by operational fluctuations in water level. The aspect ratios of side slopes should be compatible with mowing, levee maintenance, and safety concerns. Furthermore, the side slopes of levees and berms should adequately support movement of vehicles used for mosquito control along the top of the levee. While steeper side slopes cost less to construct than do shallow slope berms because steep slopes require a smaller volume of earth, steep slopes may be prone to erosion by wave action and slumping prior to establishment of groundcover.

If gently sloping embankments or peripheral-vegetated zones are needed to fulfill one or more goals for wetland use, the area potentially colonized by emergent vegetation should be minimized. Side slopes of 5:1 to 10:1 encourage thick emergent vegetation that lessens the effectiveness of mosquito abatement. Peripheral vegetation zones should be restricted to narrow widths (less than 3 feet [1 m]) or should be designed to meet the minimum needs of wildlife under consideration.

Hydrological Control

Design features and operational procedures that effectively spread and move water throughout the wetland are important for both water treatment and mosquito control. Maintenance of water conveyance structures and the ability to drain sections or the entire wetland for maintenance and emergency situations is needed. If places in the wetland cannot be drained completely, mosquito control and wetland maintenance will be compromised. Wetland managers should know the period required for complete draining and assure that valves, weirs, and other structures necessary to move water and set water depth are properly maintained. A plan for emergency draining should be developed that addresses questions such as: Where will the water be put? Are pumps required? Are permits required to discharge the water from the wetland?

An ability to change the water level can be an important feature for mosquito control in wetlands that support submerged vegetation. Occasionally raising water levels above submerged macrophytes exposes mosquito larvae to predators.

Vegetation Selection to Minimize Mosquito Production

The emergent macrophytes commonly planted in man-made wetlands have been associated with high levels of mosquito production. Even though cattails (*Typha* spp.), bulrushes (*Schoenoplectus* [= *Scirpus*] spp.), and common reed (*Phragmites australis*) have been classified as less-desirable macrophytes for nontidal wetlands, there is currently no one plant species that is highly recommended for fulfilling the multiple functions of wetland vegetation (see Collins and Resh 1989). Dense stands of emergent plants are thought to be important for the water quality performance of wetlands, but the species composition of the wetland plant community appears to be less important than the density and net biomass production of the plants. In addition to being implicated in encouraging mosquito production, dense stands of emergent vegetation reduce the effectiveness of mosquito control agents by inhibiting the penetration of aerial or water-based applications of standard larval mosquito control agents.

Plant Harvesting and Removal

Vegetation management is generally expensive; incorporating wetland design features that minimize vegetation coverage is more effective than routine plant harvesting and removal. Mechanical harvesting and controlled burning are two practices commonly considered for vegetation management in treatment wetlands. Mechanical harvesting has been recommended instead of burning when vegetation management is needed; but in 1998, for example, vegetation removal by mechanical harvesting cost as much as $5,000 to $7,000 per acre (Walton 2002). In addition to the costs associated with removing and disposing of harvested plant biomass, the mechanical equipment needed to harvest dried macrophytes is very disruptive to treatment wetlands. The drying of wetland soils and movement of heavy equipment for harvesting disrupts organically-rich wetland soils and can cause the export of significant quantities of accumulated pollutants from a treatment wetland following vegetation management.

Removing vegetation from shallow basins gives at best a short-term reduction of thick vegetative coverage in treatment wetlands, and it has been shown in some recent studies (Jiannino 2001; Thullen et al. 2002) to be ineffective for reducing mosquito populations as well. Plant regrowth rapidly replaces harvested vegetation. The reduction of macrophyte rhizome density in the substrate after burning does not offer significant benefits for long-term vegetation reduction over burning alone. Mosquito populations, particularly *Culex* species, are enhanced by the drying and disturbance of wetland substrates associated with vegetation removal. The short-term benefit for reducing mosquito production provided by reduced vegetation coverage is often overridden by relatively greater mosquito production from habitats where vegetation was partially removed. Reducing vegetation density can have a positive effect on mosquitofish (*Gambusia affinis*) density and mosquito control; however, design features that restrict emergent vegetation growth to small areas are thought to provide a comparatively more effective solution for reducing mosquito production.

Inundation of dried vegetation that has been knocked down by heavy equipment is thought to enhance wetland performance, but this management strategy is con-

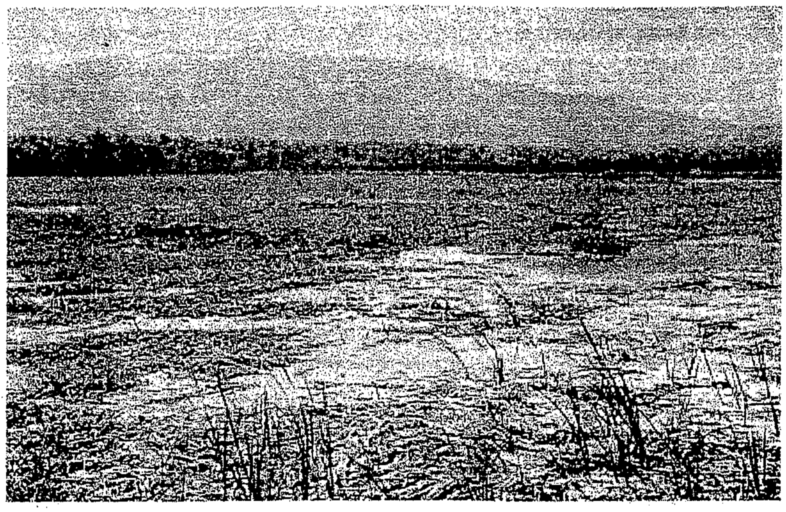

Figure 5. Emergent vegetation (cattails, *Typha* spp.) in a constructed treatment wetland. The cattails have been knocked down using heavy equipment, dried, and inundated. Although this management strategy is thought to enhance the bacterial populations responsible for water quality improvement, it caused significant levels of mosquito production that required multiple applications of mosquito control agents for nearly 2 months after reflooding. Photo: Joe B. Keiper.

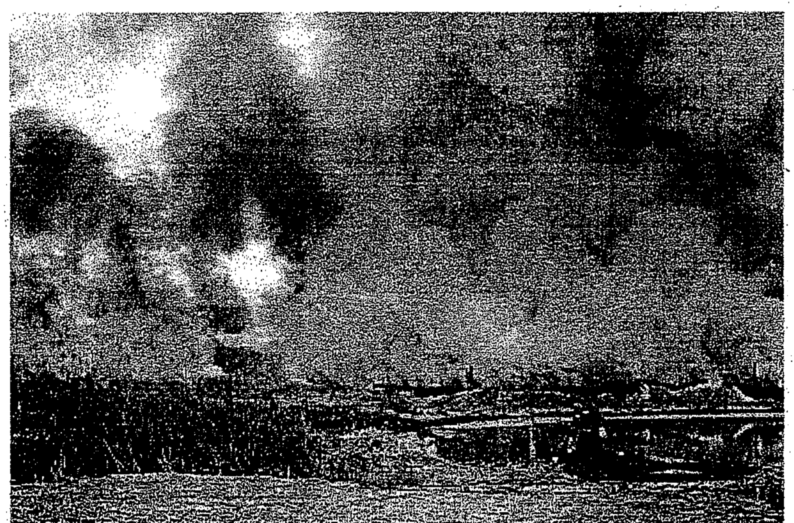

Figure 6. A controlled burn to remove dried emergent vegetation from a constructed treatment wetland. Controlled burns offer substantial cost savings when compared to harvesting and removing emergent vegetation, but they have drawbacks such as air quality concerns, extensive permitting, public relations costs, and delayed start-up because of poor postburn water quality. Photo: William E. Walton.

traindicated for mosquito control and should be discouraged (fig. 5). The rationale for this management approach is that pollutant transformation and removal processes such as aquatic microbial transformation and burial rely on high rates of reduced carbon in the form of detritus from dead plant biomass. Yet too much dead plant biomass may decrease wetland water quality. Even in treatment wetlands that produce comparatively few mosquitoes per unit area, mosquito production is significantly enhanced after this form of vegetation management, and control measures are required for more than 6 weeks after reflooding.

Plant removal by controlled burning is an alternative to mechanical harvesting (fig. 6). Like mechanical harvesting, the entire wetland or portion of the wetland to be burned will be out of service while the vegetation is thoroughly dried. Controlled burning requires extensive permitting and coordination with multiple agencies (e.g., fire control, air quality management, federal and state agencies responsible for discharge pollutants), as well as providing information to residences and businesses that are likely to be affected by the smoke and particulate fallout from burns.

While no quantitative data have been published on the effect of fire management on the performance of treatment wetlands, burning is thought to mobilize nutrients stored in the plants, and inundating plant ash can result in a temporary slug of pollutants unless the flow-through operation is postponed long enough (1 or more months) for particulate pollutants to settle. During the period that this nutrient-rich water is held in the wetland basin, mosquito production may increase and control measures may be required.

Incorporation of Plant-free Zones

For mosquito abatement, incorporating deep-water plant-free zones (see fig. 4) is more effective than either maintaining 100 percent of the wetland area in shallow water containing a dense growth of emergent macrophytes (shallow marshes), or routine harvesting of vegetation that involves drying of the wetland basin. If the latter strategy is used, harvested plant biomass should be removed from the basin before reflooding. Using raised planting beds may provide one approach to limiting emergent vegetation to narrow zones.

Wetlands comprised only of shallow-water marshes are generally no longer recommended by wetland designers. For wetlands used primarily for water quality improvement, designs commonly incorporate deep-water zones that are at least 3 feet (1 m) deeper than the surrounding cell bottom elevation and that are limited to less than 25 percent of the entire wetland surface area. However, a further increase in deep-water zones (to nearly 80 percent of the wetland surface) is being tested in wetlands where water treatment has high oxygen demands.

In multipurpose treatment wetlands that also include wildlife habitat as a goal, a hemi-marsh configuration—50 percent covered by vegetation, with deep zones making up 50 percent of the entire wetland area—follows wildlife managers' recommendations for managed wetlands. Islands are often constructed within the deep zones to increase the wetland-upland edge and to create refuges for nesting birds. Because of the potential for outbreaks of avian diseases, particularly during the hot summer period, there is no consensus among wetland managers as to the suitability of treatment wetlands as habitat for endangered waterbird species.

While deep-water zones generally reduce mosquito production from wetlands, colonization of deep-water zones by floating and submerged plants can occasionally create mosquito problems and may require significant vegetation management efforts. Floating plants such as duckweed (*Lemna* spp.) and water fern (*Azolla* spp.) may colonize open water zones that are protected from the prevailing wind. A complete coverage of the water surface by either plant can inhibit mosquito production; however, heavy mosquito production can occur within inevitable breaks in a surface mat. Submerged aquatic plants, particularly plants that create hiding places for mosquito larvae in highly dissected leaves, also may become established in deep zones. Significant management efforts and costs may be required to eliminate this plant growth.

Although at this time, no recommendation for limiting the width of plant zones can be supported by data, in one study, increasing the proportion of open water in small treatment wetlands (10,400 square feet [about 0.1 ha]) reduced total mosquito production and increased mortality of mosquito larvae (Walton and Workman 1998). However, plant zones 16 or 32 feet (5 or 10 m) wide did not significantly reduce total wetland mosquito production as compared to fully vegetated wetlands (Jiannino 2001). Collins and Resh (1989) reported that plant zones might need to be limited to as little as 3 feet (1 m) wide to provide effective fish access for mosquito predation. Limiting emergent vegetation to raised planting beds may maintain narrow plant zones (Thullen et al. 2002); however, the practicality and efficacy of this approach for large wetlands has not been determined.

Design for Biological and Chemical Control of Mosquito Populations

Maintaining low rates of mosquito production is likely to depend on periodic use of mosquito control agents. Control measures against the stages of the mosquito life cycle that occur in water are preferred to control measures directed against adult mosquitoes. After mosquitoes become adults capable of dispersing from the wetland, mosquito control becomes more difficult, costly, and requires use of insecticide across a comparatively broad geographic area. Even though the insecticides currently used to control adult mosquitoes are safe, this method of control is not universally accepted by the general public because of perceived negative impacts. Furthermore, there are no effective biological control agents for adult mosquitoes. Despite popular beliefs, mosquitoes form only a very small component of the diets of birds and bats, and adults of most mosquito species are not active during the peak daily feeding period of many purported mosquito predators such as adult dragonflies.

Mosquito-specific control measures for immature mosquitoes are available but their effectiveness declines in thick vegetation and with poor water quality. In shallow, standing water, mosquito-specific microbial insecticides can be effective for longer than 1 week; however, dilution of mosquito control agents can be significant in treatment wetlands that have short water residence times. Biological control using fish and naturally occurring insect predators is enhanced by limiting the number of dense stands of emergent vegetation.

RECOMMENDATIONS FOR ENHANCING MOSQUITO ABATEMENT EFFORTS IN CONSTRUCTED WETLANDS

- Incorporate wide embankments to allow drivable shoreline access to all wetland cells. Access should have adequate turning areas. If cells exceed approximately 20 feet (6 m) wide, vehicular access to both sides must be provided. These embankments should have a top width of no less than 13 feet (4 m) and should have side slopes no steeper than 4:1 to allow access for mowing and sampling.
- Incorporate deep-water zones that are free of emergent and aquatic plants. Nearly vertical edges at the perimeter of the wetland limit the growth of emergent vegetation but may pose a safety concern.
- Provide access structures with appropriate slopes to cross deep-water zones. Boats or amphibious vehicles can be launched into these zones for application of mosquito control agents.
- Keep embankments and all wetland areas free of power lines, trees, and other tall vegetation and obstructions that might limit aerial spraying.
- Limit the width of emergent plant zones to facilitate access by predaceous fish and for application of chemical control agents.
- Compartmentalize the wetland so that the maximum width of ponds does not exceed two times the effective distance (40 feet [12 m]) of land-based application technologies for mosquito control agents. This design feature should reduce the costs of mosquito abatement by focusing mosquito abatement on small regions of the wetland and eliminating the need to apply mosquito control agents by aircraft.
- Minimize fluctuations in water level to prevent large areas of intermittently flooded substrate or isolated pools from being created, particularly during the period of annual mosquito activity (April to November in most regions of California).
- Budget for periodic vegetation maintenance and vector control.
- Have an emergency plan that provides for immediate drainage into acceptable areas if a public health emergency occurs.

CONCLUSION

Operating a wetland represents a long-term commitment to wetland maintenance and mosquito control and also exposes the managing organization to potential legal liability. The decision to proceed with wetland construction should be made after considering the technical, regulatory, and economic factors, as well as long-term plans for vegetation maintenance and vector control.

Regardless of how a manager attains responsibility for stewardship of a wetland—building a wetland, assuming responsibility for an existing wetland, participating in a program to enhance wetland habitat, or assuming ownership of a shared wetland or land containing a wetland—as long as the wetland contains water, managers are legally responsible under the California Health and Safety Code for the costs of mosquito control or abatement of a public nuisance created by other organisms associated with that wetland.

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FOR MORE INFORMATION

You'll find more information on mosquito control in these publications from UC ANR:

Aquatic Pest Control, Publication 3337, 2001.

Mosquitoes: Pest Notes for Home and Landscape, Publication 7451, 1998. Available for free downloading from the ANR CS Web site at http://anrcatalog.ucdavis.edu.

Mosquitoes of California, 3rd edition, Publication 4084, 1978.

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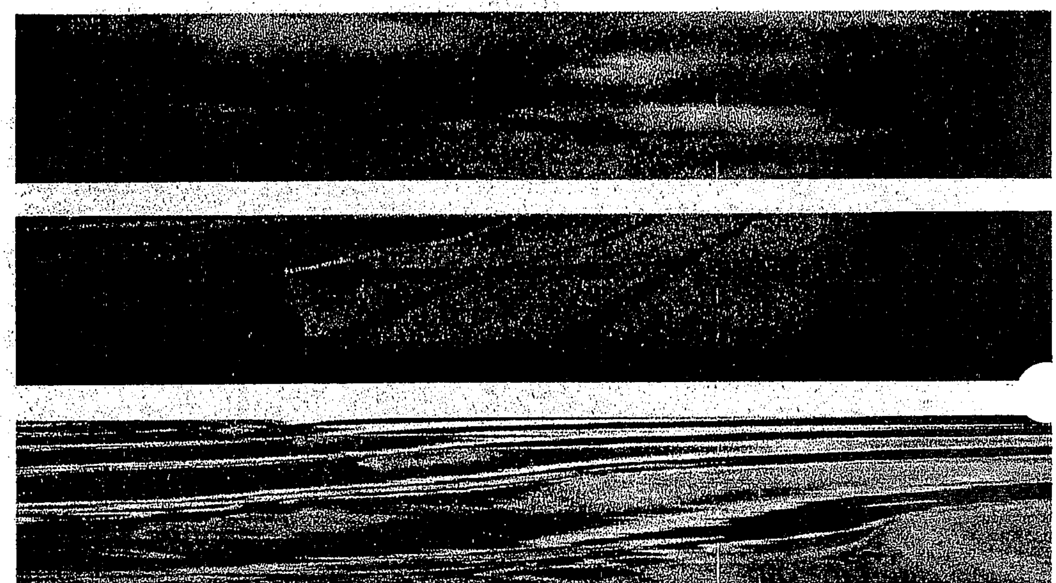
COOPERATIVE RESEARCH CENTRE FOR **CATCHMENT HYDROLOGY**

NON-STRUCTURAL STORMWATER QUALITY BEST MANAGEMENT PRACTICES - AN OVERVIEW OF THEIR USE, VALUE, COST AND EVALUATION

TECHNICAL REPORT
Report 02/11
December 2002

André Taylor / Tony Wong



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Standards
Water Quality (Natural Waters)
Runoff (Urban)
Evaluation
Monitoring
Survey
Reviews

Non-structural Stormwater Quality Best Management Practices - an Overview of their Use, Value, Cost and Evaluation

André Taylor and Tony Wong

Technical Report 02/11
December 2002

Preface

In 2001 the Cooperative Research Centre for Catchment Hydrology formed a partnership with the Victorian Environment Protection Authority to undertake research into the use, value, cost and evaluation of non-structural best management practices to improve urban stormwater quality (non-structural BMPs). Such BMPs include town planning controls, strategic planning and institutional controls, pollution prevention procedures, education and participation programs, and regulatory controls.

The primary aim of this research project was to produce monitoring protocols that could be used by local government authorities to measure the value and life-cycle cost of non-structural BMPs that improve urban stormwater quality.

Secondary objectives of this research project were to help local government authorities manage urban stormwater quality by providing:

- Quantitative information from the literature and case studies on the value of non-structural BMPs.
- Information on how structural and non-structural BMPs for urban stormwater quality improvement are being used (e.g. the extent to which 70 specific BMPs are being used around Australia, New Zealand and the United States of America).
- Funding profiles for several leading urban stormwater quality management authorities in Australia and overseas, that can be used as benchmarks when developing urban stormwater management programs.
- Information on the views of Australian and overseas urban stormwater quality managers on the effectiveness, efficiency and practicality of 41 non-structural BMPs.
- A short-list of non-structural BMPs deemed to be of most value in terms of effectiveness, efficiency, practicality, acceptance and potential for future use (based on the findings of a literature review and survey of Australian and overseas stormwater managers).
- Recommended references relating to the design of non-structural BMPs.

- A new evaluation framework that can be used for any type of non-structural BMP that aims to improve urban stormwater quality.

Four reports have been produced to communicate this work to stakeholders:

- CRC for Catchment Hydrology Report 02/11 (No. 1 in the series) is this **overview report** that describes the project's aims, background, methodology, and presents key findings in a condensed form.
- CRC for Catchment Hydrology Report 02/12 (No. 2 in the series) is a technical report on the findings of a detailed **survey** of 36 urban stormwater managers.
- CRC for Catchment Hydrology Report 02/13 (No. 3 in the series) is a technical report that presents the findings of a **literature review** on the value and life-cycle costs of non-structural BMPs to improve urban stormwater quality.
- The fourth report in the series investigates **monitoring and evaluating non-structural BMPs** for urban stormwater quality improvement. A draft version of this report has been released as a working document (CRC Working Document 02/6). The report presents guidelines and a new evaluation framework for measuring the effects and life-cycle costs of non-structural BMPs. This framework defines seven different styles of evaluation to suit the needs and budgets of a variety of stakeholders involved with stormwater management. In addition, monitoring protocols and data recording sheets have been developed to support each style of evaluation.

  This work will be published as a final CRC technical report during 2003.

Tim Fletcher
Program Leader
Urban Stormwater Quality
Cooperative Research Centre for Catchment Hydrology

1. Introduction

This report presents an overview of a project that investigated the use, value, life-cycle costs and evaluation of non-structural best management practices (BMPs) for improved urban stormwater quality and waterway health.[1]

There are numerous types of non-structural BMPs for stormwater quality improvement, but common examples include town planning controls, education programs and enforcement programs. These BMPs are already widely - and increasingly - used in Australia. Urban stormwater managers are, however, investing in these strategies in a climate of uncertainty, as little information has been available on:

- the type and magnitude of change non-structural BMPs can produce, if any (e.g. behavioural changes, improved stormwater quality, improved waterway health);
- the performance, effectiveness and efficiency of non-structural BMPs (e.g. a BMP's efficiency at minimising loads or concentrations of stormwater pollutants); and
- life-cycle costs of non-structural BMPs.

1.1 Objectives of this project

The primary aim of this project was to produce monitoring protocols to assist local government authorities to measure the value and cost of non-structural BMPs that improve stormwater quality.

Secondary objectives were to help local government authorities and other stakeholders manage urban stormwater quality by providing:

- Information on how structural and non-structural BMPs for stormwater quality improvement are being used (e.g. the extent to which 70 specific BMPs are being used around Australia, New Zealand and the USA).
- Funding profiles for several leading stormwater quality management authorities in Australia and overseas. These may be used for simple benchmarking when developing management programs or plans.
- Information on the views of Australian and overseas stormwater quality managers on the effectiveness, efficiency and practicality of 41 non-structural BMPs.
- Quantitative information from the literature and international case studies on the value of non-structural BMPs (e.g. information on whether they provide any positive benefits and if so, their pollutant removal efficiencies).
- A short-list of non-structural BMPs deemed to be of most value in terms of effectiveness, efficiency, practicality, acceptance and potential for future use (based on the findings of the literature review and survey of Australian and overseas stormwater managers).
- Recommended references providing information on designing non-structural BMPs, as few guidance materials of this nature are widely known to stormwater managers in Australia.
- An evaluation framework for non-structural BMPs for stormwater quality improvement that allows for worthwhile assessment regardless of available resources.

1.2 What are non-structural stormwater quality best management practices?

Non-structural stormwater quality best management practices (non-structural BMPs) are institutional and pollution-prevention practices designed to prevent or minimise pollutants from entering stormwater runoff and/or reduce the volume of stormwater requiring management (US EPA, 1999). They do not involve fixed, permanent facilities and they usually work by changing behaviour through government regulation (e.g. planning and environmental laws), persuasion and/or economic instruments.

[1] The term 'value' is used in this report as a collective description of the benefits of non-structural BMPs, encompassing attributes such as their:
- ability to raise people's awareness, change their attitudes and/or change their behaviour;
- performance, effectiveness and efficiency with respect to stormwater quality improvement; and
- ability to improve waterway health.

Various authors have attempted to categorise non-structural BMPs into homogeneous groups (e.g. Brown, 1999; NSW EPA, 1998; NVPDC, 1996; ASCE & US EPA, 2000; US EPA, 1999; LSRC, 2001; Aponte Clarke *et al.*, 1999; Victorian Stormwater Committee, 1999; and ASCE & US EPA, 2002). Although these classification systems vary, five core categories of non-structural BMPs feature strongly and have been used by the CRC for Catchment Hydrology to group non-structural BMPs in our research:

1. **Town planning controls:** e.g. the use of town planning instruments to promote WSUD principles in new developments, such as decreasing the area of impervious surfaces.
2. **Strategic planning and institutional controls:** e.g. the use of strategic, city-wide urban stormwater quality management plans and secure funding mechanisms to support the implementation of these plans.
3. **Pollution prevention procedures:** e.g. practices undertaken by stormwater management authorities involving maintenance (e.g. maintenance of the stormwater drainage network) and elements of environmental management systems (e.g. procedures on material storage and staff training on stormwater management).
4. **Education and participation programs:** e.g. targeted media campaigns, training programs and stormwater drain stencilling programs.
5. **Regulatory controls:** e.g. enforcement of local laws to improve erosion and sediment control on building sites, the use of regulatory instruments such as environmental licences to help manage premises likely to contaminate stormwater, and programs to minimise illicit discharges to stormwater.

1.3 Project architecture

To achieve the objectives of this project the following three tasks were undertaken:

1. A detailed survey of 36 urban stormwater managers from around Australia, New Zealand and the USA.
2. A review of the available literature on the value and life-cycle cost of non-structural BMPs to improve urban stormwater quality.
3. A review of methods used to monitor and evaluate the effects and life-cycle costs of non-structural BMPs, followed by the development of monitoring and evaluation guidelines designed primarily for use by local government authorities.

Four reports have been produced to communicate this work to stakeholders. In addition to this overview report, a technical report has been produced for each of the three tasks listed above.

2. Background

2.1 Terminology

Confusion exists in the literature with respect to the terminology surrounding non-structural BMPs because of:

- the existence of several broad terms such as 'source controls' and 'pollution prevention measures', which describe similar concepts (see Brown, 1999 and NSW EPA, 1998);
- the tendency of some authors to include vegetation-based structural BMPs such as vegetated filter strips, vegetated swales and constructed wetlands in descriptions of supposedly non-structural BMPs (e.g. NVPDC, 1996); and
- the tendency for some non-structural BMPs to provide a *framework* that results in discrete structural and non-structural BMPs at the estate or allotment scale (e.g. town planning controls are non-structural, but they produce new developments that incorporate both structural and non-structural BMPs).

This series of four reports uses the term 'non-structural stormwater quality best management practices' (non-structural BMPs), as defined in Section 1.2, to describe one set of source controls for the management of stormwater pollution. We define source controls as non-structural or structural measures to minimise the generation of excessive stormwater runoff and/or pollution of stormwater at or near the source (NSW EPA, 1998).

These reports include *temporary* erosion and sediment controls (e.g. mulching and sediment fences) in the definition of non-structural BMPs, as they do not involve the construction of fixed or permanent assets. It is acknowledged that this inclusion is debatable, however the inclusion of these BMPs in the literature review component of this project should assist the evaluation of related non-structural BMPs (e.g. multifaceted erosion and sediment control programs commonly run by government authorities).

The term 'value' is used widely in these reports as a collective description of the benefits of non-structural BMPs, encompassing attributes such as their:

- ability to raise people's awareness, change their attitudes and/or change their behaviour;
- performance, effectiveness and efficiency with respect to stormwater quality improvement; and
- ability to improve waterway health.

Definitions of additional terms and acronyms used in this report are provided in the Glossary (see Section 6).

2.2 Why non-structural BMPs are needed

In the past 20 years, Australian and overseas stormwater management agencies have become increasingly aware of the importance of urban stormwater runoff as a cause of environmental harm in waterways through pollutant discharge, altered hydrologic regime, and direct habitat destruction. For example:

- Urbanisation of the Moreton Bay catchment in Southeast Queensland from 2001 to 2020 is predicted to generate a 40% increase in the load of total nitrogen (TN) draining to the bay via stormwater unless controls are in place to manage stormwater quality (McAlister and Cavanagh, 2002). An increase in TN loads of this magnitude would produce significant degradation of ecological health, given that the bay is already under stress from elevated nitrogen loads (Dennison and Abal, 1999).
- In Melbourne, the ecological health of Port Phillip Bay is also under threat from nitrogen inputs (CSIRO, 1996). Accordingly, a target has been set to reduce the load of nitrogen entering the Port Phillip Bay from diffuse sources in the catchment (e.g. urban stormwater) by 500 tonnes per year (based on 1996 baseline levels) by 2006 (Chesterfield, 2002).
- In the USA, runoff from urban areas is now recognised as the second most prevalent cause of water quality degradation in the nation's estuaries, after discharges from industry (US EPA, 1998).

Part of the concern about this issue in Australia stems from our increasing tendency to live in the coastal zone and among major centres of urbanisation, where rivers and estuaries are under growing pressure from urban stormwater runoff. Ninety percent of resident Australians live within 100km of the coastline (Shaw, 2002).

Another cause for concern is the economic impact of urban stormwater runoff. For example, in 1997 the US EPA conservatively estimated the total cost to the American economy from illness and loss of economic output due to urban stormwater pollution to be millions of dollars each year (US EPA, 1998). Impacts on estuaries are of particular concern, as they are vulnerable to stormwater pollution and are highly valued for the environmental services they provide, such as nutrient cycling, provision of habitat for fisheries, food production, cultural values and recreation. Costanza *et al.* (1997) estimated the average global value of the ecosystem services provided by estuaries to be US$22,832 per hectare per year (in 1994 dollars).

Within this context, funding for the management of urban stormwater quality in Australia's major urban centres has increased in recent years (Taylor, 2000). In particular, new funding mechanisms and programs have been established to help manage the problem. Examples include the Commonwealth Government's Natural Heritage Trust and Urban Stormwater Initiative, the New South Wales (NSW) Stormwater Trust, the Victorian Stormwater Action Program, the West Australian Swan-Canning Clean-up Program and Brisbane City Council's Environmental Levy.

Managers responsible for these funds typically undertake activities in accordance with catchment or city-wide stormwater management plans, which define water quality-related objectives, identify and prioritise local issues, and outline a mix of structural and non-structural BMPs to achieve their objectives. These managers have the challenging task of finding the optimal combination of BMPs to minimise stormwater pollution using limited funds (Schueler, 2000a; Taylor, 2000). To do this, reliable information is needed on the value (e.g. pollutant removal efficiency) and life-cycle cost of a wide range of BMPs. For non-structural BMPs, such information has been rare and difficult to access.

During the 1990s, most government expenditure on urban stormwater management in Australia was on large, regional, structural BMPs (e.g. gross pollutant traps, ponds and wetlands) (Taylor, 2000). Since the late 1990s, the funding has increasingly shifted toward source controls for managing urban stormwater quality and achieving a more balanced mix of structural and non-structural urban stormwater strategies, particularly in NSW (Taylor and McManus, 2002). Such controls include WSUD elements in new developments (e.g. the use of stormwater recycling and infiltration at the allotment or street-scape scale) and non-structural BMPs that can be applied on a city-wide scale (e.g. town planning controls, education and participation programs, and enforcement programs).

2.3 Potential benefits of using non-structural BMPs

Potential benefits from using non-structural BMPs for city-wide urban stormwater quality management include:

- **Cost:** Some non-structural BMPs are inexpensive for stormwater management agencies to run, particularly when compared with structural alternatives. For example, where major educational and enforcement campaigns aimed at erosion and sediment control have been conducted in Australia, the revenue gained from enforcement has often resourced the campaign's total operational expenses.
- **Coverage:** Some non-structural BMPs cover broad areas compared with structural alternatives (e.g. city-wide stormwater awareness campaigns or town planning controls).
- Can be used in a **retro-fit context**: Australia's larger cities are faced with space constraints in areas undergoing redevelopment, making installation of some types of structural BMPs difficult (e.g. the use of constructed wetlands for removal of fine sediment and nutrients from high density developments with very little garden area).
- Can target **specific pollutants** of concern: For example, in Perth's established residential areas, nutrients from lawns and gardens on sandy soils threaten the quality of stormwater and shallow groundwater. Such pollution is best

managed through non-structural means (e.g. encouraging the use of xeriscaping[2], slow-release fertiliser, improved fertilisation regimes and/or soil amendment).

- The polluter pays principle and **economic incentives/disincentives** can be applied through regulation and/or enforcement programs. Unlike large, regional, structural BMPs (e.g. constructed ponds and wetlands), where the bulk of the life-cycle costs are often borne by the wider community, regulation and/or enforcement campaigns allow the cost of pollution management to be borne by individuals or sectors of the community that are polluting (e.g. those found to be illegally discharging pollutants to stormwater).
- The high **potential effectiveness** of some measures: For example, the use of mandatory town planning controls to promote the widespread adoption of WSUD in new developments.
- **Community participation:** Interactive programs such as the successful Master Gardener training programs in the USA can encourage the community to accept responsibility for urban stormwater pollution and participate in a solution.
- **Flexibility:** Unlike structural BMPs, most non-structural BMPs can be quickly modified to take advantage of new opportunities or to respond to new priorities. For example, ongoing small business/industry education programs can continually be modified to promote practices that incorporate new technology or knowledge (e.g. targeting problem areas that have been identified through annual compliance auditing).
- **Secondary benefits:** A strong argument for using some non-structural BMPs in a balanced city-wide stormwater quality management program is their secondary benefits, such as helping build a mandate for increased political support, funding and bolder initiatives. For example, the use of high profile stormwater awareness programs may help a stormwater management agency garner support for ongoing funding for stormwater quality management (e.g. a Stormwater Utility). North American researchers have surveyed communities and found the establishment of a dedicated funding mechanism and investment in educational activities are essential ingredients for success in urban stormwater quality management (Lehner *et al.*, 1999; Schueler, 2000b).

While these potential benefits appear promising, non-structural BMPs have their disadvantages. The most significant of these is uncertainty over the performance of many practices, particularly in terms of their ability to change people's behaviour, improve stormwater quality and improve the health of receiving waters.

The prevailing view of leading Australian stormwater managers appears to be that an optimal balance needs to be found between the use of non-structural and structural BMPs for stormwater quality improvement, following a decade where structural BMPs have dominated. After reviewing 100 stormwater case studies from the USA, Lehner *et al.* (1999) stated: "...stormwater management efforts build synergistically off each other; the most successful municipal strategies cover all program elements effectively" (p. 5-16).

2.4 Evaluation of non-structural BMPs

2.4.1 The status of evaluation attempts

Several authors have highlighted the lack of reliable, data on the life-cycle cost and performance of non-structural BMPs as a major impediment to their adoption (NVPDC, 1996; Taylor, 2000; Brown, 1999; US EPA, 1997a). This point of view is perhaps best expressed by the Northern Virginia Planning District Commission (NVPDC, 1996): "... many of these non-structural measures are widely recognised by scientists and watershed managers to have clear utility in an integrated nonpoint source management program. However, the lack of credible data, site screening for applicability, and specific design parameters, may result in these measures being neglected, both in research and in jurisdictional nonpoint source program development, under federal, State, and local stormwater management initiatives" (p. 1-4).

In addition, the NVPDC states "reliance on conventional [structural] BMPs stems from the fact that such approaches facilitate the engineering calculations necessary to demonstrate compliance with numerical stormwater quality standards or criteria..." (p. 1-4). This

[1] Resource sensitive landscaping.

point is particularly relevant to Australian stormwater managers as:

- numerical descriptions of water quality-related objectives are increasingly used in town planning schemes and other legislative instruments to define the quality of stormwater needed from a particular development or catchment; and
- pollutant export modelling tools are being used more widely to quantitatively demonstrate a proposed suite of BMPs will collectively improve stormwater quality so that it complies with water quality-related objectives.

The need for research into the cost and value of non-structural BMPs has been recognised in the literature for more than two decades. For example, in 1980, attempts were made to evaluate the efficiency and cost of street sweeping and the addition of flocculants to stormwater to remove colloids (e.g. Biggers *et al.*, 1980). Despite this history, modest progress has been made in quantifying the efficiency of non-structural BMPs other than street sweeping.

Perhaps the most instructive indicator of the stormwater industry's progress on measuring the life-cycle costs and pollutant removal efficiencies of non-structural BMPs for stormwater quality improvement comes from the US National Stormwater Best Management Practices Database (see http://www.bmpdatabase.org and Clary *et al.*, 2000). Established in 1999, the database summarises data on stormwater BMPs in a standardised format that has been screened by experts. When reviewed as part of this project, it contained 113 sets of data on BMPs. Only eight concerned non-structural BMPs, and all of these involved street sweeping.

In 1999, the US EPA reviewed the availability of data on the efficiency of BMPs for urban stormwater management and concluded "... there is still a great need for focused research in certain areas, particularly for newer and innovative structural BMP types, as well as non-structural BMPs. However, due to the complexity involved in isolating the reaction of a complex and highly variable system such as a watershed to one isolated input, evaluations of non-structural BMPs are ambitious tasks. Still, where stormwater management is largely driven by the availability of scarce funding, data that indicate the cost effectiveness of various control strategies are badly needed" (US EPA, 1999, p. 5-85).

2.4.2 The main impediments to evaluation of non-structural BMPs

We suggest that five factors have significantly hindered the progress of non-structural BMP evaluation:

1. Monitoring BMPs that seek to change people's behaviour is inherently difficult (Livingston, 2001) because:
   - people's behaviour is extremely complex;
   - direct measurement of people's behaviour (i.e. through an 'observational approach') can be constrained by issues such as privacy, experimental influence on behaviour and the high cost of monitoring infrequent events (e.g. annual use of lawn fertiliser);
   - studies that measure observed behaviour often produce significantly different results from those that measure self-reported behaviour (Curnow, *et al.*, 1997; Williams, *et al.*, 1997);
   - studies have found major differences or incongruities between people's attitudes and their actual behaviour (e.g. littering behaviour as noted by Williams, *et al.*, 1997);
   - finding and managing suitable control sites for non-structural BMPs designed to operate over large areas and over long time-frames is difficult (e.g. on-going stormwater awareness campaigns); and
   - the tendency for the effects of non-structural BMPs to change with time (e.g. the effect of stormwater drain stencilling on public awareness of stormwater issues over time).
2. Over a given geographic area, the effect of non-structural BMPs on stormwater quality may be subtle and masked by the effects of other management measures and sources of pollution. These confounding factors are not easily controllable in an experimental sense during monitoring (ASCE & US EPA, 2002). This complexity has lead some authors to comment that when it comes to monitoring the effects on *stormwater quality*, "... some non-structural BMPs, such as public education programs ... are virtually impossible to monitor or at best can be evaluated using trend analysis" (ASCE & US EPA, 2002, p. 46).

3. There is uncertainty over the transferability of the results obtained from some evaluation exercises, as the value of some BMPs depends on the *context* within which they are applied. For example, an education and enforcement program in a high density residential area may produce a reduction in the percentage of the population that wash their car on the street (rather than in a sewered wash bay) from 80% to 40%. An identical campaign may be run in another part of the city with similar land use, but if affordable wash bays were not as readily available, it is unlikely this magnitude of behavioural change would result.
4. Some BMPs operate synergistically (e.g. complementary education and enforcement campaigns). That is, "some individual practices may not be very effective alone but, in combination with others, may provide a key function in highly effective systems" (US EPA, 2001a, p. 2). This creates complexity for evaluation exercises as the usual reductionist strategy of monitoring a BMP in isolation may produce misleading results.
5. The determination of BMP efficiency and effectiveness suffers from comparability problems. That is, different evaluation methodologies have been used, making the results difficult to compare. Strecker *et al.* (2001) reported "... the differences in monitoring strategies and data evaluation alone contribute significantly to the range of BMP effectiveness that has been reported" (p. 144). To illustrate this point, Strecker *et al.* (2001) applied three commonly used data evaluation methods to the same structural BMP monitoring data set to derive an estimate of the pollutant removal efficiency percentage for one pollutant. The results ranged from 48% to 66%, with the range for non-structural measures expected to be significantly wider.

2.5 Sources of information on the design of best practice non-structural BMPs

This project focused on the use, value, cost and evaluation of non-structural BMPs and did not intend to produce design *guidelines* for non-structural BMPs for stormwater quality improvement. However, given the paucity of such guidelines in Australia, the low level of awareness of overseas guidelines and the need to improve the design of such measures, an effort was made to identify good sources of information during the project's literature review. Consequently, the following guidance documents are recommended.

Australian guidelines:

- 'Urban Stormwater Best Practice Environmental Management Guidelines' (Victorian Stormwater Committee, 1999).
- 'Managing Urban Stormwater - Source Controls' (Draft guidelines prepared for the State Stormwater Coordinating Committee, NSW EPA, 1998).

American documents (most are available from the internet, see the Reference Section for 'URLs'):

- 'National Menu of Best Management Practices for Storm Water Phase II' (US EPA, 2001a)*.
- 'Nonstructural Urban BMP Handbook - A Guide to Nonpoint Source Pollution Prevention and Control Through Nonstructural Measures' (Northern Virginia Planning District Commission, 1996)*.
- 'Stormwater Strategies: Community Responses to Runoff Pollution' (Numerous American case studies by the Natural Resource Defence Council, Lehner *et al.*, 1999)*.
- 'Guidance Specifying Management Measures for Sources of Nonpoint Source Pollution in Coastal Waters' (US EPA, 1997b)*.
- 'Preliminary Data Summary of Urban Stormwater Best Management Practices' (US EPA, 1999).
- 'Texas Nonpoint Source Book'. On-line BMP guideline and website (Statewide Storm Water Quality Task Force, 2002).
- 'The Practice of Watershed Protection' (Schueler and Holland, 2000).

* Note: Suggested as being the best references for non-structural BMP descriptions, design guidance, and case study information for local government authorities to use. All are freely accessible on the internet.

In addition, the following web sites are recommended for people designing, implementing and evaluating non-structural BMPs:

Australian web site:

- The New South Wales Environmental Protection Authority's 'Urban Stormwater Program': http://www.epa.nsw.gov.au/stormwater/index.asp (Provides information aimed at local government authorities designing stormwater-related education/ media campaigns).

American web sites:

- The US Environmental Protection Agency's 'Storm Water Phase II Menu of Best Management Practices':

  http://www.epa.gov/npdes/menuofbmps/menu.htm (Currently the best single source of information on a wide variety of non-structural BMPs. Presented in a simple to use, fact-sheet format).

- The US Environmental Protection Agency's 'Non-point Source Program':

  http://www.epa.gov/OWOW/NPS/index.html (Also see their 'Publications and Information Resources' page for a wide range of useful American sites and on-line documents).

- The 'Stormwater Manager's Resource Center': http://www.stormwatercenter.net/ (Aimed at local government authorities developing strategic urban stormwater management plans and programs).

- The 'Texas Nonpoint Source Book':

  http://www.txnpsbook.org/ (A detailed on-line guideline for a wide variety of BMPs).

- The American 'National Stormwater Best Management Practices Database':

  http://www.bmpdatabase.org (Provides access to BMP performance data in a standardised format for over 190 BMP studies conducted over the past fifteen years. Currently however, structural BMPs dominate the database).

3. Methodology

3.1 BMP use and funding profiles of urban stormwater management agencies

To gather information on the use of, and funding allocated to, non-structural and structural BMPs, we designed a detailed three-part survey for urban stormwater managers, which included:

1. A section asking stormwater managers to indicate for 41 non-structural BMPs and 29 structural BMPs:
   - the degree to which the BMPs were being used in their regions (using a 1 - 5 rating system); and
   - whether the use of the BMPs was increasing, decreasing or remaining static.[3]
2. A section asking stormwater managers to consider 41 non-structural BMPs and then:
   - rank the BMPs in terms of their effectiveness, efficiency and practicality (using a 1 - 5 rating system);
   - indicate the most promising BMPs for future use in their region;
   - state whether the effects and life-cycle cost of the BMPs had been reliably monitored in their region and, if so, the nature of the monitoring indicators and whether monitoring protocols had been developed; and
   - provide contact details for further information on monitoring.
3. A section on public funding for urban stormwater quality management, asking stormwater managers to indicate:
   - the primary function of their organisation (six generic categories were provided); and
   - the approximate annual expenditure by their organisation in 11 categories of management activities (e.g. capital/construction costs for structural BMPs, planning and regulatory mechanisms, education programs, enforcement programs, etc.).

We contacted the Australian stormwater managers by telephone, forwarding the survey electronically to those who agreed to participate. We invited managers in 32 agencies from Queensland, New South Wales, the Australian Capital Territory, Victoria, South Australia and Western Australia, to participate. All agreed to be involved (100%) and 25 completed surveys were received by the deadline (a return rate of 78%).

For overseas stormwater managers, specific people and agencies were targeted based on their reputation as being leaders and/or highly experienced in the management of urban stormwater quality. Twenty-four (24) agencies were invited via email to participate, of which 15 agreed (63%), with 11 surveys being received by the deadline (a return rate of 73%).

For more information on the survey methodology, see Taylor and Wong (2002a) in this series.

3.2 Relative value of non-structural BMPs

To determine those non-structural BMPs most worthy of use in the short term and thorough evaluation, we assessed and ranked the relative value of 41 non-structural BMPs by using the following three assessment methods:

1. Using data from the survey of urban stormwater managers on *their perceptions* of each BMP's "effectiveness, efficiency and practicality", drawing upon an impressive resource of collective knowledge and experience in a wide variety of contexts.
2. Using a Value Utility Function that assigned a relative Value Score to each BMP, drawing on data collected via the survey of stormwater managers. The Value Utility Function incorporated four attributes (i.e. the current degree of BMP use, the trends in use, the degree of promise for future use, and perceptions of effectiveness, efficiency and practicality) and incorporated weightings for each attribute. Also, we performed a sensitivity analysis to ensure the final ranking of BMPs was not overly sensitive to the chosen set of weightings.

[3] The majority of these BMPs were named, listed and arranged in the same manner as the Victorian Urban Stormwater Best Practice Environmental Management Guidelines (Victorian Stormwater Committee, 1999).

3. Documenting the Author's opinion following a major international literature review on the beneficial effects and costs of non-structural BMPs for stormwater quality improvement. This opinion also draws on practical experience as a former stormwater quality manager for Australia's largest local government authority.

3.3 The literature review

The literature review summarised available information on the value and cost of non-structural BMPs that is reported in the literature (e.g. journal publications, conference proceedings, guidelines and manuals) or available from Australian and overseas case studies. In particular, this review focused on *quantitative* information on BMP value (e.g. whether they provide *any* value, and if so, their pollutant removal efficiency) and cost.

To gather this information we:

- Used the survey of urban stormwater managers to identify case studies where attempts had been made to monitor and evaluate the value and life-cycle costs of non-structural BMPs.
- Reviewed the literature using library and internet searches.
- Consulted with key individuals within Australia and overseas.
- Sought unpublished information through articles placed in industry newsletters and journals within Australia.

The collected data are presented in Taylor and Wong (2002b) in this series and were of varying quality. Very few high-quality, independent performance studies have been attempted for non-structural BMPs. Consequently, much of the information is in the form of estimates and results with unknown levels of confidence.

If we were to dismiss all data and conclusions relating to the value of non-structural BMPs derived from studies that lacked detail or produced results with a low level of confidence, we would be left with very little information. Our approach was to include findings based on quantitative information, with appropriate caveats and references, to provide stormwater managers with at least some information to help guide decisions until improved information on the value and cost of non-structural BMPs is available. Given that researchers and stormwater managers have been calling for a greater investment in research in this area for at least 20 years (see Finnemore and Lynard, 1982), it is reasonable to assume stormwater managers will need to continue to cautiously draw on imperfect and limited information for the foreseeable future.

3.4 The monitoring and evaluation tools

To develop monitoring and evaluation tools that can be used by local government authorities in Australia to evaluate all types of non-structural BMP, we gathered information on methods during the survey of urban stormwater managers and the literature review. Useful information typically occurred as:

- Generic guidelines on the evaluation of stormwater BMPs (e.g. ASCE & US EPA, 2002; US EPA, 1997c; US EPA, 2001b).
- Reports on specific monitoring and evaluation exercises (e.g. monitoring the impacts of litter reduction campaigns on people's littering behaviour). These typically included details of the monitoring methodology and tailored monitoring tools (e.g. project-specific telephone survey forms, erosion and sediment control audit checklists).

4. Key Results

4.1 The survey of stormwater managers

4.1.1 Australian BMP use

Data from the survey of 25 stormwater managers from Australian agencies within five States and one Territory indicated that:

- The majority of BMPs included in the survey were associated with an increasing trend in use, particularly the non-structural variety. For example, the majority of respondents (>50%) reported an increasing trend in use for:
  - 76% of the 41 non-structural BMPs included in the survey (e.g. the use of town planning schemes and school education programs); and
  - 34% of the 29 structural BMPs included in the survey (e.g. grassed swales and vegetated filter strips).
- Three of the top four most frequently used non-structural BMPs were related to planning (e.g. strategic, city-wide planning of stormwater management and the use of town planning controls).
- Nine out of the top 11 BMPs associated with the most widespread trend of increasing use in Australia were non-structural. In addition, seven of the top 11 BMPs were closely related to the philosophy of site-based WSUD.

4.1.2 Overseas BMP use

Data from the survey of 11 stormwater managers from agencies within New Zealand and the USA indicated that:

- Compared to Australian data on current degree of use, there appeared to be:
  - A more widespread trend of increasing use of stormwater BMPs, particularly the non-structural variety. For example, the majority of overseas respondents (>50%) reported an increasing trend in use for:
    - 90% of the 41 non-structural BMPs included in the survey (e.g. the use of strategic urban stormwater management plans and city-wide maintenance operations); and
    - 38% of the 29 structural BMPs included in the survey (e.g. hydrodynamic/vortex separators and porous pavements).
  - A much higher degree of use of non-structural BMPs in general. For example, even the tenth most commonly used non-structural BMP in New Zealand and the USA had a significantly higher degree of use than the most commonly used non-structural BMP in Australia.
  - An increased use of non-structural BMPs in New Zealand and the USA that related to regulation.
- Eleven (11) out of the top 13 BMPs associated with the most widespread trend of increasing use within New Zealand and the USA were non-structural. In addition:
  - Five of the top 13 BMPs were closely related to the philosophy of site-based WSUD.
  - Three of the top five BMPs related to operations carried out by local governments/ municipalities (e.g. city-wide maintenance operations and initiatives to minimise sewer overflows).

4.1.3 Funding profiles for several leading stormwater quality management agencies

We analysed the typical relative distribution of funding for various stormwater quality management activities. This analysis found that Australian stormwater management agencies responsible for minor and major/trunk drainage spend a far greater percentage of their total stormwater quality management budget on constructing structural BMPs than their American counterparts (i.e. approximately 31% compared to 14%).

Although the leading American stormwater management agencies surveyed appear to spend a smaller portion of their stormwater quality budget on capital works than their Australian counterparts, they spend a larger portion on maintenance of structural BMPs (on average) and spend approximately the same percentage on city-wide non-structural BMPs.[4]

On average, leading Australian stormwater management agencies responsible for minor and major/trunk drainage spend approximately 57% of their total stormwater quality management budget on non-structural measures (i.e. AUD$10.41 of AUD$18.42 per person per year).

In terms of *absolute* funding allocated to stormwater quality management in agencies responsible for minor and major/trunk drainage, leading American agencies that were surveyed when compared to equivalent Australian agencies spend approximately:

- 3.8 times as much (per capita) on stormwater quality management in total; and
- 3.9 times as much (per capita) on the non-structural elements of their programs.

4.1.4 The relative value of non-structural BMPs

The survey and literature review information enabled us to develop a short-list of non-structural BMPs deemed most valuable. We developed this short-list because:

- Given the large number of non-structural BMPs, it is logical to develop monitoring tools and undertake evaluation trials on those BMPs likely to be of *most* value to urban stormwater managers.
- The desk-top evaluation of the relative value of non-structural BMPs is a useful outcome of this project in itself. This information can assist stormwater managers who are seeking an optimal mix of BMPs for their region in the absence of high-quality, locally derived data on their value. To the best of the Author's knowledge, this type of desk-top evaluation of relative non-structural BMP value has not been attempted before.

As explained in Section 3.2, three value assessment methods were used to determine the relative value of BMPs. Principal findings from these assessments were:

- The use of the three value assessment methods produced five ranked sets of non-structural BMPs (as survey data from Australian and overseas stormwater managers was kept separate). Six BMPs were represented in the top 10 rankings of all five sets. These were:
  1. Requiring stormwater quality management to be addressed in development proposals/ applications relating to stormwater quality.
  2. Development of urban stormwater management plans for the city, shire or catchment, for the improvement of urban stormwater quality and protection of urban aquatic ecosystems.
  3. Stormwater quality management addressed in construction activities *undertaken* by municipalities or State agencies.
  4. Stormwater quality addressed in a wide variety of maintenance operations.
  5. Implementing stormwater quality improvement policy in town/city planning schemes (closely related to BMP No. 1).
  6. Application of development approval/permit conditions (also closely related to BMP No. 1).
- Collectively, the overseas stormwater managers emphasised the value of non-structural BMPs involving enforcement, regulation and improved construction and maintenance practices, compared to their Australian counterparts.
- Collectively, the Australian stormwater managers emphasised the value of non-structural BMPs involving planning controls and site-based WSUD elements, compared to their overseas counterparts.

[4] For comments relating to funding profiles in this report, the 'non-structural budget' of stormwater quality management agencies does not include costs associated with construction or maintenance of structural BMPs. While manipulation of structural BMP maintenance regimes can be classed as a non-structural BMP, maintenance costs associated with structural BMPs have been excluded from the 'non-structural' budget' as they are an integral part of the life-cycle cost of structural BMPs.

4.2 The literature review

The literature review (Taylor and Wong, 2002b in this series) included approximately 200 references. This review encompassed a very wide variety of BMPs, from city-wide illicit discharge elimination programs, to the effect that the wording of signage has on people's littering behaviour.

For each of the five categories of non-structural BMPs defined in this report (see Section 1.2), the following information is provided in the literature review report:

- A brief section describing the nature of the management practices being evaluated by researchers.
- Summarised information from studies that have examined the ability of non-structural BMPs to influence people's awareness, attitudes, self-reported behaviour, actual behaviour, as well as stormwater quality and waterway health. Specifically, information is provided on the:
  - approximate costs associated with the design, implementation and maintenance of non-structural BMPs; and
  - value of non-structural BMPs (e.g. their pollutant removal efficiencies, where available).
- A summary section highlighting key findings garnered from the review. These sections will not be repeated here due to their length.

The overall finding from the literature and case studies is that non-structural BMPs can be highly valuable, and in some cases essential, for urban stormwater quality improvement. At a catchment or city-wide scale, a balanced and synergistic mix of structural and non-structural BMPs is preferable, with the non-structural BMPs having the most potential value being:

- Town planning controls involving the implementation of stormwater quality policy in town planning schemes, requiring stormwater quality to be addressed in development proposals, and applying development approval/permit conditions (such measures can result in wide-spread adoption of WSUD).
- Development of urban stormwater management plans for a city, shire, or catchment to improve urban stormwater quality and the protection of urban aquatic ecosystems.
- Illegal discharge elimination programs.
- Sustained erosion and sediment control programs that have strong enforcement elements and address both public and private sector works.
- Point source regulation of stormwater discharges (e.g. licensing and inspecting/auditing industry).
- Targeted, intensive and interactive community education and participation programs (e.g. the American Master Gardeners programs).
- The use of a wide variety of city-wide maintenance operations to improve stormwater quality, typically undertaken by local government authorities (e.g. maintenance of the stormwater drainage network and manual litter collections).
- Business/industry programs (e.g. targeted campaigns involving education, audits and/or enforcement to improve procedures and practices relating to stormwater management on commercial or industrial sites).

4.3 The monitoring and evaluation tools

After reviewing available information, we developed:

- A ***conceptual model*** of how non-structural BMPs may work to improve stormwater quality and ultimately, waterway health.
- A new ***evaluation framework*** for all non-structural BMPs that includes seven different styles of evaluation (see Appendix A). This framework accommodates the wide diversity of non-structural BMPs as well as the different characteristics of stormwater management agencies that may undertake the evaluation (e.g. their monitoring objectives and available resources).

  The seven styles of evaluation involve monitoring:

  1. BMP implementation (i.e. simple evaluation of whether the BMP has been fully implemented as designed).
  2. Changes in people's awareness and/or knowledge (i.e. evaluation of whether the BMP has increased levels of awareness and/or knowledge of a specific stormwater issue within a segment of the community).

3. Changes in people's *self-reported* attitude (i.e. evaluation of whether the BMP has changed people's attitudes, either towards the goal of the BMP or towards implementing the BMP itself, as indicated through self-reporting).
4. Changes in people's *self-reported* behaviour (i.e. evaluation of whether the BMP has changed people's behaviour, as indicated through self-reporting.)
5. Changes in people's *actual behaviour* (i.e. evaluation of whether the BMP has changed people's behaviour, as indicated through direct measurement).
6. Changes in stormwater quality (i.e. evaluation of whether the BMP, or set of BMPs, has improved stormwater quality in terms of loads and/or concentrations of pollutants).
7. Changes in waterway health (i.e. evaluation of whether the BMP, or set of BMPs, has improved the health of receiving waters).

Several of these styles may be used to evaluate the performance of a given non-structural BMP. The choice of styles will depend on the aim of the evaluation, the type of BMP (as some evaluation styles intrinsically suit specific BMPs), and the resources available to the monitoring agency. Key advantages and disadvantages of each style are summarised in Appendix A.

As a general rule, the value to stormwater managers typically increases from evaluation style No. 1 to 7, as the higher levels of evaluation increasingly link the effects of BMPs to the ecological health of water bodies that receive urban stormwater. This increase in value is however, often associated with an increase in the evaluation's complexity and cost.

- A set of five step-wise ***monitoring and evaluation protocols*** that can be used for all non-structural BMPs. The monitoring and evaluation protocols provide simple guidance on how to plan, deliver and report on a monitoring and evaluation exercise. These protocols have been written primarily for use by local government authorities as guidelines for their own work or as project briefs for specialist consultants. They have been deliberately kept short (compared to overseas equivalents), with references being made to more detailed guidelines where necessary. They also use a format that is consistent with equivalent protocols for structural BMPs developed by the CRC for Catchment Hydrology and those used in America (e.g. ASCE & US EPA, 2002).
- ***Data recording sheets*** for each monitoring and evaluation protocol to ensure that the salient details and results of the monitoring and evaluation exercise are collated in a manner that facilitates sound reporting, sharing of knowledge and continual improvement. The format of these sheets is also broadly consistent with overseas equivalents.
- ***Simple guidelines*** on how to use the monitoring and evaluation tools outlined above, and in particular, how to choose the best style(s) of evaluation to suit the objectives of the BMP and available resources. These guidelines also reference some examples of monitoring tools that could be tailored for use in typical non-structural BMP monitoring activities undertaken by local government authorities in Australia (e.g. specific survey sheets and audit checklists).

5. Conclusions and Recommendations

5.1 Conclusions

Based on the results of this project's survey of urban stormwater managers from Australia, New Zealand and the USA, we conclude that non-structural BMPs in Australia:

- are already playing a major role in urban stormwater quality improvement;
- are increasing in use; and
- will continue to increase in use if Australian programs mature in a similar way to those developed overseas.

Despite these trends, relatively little high-quality research was identified from the international literature and case studies on the ability of non-structural BMPs to improve stormwater quality. In general, the information reviewed from approximately 200 references was of a lower quality than that normally associated with equivalent studies involving *structural* BMPs for stormwater quality improvement (e.g. gross pollutant traps, constructed wetlands). This finding may reflect the relative maturity of the two areas of research and the difficulty in designing and executing sound monitoring and evaluation plans for many non-structural BMPs.

In this context, the philosophy we adopted in this project's literature review was to present the more reliable portion of the available information, despite some obvious limitations, to form a platform for future research involving improved evaluation.

The three technical reports generated from this project should assist Australian urban stormwater managers in the short and medium to long term.

In the short term, stormwater managers can now:

- Cautiously use the survey and literature review findings on the relative value and cost of non-structural BMPs to guide their decisions on the use of these BMPs until higher quality, locally-derived performance data are available.
- Use the survey and literature review findings on the relative value of non-structural BMPs to guide their decisions on which BMPs should be rigorously monitored and evaluated.
- Use the new evaluation framework, monitoring protocols and data recording sheets when assessing all types of non-structural BMPs for stormwater quality improvement to help raise the standard of monitoring and evaluation and provide valuable feedback to stakeholders on the merits and cost of these practices.
- Use information on funding profiles of leading Australian and overseas stormwater management agencies as benchmarks when developing or fine-tuning their urban stormwater quality management programs.

In the medium to long term, it is hoped that stormwater managers in Australia will able to use information on BMP value and cost that has been gathered from well-designed monitoring and evaluation programs using the newly-developed evaluation framework and monitoring tools. The accumulation of reliable, high-quality data sets on the value and cost of a wide range of non-structural BMPs will enable a greater degree of analysis when considering urban stormwater management options and produce greater confidence in the resulting strategies. It should also become more feasible to reliably predict the effect of non-structural BMPs on stormwater quality using pollutant export models such as the CRC for Catchment Hydrology's MUSIC.

5.2 Recommendations

1. Given the identified trends in the use of non-structural BMPs in Australia, the large number of non-structural BMPs and the paucity of high-quality data on their performance, more research is clearly needed. Some work is underway in Australia, particularly in New South Wales and Victoria. For example, the CRC for Catchment Hydrology is trialling the newly-developed evaluation framework, monitoring protocols and data recording sheets in Melbourne on two non-structural BMPs (i.e. a town planning control and an anti-litter educational campaign). This work is supported by funding from the Victorian State Government through the Environmental Protection Authority as part of the Victorian Stormwater Action Program.

2. Monitoring and evaluation exercises in Australia involving non-structural BMPs for stormwater quality improvement should:
   - focus on measuring the performance of those BMPs this project deemed to be of most potential value; and
   - seek to use evaluation styles No. 5 (i.e. measuring change in actual behavioural), No. 6 (i.e. measuring change in stormwater quality) and/or No. 7 (i.e. measuring change in waterway health), where resources allow. [5]

   BMPs that are seen to be a priority for evaluation include:

   - Town planning controls.
   - Strategic city-wide stormwater management plans.
   - Maintenance practices by local government authorities (e.g. the use of integrated pest management, anti-litter initiatives, the use of environmental management systems, maintenance of nodes in the stormwater network that collect pollutants, the use of manual litter collections, etc.).
   - The use of management systems to improve the quality of stormwater draining from government-managed construction sites.
   - Enforcement and education campaigns (e.g. erosion and sediment control programs).
   - Illicit discharge elimination programs.
   - Focused, intensive and interactive training programs, like the American Master Gardeners programs.
   - Licensing, auditing and education programs involving commercial and industrial premises.

3. In New South Wales and Victoria alone, considerable resources are being allocated to monitoring and evaluating a variety of non-structural BMPs, which is to be commended. However, it is recommended that greater cooperation and consistency occur between these States (and others) on how the evaluation data are reported, stored and communicated to stakeholders. We recommend that the data recording sheets produced by this project be used as standard reporting templates. These sheets are also broadly consistent with equivalent American systems, so that valuable data could also be shared internationally. We also recommend that a single Australian website be established to communicate evaluation results to stakeholders and direct them to relevant resources such as the products produced by this project.

4. In Australia, we now have detailed guidelines on how to monitor and evaluate non-structural BMPs for stormwater quality improvement as a result of this project, but we lack comprehensive guidelines on how these BMPs should be designed. Some information is available (e.g. Victorian Stormwater Committee, 1999; NSW EPA, 1998), but more is needed. More comprehensive American guidelines (e.g. US EPA, 2001a) could be tailored for use in Australia.

5. Ongoing training programs be developed to help urban stormwater managers access the best available information to select, design, implement, monitor and evaluate a wide variety of non-structural BMPs for stormwater quality improvement.

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[5] See Appendix A for an explanation of these styles of evaluation.

6. Glossary of Key Terms and Acronyms

ASCE
American Society of Civil Engineers.

BACI
An acronym for an experimental design that has sampling Before and After sampling at a Control (no action) and Intervention (action) site.. The intervention (or action) site is where the BMP has been implemented.

BMP
Best management practice - A device, practice or method for removing, reducing, retarding or preventing targeted stormwater runoff constituents, pollutants and contaminants from reaching receiving waters. Within the context of this report, BMPs primarily seek to manage stormwater quality to minimise impacts on waterway health.

BMP system
The BMP and any related stormwater the BMP is unable to manage. For example, a 'BMP system' may be a residential suburb over which a lawn fertilisation education program (BMP) is operating. The stormwater draining from this suburb may include some that is less polluted as a result of the BMP (e.g. runoff from lawns) and some that is not affected by the BMP (e.g. runoff from roads). A monitoring program may attempt to measure changes in stormwater quality as a result of the BMP. Such a program would be monitoring a 'BMP system'.

Control site
A sampling site which is as similar as possible to the intervention site (i.e. where the BMP is to be implemented) in every way, except that the BMP is not applied there.

CRC
Cooperative Research Centre for Catchment Hydrology (Australia).

Effectiveness
In the context of non-structural BMP monitoring, effectiveness is a measure of how well a BMP system meets its goals for all stormwater flows reaching the area of coverage by the BMP.

Efficiency
In the context of non-structural BMP monitoring, efficiency is a measure of how well a BMP or BMP system removes or controls pollutants. Although 'percent removal' is the most common form of expressing BMP efficiency, recent American work on structural BMP evaluation argues that 'percent removal' (when used alone) is a poor measure of BMP efficiency compared with alternatives such as the 'effluent probability method' (see ASCE & US EPA, 2002).

Evaluation
The final assessment of whether the non-structural BMP has achieved its pre-defined objectives and is usually based on some form of monitoring. However, unlike monitoring, evaluation involves an assessment of the project's success or failure.

Life-cycle cost
The total cost of the design, implementation, operation and maintenance of the BMP over its life span.

LSRC
Land of Sky Regional Council (USA).

Monitoring
The gathering of information about a non-structural BMP over time and/or space. Monitoring may involve measuring or observing change and is often the raw material or data for evaluation.

Non-structural BMP
A range of institutional and pollution prevention practices that are designed to prevent or minimise pollutants from entering stormwater runoff and/or reduce the volume of stormwater requiring management. Unlike structural BMPs, they do not involve fixed, permanent facilities, and they usually work by changing people's behaviour through government regulation (e.g. planning and environmental laws), persuasion and/or economic instruments.

NSW EPA
New South Wales Environmental Protection Authority.

NVPDC
Northern Virginia Planning District Commission.

Performance
In the context of non-structural BMP monitoring, performance is a measure of how well a BMP meets its goals for the stormwater it is designed to improve.

Stormwater utility
A utility established to generate a dedicated source of funding for stormwater pollution prevention activities where users pay a fee based on the land use and contribution of runoff to the stormwater system.

Structural BMP
Engineered devices implemented to control, treat, or prevent stormwater runoff pollution.

TN
Total nitrogen.

USA
United States of America.

US BMP Database Project
A cooperative arrangement between the American Urban Water Resources Research Council of the American Society of Civil Engineers and the US EPA to promote technical design improvements for BMPs and to better match their selection and design to local stormwater problems. The project involves collecting and evaluating existing BMP performance data, designing and creating an on-line national BMP database (http://www.bmpdatabase.org) and developing BMP performance evaluation protocols. In 2001-02, the database focused on structural BMPs for stormwater quality improvement.

US EPA
United States Environment Protection Agency.

Value
The term 'value' is used in this report as a collective description of the benefits of non-structural BMPs, encompassing attributes such as their:

- ability to raise people's awareness, change their attitudes and/or change their behaviour;
- performance, effectiveness and efficiency with respect to stormwater quality improvement (as defined above); and
- ability to improve waterway health.

WSUD
Water sensitive urban design (also known as low impact development) - WSUD aims to minimise the impact of urbanisation on the natural water cycle. Its five key objectives for water management are:

- Protect natural systems.
- Integrate stormwater treatment into the landscape.
- Protect water quality.
- Reduce runoff and peak flows.
- Add value while minimising development costs.

Xeriscaping™
An alternative landscaping technique that focuses on the conservation of water and the minimisation of stormwater pollution through plant selection and site design. Also known as resource-sensitive landscaping.

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Appendix A

An Evaluation Framework for Non-structural BMPs that Aim to Improve Stormwater Quality

Style of Evaluation	Description	Who Typically Does it	Example of Monitoring 'Tools'	Advantages	Disadvantages
1. BMP implementation	Evaluation of whether the BMP has been fully implemented as designed.	Stormwater management agencies (e.g. local or State government authorities) or community groups.	Audits with audit checklists.	• Inexpensive. • Provides the basis for more advanced styles of evaluation (see below). • Simple to design and implement. • Useful for BMPs with a relatively low risk of failure once implemented. • Can usually also evaluate the quality of implementation (e.g. feedback on the relevance and quality of training materials and delivery).	• Provides no information on whether the BMP has changed people's behaviour or water quality. • Desktop evaluation may not truly reflect what is happening 'on the ground'.
2. Changes in people's awareness and/or knowledge	Evaluation of whether the BMP has increased levels of awareness and/or knowledge of a specific stormwater issue within a segment of the community.	Stormwater management agencies, often with the help of specialist community survey consultants.	Surveys (with survey forms) that examine people's level of awareness and/or knowledge.	• Relatively inexpensive (depending on the level of confidence needed in the results). • Relatively fast. • Can directly examine levels of awareness and knowledge (i.e. this style of evaluation does not need to rely on self-reported changes to awareness and/or knowledge). • Can gather valuable information that helps to improve the design of BMP (e.g. a baseline survey for an educational program may find that a high percentage of people mistakenly believe that stormwater is a minor risk to waterway health in the region). • Can usually monitor changes in people's awareness/knowledge, attitudes and/or self-reported behaviour with the same instrument (e.g. a survey).	• Changes in awareness and/or knowledge do not necessarily lead to a change in people's attitudes, behaviour or water quality.
3. Changes in people's attitude (self-reported)	Evaluation of whether the BMP has changed people's attitudes (either towards the goal of the BMP, or towards implementing the BMP itself), as indicated through self-reporting.	As above.	Surveys (with survey forms) that examine people's self-reported attitudes.	• Relatively inexpensive (depending on the level of confidence needed in the results). • Relatively fast. • Can gather information that helps to improve the design of BMP (e.g. people's attitudes may be based on incorrect assumptions that could be easily clarified). • Can usually monitor changes in people's awareness/knowledge, attitudes and/or self-reported behaviour with the same instrument (e.g. a survey).	• Changes in people's attitudes towards stormwater management do not necessarily lead to changes in behaviour. • The evaluation process and social norms may influence *self-reported* attitudes (e.g. some survey respondents may report a 'socially acceptable' attitude rather than their actual attitude). • Potential for confusion exists depending upon the attitude being monitored (e.g. some builders may have the unchanged attitude that new erosion and sediment control laws are unnecessary, but their *attitude* towards compliance may have changed simply because of the financial consequences).

Style of Evaluation	Description	Who Typically Does it	Example of Monitoring 'Tools'	Advantages	Disadvantages
4. Changes in people's behaviour (self-reported)	Evaluation of whether the BMP has changed people's behaviour, as indicated through self-reporting.	As above.	Surveys (with survey forms) that examine people's self-reported behaviour.	• Relatively inexpensive (depending on the level of confidence needed in the results). • Relatively fast. • Can examine types of behaviour that are very difficult and expensive to directly observe or monitor (e.g. infrequent application of lawn fertiliser, disposal of used engine oil). • Can usually monitor changes in people's awareness/knowledge, attitudes and/or self-reported behaviour with the same instrument (e.g. a survey).	• Self-reported behaviour can be a very poor indicator of actual behaviour in some contexts (e.g. littering in public places).
5. Changes in people's behaviour (actual)	Evaluation of whether the BMP has changed people's behaviour, as indicated through direct measurement (e.g. an observational approach).	Specialists (e.g. research bodies, specialist consultants, trained staff from stormwater management agencies).	Observational studies (e.g. the 'Situational Litter Score' and the 'Disposal Behaviour Index' methods used for Australian littering studies) or audits with checklists (e.g. erosion and sediment control audits).	• Changes in actual behaviour is a very good indicator for likely changes to stormwater quality and waterway health. • Data from such evaluations can be used to model predicted changes to stormwater quality and waterway health. • Such evaluations can provide valuable information that can be used for BMP design or improved evaluation strategies (e.g. highlighting errors associated with monitoring *self-reported* behaviour, and identifying why certain forms of behaviour occurs).	• Can be very difficult and costly to apply in some contexts due to issues such as invasion of people's privacy and the need to monitor a large number of infrequent events. • People's behaviour that influences stormwater quality is inherently complex, and is typically influenced by many variables (e.g. people's age, whether they are in groups, their location, etc.). Designing evaluation strategies to accommodate this complexity can be challenging.
6. Changes in stormwater quality	Evaluation of whether the BMP (or set of BMPs) has improved stormwater quality in terms of loads and/or concentrations of pollutants.	Specialists (e.g. research bodies) or stormwater management agencies with a very high level of in-house expertise.	Stormwater quality monitoring programs (e.g. 'BACI' design experiments[6]). Alternatively, pollutant export modelling can be used to translate known changes in behaviour into probable changes in stormwater quality.	• Directly measures changes in stormwater quality (the primary aim of these non-structural BMPs). • The information collected may allow non-structural BMPs to be included in pollutant export modelling exercises when undertaking major stormwater quality management decisions (along with structural BMPs). • Can be used for individual non-structural BMPs or combinations of BMPs (e.g. monitoring the collective effect on stormwater quality over time of implementing a new, city-wide urban stormwater management plan).	• Relatively expensive and time-consuming (depending upon the desired level of confidence in the results). • Usually requires a very high level of technical expertise to design the monitoring program and analyse the results. • Can be difficult to measure subtle changes in stormwater quality, given the very high spatial and temporal variability of urban stormwater quality. • Can be difficult to find and maintain suitable control sites or catchments. • Typically, a variety of pollution sources and other types of BMPs heavily influence stormwater quality in areas where non-structural BMPs are applied.
7. Changes in waterway health	Evaluation of whether the BMP (or set of BMPs) has improved the health of receiving waters.	Specialists (e.g. research bodies) or environmental protection agencies with a very high level of in-house expertise.	Ecological health monitoring programs (e.g. trend analysis). Alternatively, receiving water quality *modelling* can be used to predict the ecological effect of known changes in stormwater quality (e.g. in estuary systems).	• Directly measures changes in aspects of waterway health (the *ultimate* goal of most stormwater quality managers who are implementing non-structural BMPs). • Can be an efficient form of evaluation where BMPs involve a specific stormwater pollutant with few sources (e.g. an education campaign to phase out the use of specific pesticide in an urban catchment) or where a cause-effect relationship has already been established (e.g. the relationship between sewer overflows and ambient water quality in a river).	• Relatively expensive and time-consuming (depending upon the desired level of confidence in the results). • It is often very difficult to attribute subtle, long-term changes in waterway health to the use of any particular BMP. This style of evaluation is mainly used to evaluate the *collective* affect of all catchment management activities over time. • Usually requires a very high level of technical expertise to design the monitoring program and analyse the results.

[6] 'BACI' is an acronym for an experimental design that has sampling Before and After sampling at a Control (no action) and Intervention (action) site.

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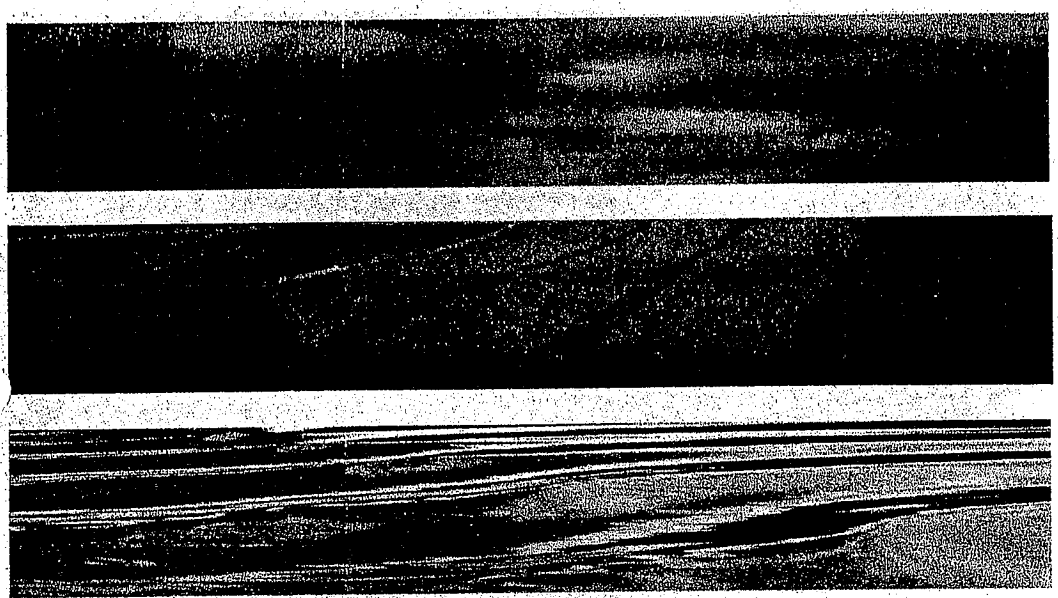

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COOPERATIVE RESEARCH CENTRE FOR
CATCHMENT HYDROLOGY

CRC AUSTRALIA

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Considerations in the Design of Treatment Best Management Practices (BMPs) to Improve Water Quality

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

Notice

This document has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for publiction. Mention of trade names, commercial products, or design procedures does not constitute endorsement or recommendation for use.

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Hugh W. McKinnon, Director
National Risk Management Research Laboratory

Abstract

For the past three decades, municipalities in the United States have successfully addressed pollution in the watershed by collecting and treating their wastewater. Currently, all municipalities provide secondary level treatment, and in some cases tertiary treatment, and industries provide best available/best practicable treatment. This has had great benefits. More rivers are meeting water quality standards, and the public health is being protected from waterborne disease. The challenge now facing us is to address pollution associated with storm water runoff, since this is now the last major threat to water quality.

It is less costly to prevent the generation of polluted runoff than to treat it. Today, many municipalities are implementing low-cost best management practices (BMPs) that prevent runoff. The lowest cost BMPs, termed non-structural or source control BMPs, include practices such as limiting pesticide use in agricultural areas or retaining rainwater on residential lots (currently termed "low impact development"). There are a set of higher cost BMPs, which involve building a structure of some kind to store stormwater until it can be discharged into a nearby receiving water. These can be more costly, especially in areas where land costs are high. The three most commonly used structural treatment BMPs that will be discussed in the document are ponds (detention/retention), vegetated biofilters (swales and filter/buffer strips) and constructed wetlands. Two categories of treatment considered in this document are ponds and vegetated biofilters. Ponds are probably the most frequently used BMP in the United States. There are three types of pond BMPs: wet ponds (retention ponds); dry ponds (notably extended detention ponds); and infiltration basins. Three different types of vegetative biofilter BMP types are discussed: grass swales, vegetated filter strips, and bioretention cells. Grass swales include three variations: traditional grass swales, grass swales with media filters and wet swales.

This document presents factors that should be considered in the design of treatment BMPs to improve water quality. The state-of-the-practice is such that existing design guides vary and the performance of treatment BMPs shows a wide range of pollutant removal effectiveness.

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Acronyms and Abbreviations

ASCE	= American Society of Civil Engineers
BMP	= best management practice
BOD	= biochemical oxygen demand
CERCLA	= Comprehensive Environmental Response, Compensation and Liability Act
CZARA	= Coastal Zone Act Reauthorization Amendments
CZMA	= Coastal Zone Management Act
COD	= chemical oxygen demand
CWA	= Clean Water Act
EPA	= Environmental Protection Agency
EPT	= ephemeroptera (mayflies), plecoptera (stoneflies), and trichoptera (caddisflies)
ESA	= Endangered Species Act
EMC	= event mean concentration
FIFRA	= Federal Insecticide, Fungicide and Rodenticide Act
FWPCA	= Federal Water Pollution Control Act
IBI	= index of biotic integrity
MDE	= Maryland Department of the Environment
MTBE	= methyl tertiary butyl ether
NEPA	= National Environmental Policy Act
NGPE	= native growth protection easement
NMFS	= National Marine Fisheries Service
NOAA	= National Oceonographic and Atmospheric Administration
NPDES	= National Pollution Elimination Discharge Program
NRCS	= Natural Resources Conservation Service
NURP	= Nationwide Urban Runoff Program
OCZM	= Office of Coastal Zone Management
RCRA	= Resource Conservation and Recovery Act
RFS	= rainfall frequency spectrum
SCS	= Soil Conservation Service
SWMM	= StormWater Management Model
TMDL	= total maximum daily loads
TN	= total nitrogen
TP	= total phosphorus
TSS	= total suspended solids
UDFCD	= Urban Denver Flood Control District
USDA	= US Department of Agriculture
USFWS	= US Fish and Wildlife Service
USGS	= US Geological Survey

USTM	= Unitied Stormwater model
WEF	= Water Environment Federation
WEPP	= Water Erosion Prediction Model
Wq_v	= water quality volume
WWF	= wet weather flow

Acknowledgments

Many people participated in the creation of this document. Technical direction was provided by USEPA's National Risk Management Research Laboratory (NRMRL). Technical writing was carried out in several stages, but culminated into a final product as a cooperative effort between the NRMRL and the contractors named below. The contractors produced a three-volume series "BMP Design Guide - Volume 1, General Considerations", "BMP Design Guide - Volume 2, Vegetative Biofilters" and "BMP Design Guide - Volume 3, Pond BMPs" which included detailed design guidance. That three-volume series will be published separately by USEPA. This document overviews factors which should be considered in the design of treatment best management practices (BMPs) to improve water quality.

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Mosquito-B... e Virus Prevention and Control
To decrease exposure to mosquitoes and the viruses they may carry:

- Limit outside activity around dawn and dusk when *Culex tarsalis* mosquitoes feed. This is particularly important for elderly adults and small children.
- Wear protective clothing such as lightweight long pants and long sleeve shirts when outside.
- Apply insect repellant to exposed skin when outside. Repellents with DEET are effective, but should be applied sparingly. Products with 10% or less of DEET are recommended for children.
- Make sure that doors and windows have tight- fitting screens. Repair or replace screens that have tears or holes in them.
- Drain all standing water on private property, no matter how small an amount.
- Stock permanent ponds or fountains with fish that eat mosquito larvae.
- Change water in birdbaths or wading pools and empty flowerpot saucers of standing water at least once a week.
- Check around faucets and air conditioner units and repair leaks or puddles that remain for several days.
- Make sure roof gutters drain properly and remove any standing water under or around structures or on flat roofs.
- Remove items that could collect water such as old tires, buckets, empty cans, and food and beverage containers.
- Eliminate seepage and standing water from cisterns, cesspools, septic tanks, and animal watering tanks.
- Do not over-water lawns and gardens to prevent standing water.

For additional information or to report a dead corvid, contact your local county health department. Colorado surveillance data for mosquito-borne viruses is available on the Colorado Department of Public Health and Environment Web site:

http://www.cdphe.state.co.us/dc/Zoonosis/zoonosis.asp

STATE OF COLORADO 1876

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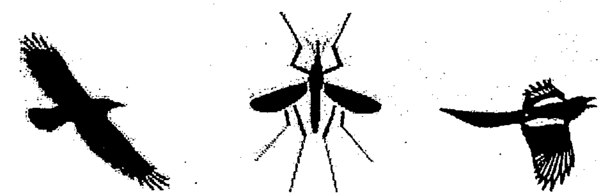
West Nile Virus and Mosquito-Borne Viruses in Colorado

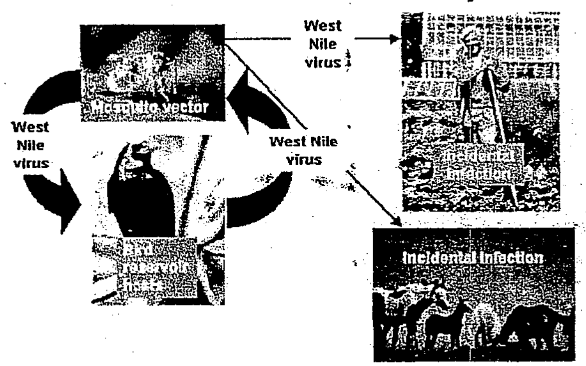


What Are The Mosquito-Borne Viruses In Colorado?
There are currently three viruses in Colorado that are transmitted by mosquitoes. A fourth virus, West Nile, is expected to reach Colorado soon.
Western equine encephalitis (WEE) is distributed across the central and western United States.
St. Louis encephalitis (SLE) is found throughout the continental United States.
California encephalitis viruses are a group of several viruses found throughout the U.S.
West Nile (WN) virus historically occurred in parts of Asia, Eastern Europe, Africa, and the Middle East. This virus was first detected in the United States in 1999 during an outbreak in New York City.

How Are People and Animals Infected with these Viruses?
These viruses are transmitted to people and animals by bites from infected mosquitoes. Only certain species of mosquitoes carry the virus and very few mosquitoes actually are infected. In Colorado, these viruses are transmitted to people by a species called *Culex tarsalis*, a medium-sized mosquito that feeds in the few hours around dawn and dusk. During the day they rest in shady, secluded areas, such as under porches, roof overhangs, tall grass, shrubs, and storm sewers. They breed in almost any source of standing water, including irrigated fields, old tires, hoof prints, flowerpots, tree holes, or any puddle of water that lasts for more than a few days.

These virus. .e maintained in a bird-mosquito-bird cycle. Mosquitoes are infected by feeding on a bird with virus in its blood. The virus is transmitted to a new host in the mosquito's saliva when the insect bites another person or animal. Humans and horses are incidental dead-end hosts in that they cannot infect other mosquitoes. Person-to-person transmission does not occur. These viruses are prevalent from May to September when mosquitoes are most abundant, but the risk to humans occurs primarily from August through early September.

West Nile Virus Transmission Cycle



What are the Symptoms?
Most people who are infected with mosquito-borne viruses do not become ill and have no symptoms. For persons who do become ill, the time between the mosquito bite and the onset of symptoms, known as the incubation period, ranges from 5-15 days.

Two clinically different types of disease occur in humans: (1) viral fever syndrome, and (2) encephalitis, an inflammation of the brain. Symptoms of the viral fever syndrome include fever, headache, and malaise. These symptoms persist for a about 2-7 days.

In rare cases, the virus can cause a more serious brain infection such as aseptic meningitis or encephalitis. These infections begin with a sudden onset of high fever and a headache, and then may progress to stiff neck, disorientation, tremors, and coma. Severe infection can result in permanent brain damage or death. M leaths occur in persons over 50 years of age. There is no specifi atment for infection with these viruses except supportive care.

Which Animals Get Infected with these Viruses?
An infected mosquito can bite any animal, but not all animals will become ill. As the reservoir host of these viruses, birds are most often infected, but other animals can be infected and become ill as well.

Birds

Mosquitoes acquire the viruses from wild birds. Infection has been reported in more than 70 bird species. With WEE and SLE, infected birds will **not** appear ill or die. However, WN virus is new to this country and does cause illness and death in native birds that have no natural resistance to infection. The highest death rates are seen among birds in the **corvid** family, which includes crows, magpies, ravens, and jays. American crows constitute the majority of birds reported positive for WN virus.

Horses
Horses are susceptible to infection with WEE and WN viruses, but not SLE. Another virus, eastern equine encephalitis (EEE) is not found in Colorado, but could be a problem if a horse travels to the eastern U.S. These diseases do not seem to be specific to a particular breed or age of horse. Clinical signs in a horse can include lack of coordination or muscle control, weakness of limbs, inability to rise, and death. Fever has been detected in less than one-quarter of all confirmed cases of WN virus. WEE, EEE, and WN virus vaccines are available for horses through veterinarians.

Components of the Colorado Mosquito-Borne Virus Surveillance Program
Local health departments and the Colorado Department of Public Health and Environment have conducted a statewide mosquito-borne encephalitis surveillance program since 1988 for WEE and SLE. In 2001, the program expanded to detect WN virus.

Sentinel Chicken Testing
Chicken flocks are strategically placed throughout the state and are tested bi-weekly during the mosquito season to detect evidence of infection with WEE, SLE, and WN viruses.

Mosquito Surveillance
Mosquitoes are collected to monitor the abundance and type of mosquitoes in the area and some are sampled for the presence of WN, WEE, and SLE viruses.

Dead Corvid Testing
Colorado began to test dead corvids for WN virus in 2001. Birds that have died within the previous two days are collected and submitted to the state laboratory by the local health department or animal control agency. Persons finding a dead crow should use gloves when handling a carcass. Information on the collection and submission of a dead corvid is available on the Colorado Department of Public Health and Environment Web site.

Equine Case Surveillance
Horses can become ill and die from infections with WEE and WN. The occurrence of horse cases in an area indicates significant virus transmission and can indicate an increased risk to humans. Veterinarians are required to report suspect cases and are encouraged to submit blood samples for testing.

Human Case Surveillance
Cases of encephalitis suspected of being caused by these viruses are physician- reportable conditions under Colorado law. The Colorado Department of Public Health and Environment lab offers testing for WEE, SLE, and WN virus on any suspected cases.

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Stormwater Sand Filter Sizing and Design
A Unit Operations Approach

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ABSTRACT

The use of sand and other media filters are gaining acceptance in the field of urban stormwater structural best management practice. Much work has been done to develop local design guidance such as in the State of Delaware and in Austin, Texas. Also, considerable field testing of these devices has occurred over the last 10 years. This paper consolidates much of the earlier work and provides the technical basis for the design of media filters for stormwater runoff treatment at any location in the United States. The approach utilizes the unit processes known to exist in urban stormwater runoff and within filter devices. The suggested design is based on hydraulic capacity of the filter media, which, in turn, is a function of the total suspended solids removed by the filter.

INTRODUCTION

Sand and other media filters remove constituents from stormwater runoff primarily through a physical process of filtering out particulates from the water. The type of media used and its grain size distribution determine how small of a particle is strained out. Coarser sands have larger pore spaces that have high flow-through rates but pass larger suspended particles. A very fine sand, or other fine media filter, has small pore spaces with slow flow-through rates and filter out smaller total suspended solids (*TSS*) particles. Some media, such as peat-sand mix, may also provide ionic adhesion or exchange for some dissolved constituents which further enhances effluent quality.

Laboratory and field tests have shown (Neufeld, 1996; EPA, 1983; Veenhuis, 1989; City of Austin, 1990) that a filter media consisting of concrete sand (ASTM C-33 mix) provides a good balance between flow-through rates and filtering efficiency. The filter performs like a classic slow sand filter that has been used to treat water for approximately 100 years. Initially the flow-through rates are high, but as the filtrate of fine sediment accumulates on its surface, flow-through rates diminish. In water treatment the quality of the effluent improves as the filtrate layer thickens. This may not be the case with stormwater. Some field tests suggest that the effluent quality improves initially, but may degrade over time, suggesting leaching out of constituents from the filtrate and a need for maintenance.

In water treatment plants, scarifying the "sealed" surface improves the filter's flow-through rates. Eventually the filter media is removed and replaced. Water treatment filters operate continuously and regular maintenance is a part of the water supply product that is sold to the consumers. However, slow sand filters are rarely used today because they are operationally inefficient and require very large land areas. Instead, multi-media rapid sand filters are the norm in this industry, but they require intense operation and frequent backwashing to keep in operation at design flow-through rates.

Stormwater filters located within a municipality have to operate occasionally, often infrequently. If they are used extensively, there will be a large number of such facilities in any given metropolitan area. As a result, simple economics and pragmatism precludes the use of rapid sand filters for urban stormwater treatment because of their intense operations and maintenance needs. Since there is likely to be a very large number of small filter sites throughout the municipality their operation and maintenance needs become overwhelming. What remains as an option is the use of slow sand filters which require only an occasional cleaning.

The challenge a designer of a stormwater filter faces is to find a design that will provide a sufficient flow-through rate to process most of the runoff events (Urbonas *et al.*, 1996a). The filter has to be made as small as possible for cost reasons, while large enough to pass through the design event(s) without backing up water onto streets, parking lots, etc. and creating nuisance or safety problems for a municipality or its private owners.

DESIGN HYDROLOGY AND *TSS* LOAD

Because of the stochastic nature and temporal variability of stormwater runoff, any stormwater media filter will need a detention storage volume upstream of it. This detention volume permits the capture of rapid runoff so as to buffer the flows that have to be processed through the filter. A filter without such a buffer would have to be very large to keep up with the instantaneous runoff rates during rainstorms. The amount of this detention volume is determined by local runoff characteristics. To deal with the stochastic nature of the runoff process, typically a *design storm* is selected. Also, the rate at which the runoff from this *design storm* is allowed to drain through the filter determines its size. This detention capture volume needs to be emptied out in a reasonable amount of time to provide volume for the next storm runoff event that may follow.

After an extensive literature search of practices in the United States in the 1980's, Urbonas and Ruzzo (1986) suggested that a capture volume upstream of a sand filter be equal to ½ watershed inch of runoff from the impervious surfaces in the tributary watershed. Subsequent studies of rainfall records in the United States and field performance of BMPs now suggest that, as a minimum, this storage volume be between the runoff from an average runoff producing storm depth (i.e., *mean* storm) shown in Figure 1 (Driscoll, et al., 1989) and the *maximized* volume (Guo and Urbonas 1996; Urbonas, *et al.*, 1996a). The *mean* and the *maximized* volumes are a function of how rapidly this volume is fully drained (i.e., evacuated) from the detention basin, or from the surcharge of a retention pond. If it takes a long time, say 48 hours to fully drain this volume, then the probability increases for another storm to occur before this volume is evacuated and a larger detention volume needs to be provided than would be needed if the design *drain time* for this capture volume is less, say 12 hours.

Guo and Urbonas suggested Equation 1 (Guo and Urbonas, 1996; Urbonas, *et al.*, 1996) that permits an engineer to make a first order estimate of the *maximized* volume P_o. This relationship and the values for coefficient *a* (see Figure 2) resulted from extensive runoff modeling performed by Guo using rainfall records from different regions of the United States. The author re-examined these rainfall records and has also developed values of coefficient *a* for the capture of the *mean* storm runoff volumes for use with Equation 1(see Figure 2).

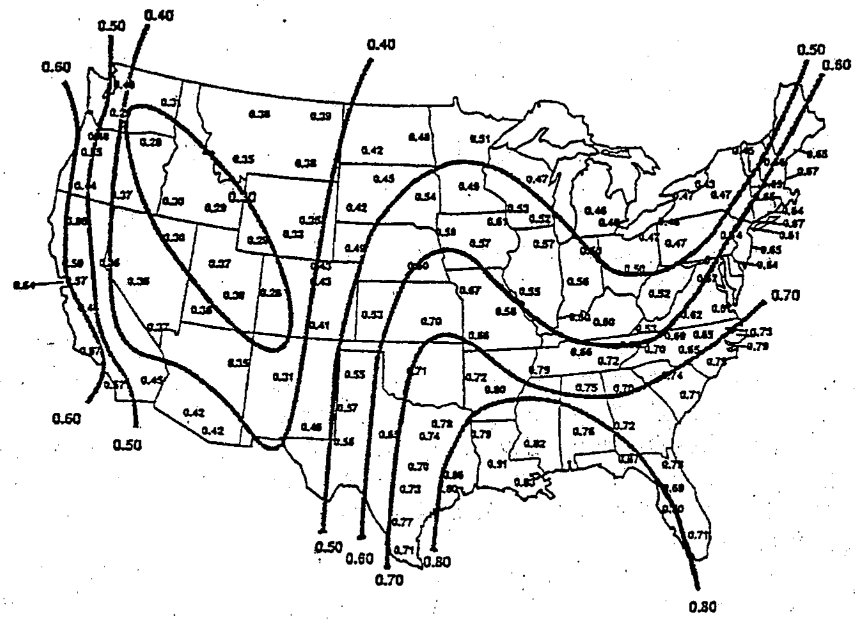
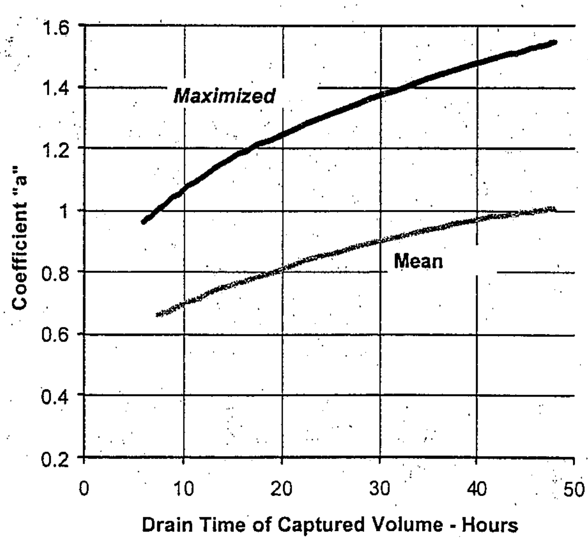


Figure 1. Mean Storm Depths in Inches of Precipitation in United States.
(Ref.: Driscoll, *et. al.*, 1989)



Drain Time in Hours	Determ. Coeff. r^2
12	0.97
24	0.91
48	0.85

Figure 2. Coefficient "*a*" to use in Equation 1.

$$P_o = a \cdot C \cdot P_6 \qquad (1)$$

In which,
- a = coefficient taken for the *maximized* or *mean* runoff volume from Figure 2
- C = catchment's runoff coefficient (see Equation 2)
- P_6 = average runoff producing storm depth from Figure 1, in inches

P_o = water quality capture volume (*maximized* or *mean* as appropriate), in inches

The catchment's runoff coefficient can be estimated using Equation 2 which was developed using rainfall and runoff data from 60 NURP sites across the United States (EPA, 1983).

$$C = 0.858 i_a^3 - 0.78 i_a^2 + 0.774 i_a + 0.04 \qquad (r^2 = 0.72) \qquad (2)$$

In which, i_a = $I_a/100$; fraction of the catchment's total area covered by impervious surfaces

I_a = percent of the catchment's area that is covered by impervious surfaces (use the <u>total</u> percent imperviousness rather than the hydraulically connected portion).

Because the filter's surface accumulates the strained-out materials over time, it is also necessary to know how much runoff can occur over an extended period of time, such as during an average year. This permits an estimate of the average annual load of the constituents in stormwater arriving at the filter and, knowing the filter's removal characteristics, the amount of the constituents removed by the filter during an average year. The annual runoff depth can be estimated using Equation 3.

$$P_A = n \cdot P_6 \cdot C \qquad (3)$$

In which, P_A = average annual total stormwater runoff from the catchment, in inches

n = average number of runoff producing storms per year from Figure 3

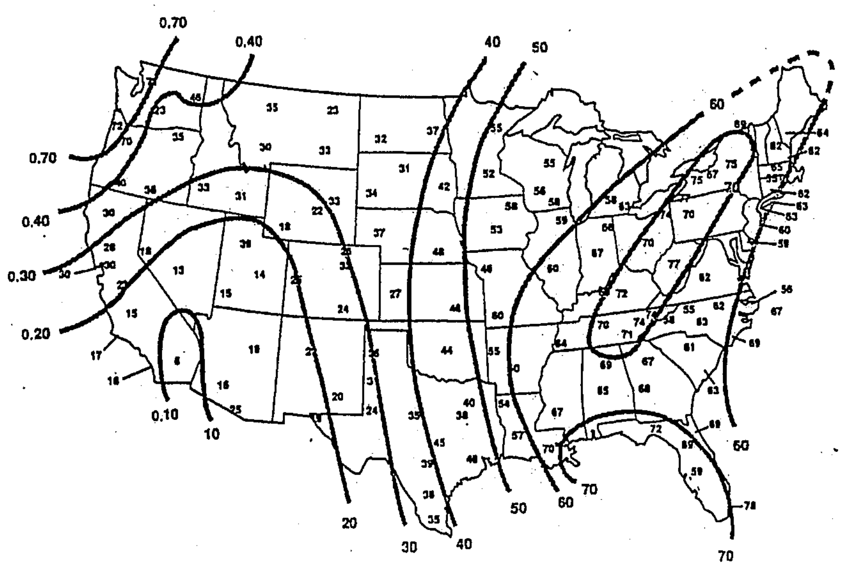


Figure 3. Number of Runoff Producing Storms in United States. (Ref.: Driscoll, *et. al.*, 1989)

Then the average annual load of *TSS* delivered by stormwater to the filter can be found using

$$L_a = \left[\left(A_c \cdot 43{,}560 \right) \cdot \left(\frac{P_A}{12} \right) \right] \cdot \left(\frac{E_s}{10^6} \cdot 62.4 \right)$$

Which can be reduced to:

$$L_a = 0.2265 \cdot A_c \cdot P_A \cdot E_s \tag{4}$$

In which, L_a = average annual *TSS* load in stormwater runoff from the tributary catchment, in pounds
A_c = area of tributary catchment, in acres
E_s = average *EMC* of *TSS* at the site, in mg/l

This annual load of *TSS*, along with the removal rates by the upstream detention/retention and by the filter, plays a dominant role in determining the size needed for a media filter. In order to proceed further with the design it is necessary to first understand how different detention/retention basin and filter combinations interact in the removal of *TSS* from the water column. Also, it will be necessary to estimate the fraction of the annual *TSS* load, L_a, that will be processed through the filter facility and the fraction that will bypass it.

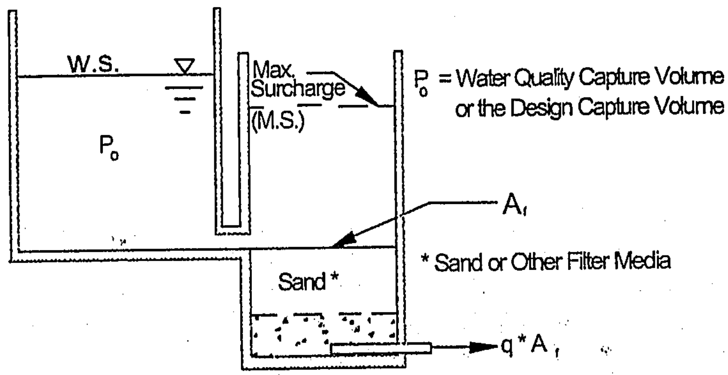
FILTER CONFIGURATIONS

There are three basic arrangements of upstream design volume storage (i.e., water quality capture volume - *WQCV*), and the filter media. Figure 4 schematically illustrates these configurations. The upstream detention captures and equalizes stormwater runoff rates to those compatible with the filter's flow-through capacity. This design volume temporarily stores the higher rates of runoff and permits stormwater to flow through a filter at rates that it is capable of handling, namely its available flow-through rate. When this design capture volume is exceeded by a larger runoff event, the excess volume ponds on the surface of the catchment immediately upstream of the filter, or it bypasses the filter.

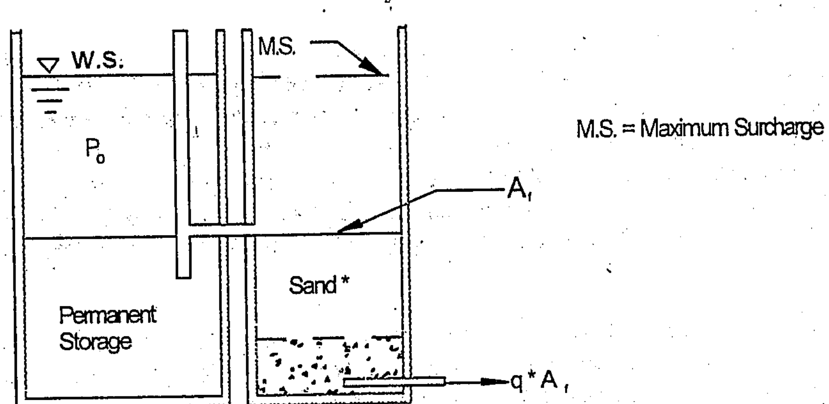
In Figure 4, Case 1 condition represents an arrangement where the filter is preceded by an extended detention basin, namely a basin that is totally evacuated of water after stormwater runoff ends. In Case 2 the filter is preceded by a retention pond with a surcharge extended detention volume above the permanent pool. In this case the permanent pool retains all or some of the runoff within it after storm runoff ends while the surcharge capture volume is totally evacuated after stormwater runoff ends. For Cases 1 and 2 the detained volume is evacuated through a flow control outlet. This outlet is designed to empty out the design capture volume over a desired time period, namely its *drain time*.

The detention outlet can also be oversized and the detention volume's evacuation rate can be governed by the size and flow-through rate of the filter itself. If this is the design condition, the filter will operate similarly to the one shown in Case 3, where at least a part of the detention volume resides directly above the filter's surface. Most common field examples for Case 1 can be found in Austin, Texas. The State of Delaware filter design is best represented by Case 3, as are the field conditions where the filter is incorporated into the banks of a retention pond above the permanent pool's surface. The latter design is commonly used in Florida. Case 3 was the condition tested in Lakewood, Colorado in 1995.

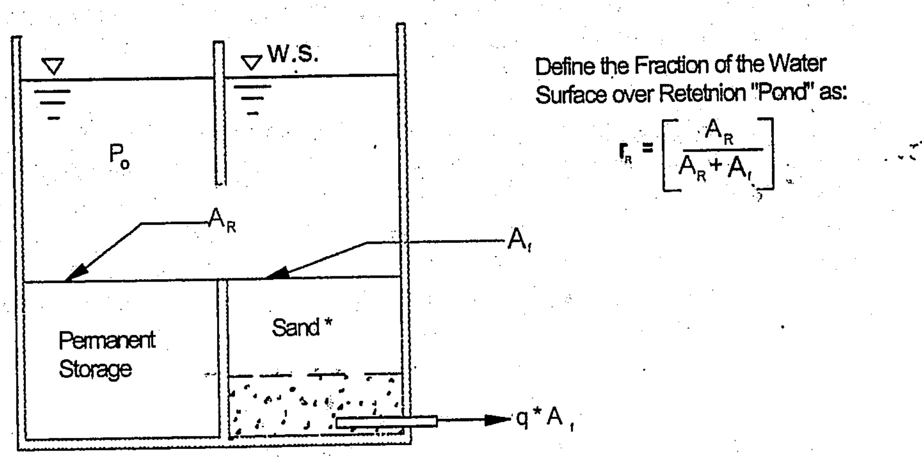
The detention/retention basin upstream of the filter also removes some of the solids since *TSS* can settle before the stormwater reaches the filter. The designer needs to estimate how much *TSS* is removed by the upstream detention/retention basin in order to estimate how much *TSS* may be left in the water column to be removed by the filter. This is not an easy estimate to make since there is much variability in the reported *TSS* removal rates by a detention or a retention basin.



Case 1: Detention Basin with Controlled Release Followed by a the Filter



Case : Retention Basin with Controlled Surcharge, Followed by a the Filter



Case 3: Combination Retention Pond & Media Filter Without Controlled Release to Filter

Figure 4. Three possible arrangements for a filter in relation to upstream detention basins.

A conservative design approach suggests that a lower value for *TSS* removals be used for design than the averages reported in literature for detention basins and retention ponds. For the same reason, *TSS* removal efficiencies used for the design of the filter itself should be based on higher removal rates than the average rates reported in the literature. The intent during the sizing of a filter is not to predict actual *TSS* removal rates accurately, but to use reasonable removal rates to arrive at realistic, possibly somewhat conservative filter size. Table 1 provides suggested design *TSS* removal rates for retention ponds and detention basins located upstream of the filter. These removal rates are somewhat lower than the averages reported in the literature. However, if locally collected information differs significantly, the designer should use such locally available data instead.

For Cases 1 and 2 defined in Figure 4 it is possible to assume that the concentration of *TSS* leaving the retention/detention basin can be estimated using :

$$E_{sd} = E_s \cdot \left(1 - \frac{R_D}{100}\right) \tag{5}$$

In which, E_{sd} = average concentration of *TSS* leaving the detention or retention basin, in mg/l
R_D = assumed percent removal rate for the retention or detention basin upstream of the filter bed (see Table 1)

The EMC of the effluent *TSS* leaving the filter after it has passed through retention or detention and the filter bed, is defined as:

$$E_{sf} = \left(1 - \frac{R_T}{100}\right) \cdot E_s \tag{6}$$

In which, E_{sf} = average annual EMC of *TSS* in the effluent from the filter bed, in mg/l
R_T = total system's average percent removal rate of *TSS*

Then the reduction in the EMC of *TSS* by the filter itself can be expressed as

$$E_{sfr} = E_{sd} - \left(1 - \frac{R_T}{100}\right) \cdot E_s$$

In which, E_{sfr} = the change in suspended solids concentration through the filter in milligrams per liter

After substituting Equation 5 into the above relationship and rearranging terms, we get

$$E_{sfr} = E_s \cdot \left(\frac{R_T - R_D}{100}\right) \tag{7}$$

For design purposes it is suggested that the value for R_T be equal to the highest reported rates of *TSS* removals by stormwater filters, namely R_T = 95 percent.

Table 1. Suggested Design Percent Removal Rates by Retention and Detention Upstream of a Media Filters for Sizing Them.

Detention Volume, P_o, Drain Time - T_d in hours	Suggested Percent Removal - R_D	
	Detention	Retention
48	60	90
24	55	85
12	50	80
6	40	75
3	30	70
1	20	50

For Case 3 shown in Figure 4 the above analysis needs to be modified. In Case 3 some of the detention storage volume is directly above the filter media. A first-order estimate of sediment removals ahead of the filter assumes that the water column that is not above the filter's surface acts as an independent retention pond. The water column that is above the filter's surface receives no pretreatment and all the *TSS* in this water is subject to removal by the filter.

Under the Case 3 scenario one can assume that the *TSS* concentration leaving the retention portion of the system can be expressed in terms of retention surface area and the total system surface area. Namely,

$$E_{sd} = r_R \cdot E_s \cdot \left(1 - \frac{R_D}{100}\right) \tag{8}$$

In which, r_R = $[A_R/(A_R+A_f)]$, ratio of the retention basin's surface area to the total system's surface area
A_R = surface area of the retention pond's permanent pool in square feet
A_f = surface area of the filter bed in square feet

Then the reduction in the EMC of *TSS* by the filter bed itself can be expressed by

$$E_{sfr} = E_s \cdot \left[\frac{R_T - r_R \cdot R_D}{100}\right] \tag{9}$$

Note that if all the detention storage is above the filter's surface, such as a basin with a sand filter bottom, $r_R = 0$ and all the *TSS* load is removed by the filter.

FILTER'S FLOW-THROUGH RATE

The classic relationship for water percolating through uniform soil media such as sand can be expressed as

$$q = k_h \cdot I \tag{10}$$

In which, q = flow velocity in inches per hour
k_h = hydraulic conductivity of the soil in inches per hour
I = hydraulic gradient in feet per foot

The relationship breaks down for a slow sand filter as fine sediment accumulates on top of its surface. In fact, field observation and laboratory tests (Neufeld, 1996; Urbonas *et al.*, 1996b) show that the flow-through rate for a sand filter (and other media as well) quickly becomes a function of the sediment being accumulated on the filter's surface. This relationship appears to be not very sensitive to the hydraulic surcharge on the filter's surface. It is represented graphically in Figure 5 and can be expressed mathematically as

$$q = k_i \cdot e^{-c \cdot L_m} \qquad (11)$$

In which, k_i = empirical flow-through constant (see Figure 5)
c = empirical exponential decay constant (see Figure 5)
L_m = cumulative unit *TSS* load accumulated on the filter's surface in pounds per square foot

It is this relationship that is used as the basis for the design procedure described later in this paper. Although the coefficients in Figure 5 are probably indicative of the expected performance for a sand filter, similar sets of coefficients can be developed for other filter media such as sand-peat mixes, etc. Namely, the procedure discussed here should be valid for other filter media provided appropriate empirical flow-through coefficients are employed . Examination of Figure 5 reveals that when the filter bed is new, the flow-through rates far exceed 12 inches per hour. As *TSS* is removed over the storm runoff season and the filtrate accumulates on the filter's surface, the flow-through rate rapidly drops off to approximately 0.9 inches per hour, after which it slowly continues to decrease to approximately 0.6 inches per hour.

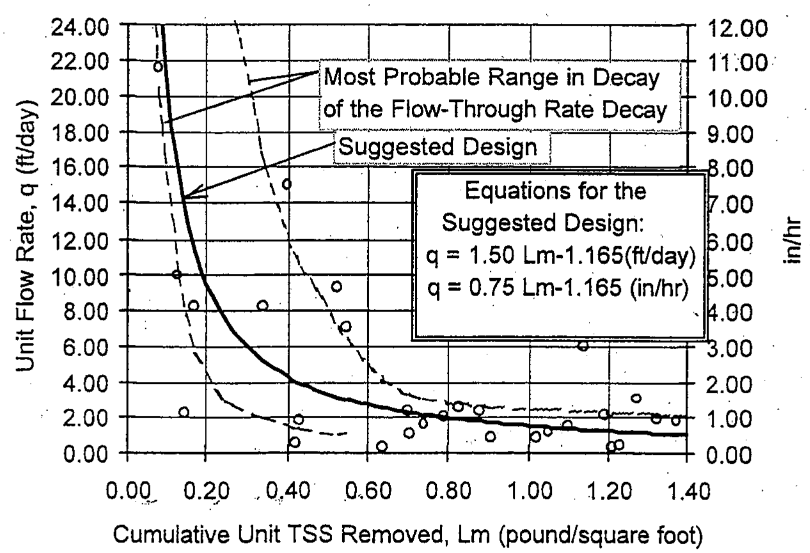


Figure 5. Flow Through Rate vs. Cumulative TSS Removed - Lakewood Sand Filter Test Site

The fraction of all runoff volume from the tributary area that will be treated through the filter facility is, in part, a function of the capture volume (i.e., detention) provided upstream of the filter. This detention volume can be bypassed by larger runoff flows, or the larger flows can first go through the detention basin before overtopping it and bypassing the filter itself. Depending on which condition occurs will also determine the amount of treatment provided to the excess volumes produced by larger storms. If the *maximized* capture volume is provided, approximately 80 to 90% of all runoff volume can be treated by the filter installation. If, however, the capture volume provided is based on the *mean* runoff volume, approximately 60% to 70% of all runoff volume will be fully processed through the filter. Approximate values of coefficient *a* to be used in Equation 1 can be found on Figure 2, which coefficient can be used to find the capture volume for the *mean* storm and the *maximized* storm.

The filter will need to be maintained to stay in operation. Its contaminated and clogged layers will need to be removed and replaced with new media. After a number of such surface cleanings (estimated at five to ten) the entire media filter will need to be replaced because lower pore spaces will also fill. The frequency of maintenance activities play a major, maybe a dominant role in the filter's design. It is appropriate then to define the *TSS* load removals in terms of the frequency of maintenance cycles the facility will experience each year. Also, since the flow-through rate in Equation 11 (i.e., Figure 5) is expressed as a function of the load removed by the unit area, it is appropriate to express the average *TSS* load removed during each maintenance cycle in terms of *TSS* load removed by each square foot of the filter. Thus,

$$L_m = \frac{L_{afr}}{A_{fm} \cdot m} \tag{13}$$

In which, L_m = average *TSS* load removed by each square foot of the filter during each maintenance cycle, in pounds per square foot per cycle

m = number of times per year the filter is cleaned and reconditioned (i.e., maintenance cycles per year). Use a fraction (i.e., 0.5) if more than one year between cleanings

A_{fm} = surface area of the filter sized on the basis of *TSS* for load removed, in square feet

SIZING THE FILTER

Rearranging the terms of Equation 13 yields an expression for estimating the filter's area, namely,

$$A_{fm} = \frac{L_{afr}}{L_m \cdot m} \tag{14}$$

which is one of two filter area relationships that have to be satisfied simultaneously. The other one is the ability of the filter to process the design storm's runoff volume (e.g., maximized volume) within the desired drain time. This condition can be expressed as

$$A_{fh} \cdot q \cdot T_d = P_o \cdot A_c \cdot 43{,}560$$

Rearranging terms the area of the filter is defined as

$$A_{fh} = \frac{P_o \cdot A_c \cdot 43{,}560}{q \cdot T_d} \tag{15}$$

In which, q = the design flow-through rate through the sand filter's surface, in inches/hour

T_d = the time it takes the volume P_o to totally drain out at the design flow-through rate q, in hours

A_{fh} = surface area of the filter based on hydraulic sizing, in square feet

The designer now has to find a filter's surface area that comes close to satisfying the condition

$$A_{fm} \approx A_{fh}$$

namely, the surface areas found using the *load removed* sizing equation and the *hydraulic sizing* equation are nearly identical.

The following design procedure is suggested for finding the required filter's surface area:

DESIGN PROCEDURE

1. *Determine the average EMC of TSS the tributary catchment will produce.*
Use local *TSS* stormwater characterization data when available. In absence of local data, use the closest regional averages of *TSS* found in stormwater reported in the Nationwide Urban Runoff Evaluation final report (EPA, 1983) or other, more current, data source. This will set a value for E_s for the design.

2. *Calculate the average annual TSS load in stormwater runoff from the design catchment.*
Use Equation 2 to find the catchment's runoff coefficient, *C*; Figures 1, 2 and 3 and Equation 3 to estimate the catchment's average annual runoff, P_A; and the value of E_s from Step 1 above, the catchment's tributary area, A_c, and the foregoing estimate of P_A in Equation 4 to estimate the average annual *TSS* load, L_a, being delivered by stormwater runoff to the filter installation.

3. *Select filter-detention/retention configuration and preselect its desired drain time (i.e., time it takes to fully evacuate the capture volume.*
It is suggested that Case 1 and 2 configurations (City of Austin, 1988) be used for tributary catchments with over one acre of impervious surface, while Case 3 be considered as a filter inlet for smaller sites (Shaver, 1994; City of Alexandria, 1992).

   It is necessary to assume or select the drain time, T_d, for the capture volume being used to size the filter. This is the determining factor for finding the "maximized" or the "mean" volume, P_o, whichever is used as the design water quality capture volume.

4. *Estimate the reduction in the EMC of TSS provided by the filter itself.*
Based on the filter's configuration being used (e.g., Case 1, 2 or 3 with a value for r_R), select the appropriate value from Table 1 for the removals by the detention or retention portion of the facility and use Equation 7 to calculate E_{sfr}.

5. *Estimate the average annual TSS load removed by the filter.*
Use Equation 12 to calculate a value for L_{afr}.
Assume b = 0.90 if a detention volume equal to P_o is provided.

6. *Determine the filter's annual maintenance frequency.*
Base this on how often the owner is willing and/or able to clean and restore the filter. For example, on the southwest coastal areas of the United States where almost all rainfall

takes place in a six-month period, if the owner is willing to clean the filter at least once a month during the wet weather months, set the value for $m = 6$. If, on the other hand the owner does not want to bother with frequent maintenance and will commit only to cleaning the filter once every two years, set $m = 0.5$.

7. *With the aid of Figure 5 select the acceptable unit TSS load before each cleaning.* Initially it is necessary to assume a value for the unit *TSS* load removed, L_m. by the filter. This value will be used with Figure 5 to make the first estimate of the needed filter's surface area.

8. *Set the water quality capture volume for this installation.* It is recommended that, as a minimum, a volume equal to the runoff from the "mean" average storm (see Figure 1) and the "maximized" volume be used for design. Using the drain time, T_d, assumed in Step 7 and Equation 1 to calculate a value for P_o.

9. *Make first estimates of the filter's area.* Calculate the filter's area, A_{fm}, using Equation 14 and the values for L_a, E_s, and L_{afr} found in Steps 1, 2 and 5 respectively.

   Also, calculate the filter's area, A_{fh}, using Equation 15 and the values for P_o; the catchment's tributary area, A_c; the flow-through rate, q, using Equation 11 based on the value of L_m; and the assumed drain time T_d for P_o assumed in Step 3.

10. *Compare the two filter areas calculated in Step 9.* If the two calculations give significantly different results, say more than 20% different; average the two areas; calculate a new value for the unit load removed by the filter, L_m; find a new flow-through rate using Equation 11 and repeat Step 9. Otherwise choose the larger surface area of the tow after rounding off, as the design area.

    Repeat this process as needed until the two area calculations are within 20% of each other. At that point use the larger of the two as the design surface area of the filter.

EXAMPLES

Example 1. A commercial site near Chicago, Illinois. The media filter will be preceded by an upstream extended detention basin. The known site conditions are as follows:

Step 1:

Tributary Area	A_c	=	1.5 acres
Expected EMC of *TSS*	E_s	=	120 mg/l
Average storm depth (Figure 1)	P_6	=	0.53 inches
Average number of storms per year ≥ 0.1 inches in depth (Figure 3)	n	=	55
Catchment's total imperviousness	I_a	=	85%

Step 2: Using Equation 2 find its runoff coefficient:

$$C = 0.858 \bullet 0.85^3 - 0.78 \bullet 0.85^2 + 0.77 \bullet 0.85 + 0.04 = 0.66$$

Using Equation 3 estimate the average annual runoff from the catchment:

$$P_A = 55 \bullet 0.53 \bullet 0.66 = 19.24\ inches$$

Using Equation 4 calculate the annual *TSS* load from the catchment:

$$L_a = 1.5 \bullet 43{,}560 \bullet \frac{19.24}{12} \bullet \frac{120}{10^6} \bullet 62.4 = 784\ lbs$$

Step 3: Select the filter's design configuration. Since the filter will be preceded by an upstream extended detention basin, we have Case 1 configuration. Also the outlet from the extended detention basin is designed to drain the capture volume in 12 hours.

Step 4: Using T_d = 12 hours, Table 1 gives for a detention basin a suggested removal rate R_D = 50 percent. Then, assuming an overall removal rate for the detention-filter system (i.e., R_T) is 95%, estimate the reduction in total solids concentration produced by the filter itself.

$$E_{sfr} = 120 \cdot \left(\frac{95-50}{100}\right) = 54\ mg/l$$

Step 5: Using Equation 12 estimate the average annual *TSS* load removal by the filter itself.

$$L_{afr} = 0.90 \cdot \frac{54}{120} \cdot 784 = 318\ lbs$$

Step 6: Determine the filter's annual maintenance frequency.
For this example assume m = 1 (i.e., once per year)

Step 7: To keep the size of the filter small while not imposing a very frequent maintenance schedule we choose to design the filter to drain at approximately 2.0 inches per hour. This means the corresponding value for L_m = 0.32 pound/square foot is found with the aid of Figure 5.

Step 8: Using T_d = 12 hours, the runoff coefficient from Step 2 and the coefficient from Figure 2 in Equation 1, find the "maximized" capture volume:

$$P_o = 1.12 \bullet 0.66 \bullet 0.53 = 0.39\ watershed\ inches\ (2{,}124\ cu.ft.)$$

Step 9: Using Equation 14:

$$A_{fm} = \frac{318}{0.32} = 994\ sq.ft.$$

Using q = 2.0 *in./hr.* in Equation 15:

$$A_{fh} = \frac{0.39 \bullet 1.5 \bullet 43{,}560}{2.0 \bullet 12} = 1{,}062\ sq.ft.$$

Step 10: Since the two areas calculated in Step 9 are well within 20% of each other, choose the larger of the two and round off. Namely the filter area scheduled for design is:

A_f = 1,060 *sq. ft.*

This design will require, on the average, one cleaning a year, each cleaning consisting of the removal and replacement of the top three inches of the sand bed. After five or more such cleanings, the entire filter bed will probably need to be replaced. A smaller filter could be used with additional cleanings each year. The designer may want to check to see if substantial savings in life-cycle costs could be achieved using higher maintenance frequencies and a smaller filter or using a larger filter with fewer maintenance cycles.

Example 2. Same as Example 1 except use a filter inlet, namely Case 3, with the retention pond's and filter's surface areas equal to each other, namely r_R = 0.5.

Steps 1 through 3 are the same as in Example 1.

Step 4. In Table 1 we find for a retention pond with T_d = 12 hours for its surcharge detention, the suggested TSS removal rate is R_D = 80 percent

then, using Equation 9

$$E_{sfr} = 120 \cdot \left[\frac{95 - 0.5 \cdot 80}{100} \right] = 66\ mg/l$$

Step 5. Using Equation 12 we find

$$L_{afr} = 0.9 \cdot \frac{66}{120} \cdot 784 = 388\ lbs.$$

Step 6. Assume m = 1.

Step 7. Using the same reasons stated in Example 1 we choose q = 2.0 *in./hr.* to begin the sizing process, thus

L_m = 0.32 lbs/ *sq. ft.*

Step 8: Same as in Example 1 @ T_d = 12 *hrs.*:

P_o = 0.39 inches (2,124 *cu. ft.*)

Step 9: Using Equation 14:

$$A_{fm} = \frac{388}{0.32} = 1{,}212\ sq.ft.$$

Using Equation 15:

A_{fh} = 1,062 *sq. ft.*

Step 10: Since these two are within 20% of each other, use the higher of the two. After rounding off recommend the following for design:

A_f = 1,200 *sq. ft.*

Again, one cleaning per year will be required to keep it operating as designed.

EXPECTED WATER QUALITY PERFORMANCE

What kind of hydraulic and water quality performance can one expect from a sand filter? The discussion above addressed the design of the filter based on hydraulic performance and how it varies as *TSS* was removed from stormwater runoff by the filter. The designer, planner and decision makers need to understand that stormwater runoff varies from zero to very large discharge numbers. It is a direct function of the precipitation, its duration and the tributary catchment's characteristics.

By providing a capture volume upstream of the filter that is in balance with the filter's flow-through capacity and after accounting for maintenance, it is possible to fully treat a large percentage of the storm runoff producing events through the filter, while treating some of the larger events only in part. The events that produce runoff at rates and volumes that exceed the capacity of the filter's physical plant will receive only partial treatment since the excess runoff will bypass the filter. Thus, the total system's performance is the composite of the filter's effluent water quality and the water quality of the bypass flow.

Hopefully, the worst polluted water will be captured by the filter's detention volume and will be treated through the filter, and only the cleaner "post first-flush" water will bypass the filter. The quality of the bypass water will also be affected by how the upstream detention or retention basin/pond is connected to the catchment's runoff.

If the basin/pond is in line with the flow after its capture volume is exceeded, stormwater will flow through the basin and the excess will overtop it. A properly designed extended detention basin or a retention pond should provide some treatment, through sedimentation, for the water that flows through it. Its efficiency may be diminished, but some sediment will be removed. A poorly designed or undersized basin may provide no water quality enhancement and may, in fact, cause some of the previously deposited sediment to resuspend and be flushed out.

If the detention/retention basin goes off-line when it is full, the excess runoff bypasses it. This arrangement is superior to in-line arrangement for high flows when the facility is not designed to handle high flows without resuspension of the previously settle solids. At the same time, it will generally produce lesser quality runoff during high flow events when the basin is properly designed to handle them.

The exact arrangement of water quality capture volume basin (i.e., retention or detention) in relation to the runoff system and the filter's size determine what one can expect the average annual EMCs that reach the receiving waters. Figure 6 illustrates the two cases, namely overflow of the excess and the bypass of the excess. To make a valid assessment of the average annual EMC for any constituent reaching receiving waters, the designer needs to flow-weight the concentrations of the effluent and the excess runoff from all the storms that occur, on the average, during a year. Namely, for Case 1 shown in Figure 6:

$$E_c = \left(k_T \cdot k_D \cdot E_i\right) \cdot \left(1 - r_{tf}\right) + E_f \cdot r_{tf} \qquad (14)$$

and for Case 2

$$E_c = \left(k_T \cdot E_i\right) \cdot \left(1 - r_{tf}\right) + E_f \cdot r_{tf} \qquad (15)$$

In which, E_c = average annual constituent's EMC downstream of the filter facility's installation, in mg/l

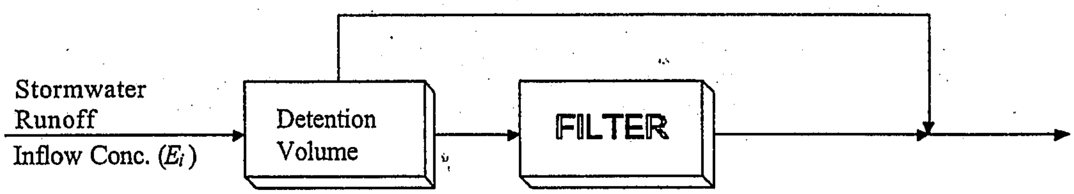
E_i = average annual constituent's EMC in the runoff inflow to the filter system, in mg/l

E_f = average annual constituent's concentration in the filter's effluent, in mg/l

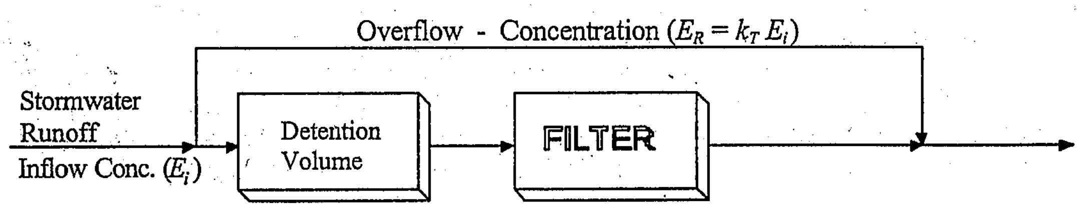
r_{pf} = fraction of the average annual runoff volume from the catchment that flows through the filter

k_D = fraction of the original constituent in the runoff that remains in the overflow water after the detention basin or retention pond overflows

k_T = coefficient of the reported constituent EMCs that represent the post "first-flush" fraction of the average EMC in stormwater runoff



Case 1. All runoff passes through the detention or retention basin upstream of the filter



Case 2. All runoff exceeding detention volume bypasses the filter and the detention/retention basin.

Figure 6. Two possible arrangements for a filter bypass with upstream detention volume.

Currently it is not possible to suggest definitive values for k_D and k_T, which coefficients depend on the constituent being considered and the actual design. However, a literature review suggests the following tentative ranges for *TSS*:

k_D = 0.3 to 0.5

and

k_T = 0.7 to 0.9

If the *maximized* coefficients suggested by Figure 2 for finding P_o are used, one can expect 80 to 90% of all runoff volume to be captured and treated through the filter, namely r_{pf} = 0.8 to 0.9. If, however, the runoff from the mean storm is used as the basis for design, one can expect approximately 60% to 70% of the runoff to be captured and treated through the filter, namely r_{pf} = 0.6 to 0.7.

Table 2 summarizes, after screening out the outliers, the findings of filter tests at four cities in the United States, namely, Alexandria, VA; Austin, TX; Anchorage, AK; and Lakewood, CO. Data for the first three were procured and consolidated into a single report by Bell et al. (1996) and the data for the Lakewood site were obtained by the Urban Drainage and Flood Control District in 1995. Note the high variability in the influent (i.e., stormwater runoff) measured concentrations for the six constituents reported here. Also note that the ratios between the high and the low concentrations are significantly less for the effluent. The variability in the influent appears to be primarily responsible for the large range in the report values of percent removed. However, most common removal rates for each constituent tend to cluster in a narrower range than the maximums. It is suggested that the designer look at the mean effluent (i.e., Out) concentrations in Table 2 to judge the filter's expected performance.

Table 2. Field Measured Performance Ranges of Sand Filters

Constituent	In or Out	Concentration *mg/l*			Percent Removed		
		Low	High	Mean	Low	High	MCR*
TSS	In	12	884	160			
	Out	4	40	16	8%	96%	80-94%
TP	In	0.05	1.4	0.52			
	Out	0.035	0.14	0.11	5%	92%	50-75%
TN	In	2.4	30	8.0			
	Out	1.6	8.2	3.8	(-130)%	84%	30-50%
TKN	In	0.4	28	3.8			
	Out	0.2	2.9	1.1	0%	90%	60-75%
TC_u	In	0.030	0.135	0.06			
	Out	0.016	0.035	0.025	0%	71%	20-40%
TZ_n	In	0.04	0.89	0.20			
	Out	0.008	0.059	0.033	50%	98%	80-90%

*MCR - Most Common Data Range

Returning to the earlier examples will illustrate the above discussion. In Example 1 an extended detention basin was used upstream of the filter. It is relatively easy to design this arrangement so that all runoff will pass through the detention basin and the excess runoff will overtop the pond. Let's further assume that k_D = 0.4 and k_T = 0.9. As a first order estimate we assume that 80% of the average annual runoff volume will pass through the basin and the filter and 20% will overflow the basin. If we assume that the filter will have an average effluent *TSS* concentration of 16 mg/l (see Table 2) then the average annual EMC of *TSS* downstream of the filter installation will be

$$E_c = (0.9 \bullet 0.4 \bullet 120) \bullet (1 - 0.8) + 16 \bullet 0.8$$

$$E_c = 21 \text{ mg/l}$$

Comparing this to the average EMC for *TSS* in stormwater runoff at that site (i.e., 120 mg/l) this installation will have 82% average annual removal efficiency for *TSS*. As a note of interest, it appears that the filter installation will produce only a marginal water quality improvement in *TSS* concentrations over a well-designed extended detention basin. Also, it appears that the filter's average effluent *TSS* and *TP* EMCs should be equivalent to one(s) produced by a well-designed retention pond. Similar estimates can be made for other constituents using the concentrations listed in Table 2.

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MITIGATION OF STORM WATER IMPACTS FROM NEW DEVELOPMENT IN ENVIRONMENTALLY SENSITIVE AREAS

Technical Report

October 2001

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INTRODUCTION

The California Regional Water Quality Control Board, Los Angeles Region (LA Regional Board) issued the final version of the Standard Urban Storm Water Mitigation Plan (SUSMP) for the County of Los Angeles and Cities in Los Angeles County on March 8, 2000. As adopted, the SUSMP included locations within or directly discharging to an environmentally sensitive area (EnvSA) as a development category to be subject to SUSMP requirements. The Building Industry Association, Western States Petroleum Association, and 32 cities filed an amended petition to the State Water Resources Control Board (State Board) to appeal certain aspects of the SUSMP. On October 5, 2000, the State Board issued its decision, *In Re: Bellflower et al.* ("SUSMP Decision").[1]

Although the SUSMP decision upheld much of the Regional Board's action, it removed EnvSAs as a development category from the SUSMP. The State Board surmised that EnvSAs were not a developmental category, but rather a locational designation. Further, the State Board expressed some concern that no threshold size had been specified that would trigger SUSMP requirements[2], and that development in EnvSAs may already be extensively regulated. Although the LA Regional Board had proposed a threshold for development within, adjacent to or directly discharging to an EnvSA in its response, the State Board determined that adequate opportunity for discussion of the threshold by interested parties had not been provided.[3] In setting aside the EnvSAs, the State Board explained the types of evidence and findings that

[1] SWRCB, 2000. State Board Order No. WQ 2000-11: In the matter of the petitions of the Cities of Bellflower, et al., the City of Arcadia, and Western States Petroleum Association,

[2] *Ibid.* at page 24.

[3] SWRCB, 2000. State Board Order No. WQ 2000-11: In the matter of the petitions of the Cities of Bellflower, et al., the City of Arcadia, and Western States Petroleum Association, page 25.

Regional Boards must make for future inclusion of the category.[4] The action to set aside EnvSAs was not to be interpreted as precedent setting.

The LA Regional Board intends to insure consistency among the requirements of the different municipal storm water permits it adopts. On July 27, 2000, the LA Regional Board adopted a renewed municipal storm water permit for Ventura County (Ventura County MS4 Permit) (Board Order No. 00-108). The Ventura County MS4 Permit included the Ventura Countywide Stormwater Quality Urban Impact Mitigation Plan (SQUIMP), which is analogous to the SUSMP for Los Angeles County. The Ventura County MS4 Permit requires that that new development controls be implemented for several development categories, including projects sited within, adjacent to or directly discharging to an EnvSA. Like the SUSMP, the SQUIMP requires a suite of water quality-related best management practices (BMPs) intended to minimize impacts from development.

Following issuance of the SUSMP decision, the Ventura County Co-permittees requested to have the language of the Ventura Permit and SQUIMP revised to conform to the changes made to the Los Angeles County SUSMP. In response, the LA Regional Board Executive Officer issued a letter, which changed portions of the Ventura County MS4 Permit language. However these changes did not modify the Ventura County MS4 Permit with respect to the EnvSA language or SQUIMP requirements. Three Ventura County MS4 Permittees petitioned the State Board against the actions of the LA Regional Board Executive Officer in making these changes to the Ventura County MS4 Permit. The State Board and LA Regional Board have held the appeals in abeyance pending the resolution of related issues during the renewal of the LA County MS4 Permit. Until these appeals are resolved, the Ventura County MS4 Permit remains in effect as adopted, including the requirements for projects in EnvSAs.

The California Regional Water Quality Control Board, San Diego Region (SD Regional Board) adopted a Municipal Storm Water Permit for San Diego County and Cities (SD County MS4 Permit) on February 28, 2001. The SD County MS4 Permit designated EnvSAs as a development category to be subject to SUSMPs, and included threshold development size and/or alteration criteria that will trigger the requirements. The threshold criteria were either the creation of 2,500 square feet of impervious surface or increasing the imperviousness of a proposed project site by ten percent above its natural condition.[5]

URBAN STORM WATER RUNOFF AND WATER QUALITY IMPACTS

Urban storm water contains pollutants that degrade water quality and adversely impact aquatic habitat. Pollutants found in storm water include suspended solids, heavy metals and a broad suite of organic compounds including pesticides, nutrients, petroleum compounds, pathogen indicators and other by-products of urban activities.[6] [7] Urban storm water has also been shown to alter water quality parameters such as pH, oxygen demand, specific

[4] See Memorandum from Craig Wilson, Chief Counsel, State Board to Regional Board Executive Officers dated Dec. 26, 2000.

[2]California Regional Water Quality Control Board, San Diego Region, San Diego County Municipal Storm Water Permit, Order No. 2001-01, 52 pp.

[6] Makepeace, D.K., Smith, D.W. and Stanley, S.J., 1995. Urban stormwater quality: summary of contaminant data. *Critical Reviews in Environmental Science and Technology*, 25(2): 93-139.

[7] Ayers, M.A., Kennen, J.G. and Stackelberg, P.E., 2000. Water quality in the Long Island-New Jersey coastal drainages, New York and New Jersey, 1996-98. U.S. Geological Survey Circular 1201.

conductance, temperature and turbidity.[8] Finally, urbanization modifies the hydrologic properties of a site, generally leading to increased volumes of runoff from a given amount of precipitation, and a more rapidly developing runoff peak.[9]

These pollutants and hydromodifications can directly result in negative impacts to biota and degrade ecosystems. Metals, organic compounds and other pollutants can have acute and/or chronic toxic effects to aquatic flora and fauna[10], and flow modifications can directly degrade the physical conditions of a habitat through erosion and deposition of sediments.[11] [12] A growing body of research links urban storm water runoff to water quality impairments and habitat degradation.[13] [14] Rivers and tributary streams, lakes, wetlands, estuaries and near shore ocean waters are susceptible to storm water impacts.

Adjacent habitats may be indirectly impacted by the degradation of aquatic areas. Fauna in riparian habitats may be negatively impacted by water quality degradation through reduced aquatic food sources, alteration of reproductive environments and habitat alteration that fosters proliferation of non-native species.

FEDERAL STORM WATER REGULATIONS

Federal storm water regulations require MS4 permittees to control storm water pollution from new developments during and after construction. U.S.EPA guidance advocates preventative measures including development design, implementation and maintenance of structural and non-structural best management practices (BMPs), and adoption of post-construction runoff ordinances.[15]

In February 2001, the U.S.EPA issued a Memorandum of Agreement (MOA) between the U.S.EPA, U.S. Fish and Wildlife Service (USFW) and the National Marine Fisheries Service (NMFS). The MOA is designed to enhance coordination of protection of endangered and threatened species pursuant to the Endangered Species Act (ESA) and the Clean Water Act (CWA). EPA believes that a coordinated national approach will insure greater protection for listed species, enhance regulatory predictability, and increase the efficiency of ESA

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[8] Schueler, Tom, 1994. The importance of imperviousness. *Watershed Protection Techniques*, 1(3) 7 pages.

[9] Booth, D. and Jackson, C.R., 1997. Urbanization of aquatic systems: degradation thresholds, stormwater detention, and the limits of mitigation. *Journal of the American Water Resources Association*, 33(5):1077-1090.

[10] Field, R. and Pitt, R.E., 1990. Urban storm-induced discharge impacts: US Environmental Protection Agency research program review; *Water Science and Technology*, 22(10/11):1-7.

[11] Sovern, D.T. and P.M. Washington, 1996. Effects of urban growth on stream habitat. In Roesner, L., ed. Effects of watershed development and management on aquatic ecosystems. ASCE Conference, August 4-9, 1996, Snowbird, Utah.

[12] May, Christopher W.; Horner, Richard R.; Karr, James R.; Mar, Brian W.; Welch, Eugene B., 1997. Effects of urbanization on small streams in the Puget Sound Lowland ecoregion, *Watershed Protection Techniques* 2(4): 483-494.

[13] Bay, S., Greenstein, D., Jirik, A. and A. Zellers, 1996. Toxicity of Stormwater from Ballona and Malibu Creeks, Southern California Coastal Water Research Project, Annual Report 1996, p. 96-104.

[14] U.S. General Accounting Office, 2001. Water Quality: Better data and Evaluation of Urban Runoff Programs Needed to Assess Effectiveness, USGAO, June 2001.

[15] For a discussion see, Radulescu, D., Swamikannu, X. and P. Hammer, 2001. Retail gasoline outlets: New development design standards for mitigation of storm water impacts, Technical Report, June 2001, California Regional Water Quality Control Board, Los Angeles Region.

consultations.[16]

Under the CWA, the Regional Board is responsible for "restoring and maintaining the chemical, physical and biological integrity of the Nation's waters". Clearly, the MOA contemplates cooperation and coordination of the Regional Board's regulatory programs to enhance the relationship between the CWA and the ESA.

In issuing MS4 Permits, the Regional Boards are expected to ensure that all federal requirements are met. New developments that occur in EnvSAs should be required to incorporate into development design and long-term maintenance planning, storm water pollution prevention methods and appropriate BMPs.

ENVIRONMENTALLY SENSITIVE AREAS

California Public Resources Code defines EnvSAs as follows:

> "Environmentally sensitive area means any area in which plant or animal life or their habitats are either rare or especially valuable because of their special nature or role in an ecosystem and which could be easily disturbed or degraded by human activities and Development."[17]

In the proposed LA County MS4 Permit these include:

(i) Significant Ecological Areas (SEAs), designated by the County of Los Angeles;
(ii) Significant Natural Areas (SNAs) designated by the California Department of Fish and Game (CDFG);
(iii) Rare, Threatened, or Endangered Species (RARE) beneficial use areas listed in the Regional Board Basin Plan, designated by the LA Regional Board; and

For the Ventura County MS4 Permit, the SEA category is substituted with the following because the Ventura County Planning Agency has not performed an equivalent designation,

(iv) Other Areas identified by the Permittees as environmentally sensitive for water quality purposes.

EnvSAs in the LA County MS4 Permit have been designated through a public process by their designating agencies. SEAs provide a habitat for rare, endangered, or threatened plant and animal species; biotic communities, vegetative associations, and species that are either one of a kind, or are restricted in distribution. These habitats often serve as concentrated breeding, feeding, or resting, or migrating grounds, and is limited in availability. They contain biotic resources that are of scientific interest. Some of these areas are important as game species habitat or fisheries; provide for the preservation of examples of relatively undisturbed natural biotic communities; and areas that are special for other reasons.[18] SNAs are areas that may

[16] USEPA, 2001. Fact Sheet: Memorandum of Agreement between the Environmental Protection Agency, Fish and Wildlife Service and National Marine Fisheries Service regarding enhanced coordination under the Clean Water Act and Endangered Species Act. EPA-823-F-01-003.

[17] See, Cal. Pub Res. Code 30107.5

[18] Los Angeles County Department of Regional Planning, 2000. Los Angeles County Significant Ecological Area update study 2000, Background Report. Prepared for Los Angeles County by PCR Services, Frank Hovore & Associates, and FORMA Systems.

support extremely rare species or habitats, support associations or concentrations of rare species or habitats, or exhibit the best examples of rare species and habitats in California.[19] The RARE beneficial use designation is assigned to "uses of water that support habitats necessary, at least in part, for the survival and successful maintenance of plant or animal species established under state of federal law as rare, threatened, or endangered.

Since most of the selection criteria for EnvSAs involve rare, endangered or threatened species and associated habitat, any negative impact to such areas acquires a higher degree of severity. In these areas, recovery from impacts is inhibited by inherently smaller populations, restricted habitat boundaries, habitat fragmentation, and boundary effects. So, for a given negative stimulus, EnvSAs will experience a potentially greater and less reversible negative response than areas with more abundant and less sensitive species or biotic assemblages. Due to this sensitivity these areas are more easily degraded, therefore they merit a higher standard of protection.

RELATED ENVIRONMENTAL PROTECTION

Selected areas in California already merit a higher standard of protection from development impacts because of location. The California Ocean Plan prohibits the discharge of "waste" to Areas of Special Biological Significance (ASBS), and requires discharges to be located far enough away to allow maintenance of natural water quality conditions in ASBS.[20] The State Board recently issued a decision regarding storm water discharges where it determined that discharges to ASBS are prohibited.[21]

In the late 1980s the Sierra Club brought a petition against the County of Los Angeles alleging a failure to conduct an environmental review of a proposed project in a protected habitat area prior to granting project approval, as specified by the Malibu Local Coastal Plan (LCP). The trial court ruling in this case resulted in the creation of an environmental review board (ERB) to regulate development in sensitive environmental resource areas.[22] The function of the ERB is to advise decision-makers of the County of Los Angeles to insure that development within sensitive environmental resource areas is consistent with the environmental protection policies of the Malibu LCP. The ERB evaluates proposed projects, makes recommendations, and suggests mitigation measures or conditions to minimize adverse environmental impacts[23]. Projects found not to be consistent with the Malibu LCP could presumably be denied a permit.

Relevant policies in the Malibu LCP include:

Policy 86:

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[19] Significant Natural Areas website: http://www.dfg.ca.gov/whdab/html/moresna.html.

[20] SWRCB, 1997. California Ocean Plan: water quality control plan – ocean waters of California. California Environmental Protection Agency, Sacramento, California.

[21] SWRCB, 2001. In the matter of the Petition of California Department of Transportation (Cease and Desist Order No. 00-87 for Crystal Cove), issued by California Regional Water Quality Control Board, Santa Ana Region. SWRCB file A-1350.

[22] Sierra Club, et al. , F.P. Angel, Counsel,Vs. County of Los Angeles and Board of Supervisors, C. Moore, Counsel, September 26, 1991, Ronald M. Sohigian, Judge.

[23] Los Angeles County Board of Supervisors, 1986. Malibu Local Coastal Program Land Use Plan.

"A drainage control system, including on-site retention or detention where appropriate, shall be incorporated into the site design of new developments to minimize the effects of runoff and erosion. Runoff control systems shall be designed to prevent any increase in site runoff over pre-existing peak flows. Impacts on downstream sensitive riparian habitats must be mitigated."

Policy 96:

"Degradation of the water quality of groundwater basins, nearby streams, or wetlands shall not result from development of the site. Pollutants, such as chemicals, fuels, lubricants, raw sewage, and other harmful waste shall not be discharged into or alongside coastal streams or wetlands."

The California Coastal Act contains provisions for an increased level of protection for resources defined as Environmentally Sensitive Habitat Areas (ESHAs). Cal. Pub. Res. Code § 30240.a states that:

"Environmentally sensitive habitat areas shall be protected against any significant disruption of habitat values, and only uses dependent on those resources shall be allowed within those areas."

On September 28, 2000, the California Coastal Commission (CCC) sent a letter to the State Board supporting the LA Regional Board's action in extending SUSMP requirements to EnvSAs.[24] Recently in commenting on a draft of the LA County MS4 permit, the CCC reiterated its support for inclusion of EnvSAs.[25] The CCC explained that the inclusion of EnvSAs is an important action that would greatly assist the State's efforts to protect the ecological integrity of land and coastal environments.

THRESHOLDS/EXEMPTIONS

The State Board in the SUSMP decision explained that Regional Boards might extend new development requirements to EnvSAs in the future if thresholds are established after full public discussion.

From a review of exemption criteria for developments in the literature, we note that CEQA uses the criterion of 2,500 square feet of impervious surface area for projects in EnvSAs as the threshold below which there is no environmental review. CEQA categorically exempts from environmental review: single-family residences or second dwelling unit in a residential zone; up to three single-family residences in an urbanized area; a duplex or similar structure in a residential area; apartments or similar structures designed for not more than six dwelling units in an urbanized area; stores, motels, offices or similar structures not using significant amounts of hazardous materials, and not exceeding 2,500 square feet in floor area.[26] The CEQA categorical exemption for up to four commercial buildings not exceeding 10,000 square feet of floor area, and not using significant amounts of hazardous materials, applies only if the

[24] California Coastal Commission, 2000. Letter dated September 28, 2000, to Craig Wilson, Chief Counsel, SWRCB, from Jaime Kooser, Deputy Director, Energy, Ocean Resources, and Water Quality.

[25] See Comment Letter from Jamie Kooser, Deputy Director, California Coastal Commission to Dennis Dickerson, Executive Officer, LA Regional Board dated July25, 2001.

[26] Title 14. California Code of Regulations, Chapter 3. Guidelines for Implementation of the California Environmental Quality Act; Article 19. Categorical Exemptions.

surrounding area is not environmentally sensitive. Commercial facilities less than 10,000 square feet and surrounded by an area that is environmentally sensitive therefore are not exempt from CEQA requirements. The CCC exempts single family residences (subject to conditions for access, water supply, etc.) from requirements for a coastal development permit.[27] The SD Regional Board excludes the applicability of new development requirements for development in EnvSAs where the change in impervious surface area is less than ten percent from the natural condition.[28] States such as Maryland, Washington, Florida, and Virginia use a threshold of 4,000 square feet or 5,000 square feet of disturbed land area for new development requirements to apply, but do not have a separate threshold for projects in EnvSAs although they require a stricter performance standard.

Although, we were unable to find an express basis in the legislative record for the CEQA threshold of 2,500 square feet of impervious area, it is reasonable to assume that the threshold derives from the typical impervious surface footprint of a single-family residential home (less than 2,500 square feet). Similarly, the typical single family lot size (less than 5,000 square feet) may be the basis of the threshold for the application of new development controls in other States. The SD Regional Board's alternative criteria of ten percent change from the natural condition appears to be based on scientific studies in the Mid-West and Pacific-Northwest which demonstrated that a more than ten percent change in impervious cover of watershed resulted in visible change to the ecological health of streams. Highly urbanized watersheds such as those in Los Angeles County usually have more than 50 percent impervious cover.

From our review of the scientific and regulatory literature, it is clear that environmental law and policy on development controls have been often framed to avoid imposing regulatory obligations on the individual homebuilder and/ or homeowner. A threshold for development in EnvSAs based on a similar objective appears to be reasonable.

DESIGN STANDARDS

The SUSMP requires the implementation of a suite of BMPs for developments, to mitigate adverse environmental impacts due to storm water and urban runoff. The suggested BMPs are designed to reduce the pollutant load in runoff and impacts from increased runoff volume and flow rates. Examples of BMPs include design elements such as clustering development, preserving existing vegetated areas, covering exposed pollutant sources and minimizing impervious surfaces, and treatment devices including detention or retention basins, oil/water separators, and filter systems.

The SUSMP does not prescribe specific BMPs, but does provide flow-based and volume-based criteria for runoff treatment. The choice of BMP or combination of BMPs is left to local control as long as the Maximum Extent Practicable (MEP) standard is met.

[27] California Public Resources Code, 30610.1. (a) Prior to certification of the applicable local coastal program, no coastal development permit shall be required for the construction of a single-family residence on any vacant lot meeting the criteria set forth in subdivision (c) and located in a specified area designated by the commission pursuant to subdivision (b).

[28] SD County MS4 Permit (Board Order No. 2001-01) at p. 16

ECONOMIC CONSIDERATION

BMPs required as part of the implementation of the SUSMP and SQUIMP will have economic impacts. Some BMPs would be implemented in most developments even if they were not explicitly required by regulation, including protection of slopes and channels and covered and contained trash and material storage areas. Other BMPs will be implemented only because they are required, and therefore potentially have a greater economic impact.

Economic impact will be case-specific and will depend on many factors. Studies about storm water BMP cost show that the size, type of development, existing environment, geology, and climate can affect the choice of BMP and its cost.[29] For example, an infiltration basin may be appropriate if the substrate is permeable, and groundwater contamination is not likely, whereas a biofiltration system that releases to the surface may be appropriate is the substrate is impermeable, or if sensitive groundwater resources are close to the surface. However, by imposing water quality requirements on the development at the design stage, cost savings can be maximized.

Clustered housing may save money on infrastructure, while minimizing the addition of impervious surface. Cost savings from alternative residential development designs have been estimated to be from 39–63% over conventional designs.[30] Commercial developments may demand certain parking space requirements, but water quality requirements can be met by pervious pavement, vegetative treatment swales, or water quality basins. Construction costs for storm water treatment BMPs for a five-acre commercial development have been estimated to range from $5,000 to $60,000 depending on the selected BMP. If water quality requirements are factored into the initial planning and design phase, total cost can be minimized and water quality benefits maximized.

JUSTIFICATION

The State Board excluded developments sited within, adjacent to, or directly discharging to EnvSAs from SUSMP requirements primarily because, it may have been mis-categorized as developmental rather than "locational", the absence of a threshold, the lack of adequate consideration by interested parties, and concerns of extensive regulation.

The LA Regional Board at this time, after nearly 12 months of public review for comment on three drafts, has provided ample opportunity for all interested parties to comment on the proposed criteria and its basis. By the nature of the designation of EnvSAs as a category to provide enhanced protection for, the basis is locational and identified as such under the Cal. Pub. Res. Code. § 30107.5. We propose a threshold of 2,500 square feet of impervious surface area or more as a threshold to trigger SUSMP requirements for projects in EnvSAs. On the issue of extensive regulation, we submit that most of the existing regulations regarding EnvSAs, are intended to exclude development entirely or limit allowed activities within the area but seldom for water quality protection. For developments that will be allowed, it is the responsibility of the State Board and Regional Boards to require effective mitigation of impacts from storm water and urban runoff and ensure at the same time that their actions do not harm

[29] Center for Watershed Protection, 1998. Cost and Benefits of Storm Water BMPs, Final Report 9/14/98, Prepared for Parsons Engineering Science, EPA Contract 68-C6-0001.

[30] *Ibid.*

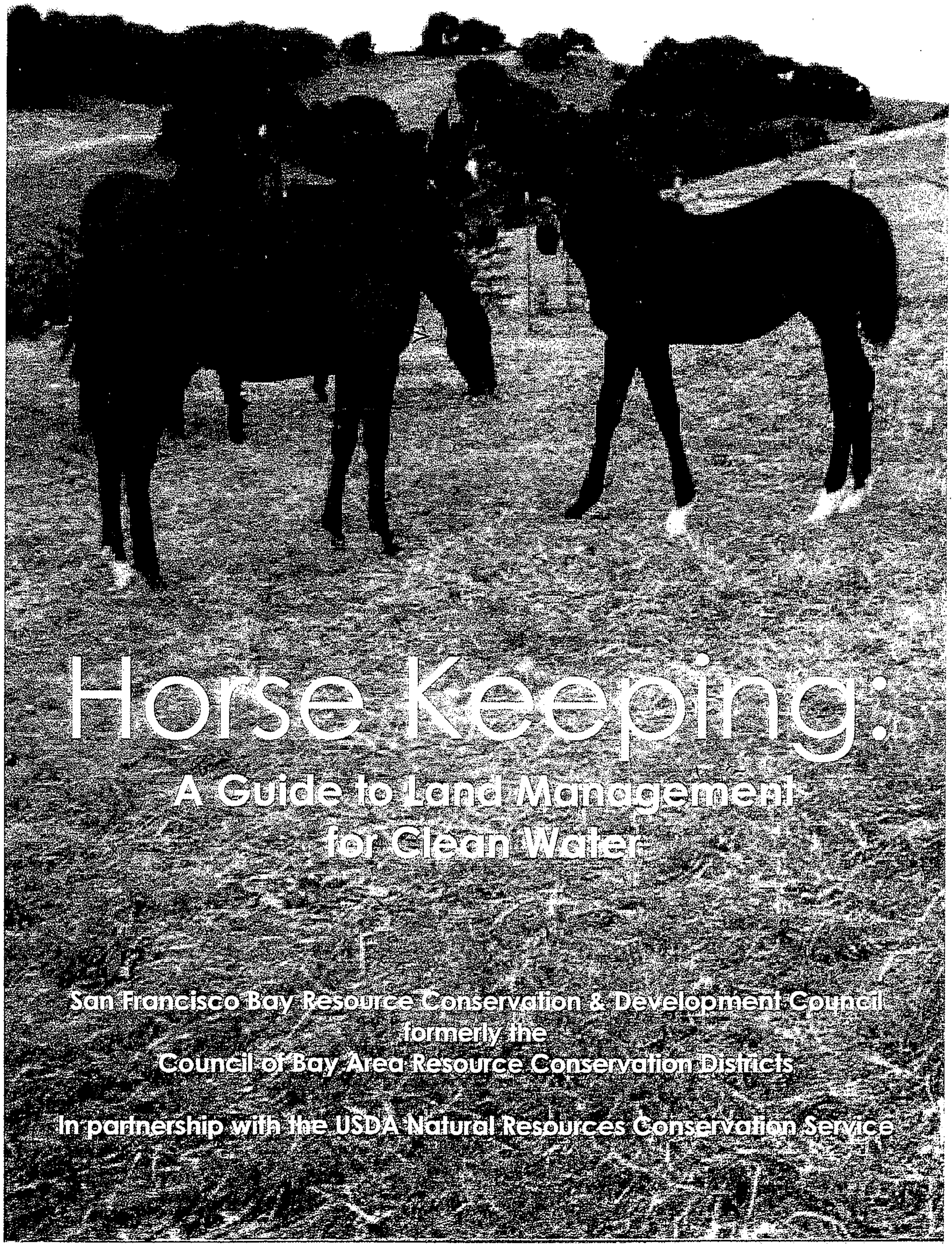
the natural resources of California.

We recommend a threshold of 2,500 square feet or more to trigger the SUSMP requirements for developments in EnvSAs. Developments that create less than 2,500 square feet of impervious area will not require a SUSMP, developments that create 2,500 square feet of impervious surface or more will require a SUSMP. Staff also proposes that the redevelopment (i.e. creation, addition, and replacement) of single-family structures (including those in EnvSAs) be excluded from SUSMP requirements.[31] Permittees may consider the threshold of altering the imperviousness cover to ten or more percent over the natural condition as an alternative approach when they submit a watershed or a regional plan for consideration by the Regional Board as a substitute for site-by-site SUSMP requirements.

CONCLUSION

EnvSAs are inherently sensitive habitats containing unique, rare, threatened or endangered species and/or assemblages of species. Their unique and sensitive nature merits a higher standard of environmental protection than more common areas with common and abundant species. Storm water and urban runoff are known to contain a wide range of pollutants and have demonstrated toxicity to plants and animals. Therefore it is necessary to mitigate impacts from storm water and urban runoff to the MEP for developments within or directly discharging to EnvSAs. Applying SUSMP requirements to these developments is feasible and can be accomplished by a range of BMPs that can be tailored to the size and type of a particular development. The recommended threshold of 2,500 square feet of impervious area for application of SUSMP requirements in EnvSAs is reasonable and consistent with current principles of environmental law and policy. The most effective and economic way to accomplish the mitigation of storm water pollution from new development is to identify and implement water quality control techniques at the planning and design stage rather than require post-construction retrofits.

[31] State of Maryland exempts existing single family structures from new development/ re-development standards, Storm Water Design Manual 2000 at p 1.13



Horse Keeping:

A Guide to Land Management for Clean Water

San Francisco Bay Resource Conservation & Development Council
formerly the
Council of Bay Area Resource Conservation Districts

In partnership with the USDA Natural Resources Conservation Service

Preface

THE HORSE HAS BEEN THE FUEL that stoked the fires of progress in time of peace and war throughout the centuries. When the need was greatest in the building of a new nation, or to carry supplies in time of war, the horse and mule responded to the call.

The horse has served as the early day equivalent of a tractor. They were our first example of rapid transportation and a true dependable friend. When all else failed they would be the food that served the top, or the bottom of the food chain.

The surge in population during the last century, with its need for increased quantities of water, along with the diminished status of the horse, has created a situation where the needs of our horse industry has become secondary and we have ended up with little political power.

So, understanding that the demographics have changed is tantamount to effecting change. Water was once a surplus commodity, is now in great demand and is the subject of lawsuits up to and including the Federal Government. Everyone wants "their share" of a safe, guaranteed-supply commodity.

The water we drink and the fish we eat require clean water, so cleaning up and maintaining available supplies of water is a job for all humanity.

The Council of Bay Area Resource Conservation Districts (RCDs) has prepared this manual as a road-map to help us be a *volunteer part of the solution, rather then a part of the problem*. Many times we see "edicts" handed down where industry has little or no input. In this undertaking the RCD is saying, "Here are graphic examples of typical problems and we would like to work with you to solve yours."

The time to look at your operation is now. The window of opportunity is open For us to manage our properties in a way to minimize or eliminate pollution. If we wait to see what happens, laws *will* be enacted that require us to make changes that may seem unfair and questionable.

Ken Brown
California State Horsemen's Association

Preface

LAND: THEY AIN'T MAKIN' IT ANY MORE, so said Will Rogers. With burgeoning population and suburban encroachment into previously rural areas there is increasing competition for scarce resources. At the same time, there is increasing attention by all levels of government to assure a clean and adequate supply of water and resource protection. Within the next decade the government intends to enforce more stringent regulation to assure clean water for the future.

Horsemen were amongst the original land conservationists is this country. We have a long tradition of respect for the environment, because it is the milieu in which we operate. We must now become proactive, taking the lead in developing Conservation Plans for our horse keeping facilities to be able to answer the challenges that will be coming to us in the future as regulatory enforcement ratchets down to the local level. Not all of our new neighbors will be livestock-friendly. Most certainly, few of them will understand that the equine is unlike most other animals in many ways.

The enlightened horse keeper should begin now to take a number of actions:

- Evaluate your property for possible impacts from sediments or nutrients into water bodies and remove any manure storage away from water bodies
- Immediately write down your manure management plan, so it is ready if challenged
- Begin a Conservation Plan that includes how you intend to modify your property if your current operations are within 50 feet of riparian corridors
- Photograph your current operation and anytime you make a change
- Begin a water monitoring data program for any creeks and seasonal drainage on your property, because you will need it sooner or later.

This manual will help you to do these things yourself. It is a treasure of resources that, when implemented, could save you time and aggravation in the future since the best defense is a good offense.

Happy Trails from Adda Quinn of EnviroHorse

Preface

THROUGHOUT THIS COUNTRY the rural landscape is in significant transition. The face of agriculture is being transformed with the resultant loss of the family farm and subsequent proliferation of impersonal agribusiness. The vast majority of our rapidly increasing population now resides in urban and suburban areas; these non-agricultural citizens are frustrated by the immitigable impact of pollution and sprawl. Caught between these two forces are small agriculturists, including equestrians.

Equestrians are becoming aware of an increasing burden. Our small farms are being consumed by population growth, but jurisdictions fail to zone for new small agricultural parcels so we can continue our lifestyle. As dense population centers with associated noise, pollution, vandalism, and other infringements move towards our fence lines we are told we have become a nuisance. Our farms are being reclassified as "recreational facilities" because we continue the tradition of sharing use of our agricultural properties with neighbors in town. After having struggled to assist with open space preservation and trail development we are told that our impact on these areas will limit our future usage.

Most dramatically, equestrians are now being asked to develop programs to limit our environmental impact. We are threatened with regulation as our urban and suburban neighbors continue to cover their landscape with high water runoff from hard surfaces; spread fertilizers on their vast tracts of artificial landscaping; pollute our waterways with poorly regulated petrochemicals, pet excrement, pesticides, herbicides, detergents, solvents, etc.; and pollute the air with various exhausts, particulate matters, and fumes.

I'm sure fellow equestrians will recognize my words as only a partial description of the problems we face. Many equestrians are concerned that efforts such as this guide are the beginnings of regulatory infringement that will continue to result in limitation of equestrian open space usage; however, this is not the case. Our friends from the Council of Bay Area Resource Conservation Districts, in partnership with the USDA Natural Resources Conservation Service, have prepared this guide to aid equestrians with the endeavor to lead their community toward responsible stewardship of open space resources. This guide has the potential to be used as a tool to demonstrate that equestrian agricultural land usage can continue as an integral component of the working landscape through voluntary programs with minimal regulatory intervention. Use this valuable tool judiciously.

Larry Gosselin DVM
Alameda County Equestrian Society,
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Introduction

This guide provides practical management information to San Francisco Bay Area horse owners on what they can do to help protect the environment. Whether a horse owner has one animal or operates a boarding facility, all equestrians play an important role in assuring that our watersheds are healthy and our creeks clean. Because of increasing pressures from human activity, all potential sources of environmental pollution are under critical scrutiny. Pollution can come from either point sources (e.g., a specific manufacturing plant) or non-point sources (e.g., livestock throughout a ranch).

All human activities, including livestock keeping, can potentially affect both land and water resources. Water resources include small seasonal drainages, creeks, ponds, and both near-surface and deep ground water. As rainwater flows across the land, it can pick up and transport pollutants such as chemicals, soil and animal wastes which can be deposited into our water resources. Degradation of water resources can affect our drinking water supplies, recreational areas and wildlife habitat, as well as cause flooding, property damage, and harm San Francisco Bay and coastal estuaries. What may appear to be a small action at the top of a watershed, can, in fact, have tremendous consequences for downstream neighbors. As a result, urban and rural communities are now working together to improve water quality through integrated watershed management programs. These programs seek to include a broad base of participants from urban, construction and agricultural sectors. Horse keeping activities, as a potential non-point source of agricultural pollution, will be increasingly scrutinized to assure that horses are not contributing to environmental degradation.

The purpose of this guide is to help horse owners take a look at the big picture and to evaluate how equine facilities might affect local natural resources. It advises evaluating your horse keeping facility to look for opportunities for improvement. It suggests that developing a Conservation Plan for a horse keeping property, which describes both short- and long-term management systems, can be used to prevent and reduce environmental degradation. Finally, it seeks to heighten awareness of the need to implement conservation measures to protect streambanks and water quality for humans and wildlife, prevent accelerated movement of soil from your property, and decrease bare soil where feasible in our increasingly urban setting. Its primary focus is on erosion control, stormwater runoff control methods, and manure management.

As our neighbors move closer to horse keeping facilities it will become more important to reduce flies and dust, and maintain good relationships in increase-ingly congested areas.

Conservation of our natural resources is a long-term commitment. While there are short-term practices that can be implemented immediately and make a tremendous positive difference for the environment, many conservation projects are long-term efforts requiring thoughtful planning and careful implementation. It will be important to custom-tailor site-specific management practices to your property. Some practices may work; others may not. Consult with professionals to minimize mistakes. Learn what works from other horse facilities, and share your knowledge with friends. Making informed decisions will save money, time, and energy—leaving more opportunity to enjoy your horses.

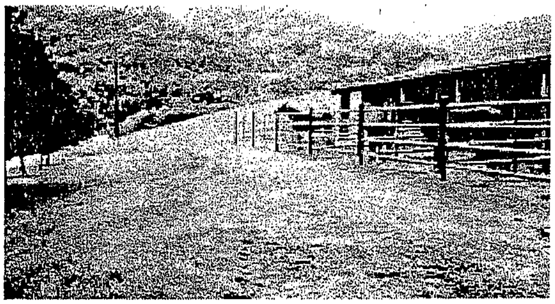
How to Use this Guide

Whether you are planning a new facility, upgrading an existing operation, need to solve a specific problem, or want to improve your natural resources, this guide can assist you with identifying problems, and suggest proper management methods for a variety of problems horse keepers might encounter. Some conservation measures will be simple and easy to implement, while others are complex and require professional technical assistance.

This guide is presented in five chapters:

- **Keeping Horses and Protecting Water Quality (Chapter 1)** introduces water quality concerns, objectives of good management, and explains how to develop and implement a Conservation Plan.
- **Evaluate Your Horse Keeping Facility (Chapter 2)** is an overview of horse facility features and activities that are common sources of water quality concerns.
- **List of Conservation Measures (Chapter 3)** used in this manual are listed and noted throughout the guide in ***bold italic.***
- **Conservation Measures to Improve Water Quality (Chapter 4)** covers specific measures to control erosion, manage stormwater runoff, and manage polluted water.
- **Resources Directory (Chapter 5)** includes a compendium of information, including how to obtain technical assistance, seeding recommendations; checklist for "winterizing" horse facilities; what facility operators should know about regulations and permits; what horse keeping managers should know about threatened and endangered species; how to measure progress using photographic monitoring techniques; how to monitor water quality using easy techniques; how to measure vegetative cover by estimating ***residual dry matter*** in pastures; suggestions for alternatives to pesticides; ways to improve songbird habitat; and a list of helpful publications and resources.

A glossary of terms is included in the back of the manual. Websites are included for reference. Website addresses frequently change, so search for keywords in a web browser or try the beginning words in a long website address.



Chapter 1

Keeping Horses and Protecting Water Quality

Healthy creeks and clean ground water reflect good land management and stewardship on the surrounding land. Good horse keeping management practices reduce potential pollution problems. It is important to be aware of the role that good horse keeping can play in the "big picture" of sustaining a healthy watershed.

Section 1.1 describes the water resources that we seek to protect—primarily surface water and ground water.

Section 1.2 presents three key objectives for horse keeping stewardship:

- Control erosion
- Keeping "clean" water clean
- Manage polluted water

Section 1.3 outlines WHY a Conservation Plan should be created and HOW to make one.

1.1 Protecting Surface Water and Ground Water Quality

Safeguarding our surface water (seasonal drainages, creeks, rivers, ponds, etc.) and ground water is an important part of horse keeping. Aquatic life is highly susceptible to pollutants from human activities. Beneficial uses of water, such as swimming, fishing, and drinking water can also be affected. Some environmental consequences of horse keeping activities that may contribute to water pollution are:

- Sediment from eroding areas such as overgrazed pastures, roads and trails, and bare soil in ***paddocks***, ***turnouts***, corrals and arenas
- Polluted water draining from manure piles and ***horse wash areas***
- Excessive nutrients (from horse waste) that wash off pastures during storms
- Removal of, or trampled vegetation at streamside areas that can lead to streambank erosion
- Removal of vegetation which filters and absorbs water and pollutants from runoff

Watersheds

Understanding the connection between land, creeks, ground water and management is a key to preventing problems. A watershed is an area of land that drains into a distinct creek, river, lake, bay or ocean. It includes all major and minor creeks, seasonal drainages, riparian corridors (the vegetated area next to streams), flood plains, and land that water flows over or through on its way to a bay or the ocean. Watersheds are named after the local creeks that drain them. It is important for landowners to know what watershed their property is located in to be aware of where water goes, who they are affected by, and who they might affect.

> A healthy watershed will maintain high water quality

A healthy watershed will have clean creeks with cool water and a thriving riparian corridor, clean and abundant ground water supplies for drinking water and other uses, and stable, well-vegetated land. A healthy watershed will maintain high water quality, provide fish and wildlife habitat, control erosion, maintain dry season creek flows, reduce flash flooding, and provide safe drinking water from wells.

Both natural conditions and human activities within a watershed influence the condition of creeks and ground water. Changes in creeks may happen suddenly as the result of a storm event (causing new streambank erosion) or a sudden change in land use (such as clearing land for development). Other problems in the watershed may accumulate and take many decades to develop—such as a creekbed becoming filled with sediment (soil particles that are transported by, suspended in, and deposited by water). Excessive sediment coming from the upper watershed often deposits in flatter reaches of channels in the lower watershed which can cause flooding and can be expensive to dredge.

Healthy Creeks[1]

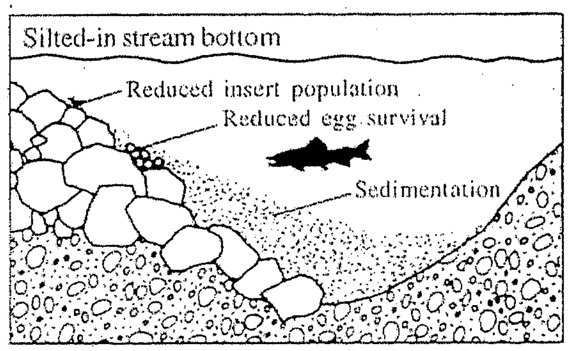
All creeks are important, whether they flow year-round (perennial), part of the year (intermittent), or just during storms (ephemeral). Even small seasonal drainages are important because they can carry water, soil, and pollutants into larger creeks.

In the San Francisco Bay Area, creeks should be managed so they are healthy for people and wildlife. Healthy creeks will have these characteristics:

- **Cool water** is critical for aquatic life. Cool water also helps reduce toxic levels of ammonia, which can come from decomposing horse waste and organic debris. Dense, overhanging vegetation helps keep water cool. Steelhead and salmon require water temperatures between 40° and 60° F.
- **Clean, clear water.** This means plenty of oxygen for fish and other aquatic wildlife to breathe. Suspended sediment, nutrients and salts from animal waste, fertilizers, sewage, and toxics such as metals, pesticides, oil, and grease degrade water quality and reduce the amount of oxygen available.
- **Thriving fish, amphibian, and aquatic insect populations.**
- **A variety of pools and riffles in streambeds** with abundant gravel and cobbles. Pools are depressions in the streambed with calm, deep water. Riffles are stretches of stream with moderate turbulence caused by water flowing over rocks. Pools and riffles are both important habitat areas for aquatic life. Gravel and cobbles are important for spawning and habitat for young fish.
- **A healthy riparian area** characterized by an abundance of native vegetation, minimal erosion, and some undercut banks for aquatic habitat. The riparian zone can provide food, cover, and water for deer, birds, and other wildlife.
- **A high water table.** Healthy creeks receive water percolating through soils in the water table. Acting like a sponge, the soil releases water gradually into creeks and other water bodies.
- **Clean ground water,** free of contaminants, that can be used for drinking water.

[1] This section is drawn from *Creek Care: A Guide for Urban Marin Residents*. Marin County Storm Water Pollution Prevention Program. 1998.

Manage horse access to small seasonal drainageways because they carry water and pollutants into larger creeks. Moving the fenceline to the left of this swale will help control erosion, keep creeks and ground water clean, and reduce muddy conditions that create problems for horses.



Too much sediment is a problem for aquatic life. When sediment fills in creek beds, it also fills in pools, eliminates shelter and fish spawning habitat, and diminishes food supplies for fish and aquatic insects. Some chemical compounds can bind to sediment—potentially creating toxic conditions for fish and other aquatic life. Courtesy of Stream Care Guide, County of Santa Cruz.

- **Water that can be used for contact and non-contact recreational activities.** Swimming, fishing and boating are popular water activities that depend on clean water.
- **Scenic beauty.** Whether in cities, suburban neighborhoods, rural areas, or parks, healthy creeks add to the scenic value of the landscape.

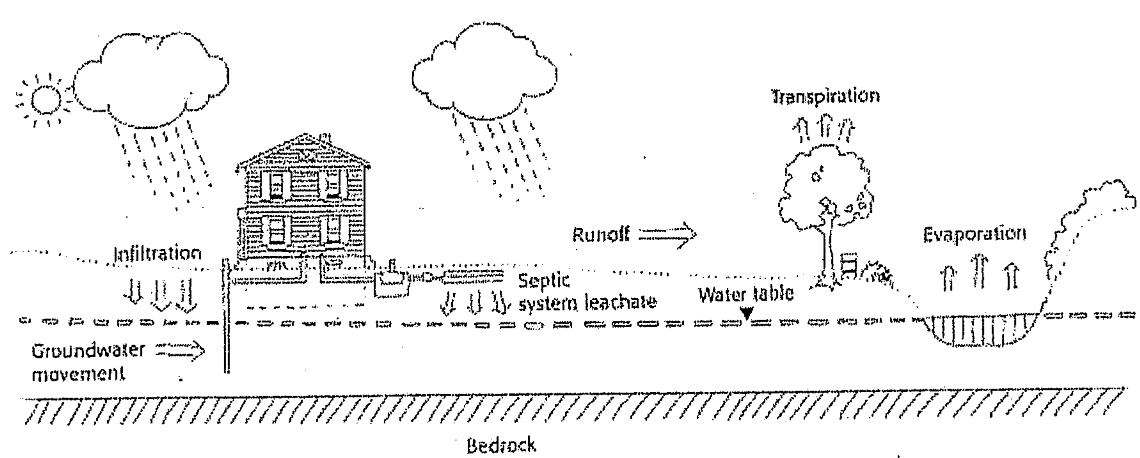
An Underground Link to Clean Ground Water

Ground water and surface water are interconnected. Water not only percolates downward; near-surface ground water also flows horizontally into surface water bodies. While ground water generally follows the same path as surface water, hillside slope is not always a reliable indicator of ground water flow.

Ground water is an important source of drinking water. As water soaks deeper and deeper into the ground, it infiltrates and recharges aquifers, the underground layers of porous rock and gravel that store water. Ground water moves through the earth as part of a dynamic flow system from recharge areas to discharge areas such as springs and wells.

The *water table* marks the boundary in which all pore space within it soil particles are saturated with water. Water tables fluctuate throughout the year and are usually highest in early spring.

Near-surface ground water is the water that collects within the soil zone, usually found at four to six feet below the soil surface and is generally most vulnerable to contamination from pollutants that leach downward through soil layers. This is important because near-surface ground water often feeds directly into creeks. Near-surface ground water should not be tapped for wells.



In the hydrologic cycle, water falls to the earth as rainfall and snow and returns to the atmosphere through transpiration and evaporation. Surface water, ground water, and near-surface ground water are interconnected and provide benefits to humans and wildlife. Your horse keeping activities can help or harm the natural resources on your property and those of your neighbors downstream. Source: *Home*A*Syst: An Environmental Risk Assessment for the Home* (NRAES-87).

The Soil and Water Connection

Different types of soils vary significantly in their capacity to hold water, the ability to percolate water, and the types of vegetation they can support. These characteristics are important because they affect the rate at which excessive nutrients, such as nitrogen from animal waste, are carried by surface flows overland and down through the soil layers. Rainfall that can not soak into the ground starts to flow overland as runoff. Surface runoff increases the erosion hazard and the possibility for sediment and manure to be washed into nearby creeks and seasonal drainages.

Soil types affect the land's ability to deal with runoff

The porosity, or infiltration rate, of a soil (ability of air or water to pass through minute surface openings) affects the rate at which rainfall can soak into the ground. Soil particle size influences how water moves through the ground. This may be a concern especially if the water table is relatively close to the surface. For example, sandy soils are the most porous soil and can absorb rainfall more quickly than other soil types. However, they may allow water to seep downward too quickly for effective filtration or decomposition of pollutants. Clay soils are the least permeable and absorb rainfall more slowly. However, water can still carry pollutants through the clay soils. In the summer, clay soils often shrink and form deep cracks that allow water to quickly percolate down into the soil many feet. Also, clay hardpans that underlie more porous soil will slow the downward flow of water and cause it to start moving horizontally beneath the surface, and water becomes "perched" upon the hardpan layer. Deep loamy soils support vigorous plant growth and deep roots are best for trapping and storing nutrients and other pollutants that percolate into the soil.

Soil compaction occurs when livestock grazes on wet soils. Grazing by large animals can cause compaction because their hooves have a relatively small area and therefore exert a high pressure. Soil particles are pressed together, reducing the pore space between them. Compaction restricts rooting depth, which reduces the uptake of water and nutrients by plants. Compaction decreases infiltration and thus increases runoff and the hazard of soil erosion.

The type of bedrock or sediment deposits below soil layers also influences how water travels into ground water aquifers. Shale, granites, and other impermeable types of rock impede the downward movement of water and pollutants. Other rock, such as limestone, can be highly permeable, allowing water to move freely into ground water. When bedrock is fractured, water can move through it vertically, laterally or unpredictably, spreading pollutants rapidly over long distances.

1.2 Stewardship Objectives

Practicing good *stewardship* can help keep horse facilities, creeks, and ground water clean. Stewardship means taking care of land and water resources on your property. Neighboring landowners can also work together to promote stewardship within their larger watershed.

Three basic stewardship objectives for horse keepers to remember are:

1. Control erosion – keep soil in place
2. Keep "clean" water clean
3. Manage "polluted" water

Each of these objectives is explained below. The management systems and conservation measures presented in Chapters 2 and 4 of this guide can help landowners meet these objectives. Not only do conservation measures help control erosion, manage stormwater runoff and prevent pollutants from reaching creeks and ground water, they also create healthier conditions for your horses.

Stewardship Objective #1: Control Erosion

Erosion occurs where soil is bare and unprotected from the forces of rainfall, flowing water, wind and gravity. While some sediment is needed to bring nutrients and substrate materials (mineral and/or organic matter that forms the streambed) to aquatic ecosystems, too much sediment causes problems and is considered a pollutant. Some soil erosion is caused by natural process. However, a great deal of erosion is "accelerated erosion" because the natural or "background" rate has been speeded up as a result of human activities. Some erosion problems may be relatively simple to solve, while others are complex.

Vegetation, geology, soil characteristics, steepness and length of slope, rainfall, and human activities (i.e., soil disturbance or alteration of natural drainages) all contribute in varying degrees to the erosion rate at a particular site. For this reason, it is important to know about the site characteristics present at each horse facility (see Section 1.2 on developing Conservation Plans).

Typical erosion areas at horse facilities

Humans can alter natural processes with livestock practices. Accelerated erosion can wash soil from areas of bare ground such as arenas, ***paddocks***, ***turnouts***, and overgrazed pastures. Severe erosion can form gullies, destabilize creek banks, and damage roads.

It is important to determine the cause of soil erosion. Accelerated erosion could be caused by uncontrolled concentrated flows from rain gutters, winter runoff from roads, removal of protective vegetation in pastures due to heavy grazing, livestock access to riparian areas when streambanks are saturated, or other ways.

Why is sediment a pollutant?

Too much sediment reduces the ability of creeks to carry floodwaters by filling in the creek bed. Sediment fills in pools, eliminates shelter and fish spawning habitat, and diminishes food supplies for fish and aquatic insects. It can be very expensive to dredge excess sediment from creekbeds, ponds and lakes.

Accelerated erosion can also pollute drinking water supplies because herbicides, pesticides, chemicals, and organic compounds can all bind to sediment—potentially creating toxic conditions for humans and aquatic life.

Basic Ways to Prevent Accelerated Erosion

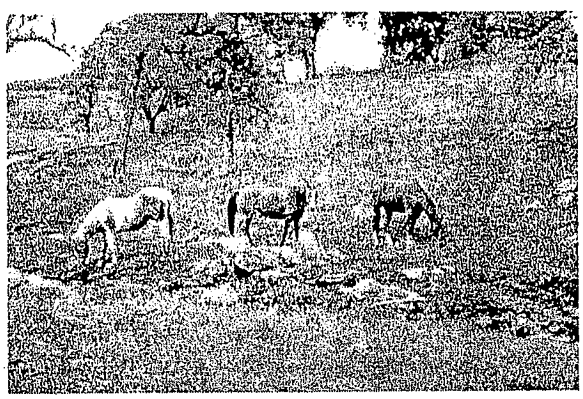
To incorporate erosion control measures into your management systems, see Chapter 2. For specific details on conservation measures listed in ***bold italic***, see Chapter 4.

- ***Keep areas well vegetated*** and restore bare areas with vegetation. Plant roots, especially those of grasses, hold soil in place and help water infiltrate into the ground rather than run off. Vegetation also dissipates the force of rainwater hitting the ground, which detaches soil particles.
- ***Avoid concentrating water. Concentrated runoff can be highly erosive.*** Try to disperse runoff by spreading it out in a thin, shallow "sheet." Areas to watch are roads, roofs, compacted soil, and other impermeable surfaces that shed water quickly and increase the amount and velocity of runoff.
- ***Control horse access and human activities in vulnerable areas*** such as wetlands, creek banks, meadows and steep hillsides. Limit access, especially during wet periods.
- ***Manage pastures to prevent heavy grazing***. Avoid soil compaction and excessive removal of vegetation by timing the use of pastures and controlling the numbers of horses. Rotate pastures to allow them to rest from grazing, to allow grasses to regrow and mature so they will reseed.
- ***Use filter strips and riparian buffers*** near creeks. Maintain a strip of ***dense*** grass downslope of bare areas such as ***paddocks*** and ***turnouts*** to help trap sediment. ***Riparian*** buffers provide valuable wildlife habitat and should contain a variety of plants including grasses, forbs, shrubs and trees.
- ***Keep creek banks vegetated*** to hold soil in place, trap sediment, and provide valuable wildlife habitat. Grasses have fibrous roots that hold the soil in place. A good indicator of root mass in grasses is the above ground growth generally equals the below ground root system. Shrubs and trees have deeper roots that are either fibrous or taproots that will anchor the soil in place.
- ***Install kick boards*** or lay railroad ties or telephone poles around arena perimeters. These will help hold footing material in place and keep it from washing away.
- ***Properly construct and maintain roads, trails, and parking lots***. Protect earthen surfaces and drainage ***ditches*** from erosion by using properly designed drainage systems, including ***diversions*** and ***culverts.*** Use appropriate surfacing materials and techniques.
- ***Use proper construction techniques***. Revegetate areas disturbed by construction. During construction install and maintain ***silt fences*** or ***straw bale sediment barriers*** to trap sediment and slow the movement of water. Avoid soil disturbing activities just before and during the rainy season.

Stewardship Objective #2: Keep "Clean" Water Clean

Rainwater flowing across the land, or in channels or pipes, is called stormwater runoff. It is important to keep this "clean" water clean by diverting it away from areas that can be a source of "pollutants" such as a ***manure storage areas***, ***horse wash areas***, and other high-use areas. Keeping "clean" water clean is easier than managing and treating it once it becomes "polluted" with manure, sediment, or chemicals.

Keeping stormwater runoff away from areas with pollutants also promotes horse health. Reducing the amount of manure and mud will help eliminate insect and worm breeding grounds, reduce bacteria and fungi that cause horse disease and hoof problems, and improve footing. It will also reduce the amount of energy that horses spend trying to keep warm while standing in mud. Managing mud and manure can make tending horses more pleasant, as well as improve aesthetics for a facility, neighborhoods, and communities.



Avoid grazing directly in creeks so horse manure and urine as well as sediment from streambank trampling does not enter waterways to create conditions detrimental to drinking water supplies, recreational activities, and the environment.

Basic Ways to Keep "Clean" Water Clean

To incorporate these measures into your management systems, see Chapter 2. For specific details on measures listed in ***bold italic***, see Chapter 4.

- **Divert "clean" water around areas with pollutants.** Use ***berms***, ***grassed waterways***, ***under - ground pipelines***, or other methods. Consider where water will be diverted to, and make sure you do not cause new problems.
- **Locate buildings and confinement areas away from creeks, steep slopes, and floodplains.**
- **Minimize disturbance to wetlands, riparian areas and meadows.**
- **Limit impacts of grading, runoff from roofs and other impermeable surfaces.**
- **Maintain vegetation and replant bare areas.**
- **Control potential runoff from water troughs.**

Stewardship Objective #3: Manage "Polluted" Water

Stormwater becomes polluted if it picks up physical, chemical or biological elements as it flows through manured or bare areas. Polluted water must be managed to prevent it from reaching creeks and/or minimize leaching (moving downward into soil) into ground water. It is easier to minimize the amount of polluted water generated, rather than treat or dispose of it.

Manure and urine can add excessive nitrogen and phosphorus to creeks. These nutrients can enhance algae blooms. The algae's subsequent death and decay can consume much of the water's oxygen that is necessary for fish to breathe. High concentrations of ammonia from animal waste is toxic to fish and other aquatic life. Salts from horse waste can change the variety of insects that a stream can support. During the rainy season, salts and nutrients in manure can leach through soils into ground water. Pathogens in livestock waste may produce fecal coliform contamination levels that may potentially impact drinking water. Manage any polluted water generated by your facility so it does not impact downstream neighbors.

Basic Ways to Manage "Polluted" Water

To incorporate these measures into your management systems, see Chapter 2. For specific details on measures listed in ***bold italic***, see Chapter 4.

- **Keep the size of intensively used areas small** to help reduce the volume of polluted water.
- **Manage Manure.** Remove manure regularly—daily is best. Cover stored manure with a roof, tarp or other cover, and direct runoff away from the ***manure storage area.***
- **Use *filter strips* to trap sediment and manure** that washes off high-use and ***manure storage areas.***
- **Maintain soil moisture during the dry season** by sprinkling with water to enhance bacterial decomposition of nutrients. When soil moisture is maintained in arenas, paddocks, feeding areas and even pastures, the natural breakdown of urea will occur. If areas are maintained as absolutely dry, this discourages the natural process.[2]
- **A waste pond** can be designed to store water for safe distribution at a later time.

[2] Michael Rugg, personal communication. 2001. California Department of Fish & Game, Yountville, CA.

Table 1 lists potential pollutants and related impacts from typical horse keeping activities, the associated problems they can create, and the water quality tests available to determine the levels of the pollutants. More information on ***water quality monitoring*** is in Section 5.7 of the Resources Directory.

Table 1: Potential Pollutants, Impacts, and Water Quality Tests

Potential Pollutants from Horse Keeping Sources	**Problems created in creeks, ponds, and wetlands**	**Easy water quality tests available for landowners**
Sediment	Reduces water clarity so fish have a harder time finding food; leads to warmer water, and also settles into creek beds which degrades aquatic habitat; fills in creeks and ponds; kills fish eggs from suffocation due to sediment filling in air spaces around eggs. Also, pollutants adhere to sediment particles, such as metals (e.g., lead, mercury) and organic materials such as pesticides.	Visual observation
Nutrients from manure and other waste • Phosphorus from soaps and manure • Ammonia (decomposition of organic nitrogen such as urea and manure)	• Stimulates the growth of algae and other aquatic plants • Un-ionized ammonia is toxic to aquatic life even in very small concentrations	Colorimetric test kit to measure total nitrate and ammonia. Test pH with electronic meter or pH test paper. Also thermometer for temperature.
Salts from horse waste	Affects the kinds of aquatic organisms which can live in a stream	Electrical conductivity probe
Excess organic material (bedding, shavings with manure, runoff from manured areas)	Acts as a source of food for aerobic, decomposing bacteria which may deplete dissolved oxygen which adversely affects aquatic life	Electrical oxygen probe or colorimeter text kit for Dissolved Oxygen (DO)
Removal of streamside trees and shrubs	Creates warmer stream temperatures which reduces the amount of oxygen water can carry; decreases a source of terrestrial insects (fish food); removes deep binding root mass that stabilizes streambanks; and reduces wildlife habitat	Thermometer
Pesticides from fly sprays, etc.	Toxic to aquatic life	Lab analysis needed – no easy tests

1.3 Plan Conservation Improvements on Your Property

Develop and implement a Conservation Plan to help you enhance ranch aesthetics, reduce expenses related to the control of drainage and erosion, protect property and land values, and to keep the facility safe for people and horses. Important stewardship elements of a Conservation Plan for horse facilities are to: 1) control erosion, 2) manage stormwater to keep "clean" water clean, and 3) manage "polluted" water. Planning is important whether you have just one backyard horse or a large, commercial horse boarding facility.

Conservation planning is a natural resource problem-solving process. The process integrates ecological (natural resource), economic, and production (such as pasture) considerations in meeting both the horse owner's objectives and the public's resource protection needs. This approach emphasizes identifying desired future conditions, improving natural resource management, minimizing conflict, and addressing problems and opportunities. This section presents information on conservation plans and outlines steps to create such a plan.

What is a Conservation Plan?

A ***conservation plan*** is a document that is developed by a landowner who wishes to manage land and water resources on the property effectively. Generally help is obtained from a natural resource specialist. The planning process can help horse keepers to identify, assess, and develop ways to avoid potential water quality problems. A plan includes: a written and pictorial description of the features of the horse facility (an inventory of developed and natural features shown on an aerial photograph or scale drawing); an evaluation of problem areas and opportunities; a schedule of operation and activities needed to solve identified problems; and maintenance and monitoring activities. Plans demonstrate awareness and commitment to conservation and good land stewardship.

Who needs a plan?

Horse properties that have creeks or seasonal drainages that lead to creeks, or that have received complaints may need a plan to demonstrate how they will manage areas of concern. If you keep horses near drinking water reservoirs or in areas with endangered species, you may be required to submit a plan to show how the environment will be protected. Owners of horse facilities may need to prepare a comprehensive conservation plan that covers more than the items discussed below in order to meet the requirements of local ordinances or a county use permit.

How do I develop a plan?

Horse owners can gather information and develop a plan by following the five steps below. Assistance may be available from the Natural Resources Conservation Service (NRCS) and Resource Conservation Districts (RCDs). The Alameda County and Southern Sonoma County RCDs have developed a planning workbook that can be completed in conjunction with a planning course or as an individual project. For further assistance, contact the NRCS, the local RCD, or UC Cooperative Extension, listed in Section 5.1 of the Resources Directory. Private consultants can also assist with developing detailed plans.

What does a plan look like?

A conservation plan can begin simply and need not be an extensive document. A plan can be handwritten and kept in a folder or a binder. It should include maps, site-specific soils and vegetation data, a record of decisions made for conservation improvements, and other reference materials. You'll want to update your plan to keep it current. A photographic record of what is done before and after imple menting a conservation plan would be helpful documentation if future questions arise.

Developing a Conservation Plan for Your Facility

The degree to which a conservation plan needs to be developed will vary according to the property description and intensity of land use. A horse facility with two flat acres, no creeks and two horses kept in small shelters with paddocks may only need to create a simple plan that diverts clean water from horse keeping and ***manure storage areas***, and describes manure management. However, a horse facility with many hilly acres experiencing natural gullying, or with many creeks on the property would be well-advised to develop and maintain a full ranch conservation plan. Thus, the facility manager is able to demonstrate to regulatory agencies concern for proper stewardship of the land and water resources.

The six steps for developing a conservation plan are listed below. Each of these steps is further explained in more detail.

1. Set goals for your operation
2. Inventory and map your resources
3. Identify, assess, and prioritize potential problem areas
4. Develop solutions
5. Properly schedule and install conservation measures
6. Maintain and monitor conservation measures

Step 1. Set goals for your operation

Set goals for an effective conservation plan. Some issues to address are:

- **Goals for your property or horse facility.** What type of operation do you currently have and how would you like it to function in 2 years, 5 years, or 10 years? What type of facilities do you currently have, and which do you plan to add? What type of conditions do you want to provide for your horses? Because the physical health, safety, and mental well-being of your horses are essential, proper housing, sufficient exercise, food and water, and regular veterinary care should be included. Make sure the goals work for you.
- **Conservation goals for land and water.** Would you like to learn more about natural resources on your property or in your area? List conservation concerns

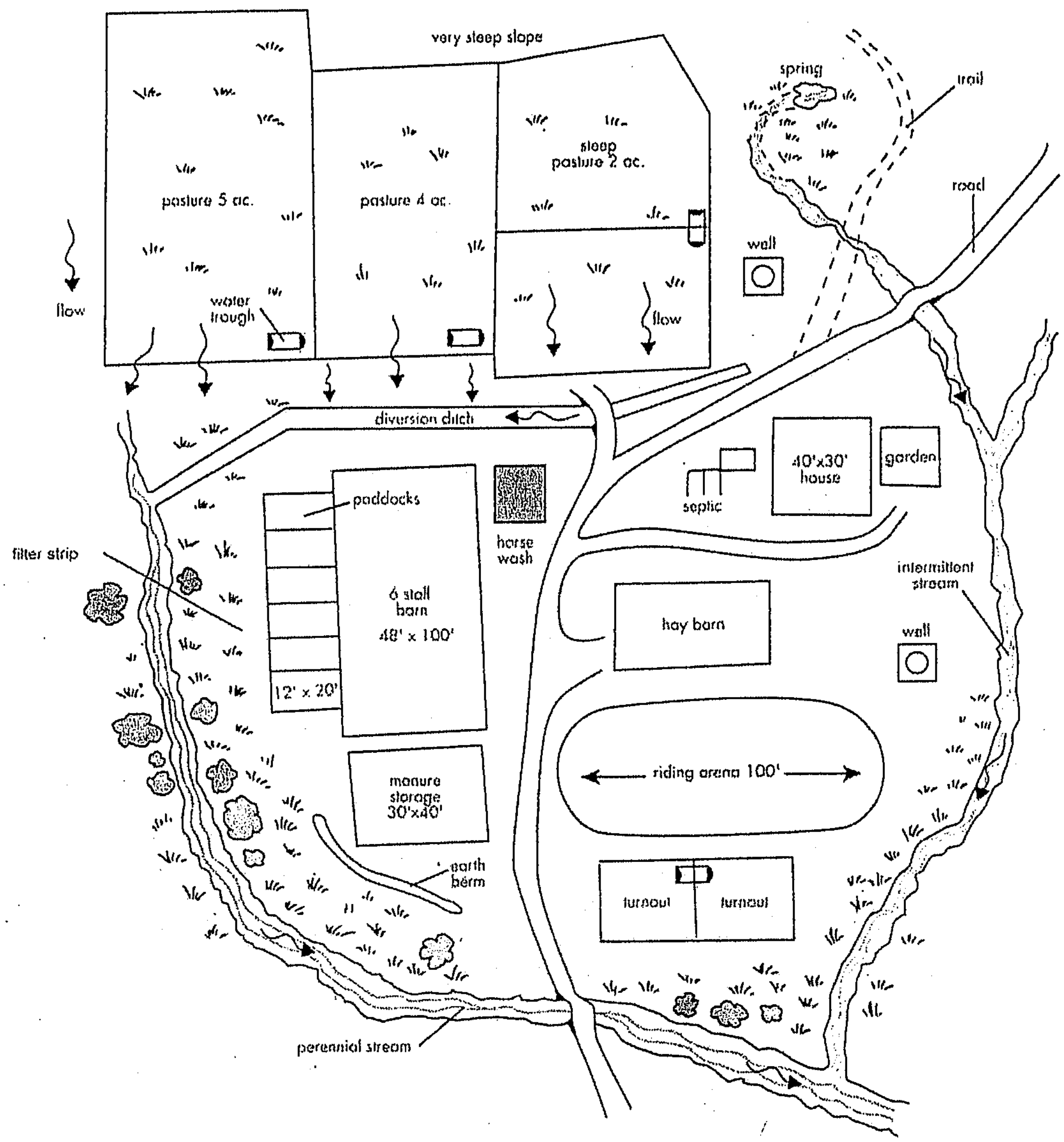
that you have such as reducing erosion, restoring a creek area, improving pasture productivity, or maintaining or improving a healthy ecosystem.
- **Financial feasibility.** Facility maintenance and improvement require time, labor, and money. Consider doing needed work in stages and set priorities. How much of the work can you do yourself? What help is available? Will you have a barn manager or employees for day-to-day operation? It is helpful to have contingency plans and funds for emergencies.

Step 2. Inventory and map your resources

A written resource inventory accompanied by a map is a record of your property and improvements. Use an aerial photograph or draw a site map on graph paper to accurately and easily plot various features. Choose a scale that fits the size of your facility, e.g., 1 inch=100 feet, or 1 inch=50 feet. This map can help you determine the approximate size of structures needed, which helps in developing cost estimates. Gather existing soils, topographic maps and aerial photos for an inventory of your facility. These maps and aerial photos are available from public agencies and private sources at reasonable costs (county planning departments, NRCS, US Geological Survey, etc.). After you have completed your map, you can add areas of conservation concern and possible future conservation measures. *(See Sample Site Plan diagram.)*

Items to include on your site map:

- **Natural water features** such as springs, creeks, seasonal drainages, wetlands, and ponds. Indicate drainage and stormwater runoff patterns, using arrows to indicate the direction of flow. Topographical maps or street maps that show local creeks can help you determine drainage patterns and identify your connection to a larger stream or that enters San Francisco Bay, another regional bay, or the ocean.
- **Water improvement projects** such as developed ***springs***, water ***troughs***, ***wells***, septic system drainfields, pipelines, and ***ditches***, as well as information such as flow rates, well depth, and dates of construction.
- **Property improvements** such as buildings, corrals, paddocks, arenas, ***fences***, pastures, roads and trails, ***bridges***, parking areas, and ***manure storage*** or ***composting*** areas, ***horse wash areas***, and other improvements.
- **Existing conservation measures** that protect soil and water resources.
- **Soil types.** Soil textures and soil depth are important for making management practice decisions. For example, steeper slopes generally have shallow soils that dry out earlier in the season. County *Soil Surveys* describe potential uses for the soil, general characteristics such as texture, erodibility, shrink/swell characteristics, water table, appropriateness for building sites and leach lines, infiltration rate, slope information, and suitability for growing plants, and contain maps (aerial photos) with the soils shown. Check with the USDA Natural Resources Conservation Service (NRCS), your local RCD, or a library to review a copy.
- Topography, terrain, and slopes can be described in your plan in general terms or with more detail if your land has been surveyed. Features to include on your



SAMPLE SITE PLAN – A site map shows natural features such as springs, creeks, winter swales, wetlands and ponds. Improvements are shown as well—wells, **water troughs, diversion ditches, berms,** *septic system drainfields, pastures,* **fencing, turnouts,** *barns, arenas, and* **compost area.** *A site plan is an essential part of a conservation plan.*

site map are steep slopes, low lying areas, rocky areas, landslides, and flood-prone areas. Contour lines show slope on topographic maps. Mapping tools, used with topographical maps, allow easy estimation of slopes and acreage. Topographic maps are available from local map stores, or http://topomaps.usgs.gov/, or http://www.topozone.com. Maps of landslide areas may be available for your region from the US Geological Survey, and often from NRCS or your local county planning department.

- **Vegetation and plant communities** differ in their requirements for moisture, shade, soil drainage, and soil fertility. Examples of plant communities in the San Francisco Bay Area include broadleaf evergreen woodland or forest, oak woodland, grassland, riparian (streamside forest), coastal scrub, and chaparral. If you need assistance in describing the wetland communities on your property, consult a US Fish and Wildlife Service "National Wetlands Inventory" map. These are available from the NRCS or your local RCD.
- **Wildlife habitat.** You may wish to note any important wildlife habitat areas or keep track of animal activity. Riparian habitats are especially rich in birds (both migratory and resident) and aquatic species. To find out if you have any threatened, endangered, or special status species on or near your property, contact the California Department of Fish and Game. For information on backyard conservation or wildlife habitat improvement projects, contact your local RCD.
- **Climate.** Average annual rainfall information is available from several sources such as local water districts, *Soil Surveys*, and the US Weather Service. The RCDs and NRCS have National Oceanic and Atmospheric Administration maps that show rainfall intensity. This is important for designing conservation measures (for example, how many inches per hour in a 25-year storm). A rain gauge and knowledge of local weather characteristics will allow you to monitor conservation measures during large storms. Talk to your family and neighbors to find out about any historical weather-related incidents on your property.
- **Ground water conditions** are important to know before installing wells or septic systems. Water districts, the local planning department or public health departments may have information on local ground water resources. Well records give an estimate of the depth to the water table at your property. Be sure to identify any near-surface ground water areas that may be vulnerable to contaminants.
- **Other natural resources information.** For information on geology, wetlands, air quality, or other features of interest, contact government agencies, libraries, and possibly the internet.

Look at your property as a whole to help develop priorities

Step 3. Identify, assess, and prioritize potential problem areas

Look at your property as a whole to help you develop priorities. Refer to Chapter 2: Evaluate Your Horse Keeping Facility to help identify common sources of water quality concern. Steps to consider:

- **Evaluate your water quality to see if you have a problem.** Check areas upstream and downstream of intensively used areas. Many water quality tests are simple to perform, by conducting self-testing from kits. See Section 5.7 of the Resources Directory for water quality monitoring information.
- **Identify potential problem areas** by taking a walk around your facility, preferably during or immediately after a heavy rainfall. Use the site map as a guide and take notes.

For example, draw arrows on the site map to show runoff and drainage patterns, note bare areas such as overgrazed pastures, shade areas of streambank erosion or where sediment deposits, and note areas where pollutants may be present (such as ***manure storage areas***, ***horse wash areas***, or runoff from intensively used or "high-use" horse keeping areas).

- **Assess situations and prioritize areas in need of attention.** During the monitoring or field visit did you discover specific water quality issues you need to address? Are they big problems? Are they related to controlling erosion or managing stormwater runoff?

  Set priorities for the areas you wish to tackle. Give high priority to problem areas that need immediate attention, and then address areas of lesser concern in stages or as part of a long-term strategy. Examples of situations needing immediate attention are where a ***manure storage area*** drains directly to a creek or runs off onto neighboring property, or an actively eroding streambank threatens property or structures.
- **Review your goals** and make sure the planned improvements help you achieve your goals. Revise your goals if necessary.

Step 4. Develop solutions

Select conservation measures that will help solve problems and achieve your goals. Chapter 4 of this guide describes conservation measures that are structural or management practices. Read through this guide, talk to other equestrians, ask questions at your local feed and stable supply stores, and seek technical assistance to determine what options will work best for you. Consult your local RCD or NRCS for assistance. Things to keep in mind include:

- **Conservation measures need to fit the unique conditions at your facility.** For example, if you have highly erosive soils, be sure that sediment is not picked up by runoff. If your streambanks are eroding, do not direct concentrated water flows into those areas. What works for others on their property may not work for you.
- **Conservation measures often work in combination.** Be aware of how they fit together, e.g., applying ***seed*** and ***mulch*** or connecting roof ***gutters*** and ***downspouts*** to a conveyance system that carries the runoff to an erosion resistant outlet at a creek.
- **Start at the source.** Seek solutions for smaller areas near the source of the problem. Sometimes minor changes in management techniques can produce the desired result at little or no cost. For example, empty ***manure storage areas*** before the winter, remove horses from a pasture when grass has been grazed down in order to allow for regrowth, or reseed a ***filter strip*** in the fall.
- **Include a manure management strategy.** Address manure collection, storage, spreading, use and/or disposal. Consider site-specific characteristics of your property and operation to determine what manure management systems will

work best. The strategy should include proximity of manure management locations to creeks, soil type, type of bedding material, number of horses, labor, equipment, and access.

- **Be aware of local, state, and federal regulations that apply to your projects.** Check carefully to be sure you have obtained all necessary permits before developing, expanding, or renovating a horse facility. You are responsible for being informed and for following regulations. See the Resources Directory, Sections 5.4 and 5.5 for more information on permits.
- **This will be a long-term process.** Some measures you may try, may not work. Your plan is a living document meant to change over time and be a record of important things you learn about the stewardship of your property.

Step 5. Schedule and properly install conservation measures

Schedule construction during the dry season, before the winter rains. Allow time to obtain permits. Careful installation will help your projects succeed.

- **Know when to seek professional design assistance.** Medium- to large-scale erosion control and drainage projects will likely require professional design to limit the hazard of washouts, flooding, and impact to neighboring properties. Conservation measures can fail or make problems worse if they are not properly installed. Extensive grading projects are likely to require permits and professional installation.

> Careful installation will help your projects succeed

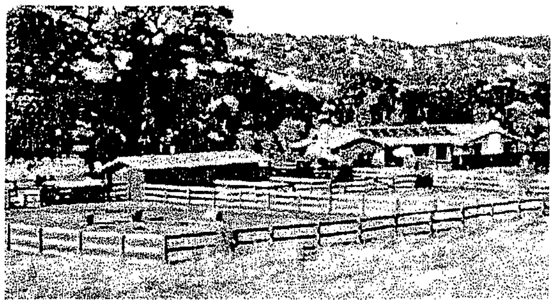
Step 6. Maintain and monitor conservation measures

Regular maintenance is crucial to the effectiveness of conservation practices. Is there room for improvement? What other conservation measures and management systems might help? Regular monitoring and maintenance will help your projects succeed. Remember to:

- **Monitor your project.** Maintenance may necessitate cleaning plant debris from gutters and pipe inlets, removing sediment from water conveyance structures, or mowing grass ***filter strips*** to keep the grass actively utilizing nutrients. The more useful monitoring takes place with a shovel and rain boots, walking the facility during and after a rainstorm to make sure all drainage is functioning properly. Make necessary repairs a part of your "winterization" effort. (See the Winterization Checklist in Section 5.3 of the Resources Directory.) A rain gauge will help you track rainfall amounts by storm, month, and year.
- **Be prepared,** especially after a series of storms when soils are fully saturated. This is when floods and most landslides occur. Have an emergency back-up plan and make sure that your employees and family know the plan. Have emergency repair materials on hand, such as burlap bags and sand, or straw

bales, and know the proper way to install temporary fixes. (See Section 4.1 for information on emergency repairs.)

- **Photographic monitoring** will show the results of your management decisions. (See Section 5.6 of the Resources Directory.)
- **Monitor water quality** of creeks that flow by the facility, with do-it-yourself water quality test kits, and record your efforts. (See Section 5.7 in the Resources Directory.)
- **Document your efforts** to protect natural resources. Record the implementation, maintenance, and monitoring of conservation measures. Record keeping will help you decide how to further improve conditions for your horses and water quality. Your documentation might help you meet local, state, and federal water pollution control requirements.
- **Adjust** your conservation plan based on the results of monitoring.



Chapter 2:

Evaluate Your Horse Keeping Facility

Keeping in mind our three key stewardship objectives, to 1) control erosion, 2) keep "clean" water clean, and 3) manage "polluted" water, we will now evaluate typical features and activities at horse facilities that are common sources of water quality concerns. For example, a ***roof runoff*** system includes the following conservation measures: ***gutters, downspouts***, and ***drainage*** to a ***filter strip*** or ***outlet***. The possible problem areas, as well as ways to manage water are discussed.

Horse owners can implement some management systems themselves. Professional design and installation assistance will be required for other systems. Specific conservation measures, in ***bold italic,*** are further defined in Chapter 4.

Typical places that can be problem areas at horse facilities are:

- **Section 2.1** Roof unoff
- **Section 2.2** High-Use Areas
- **Section 2.3** Manure Management
- **Section 2.4** Composting Horse Manure
- **Section 2.5** Horse Wash Areas
- **Section 2.6** Pasture Management
- **Section 2.7** Water Resources: Creeks, Ponds and Wells. Managing Septic Systems
- **Section 2.8** Design and Maintenance for Roads, Trails, and Stream Crossings
- **Section 2.9** Construction Management

2.1 Roof Runoff

Diverting roof runoff from horse keeping areas in order to minimize creation of mud will result in both healthier animals and cleaner surface water on your property.

Take a look during or after a storm to determine where the "clean" roof runoff drains from: barns, covered arenas, or other buildings. Observe whether or not water is causing erosion, creating mud, or entering areas that contain manure. For more details, see Chapter 4.2: Stormwater Management Measures, Roof Runoff Collection.

Management Strategies for Buildings

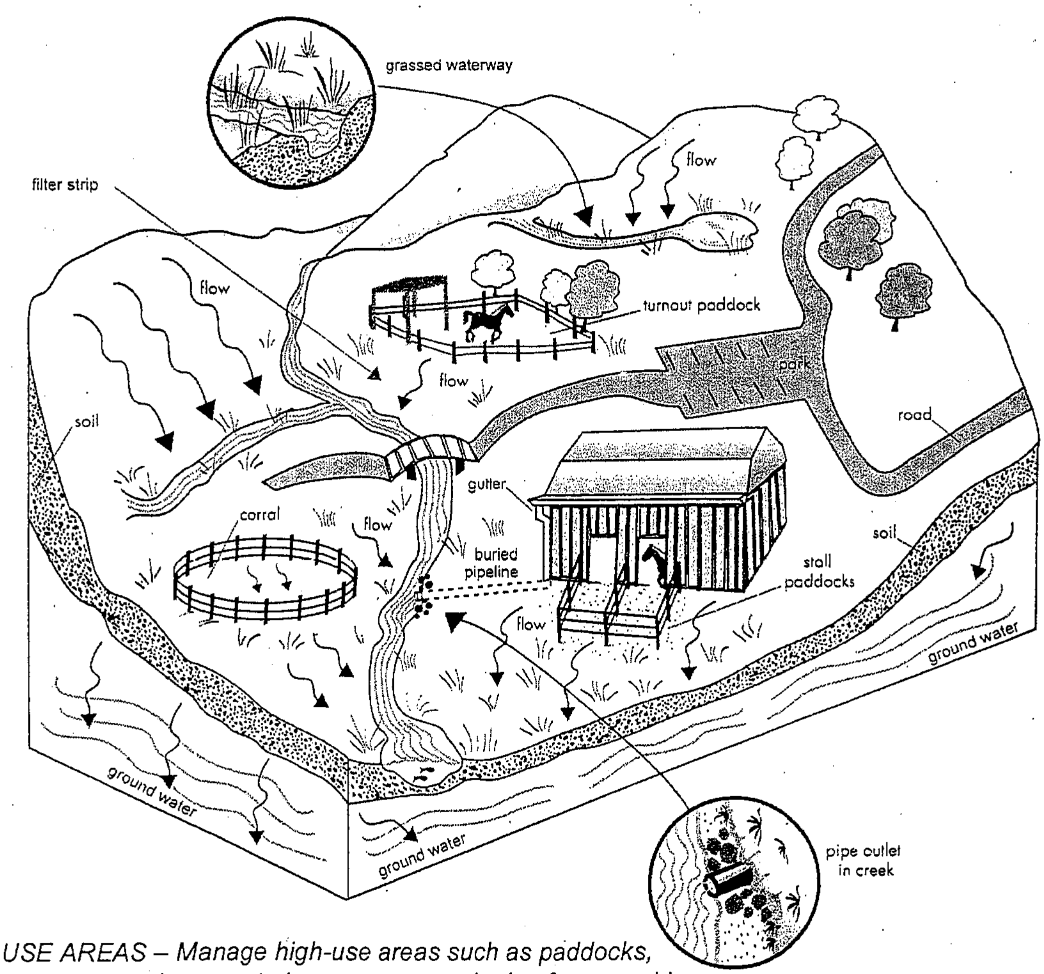
- Locate buildings on elevated ground or built-up pads. Slope the land gently away from building foundations. Locate new buildings well away from creeks and flood-prone areas. Avoid disturbing wetlands.
- Use ***gutters*** and ***downspouts*** to direct roof runoff away from erodible land or areas with manure such as ***paddocks*** and ***turnouts*** adjacent to or attached to barns. "Clean" roof runoff should not flow through areas where it can pick up pollutants.
  Using ***gutters*** and ***downspouts*** is especially important for large barns and covered arena roofs that can shed considerable volumes of water during storms. This "clean" water should be directed via pipe or ***ditch*** to an outlet point that will not erode.
- If roofs do not have ***gutters***, slope roofs away from high-use and ***manure storage areas***.
- Install ***subsurface drains*** (perforated pipe) with gravel filled trenches below eves to collect standing water and direct it away from buildings.
- Divert water from surrounding slopes away from buildings. Install ***diversions*** or ***berms*** to direct water away from buildings. Convey water to a ***filter strip*** or ***grassed waterway***. Make sure the ***diversion*** or conveyance method does not cause erosion.
- Place ***energy dissipaters***, such as rock, at pipe outlets to prevent erosion.
- Revegetate areas that have been graded or disturbed to prevent erosion. Maintain ***grassed waterways*** and ***ditches***.
- Follow county regulations regarding creek or other setbacks, such as property line, well, or septic leach field setbacks, and obtain necessary grading permits.

2.2 High-Use Areas

In this guide, the term "high-use areas" refers to specific fenced areas of bare ground where horses are kept, confined, exercised, trained, or ridden. Examples of "high-use areas" are ***paddocks*** attached to stalls, ***turnouts***, circle pens, arenas, and livestock alleyways between paddocks and barnyards.

Because these high-use areas often lack vegetation, they can be subject to erosion. They are also likely to contain manure and urine that must be prevented from being carried by runoff into creeks. It is important to prevent leachate from accumulated manure from being carried into the creeks as runoff, or downward through soil into the ground water.

Mud and accumulation of manure in high-use areas can also pose health problems for horses, and make access difficult for people.

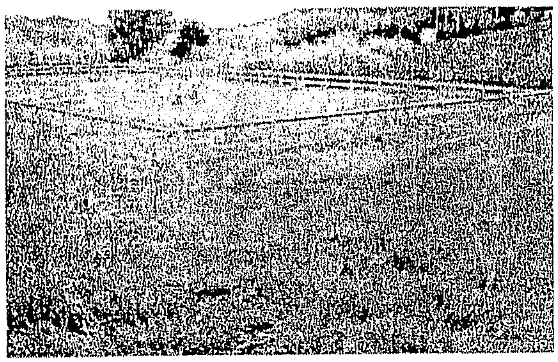


HIGH USE AREAS – Manage high-use areas such as paddocks, corrals, turnouts and arenas to keep manure and urine from reaching creeks, prevent leachate from being carried downward into the soil and ground water, and reduce erosion. Map the flow of drainage at your facility and look for ways to keep "clean water" clean. Consider using conservation measures such as **turnout paddocks** *and grass* **filter strips.**

Management Strategies for High-Use Areas

Consider location and size

- Locate high-use areas on higher ground with a slight slope for drainage (1-2%). Locate high-use areas away from low spots, drainages, floodplains, or areas that receive a lot of upslope runoff. If there are chronic drainage problems, facilities may need to be relocated.



Maintain grass **filter strips** *adjacent to high-use areas such as arenas to help trap and filter sediment and manure that flow off of these areas.*

- Limit the size of high-use areas to what is truly needed. The smaller the area, the less "polluted" runoff will need to be addressed.
- Locate high-use areas in flatter portions of the property. Avoid steep slopes (generally over 30% slope) that are susceptible to erosion.
- Use ***fencing*** to reconfigure the shape of the high-use area to suit the terrain. Follow county regulations that may require setbacks from creeks, wells, septic leach fields and property lines.
- Consider wind direction for dust control.

A grass **filter strip** *will help trap sediment that may run off a horse paddock. Be sure to develop good drainage in high-use areas such as horse paddocks. Create built-up pads, use proper footing materials, and divert clean stormwater around paddocks to help reduce mud.*

Maintain vegetation around high-use areas

- Develop and maintain a ***filter strip*** of dense grass between drainages (even small, seasonal ones) and high-use areas to trap and filter sediment from runoff. See Section 4.3 for more information on ***filter strips***.
- Reseed grass, if necessary. ***Seeding*** recommendations are in Section 5.2 of the Resources Directory.

Improve drainage in and around high-use areas

- Use base rock and sand to improve drainage in high-use areas and to improve the surface or footing. For horses' health, high-use areas should have well-drained surfaces. "Road base" which consists of a mixture of clay, sand and crushed rock (or gravel) may be needed as a foundation for horse comfort in stalls and small ***paddocks***. Too fine a surface may not allow water to infiltrate and can cause ponding.
- Create built-up pads by "crowning" (building up the center) the pads to promote runoff rather than ponding and infiltration.
- Place filter fabric underneath the drain rock in stalls and small ***paddocks*** to prevent the rock from mixing in with the soil and subsiding. It costs a bit more money up front, but works better in the long run. The alternative is to keep adding rock, which adds stability to the site, however, it could be an ongoing expence.

- Prevent "footing" material from washing off site. Footing that washes off high-use areas could become a form of sediment that should not be allowed to enter creeks and seasonal drainages. Kickboards, made of railroad ties, telephone poles, or boards placed around the perimeter help prevent footing from washing away.
- Use a ***diversion*** to route "clean" stormwater runoff around the high-use area.
- Locate shelters along the edges of ***paddocks*** rather than in the middle so roof drainage can be more easily controlled.

Manage manure regularly

- Regular clean up of manure, soiled bedding, and uneaten feed will minimize the amount of pollutants in high-use areas. Uncollected manure adds to mud problems because it absorbs water. Scrape or otherwise remove manure before winter. Evaluate the manure management element of your ***conservation plan***.

Keep paddocks, corrals, and arenas as dry as possible during the winter rainy season

- Plan horse traffic patterns to avoid wet areas and minimize the formation of areas without vegetation. Select drier areas for the location of gates and other high traffic uses.
- Consider using deep bedding to prevent horses from standing in mud. These bedding materials are usually wood products, up to a foot in depth and can be used in outdoor situations. Various commercial products are available. A filter fabric may be required beneath the deep bedding to keep it from being trampled into the soil. Kickboards placed around the perimeter help retain the bedding on-site. Be aware that wood shavings, once saturated, can produce sufficient amounts of tanolignic materials to create a toxic leachate, which can pollute runoff.
- Use rubber mats over "road base" with bedding materials to keep stalls and other high-use areas dry in the winter.
- "Scratches,"also known as "grease heel," "grease," "cracked heels," or "mud fever," is a dermatitis (inflammation of the skin) of the heel and rear side of the pastern area. It can develop or be aggravated when horses stand in muddy corrals for long periods without relief.[3]
- Use clean fill such as soil for low spots. Don't use manure. As an organic material, manure holds water and actually adds to mud problems.

[3] James, Ruth B., DVM. 1990. *How To Be Your Own Veterinarian (Sometimes): A Do-It-Yourself Guide For The Horseman.* North Carolina: Alpine Press.

- Consider using ground oyster shell or various commercial products to dry urine-soaked or wet areas.
- Plant grasses, shrubs, and trees around high-use areas to utilize excess water, and to help keep the area drier.
- Native trees and shrubs such as California bay laurel, toyon and coffeeberry continue to use water during the winter when deciduous trees are dormant. (Do not plant anything that is toxic to horses. If oleander, oaks, walnut trees, etc., are consumed, they will make horses sick). Trees work well on the north side of a high-use area where they will not block the sun's rays. Protect trees from damage by horses by using heavy fencing, or horses will push down the fence to eat the leaves and bark. Trees in paddocks may have problems because horses also like to scratch on tree trunks and long limbs. Compaction of soil within the trees' drip line can harm roots.

> **Weed References**
>
> For noxious weed information, visit the California Department of Food and Agriculture ENCYCLOWEEDIA: http://www.cdfa.ca.gov/phpps/ipc/encycloweedia/encycloweedia hp.htm
>
> To learn more about noxious weed eradication in your county, visit the CALWEED Database, California Noxious Weed Control Projects Inventory: http://endeavor.des.ucdavis.edu/weeds/

Practice dust control measures

- Keep areas as vegetated as possible.
- Plant native trees for windbreaks and dust screens. Keep horses away from plantings by installing conventional horse ***fencing*** or an electric fence.
- Sprinkle water on arenas and ***paddocks*** to keep down dust during the summer. This also helps degrade urine salts that could otherwise accumulate in arid western soils during the long dry summer.[4]

2.3 Manure Management

Proper manure management will help maintain a healthy environment for horses, provide a clean and safe working area for people, and protect water quality in creeks and ground water. Effective manure management can reduce waste volume, removal costs, fly breeding, and neighbor complaints.

Management Strategies for Manure Storage Areas

Develop and implement a manure management element for your *Conservation Plan*

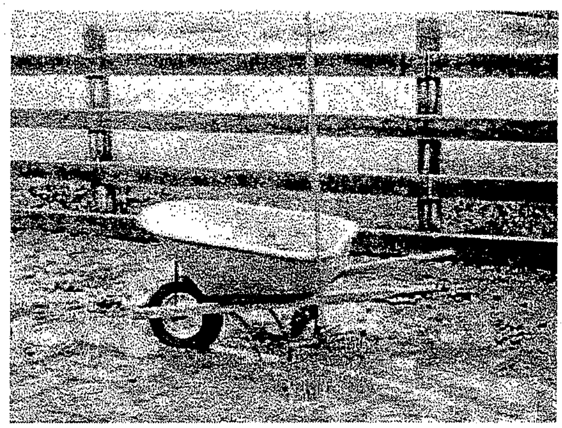
- Be sure to include a description of the facility's plans for manure collection, storage, and use or disposal.
- Consider characteristics of your property and operation to determine what manure management strategies will work best. Take into account: proximity of manured areas and manure handling areas to creeks, runoff from surrounding slopes, soil type, presence of near-surface ground water, type of bedding

[4] Michael Rugg, personal communication. 2001. California Department of Fish & Game, Yountville, CA.

material, volume of material (manure and bedding), number of horses, availability of labor and equipment, and access for clean-out and storage areas.
- Develop storage options. Storage facilities could include covered bins, sheds, concrete pads with low walls, windrows, piles covered with plastic tarps, dumpsters, trucks, or covered garbage cans. One 1000-pound horse may produce 0.75 cubic feet per day of solid waste plus urine.[5] Remember to add the volume of bedding when sizing a storage facility.
- Develop options for manure utilization such as ***composting***, disposal, and land application. Determine the pasture or crops available to utilize nutrients in the manure or compost produced.
- Talk to your neighbors and local RCD. Your solution should be appropriate to your area. It may be possible to develop solutions for a neighborhood or even a region.

Clean up manure

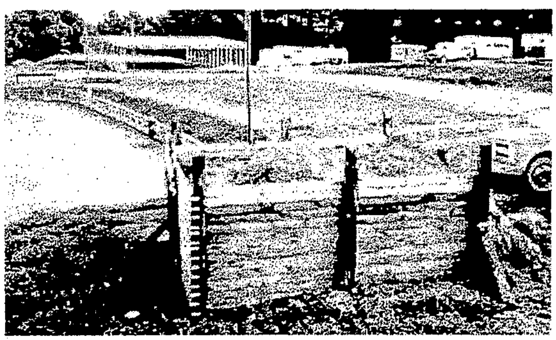
- Clean up manure, soiled bedding, and uneaten feed from stalls and ***paddocks*** regularly. Daily removal is best, especially during the rainy season.
- Use proper tools and a convenient storage site to simplify clean up. Find a manure fork that works. Some carts are too big, while others are hard to push around or awkward to dump.
- Scrape or otherwise remove manure from high-use areas, such as corrals and arenas.
- Pick up or spread manure periodically if horses deposit it in one area.



Proper manure management is essential for horse owners. Manure cleanup, storage, and use are critical components of conservation planning and good stewardship.

Store manure and compost properly

- Store manure and compost away from creeks and wells.
- Make sure that the ***manure storage, compost area***, or disposal container is appropriately located and sized for loading and unloading and can handle the appropriate quantity of manure cleanouts. Loading ramps are useful if manure can be loaded directly into a dump truck or dumpster. If tractors will be used, be sure the facility is large enough and strong enough for the equipment.
- Locate the storage or ***composting area*** on a water-tight surface such as compacted clay,



Composting manure may be an excellent way to handle large quantities of manure and create a useful product. Be sure to calculate the waste volume and allow for equipment access. Proper stormwater management and drainage should be installed near composting areas.

[5] Livestock Waste Facilities Handbook. 1985. Midwest Plan Service–18. Iowa State University, Ames, Iowa.

concrete, or plastic to reduce the potential for seepage of leachate (liquids high in salts and nutrients draining from manure piles) into ground water.

- Check regulations and required permits before grading for manure storage pads, especially when working around environmentally sensitive areas such as wetlands or streams.
- Install proper stormwater management and drainage measures (see Section 4.2) to route stormwater away from the area. Divert any runoff that leaves the ***manure storage*** or ***composting area*** to a ***filter strip***. Vegetation will utilize the nutrients in manure and help filter manure particles that are carried along in runoff.
- Use a ***cover***, such as a tarp, to protect stockpiled manure from winter rains. Shape piles in long rows, so that the width fits the size of the plastic sheeting used to cover the manure. Tie or weigh down edges and corners as necessary.
- Empty storage areas before the winter rains to reduce the volume of manure that must be contained.
- Take odor into account by considering prevailing winds, and distance to your neighbors.

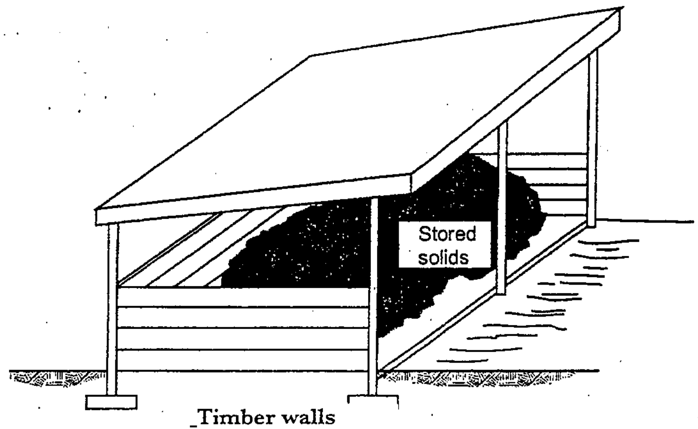
Develop and implement a nutrient management element in your *Conservation Plan*

- Take into account your pasture's needs and determine the amount, placement, and timing of ***manure application or spreading*** to maximize plant growth and minimize the potential for polluting creeks and ground water.
- Have your soil analyzed by a laboratory ***before spreading manure*** to determine fertilizer needs, and establish a baseline for future monitoring. This is especially important if manure has been applied to the field for many years. Nutrients such as nitrogen and phosphorous are released over time (many years), so a field that has been used for manure disposal may already be quite high in nutrients and salts.
- Consider having a laboratory analysis of your horse manure to determine the total analysis. This will help ensure that ***manure application*** meets, but does not exceed plant nutrient requirements. For example, some of the nitrogen in manure may not be immediately available for plant use or additional fertilizer may be needed for specific nutrients.

Visual Inspections of Manure Storage Areas

Examine the condition of, and make any repairs to:

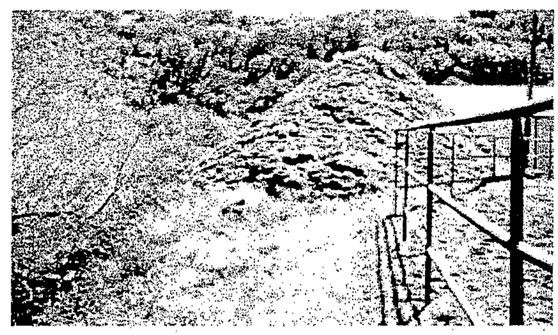
- Concrete – Cracks or openings, signs of infiltration, crumbling or rust
- Wood – Splitting, buckling or rotting
- Earthen containment walls – Settling, seepage, slumps, or animal burrows
- Wall alignment (vertical and horizontal) – Curves or bulges
- Foundation – Erosion or piping
- Liners – Tears



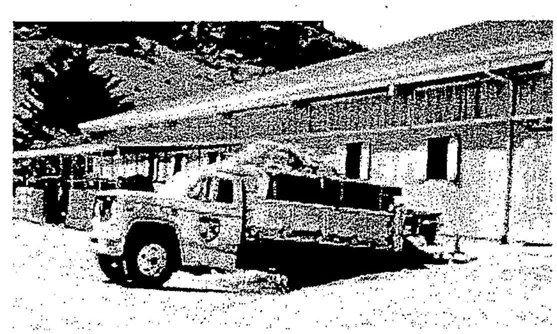
Stockpile manure on an impermeable surface. Size the manure storage area according to the amount of manure and bedding produced. The base must be a water tight surface to reduce the potential for seepage of leachate into ground water. The surface must be designed so it can be scraped with a shovel for small facilities, or a front-end loader for larger facilities. Cover the manure storage area so there is no liquid draining from the stack. A tarp or roof must drain away from the manure stack. Roof height should be a minimum of 7 feet, and also be designed to accommodate heavy equipment. Liquid from the manure may accumulate in the storage area and should be absorbed and removed with the bedding material. Empty the storage area before winter to reduce the amount of material to be stored.

Use compost and manure properly as a fertilizer and soil conditioner

- Properly calibrate your manure spreader to avoid over-application. Applying more manure than plants will utilize wastes nutrients. Excessive nitrogen and phosphorus in soils can be lost to ground water by leaching or to surface water through runoff.
- Apply manure and compost to actively growing pasture in the spring so nutrients will be utilized. Wait until after the winter rains when the ground is firm. Additional application in the fall before the winter rains will free up space in the ***manure storage area*** for the winter.
- Do not spread manure near creeks or on steep slopes where it can be carried to creeks by stormwater runoff.
- ***Compost*** bedding materials with manure before application. If undecomposed bedding is applied with the manure, soil organisms will use the available nitrogen to decompose the bedding—reducing the nitrogen accessible for plant growth.
- Use caution when spreading horse manure that has not been composted. Manure may contain weed seeds brought in with hay. Buy hay certified by the Agricultural Commissioner as "weed free," or compost horse



Never store manure near creeks. Rainwater running through this manure pile would run directly into the creek below to the left. Excessive nitrogen from manure feeds algae blooms that ultimately consume much of the oxygen in water. Ammonia from urine and manure can be toxic to aquatic life.



Local nurseries, landscapers, gardeners, agricultural operations, or community gardens may want manure. A hauler may be able to regularly pick up manure from neighboring horse owners. Manure should be composted before using in gardens.

manure to kill weed seeds. Also, spreading manure onto pastures may risk the spreading of internal parasites, if not composted.

- Incorporate manure or compost immediately into the soil by shallow disking or harrowing to increase nutrient availability for plants.
- Spread compost under the canopy cover (drip line) of trees, and be careful not to bury the root crown.
- Keep records of manure and soil tests.
- Keep records of manure and fertilizer applications, and the results of forage production.
- Give away or sell good quality composted manure.

Dispose of manure properly

Do not store manure near creeks or in places where runoff from manure piles can affect creeks or ground water.

- ***Compost*** manure into topsoil and use this valuable by-product to enhance your own property; give it away to local farmers with pasture, orchards, vineyards or annual crops; landscapers; community gardens; or sell it.
- Haul manure away for disposal. While this is usually a costly alternative, it may be the only one available for certain properties. If so, work with neighbors to encourage a local ***manure hauling*** system.
- Exchange, recycle or swap manure with others. The California Materials Exchange (CalMAX) links those looking for organic material or compost with stables providing horse manure. For more information, visit the website at http://www.ciwmb.ca.gov/calmax. Local programs such as the Sonoma Materials Exchange (SonoMax) is a free service helping local business find reuse and recycling opportunities. The goal is to reduce the amount of waste in landfills while giving business an opportunity to save on disposal costs. For a listing, contact: http://www.recyclenow.org/sonomax

2.4 Composting Horse Manure

Caring for your horses can require a considerable amount of time, energy and expense managing manure and soiled bedding. ***Composting*** manure decreases the volume of waste. It is easier to handle composed manure, and turns the waste into a usable product.

Composting Horse Manure: Turn Straw into Gold

For some horse facilities, ***composting*** horse waste may be an effective method to handle manure and stall waste generated by horses. ***Composting*** manure requires controlling conditions to speed up the natural process of decomposition. The benefits of ***composting*** include efficient manure management, reduction in manure volume by more than 50%, lower risk of surface and ground water contamination, and fewer odors. Compost heat kills worm larvae and reduces the parasite transmission between horses, as well as eliminates breeding ground for flies. Compost is a great soil conditioner—organic matter improves soil structure, drainage, and water retention. It also provides nutrients for plants, and the heat kills weed seeds and pathogens.

Compost basics[6]

Horse waste can be composted in numerous ways, although all methods require the same basic ingredients and conditions. Compost is created from a blend of nitrogen rich materials such as manure, carbon rich materials such as bedding, air, and water. Horse manure alone has close to the desired carbon to nitrogen ratio of 30:1. The compost material should be as wet as a wrung out sponge and well aerated to provide a favorable environment for the microbes that decompose horse waste. ***Composting*** requires one to three months depending on your method and management.

Manure is breaking down into **compost**, *laid out in windrows for easy turning by tractor. Compost is curing at a different stage in each windrow, and new manure is constantly added to new windrows. Nitrogen-rich materials (such as manure), carbon rich materials (such as bedding), air, and water are used to create compost. Proper moisture and aeration are important. Turning horse manure into compost takes one to three months.*

Different methods of ***composting*** include using bins and turning the compost by hand (for aeration) or long windrows that are either turned with equipment or passively aerated with perforated pipes running through them, that require mechanical blowers and pipes to force air through windrows or piles. It is

Make **compost** *in bins or long windrows that are turned with equipment or aerated with perforated pipe. Piles should be less than 6-8 feet high.*

[6] Information drawn from: *On-farm Composting Handbook* (NRAES-54), Northeast Regional Agricultural Engineering Service Cooperative Extension, 1992. New York.

important to maintain proper height (lower than 6-8 feet) and moisture levels, especially during hot and dry conditions. Piles more than 12 feet high with less than 25-45 percent moisture content could spontaneously catch on fire.

Planning your composting project

The number of horses, labor and equipment available, space available, and management cost and time will determine whether ***composting*** will work for you and the method to use. To learn about ***composting*** options, talk with local certified Master Composters and Master Gardeners (who provide public assistance through the University of California Cooperative Extension) and visit horse facilities that compost. Also see the *Composting Horse Waste* Fact Sheet published by the Council of Bay Area Resource Conservation District's Equine Facilities Assistance Program. Contact your local RCD for a copy. (See Section 5.1 of the Resources Directory for contact information.) Private consultants may be needed to help you develop a large-scale system.

Factors to consider in planning your project:

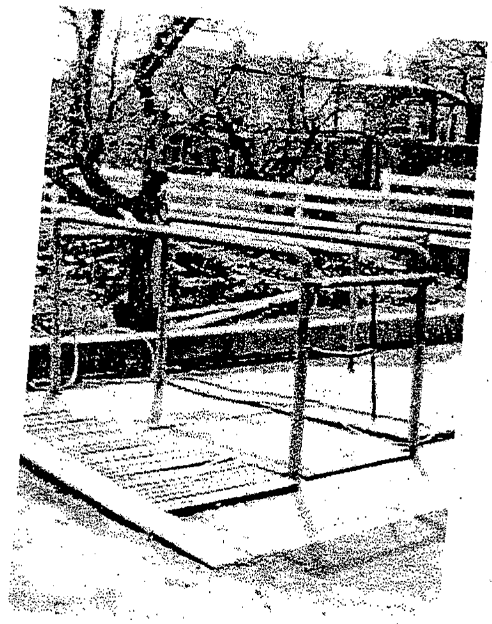
- **Size**. Plan adequate room to handle the anticipated volume of horse waste plus equipment access. If you have a large operation, check with your local planning department before establishing a ***composting*** operation. Generally, horse waste can be composted and used on-site without a permit from the state although there may be notification, filing and record keeping requirements. Counties and local governments will probably require review of an operation plan.
- **Zoning regulations**. These may require setbacks from creeks or property boundaries. The regulatory aspects of ***composting*** are covered in Title 14, Division 7, Chapters 3.1 and 5.0 of the California Code of Regulations. County permitting departments may have requirements that need to be met.
- **Slope and drainage**. To prevent stormwater runoff from entering ***compost areas***, windrows and bins should be on flat ground or oriented up and down a very gentle slope (not across the slope where more water can drain into the pile). The surface area should be compacted or paved to prevent seepage, particularly in an area with sandy or gravelly soils or with a high water table. Any compost runoff should be directed to a ***waste pond*** or ***filter strip***.
- **Water supply**. A nearby source of water is often needed because ***composting*** may require additional water to maintain moisture content.
- **Wind**. Wind direction is important to consider for dust control and odors. For example, downwind neighbors may be affected when piles are turned.
- **Conservation Measures**. Be sure to include the same conservation measures as you would for ***manure storage areas*** (see Section 2.3, Manure Management).
- **Combustibility**. Under certain conditions, immature compost can undergo self-heating and spontaneous combustion from the heat generated by microbial decomposition. Confined storage, which traps heat, may exacerbate these conditions. Management plans should be developed to prevent this occurrence and contingency plans should be in place to respond appropriately if self-heating occurs.

2.5 Horse Wash Areas

Runoff from horse wash areas may contain soap and limited quantities of manure, chemicals and pesticides from horse health and grooming products that should not be allowed to reach nearby creeks or percolate into ground water.

Management Strategies for Horse Wash Areas

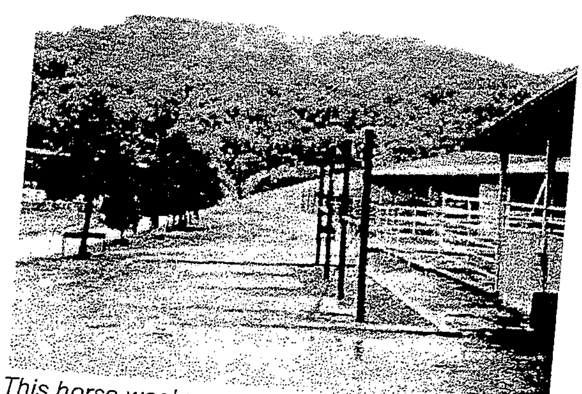
- Prevent wash water from percolating into permeable soils if there is near-surface ground water or a high water table. A storage ***tank*** for wash water may be necessary.
- Elevate the wash area with a built-up layer of crushed rock if the wash area is fairly flat. Wash water should drain away from the area to a ***filter strip*** or other vegetated area.
- Do not allow water from horse wash areas to flow into creeks, ponds or seasonal drainages.
- Keep the wash area free of manure and horse care products.
- Prevent wash water from flowing into storm drains (storm drains typically drain into creeks).
- Create a ***filter strip*** downslope of the wash area, or move the wash area to an area where a ***filter strip*** can be developed. Make sure the ***filter strip*** can accept the amount of wash water generated. Use ***berms***, or other conveyance measures, if necessary to contain and direct water to the ***filter strip***.
- Consider using ***constructed wetlands, grassed waterways*** or ***waste ponds*** as treatment areas for horse wash water.



A curb directs horse wash water away from the creek. Keep horse wash water out of creeks, seasonal drainages, and storm drains. Horse wash areas should be kept clean of manure and grooming products.

Use horse grooming and health care products properly

- Use a shut-off nozzle or low-flow nozzle at the end of the hose.
- Consider sponging off your horse to conserve water.
- Use plain water to rinse horses—avoid using soap as much as possible.
- Follow instructions, read environmental warnings, use only the recommended amounts, and clean up spills. Even biodegradable horse grooming and health care products can have a negative effect on water quality.



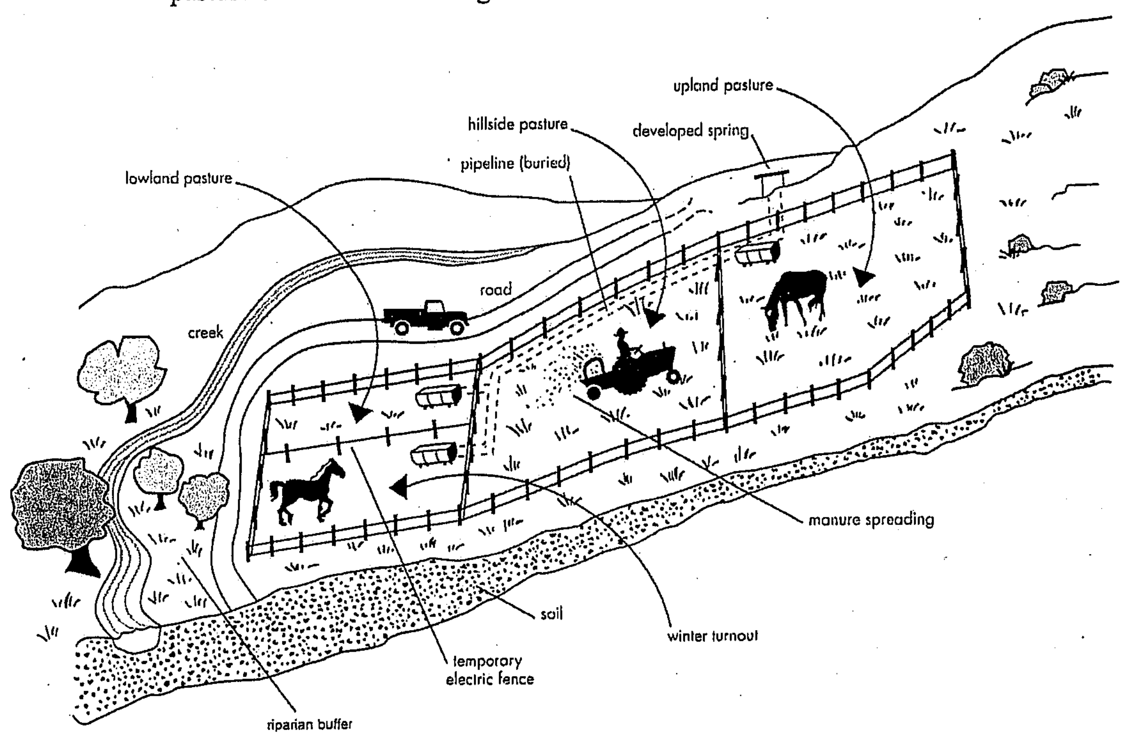
This horse wash area drains into a grass ***filter strip*** *(along the row of trees). The filter strip traps sediment, horse manure and other contaminants.*

- Use products that do not contain surfactants if wash water might eventually enter creeks. Surfactants, a group of chemicals that make detergents more effective cleaners, are extremely toxic to all aquatic life and can even impair the ability of young salmonids (steelhead and coho salmon) to adapt to ocean waters after they leave freshwater streams.

2.6 Pasture Management

When managing pastures, consider yourself in the business of growing grass. Grass will provide more forage for your horses and protect the soil from erosion. In healthy pastures, grass roots increase the soil's absorption of rainfall, storing moisture to prolong the growing season. In turn, a longer growing season produces more grass. Grass stems slow the rate of overland stormwater runoff. Slowing the rate and reducing the amount of runoff from hillside pastures may reduce drainage problems elsewhere on your property. A grass cover with little bare soil is ideal.

Horses can damage pastures quickly without ***grazing management***. Renovation of pastures is costly. Take care of what you have by controlled ***grazing*** and "resting" pasture so it has time to regrow.



PASTURES – Proper pasture management can include using **cross-fencing** *to promote uniform pasture use, controlling the number of horses and* **grazing distribution** *within pastures, controlling horse access to creeks, developing a* **spring** *as a new water source, and restricting pasture access during the wet season.*

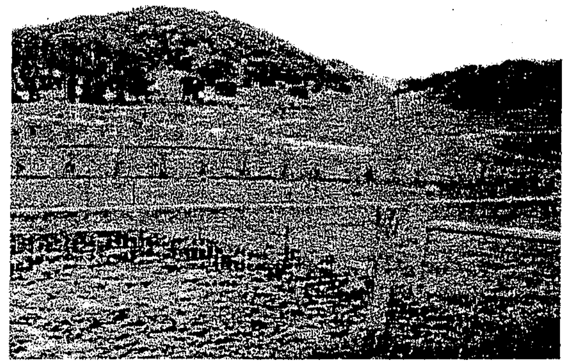
Management Strategies for Pastures[7]

Control horse access to creeks and other water sources

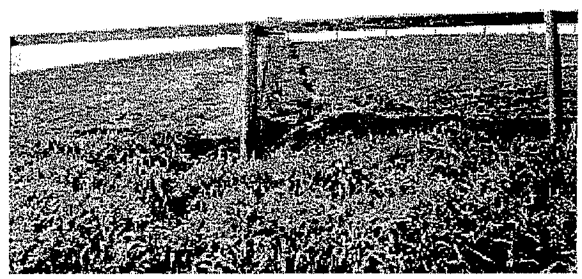
- Control horse access to creeks to prevent manure and urine from being directly deposited in or near creek channels. ***Fencing*** to keep horses out of creeks may be necessary.
- Control horses ***grazing*** along creek banks to reduce trampling and erosion of banks that leads to sedimentation of waterways.
- ***Graze*** riparian areas seasonally when soils are dry enough to withstand the weight of the horses, to keep streambanks from being trampled and broken down.
- Provide horses with alternative sources of water if creek ***fencing*** is installed. Small pasture shelters may be necessary to provide a new source of shade and shelter.
- For crossings or water source, narrow horse access to a point at a creek where the channel can be armored or protected with gravel or other means.

Improve animal distribution to help reduce bare areas and control undesirable weeds.

- Manage the number of horses and control ***grazing distribution*** to prevent heavy grazing.
- Develop and adjust a rotation ***grazing*** schedule to provide pastures with periods of ***grazing*** interspersed with periods of rest.
- Locate feed, salt, minerals, and water away from creeks. Regularly move the salt blocks to distribute ***grazing***. Place hay piles far apart with more piles than the number of horses being fed. This will minimize trampling from fighting horses and maximize distribution.
- Use ***cross-fencing*** (dividing up a pasture with fencing into smaller cells) to improve



Overgrazing occurs when plants are so heavily grazed that the root system dies back and plants eventually become less productive or die. A balance of grazing and pasture rest will prevent overgrazing, improve forage production, and keep weeds down.

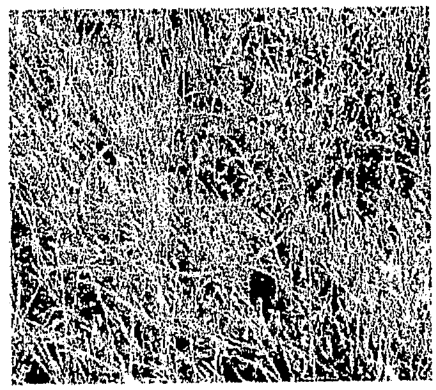


Be sure to control horse access to vulnerable erosion areas such as a rill in a pasture. Repairing a problem early and installing temporary **fencing** *can help prevent the need for a more costly fix later (such as when a rill turns in to a gully).*

Overgrazed pastures lack plant cover and are susceptible to erosion. Keep horses out of highly erodible areas and **seed** *bare areas. Gully repair is likely to require professional assistance.*

[7] USDA, NRCS - California, Field Office Technical Guide, Prescribed Grazing, July 2000.

Adequate **"Residual Dry Matter"** *(RDM) leaves enough plant residue on the soil surface to protect against soil erosion, and leaves a sufficient seed source for annual pasture regeneration. RDM is measured in the fall, just before the winter rains. The minimum levels of RDM that should remain in a pasture is 800 – 1000 lb/ac in the San Francisco Bay area. This pasture has 900 lb/ac of RDM. Pasture production varies from year to year, with rainfall being a primary influence. Therefore grazing must* be monitored and grazing levels adjusted, each year



Residual Dry Matter *(RDM) is used as a tool to determine adequate erosion control on pastures. RDM is measured by clipping the grass in a ring, and measuring the weight of the dried grass. This site has 900 lb/ac of RDM. For visual estimates of RDM, refer to the "Residual Dry Matter Monitoring Photo-Guide" produced by Wildland Solutions.*

evenness of pasture use. ***Cross-fence*** pastures according to the terrain, soil wetness, and land sensitivity (e.g., steep slopes will erode more easily). Lowland pastures will probably stay green later into the summer and may be too wet to be grazed without damage in the winter. You may need to add alternative water sources for horses.

Portable electric fencing is easily installed and affordable, and can be used to define ***grazing*** areas if the horses are allowed to acclimate to the new fencing (temporary flagging helps to demarcate the fencing).

- Provide alternative sources of water by developing ***springs*** or extending an existing water system.
- Small pastures should be used for exercise rather than forage production.
- Maintain sufficient ***residual dry matter (RDM)*** for pasture reseeding and erosion control. RDM is the amount of dry grass stems left behind after the grazing season has ended. Be prepared to move horses to another pasture or a ***paddock*** once target RDM levels are reached or exceeded. The rule of thumb is to leave 4 inches of grass stems in the pasture. See Section 5.8 of the Resources Directory for more information on RDM.

Properly manage pasture use

- Turn horses out for only a limited period of ***grazing*** each day to increase the duration of a pasture's use and to reduce soil compaction. ***Grazing*** when the soil is wet causes soil compaction. The soil particles are pressed together by concentrated pressure from livestock hooves, reducing the pore space between soil particles. A dry soil is more resistant to compaction than a moist or wet soil. Compaction restricts rooting depth, which reduces the uptake of water and nutrients by plants. This affects the activity of soil organisms by decreasing the rate of decomposition of soil organic matter and subsequent release of nutrients. Compaction decreases infiltration and thus increases runoff and the hazard of water erosion.

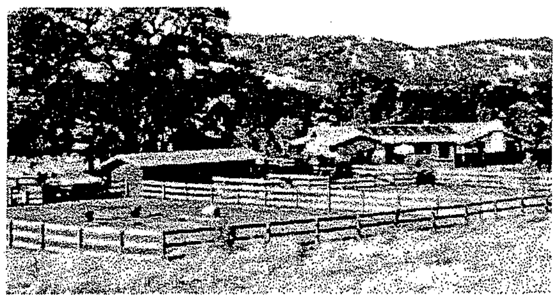
Control winter access to soggy pastures to help prevent pollutants from leaching into the ground water and to keep horses out of the mud. Fence out springs and seeps.

- Feed horses before turning them out to reduce the ***grazing*** pressure on grasses.
- Remove or spread manure if it has accumulated in a particular area. This will promote plant growth and reduce parasite populations. Horses should not be forced to eat the forage where manure is deposited.
- Restrict use of wet pastures. Some pastures may be too wet to use during the rainy winter months. Confine horses to ***paddocks*** during this time and use pastures seasonally during the dry months.

Develop and use turnout paddocks

- Develop ***turnout paddocks*** in flatter portions of pastures, away from creeks. Turnout areas include exercise lots, pens, corrals, and small ***paddocks***. Follow the guidelines for high-use areas (See Section 2.2).

  Paddock size depends on the number of horses and other considerations. Keep ***paddocks*** to a minimal size to limit the amount of bare ground. General guidelines are a minimum size of 600-800 square feet per horse, with a slope of less than 5% and good drainage. Keep the paddock surface as dry as possible during the rainy season to reduce the possibility of polluted water from running off the area, and also be healthier for horses.



Turnout paddocks *(exercise lots, pens, corrals, and small paddocks) can be used to keep horses off wet pastures. This will help protect pasture soils and grass cover.*

- Preserve pastures by keeping horses in ***turnout areas*** when grass has been grazed down (less than 4-6 inches high).

Follow seasonal pasture management strategies

- Keep horses in ***turnout paddocks*** and off pastures when soils are wet.
- Give exuberant horses time in a ***turnout area*** during the rainy season before putting them on pasture. This will help horses release their energy and protect turf from being churned.
- Keep horses off steeper slopes when pastures are wet.
- ***Seed*** and ***mulch*** bare areas.

- Remove weeds as necessary and make sure that removal occurs at the proper time of year (this will vary by weed species).
- Monitor grass height and weed growth at the end of the growing season (late spring/early summer).

Watch gully formation and accelerated erosion

- Keep areas well vegetated to minimize soil erosion.
- Use ***fencing*** to keep horses out of highly erodible areas.
- Stabilize gullies as recommended by a professional. Options include headcut repair, ***check dams***, grading side slopes and revegetating. See Section 4.1 for more information on these conservation measures.
- ***Seed*** and ***mulch*** bare areas to protect the soil from erosion and maintain desired grass species. (See Section 5.2 of the Resources Directory for seeding recommendations.)

Grass Facts

Plants need energy for growth, maintenance, and reproduction. Green plants get energy from sunlight, *nowhere else!* Green leaves and stems act as solar energy collectors. Roots need the collected energy for growth and replacement. In general, large amounts of leaves and stems can provide energy for a large root system; small amounts of leaves and stems can only support a small root system. As a rule of thumb, the above ground portion of the plant is equal to the underground root system.

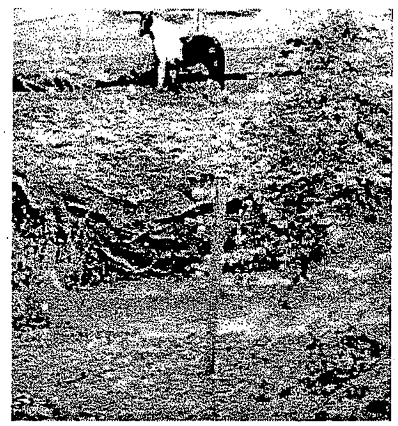
Severe grazing creates an imbalance between the energy provided by the plant's solar collector and the needs of the roots. If the solar collector is kept grazed, the root system will die back to match the energy available. Plants with small, shallow root systems will be far less productive or may even die. This is overgrazing. Overgrazing occurs plant by plant. Since horses are selective grazers, their preferred plants may be overgrazed even when the pasture as a whole looks ungrazed.

Adequate rest periods following grazing allow the plant to rebuild its solar collector and restore roots. The length of rest required will change as the growing conditions change. Grazing years should be planned to provide adequate recovery periods and minimize overgrazing of plants. Long periods of rest are sometimes damaging to individual plants and pastures if excessive thatch builds up. Balancing grazing and rest improves forage production and minimizes weed problems.[8]

[8] *How Grass Grows—The" REST" of the Story.* USDA Natural Resources Conservation Service.

2.7 Water Resources: Creeks, Springs and Wells. Managing Septic Systems

Water resources need special attention and protection. Healthy riparian areas along creeks and springs support a variety of plant and animal species, help control erosion, filter pollutants in runoff, and add beauty and diversity to the landscape. Creeks are vulnerable to erosion and other impacts from activities along streambanks. Creeks and smaller seasonal drainages transport pollutants downstream to lakes, larger streams and rivers, bays and eventually to the ocean. Every landowner can help maintain and enhance riparian areas. Springs provide water for wildlife and can be important sources of habitat for amphibians.



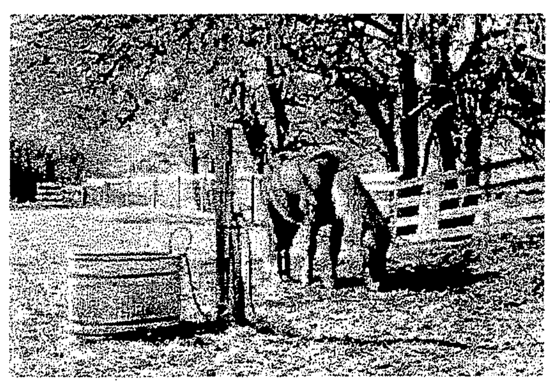
Restrict horses from creeks to help keep manure and urine from being deposited in creeks and minimize erosion on streambanks. Use **fencing** *to help manage horse access to riparian areas. Riparian areas can be grazed seasonally when streambanks soils are dry enough to withstand trampling.*

Wells tap into ground water for drinking water supplies and irrigation. Ground water resources are vulnerable to pollutants that can leach through the soil. Ground water also keeps dry-season flows (underground flows) in streams in some areas.

Management Strategies for Surface Waters

Control horse access to springs, creeks, seasonal drainages, and ponds

- ***Fencing*** can be used to keep horses out of riparian areas.
- Graze riparian areas, if necessary, only during the dry season.
- Design ***stream crossings*** to minimize erosion. For more information, see Roads, Trails and Stream Crossings in Section 2.8.
- Develop alternative water sources for horse confinement areas that are located away from creeks and springs. Conservation measures to consider are ***spring development*** with buried ***pipelines,*** and ***troughs,*** extending existing water systems, installing ***storage tanks,*** and utilizing "nose pumps" where the animal presses a trigger to release water.



An alternative water source is critical if horses are restricted from creeks. Be sure to locate water troughs away from creeks, drainages, and springs. Try using a "nose pump" that allows horses to pump their own water.

Manage runoff properly

- Set buildings, covered arenas, high-use areas, ***horse wash areas***, ***manure storage areas***, ***roads and trails*** back away from creeks.
- Prevent polluted runoff from reaching creeks and springs.
- Maintain a ***filter strip*** and/or ***riparian buffer*** between creeks and high-use areas.

- Control erosion to reduce the amount of sediment that fills ponds.

Monitor the creeks

- Landowners who wish to develop baseline data about the quality of water on their properties are encouraged to learn how to monitor their water resources. ***Water quality monitoring*** information is provided in Section 5.7 of the Resources Directory.
- Monitor water quality, especially during the rainy season.

Enhance riparian areas

- Create and maintain a ***riparian buffer*** along the creek to help slow and disperse surface runoff, settle sediment, and filter pollutants. Use native plants to enhance wildlife habitat. (See Section 4.3 Riparian Buffer, for more information.)
- Monitor and stabilize streambank erosion. Seek professional advice for severe erosion and problems on larger streams. These areas may require intensive "bioengineering" or "hard" engineered structures (such as rock riprap) to stabilize the streambank, as well as a ***riparian buffer***. Be sure to obtain required permits. For more information on streambank stabilization, see Section 4.1. For permit information see Sections 5.4 and 5.5 of the Resources Directory.
- Be aware of any habitat needs or areas for threatened or endangered species on your property. See Section 5.5 of the Resources Directory for more information.

Management Strategies for Wells

Keep well water free of harmful contaminants for the health of you and your livestock. Improperly constructed or older wells can create a pathway for fertileizer, bacteria, nutrients, pesticides, or other materials to enter your water supply and the ground water. Once in the ground water, contaminants can flow from your property to a neighbor's well, or from a neighbor's property to your well. After your water becomes polluted, the only options may be to treat water after pumping, drill a new well, or get water from another source. Time and money spent protecting your well water is a bargain compared to the loss of clean water and an associated decrease in property value.

Properly site wells

- Choose a location where surface water drains away from the well. Avoid placing wells in soil depressions.
- Be aware of how ground water flows. If you live in an area with a high water table (or if you have an existing shallow well), ground water often flows in the same direction as surface water. However, surface slope is not always a reliable indicator of ground water flow—meaning ground water may not always move downslope.
- Locate wells upslope of, and well away from, horse confinement areas, fuel tanks, septic fields, or pastures that may receive too much fertilizer.

- Check with your county permitting department for any well setback or well construction requirements and follow local regulations about the proximity of horse confinement areas to well heads.

Regularly test wells
- Establish a water quality baseline to help detect changes.
- Test wells annually for the four most common indicators of trouble: bacteria, nitrates, pH, and total dissolved solids. A more complete water analysis will tell you about its hardness, corrosivity, iron, sodium, and chloride content. In addition, you may choose to obtain a broad scan test of your water for other contaminants such as pesticides. Local conditions may warrant additional testing.
- Talk to your neighbors. If they have had their wells tested, they may be able to provide you with information on water quality in the area. In addition, county or state health departments may have records of water quality tests in your area.
- Have older, shallow wells periodically checked by a qualified well driller or pump installer. Wells older than thirty years are apt to be shallow and more poorly constructed. Older pumps are more likely to leak lubricating oil. Older wells usually have thinner casings that may be cracked or corroded.

Older wells are more likely to provide a conduit for precipitation and runoff to reach the water table without being filtered through the soil. Wells have steel or plastic pipe "casings" to prevent the collapse of the well hole after drilling. the space between the casing and the sides of the hole are sealed with grout or bentonite clays and the well capped to prevent surface water from entering the well. The depth of the new seal depends on the soil type but should be at least twenty feet. Casing should extend at least 12 inches above the surface or 1 to 2 feet above the highest recorded flood level for the site. Contact county heath or permitting departments for local specifications.

Keep well areas clean and accessible
- Keep contaminants as far away as possible.
- Check nearby fuel tanks or septic systems on a regular basis.

Properly fill and seal unused and abandoned wells for safety, and to prevent waterborne pollutants from reaching ground water
- Contact a licensed, registered well driller or pump installer for this work. A permit is normally required to assure proper well destruction.

Management Strategies for Septic System Drainfields

Properly functioning septic systems depend on good dispersal of wastewater in the drain field and the ability of water to percolate through the soil at a steady rate.

Taking care of drainfields will enhance and preserve the ability of your septic system to break down potential contaminants (such as viruses, bacteria, nutrients, and organic waste) and keep them from contaminating ground water or nearby creeks.

- Keep drain fields covered with grass. Avoid planting trees and shrubs whose deep roots can damage pipes.
- Divert roof and surface runoff away from drainfields. Saturated soil is not effective for treating wastewater.
- Minimize activities that compact drainfield soils. Compaction decreases the ability of water to percolate through the soil, reduces the amount of oxygen available for waste-digesting microbes, and may shorten the life span of the drain field. Activities to watch include ***grazing*** and corrals directly over the leach field, particularly when soils are wet; vehicle use (which can also damage pipes); "high-use" horse activities; as well as paving, constructing buildings, and piling heavy objects.
- Nonstandard septic systems, such as mounds, at-grades, pressure distribution systems, sand filter, etc., can be especially fragile and should be well ***fenced*** for their protection. Local health or permitting departments can offer more specific advice.
- Follow local regulations about the proximity of horse confinement areas to septic leach fields.

2.8 Design and Maintenance for Roads, Trails and Stream Crossings

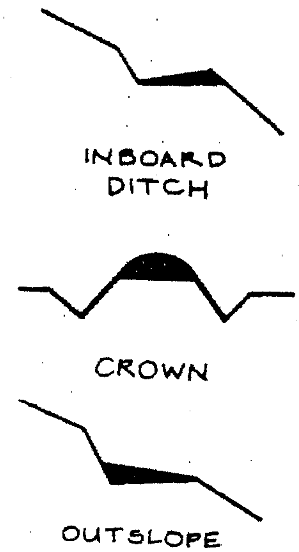
Proper road, trail and ***stream crossing*** design and maintenance will help control erosion. Improperly constructed or maintained roads can cause chronic erosion problems. Unsurfaced roads and horse trails can contribute sediment to creeks and can become dangerous or impassable for horses and vehicles. Even annual regrading of small washouts or eroded areas can contribute significant amounts of sediment to the nearest stream.

Develop longer-term solutions, such as a durable road base, compaction, and gravel surfacing to save time and money while reducing inconvenience, increase-ing safety, and controlling sediment from reaching creeks.

Management Strategies for Roads and Trails

Properly design and construct roads and trails

- Consider the type and amount of expected traffic, speed, loads, climatic conditions, and environmental resources in need of protection. Keep roads to a minimum, the fewer roads, the less maintenance and erosion. Follow sound engineering measures to insure that the road meets the requirements of its intended use and that maintenance requirements are in line with operating budgets. The *Handbook for Forest and Ranch Roads* is a good resource. To obtain this publication, call the Mendocino County Resource Conservation District at (707) 468-9223.
- Understand how roads are constructed and drained to help determine the appropriate strategy for your property. Roads are constructed to drain in three different ways:
  - **Insloped roads** are graded into the slope and drain to an inboard ***ditch***. ***Ditches*** provide surface drainage for the roadway and should be designed to protect the road surface from upslope runoff.
  - **Crowned roads** are higher in the middle and drain water off to both sides. Crowned roads require more initial grading and regular ***ditch*** maintenance.
  - **Outsloped roads** follow natural drainage patterns and runoff drains across the road in even sheets. Typically, outsloped roads are less expensive to construct and easier and cheaper to maintain. ***Culverts*** and ***ditches*** are not required except where the road crosses small drainages. The addition of large amounts of stormwater runoff from above outsloped roads may cause excessive erosion. Roads may have to be surfaced, regraded, or re-routed.
- Develop adequate cross drainage. Long stretches of inboard ***ditch*** accumulate a lot of water that can cause extensive gullying of the ***ditch***, destabilize the roadbed, and undermine the hillside. Some form of cross-drainage is required at regular intervals to channel runoff across the road to non-erodible outfalls, such as ***energy dissipaters***, on the outboard side. Even if a road has some cross-drainage, additional measures may be needed to help prevent washouts. Selecting a method to transport water across a road depends on road location, amount of use and maintenance, the volume of flow, and budget considerations.



Roads are constructed to drain in three ways. Insloped roads are graded into the slope and drain to an inboard ditch. Crowned roads are higher in the middle and drain water off to both sides. Outsloped roads follow natural drainage patterns, and runoff drains across the road in even sheets. Outsloped roads are generally less expensive to construct and easier and cheaper to maintain.

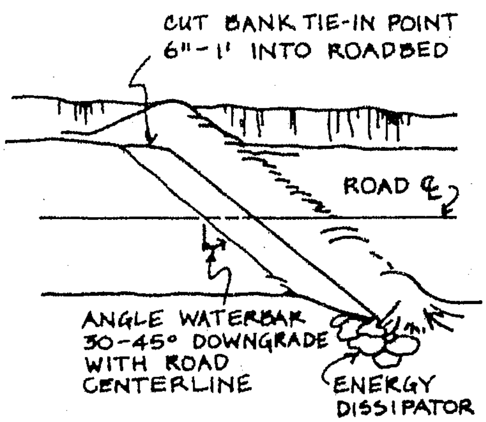
A muddy swale is created by improper drainage from a road (uphill of this photo). A properly constructed and maintained road will help control erosion. Culverts and waterbars can provide **cross-drainage**. *Some roads may need surfacing with gravel, while others should be avoided during the wet months.*

Cross-drainage techniques to consider include:

- ***Culverts.*** Culverts are likely to need professional design to handle anticipated flow. Angle ***culverts*** about 30 degrees downgrade to assure proper water movement and prevent plugging and erosion at the inlet. Compact the backfill to prevent water from flowing through the road base. ***Culverts*** should be used in upland areas and avoided for ***stream crossings***, where ***bridges*** are more appropriate.

  Inlet and outlet design is important to prevent erosion. Inlet design must not allow "piping" (water flowing along the outside of the pipe) that could loosen the soil and wash out the pipe. ***Culvert*** outlets should extend at least two feet beyond the edge of the road and empty onto an ***energy dissipater*** (such as rock riprap). For outlets on steep slopes, use a ***lined waterway*** or ***underground pipeline*** to safely convey water to the base of the slope.
- **Rolling Dips** are dips in the grade of the road. Rolling dips are installed in a road bed to drain the road surface and prevent rilling and surface erosion, and are most frequently used on outsloped roads. To effectively direct runoff to the side of the road, the axis of a rolling dip should be angled about 30 degrees to the road alignment.
- **Waterbar.** This is a shallow ditch placed 30 to 45 degrees downslope across the road surface to control surface runoff on low use roads. The excavated material from the ***waterbar*** is piled in a rounded ***berm*** downslope of the waterbar to form an additional water barrier. ***Waterbars*** are a temporary and very effective means of breaking up surface flow on sloped portions of road. Often they must be reconstructed every year as they wear down.

Waterbars work best on roads that receive little winter traffic. In a pinch, they can be constructed with hand tools. Installing a series of ***waterbars*** reduces the flow volume individual waterbars must handle. ***Waterbars*** can be reinforced with logs, gravel, or a mixture of soil and cement.



Waterbars *are a temporary form of cross-drainage. To create a waterbar, dig a shallow ditch 30 to 45 degrees downslope across the road. Pile the excavated material in a rounded berm downslope of the waterbar. Waterbars need to be monitored and maintained throughout the winter.*

- Follow natural contours and slopes to minimize disturbance of drainage patterns. Avoid building roads on unstable slopes or at too steep of a grade. Grades normally should not exceed 10 percent slope except for short lengths. Minimize cuts and fills, and stabilize the side-slopes of all cuts and fills. Areas with geological hazards (such as old landslides) should be avoided.

  Set roads and trails back from creeks and maintain a ***riparian buffer.***

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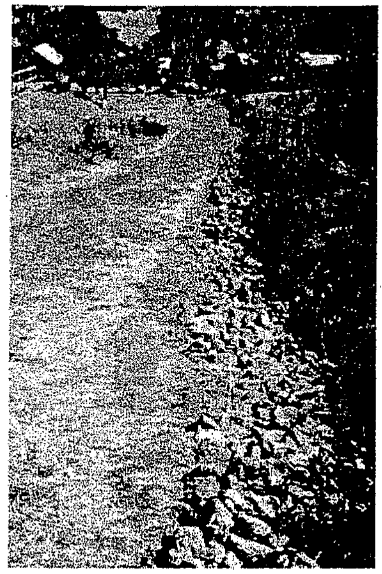
Maintain roads, trails, culverts, and ditches

- Go out during a storm, shovel in hand, when you can see drainage patterns and areas that require urgent attention.
- Check for erosion and drainage problems, particularly on road surfaces, ***ditches***, and cross-drainage structures. Often the main cause of soil erosion is from the power of concentrated runoff that roads and trails collect and channel.
- Look for ***ditches*** or ***culverts*** that are washed out, blocked with debris, or are causing downstream erosion at the outlet.
- Keep ***ditches*** vegetated with grass to help maintain stability.
- Keep ***ditches*** cleared of sediment. Vegetated ***ditches*** with a gentle slope of 2 to 6 percent will prevent sediment deposition and allow rapid drainage. For chronic sediment problems, address the erosion source.
- Keep inlets clear. Remove debris before the rainy season and check during and after storms. Look upstream for any material that could wash into the ***culvert***. Consider another method of cross-drainage or address the upstream source of debris if ***culverts*** plug after every major storm.
- Consider using ***trash racks*** to trap debris, if you can maintain them. While trash racks can help keep ***culverts*** open, unmaintained racks can cause more erosion problems than the original debris.
- Control upslope erosion sources to prevent sediment from filling cross-drainage ***culverts***.
- Install and maintain ***energy dissipaters*** at outlets.



A ***rock-lined ditch*** *is necessary along this steep road. Well-constructed and maintained ditches are key to the long-term stability of an insloped or a crowned road.*

Maintain and improve road and trail surfaces

- Regrade roads to smooth the surface and prevent rills from expanding.
- Provide adequate cross-drainage using ***culverts*** and ***waterbars***.
- Resurface roads and trails that have high traffic, chronic erosion problems, undesirable amounts of dust, or steep grades. For muddy roads, consider using a gravel road base laid over a layer of filter fabric to prevent the gravel from mixing with mud.
- Limit or avoid using certain roads and trails during the winter, particularly those on highly erodible soils.
- Limit side-trails where possible. Shortcuts, especially up steep slopes and across streams, can create highly erodible sections of trail. Encourage riders to stay on established trails.
- Sow grass seed on seldom-used roads and adjoining areas of exposed soil. ***Seeding*** should occur before October 15 to ensure adequate growth.

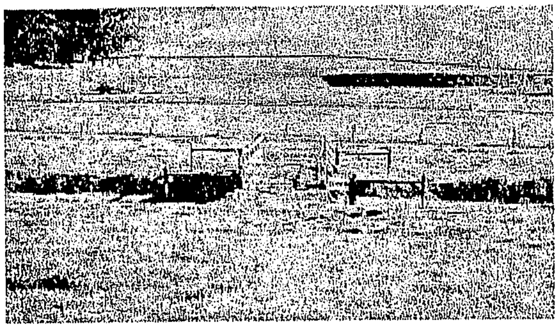
Roads not used in the winter can be "put to bed" for the season. This road has been seeded and will not be used again until the spring. Roads should be properly graded, seeded and mulched, to help prevent erosion. ***Seeding*** *should occur before October 15 to ensure adequate growth before the winter rains.*

Put abandoned roads "to rest"

- Grade, ***seed*** and ***mulch***, or use an ***erosion control blanket*** when putting roads to rest for the rainy season. Jute netting with a layer of straw underneath can also be used. Straw wattles (bundles) can also help with erosion control. (For information on ***erosion control blankets*** and straw wattles, see Section 4.1: Erosion Control – Gully Repair.) For roads with chronic erosion problems, laying roads to rest may be an appropriate strategy from an economic, environmental, or safety standpoint.

Stream Crossings

- Select an appropriate crossing (either a ***bridge***, **rolling dip**, ***ford***, *or* ***culvert***). Select a crossing location that will least impact streambanks and riparian vegetation.



This stream crossing keeps livestock from trampling the streambanks. Stream crossings, such as **bridges, fords** *and* **culverts,** *should be located and designed to minimize impacts to streambanks and riparian plants. Bridges work best on larger streams and have the least impact on aquatic life. Permits are generally required.*

◆ ***Culverts*** should be properly sized and installed. They should follow the same alignment as the creek and exit at the same level as the channel downstream.

◆ ***Fords*** may be required for crossing small seasonal drainages or where debris can clog ***culverts***. ***Fords*** should be surfaced with concrete to prevent erosion. ***Fords*** require site-specific engineering design. A correctly designed ***ford*** should require very little maintenance. If horses will use the ***ford***, be sure to roughen the concrete surface, when pouring the concrete, for traction.

◆ ***Bridges*** are best for larger streams and where there is a lot of floating debris. ***Bridges*** have fewer impacts on aquatic life than other crossings.

- Remember ***ditches*** in the design process. Well-constructed and maintained ***ditches*** are key to the long-term stability of an insloped or a crowned road. Slope the sides of drainage ***ditches*** if possible to control erosion. ***Ditches*** on steeper slopes may need to be lined with rock. Steep-side ***ditches*** will erode more easily than those with 2:1 side slopes. Flat-bottomed ***ditches*** with a 1-2 foot wide bottom are less subject to scouring than V-bottom ditches. ***Ditches*** on steep slopes may require ***check dams*** for grade control (you may want to consult a professional for advice and design).
- Stream crossing references. Check these internet reference sites for additional information on designing stream crossings for fish passage:

  National Marine Fisheries Service
  http://swr.nmfs.noaa.gov/habitat.htm
  Click on Stream Crossing Guidelines

Washington Department of Fish and Wildlife
http://wdfw.wa.gov/recovery.htm
Click on Fish Passage Design at Road Culverts

- Obtain necessary permits. County, state, and federal ordinances regulate many aspects of road construction, reconstruction, and maintenance. Creek crossings will likely require a Streambed Alteration Agreement from the California Department of Fish and Game and can require permits from the US Army Corps of Engineers and the Regional Water Quality Control Board. County public works and building departments may have grading ordinances that describe how roads may be constructed and connected with existing public roads. Other state regulatory agencies with jurisdiction on road construction and related activities include the California Department of Transportation, California Department of Forestry and Fire Protection, and California Coastal Commission (for work in the Coastal Zone). See Sections 5.4 and 5.5 of the Resources Directory for more information on regulations and permits.

- Schedule construction and maintenance activities to minimize soil erosion and allow for revegetation of disturbed areas before winter rainfall. Although some soil moisture is advantageous for roadbed compaction, wait until winter runoff has slackened and soils have begun to dry in the late spring before beginning construction. Heavy equipment should not be used on wet soils. Prevent sediment from entering creeks during and after construction. After construction, revegetate road banks and disturbed areas before the winter rains. ***Seed*** and ***mulch*** for revegetation by October 15.

2.9 Construction Management

Proper construction is important whether building a new horse facility or making improvements at an existing facility. Appropriate installation of erosion control and drainage structures can help protect water quality and reduce future maintenance.

Construction Management Strategies

- Seek technical advice and professional design assistance. Drainage systems must be sized for water volume and velocity.
- Obtain the proper permits for grading and working in streams. See Sections 5.4 and 5.5 of the Resources Directory for more information.
- Avoid grading during the rainy season.
- Minimize disturbance along the edges of creeks.
- Be sure equipment operators fully understand the purpose and extent of grading. Flag-off special areas that you want to protect.
- Implement erosion control measures, such as ***seeding*** and ***mulching*** or installing ***erosion control blankets***, immediately following grading. Utilize emergency measures such as ***straw bale sediment barriers*** until permanent structures can be installed.
- Monitor and maintain all erosion control measures.

Chapter 3

List of Conservation Measures

A conservation measure is a specific treatment, such as a management decision, activity, practice, or structure, that provides a practical, effective, and economical means to prevent or reduce water pollution. Protecting creeks and water quality can create a healthier environment for horses by reducing mud and manure areas.

Table 2 lists conservation measures discussed throughout this guide in ***bold italic*** and identifies the main section(s) in which they are found. Note that conservation measures and suggestions in this guide rely extensively on the standards and specifications of US Department of Agriculture's Natural Resources Conservation Service.[9] Horse owners may need to seek professional assistance with some measures. Conservation measures with an asterisk (*) have an NRCS standard and specification with specific design criteria. Some standards and specifications have different names than used in this guide, which are marked with a footnote, and NRCS practice names are given at the end of the table. Visit the website: http://www.nrcs.usda.gov/technical/efotg/, or contact your local NRCS office for details.

[9] Conservation practices in this section are drawn from USDA Natural Resources Conservation Service *Field Office Technical Guide*. Davis, CA, 1986.

Table 2: Horse Keeping Conservation Measures

Conservation Measures	Section	Page Number
Conservation plan	1.1, 2.3	11, 24
Erosion control Conservation Measures	4.1	52
Seed [A]*	4.1, 5.2	52, 79
Mulch [B]*	4.1, 5.2	52, 80
Erosion control blanket [C]*	4.1	53
Gully repair	4.1	53
Check dam [D]*	4.1	60
Streambank stabilization [E]*	4.1	55
Emergency Erosion Control Measures	4.1	58
Sandbag	4.1	59
Sandbag pipeline drop inlet	4.1	61
Silt fence	4.1	61
Straw bale check dam	4.1	60
Straw bale sediment barrier	4.1	60
Straw bale waterbar	4.1	59
Road Related Erosion Control [F]* including Stream Crossing	2.8	40
Bridge	2.8	44
Ford	2.8	44
Culvert	2.8	41
Ditch	2.8	41
Waterbar	2.8	42
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Stream Crossing	2.8	44
Pasture Management	2.6	32
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Grazing distribution [G]*	2.6, 5.8	33, 94
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Spring development*	2.7	37
Storage tank [H]*	2.7	37
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Monitor grass growth	2.6	34
Residual dry matter; monitoring grass residue	5.8	93
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Conservation Measures	Section	Page Number
Stormwater Management Measures		
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Roof runoff management*	2.1, 4.2	20, 62
Gutter	2.1, 4.2	20, 62
Downspout	2.1	20
Splash pad	2.1	20
Subsurface drain*	2.1	20
Runoff Diversion	4.2	63
Diversion*	4.2	63
Berm	4.2	63
Runoff Conveyance	4.2	63
Grassed waterway*	4.2	64
Lined waterway*	4.2	65
Drop inlet	4.2	65
Sediment basin*	4.2	65
Underground pipeline*	4.2	65
Discharge Area	4.2	66
Energy dissipater[I]*	4.2	66
Polluted Water management measures	4.3	66
Filter strip*	4.3	66
Riparian buffer*	4.3	67
Willow sprigging[J]*	4.3	71
Constructed wetland*	4.3	72
Waste pond*	4.3	72
Pond sealing or lining*	4.3	72
Horse wash area	2.5	31
Paddock	2.6	35
Turnout	2.6	35
Water quality monitoring	5.7	90
Manure Management[K]*	2.3	24
Manure storage area[L]*	2.3	24
Manure transfer* or hauling	2.3	28
Manure application[M,N]* ***or spreading***	2.3	27
Composting manure	2.4	29
Compost area[O]*	2.4	30
Water quality monitoring	5.7	90

Natural Resources Conservation Service names for standards and specifications:

[A] Critical area planting
[B] Critical area planting – straw mulch
[C] Critical area planting – erosion control blanket
[D] Grade stabilization structure
[E] Streambank protection
[F] Access road
[G] Prescribed grazing
[H] Trough or tank
[I] Rock riprap
[J] Critical area planting – woody cuttings
[K] Waste management system
[L] Waste storage facility
[M] Nutrient management
[N] Waste utilization
[O] Composting facility

Chapter 4:

Conservation Measures to Improve Water Quality

Conservation measures offer options for making improvements at a horse facility and are designed to assist land users to effectively reduce sources of pollution at horse facilities. You have seen the list of conservation measures (Chapter 3) and references to these conservation measures in Chapter 2. Material in this chapter is designed to assist horse owner knowledge and understanding of how management practices function together within a facility. Now, we will discuss in detail how the items tie together.

This chapter is presented in three sections:

- **Section 4.1:** Erosion Control Conservation Measures
- **Section 4.2:** Stormwater Management Measures: Keep "Clean" Water Clean
- **Section 4.3:** Measures to Manage "Polluted" Water

4.1 Erosion Control Measures

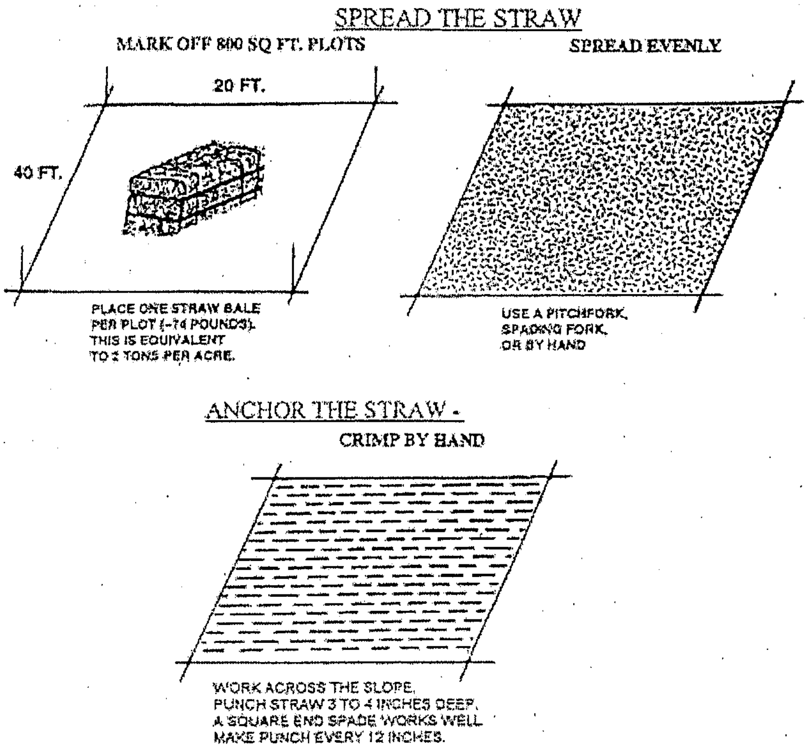
Erosion is easier to control in its early stages when revegetation or simple drainage improvements may be all that are necessary. Once eroded, soils are less productive, and can be more difficult to revegetate. Watch for accelerated erosion in vulnerable areas such as steep slopes and landslides, pastures, gullies, intensively used horse areas such as ***paddocks*** and ***turnouts***, streambanks, unsurfaced roads, road cuts, parking lots, and construction areas.

Seed and Mulch for effective Revegetation

Straw mulch is being applied after tractor work was done to smooth out a gully. ***Seeding*** *and* ***mulching*** *are effective and low-cost erosion control measures. When seeding and mulching bare areas, be sure to prepare the seedbed by removing weeds, and roughening the seedbed. Grass seed should be spread by October 15. Mulch should be weed free.*

Seeding and ***mulching*** provide effective revegetation.. ***Seeding*** is usually needed for ***filter strips***, ***grassed waterways*** and ***pastures***, as part of erosion control, or after construction. A complete seed mix and specifications are in Section 5.2 of the Resources Directory. ***Seeding*** and ***mulching*** tips to keep in mind are:

- Be sure to plant before the rainy season, generally by October 15.
- Properly prepare the seedbed. The area should be weed free. Have a firm seedbed that has been roughened by disking, harrowing, or a similar method. Or use a no-till drill to seed directly into existing grasses, which will minimize erosion.
- Legumes (clovers) must be inoculated with nitrogen fixing bacteria immediately before planting. This will help increase legume production and nitrogen fixation. (See Section 5.2, Legume Inoculation.)
- Maximize the use of native species.
- Do not use fertilizers with native grasses, as weedy annuals will compete for the extra nutrients.
- Use ***mulch***, preferably straw, after seeding. Crimp the straw with a shovel for small areas, or a tractor with tracks for large areas, to anchor it in place. Make sure straw is certified weed free. Rice straw is a good option because the weeds that grow with rice only survive in an aquatic environment.
- Straw wattles can be used to break-up the rainfall over long slopes.
- Keep the soil moist until the rainy season begins.
- Periodically mow or graze, and weed to control noxious weeds and reduce fire danger.
- Restrict human and horse access until grasses are well established.

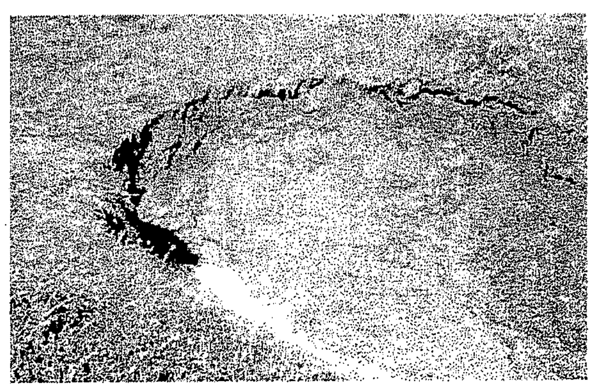


Apply straw **mulch** *at a rate of two tons per acre (or one 74 pound bale per 800 square feet, at a uniform depth of 2 to 3 inches). Straw can be anchored by hand punching, or in larger areas, by using rollers, crimpers, or a disk.*

Gully Repair

Certain highly erodible soils are particularly susceptible to gully formation. Gullies will deepen and widen if left unchecked. To develop an effective repair, determine what caused the gully to form. Any change in drainage patterns that concentrate water, such as ***ditches*** or road ***culverts***, are likely suspects and may be easy to remedy.

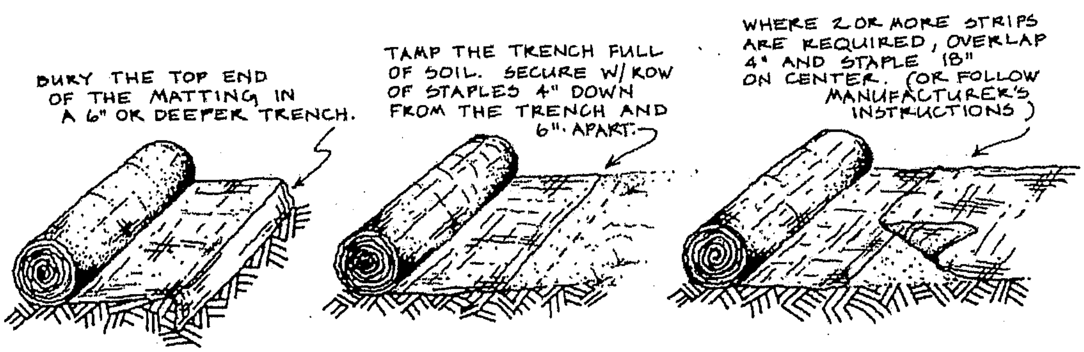
Steps to stabilize a gully include: 1) stopping the gully headcut, so it will not continue to move uphill, and 2) controlling the gully downcut so it will not continue to deepen and widen. Options for ***gully repair*** include one or more of the following: ***fence*** livestock out, install a ***grassed waterway*** or ***lined waterway***, line the headcut with rock to keep it from moving upslope, install rock ***check dams*** to stop downcutting, grade side slopes and ***seed*** and ***mulch*** the area. ***Erosion control blankets***, and straw wattles may also be needed. Avoid using ***erosion control blankets*** with plastic netting as birds and other small animals can become trapped in the mesh.



A gully headcut needs stabilization to keep it from moving upslope. Measures are also needed to control deepening and widening of the gully. Horses should be restricted from gullies as trampling can exacerbate erosion problems or damage repairs.

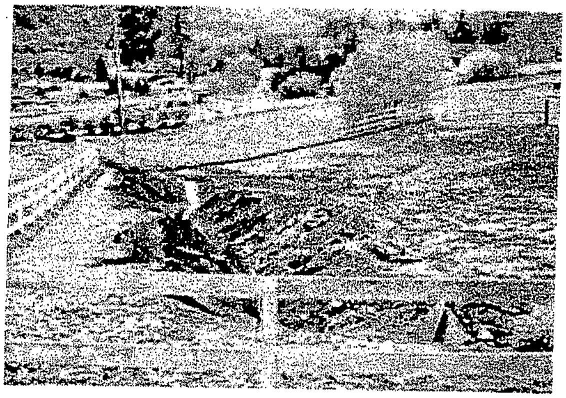
Erosion Control Blankets are effective tools for the prevention of erosion. Erosion control blankets are made from bio-degradable substances such as straw, coconut, or wood fiber, bonded in place with a variety of netting and stitch patterns. Erosion control blankets are placed onto prepared, seeded, soils to prevent washing away of the seed and erosion of the prepared seed bed. After the vegetation grows the erosion control blanket degrades over time until only the vegetation is left in place. The vegetation, once established, provides permanent erosion control. Erosion control blankets are available in a variety of sizes and grades. For photos and installation recommendations, search "erosion control blanket" on an internet search site for various vendors.

Straw wattles are man-made cylinders of compressed, weed-free straw (wheat or rice), 8 to 12 inches in diameter and 20 to 25 feet long. They are encased in jute, nylon or other photodegradable materials, and have an average weight of 35 pounds. They are installed in a shallow trench forming a continuous barrier along the contour (across the slope) to intercept water running down a slope. Straw wattles are used to increase infiltration, reduce erosion, and help retain eroded soil on the slope. Straw wattles should be effective for a period of one to two years, providing short-term protection on slopes where permanent vegetation will be established to provide long-term erosion control. Search "straw wattles" on an internet search site for various vendors.

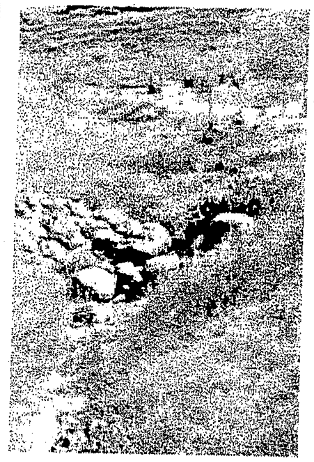


***Erosion control blankets** must be carefully installed to be effective. Make sure the upper end is securely tucked into a small trench. Blankets range from simple jute netting that works best if straw is laid underneath, to heavy duty coconut fiber. Avoid using blankets with plastic netting as birds and small animals can become trapped in the mesh.*

You will likely need technical assistance before attempting to repair a gully. *Groundwork: A Handbook for Erosion Control in Northern California* contains hands-on, practical advice. Contact the Marin County Resource Conservation District at 415-663-1170 to obtain or review a copy.



It is easier to stabilize a small or beginning gully than to repair a large gully system. Where is the runoff coming from? Can it be diverted? Should it go into an underground pipe? Or perhaps careful placement of rock and proper use of erosion control fabrics will make a successful project. Site specific recommendations are needed for gullies.



Rock ***check dams*** *are a common gully repair.* ***Gully repair*** *is site-specific, so obtain technical assistance. Be sure to acquire any permits from the county, California Department of Fish and Game, Regional Water Quality Control Board, and the US Army Corps of Engineers. Continue to monitor and maintain your projects after installation.*

Streambank Stabilization[10]

Evaluate and determine the cause of the problem. Streambank erosion may be caused in three ways or by a combination of the following processes:

Surface flow. Water flowing over the top of the ground usually causes steep, vertical bank erosion. Common sources include ***culverts***, driveways, ***ditches***, or drainage from roofs. Addressing the cause, either by redirecting or slowing the flow and dissipating its energy, will go a long way toward solving the problem.
Ground water. Water flowing a few inches to a few feet below the ground frequently surfaces (or "daylights") on a streambank before reaching the creek channel. This makes streambanks vulnerable to erosion. Although ground water flow can cause or exacerbate erosion, it can also be an asset if you plan to control erosion using vegetative methods. Check to make sure you are not indirectly contributing excess subsurface flow through irrigation.
Stream dynamics. Natural changes—such as big storm events or human activities—can cause the stream channel to adjust. For example, when areas are paved and vegetation is removed to construct buildings and roads, less water soaks into the soil and run-off is increased. This increases storm flows and contributes to flooding problems. Removing vegetation along a creek can reduce streambank stability. This can lead to streambank failure, particularly during major storm events.

Once you have determined the cause of the streambank erosion, you can plan, install, monitor and maintain your repair.

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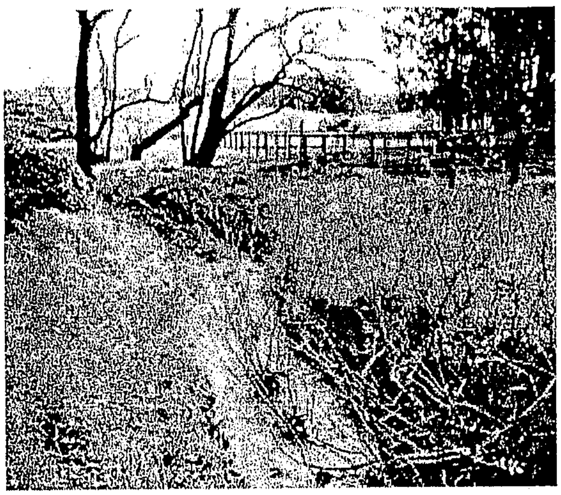
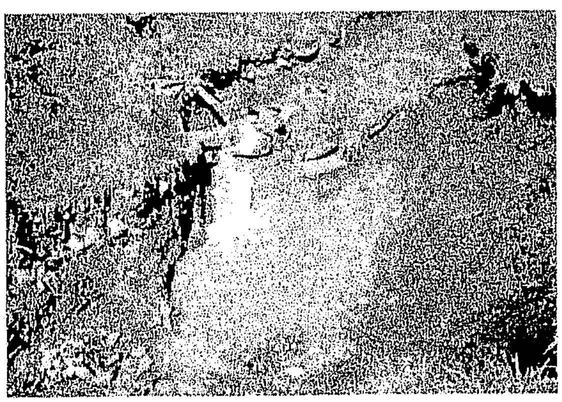
[10] This information was drawn from the Marin County Stormwater Pollution Prevention Program brochure, *Repairing Streambank Erosion*. 1997.

Determine if the site needs repair

Not all erosion is bad. Streams need to be able to adjust to events in the watershed by changing their shape. Undercut banks and fallen trees provide important habitat for aquatic life. Erosion should be controlled if it threatens a structure, road, utility pole, other property, or prime riparian habitat; is extremely active; or is caused by a human factors (such as a road).



Plant grasses and shrubs (preferably natives) on streambanks to reduce erosion. Streambanks with sparse cover are a common source of erosion. Eroding areas should be repaired if they threaten a structure, road, utility pole, other property, or prime riparian habitat; is extremely active; or is caused by a human-made change, such as a road.



When undertaking a **streambank repair** *project, take photos and make sketches of the site, seek professional assistance for major or complex repairs, incorporate native plants into projects, and be sure to obtain the proper permits. Monitoring and maintenance is critical during the first few years after installation.*

Document the site

If you repair the erosion site yourself, you will need information for calculating materials and getting permits. If an engineer or agency is helping you, this information will save them time and you money. Take photographs (and include a reference object such as a fence line or tree), sketch the site including measurements and any biological information you have, and note any observations you have of the situation.

Determine if this should be a cooperative project

If many of your neighbors have similar streambank erosion, consider working together. Benefits include sharing the permit and planning costs, building repairs that complement and even enhance each other, and, if done in conjunction with a local agency or group, may be eligible for private or government grant programs.

Determine if you need professional help

Consider professional help when the repair is major, and/or an ineffective repair could result in significant damage to a structure, road, or other valuable property; working space is limited; and county regulations and common sense dictate professional design. Civil engineers, biologists, and other restoration specialists can help design repairs. Ask the individual or firm if they have done this type of work before. When, where, and for whom? How do they plan to repair the site? How will they access the site? What type of equipment will be used? How long will the work take? What is the estimated cost of designing and constructing the repair? Can they assist you in obtaining permits? Visit project sites that they have repaired, and discuss the project with the landowner.

Consider a range of design options

Find out what has worked in your area. Be sure **not** to constrict the channel. Keep fish and wildlife habitat in mind. (For stream crossing information, see Section 2.8 on Roads.) If salmon or steelhead passage is expected, follow ***culvert*** design guidelines by the California Department of Fish & Game and the National Marine Fisheries Service. Also, your local Resource Conservation District, or the Natural Resource Conservation Service are good sources of information. See Section 5.1 of the Resources Directory for contact information.

Incorporate native plants into the repair. The extensive root systems of some native plants can help with streambank stability. Even rock riprap can be interspersed with willows or other trees to enhance habitat. Willow wattle walls, brush mattresses, and other techniques described in *Groundwork: A Handbook for Erosion Control in Northern California* can stabilize streambanks completely with *live* materials, which is preferable.

Obtain necessary permits

Acquire permits before construction. Most stream repair work requires a Streambed Alteration Agreement from the California Department of Fish and Game. Most counties require grading or building permits for work in stream channels. Permits will likely be required from the US Army Corps of Engineers and the Regional Water Quality Control Board. See Sections 5.4 and 5.5 of the Resources Directory for permit information.

Install your project properly

Streams are a demanding and often unforgiving work place. Never underestimate the force of moving water. Pay attention to small details that will make the difference between a successful repair and a headache. Follow all permit requirements. Most work will need to be completed by October 15. See Section 2.8 for Stream Crossing references.

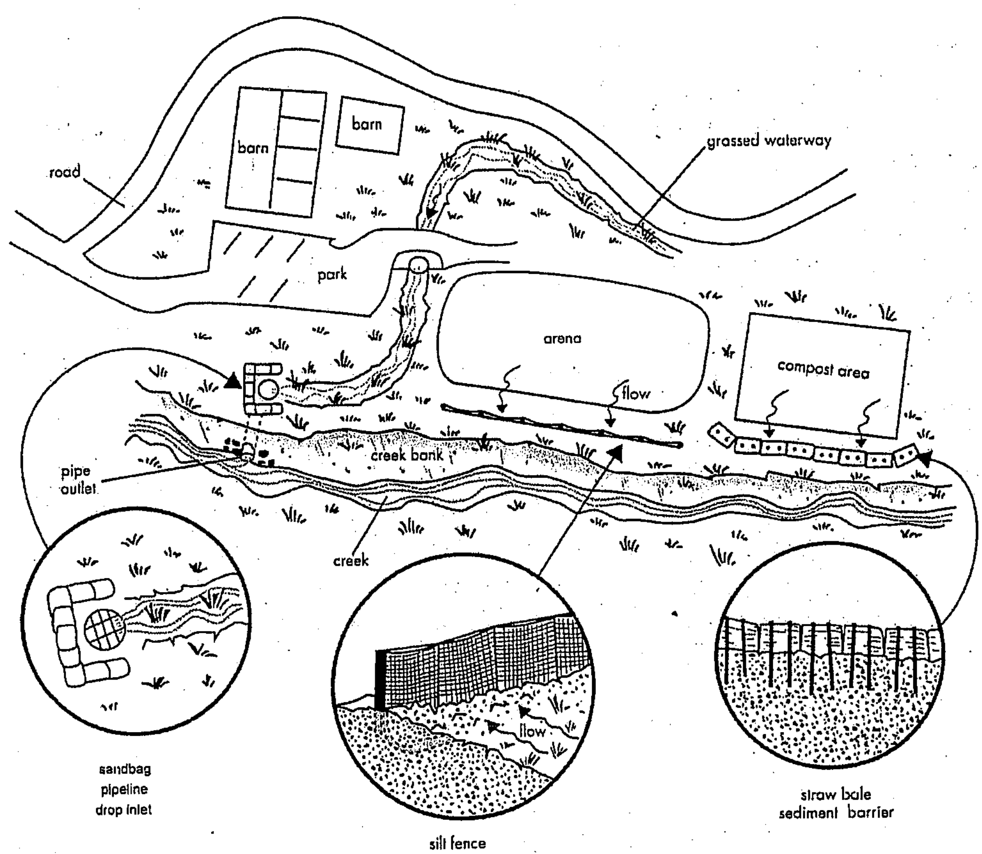
Monitor and care for your repair

Many failures are caused by small problems that could have been avoided if caught early. Check your repair before the winter rainy season, and during and after each storm. Establish a location where you can take "before" and "after" photos.

Emergency Erosion Control Measures

The emergency erosion control measures described in this section are temporary actions that property owners can install themselves. These measures are low-cost, and often do not require special expertise to design or install. However, they require constant maintenance and generally last only one season. They are designed to retain or divert stormwater runoff, reduce flood damage, stabilize overwhelmed drainage structures, or stop erosion. It is best to put in erosion control measures before the rainy season, although these measures can be installed anytime you notice a problem or potential problem.

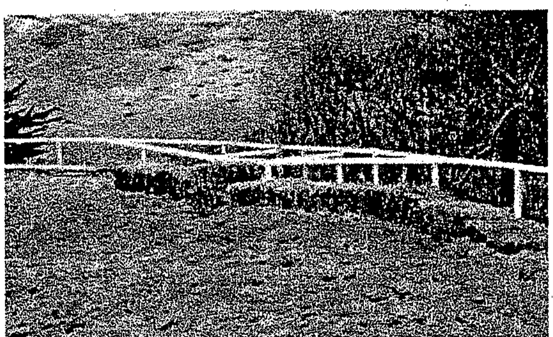
All of these measures should be considered temporary until access, weather, time, or money allows more permanent solutions to be implemented. For example, straw bales usually rot after one year. Proper companion measures may also be necessary if the temporary fix fails (which often happens), and then creates a bigger problem. It is important to develop long-term solutions for erosion sites.



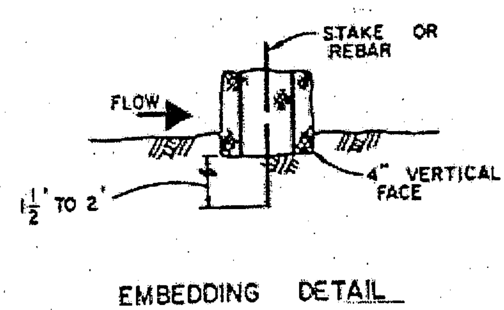
EMERGENCY MEASURES – Use emergency erosion control measures to divert stormwater runoff, reduce flood damage, stabilize overwhelmed drainage structures, or stop erosion. Temporary measures to consider are **sandbag pipeline drop inlets, silt fences,** *and* **straw bale sediment barriers.** *All require proper installation and maintenance, and should be replaced with permanent measures as soon as possible.*

Straw bale sediment barriers

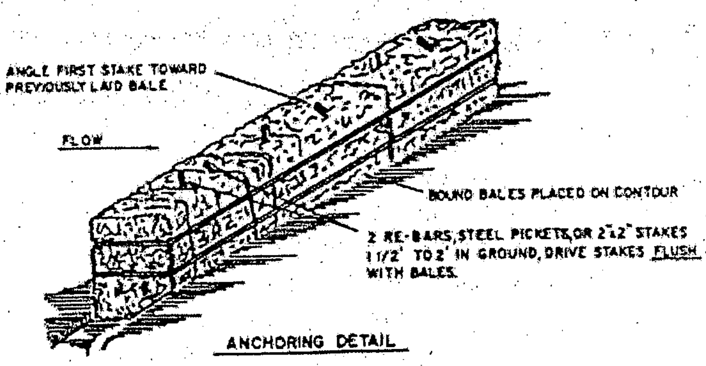
These are used to retain sediment while allowing water to infiltrate through.[11] Install and anchor straw bales as described (in ***straw bale waterbar***). Care should be taken so runoff does not backup behind the barrier and flow around the ends where the concentrated water can cause erosion.



*A **straw bale sediment barrier** retains sediment while allowing water to pass through. Bales need to be anchored with stakes or rebar. Be sure that water cannot flow around the barrier and cause downslope erosion.*



*When using straw bales as a **waterbar** or sediment barrier, place bales in a trench at least 4 inches deep. Drive two metal fence posts or rebar for stakes through each bale and at least 1 to ound.*



Abut the ends of straw bales tightly against one another. Angle the first stake toward a previously laid bale to force the bales together. Cram loose straw between bales to help seal joints. If using two rows stacked (one atop each other), overlap the joints by at least 15 inches or more.

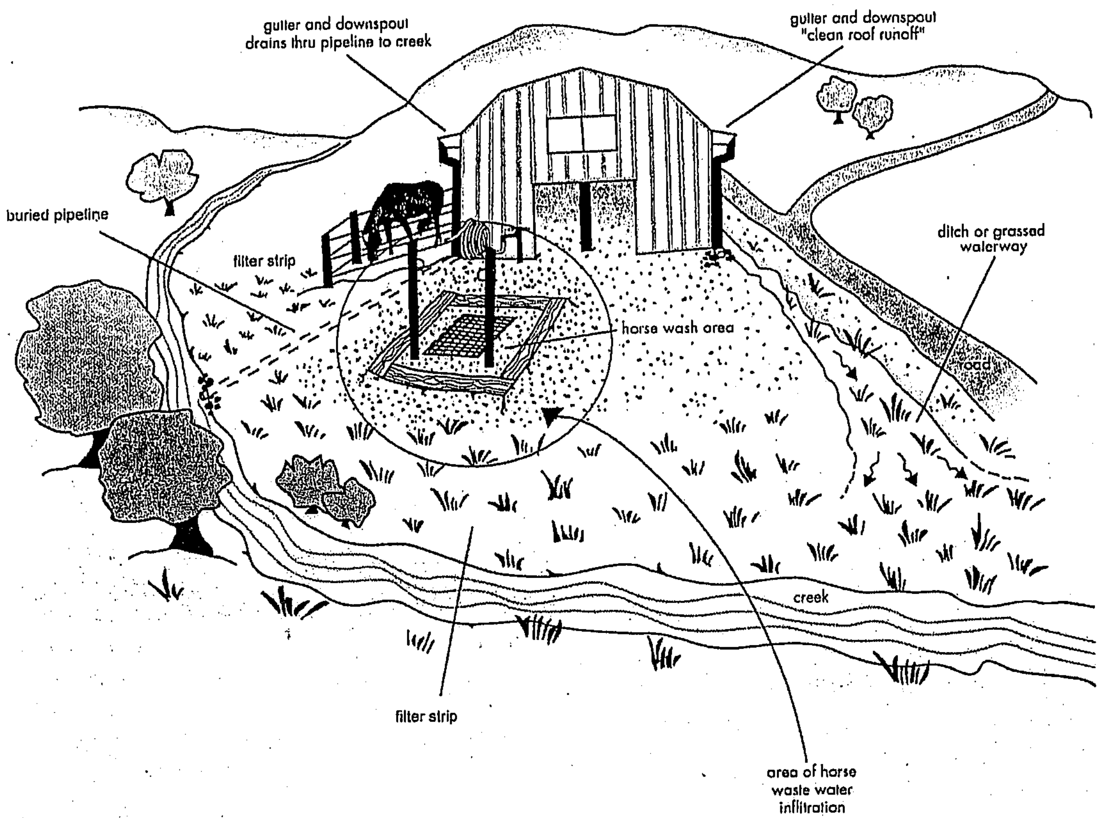
Straw bale check dam

These can be used to stabilize eroding gullies and ditches. ***Straw bale check dams*** in gullies and ditches are prone to failure and can cause worse erosion problems unless properly installed. Have them installed by an experienced person, or gather further information from NRCS.

Table 3. Straw bale check dam – design limits

Slope	Maximum Drainage Area	Maximum Slope Length Between Check Dams
0 – 15%	1 acre	200 feet
15 – 20%	½ acre	100 feet
>20%	Not Recommended	—

[11] Emergency barrier structures can typically contain the stormwater runoff from one acre and 100 feet of slope length for slopes up to 15 percent; or one-half acre and 50 feet of slope length for slopes greater than 15 percent.



STORMWATER MANAGEMENT – Managing runoff from roofs will help keep "clean" water clean. **Gutters** *and* **downspouts** *can direct clean stormwater away from bare or manured areas.* **Diversions** *or* **berms** *can direct water away from buildings. Buried* **pipelines** *can convey clean water to a creek. Polluted runoff from a* **horse wash area** *should flow into a* **waste pond** *or through a* **filter strip** *before it reaches a creek.*

Gutters

Size ***gutters*** to handle the volume of rainfall calculated for the roof size. ***Gutters*** should have sufficient support to withstand anticipated water. You may need to seek professional help for gutter and downspout sizing. ***Gutters*** may not be required if roof runoff does not drain into ***manure storage*** or animal confinement areas. In such cases, gravel ***splash pads***, vegetation, or ***subsurface drains*** along building foundations may be sufficient to control runoff and prevent erosion.

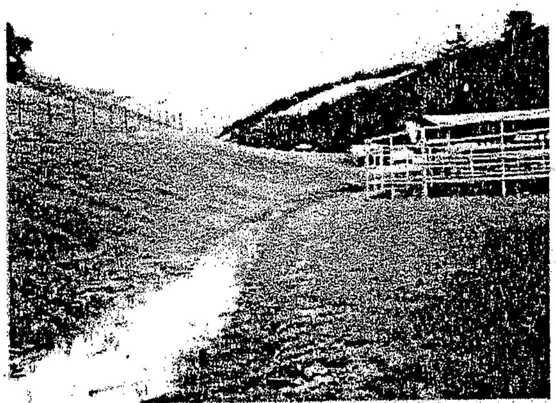
Downspouts

Fasten ***downspouts*** securely at the top and bottom, with intermediate supports if required. Protect downspouts from damage by animals and equipment.

Splash pads

When downspouts empty onto the ground, surface elbows should direct water away from the building and empty onto ***splash pads*** or other ***energy dissipaters*** to prevent erosion.

Conveyance structures include ***grassed waterways, lined waterways, drop inlets,*** and ***underground pipelines***. These are described below.



Grassed waterways *convey concentrated runoff along gradual slopes. They require professional calculations of water volume and velocity. Grass must be established before the waterway is ready to carry winter runoff. Upkeep is needed to maintain capacity, grass cover, and the outlet (or end point).*

An **erosion control blanket** *can help stabilize the channel until the grass is fully established. It can also be used as an immediate repair for grassed areas that are damaged by horses, machinery, or erosion.*

Grassed waterway

A grassed water is a wide, shallow, flat-bottomed channel or ditch, with gentle side slopes that conveys concentrated runoff along gradual slopes without causing erosion or flooding. ***Grassed waterways*** generally work well with water velocities of 5 feet per second (fps). For channels with poor grass cover and little maintenance, the velocity should not exceed 3 - 5 fps. Water velocities over 5 cfs need a ***lined waterway***. A professional should calculate the volume and velocity for site-specific conditions. During construction, stockpile topsoil and re-spread where necessary to provide a seedbed for the grass. Excess earth should be spread where it will not interfere with flow into the waterway.

Sufficient vegetation must be established in the waterway before it carries runoff from heavy winter rains. Seedbed preparation, time of ***seeding***, seeding mixture and rate, and fertilizer requirements are site-specific. Special protection such as a biodegradable ***erosion control blanket*** may be required to help stabilize the channel until vegetation is fully established. (Use heavy duty blankets in situations with flowing water. Avoid using blankets with plastic netting so that birds and small animals do not become trapped.) Supplemental irrigation will help establish grass sooner.

Maintenance is required to ensure waterway capacity, vegetative cover, and the outlet. Vegetation damaged by horses, machinery, or erosion must be repaired promptly. Give special attention to outlets and points where concentrated flow enters the ***grassed waterway***. Maintenance tasks should include checking for sediment accumulation and erosion, removing debris, and making necessary repairs.

Rock **energy dissipaters** *reduce the velocity and energy of concentrated storm flows. They are used at the outlets of pipelines, culverts, or other conveyance structures. Calculate the size of rock needed and place rock carefully. Make sure dissipaters are in place before the rainy season.*

Discharge Area

"Clean" water can be discharged into another conveyance structure, a seasonal drainage, creek, ***constructed wetland***, or directed to a ***filter strip*** or pasture. Be sure to use ***energy dissipaters*** to control potential erosion.

Energy dissipaters

These are placed at channel outlets to reduce the velocity and energy of concentrated storm flows, prevent scour, and minimize downstream erosion. They may be needed at the outlets of ***underground pipelines***, ***culverts***, or where ***lined waterways*** discharge to unlined conveyances, e.g., a rock channel discharges into a ***grassed waterway***.

Rock is a common ***energy dissipater***. The type and size of an ***energy dissipater*** depends on local factors. Rock should be carefully and tightly placed over a filter fabric. Loose rock can wash away during high flows. Rock should be angular and large enough to withstand heavy flows.

4.3 Measures to Manage "Polluted" Water

"Polluted" water must be managed so that it does not reach creeks or leach into ground water. Conservation measures that can help utilize nutrients, or store waste water until it can be utilized are:

- Filter Strip
- Riparian Buffer
- Willow sprigging
- Constructed Wetland
- Waste Pond

Filter Strip

A ***filter strip*** is an area of grass designed specifically to trap sediment, horse manure and other pollutants before they enter surface water, such as a creek or a pond. Actively growing grass will use the nutrients in runoff that comes from a manured area. ***Filter strip***s can be developed downslope of high-use areas to trap sediment and manure that washes off of these areas.

A **riparian buffer** *has a mix of trees, shrubs and grasses and is located adjacent to and upslope from creeks. The riparian buffer reduces excess amounts of sediment, organic material, nutrients, pesticides and other pollutants in surface runoff and reduces excess nutrients and other chemicals in shallow ground water flow. The buffer also creates riparian habitat and corridors for wildlife, as well as shade to lower water temperature to improve habitat for fish and other aquatic organisms.*

- Grasses, shrubs, and trees to utilize excess nutrients.
- Trees and shrubs help stabilize streambanks and create a shade canopy to cool water for aquatic life, reduce floodwater velocity and erosive power, and trap debris during floods. A diverse mix of grasses, shrubs, and trees that provide wildlife habitat for a wide range of mammals, reptiles, amphibians, birds, and invertebrates species. Connected stretches of buffers become wildlife corridors.
- A visual screen that also acts as a windbreak and helps capture dust.

Many riparian areas in the San Francisco Bay Area have been cleared of vegetation, or creek channels have been lined with concrete. This section outlines steps to enhance your existing ***riparian buffer*** or to restore a degraded buffer.

1. **Evaluate the existing riparian area to identify any repairs** (such as an eroding streambank or bare areas that need replanting) and management constraints (such as the need for livestock control ***fencing***, ***stream crossing***, and/or an alternative water source).
2. **Determine the minimum buffer width.** The width may vary a great deal depending on site conditions, vegetation, soil type, and landowner objectives. Generally, the wider the buffer, the greater the overall level of benefit. Although a narrow buffer provides more benefits than no buffer at all, wildlife habitat benefits will be reduced. Narrow buffers require careful consideration of slope and selection of vegetation to insure effectiveness. Greater width may be required for shrub and tree vegetation, on steeper slopes, or where sediment loads are particularly high. Some counties require setbacks from creeks.
3. **Consider slope when determining infiltration benefits.** Buffers with a gentle slope and even surface will allow water to flow slowly through the buffer in a thin layer as "sheet flow." These buffers will have more infiltration than buffers in steeper areas where water flow is concentrated or even flows in tiny channels (rills). Riparian areas should not be graded to change the slope. Grading within riparian areas can require a permit from the California Department of Fish and Game and other agencies.

take place in November or early December when the plants are dormant, and container grown trees and shrubs should be planted between November and February. Planting should occur after the first storms and before soil is saturated during the winter.

- Irrigate and ***mulch*** to enhance tree and shrub survival. A temporary drip irrigation system (for the critical first three years) will help ensure plant success. Thoroughly composted manure makes good mulch.
- Incorporate existing trees and perennial vegetation into the buffer. Be sure not to plant inside the drip line of mature trees.
- Consider removing non-native exotic species that can crowd out existing and new native vegetation. Invasive non-native species to watch include giant reed (*Arundo donax*); periwinkle (*Vinca major*); Scotch, French, and Spanish broom; Himalayan blackberry; tree-of-heaven; bamboo; pampas grass; German and English ivy; acacia; and ice plant.
- Obtain required permits for grading and certain repairs. See Sections 5.4 and 5.5 of the Resources Directory for more information.

Maintenance Tips

- Control weeds by mowing and ***mulching*** until trees and shrubs are large enough to compete on their own. This is typically required for the first two to three years after planting.
- Protect tree and shrub plantings from wildlife, such as deer, rabbits and mice, with short collars of plastic protective tubing, "gopher baskets," wire cages, or similar forms of protection.
- Check the irrigation system periodically to make sure it is functioning properly.
- Control livestock ***grazing*** of the buffer area. Once the vegetation is established, you may want to initiate a limited ***grazing*** regime in the buffer. The best time to graze is in the spring when the rains have subsided and the ground is firm.
- Replant areas where plants do not "take."
- Periodically mow grasses to help maintain vigorous plant growth and promote additional nutrient uptake.
- Do not apply fertilizers or manure, and limit pesticides and herbicides in the buffer zone.

6. **Develop alternative water sources for horses.** If horses are excluded from the creek, they will need another source of drinking water. Horses consume approximately 8-12 gallons of water per day. Alternative water options include ***spring development*** with buried ***pipelines,*** and ***troughs,*** or extending existing water systems. You may also need a ***storage tank.***

Constructed Wetland

Constructed wetlands "treat" waste from confined animal operations, surface runoff, and manure storage area leachate. Approximately two feet deep, these wetlands have water-loving plants that are capable of removing large amounts of nutrients from the water. Retention time and release rate will depend upon the size of the wetland and period needed to extract the nutrients.

Constructed wetlands must be professionally designed to handle the volume of waste or stormwater runoff, particularly the "first flush" that contains a high concentration of pollutants. Careful construction is required to ensure that the ground is properly prepared and permits may be needed.

Waste Pond

Horse manure is best handled as a solid.[14] If a ***waste pond*** is required by local regulation, then this overview of ***waste ponds*** can help in the planning stages. A waste storage pond collects runoff of polluted water and gives the manager control over the scheduling and timing of waste distribution over the land. Adequate storage gives flexibility to schedule ***manure application*** when spreading operations do not interfere with other necessary tasks, when weather and field conditions are suitable, and when pasture or crops can best use the nutrients in the waste.

***Waste ponds** can be used to store polluted runoff. Waste from the pond is typically irrigated or spread on land. Pond maintenance will ensure proper functioning. A professional can assist with pond sizing. Trees and shrubs have been planted around this waste pond to screen it from the road.*

Pond location is important. It should be convenient to the operation with suitable soils that when properly compacted, will be impervious to seepage into the ground water. Various materials are available for ***pond lining***, such as compacted clay or geotextile fabric.

Utilization of the contents in the ***waste pond*** is commonly done by land application. This includes selecting the fields, scheduling ***manure application,*** designing the distribution system, and selecting necessary equipment. It also includes determining application rates and volumes, value of recycled products, and installation and management costs associated with the utilization process.

Pond sizing needs to done by a professional to take into consideration the required storage volume, storage period, and the type, estimated size, location, and installation cost of the pond. Permits are usually required for ***waste pond*** construction; contact local and state officials (see Sections 5.4 and 5.5 of the Resources Directory). Maintenance and protection of the pond are needed to ensure its longevity.

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14 *Feedlots Preliminary Data Summary*. December 31, 1998. EPA. Available at <www.epa.gov/ostwater/guide/feedlots/execsumm.pdf>

5.1 Technical Assistance

Technical assistance is available from the following organizations. Advice is offered as a free service from the RCDs, NRCS, and UC Cooperative Extension.

Resource Conservation Districts

Resource Conservation Districts (RCDs) have been helping landowners to apply conservation measures on Bay Area farms and ranches since the 1930s and can help equine facility landowners in a similar way. RCDs provide information, technical assistance, and implementation of natural resource conservation projects. RCDs work in partnership with the USDA Natural Resources Conservation Service. They are non-regulatory special districts governed by a local volunteer board of directors.

Check with your local RCD to learn about specific services provided in your area. RCDs offer workshops and courses for landowners, as well as one-on-one meetings. In the San Francisco Bay Area, nine RCDs are also part of the Council of Bay Area RCDs and work together on shared natural resource issues. The following RCDs participated in the Equine Facilities Assistance Program. To find other RCDs, visit http://www.carcd.org/

Marin County RCD
P.O. Box 1146
Point Reyes Station, CA 94956
Phone: (415) 663-1170
Fax: (415) 663-0421
http://www.sonomamarinrcds.org/

Southern Sonoma County RCD
1301 Redwood Way, Suite 170
Petaluma, CA 94954
Phone: (707) 794-1242, ext 3
Fax: (707) 794-7902
http://www.sonomamarinrcds.org/

Contra Costa RCD
5552 Clayton Road
Concord, CA 94521
Phone: (925) 672-6522
Fax: (925) 672-8064

Alameda County RCD
1996 Holmes Street
Livermore, CA 94550
Phone: (925) 371-0154
Fax: (925) 371-0155
http://www.baysavers.org/

San Mateo County RCD
625 Miramontes Street, Suite 206
Half Moon Bay, CA 94019
Phone: (650) 726-4660
Fax: (650) 726-0494

University of California Cooperative Extension

The University of California Cooperative Extension (UCCE) is part of a statewide system of specialists and county-based farm advisors who work to bring the University's research-based information to Californians. UCCE's many teaching tools include workshops, demonstrations, field days, meetings, conferences, video programs, newsletters, and manuals. Several publications relate directly to horse keeping and are available from University of California Agriculture and Natural Resources Communication Services, (800) 994-8849. Contact your local office for information about workshops and assistance. Listed below are counties participating in the Equine Facilities Assistance Program. To find a local office in other areas, visit http://vcanr.org/ce.cfm

Marin County Cooperative Extension
1682 Novato Boulevard, Suite 150B
Novato, CA 94947
Phone: (415) 499-4204
Fax: (415) 499-4209
Email: cemarin@ucdavis.edu
http://cemarin.ucdavis.edu

Alameda County Cooperative Extension
1131 Harbor Bay Parkway, Suite 131
Alameda, CA 94502
Phone: (510) 567-6812
Fax: (510) 567-6813
Email: cealameda@ucdavis.edu
http://cealameda.ucdavis.edu

Sonoma County Cooperative Extension
133 Aviation Blvd, Suite 109
Santa Rosa, CA 95403
Phone: (707) 565-2621
Fax: (707) 565-2623
Email: cesonoma@ucdavis.edu
http://cesonoma.ucdavis.edu/

San Mateo County Cooperative Extension
625 Miramontes Street, Suite 200
Half Moon Bay, CA 94019
Phone: (650) 726-9059
Email: cesanmateo@ucdavis.edu
http://cesanmateo.ucdavis.edu/

Contra Costa County Cooperative Extension
75 Santa Barbara Road, 2nd Floor
Pleasant Hill, CA 94523-4488
Phone: (925) 646-6540
Email: cecontracosta@ucdavis.edu
http://cecontracosta.ucdavis.edu/

5.2 Seeding Recommendations for Horse Facilities in the San Francisco Bay Area

Conservation Measures

You have evaluated your horse facility and come to the conclusion that excessive soil erosion is coming from a **pasture** or high-use area (**critical area**), such as paddocks, turn-out areas, roads, or a parking lot. Perhaps you need to convey water around a barn through a **grassed waterway**. Or maybe rainwater flows through a manured area, and you want to use a **filter strip** to reduce pollutants in the polluted water. The vegetation planted for these conservation practices will reduce soil erosion, increase infiltration, percolation, and ground water recharge.

These seeding recommendation mixtures are for general dryland (non-irrigated) purposes. Specific recommendations will vary based on site evaluation that would take into account rainfall, length of growing season, soils, etc. Since the San Francisco Bay Area has many micro-climates, your local USDA Natural Resources Conservation Service, UC Cooperative Extension Farm Advisor, or local seed supplier can help with specific suggestions. Different grass species are suitable for different purposes. Perennial grasses are deeper rooted and certain species are sod-forming (rather than bunchgrasses), which protects the soil from excessive erosion. Annual grasses provide a quick cover and reseed themselves each year.

Filter Strip

A grass filter strip is designed to treat runoff situated between high-use areas and environmentally sensitive areas, such as a creek, seasonal drainage or pond. The filter strip will reduce sediment, sediment adsorbed pollutant loading in runoff, and dissolved contaminant loading in runoff. Also, a filter strip will restore, create or enhance habitat for wildlife and beneficial insects.

A filter strip must be designed so overland flow (runoff) entering it must be primarily sheet flow. Concentrated flow must be dispersed into sheet flow, before entering the filter strip. The minimum width is 20 feet to reduce sediment. Additionally, to reduce dissolved pollutants in runoff, the minimum width is 30 feet. Local site criteria may require filter strip widths of up to 100 feet. *(Reference: USDA NRCS Field Office Technical Guide, Filter Strip.)*

Grassed Waterway

Imagine a gentle flat-bottomed ditch, fully clothed in grass, with gentle side slopes. This simple design is a grassed waterway—a designed channel that is mechanically shaped or graded with a bulldozer, and seeded with grass for the stable conveyance of runoff. The grassed waterway will convey runoff without causing erosion or flooding. As with all engineered conveyances, the grassed waterway must be designed to withstand the velocity of water anticipated. The site must be assessed to see if the waterway needs to be lined for higher water velocities with erosion control matting, rock or concrete. Grassed waterways

Plants should have the ability to provide adequate ground cover, canopy cover and root mass for erosion protection. High seeding rates are needed to insure adequate vegetative cover because these sites have been severely eroded or disturbed, have low fertility, and few resident seeds.

Pasture

It is time to reseed a pasture when horses excessively use one area of pasture, or selectively graze desirable plants and leave the less desired plants. Nearly all pastures have areas where horses concentrate such as around water and feed areas. Under continuous use, these are always overgrazed.

Installation Criteria

Timing: Plant before the rainy season, October 15th of the year.

Seeding rate: Seeding rates are for 100% Pure Live Seed (PLS), and are broadcast (by hand or broadcast seeder) rates. Seed bag "tags" tell the percent purity for PLS and germination rate. If seed bag tag states less than 100% PLS, increase the amount of seed in proportion to the percentage needed (germination x purity). Time since the date of seed test on the tag should not exceed 9 months.

Seedbed preparation: The area to be planted must be weed free and have a firm seedbed which has been previously roughened by disking, harrowing, or otherwise worked to a depth of 2 to 4 inches, except when planting no-till. No implement should be used that would create an excessive amount of downward movement of soil on sloping areas. Weeds and other debris that would interfere with seeding or maintenance should be removed.

Legume Inoculation: All legumes (clovers) should be "inoculated" before planting with a pure culture of nitrogen-fixing bacteria and prepared specifically for that plant species. This is done immediately prior to planting. The seeding rate does not include the weight of inoculant and seed coating.

Why: All legumes, including clover, have the ability (in cooperation with legume bacteria) to draw nitrogen from the air and store it in the small nodules that form on the roots. Studies have shown an increase in forage production and nitrogen fixation when seed is properly inoculated. On poorer soils, the clover seed may be a complete failure if not properly inoculated. The bacteria are helpful to young plants as roots begin to develop, increasing their chance to grow successfully.

How: Put seed on canvas, in tub or other container. Mix the inoculating culture with the seed and stir until the seed is well covered. Mix with grass seed selected. Prevent from drying out by sun or wind. Plant immediately.

Mulch: A straw mulch cover should be uniformly distributed over the seeded area within 48 hours following the seeding. Straw mulch should be applied at a rate of

5.3 Winterization Checklist

Preparing for the rainy season while the weather is still nice can save a lot of time in the long run. Take time to inspect your facility before the rains start. Write and post a "winterization" checklist in your barn to help set priorities, organize work, and take action. It is important to check many of these areas throughout the winter, particularly during and after major storms. A sample list below covers management strategies discussed in this guide.

Buildings

- ❑ Inspect, repair, and remove debris from ***gutters*** and ***downspouts***. Make sure ***gutters***, ***downspouts*** and pipelines are connected.
- ❑ Clear debris from ***diversions***, ***pipe inlets***, grates, ***culverts***, and ***trash racks***.
- ❑ Make sure ***energy dissipaters*** (such as rock) are placed at outlets.

High-Use Areas

- ❑ Replenish footing in high-use areas.
- ❑ Make sure kickboards are in place to help keep footing material in place.
- ❑ Clear debris from ***diversions*** and other drainage structures.

Manure Management

- ❑ Scrupulously clean out ***paddocks***.
- ❑ Remove all horse waste from ***manure storage areas*** by the fall.
- ❑ Cover ***manure storage areas*** and provide runoff controls. Make sure "clean" water is diverted from manured areas.
- ❑ Apply manure to pastures in early fall, and in spring when grasses are actively growing. Do not spread manure near creeks.

Pasture Management and Filter Strips

- ❑ Re-seed pastures and grass ***filter strips*** by October 15, if needed. Remove weeds regularly.
- ❑ Mow, maintain and/or reseed grass ***filter strips*** downslope of high-use areas.
- ❑ In the fall, check ***Residual Dry Matter*** (RDM) levels in pastures. (See Section 5.8 of the Resources Directory.)

Roads and Trails

- ❑ Clean out ***ditches***, ***culvert*** inlets, and ***trash racks***.
- ❑ Make sure ***waterbars*** and ***energy dissipaters*** are in place and functional.
- ❑ Check roads and trails after storms for any emergency repairs.
- ❑ Close roads and trails not essential for winter traffic. ***Seed*** and ***mulch*** seldom used roads or trails by October 15.

Permit Overview

Federal, state, and local water quality or other environmental laws may apply to your project to develop, expand, or renovate a horse facility, or even to control streambank erosion. If you are working in or near streams, you likely need a permit. Consultants can help you navigate the permit maze. Here is a list of agencies and their regulatory requirements that may be applicable to horse keeping facilities. Also see Section 5.5 for threatened and endangered species.

US Army Corps of Engineers

The Corps of Engineers has regulatory authority under Section 404 of the federal Clean Water Act and Section 10 of the Rivers and Harbors Act. A 404 permit is required for work involving the placement of fill in any "waters of the United States" which includes wetlands as well as perennial, seasonal and ephemeral creeks. A Section 10 permit is required for projects affecting "navigable waters." Corps jurisdiction extends up to the ordinary high water line for non-tidal waters and up the high tide line (for dredge and fill) or mean high water line (for work or structures) in tidal waters. Most landowner projects should fall under the Section 404 Nationwide Permit Program. Pre- or post-project notification may be required. There is no filing fee and permit processing can take up to one year.

- Contact the San Francisco District Regulatory Branch at (415) 977-8462 or http://www.spn.usace.army.mil/regulatory/

California Department of Fish and Game

The California Department of Fish and Game (DFG) requires a Stream Alteration Agreement for projects that occur in or near creeks or streambanks. This permit is necessary for any work that will divert or obstruct the natural flow of water, change the bed, channel, or bank of any stream, or use any material from a streambed. DFG will review the application for compliance with the California Environmental Quality Act (CEQA). The application is $132 and turn-around time can be several months or longer. For permit information or assistance from DFG, contact a regional office or http://www.dfg.ca.gov/1600

- Central Coast Regional office is located in Yountville: (707) 944-5500
- Marine Regional Office is located in Monterey: (831) 649-2870
- A Marine Region field office is located in Menlo Park: (650) 688-6340

Regional Water Quality Control Board

For activities requiring a permit from the US Army Corps of Engineers, the RWQCB must issue a 401 Water Quality certification to ensure that the proposed activity will not violate State water quality standards. A filing fee is required and can be $500 or greater.

- For creeks and tributaries draining into San Francisco Bay, contact:
  San Francisco Bay Regional Water Quality Control Board
  (510) 622-2300 or http://www.swrcb.ca.gov/rwqcb2

County and City Ordinances

Local cities and counties generally have regulations regarding grading, setbacks, zoning, building, horse density, discharge restrictions, stormwater runoff, odors, pests, and nuisances. Contact your city and county governments for more information.

California Environmental Quality Act (CEQA) Review

Landowners, as well as state and local governments must comply with the California Environmental Quality Act. The main purpose of a CEQA review is to identify and prevent significant potential environmental impacts. CEQA requires the preparation of an initial study and then a Negative Declaration or an Environmental Impact Report.

Some agencies, such as the California Department of Fish and Game, will review permit applications for CEQA compliance. For large projects, cities and counties may require a CEQA review. For more information, contact your city or county planning departments or the California Department of Fish and Game.

Permit Tips

These tips can help you with the often complex permit process.

1. Find out if your project is regulated or requires a permit. If you go ahead without the proper permits or without following permit approval conditions, it will very likely cost you time, money, and goodwill.

2. Carefully select and design your site to eliminate or reduce environmental impacts.

3. Consult early with permitting and regulatory agencies so their concerns can be addressed. Your local planning department may be able to give you a good idea of the permitting process.

4. Have written descriptions and site plans available.

5. Learn the rules. Study the regulations of those agencies that must approve your project.

6. Pay attention to details. Follow all the rules. Respond promptly to requests for information. Be on time for meetings. Do not cut corners.

7. Be flexible. While protecting water quality and creeks is a prime responsibility of agencies, they may be willing to consider alternative project designs that still meet your needs.

8. Get everything in writing to help prevent misunderstandings.

9. Plan time for permitting and be patient, as well as persistent.

National Marine Fisheries Service

The National Marine Fisheries Service (NMFS) regulates the recovery of anadromous (ocean-going) species listed under the Endangered Species Act, such as salmon (coho *or silver*, and Chinook *or king*) and steelhead. NMFS is a part of the National Oceanic and Atmospheric Administration (NOAA), and provides expertise in the area of fish passage and fisheries restoration. NMFS identifies issues to protect, conserve and restore habitats vital to self-sustaining populations of salmonids in California. The agency operates under the authority of the Clean Water Act, California water rights, and authorities that influence adequate water for fish, Endangered Species Act, National Environmental Policy Act, and the Fish & Wildlife Coordination Act. For endangered species consultation or assistance to landowners for fisheries restoration efforts, call the National Marine Fisheries Service in Santa Rosa: (707) 575-6050, or visit their website at: http://swr.nmfs.noaa.gov/sro.htm

5.7 Water Quality Monitoring

Testing your surface water will help maintain a healthy environment for horses, fish and aquatic life, and human use. With inexpensive equipment and a little training, horse owners can monitor the quality of water on their property. This section presents an overview of monitoring.[15] For complete information on setting up your own monitoring program and obtaining test kits, contact your local RCD or the Council of Bay Area RCDs for a horse owners monitoring information packet.[16]

Water Quality Variables

The following is a description of the water quality variables and their measurements that are commonly tested by agricultural landowners and regulatory agencies.

Ammonia. Ammonia results from decomposition of manure and other organic debris by microbes, and is toxic to fish and aquatic invertebrates. Total ammonia is composed of two forms: ionized ammonia (NH_4^+), and un-ionized ammonia (NH_3). Of these two forms, the un-ionized NH_3 is far more toxic. The percent of total ammonia in the harmful un-ionized form increases with higher water temperatures and pH values. Un-ionized ammonia can be lethal at concentrations of 0.025 parts per million (ppm.) Higher levels of ammonia are toxic to fish and other organisms. Ammonia is naturally produced by fish and is excreted primarily through their gills. Ammonia excretion is reduced if there are high ammonia levels in surrounding waters, causing high blood ammonia levels in fish. Fish respond to this increase in blood ammonia by reduced feeding that slows metabolic ammonia production. High blood ammonia levels increase a fish's need for oxygen, while at the same time reducing the ability of the fish's blood to transport oxygen. High ammonia levels can damage gills and ultimately kill fish.

Total ammonia can be measured with an electronic ammonia probe or colorimetric kit. Colorimetric kits are inexpensive and relatively accurate. They rely on chemical reactions in which chemicals bind, and then react with ammonia to form a colored product. The intensity of the color then gives a relative indication of the amount of ammonia present.

Conductivity. Conductivity is simply a measure of the capacity of water to transmit an electrical current. Conductivity is useful in detecting pollution from livestock urine due to the high concentration of salts in urine, and the fact that the salts persist much longer than ammonia. High salt concentrations in sur-

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15 This information was drawn from the *Water Quality Variables and Water Testing for Rural Landowners* fact sheets prepared by the Marin Coastal Watershed Enhancement Project. 1995.

16 *Simply the Facts on Animal Waste and Water Monitoring.* Fact sheet series. USDA Natural Resources Conservation Service and AmeriCorps. 1995.

Sediment. Excessive sediment from erosion can fill in gravel beds used by salmon and steelhead for spawning. This can make the beds unsuitable for spawning or smother developing eggs in the gravel. Sediment can also fill in deep pools that remain cool in the summer and provide habitat for young fish. Sediment can be measured by allowing a water sample to stand and measuring the amount of sediment that settles. Imhoff sediment cones or tall glass jars can be used for this purpose.

Where and When to Test

Testing at your upstream and downstream property boundaries (where water enters and leaves your property) will tell you how clean the water flowing into your property is, and whether or not conditions on your property are contributing to water quality problems. If water is more polluted at the downstream boundary, test water upstream on your property to find pollution sources. Check for problems near areas of high-use, manure storage, field applications of manure, and ***horse wash areas***. Also check tributary drainages to see if problems are coming from upslope areas. By actively monitoring the water quality conditions on the property, the monitoring results could be a helpful tool in your defense if a dispute arises.

Tests should be done at least monthly throughout the year (in areas with year round water) and more often in the rainy season. Because runoff from early rains can have high concentrations of animal waste that has accumulated over the summer, it is important to test after the first storm that causes runoff. Test immediately after significant storm events (1 inch or more of rain in 24 hours) as these storms pose big threats to water quality. It may be helpful to have a rain gauge at the facility to track the amount of rain in each major storm as well as the total annual rainfall.

Keep records to provide a comparison of water quality over the years. You should be able to detect changes that show the effectiveness of your conservation measures.

Visual estimation can be done using the following descriptions:

- High RDM – Little or no patchy appearance. Unused plant matter averages three or more inches in height and small objects are hidden. Light grazing results in high RDM.
- Medium RDM – Patchy appearance with an average of 2 inches of unused plant matter and little bare soil. Small objects will not show at a distance of 20 feet of more.
- Low RDM – Less than two inches of unused plant matter. Small objects and areas or bare soil are visible at 20 feet or more. Heavy grazing results in low RDM.

For more information on conducting RDM monitoring, contact your local RCD or NRCS office.

Common Grazing Terms

Carrying capacity. The maximum number of horses a pasture will provide feed for, while leaving adequate vegetation for pasture regeneration and protection from soil erosion. Carrying capacity depends on the soil's fertility and potential for erosion, slope, climate, the length of the growing season, and management. Carrying capacity can vary from year to year due to weather and previous use.

Grazing distribution. Ideal grazing distribution results in pastures with a uniform cover of ***residual dry matter*** (RDM) remaining at the start of the winter rains to protect the soil surface from erosion and reduce the establishment of unwanted weeds. However, horses are selective grazers and will selectively graze immature forage, which results in spot grazing. Areas with short, new growth are repeatedly grazed while other areas mature past the point of being desirable forage. As desirable plants are grazed out, weedy species tend to increase. Good grazing distribution prevents horses from too heavily "overgrazing" their favorite grass. Even with the proper stocking rate, grazing distribution can be a problem in larger pastures.

Residual Dry Matter (RDM). This is the amount of plant residue left in the field after grazing, expressed in pounds per acre.

Rotation grazing. Moving horses to a fresh pasture after the old pasture has been grazed to the desired level.

Season of Use. Optimal pasture productivity depends on controlling "when" and "how long" horses have access to pasture. Year-round access to pastures may not be an option. When to have horses on pasture depends on soil moisture and amount of forage available. Horses can compact wet soil, making it harder for grasses to grow and can readily trample wet turf.

proper drainage will greatly reduce the amount of mud and water insects in which flies can breed.

Encourage beneficial insects, birds, and bats

- **Good bugs.** "Fly parasites" are gnat-sized, nocturnal wasps, which lay their eggs in the developing pupae of flies, thereby reducing or nearly eliminating the fly population. They do not harm humans or animals in any way—in fact, you won't even notice their presence. To find the parasites, try local garden stores, check the ads in horse publications, and look in farm supply catalogs. Discuss with the supplier the number of fly parasites and the frequency of release your conditions require to optimize effectiveness.
- **Helpful birds.** Encourage insect-eating birds to move into your barn area as an excellent means to reduce the flying insect population. Swallows are voracious insect eaters consuming up to 6,000 insects per day! Cliff swallows build mud nests when they arrive in spring. Help them along by providing puddles of water where they can gather mud. Screen off areas (using 1/2 inch or smaller wire mesh) where you don't want them. Nest boxes for bluebirds, tree swallows and violet-green swallows can be built or purchased. Nest box plans are available from the Natural Resources Conservation Service. Consult your local Audubon Society, birding organization, or wild bird store for more information. Also see *Steps to Improving Songbird Habitat at your Horse Ranch* in Section 5.10 of the Resources Directory.
- **Bat friends.** Bats eat nocturnal flying insects such as mosquitoes. One bat can eat up to 600 mosquitoes per hour, more than 5,000 per night. They also eat other agricultural pests. Bat houses can be placed on a barn, pole, tree, or the side of a house. The best habitat for bats is within a half mile of a stream, pond, or wetland. Bat houses need to be placed by early April, and it can take up to two years for a bat colony to find the house. Bat houses can be built or ordered through garden catalogs. Bat Conservation International is a good source for more information.

  Be sure to consult your veterinarian for recommendations on vaccinating your horses against rabies. Bat rabies accounts for approximately one human death per year in the United States.

Trap insects

Several types of simple insect traps can be useful for reducing the flying insect population. Flypaper is one of the easiest and cheapest. Pheromone traps are simple jars with one-way lids. A small amount of pheromone solution, a natural substance that attracts flies, is placed in the jar. The flies (and yellow jackets!) buzz into the jar, can't get out, and die. Traps are sold by different companies under various names. Check farm and horse supply outlets.

You can make your own bait jars to trap flies very cheaply and easily. Take an old mayonnaise or similarly sized jar and punch several holes through the lid. Put in

5.10 Improving Songbird Habitat on Your Horse Ranch

Fact sheet prepared by Point Reyes Bird Observatory
California Partners in Flight and the Riparian Habitat Joint Venture

Equestrians are people who love horses and enjoy being with them outdoors. Many stables or breeding facilities are located on large sections of land, often including creeks or sections of wooded habitat that could sustain a healthy population of native birds. These guidelines are beneficial for both birds and the horse owner, whether you have one horse or an entire stable.

The songbird-breeding season lasts from late March through August in California. During this period, songbirds are constantly busy building nests and raising their young. It is during this period that they are most vulnerable to predators, changes in vegetation and food supply. There are many steps that can be taken to make this time a productive one for birds on your land. We'd like to encourage horse and wildlife lovers to turn their stables into a productive place for bird populations. By providing habitat – especially natural nest sites and foraging areas – you can play an important role in ensuring healthy bird populations for the future. In turn, riding around your property will be more enjoyable with healthy habitat and birds to look at.

Preserve and restore existing "on ranch" native habitat

The best way to begin helping birds is by leaving and enhancing the native vegetation on and around your horse ranch. Native vegetation provides the best nest cover and feeding sites for breeding birds. The following are steps you can take to enhance the existing native habitat on your horse ranch:

- **Fence horses and livestock out of creeks, wetlands, lakes and ponds**—this will increase the native vegetation around creeks and streams which is crucial for breeding songbirds as well as to help reduce muddy areas around water sources that can cause horse ailments such as thrush, mud fever and scratches. Cost effective watering sources are available to supply your horses with water on dry ground.
- **Build water crossings** across creeks to enable horses to move between pastures without damaging the creek or other drainages.
- **Line pastures and driveways** with native trees, shrubs, and grasses to create habitat for birds. This will also eliminate wind, help control weeds toxic to horses such as star thistle, and provide shade for horses. Make sure these areas are ***fenced*** to prevent horses from entering these areas. When possible, connect these rows to existing habitat on creeks or other natural areas on your ranch.
- **Avoid non-native** trees and shrubs such as eucalyptus, tamarisk and broom, when designing your jumping, cross-country, and trail courses. Contact your native plant society for suggestions on native plants and shrubs appropriate to your area. For a list of native plant societies see PRBO's website at http://www.prbo.org/
- **Leave dead trees or dead limbs** for cavity nesting species such as woodpeckers, bluebirds, nuthatches, and titmice.
- **Provide nest material** such as grass clippings, leaf litter, and horsehair.

5.11 Helpful Publications and References

Equine Facilities Assistance Program Fact Sheets

The following fact sheets were developed as part of the Equine Facilities Assistance Program. To obtain copies, contact the Council of Bay Area Resource Conservation Districts at (707) 794-1242, ext. 121, or your local Resource Conservation District.

Number 1:	*Program Background*
Number 2:	*Composting Horse Manure*
Number 3:	*Conservation Measures to Reduce Non-point Source Pollution at Horse Facilities*
Number 4:	*Photographic Monitoring for Equestrian Facilities*
Number 5:	*Horse Paddocks: Designed and Managed to Protect Water Quality*
Number 6:	*Controlling Yellow Starthistle*
Number 7:	*Dryland Pasture for Horses*
Number 8:	*Portable Backyard Garden*
Number 9:	*Horse Manure Management*
Number 10:	*Stormwater Runoff Management at High-use Areas*

Horse Owners Guide to Water Quality Protection brochure is also available.

Erosion and sediment control

Erosion and Sediment Control Field Manual. 1999. San Francisco Bay Regional Water Quality Control Board. 1999. Contact: Friends of the San Francisco Estuary at (510) 622-2419.

Groundwork: A Handbook for Erosion Control in North Coastal California. 1987. Liza Prunuske. Marin County Resource Conservation District. Contact Marin County RCD at (415) 663-1170 or: marinrcd@svn.net

Principles & Practices of Erosion Control. Santa Cruz County Resource Conservation District. Contact: Santa Cruz RCD at (831) 464-2950.

Repairing Streambank Erosion. 1997. Brochure prepared by Prunuske Chatham, Inc. for Marin County Stormwater Pollution Prevention Program.

Start at the Source: Design Guidance Manual for Stormwater Quality Protection. 1997. Tom Richmond and Associates. Bay Area Stormwater Management Agencies Association (BASMAA). New York: Forbes Custom Publishing.

Water resources/watersheds/riparian environments

Creek Care: A Guide for Urban Marin Residents. Martha Neuman. Marin County Stormwater Pollution Prevention Program. Contact MCSTOPP at (415) 485-3363.

Guide to Stream Project Permitting for the State of California. California Association of Resource Conservation Districts. Call (916) 447-7237 or contact http://www.carcd.org/

Horse Handbook, Housing and Equipment. 1971. Midwest Plan Service. Iowa State University. MWPS-15.

Horse Industry Handbook, A Guide to Equine Care and Management. 1993. Kentucky: American Youth Horse Council. Call (606) 226-6011.

Horse Management Program (video). 1998. Resource Conservation District of the Santa Monica Mountains. 122 North Topanga Canyon Blvd, Topanga CA 90290. Call: (310) 455-1030. Cost is $5.

Horsekeeping on a Small Acreage, Facilities Design and Management. 1990. Cherry Hill. Vermont: Storey Books.

Pollution Control for Horse Stables and Backyard Livestock. 1994. Terrene Institute.

San Diego County Association of Resource Conservation Districts. 1990. Backyard Ranches, A Horse Management Program for San Diego County.

Shelter and Care of the Backyard Horse. 1983. University of California. Division of Agricultural Sciences. Leaflet 21337. Call (800) 994-8849.

Small Ranch Manual, A Guide to Management for Green Pastures and Clean Water. 1995. University of Nevada Cooperative Extension. University of Nevada Reno.

Stable and Horse Management in the Santa Monica Mountains, A Manual on Best Management Practices for the Reduction of Non-point Source Pollution. 1999. Resource Conservation District of the Santa Monica Mountains.

Tips on Land and Water Management for Small Farms and Livestock Owners in Western Washington. 1998. King Conservation District. Washington. For more information, call: (206) 764-3410, email: district@kingcd.org or visit: www.kingcd.org

Workbook: Water Quality Planning Course for Equine Facilities. 1999. Alameda County Resource Conservation District. Contact ACRCD at (925) 371-0154.

Pasture management

Establishing and Managing Irrigated Pasture for Horses. 1982. Division of Agricultural Sciences, University of California, Leaflet 21164. Call (800) 994-8849.

How Grass Grows – The "REST" of the Story. USDA Natural Resources Conservation Service.

Management of Small Pastures. 1980. Division of Agricultural Sciences, University of California, Leaflet 2906. Call (800) 994-8849.

National Range and Pasture Handbook. 1997. USDA Natural Resources Conservation Service. Website: http://www.glti.nrcs.usda.gov/technical/publications/nrph.html

Residual Dry Matter Monitoring Photo-Guide. 1998. Wildland Solutions, 234 Park St., Clyde, CA 94520.

Roads and trails

Does Horse Manure Pose A Significant Risk to Human Health? Adda Quinn. Email: envirohorse@yahoo.com or http://www.californiastatehorsemen.com/envirohorse.htm

Glossary

Aquatic life. Plants or animals that require water and associated riparian habitat to live.

Clean water. Rainfall that has not come into contact with a pollutant such as horse manure, or picked up pollutants such as sediment.

Concentrated water. Water flow that has increased in volume and velocity due to either natural drainage or human-made diversion of drainage.

Conservation measure. Any management practice, activity, or structure to prevent or reduce water pollution and/or enhance natural resourcess.

Conservation plan. A set of decisions for a long-term management strategy to protect and enhance natural resources for a property. These decisions are recorded in a conservation plan, which documents decisions made and describes the schedule of operations and activities needed to solve identified problems. Maintenance and monitoring are also included.

Polluted water. Water that has become adversely affected physically, chemically, or biologically by chemicals or other additives, such as manure or sediment.

Contaminant. The impairment of water quality by waste to a degree that creates a hazard to public health through the spread of disease.

Creek. A watercourse smaller than a river. Used in this guide to cover all sizes and types of fresh water bodies such as rivers and streams. May or may not have year-round surface flow.

Diversion. A channel or structure to divert water at a non-erosive velocity to sites where it can be used or discharged at an erosion resistant outlet.

Downslope. Downhill.

Drainage. Movement of water downward through the soil or across land.

Erosion. The wearing away of land surface by wind or water. Occurs naturally from weather or runoff, but can be intensified or accelerated by human activity.

Ground water. Water stored underground that fills the spaces between soil particles or rock fractures. (Also see near-surface ground water.)

Horse facility. In this guide, the areas used in caring for horses (i.e., barns, paddocks, turnouts, arenas, etc.) whether for a single backyard horse or a larger boarding operation.

Horse waste. Manure, urine, used bedding, and spoiled hay.

Impervious/ impermeable surface. Any surface that cannot be easily penetrated by water, such as roofs, compacted soils, and paved areas.

Leachate. Liquid which has come into contact with or percolated through manure being stockpiled or stored; contains dissolved or suspended particles and nutrients.

Manure. In this guide, manure includes both the feces and urine from horses.

Near-surface ground water. Ground water just below the soil surface and above the normal water table due to water-saturated soils. As well as slowly moving downward, near-surface ground water generally flows in the same direction as the surface runoff above until it reemerges to the surface at a creek.

Nonpoint source pollution. The diffuse discharge of pollutants that can occur specific physical, chemical, and biological properties to support plant growth. Soil is grouped into three basic types based on particle size: clay has small particles; silt/loam has medium size particles; and sand/gravel has large particles.

Stormwater runoff. Clean rain water that flows over the land surface without entering the soil.

Turnout. A high-use area where horses are "turned out" for exercise after being confined in stalls. Turnouts can be exercise lots, small paddocks, pens, or corrals. These areas are typically bare and not managed as pastures.

Upslope. Uphill.

Water quality. Describes the chemical, biological, and physical characteristics of water. The quality of water can limit its specific use or ability to support various beneficial uses such as water supplies for municipalities, industry, agriculture, recreation, and fish and wildlife habitat.

Watershed. Total land area that drains into a particular creek, river system, or bay. It includes major and minor creeks, seasonal drainages, hillsides, and floodplains. Watershed boundaries are defined by the ridges that separate drainage between watersheds.

Water table. The underground boundary below which all spaces between soil particles are saturated with water. Water tables fluctuate throughout the year but are usually highest in early spring.

Wetlands. Areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil conditions.

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Horse Keeping: A Guide to Land Management for Clean Water

This is the label for the spine of a binder.

- Obtain a 1" binder with clear windows in the front, back, and spine.
- Cut out this label, and insert it in the spine of the binder.

Place the front cover in the front of the binder, and the back cover sheet in the back of the binder.

Storm Water Program

California State University, Sacramento (CSUS)

University of California, Davis (UCD)

California Department of Transportation (Caltrans)

Lessons Learned: The Caltrans Storm Water Best Management Practice Retrofit Pilot Study

Presented at:

California Water Environment Association, 72nd Annual Conference, Sacramento, California, April 16-19, 2000.

Authors:

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Disclaimer:

This work reflects the author's opinions and does not represent official policy or endorsement by the California Department of Transportation, the California State University, or the University of California.

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Lessons Learned: The Caltrans Storm Water Best Management Practice Retrofit Pilot Study

Brian Currier, Glenn L. Moeller

ABSTRACT

In 1997, Caltrans began an extensive program to evaluate structural best management practices (BMPs) for the treatment of storm water. Thirty-nine structural BMPs were designed for installation at Caltrans facilities in the Los Angeles and San Diego areas including roadways, maintenance yards, and park and ride lots. BMPs being evaluated include: extended detention basins, drain inlet inserts, infiltration basins and trenches, oil/water separators, media filters, multi-chambered treatment trains, biofiltration swales and strips, wet basins, and Continuous Deflective Separators™ (CDS). Constituent removal efficiencies, capitol costs, and annual operation and maintenance costs are key factors in determining the cost effectiveness of the BMPs. BMP influent and effluent water quality are being monitored to determine each BMP's constituent removal efficiency. Issues concerning siting, design, construction, operation, maintenance, monitoring, and vector control are also significant factors in determining the effectiveness and applicability of retrofitting BMPs into Caltrans facilities. This paper will describe the lessons learned during siting, designing, constructing, and the first year of operating and monitoring the BMPs. The unique challenges associated with siting, constructing, and monitoring BMPs on existing Caltrans facilities has been reflected in the BMP construction costs.

INTRODUCTION

This paper presents the lessons learned while siting, designing, constructing, operating, and monitoring 35 of the 39 BMPs retrofitted into Caltrans facilities in San Diego and Los Angeles Counties, as part of the Caltrans BMP Retrofit Pilot Program. The installation of the other four BMPs is still in progress. Many of the lessons applicable to a specific phase were discovered through experiences later in the implementation process These lessons will be included with the discussion of the applicable project phase. Siting, design, and construction practices available from literature are not presented, as they are already available. Table 1 contains a description the BMPs, the facilities where they're located, and their approximate costs.

Table 1. Stormwater BMP Descriptions and Associated Retrofit Cost

Location: BMP type	Influent Sources [a]	Drainage Area (acres)	Approximate Construction Costs [b] (Thousand $s)
Los Angeles Sites			
I-605/SR-91: Infiltration Basin	91 westbound and cerritos MS	4.2	273
I-210 East of Orcas: CDS™ (hydrodynamic device)	Westbound I-210	1.1	30 (Est.)
I-210 East of Filmore: CDS™	E&W I-210, and SR118 connector	2.5	30 (Est.)
I-5/I-605: EDB (Extended Detention Basin)	I-605 and 5 to 605 connector	6.8	142
I-605/SR-91: Extended Detention Basin	Southbound 605	4.2	137
Paxton Park & Ride: Media Filter	Park & Ride	1.3	331 (Est.)
Metro MS: MCTT (Multi-Chambered Treatment Train)	Maintenance station	4.6	893 (Est.)
Alameda MS:Oil/Water Sep.	Maintenance station	0.8	178
Eastern MS: Media Filter	Maintenance station	1.5	341
Foothill MS: Media Filter	Maintenance station	1.8	479

Termination P&R: Media Filter	Park & Ride	2.8	450
Via Verde P&R: MCTT	Park & Ride	1.1	375
Lakewood P&R: MCTT	Park & Ride	1.9	456
Altadena: Biofilter Strip	Maintenance station	1.7	218
Altadena: Infiltration Trench	Inline w/strip	1.7	Built w/above
Foothill MS: Fossil Filter™ DII (Drain Inlet Insert)	Maintenance station	0.2	68 (including drainage reconstruction)
Foothill MS: Streamgaurd™ DII	Maintenance station	1.6	Built w/above
LasFlores MS: Fossil Filter™ DII	Maintenance station	0.2	88 (including drainage reconstruction)
LasFlores MS: Streamgaurd™ DII	Maintenance station	0.8	Built w/above
Rosemead MS: Fossil Filter™ DII	Maintenance station	0.3	65 (including drainage reconstruction)
Rosemead MS: Streamgaurd™ DII	Maintenance station	1.2	Built w/above
I-605/SR-91: Biofilter Strip	N.B. I-605	0.5	193
I-605/SR-91: Biofilter Swale	WB SR-91to SB I-605 connector	0.2	Built w/above
by Cerritos MS: Biofilter Swale	Westbound SR-91	0.4	59
I-5/I-605: Biofilter Swale	Sounthbound I-5	0.7	97
I-605/ Del Amo: Biofilter Swale	Northbound I-605	0.7	124
San Diego Sites			
I-5/SR-56: Extended Detention Basin	SB I-15, SR78, and connector	5.3	166
I-15/SR-78: Extended Detention Basin	SB I-5, 56/5 connector	13.4	855
I-5/La Costa (West): Infiltration Basin	SB I-5, & off ramp	3.2	241
I-5/La Costa (East): Wet Basin	Northbound I-5	4.2	694
I-5/Manchester (East): Extended Detention Basin	Northbound I-5, Man. Offramp	4.8	369
Kearney Mesa MS: Media Filter	Maintenance station	1.5	340
Escondido MS: Media Filter	Maintenance station	0.8	451
La Costa P&R: Media Filter	Park & Ride	2.8	242
SR-78/I-5 P&R: Media Filter	Park & Ride	0.8	231
Melrose Ave/SR-78: Biofilter Swale	Eastbound SR 78	2.4	156
I-5 Palomar Airport: Biofilter Swale	Southbound I-5	2.3	142
Carlsbad MS: Biofilter Strip	M.S. (0.7 acres bypasses trench)	2.4	196
Carlsbad MS: Infiltration Trench	Trench inline w/ 1/2 of Bio Strip	1.7	Built w/above

a. The influent sources are portions of the areas listed in the table and may also include landscaped adjacent landscaped areas, especially roadside BMPs.

b. Approximate Construction Cost include cost associated with the construction items to allow monitoring of BMP performance.

SITING

The type and number of BMPs to be sited for this pilot study was pre-determined. The urban watershed in which they were to be sited was also known. Lessons learned applicable to siting regard space requirements, site requirements, and permitting requirements. The challenge was to find sites were the BMPs would function properly and where operations, maintenance and monitoring of the devices could be reasonably achieved. This is the reverse of normal BMP installation where the area to be treated is defined, and the challenge is to find a BMP amenable to that specific drainage area. In either case, the lessons presented may help avoid unforeseen problems with site specific conditions.

Local Permits and Regulatory Restrictions

During siting, be aware of local and regional permit requirements and restrictions that could impact construction, operations, or maintenance. Identifying these requirements early will jump-start applying for the appropriate permits, and allow selecting BMPs that will have a reduced impact. Many of our BMPs fell under the jurisdiction of the California Coastal Commission. Several sites had Coastal Zone Act Reauthorization Amendment (CZARA) permits administered by the local municipalities, and the municipality provided approval of the projects. An example of a significant impact was a biofilter swale at the Palomar Airport Road on Interstate 5. An existing permit for the site required impacted trees to be replaced at a five to one ratio. The biofilter was redesigned to avoid impacting three of the existing trees. This type of problem can be avoided by installing small footprint BMPs or by choosing sites to minimize impacting on existing trees.

Caltrans internal process requires certified biologist to assess the impact of projects to the environment. Impacts form construction of the device must be considered as well as impacts from the device itself. For instance, certain noise levels harass some species of concern. While all Caltrans pilot projects qualified for categorical exemptions, early coordination between the local Fish and Wildlife Service office and pilot team biologists assisted in establishing construction and maintenance schedules. The schedules were generally responsive to nesting periods of migratory birds and endangered species. If sensitive species are nearby, selecting a BMP relatively unattractive to those species may be a good strategy, as maintenance of the BMP could be impacted if the species utilize the BMP. Also, avoid BMPs with maintenance activities deemed harassing to nearby species. Alternative BMPs, such as those that can be covered or that have no vegetation or other attractive features, may be a better choice, as consistent maintenance is critical to the performance of structural BMPs.

Site Specific Requirements

During siting, it is also beneficial to talk to the local supervisor of the site as well as public works. Talking to people familiar with the site will often reveal undocumented information that affects the project. For instance, the City of San Dimas was responsible for the landscaping on Caltrans' right of way at the Via Verde Park and Ride, thus requiring coordination with the city. Communication with the permit inspector, who knew of the situation, during siting or design could have allowed coordination prior to construction.

When surveying a site, the space available must be calculated using safety setbacks required by existing standards. For Caltrans rights of way, a 30 ft minimum setback from the traveled way must be used for any device, obstruction, or drop-off that could damage an errant vehicle. When space doesn't allow for this setback, devices such as metal beam guard rail can be used to 'protect' the device. For example, the California Highway Patrol requested that a fiberglass monitoring cabinet be relocated to avoid vehicle impact. It was moved, and within weeks, a vehicle lost control and passed over the original location (unfortunately, another vehicle struck the relocated equipment, soon after).

General Siting Guidance

Proximity to wells, proximity to foundations, soil conditions, groundwater elevations, drainage area, and flood routing are other factors to consider during siting. Information on these factors is widely available so they are listed here for convenience in making a complete site survey.

DESIGN

The design phase should address as many of the challenges of implementing a BMP as possible. Lessons learned applicable to design were mainly discovered in the later phases of construction, operation, and maintenance. Design is the work between when a site has been selected and a contracted is awarded for construction. This includes developing plans and specifications and writing the Notice to Contractors. Design lessons learned focus on initial investigation, coordination, on-going facility operations, design specifications, vendor coordination, public awareness, and documentation. Design changes and resulting lessons learned after the contract was awarded or ground was broken are discussed in the construction section of this paper.

Initial Investigation and Coordination

When a site is selected for installation of a BMP, all on-going and planned construction activities in the area should be determined. Coordinating BMP construction to coincide with redevelopment or new construction can save on costs such as mobilization. Also, smaller jobs like BMP installation may not be attractive to many contractors, and getting competitive bids will be easier if combined with other work. Recently installed drainage works could require removal to construct the BMP. Coordinating with other projects on the site could also allow expansion of the BMP drainage area so runoff from a larger area could be treated. If time had permitted, coordination at the 5/78 Park and Ride could have reduced construction cost of a sand filter. Had construction been coordinated, shoring and landscaping costs would have been reduced. To avoid demolition of a section of the upper portion of the Park and Ride, shoring was required that would not have been had the BMP been constructed first. Also, recently planted palm trees in the area required for the shoring operation would not have been dug up and replanted if the BMP was built with the larger improvement project. Finally, drainage from the upper portion of the park and ride could have been diverted to the BMP. Currently only the lower half of the park and ride is treated.

If a thorough site investigation cannot be performed before beginning construction, requiring the contractor to accomplish this investigation should be the first work performed. Preliminary excavation (pot-holing) should be used to determine the accuracy of 'as builts' as well as to discover other items that could require relocation of the device or increase excavation costs. Having this knowledge before excavation may allow for adjustments and cost savings. At the Altadena Maintenance Station in Los Angeles County, the pavement was only an inch thick in the excavation area. The edge of the original pavement cut could not stand up to the equipment traffic and a change order was required at the end of the project to re-cut past the damaged area and repave a larger amount than was previously anticipated. The thin pavement could have been discovered during siting or design by simply investigating the pavement with a pickaxe, and the additional work could have been included in the original work order. Depending on the terms of the change order, this may not save construction costs, but it should save administrative time and prevent disputes of the additional work.

Site Specific Requirements and On-going Facility Operations

Provisions to allow for the on-going operation or function of the site to be retrofitted should also be included in the original work order. For example, material storage bins at the Altadena and Foothill maintenance stations were located where the BMP was to be built. The yard operators requested the contractor construct the new bins specified in the plans before the old ones were removed. This schedule change would have added costs for the contractor and required a change order. Since the contractor was working on 8 different sites, he was able to re-schedule by switching demolition crews to other unaffected sites. Because this may not always be the case, the work plan should include a work schedule that allows vital operations to continue. Other examples include the Via Verde Park and Ride where site operators required a bicycle storage shed be relocated, so as not to affect commuters who ride bikes to the park and ride. Similarly, the sand filter at 5/78 required shoring not originally specified. Construction without the shoring would require the removal and re-construction of a portion of the upper parking lot. The need to maintain use of those parking spots and not disturb the recently constructed lot should have been identified early, and reflected in the work description.

BMP Specifications and Vendor Coordination

Besides water quality performance goals, product reliability and consistency, product availability, product flexibility, vector control, hydraulic performance and maintenance requirements can influence the design specifications of BMPs. Early consideration of these factors should allow for more efficient BMP implementation.

1) Product Reliability and Consistency

Begin ordering materials with long lead times as soon as possible (i.e. once the design is far enough along to determine items that must supplied to or ordered by the contractor). Some products have long lead times and others may have unanticipated delivery or fabrication problems. For example, at a San Diego site the designer determined that the flumes specified for flow monitoring would not be available before the expected project completion date. The BMP designer researched and specified an alternative cutthroat flume. However, the cutthroat flume performance was insufficiently verified and didn't perform to standard. Additionally, the flumes were built on-site from concrete which resulted in measurement precision much less than that obtainable with fiberglass flumes. Follow-up investigation revealed that even if the flumes could be calibrated, they didn't work very well on the low flows (< 0.1cfs) being monitored. These flumes were later replaced, months after construction was completed. The lesson here is don't specify an alternative product, regardless of delivery problems of the original, unless adequate performance of the alternative can be verified. Similarly, some BMP installations in Los Angeles specified concrete monitoring pads that were smaller than the fiberglass equipment enclosures that arrived later. A change order to widen the pads was required. Once again, checking the specifications of the product ordered would have resulted in the correct pad dimensions in the original plans.

Guidelines on the acceptance of the quality of material should also be included in the specifications. For example, the plant material for the biofilters in both Los Angeles and San Diego, was grown in flats at a nursery. When the sod was delivered, the construction crews found two problems: First, the area of each flat was miscalculated by measuring the dimensions of the grass and not the flat. Second, most of the sod had poor coverage with many of the flats having no plant material. These problems could have been prevented if the height and coverage of the plant material was specified and if the sod area was determined properly at the time of planting at the nursery.

2) Product Availability

Use care when specifying proprietary devices and materials. The compost media for the Kearny Mesa media filter was in a canister configuration. The manufacturer delivered a different media, claiming it would work better. The media was accepted, but specifying proprietary devices may force one to accept revised technologies or maintenance methods that may change the practicality of the device.

3) Product Flexibility

Avoid using pre-cast units. Typically, the elevations in as-builts are not reliable enough to order pre-cast units with pre-set orifices to tie into the existing drainage system. Cast-in-place features allow the contractor to make adjustments necessary because of both the actual field conditions and changes resulting from the construction process. For instance,Pre-cast G2 inlets at the Rosemead, Foothill, and Los Flores Maintenance Stations had to be modified and grouted because of differences between design and field conditions. This resulted in added time and expense.

4) Vector Production

A vector borne disease control expert reviewed each BMP design. Initially, the biofilter devices were considered a low threat for mosquito production, and no design changes were recommended. However, during operations it was discovered that the energy dissipaters and flow spreaders were very effective mosquito incubators. Subsequently, these structures were grouted in and rip-rap was set in the grout to perform the function of the shallow recesses. This reduced the need to abate mosquito larva in these devices. Future design of BMPs should avoid standing water for longer than the incubation period of mosquitoes, 72 hours.

Vector experts also required that BMPs with potential for breeding mosquitoes, such as basins, be designed to incorporate access to the site for inspection and abatement of vectors. The method of abatement uses control material broadcast from a truck. The distance from the access road to any part of the BMP had to be within the broadcast range of the equipment used by the local vector control authority. Easy access to the BMP also makes maintenance easier and safer.

5) Hydraulic Performance

Flow spreader and similar BMP features should not be designed for one specific flow rate, as storm water flows vary greatly within an event as well as between events. The flow spreader at the Carlsbad maintenance station infiltration trench was designed to spread flow from the target treatment volume. Smaller, more frequent flows, were not spread properly, and caused water to concentrate on one side of the infiltration trench.

6) Maintenance Requirements

Railings, ladders, steps, and vehicle access to sedimentation chambers of sand filters should be included in the original BMP designs. These basins have vertical drops to save space, while cost prevented them being covered. Railings should be provided to avoid accidents in what could be considered an attractive nuisance. Ladders were added later as a change order, but steps and railing would be better. Vehicle access would ease sediment removal, inspections, and vector treatment.

Public Notification

Prior to construction, the community should be educated on the purpose and potential impact of the project. Prior knowledge can avoid confusion and unnecessary public reaction. At the Via Verde Park and Ride installation of a Multi-Chambered Treatment Train, the public was concerned that all the spaces used during the construction of the device would be lost completely. When it was explained that many spaces would be returned following completion of construction the public's concerns were substantially relieved.

Pre-construction Documentation

Pre-construction photography of the site should be done to document existing site conditions. Disputes can arise with contractors regarding damage done during construction. Also, if the work description requires the contractor to return the landscaping or other site feature to their existing condition, photographs will reduce or eliminate disputes. Photographs of landscaping prior to sand filter installation at Termination Park and Ride and the MCTT installation at the Via Verde Park and Ride could have eliminated such disputes.

CONSTRUCTION

Many of the lessons learned during construction were included in the design section, as action taken in the design phase could prevent problems during construction. Lessons specific to construction will help resolve or avoid disputes, save time and money, and improve initial BMP performance. As with the previous phase, site photographs taken throughout construction may help resolve disputes with the contractor.

Installation Specifications

Proprietary devices may come with installation instructions. These instructions should be viewed as guidelines, or results in the field may not be satisfactory. For the drain inlet inserts, two types of inserts were installed. The fabric insert called for removal of the inlet grate, placing of the fabric, and replacement of the grate. This technique allows for water to seep past the edge of the grate. Also, the fabric tends to slip into the drain inlet when the weight of water and accumulated sediment pull it down. The solution was to rip strips of wood to wedge the fabric against the walls of the drain inlet. This allowed better flow through the device and added resistance to help prevent slipping. The other type of inlet insert required the installation of a framework that held rectangular canisters containing a filtering media. The framework and canisters had to be ordered to the size of the inlet to be retrofitted. The tolerances in fabrication resulted in installations that had gaps up to 0.1" at the Rosemead Maintenance Station installation. Though small, this did allow a small portion of stormwater runoff to bypass the device untreated. The solution was to use silicon caulk and/or shims to prevent water from bypassing the device. In both cases, specifying a 'water-tight installations by use of shims or caulk' will have the drain inlet inserts off and running and avoid re-installation. In general, always specify that all connections are sealed and bypass is not allowed, except for where bypass features are included for flood routing purposes.

Quality Control

Quality control during the surveying and construction is critical because many BMPs in a retrofit environment require tight tolerances due to available hydraulic head. Adjustments were required at the 605/91 Infiltration Basin inlet/outlet/overflow structure. Also, the diversion structure for the influent to the Lakewood Park and Ride was partially removed and re-grouted at the proper elevation. Many other sites, such as at the I-5/SR-56, I-15/SR-78, and the I-5/I-605 extended detention basins, had minimal available hydraulic head and construction was successfully controlled to achieve the design requirements.

For future reference and as a resource for BMP operation and maintenance crews, accurate as-builts should be submitted. In the case of the wet basin at I5/La Costa in San Diego County, the maintenance program for vegetation management is tied to the 'as-constructed' condition. The maintenance crews use the plans as a reference. Also, future changes to a BMP require accurate knowledge of existing conditions, and existing conditions are rarely reflected in the original plan set because of adjustments required during construction.

At the Lakewood Park and Ride, the contractor tied into existing electrical power on site. During construction, it was determined that the voltage to the MCTT for operating it's two pumps was insufficient. The contractor tried to pull the wiring, but it 'wouldn't budge.' Because construction was already behind schedule, the problem was left for the operation and maintenance crews to deal with and the contractor was released from the job. The operation crew had a voltage booster installed. The resulting performance was improved, but still less than ideal. It would have been better to force the original contractor to supply adequate power. The added delay in construction could make up for downtime due to insufficient performance of an inadequately constructed BMP.

CONCLUSIONS

Siting and design are the most critical phases of BMP implementation. Problems addressed early within these processes can save time and money, and result in better BMP performance. As a whole, the lessons learned in this BMP pilot study present a lesson-in-itself. That is, the phase most rushed will be the phase with more mistakes or oversights. Also, a mistake or oversight in early phases may plaque the subsequent stages including operation and maintenance of the BMP.

Siting should start contacting agencies and internal management of the sorrounding area to use them as a resource in early identification of conflicts. On average, additional investigation and coordination, seems to pay for itself in later phases of the project. However, the cost of added investigation must be weighed by the potential cost savings. In the case of the sand filter at I-5 and La Costa Ave. Park and Ride, there existed sufficient flexibility in space that potholing to determine the exact location of the 24" discharge pipe would be meet or exceed the cost to modify the design during the construction process. In this case, exploration costs were reduced because of sufficient flexibility.

Design of the BMP devices should be responsive to maintenance, on-going facility operations, vector and safety concerns. Poor design will result in poorly functioning BMPs, or in BMPs that create safety and public health liabilities. Proper work plan preparation can minimize impact to on-going facility operations and minimize conflicts between facility operators and the contractor.

Even proper siting and design can not guarantee against challenges with construction. Following good construction management practices will avoid most problems identified. For retrofit construction, allow a time contingency to deal with unforeseen challenges. This would allow time for detailed inspection and correction of any insufficient work items.

For each phase of BMP implementation, the tradeoff between time and quality will hold true. If time is tightly constrained, some amount of inefficiency (cost increase) is expected. The goal, however, is to have the most efficient process that is constrained by the project's available resources and time.

Compost
Demonstration Project,
Placer County:

Use of Compost and Co-Compost as a Primary Erosion Control Material

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Executive Summary

Yard trimmings and other green materials currently account for over 30 percent of the volume entering California landfills annually. California statute requires landfill volumes to be reduced by 50 percent by the year 2000. In an attempt to meet these requirements, the California Department of Transportation (Caltrans) entered into an agreement with the University of California, Davis (UC Davis) to evaluate the potential for use of green materials composts (GMC) and co-composted materials (CCM; a mixture of green materials and municipal biosolids) for use as primary erosion control amendments for revegetation of Caltrans roadsides.

The research presented here is the initial part of a multi-year project designed to (1) characterize current GMC and CCM products in California to provide information to Caltrans staff for developing specifications for compost use during revegetation, (2) evaluate the performance of surface applications of GMC for primary erosion control in a controlled rainfall facility, (3) evaluate the effect of plant available nutrients provided by GMC and CCM materials for long-term support of vegetative communities, and (4) develop field plots demonstrating the use of composted materials in locations in northern and southern California. The information contained in this report summarizes part of the first objective involving characterization of composted products from private and municipal producers in California during winter 1998-99, as well as describing one of the compost demonstration plots in the Lake Tahoe Basin. Results from remaining objectives will be made available as the project progresses to completion, scheduled for 2001.

Introduction

Compost Definitions

Compost consists of the relatively stable decomposed organic materials resulting from the accelerated biological degradation of organic material under controlled, aerobic conditions (Storey, 1995, Epstein, 1997). Another definition is "the disinfected and stabilized product of the decomposition process that is used or sold for use as a soil amendment, artificial topsoil, growing medium amendment or other similar uses" (Texas Senate Bill 1340; Storey, 1995). This decomposition process converts potentially toxic or putrescible organic matter into a stabilized state that can improve soil for plant growth.

Composting organics has other beneficial effects, including diverting landfill wastes to alternative uses, removal of pathogen inocula or weed seeds and decomposition of petroleum, herbicide or pesticide residues. These aspects, though important, will not be considered here, nor will the potential for metal transport or accumulation by organic molecules. The focus of the project described here is to evaluate the benefits of using GMC as a mechanical aid for primary erosion control and as a nutrient source for sustainable revegetation of degraded soils.

Potential for Use of Compost as a Primary Erosion Control Material

A primary limiting factor in the revegetation of degraded soils is the loss of the erosion-resistant plant litter layer and soil nutrients during and after disturbance of the soil resource (Bradshaw and Chadwick, 1980). Loss of plant litter and mulch material results from erosion or physical removal during construction. The first soil horizons to be removed are typically deposited at the bottom during fill slope construction. The remaining soil surface is exposed and the nutrients in the previous topsoil horizons are buried beyond the reach of plant roots.

Revegetation of drastically disturbed sites often requires protection of the bare soil surface from erosion. The bare soil particles are vulnerable to raindrop impact, which detaches or close-packs the disaggregated fines. When the surface of the soil seals and becomes resistant to percolation of precipitation, overland flow is increased, resulting in sheet and rill erosion. Composts are shown to reduce these types of erosion, as noted in the literature review below.

Loss of topsoil during disturbance also reduces the ability of the vegetative community to regrow because the soil's nutrient reserves are depleted. Inadequate pools of plant-available nitrogen (N) can restrict growth on the site for extended periods of time because N is needed in relatively large amounts for regeneration of the shoots, roots, litter layers, and for microbial biomass. Because soluble fertilizer N is easily depleted from the soil by leaching or plant uptake, the regeneration of the plant community is expected to be improved by the application of larger, stabilized pools of N that mimic the organic matter lost during topsoil removal. Recent work in the Tahoe Basin suggests that these long-term, slowly available pools are better correlated with the soil's ability to support plant growth, than are soluble (KCl-extractable) N levels (Claassen and Hogan, 1998).

While many organic or chemically based soil amendments can provide N for early phases of plant establishment, few provide N for a long-term, multi-year period of community development. GMC, on the other hand, may provide this type of N release because the composting process converts readily degradable organic materials into stabilized, partially humified materials (Epstein, 1997). Before evaluating the nutrient contents of GMC products in California, the practices and results from projects in other states will be reviewed.

Review of Existing Projects in States Other Than California

Texas Transportation Institute

The Texas Transportation Institute, Hydraulics and Erosion Control Field Laboratory, affiliated with the Texas A&M University system, has developed a testing facility with large, life-sized experimental slopes for uniform testing of erosion control materials. A study on compost application (Storey, 1995) tested three materials on 1:3 slopes with both clay and sandy loam textured soils. Plot size was 6.1 m wide by 21.35 m downslope (1:3 slope plots). These materials included co-compost (mixed yard trimmings and municipal sewage sludge), shredded wood with polyacrylide tackifier (6.75 kg/ha), and shredded wood with a hydrophilic colloid tackifier (56 kg/ha).

Treatments were amended with organic materials to a depth of 76 to 101 mm (3 to 4 in) over the clay or sandy loam soil. Soils were seeded with a standard warm season revegetation grass mix for the central Texas area. Vegetation establishment criteria were a minimum coverage of 80 percent for the clay soils and 70 percent for the sandy loam soils within 6 months of seeding. Rain simulations tested for sediment loss on the plots, using 1-, 2-, and 5-year simulated storm events. The erosion control objectives are that the treatment should protect the seed bed from a short-duration, 1-year return frequency event (99 percent probability of occurrence within a given year) within the first month after installation, from a 2-year return frequency event (50 percent probability) within the first 3 months following installation, and from a 5-year return frequency event (20 percent probability) within the first 6 months of installation. Rainfall simulations were designed to model events within the Houston/Dallas/Austin region. To be included in the Texas Department of Transportation-approved Material List for Standard Specification Item 169 (Soil Retention Blanket), the sediment loss had to be 0.34 kg/10 m^2 or less from the clay soils and 12.21 kg/10 m^2 or less from the sandy loam soils.

Sediment loss from the compost-amended plots during simulated rainfall tests was right at 0.34 kg/10 m^2 from the clay plots and was 3.88 kg/10 m^2 for the sandy loam plots. Vegetation cover was 99 percent on the clay and 92 percent on the sandy loam. The two tackified wood chip treatments produced 0.15 and 0.30 kg/10 m^2 sediment loss on the clay soil and 11.27 and 10.97 kg/10 m^2 sediment loss on the sandy loam. Vegetation establishment was around 50 percent for several of the tackified wood chip treatments, disallowing them from approval under Texas Department of Transportation standards. The fact that much of the vegetative cover established in the compost treatment came from weed seed, not the desired seed mix, points out the need for quality control in compost products. Costs for the compost were below the average cost of synthetic or organic blankets tested by the facility.

Portland Metro, Portland Oregon

The goal of a Portland Metro project was to demonstrate that yard trimmings compost can be used effectively to control nonpoint-source pollution (Ettlin and Stewart, 1993; Metro, 1994). The project used both "coarse" compost materials (containing chunks of wood and branches up to 152 mm [6 in] in length) and "medium" compost materials, the fraction remaining following screening of the coarse compost through a 16-mm (5/8-in) trommel. Leaf compost was collected from residential streets in the city of Portland.

Thirteen test plots measuring 2.74 x 9.75 m (9 x 32 ft) were constructed on slopes of 34 and 42 percent. Surface runoff was collected in plastic sheeting at the base of the slope. A 3-in mulch layer was applied either as a uniform covering or as a barrier at the base of the plot. Two conventional methods, sediment fences, and wood fiber hydromulch with tackifier treatments were also tested and compared to untreated controls. During and after three storm events in March 1993, 364 samples were collected and tested for suspended solids, settleable solids, turbidity, total solids, metals, nitrate N, total N, and chemical oxygen demand. Suspended solids were lower on the compost treatments than with the sediment fences and similar to the wood fiber hydromulch. Composts also adsorbed metals, reducing metal runoff. The need for high-quality, mature compost was noted.

Subsequent to this study, field plots were constructed in the Portland area utilizing compost as erosion control material to demonstrate use and to increase the market demand for yard trimmings compost materials. Three field sites were established on roadside, housing development, and mobile home park projects. All compost materials were applied to a depth of 76 to 102 mm (3 to 4 in). Materials were brought to the top of the slope by tractor bucket or backhoe. Materials were then spread by hand. The first site (Springwood Drive, Beaverton) had a 14-degree slope at the bottom and a 7.6 m (25-ft) slope length, and the slope drains into an existing wetland. At the second site (Marylhurst, Lake Oswego), slopes ranged from 0 to 30 degrees. The third site (McLoughlin Boulevard, Portland) contained two areas with slope angles of 35 degrees and slope lengths of 3 to 18.3 m (10 to 60 ft). A third area had a slope angle of 15 degrees and a slope length of 4.6 m (15 ft), and a fourth area had a 1- to 5-degree slope and a slope length of 48.8 m (160 ft).

Results from the three demonstration projects suggest the following beneficial uses from compost application. A thick compost layer can provide a surface covering for foot or vehicle traffic onto soils that are otherwise too muddy and wet to support traffic. A compost layer at the exit of a site will reduce mud tracking onto local streets and into storm drains. A 76-mm (3-in) layer of compost was found to be effective. One demonstration site coordinator suggested using a specification of a "minimum" of 3 inches. Compost screened to 38 mm (1½ in) or less is recommended for erosion control on steeper slopes. Slopes of up to 35 degrees were effectively treated. The compost layer should be extended over the top of the slope for 0.6 to 1 m (2 to 3 ft) at a 300- to 450-mm (12- to 18-in) depth to diffuse ponded water entering the top of the slope. Compost that has been screened to 19 mm (¾ in) or less is recommended for slopes that are to be landscaped. A moisture content of less than 25 percent makes application most efficient and enables the compost layer to readily adsorb larger amounts of rainfall immediately after application. Mature compost will function to release nutrients into the soil more readily than immature compost. Contaminants (plastic, glass, undecomposed plant material) detract from the aesthetic benefits of compost amendment. As a result of the study and field plots, members of several local governments incorporated the use of compost into their specifications.

Other Miscellaneous Studies Outside of California

Various studies were located in the literature search that provide smaller, though relevant, findings regarding the development and use of GMC. They are listed in a nonprioritized sequence below.

Leaf composting facilities exist in 140 of the 351 municipalities in Massachusetts (Fulford et al., 1993). Grass clippings have high nutrient contents and therefore are potentially putrescible. Careful management is required to maintain aerobic conditions and to control nutrients and odor moving off site. New Alchemy Institute, BioThermal Associates, and Woods End Research Laboratory cooperated on a study designed to determine the impacts on air, water, and soil from composting grass clippings in windrows, including the fate of pesticide residues. Ratios of greater than 1 part grass to 3 parts tree leaves in the compost mix resulted in excess nitrate production. Some nitrate, chloride, and potassium leached beneath the piles, but little of the total N left the piles. Pesticide residues were very low.

In the late 1980's, Florida Department of Transportation maintenance crews typically chipped vegetation trimmings and spread them beneath plantings (Henry and Bush, 1996). After a large pile caught fire and exposed some barrels stored under the chipped material, the informal process of composting on site was shut down. An official composting and recycling program was restarted in 1992. As part of the development program, the University of Florida Horticultural Sciences Department conducted a study on proper use of composted waste materials for roadside applications. Current turfgrass applications of about 4000 tons of fertilizer per year are proposed to be replaced by 20,000 to 40,000 tons of compost per year, pending study by the University of Florida.

Although composts have been evaluated for their ability to improve plant growth for many years, most studies have involved municipal solid waste composts (MSWC, or mixed municipal garbage) or sewage sludge composts. Further, many of these tests produce little detailed data on characterization or use (Henry et al., 1991). A University of Washington study (Henry and Harrison, 1992) mainly reports analyses of totals of metal elements, with little bioavailability data.

Humic acids from green materials composts were compared with leonardite humic acids for their effect on aggregation of a silty-clay Fluvisol (Canarutto et al., 1996). Higher rates of leonardite humic acids (0.2 to 0.8 percent humic acid addition) decreased aggregates in the microaggregate classes ranging from 38 to 250 micrometers in diameter, while no change was generated by humic acids from GMC. Humic acids from GMC materials decreased the size of the clod (thick, hard-setting crust) as the soil dried.

MSWC additions to soils were associated with shifts in the bacterial populations, probably as a result of increased carbon substrates (Press et al., 1996). Newsprint plus poultry litter caused shifts to Gram negative bacteria (common root colonizers and biocontrol organisms) compared to newsprint plus ammonium nitrate. Increases in bacterial populations that have beneficial effects on plant growth may indicate changes in soil quality. Materials that contained initial carbon to nitrogen (C:N) ratios of 20:1 and were composted for 9 weeks increased fungal populations compared to materials with C:N ratios of 60:1. Straight newsprint applications to surfaces increased cotton plant rot disease and soreshin disease, both caused by fungal pathogens. Application of material with C:N ratios of < 30:1 increased bacterial populations.

Quality of compost materials is closely linked to process (Barnes and Heimlich, 1992). The best way to bulk up high nutrient grass clippings (when compared to straw and wood chips) was found to be with tree leaves. Odor problems developed when pile temperatures exceeded 65 °C (150 °F).

Grass materials were composted in a trapezoidal windrow system about 3 m high by 53 m wide (10 ft by 175 ft) (Logsdon, 1993). Grass materials are bulked with tree leaves or wood chips. Odor problems were controlled when 5 parts leaves or chips were used to 1 part grass material. Plastic bags compound the problem of odor production. Because of recurring odor problems, the Hunting Woods, Michigan, facility refuses to collect grass clippings.

In Jacksonville, Florida, high-C-content materials (tree leaves) are placed in alternate windrows during February and then the inter-row spaces are filled with high-N-content grass clippings in the spring and summer (Kelly, 1993). The two piles are then blended together and turned five times in a 90-day composting process.

A dune stabilization project in Ft. Lauderdale, Florida, utilized 76 mm (3 in) of compost with grass plugs (Sea oats) planted on 46 cm centers (18 in) (Hamilton et al., 1993). Drip irrigation pipe was installed, followed by another 76 mm (3 in) of mulch material. With these intensive treatments, plant growth within a single 5-month season was equivalent to that of a 5-year growth without treatment.

In a study of yard trimmings compost usage in Minnesota, macronutrients and micronutrients were tested, but only soluble (extractable) N pools were measured (Gurkewitz, 1989). With a C:N ratio of approximately 49, the material is not expected to release additional N until it is further stabilized. Metals were below Minnesota's regulatory limits.

Setting testable standards for "high quality" is difficult. Hegberg et al. (1991) measured a wide range of metals, all of which were beneath the Minnesota standards. Extractable and total N levels were measured, but mineralizable N pools were not.

Selected Projects in California

Caltrans Compost and Co-Compost Study

Caltrans developed a project entitled "Evaluation of compost and co-compost materials for highway construction" (Sollenberger, 1987) that tested sewage sludge composts and sludge/municipal refuse co-composts. The materials were found to be usable as fertilizers, soil amendments, and erosion control materials only if the quality was good (permissable contents of heavy metals, toxic organics, pathogenic organisms, and low content of glass, plastic and metal). Because the focus of the Sollenberger (1987) study was on sludge and municipal refuse composts, the data are of little use regarding the current erosion control project, except to illustrate the relatively clean, low-contaminant content of GMC compared to composted municipal solid waste materials.

Caltrans Green Material Mulch Demonstration

A second Caltrans-funded project addressed the use of green material for surface application on roadways (Pollock and Moreno, 1993). This project was developed in cooperation with the California Integrated Waste Management Board for the purpose of determining whether green materials, including residential yard clippings, and similar clean organic refuse could be used for weed control, soil improvement, conservation of irrigation water, plant fertilization, and aesthetic improvement of landscape sites. The materials utilized were variously called "mulch" and "composted mulch" but were, in fact, not compost. Composted materials are those that have undergone thermophilic decomposition and organic matter stabilization. The materials used in this study contained particle sizes such that 82 to 99 percent (Caltrans District 3) or 62 to 99 percent (District 11) passed through a 9.5-mm screen. The District 3 materials were characterized as having a greater volume of 6.3 mm (1/4-in) particles, with smaller proportions of larger and smaller particles. The District 11 materials contained either fine-sized particles plus wood chips and cuttings less than 150 mm (6 in) in length (Miramar source materials), or particles from 150 to 450 mm (6 to 18 in) in length (Otay Landfill source materials).

Results from both districts indicate that plant growth was generally improved as a result of increased moisture retention, more moderate soil temperatures, and an enhanced habitat with greater fungal, insect, and vertebrate animal activity. The mulch materials were observed and measured to be very low in nutrient content. Quality control criteria were difficult to establish, but will be critical for widespread use of mulch materials. The reports advised that composted mulch materials should not be applied within the dripline of trees because of the observation of increased fungal rot of existing trees. Equal mixes of green materials and wood chips appear to benefit plant growth, and mulch depths of not less than 300 mm (12 in) are recommended. In conclusion, this study documented benefits of mulch materials for improved vegetative growth, but did not evaluate composted green materials. Even where the mulch materials were partially composted, their use and application was as a surface mulch rather than as an incorporated soil amendment.

Santa Cruz County Projects

Benefits and concerns regarding agricultural uses of uncomposted green materials are reviewed well in the final report for the Green Waste Demonstration Program for Santa Cruz County (Buchanan and Grobe, 1997). In this program, a number of agricultural uses for processed green materials (chipped, but not already composted) were identified and evaluated. These uses included on-farm composting, permanent mulching of row crops and farm roads, applications related to flower production in fields and greenhouses, and direct soil incorporation. This information represents an alternative use of green materials and can provide insight on some of the benefits and problems associated with the use of GMC in field situations.

End uses of the uncomposted green materials varied greatly. A farming operation with a loamy sand soil used a 76- to 102-mm (3- to 4-in) layer as a roadway mulch to reduce dust during summer and erosion during the rainy season. A coarse grind and a high C:N ratio were an advantage in reducing decomposition rates. Greenhouse applications of 51 to 76 mm (2 to 3 in) depth required adequate ventilation to reduce buildup of ammonia gas from the green material. One greenhouse mulch material was too dry at application, generating respiratory complaints. One case of contact with poison oak was reported. A field amended with 11.2 to 13.4 megagrams/ha (5 to 6 tons/ac) performed well when plants received preplant N application. Green material was generally found to be equivalent to redwood sawdust or rice hull for adding organic matter to soils. Another field application with 56 megagrams/ha (25 tons/ac) of green material incorporated into the soil reduced growth on raspberries due to N deficiency. Even with supplemental N, the plants performed poorly. Non-screened material greater than 16 mm (5/8 in) was difficult to apply mechanically.

Consistent production quality and characterization are recognized as being key to increasing the use of these heterogeneous organic materials. Many of the characteristics varied greatly as a result of storage time and conditions (temperature, aeration, moisture and leaching). Nitrogen content, for example, varied by 385 percent. Nitrogen measured from selected samples taken immediately after grinding was 1.7 percent, but decreased rapidly with time, from 1.7 percent to 0.49 percent after 3 weeks. Other macronutrients (K, Ca, Mg, SO_4) varied by 333, 460, 330, and 320 percent. Product variability could be reduced by segregation of loads with higher proportions of tree leaves, grass or other succulent materials for use in compost production, while loads with more woody material could be separated for use as soil surface mulch or topdressing. Analysis of metals in these green waste materials shows little evidence for excessive contamination for metals under California Title 14 and U.S. Environmental Protection Agency (EPA) 503 regulations. Some batches of ground and recycled wood waste may, however, have lead and arsenic contamination resulting from contamination from paints and wood preservatives.

Only one complaint was made regarding contamination from inerts (plastic, rubber, aluminum) during the demonstration program. The presence of viable weed seeds in uncomposted green materials was common. Source separation of leafy materials and fines (dirt and ground up plant material) from compost feedstock materials will reduce spread of weed seeds. Coarse woody feedstocks can be directed to uses involving uncomposted materials. To limit the spread of pitch canker, an endemic disease of Monterey Pine in the coastal area around Santa Cruz, it is recommended that uncomposted materials not be transported to other forested areas in the state.

Reasons given by growers for not wanting to use uncomposted green materials include lack of equipment and space, fear of disease and weed seed problems, and familiarity with use of manures as soil amendments rather than green materials.

An earlier report (Grobe and Buchanan, 1993) reported that typical successful application rates for soil amendment range from 11.2 to 22.4 megagrams/ha (5 to 10 tons/ac). User concerns involve (in decreasing order of importance) contaminants, price, pathogens, salt, and nutrient content. Composts improve microbial activity that can act to reduce root pathogens and improve nitrogen use efficiency.

Caltrans Compost Demonstration at Brockway Summit, Placer County (in progress)

In the fall of 1998 a compost demonstration was constructed at Brockway Summit on State Highway 267 in Placer County, at the north end of the Lake Tahoe Basin. This project involved a long series of southwest-facing road cuts totaling 3.6 ha (9 ac), with 2:1 (horizontal:vertical) slope angles. The parent materials are volcanic mudflows that were cut to 5 to 8 m below the previous soil surface.

The existing erosion control specification for the site was modified to create three additional treatments designed to contrast the performance of various slope amendments. Each of four treatments—specified, zero control, compost, and compost plus specified—was repeated on three separate slopes (Table 1). The slope amendments were stable through the winter of 1998–1999 with only small areas of slippage. Plant growth and soil nutrient content will be monitored for several years after application.

Table 1. Treatments applied to the Brockway Summit Compost Demonstration Project in Placer County, State Highway 267.

Treatment Code	Application Number	Description
SPECIFIED	Application 1	600 kg/ha compost, 800 kg/ha organic soil amendment (Biosol), 150 kg/ha fiber, and seed materials
	Application 2	Pine needles to a depth of 25 mm
	Application 3	600 kg/ha compost, 400 kg/ha organic soil amendment (Biosol), 150 kg/ha fiber, and 140 kg/ha tackifier
ZERO CONTROL (omit compost and organic soil amendment)	Application 1	150 kg/ha fiber, and seed materials
	Application 2	Pine needles to a depth of 25 mm
	Application 3	150 kg/ha fiber and 140 kg/ha tackifier
COMPOST (replace compost and organic soil amendment with equivalent N amount from GMC)	Application 1	150 kg/ha fiber and seed materials
	Application 2	Pine needles to a depth of 25 mm
	Application 3	150 kg/ha fiber and 140 kg/ha tackifier
	Application 4	10 cu yd (approximately 9000 kg/ha GMC)
COMPOST + SPECIFIED (amend with both GMC and specified compost, organic soil amendment)	Application 1	600 kg/ha compost, 800 kg/ha organic soil amendment (Biosol), 150 kg/ha fiber, and seed materials
	Application 2	Pine needles to a depth of 25 mm
	Application 3	600 kg/ha compost, 400 kg/ha organic soil amendment (Biosol), 150 kg/ha fiber, and 140 kg/ha tackifier
	Application 4	10 cu yd (approximately 9000 kg/ha GMC)

Survey of Compost Products in California

Layout of Study

To evaluate the nutrient levels in current GMC and CCM products in California, 22 composted or co-composted materials and 1 uncomposted material were sampled in December 1998 and January 1999. The purpose of the sampling survey was not to check products against an existing criteria for quality, but to evaluate the range of material that would be available to Caltrans at a given point in time, should a revegetation project require GMC for use as a primary erosion control material and soil amendment.

Sampling and Analysis Methods

A standard sampling protocol was used for collection of material from producer sites. The "typical" material from each producer that would be shipped out to a large project was selected and then sampled from four evenly spaced points around the pile. A 4-liter (1.057-gal) volume was collected at each sampling point. Samples were collected at 1-m depths into the pile at a height of about 1–3 m from the base. Temperatures were measured at each sampling point to characterize whether the pile was still respiring or had cooled off. Surface samples were not collected because this zone made up relatively little of the volume of the bulk of the pile.

One composite sample was created for each source material and was submitted for commercial compost analysis (A91 compost evaluation, Soil and Plant Laboratory, Santa Clara, California). These analyses were averaged by compost source material (green materials compost, biosolids/green material co-compost, agricultural byproduct composts, or other sources).

Results

Fourteen of the samples listed in Table 2 were green materials composts (GMC). Four samples were biosolids/green material co-composts (CCM). Three were agricultural byproduct composts (AGC). Two materials were listed as "Other": the Brea material was an uncomposted green material, and the Upper Valley material was a grape pomace/prunings compost. The 21 remaining compost materials were averaged by source material.

General Chemical and Physical Characteristics

GMC materials had much lower salinity than either CCM or AGC (Table 3). Much of the nearly 32 dS/m salinity measured in AGC came from KCl or NaCl. The salinity of the CCM was about half (16 dS/m) of the AGC. GMC had the lowest average salinity at 9.4 dS/m. The pH of the AGC was also the highest at 8.7. The pH of GMC averaged 7.6 while the CCM was slightly under 7.0.

The AGC was somewhat finer in particle size than either the GMC or CCM, having virtually all the material less than 1/2 in. Two-thirds of the AGC also passed the 1-mm sieve, while approximately half of the GMC and approximately a third of the CCM was that fine. Bulk density of the dry material was similar (726 to 840 lb/cu yd).

Table 2. List of compost and co-compost producers, in alphabetical order, with compost source material listed at right. See Appendix C for key to acronyms and abbreviations.

Producer	Source Material
1. Agri-Fuels, Inc., 24478 Road 140, Tulare, CA 93274	GMC
2. BFI Organics, Newby Island Composting Facility, 1601 Dixon Landing Rd., Milpitas, CA 95035	GMC
3. Brea Green Recycling, 1983 Valencia Ave., Brea, CA 92621	Uncomposted green materials
4. Cold Canyon Landfill, 2268 Carpenter Canyon Rd., San Luis Obispo, CA 93401	GMC
5. Community Recycling and Resource Recovery, 1261 N. Wheeler Ridge Rd., Lamont, CA 93241	CCM
6. Contra Costa Landscaping, P.O. Box 2069, Martinez, CA 94553	GMC
7. EKO Systems, Inc., 8100-100 Chino/Corona Rd., Corona, CA 91720	AGC
8. Foster Farms, 12997 West Highway 140, Livingston, CA 95334	AGC
9. Gilton Resource Recovery Transfer Station, 880 South McClure Rd., Modesto, CA 95354	GMC
10. Greenway Compost, 3210 Oceanside Blvd., Oceanside, CA 93056 (El Corazone)	GMC
11. Mt. Vernon Recycling Facility, City of Bakersfield, 2601 S. Mt. Vernon Ave., Bakersfield, CA 93309	GMC
12. New Era Farm Service, 23004 Rd 140, Tulare, CA 93274	AGC
13. North Valley Organic Recycling, P.O. Box 1159, Chico, CA 95927	GMC
14. Recyc, Inc., 114 Business Center Dr., Corona, CA 91720	GMC
15. Redding, City of, Transfer/Recycling Facility, 2255 Abernathy Ln., Redding, CA 96003	GMC
16. Sacramento, City of, Solid Waste Division, 20 28th St., Sacramento, CA 95814	GMC
17. San Diego, City of, Environ. Serv. Dept., 9601 Ridgehaven Court, Ste. 320, San Diego, CA 92123	GMC
18. San Joaquin Compost, 12321 Halloway Rd., Lost Hills, CA, 93249	CCM
19. Santa Rosa, City of, Laguna Treatment Plant, 4300 Llano Rd., Santa Rosa, CA 95407	CCM
20. Sonoma Compost, 550 Meacham Rd., Petaluma, CA 94952	GMC
21. Turlock, City of, 901 S. Walnut Rd., Turlock, CA 95380-5123	CCM
22. Upper Valley Disposal and Recycling, P.O. Box 382, 1285 Whitehall Ln., St. Helena, CA 94574	Grape pomace composts
23. Zanker Road Resource Mgmt., 705 Los Esteros Rd., San Jose, CA 95134	GMC

Table 3. Summary table of characteristics by source material from 21 compost producers, excluding source materials that are not GMC, CCM, or AGC. See Appendix C for key to acronyms and abbreviations. Analyses from Soil and Plant Laboratory, Inc., Santa Clara, CA (A91 Compost Evaluation).

Total Nutrient Contents and Other Characteristics

		Total nutrient contents												Other characteristics			
		% N	% P	% K	% Ca	% Mg	% Na	% S	ppm Cu	ppm Zn	ppm Mn	ppm Fe	ppm B	TEC	half sat%	pH	ECe
All materials																	
	X	1.4	0.6	0.9	2.3	0.6	0.2	49.9	123.6	263.8	356.3	15363	58.4	513.3	60.8	7.7	14.0
	s	0.4	0.6	0.6	0.7	0.2	0.1	50.5	89.0	168.4	136.3	7261	19.3	156.8	25.2	0.6	9.2
	CV	30.5	97.4	64.8	30.5	34.5	61.8	101.2	72.1	63.8	38.3	47	33.0	30.5	41.5	8.1	65.6
Green material composts (GMC)																	
	X	1.2	0.3	0.8	2.0	0.6	0.2	20.5	75.4	182.5	343.9	14874	58.4	485.6	64.1	7.7	9.4
	s	0.2	0.0	0.3	0.5	0.2	0.1	21.7	31.0	50.5	125.7	7351	13.4	88.3	22.0	0.3	4.4
	CV	17.8	18.2	30.1	23.3	29.0	50.9	106.1	41.2	27.7	36.6	49	23.0	18.2	34.3	3.5	46.4
Co-composted biosolids/green materials (CCM)																	
	X	1.9	1.5	0.4	2.6	0.5	0.2	96.4	261.5	536.8	283.8	18785	48.0	691.5	66.0	7.0	16.8
	s	0.6	0.5	0.1	0.6	0.1	0.0	33.4	43.6	190.5	92.5	8939	19.0	241.4	39.2	0.7	5.8
	CV	29.4	29.9	32.8	21.9	22.9	26.4	34.6	16.7	35.5	32.6	48	39.6	34.9	59.4	10.3	34.4
Agriculture byproducts composts (AGC)																	
	X	1.3	1.2	2.1	3.0	0.9	0.4	125.2	164.7	279.3	511.0	13082	72.3	405.0	38.7	8.7	31.9
	s	0.5	0.6	0.7	1.2	0.3	0.1	43.2	115.4	130.2	150.5	4819	38.8	145.4	7.0	0.4	5.3
	CV	38.7	55.0	33.8	41.0	31.8	32.8	34.5	70.1	46.6	29.4	37	53.6	35.9	18.2	4.7	16.7

Available Nutrient Levels

		NaCl extract					Bicarb extract	DTPA extract				Sat ext			Dil acid % Fe
		ppm NO_3-N	ppm NH_4-N	ppm K	ppm Ca	ppm Mg	ppm PO_4-P	ppm Cu	ppm Zn	ppm Mn	ppm Fe	ppm B	% ECe Na	meq/L Cl	
All materials															
	X	341.6	739.7	6587.0	4533.6	1436.6	493.8	17.0	78.6	72.8	265.6	2.7	29.3	53.4	0.4
	s	413.2	1239.6	2954.9	2366.1	432.0	526.3	23.2	45.0	39.7	203.0	2.3	27.3	44.4	0.4
	CV	121.0	167.6	44.9	52.2	30.1	106.6	136.0	57.2	54.6	76.4	84.2	93.0	83.1	103.4
Green materials composts (GMC)															
	X	199.5	142.4	6752.2	4578.6	1514.9	277.4	6.4	56.1	77.0	234.6	2.0	18.7	43.4	0.2
	s	272.6	176.7	1497.8	1654.0	471.2	108.8	3.8	20.2	37.6	187.4	1.6	15.7	25.5	0.2
	CV	136.6	124.0	22.2	36.1	31.1	39.2	58.8	35.9	48.9	79.9	83.4	83.7	58.7	96.2
Co-composted biosolids/green materials (CCM)															
	X	950.8	3119.8	2898.5	6448.5	1426.5	729.5	36.1	131.5	53.0	361.0	2.3	25.5	27.8	0.9
	s	384.1	816.2	1094.7	3564.6	186.9	686.3	6.8	37.1	46.0	257.1	1.3	12.9	21.7	0.5
	CV	40.4	26.2	37.8	55.3	13.1	94.1	18.9	28.2	86.8	71.2	57.2	50.4	78.0	57.9
Agriculture byproducts composts (AGC)															
	X	192.7	353.3	10734	1770.3	1084.3	1189.3	41.1	112.7	79.3	283.3	6.9	83.8	134.2	0.3
	s	293.9	337.8	4211.1	585.5	375.6	906.6	53.2	68.1	49.2	243.5	1.3	17.9	54.5	0.3
	CV	152.5	95.6	39.2	33.1	34.6	76.2	129.4	60.5	62.0	86.0	19.2	21.4	40.6	100.4

Physical Characteristics

		% Overs, 1"	% Overs, 1/2"	These analyses on 1/2" minus material: Bulk density, lb/cu yd	Moisture content, %	Water, lb/cu yd	Dry matter, lb/cu yd	Organic fraction, lb/cu yd	Mineral fraction, lb/cu yd	Organic %	% of material passing screen size listed (mm): 9.51 mm	6.35 mm	4.75 mm	2.38 mm	1.00 mm	0.50 mm	C:N ratio
All materials																	
	X	0.0	1.4	1222.8	35.7	424.7	798.8	285.1	513.0	35.7	97.7	92.4	88.0	73.2	48.7	29.8	16.4
	s	0.0	1.3	271.4	11.1	134.2	263.7	54.9	261.7		2.7	6.9	8.9	13.0	13.9	12.6	5.9
	CV		89.6	22.2	31.0	31.6	33.0	19.2	51.0		2.8	7.5	10.1	17.8	28.6	42.2	35.7
Green material composts (GMC)																	
	X	0.0	1.5	1168.6	38.0	442.4	726.4	283.9	442.6	39.1	97.7	91.7	87.3	72.6	49.0	30.3	18.9
	s	0.0	1.3	254.8	9.2	146.3	189.6	21.8	194.6		2.3	6.4	7.7	9.3	10.5	11.2	5.3
	CV		84.7	21.8	24.2	33.1	26.1	7.7	44.0		2.4	7.0	8.9	12.8	21.5	37.0	28.0
Co-composted biosolids/green materials (CCM)																	
	X	0.0	2.0	1295.3	38.0	457.0	840.3	313.5	524.5	37.3	96.3	89.9	83.0	61.7	34.5	19.1	12.5
	s	0.0	1.3	343.8	15.0	87.6	406.1	52.2	378.7		4.3	9.4	11.7	15.3	15.8	13.9	3.6
	CV		65.7	26.5	39.4	19.2	48.3	16.6	72.2		4.5	10.4	14.1	24.8	45.7	73.2	29.1
Agriculture byproducts composts (AGC)																	
	X	0.0	0.2	1378.7	21.9	298.7	1081.7	253.0	826.7	23.4	100.0	98.7	97.7	91.3	65.8	42.1	10.3
	s	0.0	0.4	264.0	2.1	34.0	233.0	140.6	203.2		0.0	1.5	1.8	5.2	1.1	4.0	3.6
	CV		173.2	19.2	9.5	11.4	21.5	55.6	24.6		0.0	1.5	1.9	5.7	1.6	9.5	35.4

Macronutrient Contents

Total nitrogen was highest (1.9 percent) in the biosolids/green material co-composts (CCM) (Table 3). GMC and AGC were similar at 1.2 and 1.3 percent N. The amount of this N that will mineralize (release) and become available for plant uptake depends on the available C. These assays only provided an estimate of the C:N ratio. A ratio less than 20 is generally expected to indicate a material that will mineralize N, although this depends on the quality of the C. The GMC had a C:N ratio of about 19, the CCM of about 12, and the AGC of about 10. Extractable (immediately available, solution N) did not follow this trend. CCM had by far the highest extractable N at over 3100 ppm, followed by AGC at 353 ppm and GMC at 142 ppm. Further work is needed to adequately evaluate the ability of the compost to provide N for plant growth.

The variability of these N assays between producers within each source material group was moderate to high. Typical soil samples may have a coefficient of variation (CV) of about 20 percent. This is approximately the CV value of the total N for the GMC, while the variability of the CCM and AGC materials was much higher. This suggests that GMC samples will be more consistent between producers and can be characterized more reproducibly by specifications. In contrast, the extractable N levels for GMC and AGC had CVs greater than 100 percent, while for CCM the CV was 40 percent for nitrate and 26 percent for ammonium. A higher CV is expected from this soluble, easily changed N pool.

Phosphorus (P) levels were 0.2 percent for GMC, 1.5 percent for CCM, and 1.1 percent for AGC. The high P level is typical for material containing biosolids. GMC had the lowest CV for total P, and would be the best characterized by a specification.

Potassium (K) was moderate (0.8 percent) in GMC and 0.4 percent in the CCM. The AGC had much higher total K (2.1 percent), which contributes partly to the high salt content. Sodium (Na) was also over twice as high in the AGC as in the other two materials.

Sulfur (S) was much lower in GMC (20 meq/l) than CCM (96 meq/l) or AGC (125 meq/l).

Calcium (Ca) was similar in all source materials (2 to 3 percent). Magnesium (Mg) was twice as high in the AGC (0.9 percent) as in the CCM and GMC (0.5 to 0.6 percent).

Total copper (Cu) and zinc (Zn) were much lower than the legal limits cited for these metals in municipal solid waste compost in Minnesota and New York (Hegberg et al., 1991). Within the products sampled from California, total Cu and Zn in GMC were about a third of those in the CCM samples. Bioavailable metals were measured by the DTPA extracts, which generally followed the same trends as the total levels. Similarly, baseline data in the Santa Cruz Green Waste Demonstration Project (Buchanan and Grobe, 1977) showed little evidence for excessive contamination for metals under California Title 14 and US EPA 503 regulations.

In general, the variability of the 21 compost samples was very high when viewed as a whole, but when the samples were separated by source material, the variability was reduced. Based only on the N assay data, specifications for total N in GMC should work reasonably well, although statistical evaluation of the data is still in progress. In contrast, the variability in the extractable N levels was greater than the mean, making this parameter difficult to specify. Typical CVs for other compost characteristics ranged from 40 to 80 percent, making specification of these characteristics difficult as well. Further data analysis will be done, perhaps to evaluate a "minimum content" type of specification rather than an average.

Future Study Directions

Duplicate samples from the field survey will be analyzed at UC Davis for the content and release rate of various N pools contained within the compost. These N pools include short-term or extractable (soluble) N, mineralizable N, which is more gradually available, and total N, which is the sum of all forms. These three tests are existing, standard tests for N availability, but they do not evaluate slow-release N that is needed during the years that the plant community is regenerating. Methods to measure this pool of "slowly available" or "organically stabilized" N are being developed. This N fraction is particularly interesting because it is expected to be more rapidly available than much of the total N pool, but is slower and longer- lasting than the extractable and mineralizable N pools. This assay is intended to allow more effective screening of compost materials for appropriate N composition, N release rate, and maturity. Tests will continue through the summer of 2000.

Conclusions

Field application projects in California and other states suggest that GMC is an excellent amendment material for erosion control and revegetation of degraded soils. Preliminary analysis of compost products from different producers in California suggests great variability, making accurate specification and amendment difficult. Further work is in progress regarding methods for evaluating desired characteristics of compost products and for development of monitoring methods for compost performance in the field. In particular, information is needed on release of plant-available N for plant growth and community development. This parameter is critical, since inadequate N has been observed to reduce plant establishment on harsh sites. The effectiveness of surface application of composted materials in retaining moisture also needs to be documented in field situations.

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Appendix A: Tables 4–9

Laboratory Analysis of Compost Materials From Statewide Compost Survey

Table 4. Macronutrient concentrations of compost materials, by producer. See Appendix C for key to abbreviations and acronymns.

		Total Concentrations – Macronutrients						
Producer code #	Source	% N	% P	% K	% Ca	% Mg	% Na	% S
1	GMC	1.35	0.32	1.27	1.84	0.48	0.16	17.10
2	GMC	1.47	0.20	0.91	2.07	0.53	0.16	2.20
4	GMC	1.08	0.18	0.61	1.96	0.66	0.14	6.10
5	GMC	0.92	0.26	0.46	2.16	0.77	0.09	12.70
6	GMC	1.32	0.32	1.20	2.49	0.57	0.27	36.40
7	GMC	1.20	0.27	1.02	1.68	0.44	0.24	11.20
10	GMC	0.96	0.20	0.68	1.62	0.39	0.27	58.80
12	GMC	1.06	0.28	0.99	1.86	0.51	0.10	23.10
14	GMC	1.34	0.24	0.67	2.64	0.63	0.06	11.90
15	GMC	1.32	0.30	1.01	1.55	0.45	0.26	16.80
16	GMC	1.00	0.19	0.74	1.38	0.68	0.15	9.60
17	GMC	1.32	0.26	0.80	1.68	0.59	0.10	4.20
22	GMC	1.71	0.27	0.45	2.19	0.54	0.04	2.20
24	GMC	1.42	0.27	0.92	3.08	1.07	0.11	74.40
111	CCM	1.50	1.06	0.53	2.90	0.63	0.17	131.20
119	CCM	2.73	1.28	0.26	1.77	0.38	0.11	53.90
120	CCM	1.92	2.10	0.35	2.55	0.50	0.13	88.10
121	CCM	1.56	1.60	0.54	3.01	0.42	0.20	112.50
208	AGC	1.68	1.72	2.98	4.36	1.17	0.53	123.10
209	AGC	1.50	1.26	1.76	2.26	0.60	0.39	169.40
213	AGC	0.73	0.47	1.69	2.26	0.93	0.27	83.10
303	Other	0.89	0.14	0.62	1.53	0.37	0.16	14.30
323	Other	2.30	0.41	2.87	0.91	0.40	0.04	16.90

Table 5. Micronutrient concentrations and other chemical characteristics of compost materials, by producer. See Appendix C for key to abbreviations and acronymns.

		Total Concentrations – Micronutrients					Half sat %	Other Chemical Characteristics			
Producer code #	Source	ppm Cu	ppm Zn	ppm Mn	ppm Fe	ppm B		TEC	pH	Qual lime	ECe
1	GMC	128	226	249	11970	42	45	371	7.7	low	16.0
2	GMC	48	145	199	8057	48	116	513	7.9	low	5.1
4	GMC	56	135	459	20510	68	48	433	7.3	low	6.4
5	GMC	54	130	430	19620	67	50	481	7.2	low	7.6
6	GMC	119	287	277	14180	84	52	456	7.8	med	13.6
7	GMC	40	111	221	7853	45	91	456	7.4	none	6.3
10	GMC	106	239	340	36850	69	61	356	7.3	low	12.9
12	GMC	59	168	249	12440	64	38	398	7.7	med	13.8
14	GMC	85	191	383	12600	75	56	573	8.0	med	6.3
15	GMC	46	207	252	11040	49	62	572	8.0	low	14.0
16	GMC	41	127	248	12410	41	69	521	7.9	low	7.7
17	GMC	114	185	501	14350	46	62	487	7.6	low	5.5
22	GMC	71	181	629	9817	61	95	691	7.8	low	2.6
24	GMC	88	223	377	16540	59	52	490	7.5	med	13.8
111	CCM	290	490	288	30030	70	42	976	7.4	med	21.5
119	CCM	202	337	404	11770	37	112	673	6.7	low	9.3
120	CCM	256	795	180	11420	28	26	388	6.1	x	21.2
121	CCM	298	525	263	21920	57	84	729	7.7	low	15.2
208	AGC	154	379	636	17420	116	38	243	8.2	h	37.5
209	AGC	285	327	553	7895	42	46	448	8.9	low	31.2
213	AGC	55	132	344	13930	59	32	524	8.9	med	26.9
303	Other	51	116	185	10010	40	61	355	7.3	low	5.4
323	Other	33	38	120	4582	60	71	748	7.6	low	9.0

Table 6. Available nutrient concentrations, by producer. See Appendix C for key to abbreviations and acronymns.

		Available Nutrient Levels									
		NaCl extract					Bicarbonate extract	DTPA extract			
Producer code #	Source	ppm NO_3-N	ppm NH_4-N	ppm K	ppm Ca	ppm Mg	ppm PO_4-P	ppm Cu	ppm Zn	ppm Mn	ppm Fe
1	GMC	485	11	8434	3133	925	231	5.8	50.0	50.0	226.0
2	GMC	36	12	8444	3798	2174	358	6.0	62.0	94.0	198.0
4	GMC	40	197	5191	4005	1254	128	4.2	24.0	88.0	106.0
5	GMC	962	14	4541	5802	1787	209	7.8	48.0	50.0	204.0
6	GMC	25	248	8571	3168	860	218	16.2	98.0	64.0	364.0
7	GMC	27	10	7529	3294	1540	281	1.8	42.0	110.0	62.0
10	GMC	163	79	5784	3791	1147	86	12.4	94.0	32.0	754.0
12	GMC	476	360	7283	3478	698	278	3.4	54.0	36.0	140.0
14	GMC	84	616	6057	6057	1550	269	6.6	46.0	76.0	140.0
15	GMC	165	13	8369	4990	1582	524	5.4	58.0	56.0	172.0
16	GMC	25	94	6501	4323	1966	390	3.6	34.0	56.0	70.0
17	GMC	24	81	7012	3728	1784	336	5.4	62.0	170.0	156.0
22	GMC	263	19	3963	9263	2097	307	4.0	50.0	74.0	202.0
24	GMC	18	240	6852	5271	1845	268	7.6	64.0	122.0	490.0
111	CCM	793	3298	3750	10767	1344	200	43.2	176.0	46.0	664.0
119	CCM	1335	3904	2141	5376	1690	762	29.0	104.0	118.0	280.0
120	CCM	1187	1972	1781	2271	1414	1688	40.4	98.0	10.0	56.0
121	CCM	488	3305	3922	7380	1258	268	31.6	148.0	38.0	444.0
208	AGC	20	7	5902	2446	1206	650	17.0	152.0	54.0	564.0
209	AGC	26	682	12682	1453	1384	2236	102.0	152.0	136.0	158.0
213	AGC	532	371	13619	1412	663	682	4.2	34.0	48.0	128.0
303	Other	21	229	4983	2781	1191	105	1.2	32.0	68.0	74.0
323	Other	21	1180	22064	1317	1641	1089	1.6	18.0	86.0	148.0

Table 7. Available nutrient concentrations, by producer. See Appendix C for key to abbreviations and acronymns.

Producer code #	Source	Sat ext ppm B	Sat ext % ECe Na	Sat ext meq/L Cl	Dil acid % Fe
1	GMC	1.8	19.4	70.4	0.1
2	GMC	0.7	8.0	21.8	0.2
4	GMC	1.0	12.7	39.4	0.2
5	GMC	2.8	2.6	7.0	0.2
6	GMC	5.1	41.5	66.2	0.2
7	GMC	0.5	17.7	33.8	0.2
10	GMC	2.3	50.4	62.0	1.0
12	GMC	5.6	21.0	59.2	0.2
14	GMC	2.4	3.2	22.0	0.2
15	GMC	0.8	42.0	85.9	0.2
16	GMC	0.4	17.7	49.3	0.1
17	GMC	1.0	6.3	25.4	0.2
22	GMC	1.0	0.9	2.3	0.1
24	GMC	2.2	18.8	62.7	0.3
111	CCM	4.1	38.7	56.3	1.2
119	CCM	1.2	9.1	9.2	0.5
120	CCM	1.5	32.0	12.7	0.4
121	CCM	2.3	22.2	33.1	1.5
208	AGC	7.6	81.7	197.0	0.7
209	AGC	7.8	102.6	107.0	0.1
213	AGC	5.4	67.0	98.6	0.2
303	Other	0.6	11.3	24.6	0.2
323	Other	0.9	1.2	6.3	0.2

Table 8. Physical and chemical characteristics of compost materials, by producer. See Appendix C for key to abbrèviations and acronymns.

				1/2" Minus Material							
Producer code #	Source	Wt retained 1"	Wt retained 1/2"	Bulk dens, lb/cu yd	Moisture %	Water fraction, lb/cu yd	Dry matter, lb/cu yd	Organic fraction, lb/cu yd	Mineral fraction, lb/cu yd	Organic fraction, %	C:N ratio
1	GMC	0	0	1506	33.6	506	1000	292	708	29.2	12.0
2	GMC	0	2.6	806	50.5	407	399	286	113	71.8	27.1
4	GMC	0	0.9	1094	24.1	264	830	283	547	34.7	17.5
5	GMC	0	3.4	1653	44.5	736	917	243	674	26.5	16.0
6	GMC	0	0.4	1166	35.6	415	751	277	474	36.9	15.5
7	GMC	0	4.5	797	40.5	323	474	285	190	60.0	27.8
10	GMC	0	1.5	1088	38.8	422	666	278	388	41.8	24.2
12	GMC	0	1.5	1370	26.4	362	1010	263	745	26.1	13.7
14	GMC	0	0.8	1241	33.3	413	828	343	485	41.4	17.2
15	GMC	0	0.5	1459	47.9	699	760	271	490	35.6	15.0
16	GMC	0	1.1	935	35.7	334	601	283	319	47.0	26.1
17	GMC	0	2.5	1017	32.4	330	687	283	404	41.2	17.3
22	GMC	0	1.2	1110	56.6	628	482	299	183	62.0	20.1
24	GMC	0	0.4	1119	31.7	355	764	288	476	37.7	14.7
111	CCM	0	0.3	1501	29.6	444	1060	311	746	29.4	10.9
119	CCM	0	2.2	1036	56.1	581	455	338	117	74.3	15.1
120	CCM	0	3.5	1671	22.5	376	1300	363	932	28.0	8.1
121	CCM	0	2	973	43.9	427	546	242	303	44.4	15.8
208	AGC	0	0	1438	20.7	298	1140	409	731	35.9	11.9
209	AGC	0	0	1090	24.3	265	825	136	689	16.5	6.1
213	AGC	0	0.7	1608	20.7	333	1280	214	1060	16.8	12.8
303	Other	0	0.7	891	13.7	122	769	303	466	39.4	24.6
323	Other	0	1	1043	43.8	457	586	491	95	83.8	20.2

Table 9. Physical characteristics of compost materials, by producer. See Appendix C for key to abbreviations and acronymns.

Producer code #	Source	% passing 9.51 mm	% passing 6.35 mm	% passing 4.75 mm	% passing 2.38 mm	% passing 1.00 mm	% passing 0.50 mm
1	GMC	98.9	97.1	94.9	83.4	61.7	41.7
2	GMC	92.7	84.7	78.1	64.2	43.1	24.1
4	GMC	100	96.9	92.3	76.2	53.8	36.2
5	GMC	98.6	93	88.8	69.9	34.3	11.2
6	GMC	100	100	96.6	84.3	54.9	33.8
7	GMC	98.6	93.7	86.7	72.7	52.4	35
10	GMC	96.9	86.6	81.9	65.4	42.5	26.8
12	GMC	100	96.1	91.5	82.4	64.1	45.8
14	GMC	96.6	93.9	91.6	76.5	53.1	34.6
15	GMC	96.2	77.9	70.2	50.4	25.2	8.4
16	GMC	97.3	86.3	82	71.6	54.6	40.4
17	GMC	98	87.2	81.8	65.5	44.6	29.7
22	GMC	93.6	90.9	88.2	72.7	46.4	19.1
24	GMC	100	100	97.5	80.8	55.8	37.5
111	CCM	100	98.9	96.3	82.5	57.1	39.2
119	CCM	92	81.8	72.7	46.6	21.6	8
120	CCM	100	97	89.3	62.4	32.9	17.1
121	CCM	93.1	81.8	73.6	55.3	26.4	11.9
208	AGC	100	98.9	98.9	94.7	66.8	44.2
209	AGC	100	100	98.6	93.8	66	37.5
213	AGC	100	97.1	95.6	85.3	64.7	44.6
303	Other	99.4	98.1	94.3	82.3	62.7	47.5
323	Other	100	99.2	98.4	49.2	34.7	23.4

Appendix B: Draft Specifications

Interim Caltrans Specification for Compost

Compost shall be derived from green material consisting of chipped, shredded, or ground vegetation; clean, processed, recycled wood products; Class A, exceptional-quality biosolids composts, as required by U.S. EPA regulations (40 CFR, Part 503c); or a combination of green material and biosolids compost. The compost shall be processed or completed to reduce weed seeds, pathogens and deleterious material, and shall not contain paint, petroleum products, herbicides, fungicides, or other chemical residues that would be harmful to plant or animal life. Other deleterious material, plastic, glass, metal, or rocks shall not exceed 0.1 percent by weight or volume.

A minimum internal temperature of 57°C shall be maintained for at least 15 continuous days during the composting process. The compost shall be thoroughly turned a minimum of five times during the composting process and shall go through a minimum 90-day curing period after the 15-day thermophilic composting process has been completed. Compost shall be screened through a maximum 6-mm screen.

The moisture content of the compost shall not exceed 35 percent. Moisture content shall be determined by California Test 226. Compost products with a higher moisture content may be used, provided the weight of the compost is increased to equal the weight of the compost with a moisture content of 35 percent. Compost will be tested for maturity and stability with a Solvita test kit. The compost shall measure a minimum of "6" on the maturity and stability scale.

***Note:** The screen size and the maturity/stability measurement may change, depending on the intended use of the compost.*

Appendix C: Acronyms and Abbreviations

ac .... acre

AGC .... agricultural byproducts compost (manure, feathermeal, bedding)

bicarb .... bicarbonate extract (Olsen test)

Ca .... calcium

CCM .... co-composted materials (biosolids/green materials compost)

CFR .... Code of Federal Regulations

cm .... centimeters

Cu .... copper

cu .... cubic

CV .... coefficient of variation [(s/X)* 100]

dil acid .... dilute acid extract

dS .... deciSiemens

DTPA .... diethylenetriamine pentaacetic acid

ECe .... electrical conductivity measured on a saturated extract

extract .... the procedure of estimating the nutrient content of materials by mixing it with a specific solution and removing the solution for analysis

ft .... foot

GMC .... green materials compost

ha .... hectare

half sat %... the half saturation percentage is the percentage of water equal to half of the saturated capacity of the compost

in .... inch

K .... potassium

KCl .... potassium chloride

kg .... kilogram

l .... liter

m .... meter

meq .... millequivalent

Mg .... magnesium

mg .... milligram

mm .... millimeter

N .... nitrogen

Na .... sodium

NaCl .... sodium chloride

NH_4-N .... ammonium nitrogen

NO_3-N .... nitrate nitrogen

O .... oxygen

P .... phosphorus

pH .... negative log of hydrogen ion activity

PO_4-P .... phosphate phosphorus

ppm .... parts per million

S .... sulfur

s .... standard deviation

sat ext .... saturation extract

SO_4 .... sulfate

TEC .... total exchangeable cations (measured on saturation extract, except for sodium)

X .... mean

yd .... yard

Zn .... zinc

G3691-7

The Wisconsin Storm Water MANUAL

Vegetated water courses can be designed to achieve several goals including water conveyance, treatment, and/or infiltration. While the approach to design is similar for all these goals, choose design parameters in accordance with the objective of the specific project. For example, the maximum permissible velocity might be used for conveyance channels, but a much lower velocity may be used for channel design where the primary purpose is water treatment or infiltration.

Grassed Swales

Grassed swales are concave, vegetated conveyance systems that can improve water quality through infiltration and filtering. A swale can be a natural depression or a constructed, parabolic or trapezoidal channel. Swales are designed to treat the water quality volume and to provide stable conveyance of higher flows. Placing check dams at regular intervals along the channel length perpendicular to the direction of flow may enhance treatment capability.

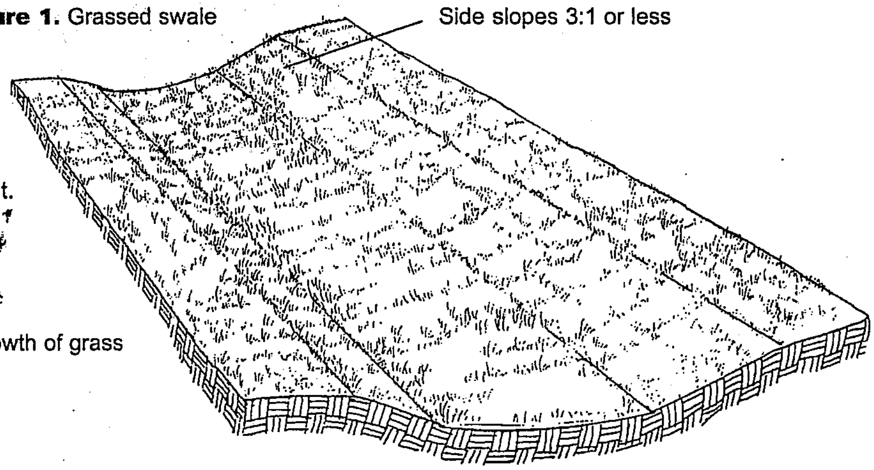
Grassed swales are appropriate alternatives to curb and gutter in residential settings, industrial parks, institutional areas and highway medians. They are used in combination with other management practices to provide pretreatment and flow attenuation. The amount of flow they receive may need to be limited for maximum treatment capability. In addition, if located on permeable soils, a portion of the flow will infiltrate into the ground, decreasing the runoff volume. Historically, swales have been designed as conveyance facilities. This chapter discusses the swale's ability to carry water while stressing the design parameters that can enhance pollutant removal.

Principles

Grass swales employ sedimentation and biofiltration as their primary pollutant removal mechanisms. Biofiltration includes filtration, infiltration, adsorption and biological uptake. When soils allow significant infiltration, pollutant removal mechanisms include adsorption of heavy metals and phosphorus onto soil particles and biological metabolism of organic pollutants.

Grassed swales encourage deposition of sand and soil aggregates if the velocity through the swale is less than 1.5 feet per second (ft/s). Even at this low velocity swales will not be effective in removing primary clay and silt particles. Velocities in excess of approximately 5 to 8 ft/s may reduce treatment effectiveness and may induce erosion. Table 1 illustrates typical removal efficiencies of a well designed, well maintained, conventional swale.

Figure 1. Grassed swale



Source: Modified from Galli, 1992

Table 1. Estimated removal efficiencies for grass swales

Pollutant	% Removal
Total suspended solids	70%
Total phosphorous	30%
Total nitrogen	25%
Trace metals	50–90%

(Schueler, 1992)

Field tests of swales, with and without check dams, have shown mixed results. In some cases, pollutant levels in the discharge water from the swale have increased. This may be due to over-fertilization and pesticide/herbicide use on lawns that drain to the swale. Leaching from culverts may increase metal levels as well. It is expected, however, that the use of check dams to increase detention and sedimentation will result in significant improvement in pollutant removal.

Planning guidelines

Grassed swales are appropriate in low and medium density residential areas in place of, or as supplements to, curb and gutter. Industrial and institutional areas (such as schools, hospitals, etc.) may also be suitable. Culverts may need to be constructed under driveways, modifying the flow pattern across the swale.

Swales can be used for 0- to 50-acre sites with the number and length of swales dictated by the topography and flows from the contributing area. The width of a swale depends on the flow rate and velocity through the swale. Minimum length and width requirements to achieve water quality improvements may limit the use of a swale at some sites.

Soil suitability is a key factor in a system designed for infiltration. While infiltration is desirable, highly permeable soils increase the potential for groundwater contamination. The volume of water that infiltrates into the soil may be greatly reduced because of compaction during construction. Compacted soil, coupled with the short residence time, reduces the potential for infiltration. Increasing the residence time and careful construction maximizes a swale's infiltration capability. If a swale is designed to infiltrate, the site must meet the same criteria for soil type, infiltration rate and separation to groundwater and bedrock as an infiltration basin or trench.

A swale may be considered a pretreatment unit and used in combination with other management practices to achieve the desired water quality treatment level for the 1.5-inch rain, and peak shaving for the 2-year, 24-hour storm. Swales designed for conveyance are often constructed to pass the peak flows from a 10-year, 24-hour duration storm or greater.

A maximum drain time of 24 hours is recommended to alleviate homeowner concerns about standing water and the possible nuisance conditions standing water may encourage. Homeowner education may be necessary to discourage use of the swale for leaf piling, burning or trash disposal. In some areas, homeowners are responsible for mowing in and around the swale. However, this practice should be discouraged because grass height is an important operational parameter, directly related to the design depth and velocity of the flow in the channel. Homeowners typically do not have mowers capable of cutting grasses above 6 inches. The local unit of government should carry the responsibility for mowing the swale and maintaining the buffer area.

Local officials should consider the advantages and disadvantages of swales over curb and gutter in a residential area. On the positive side, swales cost less, drain rain from the road surface more efficiently, improve water quality, attenuate flows and provide groundwater recharge. Conversely, they require more right-of-way and may not be compatible with sidewalk design. They need to be seeded and mowed and can be damaged by snowplows and parking. They cannot be used on poorly drained soils, steep slopes or where the swale has no outlet such as a stream, lake or storm sewer system.

A long swale serving a small watershed, where the swale density (feet of swale per acre of drainage basin) is large, will encourage infiltration. However, if the number of driveways and therefore the number of culverts is too great, the swale's effectiveness diminishes (MD-DOE,1984b).

Design considerations

Swales have been used as conveyance systems for many years. If swales are intended for use as practices not only for conveyance but also for water quality improvement, use the following design criteria.

Soils. The soil's infiltrating capability is a factor in locating swales. As with infiltration basins and trenches, swale infiltration rates measured in the field should be between 0.5 and 5.0 inches per hour (in./hr.). The suitable soils are sand, loamy sand, sandy loam, loam and silty loam, Types A, B and C soils* (with some restrictions on A and C soils). Coarse, highly permeable soils provide little treatment capability and soils with very low permeabilities do not provide adequate infiltration during the short retention time in the channel. The erodibility of the soil is also a consideration in designing a grassed swale since the swale must be able to carry the estimated flows without eroding the swale or destroying the vegetation.

Shape. Swales should be parabolic or trapezoidal in shape. If adequate capacity is available to handle peak design flows, check dams may be used to increase in-channel detention. Parabolic swales are most like nature and less prone to meander under low flow conditions. Trapezoidal swales provide additional area for infiltration but may tend to meander at low flows and eventually revert to a parabolic form. Triangular channels provide little area for infiltration and are prone to erode since flows are concentrated. A swale should be designed for small to moderate storm events. If possible, the natural drainage patterns should be maintained and left undisturbed, provided the soils are stable.

Dimensions. The side slopes in the channel should be 3:1 (horizontal:vertical) or more to increase surface area, and to provide stability and access to equipment. Slopes 4:1 or flatter are safer for mowing equipment. A minimum swale length of at least 200 feet is necessary to achieve particulate pollutant removal. Velocities during the 1.5-inch rain event should not exceed 1.5 ft/s if deposition is to occur.

Vegetative cover. A dense vegetative cover slows the flow of water through the swale and increases treatment. Choose vegetation that can be maintained on the site and can tolerate being wet for 24 hours. Do not mow the grass beneath the water quality design depth. The swale velocity must not exceed erosive levels for the vegetative cover in the channel (see table 2 for examples of grasses and their related velocities).

Slopes. Swales are limited by the area's topography. Slopes of less than 5% are desirable. Erosion, channelization or diversion around the check dam can occur whenever flows exceed stabilization design considerations. Unless the swale is very carefully constructed and maintained, slopes of less than 1% may result in excessive ponding unless an underdrain is provided. Slopes in excess of 4% often result in high velocity, concentrated flows unless check dams are present. Infrequent overtopping of the swale may be tolerated if the flooding does not damage the swale or nearby property. An initial field survey will determine the natural grade of the area and other unique landscape features or traffic patterns that may affect the alignment and/or capacity of the swale.

Design calculations

The design of swales intended for water quality improvement must include the following elements:

- The water quality volume and design flow rates must be calculated using an appropriate hydrologic model.
- The accepted design criteria for water quality improvements are the 1.5-inch rain event and the 2-yr, 24-hour event for peak shaving. Using these criteria, the volume of water to be treated is equal to the 1.5-inch rain upland runoff volume, plus the rain that falls on the surface of the swale, minus the infiltration volume from the swale bottom surface. Flows above the treatment storm should pass through or around the swale.
- The desired shape is parabolic or trapezoidal. Design calculations will vary with the channel geometry.
- The capacity calculation for the peak discharge must use the continuity equation and Manning's Equation or design tables for channel dimensions using appropriate retarding factors.
- A maximum ponding time (Tp), of 24 hours is appropriate in residential areas.
- A maximum depth based on soil infiltration rate, f, must be calculated using dmax = (f)(Tp).
- The maximum velocity must not exceed that causing erosion of the vegetative liner. A treatment velocity of approximately 1.5 ft/s for the water quality event is desirable to encourage pollutant removal and infiltration.

Table 2. Permissible velocities for various ground covers.

No.	Cover	Slope range (%)	Permissible velocity (feet/second) Erosion resistant soils	Easily eroded soils
1	Bermudagrass (Bynodon dactylon)	0–5	8	6
2	Kentucky 31 Tall fescue (Festuca arundinacea)	0–5	7	5
3	Grass-legume mixture	0–5	5	4
4	Red fescue Redtop (Agrostis Alba) Lespedeza servicea Alfalfa	0–5	3.5	2.5
5	Annuals* Common Lespedeza Sudangrass	0–5	3.5	2.5
6	Rock riprap section (for temporary construction)	5–10	8	6.5

**Annuals are used on mild slopes (less than 3 %) or as temporary protection until permanent covers are established. Use on slopes steeper than 5 % is not recommended.*

Source: Modified from USDA-SCS, 1988

- Side slopes should be at 3:1 or flatter for a vegetative liner and 2:1 for rip rap.
- Check dams may be installed if adequate capacity is maintained for design storms.

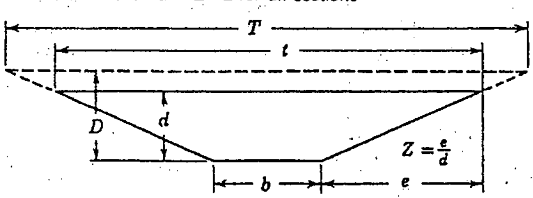
Swale design is described by the USDA Natural Resources Conservation Service (USDA-SCS, 1988). When designing the swale for conveyance and/or water quality, the drainage area must be delineated and broken into reaches or areas where the grade or vegetation changes. Runoff rates and volumes are calculated using an appropriate hydrologic model. The slope of the swale can be determined from topographic maps, profiles or cross sections. The swale is first designed to be able to pass the peak flows safely. The design capacity is calculated using Manning's formula or the look-up tables (tables 4a-4h) based on the vegetative retardance factors as described below (Table 3). The swale cross section and the liner preference are selected based on site conditions. For water quality, a parabolic shape and vegetative liner are preferred.

The design tables that follow are from the *Engineering Field Manual* (USDA-SCS, 1988). Table 3 classifies the different vegetative liners according to their retardance value. Using these relationships and table 2 for permissive velocity, the dimensions of the swale can be determined from tables 4a-4h. These tables assume a retardance no greater than a short grass (designated as D) when developing the safe velocity. The design capacity is based on the design height and type of vegetation, with a retardance of C or B for taller and/or thicker grasses. Tables 4a-4h provide the top width (in feet), depth (in feet) and velocity (in feet/second) at capacity when the grass is tall, for a given peak flow, safe velocity and grade. The peak flow in these tables assumes a 10-year, 24-hour storm event. The dimensions given in these tables do not account for the depth of the vegetative liner, sedimentation and freeboard. This additional space requirement must be taken into consideration when designing the swale.

Both the inlet and outlet of a swale must be designed with the intent of dissipating the flow energy, particularly if the flow comes from a concrete structure and enters a vegetative lining. Every swale must discharge to a stable outlet such as a waterway, open channel, subsurface system or similar management practice. The outlet must be constructed in such a way as to prevent scour in the receiving unit.

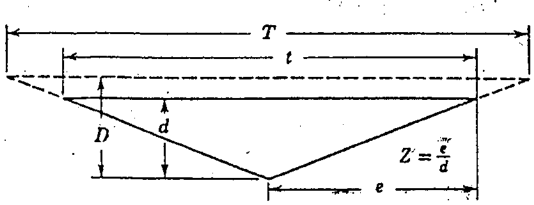
Figure 2. Channel cross section, wetted perimeter, hydraulic radius and top formulas.

Note: Freeboard = $D-d$ for all sections



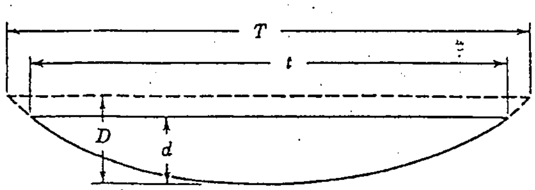
Cross-Sectional Area a	Wetted Perimeter, p	Hydraulic Radius $R=\frac{a}{p}$	Top Width
$bd + Zd^2$	$b + 2d\sqrt{Z^2+1}$	$\frac{bd + Zd^2}{b + 2d\sqrt{Z^2+1}}$	$t = b + 2dZ$ $T = b + 2DZ$

Trapezoidal cross section



Cross-Sectional Area a	Wetted Perimeter, p	Hydraulic Radius $R=\frac{a}{p}$	Top Width
Zd^2	$2d\sqrt{Z^2+1}$	$\frac{Zd}{2\sqrt{Z^2+1}}$ or $\frac{d}{2}$ approx.	$t = 2dZ$ $T = \frac{D}{d}t$

Triangular cross section



Cross-Sectional Area a	Wetted Perimeter, p	Hydraulic Radius $R=\frac{a}{p}$	Top Width
$\frac{2}{3}td$	$t + \frac{8d^2}{3t}$	$\frac{t^2d}{1.5t^2 + 4d^2}$ or $\frac{2d}{3}$ approx.	$t = \frac{a}{0.67d}$ $T = t\left(\frac{D}{d}\right)^{1/2}$

Parabolic cross section

Source: USDA-SCS, undated

Table 3. Classification of vegetation cover as to degree of retardance

Retardance	Cover	Condition
A	Weeping lovegrass	Excellent stand, tall (average 30 inches)
	Reed canarygrass or yellow bluestem ischaemum	Excellent stand, tall (average 36 inches)
B	Smooth bromegrass	Good stand, mowed, average 12 to 15 inches)
	Bermuda grass	Good stand, tall (average 12 inches)
	Native grass mixture (little bluestem, blue grama and other long and short Midwest grasses)	Good stand, unmowed
	Tall fescue	Good stand, unmowed (average 18 inches)
	Sericea lespedeza	Good stand, not woody, tall (average 19 inches)
	Grass-legume mixture — timothy, smooth bromegrass or orchardgrass	Good stand, uncut (average 20 inches)
	Reed canarygrass	Good stand, uncut (average 12 to 15 inches)
	Tall fescue, with birdsfoot trefoil or ladino clover	Good stand, uncut (average 18 inches)
	Blue grama	Good stand, uncut (average 13 inches)
C	Bahiagrass	Good stand, uncut (6 to 8 inches)
	Bermudagrass	Good stand, mowed (average 6 inches)
	Redtop	Good stand, headed (15 to 20 inches)
	Grass-legume mixture — summer (orchardgrass, redtop, Italian ryegrass and common lespedeza)	Good stand, uncut (6 to 8 inches)
	Centipedegrass	Very dense cover (average 6 inches)
	Kentucky bluegrass	Good stand, headed (6 to 12 inches)
D	Bermudagrass	Good stand, cut to 2.5-inch height
	Red fescue	Good stand, headed (12 to 18 inches)
	Buffalograss	Good stand, uncut (3 to 6 inches)
	Grass-legume mixture—fall, spring (orchardgrass, redtop, Italian ryegrass and common lespedeza)	Good stand, uncut (4 to 5 inches)
	Sericea lespedeza or Kentucky Bluegrass	Good stand, cut to 2-inch height Very good stand before cutting
E	Bermudagrass	Good stand, cut to 1.5-inch height
	Bermudagrass	Burned stubble

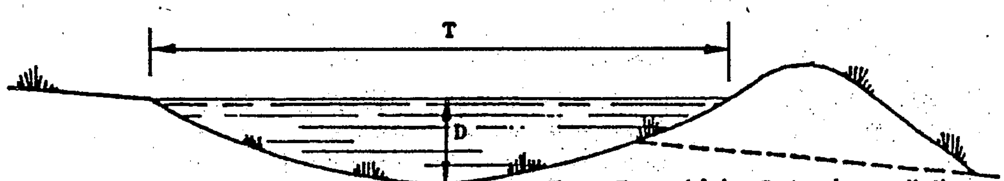
Source: USDA-SCS, 1988

Table 4a. Parabolic waterway design.

V1 FOR RETARDANCE "D", TOP WIDTH (T), DEPTH' (D) AND V2 FOR RETARDANCE "C"

GRADE 2.00 PERCENT

Q CFS	V1=2.0			V1=2.5			V1=3.0			V1=3.5			V1=4.0			V1=4.5			V1=5.0			V1=5.5			V1=6.0		
	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2
5	5.9	0.9	1.5																								
10	12.4	0.8	1.5	8.1	0.9	2.0	5.9	1.0	2.5																		
15	18.5	0.8	1.5	12.3	0.9	2.0	9.3	1.0	2.5	6.8	1.1	3.0	4.7	1.4	3.5												
20	24.7	0.8	1.5	16.7	0.9	2.0	12.5	1.0	2.5	9.4	1.1	3.0	7.0	1.2	3.6	4.7	1.5	4.1									
25	30.8	0.8	1.5	20.8	0.9	2.0	15.9	1.0	2.4	11.8	1.1	3.0	9.0	1.2	3.5	6.8	1.3	4.1									
30	37.0	0.8	1.5	25.0	0.9	2.0	19.0	1.0	2.5	14.3	1.1	3.0	11.0	1.2	3.5	8.5	1.3	4.1	6.4	1.5	4.7						
35	43.2	0.8	1.5	29.1	0.9	2.0	22.2	1.0	2.5	16.9	1.0	3.0	12.9	1.1	3.5	10.1	1.3	4.1	7.8	1.4	4.7						
40	49.3	0.8	1.5	33.3	0.9	2.0	25.3	1.0	2.5	19.3	1.0	3.0	14.8	1.1	3.5	11.6	1.3	4.1	9.1	1.4	4.7	7.1	1.6	5.2			
45	55.5	0.8	1.5	37.4	0.9	2.0	28.5	1.0	2.5	21.7	1.0	3.0	16.7	1.1	3.5	13.1	1.3	4.1	10.4	1.4	4.7	8.2	1.6	5.2			
50	61.7	0.8	1.5	41.6	0.9	2.0	31.7	1.0	2.5	24.1	1.0	3.0	18.8	1.1	3.5	14.7	1.2	4.1	11.7	1.4	4.7	9.3	1.5	5.3	7.1	1.8	5.8
55	67.8	0.8	1.5	45.7	0.9	2.0	34.8	1.0	2.5	26.5	1.0	3.0	20.7	1.1	3.5	16.2	1.2	4.1	12.9	1.4	4.7	10.4	1.5	5.3	8.2	1.7	5.8
60	74.0	0.8	1.5	49.9	0.9	2.0	38.0	1.0	2.5	28.9	1.0	3.0	22.6	1.1	3.5	17.7	1.2	4.1	14.1	1.4	4.7	11.4	1.5	5.3	9.2	1.7	5.8
65	80.2	0.8	1.5	54.0	0.9	2.0	41.1	1.0	2.5	31.4	1.0	3.0	24.5	1.1	3.5	19.5	1.2	4.1	15.4	1.3	4.7	12.4	1.5	5.3	10.1	1.7	5.8
70	86.3	0.8	1.5	58.2	0.9	2.0	44.3	1.0	2.5	33.8	1.0	3.0	26.3	1.1	3.5	21.0	1.2	4.1	16.6	1.3	4.7	13.5	1.5	5.3	11.0	1.6	5.8
75	92.5	0.8	1.5	62.3	0.9	2.0	47.5	1.0	2.5	36.2	1.0	3.0	28.2	1.1	3.5	22.4	1.2	4.1	17.8	1.3	4.7	14.5	1.5	5.3	11.8	1.6	5.8
80	98.7	0.8	1.5	66.5	0.9	2.0	50.6	1.0	2.5	38.6	1.0	3.0	30.1	1.1	3.5	23.9	1.2	4.1	19.0	1.3	4.7	15.5	1.5	5.3	12.7	1.6	5.8
85	104.8	0.8	1.5	70.6	0.9	2.0	53.8	1.0	2.5	41.0	1.0	3.0	32.0	1.1	3.5	25.4	1.2	4.1	20.3	1.3	4.7	16.5	1.5	5.3	13.6	1.6	5.8
90	111.0	0.8	1.5	74.8	0.9	2.0	57.0	1.0	2.5	43.4	1.0	3.0	33.8	1.1	3.5	26.9	1.2	4.1	21.8	1.3	4.6	17.5	1.5	5.3	14.4	1.6	5.8
95	117.2	0.8	1.5	78.9	0.9	2.0	60.1	1.0	2.5	45.8	1.0	3.0	35.7	1.1	3.5	28.4	1.2	4.1	23.0	1.3	4.6	18.6	1.5	5.3	15.3	1.6	5.8
100	123.3	0.8	1.5	83.1	0.9	2.0	63.3	1.0	2.5	48.2	1.0	3.0	37.6	1.1	3.5	29.9	1.2	4.1	24.2	1.3	4.6	19.6	1.5	5.3	16.2	1.6	5.8
105	129.5	0.8	1.5	87.3	0.9	2.0	66.4	1.0	2.5	50.6	1.0	3.0	39.5	1.1	3.5	31.4	1.2	4.1	25.4	1.3	4.6	20.6	1.5	5.3	17.0	1.6	5.8
110	135.7	0.8	1.5	91.4	0.9	2.0	69.6	1.0	2.5	53.0	1.0	3.0	41.3	1.1	3.5	32.9	1.2	4.1	26.6	1.3	4.7	21.6	1.4	5.3	17.9	1.6	5.8
115	141.8	0.8	1.5	95.6	0.9	2.0	72.8	1.0	2.5	55.4	1.0	3.0	43.2	1.1	3.5	34.4	1.2	4.1	27.9	1.3	4.7	22.6	1.4	5.3	16.7	1.6	5.8
120	148.0	0.8	1.5	99.7	0.9	2.0	75.9	1.0	2.5	57.9	1.0	3.0	45.1	1.1	3.5	35.9	1.2	4.1	29.1	1.3	4.7	23.9	1.4	5.2	19.5	1.6	5.8
125	154.1	0.8	1.5	103.9	0.9	2.0	79.1	1.0	2.5	60.3	1.0	3.0	47.0	1.1	3.5	37.4	1.2	4.1	30.3	1.3	4.7	24.8	1.4	5.2	20.4	1.6	5.8
130	160.3	0.8	1.5	108.0	0.9	2.0	82.3	1.0	2.5	62.7	1.0	3.0	48.8	1.1	3.5	38.9	1.2	4.1	31.5	1.3	4.7	25.8	1.4	5.3	21.2	1.6	5.8
135	166.5	0.8	1.5	112.2	0.9	2.0	85.4	1.0	2.5	65.1	1.0	3.0	50.7	1.1	3.5	40.3	1.2	4.1	32.7	1.3	4.7	26.8	1.4	5.3	22.1	1.6	5.8
140	172.6	0.8	1.5	116.3	0.9	2.0	88.6	1.0	2.5	67.5	1.0	3.0	52.6	1.1	3.5	41.8	1.2	4.1	33.9	1.3	4.7	27.8	1.4	5.3	22.9	1.6	5.8
145	178.8	0.8	1.5	120.5	0.9	2.0	91.8	1.0	2.5	69.9	1.0	3.0	54.5	1.1	3.5	43.3	1.2	4.1	35.1	1.3	4.7	28.8	1.4	5.3	23.7	1.6	5.8
150	185.0	0.8	1.5	124.6	0.9	2.0	94.9	1.0	2.5	72.3	1.0	3.0	56.4	1.1	3.5	44.8	1.2	4.1	36.3	1.3	4.7	29.8	1.4	5.3	24.6	1.6	5.8

PARABOLIC WATERWAY DESIGN
(RETARDANCE "D" AND "C")

T - Top width, Retardance "C"
D - Depth, Retardance "C"
V_2 - Velocity, Retardance "C"
V_1 - Velocity, Retardance "D"

Note – Depth "D" does not include allowance for freeboard and settlement.

Table 4b.

V1 FOR RETARDANCE "D". TOP WIDTH (T), DEPTH' (D) AND V2 FOR RETARDANCE "C"

GRADE 3.00 PERCENT

Q CFS	V1=2.0			V1=2.5			V1=3.0			V1=3.5			V1=4.0			V1=4.5			V1=5.0			V1=5.5			V1=6.0		
	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2
5	7.4	0.7	1.4	4.9	0.8	1.9	3.2	1.0	2.3																		
10	15.1	0.7	1.4	10.2	0.8	1.9	7.6	0.8	2.4	5.7	0.9	2.9	4.0	1.1	3.4												
15	22.6	0.7	1.4	15.6	0.8	1.9	11.5	0.8	2.4	8.8	0.9	2.9	6.7	1.0	3.4	5.1	1.1	4.0									
20	30.1	0.7	1.4	20.7	0.8	1.9	15.5	0.8	2.4	11.8	0.9	2.9	9.2	0.9	3.4	7.2	1.0	4.0	5.5	1.2	4.6						
25	37.6	0.7	1.4	25.9	0.8	1.9	19.4	0.8	2.4	15.0	0.9	2.9	11.6	0.9	3.4	9.2	1.0	4.0	7.2	1.1	4.6	5.6	1.3	5.1			
30	45.1	0.7	1.4	31.1	0.8	1.9	23.3	0.8	2.4	18.0	0.9	2.9	14.0	0.9	3.4	11.1	1.0	4.0	8.9	1.1	4.6	7.1	1.2	5.2	5.3	1.5	5.7
35	52.7	0.7	1.4	36.2	0.8	1.9	27.1	0.8	2.4	21.0	0.9	2.9	16.5	0.9	3.4	13.0	1.0	4.0	10.5	1.1	4.6	8.4	1.2	5.2	6.7	1.4	5.7
40	60.2	0.7	1.4	41.4	0.8	1.9	31.0	0.8	2.4	24.0	0.9	2.9	18.9	0.9	3.4	14.9	1.0	4.0	12.0	1.1	4.6	9.8	1.2	5.2	7.9	1.3	5.7
45	67.7	0.7	1.4	46.6	0.8	1.9	34.9	0.8	2.4	27.0	0.9	2.9	21.2	0.9	3.4	17.0	1.0	4.0	13.6	1.1	4.6	11.1	1.2	5.2	9.1	1.3	5.7
50	75.2	0.7	1.4	51.8	0.8	1.9	38.8	0.8	2.4	29.9	0.9	2.9	23.6	0.9	3.4	18.9	1.0	4.0	15.2	1.1	4.6	12.4	1.2	5.2	10.2	1.3	5.7
55	82.8	0.7	1.4	56.9	0.8	1.9	42.6	0.8	2.4	32.9	0.9	2.9	25.9	0.9	3.4	20.8	1.0	4.0	16.7	1.1	4.6	13.7	1.2	5.2	11.3	1.3	5.7
60	90.3	0.7	1.4	62.1	0.8	1.9	46.5	0.8	2.4	35.9	0.9	2.9	28.3	0.9	3.4	22.7	1.0	4.0	18.5	1.1	4.5	14.9	1.2	5.2	12.4	1.3	5.7
65	97.8	0.7	1.4	67.3	0.8	1.9	50.4	0.8	2.4	38.9	0.9	2.9	30.6	0.9	3.4	24.6	1.0	4.0	20.0	1.1	4.5	16.2	1.2	5.2	13.5	1.3	5.7
70	105.3	0.7	1.4	72.4	0.8	1.9	54.3	0.8	2.4	41.9	0.9	2.9	33.0	0.9	3.4	26.4	1.0	4.0	21.5	1.1	4.5	17.5	1.2	5.2	14.5	1.3	5.7
75	112.8	0.7	1.4	77.6	0.8	1.9	58.1	0.8	2.4	44.9	0.9	2.9	35.3	0.9	3.4	28.3	1.0	4.0	23.1	1.1	4.5	19.1	1.2	5.1	15.6	1.3	5.7
80	120.4	0.7	1.4	82.8	0.8	1.9	62.0	0.8	2.4	47.9	0.9	2.9	37.7	0.9	3.4	30.2	1.0	4.0	24.6	1.1	4.5	20.3	1.2	5.1	16.7	1.3	5.7
85	127.9	0.7	1.4	88.0	0.8	1.9	65.9	0.8	2.4	50.9	0.9	2.9	40.1	0.9	3.4	32.1	1.0	4.0	26.1	1.1	4.5	21.6	1.2	5.1	17.8	1.2	5.7
90	135.4	0.7	1.4	93.1	0.8	1.9	69.8	0.8	2.4	53.9	0.9	2.9	42.4	0.9	3.4	34.0	1.0	4.0	27.7	1.1	4.5	22.9	1.2	5.1	18.9	1.2	5.7
95	142.9	0.7	1.4	98.3	0.8	1.9	73.6	0.8	2.4	56.9	0.9	2.9	44.8	0.9	3.4	35.9	1.0	4.0	29.2	1.1	4.5	24.1	1.2	5.1	20.2	1.2	5.7
100	150.5	0.7	1.4	103.5	0.8	1.9	77.5	0.8	2.4	59.9	0.9	2.9	47.1	0.9	3.4	37.8	1.0	4.0	30.7	1.1	4.5	25.4	1.2	5.1	21.2	1.2	5.7
105	158.0	0.7	1.4	108.7	0.8	1.9	81.4	0.8	2.4	62.8	0.9	2.9	49.5	0.9	3.4	39.6	1.0	4.0	32.3	1.1	4.5	26.7	1.2	5.1	22.3	1.2	5.7
110	165.5	0.7	1.4	113.8	0.8	1.9	85.3	0.8	2.4	65.8	0.9	2.9	51.8	0.9	3.4	41.5	1.0	4.0	33.8	1.1	4.6	27.9	1.2	5.1	23.3	1.2	5.7
115	173.0	0.7	1.4	119.0	0.8	1.9	89.1	0.8	2.4	68.8	0.9	2.9	54.2	0.9	3.4	43.4	1.0	4.0	35.4	1.1	4.6	29.2	1.2	5.1	24.4	1.2	5.7
120	180.5	0.7	1.4	124.2	0.8	1.9	93.0	0.8	2.4	71.8	0.9	2.9	56.5	0.9	3.4	45.3	1.0	4.0	36.9	1.1	4.6	30.5	1.2	5.1	25.5	1.2	5.7
125	188.1	0.7	1.4	129.4	0.8	1.9	96.9	0.8	2.4	74.8	0.9	2.9	58.9	0.9	3.4	47.2	1.0	4.0	38.4	1.1	4.6	31.7	1.2	5.1	26.5	1.2	5.7
130	195.6	0.7	1.4	134.5	0.8	1.9	100.8	0.8	2.4	77.8	0.9	2.9	61.2	0.9	3.4	49.1	1.0	4.0	40.0	1.1	4.6	33.0	1.2	5.1	27.6	1.2	5.7
135	203.1	0.7	1.4	139.7	0.8	1.9	104.6	0.8	2.4	80.8	0.9	2.9	63.6	0.9	3.4	51.0	1.0	4.0	41.5	1.1	4.6	34.3	1.2	5.1	28.6	1.2	5.7
140	210.6	0.7	1.4	144.9	0.8	1.9	108.5	0.8	2.4	83.8	0.9	2.9	66.0	0.9	3.4	52.8	1.0	4.0	43.0	1.1	4.6	35.6	1.2	5.1	29.7	1.2	5.7
145	218.2	0.7	1.4	150.1	0.8	1.9	112.4	0.8	2.4	86.8	0.9	2.9	68.3	0.9	3.4	54.7	1.0	4.0	44.6	1.1	4.6	36.8	1.2	5.1	30.7	1.2	5.7
150	225.7	0.7	1.4	155.2	0.8	1.9	116.3	0.8	2.4	89.8	0.9	2.9	70.7	0.9	3.4	56.6	1.0	4.0	46.1	1.1	4.6	38.1	1.2	5.1	31.8	1.2	5.7

PARABOLIC WATERWAY DESIGN
(RETARDANCE "D" AND "C")

Table 4c.

V1 FOR RETARDANCE "D". TOP WIDTH (T), DEPTH' (D) AND V2 FOR RETARDANCE "C"

GRADE 4.00 PERCENT

Q CFS	V1=2.0			V1=2.5			V1=3.0			V1=3.5			V1=4.0			V1=4.5			V1=5.0			V1=5.5			V1=6.0		
	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2
5	8.5	0.6	1.4	5.9	0.7	1.8	4.1	0.8	2.3																		
10	17.2	0.6	1.4	12.1	0.7	1.8	8.8	0.7	2.3	6.7	0.8	2.8	5.2	0.9	3.3	3.8	1.0	3.9									
15	25.8	0.6	1.4	18.1	0.7	1.8	13.4	0.7	2.3	10.3	0.8	2.8	8.1	0.8	3.4	6.4	0.9	3.9	4.9	1.0	4.5						
20	34.4	0.6	1.4	24.2	0.7	1.8	17.8	0.7	2.3	13.9	0.8	2.8	10.9	0.8	3.4	9.7	0.9	3.9	6.9	1.0	4.5	5.5	1.1	5.0			
25	43.0	0.6	1.4	30.2	0.7	1.9	22.3	0.7	2.3	17.4	0.8	2.8	13.8	0.8	3.3	10.9	0.9	3.9	8.8	1.0	4.5	7.1	1.0	5.1	5.7	1.2	5.6
30	51.6	0.6	1.4	36.3	0.7	1.9	26.7	0.7	2.3	20.8	0.8	2.8	16.5	0.8	3.3	13.2	0.9	3.9	10.7	0.9	4.5	8.7	1.0	5.1	7.1	1.1	5.6
35	60.2	0.6	1.4	42.3	0.7	1.9	31.1	0.7	2.3	24.3	0.8	2.8	19.3	0.8	3.4	15.6	0.9	3.9	12.5	0.9	4.5	10.3	1.0	5.0	8.4	1.1	5.6
40	68.8	0.6	1.4	48.3	0.7	1.9	35.6	0.7	2.3	27.8	0.8	2.8	22.0	0.8	3.4	17.8	0.9	3.9	14.4	0.9	4.5	11.8	1.0	5.0	9.8	1.1	5.7
45	77.4	0.6	1.4	54.4	0.7	1.9	40.0	0.7	2.4	31.2	0.8	2.8	24.8	0.8	3.4	20.0	0.9	3.9	16.4	0.9	4.4	13.3	1.0	5.0	11.1	1.1	5.7
50	86.0	0.6	1.4	60.4	0.7	1.9	44.5	0.7	2.4	34.7	0.8	2.8	27.5	0.8	3.4	22.2	0.9	3.9	18.2	0.9	4.4	14.9	1.0	5.0	12.3	1.1	5.7
55	94.6	0.6	1.4	66.5	0.7	1.9	48.9	0.7	2.4	38.2	0.8	2.8	30.3	0.8	3.4	24.4	0.9	3.9	20.0	0.9	4.4	16.6	1.0	5.0	13.6	1.1	5.7
60	103.2	0.6	1.4	72.5	0.7	1.9	53.4	0.7	2.4	41.7	0.8	2.8	33.0	0.8	3.4	26.6	0.9	3.9	21.8	0.9	4.5	18.1	1.0	5.0	14.9	1.1	5.7
65	111.8	0.6	1.4	78.5	0.7	1.9	57.8	0.7	2.4	45.1	0.8	2.8	35.8	0.8	3.4	28.9	0.9	3.9	23.6	0.9	4.5	19.6	1.0	5.0	16.2	1.1	5.7
70	120.4	0.6	1.4	84.6	0.7	1.9	62.3	0.7	2.4	48.6	0.8	2.8	38.6	0.8	3.4	31.1	0.9	3.9	25.4	0.9	4.5	21.1	1.0	5.0	17.7	1.1	5.6
75	129.0	0.6	1.4	90.6	0.7	1.9	66.7	0.7	2.4	52.1	0.8	2.8	41.3	0.8	3.4	33.3	0.9	3.9	27.2	0.9	4.5	22.6	1.0	5.0	19.0	1.1	5.6
80	137.6	0.6	1.4	96.7	0.7	1.9	71.2	0.7	2.4	55.5	0.8	2.8	44.1	0.8	3.4	35.5	0.9	3.9	29.1	0.9	4.5	24.1	1.0	5.0	20.2	1.1	5.6
85	146.2	0.6	1.4	102.7	0.7	1.9	75.6	0.7	2.4	59.0	0.8	2.8	46.8	0.8	3.4	37.7	0.9	3.9	30.9	0.9	4.5	25.6	1.0	5.0	21.5	1.1	5.6
90	154.8	0.6	1.4	108.7	0.7	1.9	80.0	0.7	2.4	62.5	0.8	2.8	49.6	0.8	3.4	39.9	0.9	3.9	32.7	0.9	4.5	27.1	1.0	5.0	22.8	1.1	5.6
95	163.4	0.6	1.4	114.8	0.7	1.9	84.5	0.7	2.4	65.9	0.8	2.8	52.3	0.8	3.4	42.2	0.9	3.9	34.5	0.9	4.5	28.6	1.0	5.0	24.0	1.1	5.6
100	172.0	0.6	1.4	120.8	0.7	1.9	88.9	0.7	2.4	69.4	0.8	2.8	55.1	0.8	3.4	44.4	0.9	3.9	36.3	0.9	4.5	30.1	1.0	5.0	25.3	1.1	5.6
105	180.6	0.6	1.4	126.9	0.7	1.9	93.4	0.7	2.4	72.9	0.8	2.8	57.8	0.8	3.4	46.6	0.9	3.9	38.1	0.9	4.5	31.6	1.0	5.0	26.5	1.1	5.6
110	189.2	0.6	1.4	132.9	0.7	1.9	97.8	0.7	2.4	76.3	0.8	2.8	60.6	0.8	3.4	48.8	0.9	3.9	39.9	0.9	4.5	33.1	1.0	5.0	27.8	1.1	5.6
115	197.8	0.6	1.4	138.9	0.7	1.9	102.3	0.7	2.4	79.8	0.8	2.8	63.3	0.8	3.4	51.0	0.9	3.9	41.7	0.9	4.5	34.6	1.0	5.0	29.0	1.1	5.6
120	206.4	0.6	1.4	145.0	0.7	1.9	106.7	0.7	2.4	83.3	0.8	2.8	66.1	0.8	3.4	53.3	0.9	3.9	43.6	0.9	4.5	36.1	1.0	5.0	30.2	1.1	5.7
125	215.0	0.6	1.4	151.0	0.7	1.9	111.2	0.7	2.4	86.8	0.8	2.8	68.8	0.8	3.4	55.5	0.9	3.9	45.4	0.9	4.5	37.6	1.0	5.0	31.5	1.1	5.7
130	223.7	0.6	1.4	157.1	0.7	1.9	115.6	0.7	2.4	90.2	0.8	2.8	71.6	0.8	3.4	57.7	0.9	3.9	47.2	0.9	4.5	39.1	1.0	5.0	32.7	1.1	5.7
135	232.3	0.6	1.4	163.1	0.7	1.9	120.1	0.7	2.4	93.7	0.8	2.8	74.3	0.8	3.4	59.9	0.9	3.9	49.0	0.9	4.5	40.6	1.0	5.0	34.0	1.1	5.7
140	240.9	0.6	1.4	169.1	0.7	1.9	124.5	0.7	2.4	97.2	0.8	2.8	77.1	0.8	3.4	62.1	0.9	3.9	50.8	0.9	4.5	42.1	1.0	5.0	35.2	1.1	5.7
145	249.5	0.6	1.4	175.2	0.7	1.9	129.0	0.7	2.4	100.6	0.8	2.8	79.8	0.8	3.4	64.3	0.9	3.9	52.6	0.9	4.5	43.6	1.0	5.0	36.5	1.1	5.7
150	258.1	0.6	1.4	181.2	0.7	1.9	133.4	0.7	2.4	104.1	0.8	2.8	82.6	0.8	3.4	66.6	0.9	3.9	54.4	0.9	4.5	45.1	1.0	5.0	37.8	1.1	5.7

PARABOLIC WATERWAY DESIGN
(RETARDANCE "D" AND "C")

Table 4d.

V1 FOR RETARDANCE "D", TOP WIDTH (T), DEPTH' (D) AND V2 FOR RETARDANCE "C"

GRADE 5.00 PERCENT

Q CFS	V1=2.0			V1=2.5			V1=3.0			V1=3.5		
	T	D	V2	T	D	V2	T	D	V2	T	D	V2
5	9.5	0.6	1.4	6.7	0.6	1.8	4.7	0.7	2.3	3.5	0.8	2.8
10	19.0	0.6	1.4	13.7	0.6	1.8	9.7	0.7	2.3	7.6	0.7	2.8
15	28.5	0.6	1.4	20.5	0.6	1.8	14.8	0.7	2.3	11.7	0.7	2.8
20	38.0	0.6	1.4	27.3	0.6	1.8	19.7	0.7	2.3	15.5	0.7	2.8
25	47.5	0.6	1.4	34.1	0.6	1.8	24.6	0.7	2.3	19.4	0.7	2.8
30	57.0	0.6	1.4	40.9	0.6	1.8	29.5	0.7	2.3	23.3	0.7	2.8
35	66.5	0.6	1.4	47.7	0.6	1.8	34.4	0.7	2.3	27.2	0.7	2.8
40	76.0	0.6	1.4	54.6	0.6	1.8	39.4	0.7	2.3	31.0	0.7	2.8
45	85.5	0.6	1.4	61.4	0.6	1.8	44.3	0.7	2.3	34.9	0.7	2.8
50	95.0	0.6	1.4	68.2	0.6	1.8	49.2	0.7	2.3	38.8	0.7	2.8
55	104.6	0.6	1.4	75.0	0.6	1.8	54.1	0.7	2.3	42.7	0.7	2.8
60	114.1	0.6	1.4	81.8	0.6	1.8	59.0	0.7	2.3	46.6	0.7	2.8
65	123.6	0.6	1.4	88.6	0.6	1.8	63.9	0.7	2.3	50.4	0.7	2.8
70	133.1	0.6	1.4	95.5	0.6	1.8	68.9	0.7	2.3	54.3	0.7	2.8
75	142.6	0.6	1.4	102.3	0.6	1.8	73.8	0.7	2.3	58.2	0.7	2.8
80	152.1	0.6	1.4	109.1	0.6	1.8	78.7	0.7	2.3	62.1	0.7	2.8
85	161.6	0.6	1.4	115.9	0.6	1.8	83.6	0.7	2.3	65.9	0.7	2.8
90	171.1	0.6	1.4	122.7	0.6	1.8	88.5	0.7	2.3	69.8	0.7	2.8
95	180.6	0.6	1.4	129.6	0.6	1.8	93.4	0.7	2.3	73.7	0.7	2.8
100	190.1	0.6	1.4	136.4	0.6	1.8	98.4	0.7	2.3	77.6	0.7	2.8
105	199.6	0.6	1.4	143.2	0.6	1.8	103.3	0.7	2.3	81.5	0.7	2.8
110	209.1	0.6	1.4	150.0	0.6	1.8	108.2	0.7	2.3	85.3	0.7	2.8
115	218.6	0.6	1.4	156.8	0.6	1.8	113.1	0.7	2.3	89.2	0.7	2.8
120	228.1	0.6	1.4	163.6	0.6	1.8	118.0	0.7	2.3	93.1	0.7	2.8
125	237.6	0.6	1.4	170.5	0.6	1.8	123.0	0.7	2.3	97.0	0.7	2.8
130	247.1	0.6	1.4	177.3	0.6	1.8	127.9	0.7	2.3	100.8	0.7	2.8
135	256.6	0.6	1.4	184.1	0.6	1.8	132.8	0.7	2.3	104.7	0.7	2.8
140	266.1	0.6	1.4	190.9	0.6	1.8	137.7	0.7	2.3	108.6	0.7	2.8
145	275.6	0.6	1.4	197.7	0.6	1.8	142.6	0.7	2.3	112.5	0.7	2.8
150	285.1	0.6	1.4	204.6	0.6	1.8	147.5	0.7	2.3	116.4	0.7	2.8

Q CFS	V1=4.0			V1=4.5			V1=5.0			V1=5.5			V1=6.0		
	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2
5															
10	6.0	0.8	3.3	4.7	0.8	3.8	3.4	1.0	4.4						
15	9.2	0.7	3.3	7.3	0.8	3.8	5.9	0.9	4.4	4.7	1.0	5.0			
20	12.4	0.7	3.3	9.9	0.8	3.8	8.0	0.9	4.4	6.5	0.9	4.9	5.3	1.0	5.5
25	15.5	0.7	3.3	12.6	0.8	3.8	10.1	0.8	4.4	8.3	0.9	5.0	6.8	1.0	5.6
30	18.6	0.7	3.3	15.1	0.8	3.8	12.2	0.8	4.4	10.1	0.9	5.0	8.3	1.0	5.6
35	21.7	0.7	3.3	17.6	0.8	3.8	14.5	0.8	4.4	11.8	0.9	5.0	9.8	1.0	5.6
40	24.8	0.7	3.3	20.1	0.8	3.8	16.5	0.8	4.4	13.6	0.9	5.0	11.3	1.0	5.5
45	27.9	0.7	3.3	22.6	0.8	3.8	18.6	0.8	4.4	15.5	0.9	4.9	12.8	1.0	5.5
50	31.0	0.7	3.3	25.1	0.8	3.8	20.6	0.8	4.4	17.2	0.9	4.9	14.3	1.0	5.5
55	34.1	0.7	3.3	27.6	0.8	3.8	22.7	0.8	4.4	18.9	0.9	4.9	15.9	0.9	5.5
60	37.2	0.7	3.3	30.1	0.8	3.8	24.7	0.8	4.4	20.6	0.9	4.9	17.3	0.9	5.5
65	40.3	0.7	3.3	32.6	0.8	3.8	26.8	0.8	4.4	22.3	0.9	4.9	18.8	0.9	5.5
70	43.4	0.7	3.3	35.1	0.8	3.8	28.9	0.8	4.4	24.0	0.9	4.9	20.2	0.9	5.5
75	46.5	0.7	3.3	37.7	0.8	3.8	30.9	0.8	4.4	25.7	0.9	4.9	21.6	0.9	5.5
80	49.6	0.7	3.3	40.2	0.8	3.8	33.0	0.8	4.4	27.4	0.9	4.9	23.1	0.9	5.5
85	52.7	0.7	3.3	42.7	0.8	3.8	35.0	0.8	4.4	29.1	0.9	5.0	24.5	0.9	5.5
90	55.8	0.7	3.3	45.2	0.8	3.8	37.1	0.8	4.4	30.9	0.9	5.0	26.0	0.9	5.5
95	58.9	0.7	3.3	47.7	0.8	3.8	39.2	0.8	4.4	32.6	0.9	5.0	27.4	0.9	5.5
100	62.0	0.7	3.3	50.2	0.8	3.8	41.2	0.8	4.4	34.3	0.9	5.0	28.8	0.9	5.5
105	65.1	0.7	3.3	52.7	0.8	3.8	43.3	0.8	4.4	36.0	0.9	5.0	30.3	0.9	5.5
110	68.2	0.7	3.3	55.2	0.8	3.8	45.3	0.8	4.4	37.7	0.9	5.0	31.7	0.9	5.5
115	71.3	0.7	3.3	57.7	0.8	3.8	47.4	0.8	4.4	39.4	0.9	5.0	33.2	0.9	5.5
120	74.3	0.7	3.3	60.2	0.8	3.8	49.5	0.8	4.4	41.1	0.9	5.0	34.6	0.9	5.5
125	77.4	0.7	3.3	62.7	0.8	3.8	51.5	0.8	4.4	42.8	0.9	5.0	36.0	0.9	5.5
130	80.5	0.7	3.3	65.2	0.8	3.8	53.6	0.8	4.4	44.6	0.9	5.0	37.5	0.9	5.5
135	83.6	0.7	3.3	67.8	0.8	3.8	55.6	0.8	4.4	46.3	0.9	5.0	38.9	0.9	5.5
140	86.7	0.7	3.3	70.3	0.8	3.8	57.7	0.8	4.4	48.0	0.9	5.0	40.4	0.9	5.5
145	89.8	0.7	3.3	72.8	0.8	3.8	59.8	0.8	4.4	49.7	0.9	5.0	41.8	0.9	5.5
150	92.9	0.7	3.3	75.3	0.8	3.8	61.8	0.8	4.4	51.4	0.9	5.0	43.2	0.9	5.5

PARABOLIC WATERWAY DESIGN
(RETARDANCE "D" AND "C")

Table 4e.

V1 FOR RETARDANCE "D", TOP WIDTH (T), DEPTH' (D) AND V2 FOR RETARDANCE "B"

GRADE 2.00 PERCENT

Q CFS	V1=2.0			V1=2.5			V1=3.0			V1=3.5		
	T	D	V2	T	D	V2	T	D	V2	T	D	V2
5	7.1	1.2	0.9									
10	14.7	1.2	0.9	9.5	1.3	1.2	7.0	1.4	1.5			
15	22.0	1.2	0.9	14.5	1.3	1.2	10.8	1.4	1.5	8.0	1.5	1.9
20	29.3	1.2	0.9	19.6	1.2	1.2	14.6	1.3	1.5	10.9	1.5	1.9
25	36.6	1.2	0.9	24.4	1.2	1.2	18.5	1.3	1.5	13.8	1.4	1.9
30	43.9	1.2	0.9	29.3	1.2	1.2	22.2	1.3	1.6	16.6	1.4	1.9
35	51.2	1.2	0.9	34.2	1.2	1.2	25.8	1.3	1.6	19.6	1.4	1.9
40	58.5	1.2	0.9	39.0	1.2	1.2	29.5	1.3	1.6	22.4	1.4	1.9
45	65.8	1.2	0.9	43.9	1.2	1.2	33.2	1.3	1.6	25.2	1.4	1.9
50	73.1	1.2	0.9	48.8	1.2	1.2	36.8	1.3	1.6	28.0	1.4	1.9
55	80.4	1.2	0.9	53.6	1.2	1.2	40.5	1.3	1.6	30.7	1.4	1.9
60	87.7	1.2	0.9	58.5	1.2	1.2	44.2	1.3	1.6	33.5	1.4	1.9
65	95.0	1.2	0.9	63.4	1.2	1.2	47.9	1.3	1.6	36.3	1.4	1.9
70	102.3	1.2	0.9	68.2	1.2	1.2	51.6	1.3	1.6	39.1	1.4	1.9
75	109.6	1.2	0.9	73.1	1.2	1.2	55.2	1.3	1.6	41.9	1.4	1.9
80	116.9	1.2	0.9	78.0	1.2	1.2	58.9	1.3	1.6	44.7	1.4	1.9
85	124.2	1.2	0.9	82.9	1.2	1.2	62.6	1.3	1.6	47.4	1.4	1.9
90	131.5	1.2	0.9	87.7	1.2	1.2	66.3	1.3	1.6	50.2	1.4	1.9
95	138.8	1.2	0.9	92.6	1.2	1.2	69.9	1.3	1.6	53.0	1.4	1.9
100	146.1	1.2	0.9	97.5	1.2	1.2	73.6	1.3	1.6	55.8	1.4	1.9
105	153.4	1.2	0.9	102.3	1.2	1.2	77.3	1.3	1.6	58.6	1.4	1.9
110	160.7	1.2	0.9	107.2	1.2	1.2	81.0	1.3	1.6	61.4	1.4	1.9
115	168.0	1.2	0.9	112.1	1.2	1.2	84.7	1.3	1.6	64.2	1.4	1.9
120	175.3	1.2	0.9	117.0	1.2	1.2	88.3	1.3	1.6	67.0	1.4	1.9
125	182.6	1.2	0.9	121.8	1.2	1.2	92.0	1.3	1.6	69.7	1.4	1.9
130	189.9	1.2	0.9	126.7	1.2	1.2	95.7	1.3	1.6	72.5	1.4	1.9
135	197.3	1.2	0.9	131.6	1.2	1.2	99.4	1.3	1.6	75.3	1.4	1.9
140	204.6	1.2	0.9	136.5	1.2	1.2	103.1	1.3	1.6	78.1	1.4	1.9
145	211.9	1.2	0.9	141.3	1.2	1.2	106.7	1.3	1.6	80.9	1.4	1.9
150	219.2	1.2	0.9	146.2	1.2	1.2	110.4	1.3	1.6	83.7	1.4	1.9

Q CFS	V1=4.0			V1=4.5			V1=5.0			V1=5.5			V1=6.0		
	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2
5															
10															
15	5.5	1.9	2.1												
20	8.1	1.6	2.3	5.5	2.1	2.6									
25	10.4	1.6	2.3	7.9	1.8	2.7									
30	12.7	1.5	2.3	9.7	1.7	2.7	7.3	2.0	3.1						
35	14.9	1.5	2.3	11.5	1.7	2.7	8.9	1.9	3.2						
40	17.1	1.5	2.3	13.3	1.6	2.8	10.4	1.8	3.2	8.0	2.1	3.6			
45	19.3	1.5	2.3	15.0	1.6	2.8	11.8	1.8	3.2	9.2	2.0	3.7			
50	21.7	1.5	2.3	16.7	1.6	2.8	13.2	1.8	3.2	10.5	1.9	3.7	7.9	2.3	4.1
55	23.9	1.5	2.3	18.5	1.6	2.8	14.6	1.7	3.2	11.7	1.9	3.7	9.2	2.2	4.1
60	26.0	1.5	2.3	20.2	1.6	2.8	16.0	1.7	3.2	12.8	1.9	3.7	10.2	2.1	4.1
65	28.2	1.5	2.3	22.1	1.6	2.8	17.4	1.7	3.3	14.0	1.9	3.7	11.3	2.1	4.2
70	30.3	1.5	2.3	23.8	1.6	2.8	18.8	1.7	3.3	15.2	1.9	3.7	12.3	2.1	4.2
75	32.5	1.5	2.3	25.5	1.6	2.8	20.1	1.7	3.3	16.2	1.8	3.7	13.2	2.0	4.2
80	34.6	1.5	2.3	27.2	1.6	2.8	21.5	1.7	3.3	17.4	1.8	3.8	14.2	2.0	4.2
85	36.8	1.5	2.3	28.9	1.6	2.8	22.9	1.7	3.3	18.5	1.8	3.8	15.1	2.0	4.2
90	39.0	1.5	2.3	30.6	1.6	2.8	24.6	1.7	3.2	19.6	1.8	3.8	16.1	2.0	4.2
95	41.1	1.5	2.3	32.3	1.6	2.8	25.9	1.7	3.3	20.8	1.8	3.8	17.0	2.0	4.2
100	43.3	1.5	2.3	34.0	1.6	2.8	27.3	1.7	3.3	21.9	1.8	3.8	18.0	2.0	4.2
105	45.4	1.5	2.3	35.7	1.6	2.8	28.6	1.7	3.3	23.0	1.8	3.8	18.9	2.0	4.2
110	47.6	1.5	2.3	37.3	1.6	2.8	30.0	1.7	3.3	24.1	1.8	3.8	19.8	2.0	4.2
115	49.8	1.5	2.3	39.0	1.6	2.8	31.3	1.7	3.3	25.3	1.8	3.8	20.8	2.0	4.2
120	51.9	1.5	2.3	40.7	1.6	2.8	32.7	1.7	3.3	26.7	1.8	3.7	21.7	2.0	4.2
125	54.1	1.5	2.3	42.4	1.6	2.8	34.1	1.7	3.3	27.8	1.8	3.7	22.6	1.9	4.3
130	56.2	1.5	2.3	44.1	1.6	2.8	35.4	1.7	3.3	28.9	1.8	3.7	23.6	1.9	4.3
135	58.4	1.5	2.3	45.8	1.6	2.8	36.8	1.7	3.3	30.0	1.8	3.7	24.5	1.9	4.3
140	60.6	1.5	2.3	47.5	1.6	2.8	38.1	1.7	3.3	31.1	1.8	3.7	25.4	1.9	4.3
145	62.7	1.5	2.3	49.2	1.6	2.8	39.5	1.7	3.3	32.3	1.8	3.7	26.4	1.9	4.3
150	64.9	1.5	2.3	50.9	1.6	2.8	40.8	1.7	3.3	33.4	1.8	3.7	27.3	1.9	4.3

PARABOLIC WATERWAY DESIGN
(RETARDANCE "D" AND "B")

Table 4f.

V1 FOR RETARDANCE "D", TOP WIDTH (T), DEPTH' (D) AND V2 FOR RETARDANCE "B"

GRADE 3.00 PERCENT

Q CFS	V1=2.0			V1=2.5			V1=3.0			V1=3.5			V1=4.0			V1=4.5			V1=5.0			V1=5.5			V1=6.0		
	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2
5	8.8	1.0	0.8	5.8	1.1	1.1	3.9	1.5	1.3																		
10	18.0	1.0	0.8	12.1	1.1	1.2	8.9	1.1	1.5	6.6	1.3	1.8	4.7	1.5	2.1												
15	27.0	1.0	0.8	18.3	1.1	1.2	13.5	1.1	1.5	10.3	1.2	1.8	7.9	1.3	2.2	6.0	1.5	2.5									
20	35.9	1.0	0.8	24.4	1.1	1.2	18.2	1.1	1.5	13.8	1.2	1.8	10.7	1.3	2.2	8.3	1.4	2.6	6.4	1.6	3.0						
25	44.9	1.0	0.8	30.5	1.1	1.2	22.8	1.1	1.5	17.5	1.2	1.8	13.4	1.3	2.2	10.6	1.4	2.6	8.3	1.5	3.0	6.4	1.7	3.4			
30	53.9	1.0	0.8	36.6	1.1	1.2	27.3	1.1	1.5	20.9	1.2	1.8	16.2	1.3	2.2	12.8	1.4	2.6	10.2	1.5	3.0	8.1	1.6	3.5	6.0	1.9	3.9
35	62.8	1.0	0.8	42.7	1.1	1.2	31.8	1.1	1.5	24.4	1.2	1.8	19.1	1.2	2.2	15.0	1.3	2.6	12.0	1.4	3.0	9.6	1.6	3.5	7.6	1.7	3.9
40	71.8	1.0	0.8	48.8	1.1	1.2	36.4	1.1	1.5	27.9	1.2	1.8	21.9	1.2	2.2	17.2	1.3	2.6	13.8	1.4	3.1	11.1	1.5	3.5	9.0	1.7	4.0
45	80.8	1.0	0.8	54.9	1.0	1.2	40.9	1.1	1.5	31.3	1.2	1.8	24.6	1.2	2.2	19.6	1.3	2.6	15.5	1.4	3.1	12.6	1.5	3.5	10.2	1.7	4.0
50	89.7	1.0	0.8	60.9	1.0	1.2	45.4	1.1	1.5	34.8	1.2	1.8	27.3	1.2	2.2	21.8	1.3	2.6	17.3	1.4	3.1	14.1	1.5	3.5	11.5	1.6	4.0
55	98.7	1.0	0.8	67.0	1.0	1.2	50.0	1.1	1.5	38.3	1.2	1.8	30.0	1.2	2.2	24.0	1.3	2.6	19.1	1.4	3.1	15.5	1.5	3.5	12.7	1.6	4.0
60	107.7	1.0	0.8	73.1	1.0	1.2	54.5	1.1	1.5	41.8	1.2	1.8	32.7	1.2	2.2	26.1	1.3	2.6	21.0	1.4	3.1	16.9	1.5	3.6	14.0	1.6	4.0
65	116.6	1.0	0.8	79.2	1.0	1.2	59.0	1.1	1.5	45.2	1.2	1.8	35.5	1.2	2.2	28.3	1.3	2.6	22.8	1.4	3.1	18.4	1.5	3.6	15.1	1.6	4.0
70	125.6	1.0	0.8	85.3	1.0	1.2	63.6	1.1	1.5	48.7	1.2	1.8	38.2	1.2	2.2	30.5	1.3	2.6	24.5	1.4	3.1	19.8	1.5	3.6	16.3	1.6	4.1
75	134.6	1.0	0.8	91.4	1.0	1.2	68.1	1.1	1.5	52.2	1.2	1.9	40.9	1.2	2.2	32.6	1.3	2.6	26.2	1.4	3.1	21.5	1.5	3.5	17.5	1.6	4.1
80	143.6	1.0	0.8	97.5	1.0	1.2	72.7	1.1	1.5	55.7	1.2	1.9	43.6	1.2	2.2	34.8	1.3	2.6	28.0	1.4	3.1	23.0	1.5	3.5	18.8	1.6	4.1
85	152.5	1.0	0.8	103.6	1.0	1.2	77.2	1.1	1.5	59.1	1.2	1.9	46.3	1.2	2.2	37.0	1.3	2.6	29.7	1.4	3.1	24.4	1.5	3.6	20.0	1.6	4.1
90	161.5	1.0	0.8	109.7	1.0	1.2	81.7	1.1	1.5	62.6	1.2	1.9	49.1	1.2	2.2	39.1	1.3	2.6	31.5	1.4	3.1	25.8	1.5	3.6	21.2	1.6	4.1
95	170.5	1.0	0.8	115.8	1.0	1.2	86.3	1.1	1.5	66.1	1.2	1.9	51.8	1.2	2.2	41.3	1.3	2.6	33.2	1.4	3.1	27.2	1.5	3.6	22.6	1.6	4.0
100	179.5	1.0	0.8	121.9	1.0	1.2	90.8	1.1	1.5	69.6	1.2	1.9	54.5	1.2	2.2	43.5	1.3	2.6	35.0	1.4	3.1	28.7	1.5	3.6	23.8	1.6	4.0
105	188.4	1.0	0.8	128.0	1.0	1.2	95.4	1.1	1.5	73.0	1.2	1.9	57.2	1.2	2.2	45.6	1.3	2.6	36.7	1.4	3.1	30.1	1.5	3.6	25.0	1.6	4.0
110	197.4	1.0	0.8	134.1	1.0	1.2	99.9	1.1	1.5	76.5	1.2	1.9	60.0	1.2	2.2	47.8	1.3	2.6	38.4	1.4	3.1	31.5	1.5	3.6	26.2	1.6	4.0
115	206.4	1.0	0.8	140.1	1.0	1.2	104.4	1.1	1.5	80.0	1.2	1.9	62.7	1.2	2.2	50.0	1.3	2.6	40.2	1.4	3.1	32.9	1.5	3.6	27.4	1.6	4.0
120	215.3	1.0	0.8	146.2	1.0	1.2	109.0	1.1	1.5	83.5	1.2	1.9	65.4	1.2	2.2	52.2	1.3	2.6	41.9	1.4	3.1	34.4	1.5	3.6	28.6	1.6	4.0
125	224.3	1.0	0.8	152.3	1.0	1.2	113.5	1.1	1.5	86.9	1.2	1.9	68.1	1.2	2.2	54.3	1.3	2.6	43.7	1.4	3.1	35.8	1.5	3.6	29.8	1.6	4.0
130	233.3	1.0	0.8	158.4	1.0	1.2	118.1	1.1	1.5	90.4	1.2	1.9	70.9	1.2	2.2	56.5	1.3	2.6	45.4	1.4	3.1	37.2	1.5	3.6	30.9	1.6	4.0
135	242.3	1.0	0.8	164.5	1.0	1.2	122.6	1.1	1.5	93.9	1.2	1.9	73.6	1.2	2.2	58.7	1.3	2.6	47.2	1.4	3.1	38.6	1.5	3.6	32.1	1.6	4.1
140	251.2	1.0	0.8	170.6	1.0	1.2	127.1	1.1	1.5	97.4	1.2	1.9	76.3	1.2	2.2	60.8	1.3	2.6	48.9	1.4	3.1	40.1	1.5	3.6	33.3	1.6	4.1
145	260.2	1.0	0.8	176.7	1.0	1.2	131.7	1.1	1.5	100.9	1.2	1.9	79.0	1.2	2.2	63.0	1.3	2.6	50.7	1.4	3.1	41.5	1.5	3.6	34.5	1.6	4.1
150	269.2	1.0	0.8	182.8	1.0	1.2	136.2	1.1	1.5	104.3	1.2	1.9	81.7	1.2	2.2	65.2	1.3	2.6	52.4	1.4	3.1	42.9	1.5	3.6	35.7	1.6	4.1

PARABOLIC WATERWAY DESIGN
(RETARDANCE "D" AND "B")

Table 4g.

V1 FOR RETARDANCE "D", TOP WIDTH (T), DEPTH' (D) AND V2 FOR RETARDANCE "B"

GRADE 4.00 PERCENT

Q CFS	V1=2.0			V1=2.5			V1=3.0			V1=3.5			V1=4.0			V1=4.5			V1=5.0			V1=5.5			V1=6.0		
	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2
5	10.1	0.9	0.8	7.0	1.0	1.1	4.9	1.1	1.4																		
10	20.5	0.9	0.8	14.4	0.9	1.1	10.3	1.0	1.4	7.9	1.1	1.8	6.1	1.2	2.1	4.5	1.4	2.4									
15	30.7	0.9	0.8	21.5	0.9	1.1	15.7	1.0	1.4	12.0	1.1	1.8	9.4	1.1	2.1	7.4	1.2	2.5	5.8	1.4	2.8						
20	40.9	0.9	0.8	28.6	0.9	1.1	20.9	1.0	1.4	16.3	1.0	1.8	12.6	1.1	2.1	10.1	1.2	2.5	8.0	1.3	2.9	6.3	1.4	3.3			
25	51.1	0.9	0.8	35.8	0.9	1.1	26.1	1.0	1.4	20.3	1.0	1.8	16.0	1.1	2.1	12.7	1.2	2.5	10.2	1.3	2.9	8.2	1.4	3.4	6.5	1.5	3.8
30	61.3	0.9	0.8	42.9	0.9	1.1	31.4	1.0	1.4	24.4	1.0	1.8	19.2	1.1	2.1	15.2	1.2	2.5	12.3	1.3	2.9	10.0	1.3	3.4	8.1	1.5	3.8
35	71.5	0.9	0.8	50.1	0.9	1.1	36.6	1.0	1.4	28.3	1.0	1.8	22.4	1.1	2.1	18.0	1.2	2.5	14.4	1.2	2.9	11.7	1.3	3.4	9.6	1.4	3.8
40	81.8	0.9	0.8	57.2	0.9	1.1	41.8	1.0	1.5	32.4	1.0	1.8	25.6	1.1	2.1	20.6	1.2	2.5	16.5	1.2	2.9	13.5	1.3	3.4	11.1	1.4	3.8
45	92.0	0.9	0.8	64.4	0.9	1.1	47.0	1.0	1.5	36.4	1.0	1.8	28.8	1.1	2.1	23.1	1.2	2.5	18.8	1.2	2.9	15.2	1.3	3.4	12.6	1.4	3.9
50	102.2	0.9	0.8	71.5	0.9	1.1	52.2	1.0	1.5	40.5	1.0	1.8	32.0	1.1	2.1	25.7	1.2	2.5	20.9	1.2	2.9	17.0	1.3	3.4	14.0	1.4	3.9
55	112.4	0.9	0.8	78.7	0.9	1.1	57.5	1.0	1.5	44.5	1.0	1.8	35.2	1.1	2.1	28.2	1.2	2.5	23.0	1.2	2.9	18.9	1.3	3.4	15.4	1.4	3.9
60	122.6	0.9	0.8	85.8	0.9	1.1	62.7	1.0	1.5	48.5	1.0	1.8	38.4	1.1	2.2	30.8	1.2	2.5	25.1	1.2	2.9	20.6	1.3	3.4	16.9	1.4	3.9
65	132.8	0.9	0.8	93.0	0.9	1.1	67.9	1.0	1.5	52.6	1.0	1.8	41.5	1.1	2.2	33.4	1.2	2.5	27.2	1.2	2.9	22.3	1.3	3.4	18.3	1.4	3.9
70	143.1	0.9	0.8	100.1	0.9	1.1	73.1	1.0	1.5	56.6	1.0	1.8	44.7	1.1	2.2	35.9	1.2	2.5	29.2	1.2	2.9	24.0	1.3	3.4	20.0	1.4	3.9
75	153.3	0.9	0.8	107.3	0.9	1.1	78.3	1.0	1.5	60.7	1.0	1.8	47.9	1.1	2.2	38.5	1.2	2.5	31.3	1.2	2.9	25.7	1.3	3.4	21.4	1.4	3.9
80	163.5	0.9	0.8	114.4	0.9	1.1	83.6	1.0	1.5	64.7	1.0	1.8	51.1	1.1	2.2	41.0	1.2	2.5	33.4	1.2	2.9	27.4	1.3	3.4	22.8	1.4	3.9
85	173.7	0.9	0.8	121.6	0.9	1.1	88.8	1.0	1.5	68.8	1.0	1.8	54.3	1.1	2.2	43.6	1.2	2.5	35.5	1.2	2.9	29.1	1.3	3.4	24.2	1.4	3.9
90	183.9	0.9	0.8	128.7	0.9	1.1	94.0	1.0	1.5	72.8	1.0	1.8	57.5	1.1	2.2	46.2	1.2	2.5	37.6	1.2	2.9	30.8	1.3	3.4	25.7	1.4	3.9
95	194.1	0.9	0.8	135.9	0.9	1.1	99.2	1.0	1.5	76.8	1.0	1.8	60.7	1.1	2.2	48.7	1.2	2.5	39.7	1.2	2.9	32.5	1.3	3.4	27.1	1.4	3.9
100	204.4	0.9	0.8	143.0	0.9	1.1	104.4	1.0	1.5	80.9	1.0	1.8	63.9	1.1	2.2	51.3	1.2	2.5	41.7	1.2	2.9	34.2	1.3	3.4	28.5	1.3	3.9
105	214.6	0.9	0.8	150.2	0.9	1.1	109.7	1.0	1.5	84.9	1.0	1.8	67.1	1.1	2.2	53.9	1.2	2.5	43.8	1.2	2.9	35.9	1.3	3.4	29.9	1.3	3.9
110	224.8	0.9	0.8	157.4	0.9	1.1	114.9	1.0	1.5	89.0	1.0	1.8	70.3	1.1	2.2	56.4	1.2	2.5	45.9	1.2	2.9	37.6	1.3	3.4	31.3	1.3	3.9
115	235.0	0.9	0.8	164.5	0.9	1.1	120.1	1.0	1.5	93.0	1.0	1.8	73.5	1.1	2.2	59.0	1.2	2.5	48.0	1.2	2.9	39.3	1.3	3.4	32.7	1.3	3.9
120	245.2	0.9	0.8	171.7	0.9	1.1	125.3	1.0	1.5	97.1	1.0	1.8	76.7	1.1	2.2	61.5	1.2	2.5	49.9	1.2	3.0	41.0	1.3	3.4	34.2	1.3	3.9
125	255.5	0.9	0.8	178.8	0.9	1.1	130.5	1.0	1.5	101.1	1.0	1.8	79.9	1.1	2.2	64.1	1.2	2.5	52.0	1.2	3.0	42.7	1.3	3.4	35.6	1.3	3.9
130	265.7	0.9	0.8	186.0	0.9	1.1	135.8	1.0	1.5	105.1	1.0	1.8	83.0	1.1	2.2	66.7	1.2	2.5	54.1	1.2	3.0	44.4	1.3	3.4	37.0	1.3	3.9
135	275.9	0.9	0.8	193.1	0.9	1.1	141.0	1.0	1.5	109.2	1.0	1.8	86.2	1.1	2.2	69.2	1.2	2.5	56.1	1.2	3.0	46.1	1.3	3.4	38.4	1.3	3.9
140	286.1	0.9	0.8	200.3	0.9	1.1	146.2	1.0	1.5	113.2	1.0	1.8	89.4	1.1	2.2	71.8	1.2	2.5	58.2	1.2	3.0	47.8	1.3	3.4	39.9	1.3	3.9
145	296.3	0.9	0.8	207.4	0.9	1.1	151.4	1.0	1.5	117.3	1.0	1.8	92.6	1.1	2.2	74.4	1.2	2.5	60.3	1.2	3.0	49.6	1.3	3.4	41.3	1.3	3.9
150	306.5	0.9	0.8	214.6	0.9	1.1	156.7	1.0	1.5	121.3	1.0	1.8	95.8	1.1	2.2	76.9	1.2	2.5	62.4	1.2	3.0	51.3	1.3	3.4	42.7	1.3	3.9

PARABOLIC WATERWAY DESIGN
(RETARDANCE "D" AND "B")

Table 4h.

V1 FOR RETARDANCE "D", TOP WIDTH (T), DEPTH' (D) AND V2 FOR RETARDANCE "B"

GRADE 5.00 PERCENT

Q CFS	V1=2.0			V1=2.5			V1=3.0			V1=3.5			V1=4.0			V1=4.5			V1=5.0			V1=5.5			V1=6.0		
	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2	T	D	V2
5	11.3	0.8	0.8	8.0	0.9	1.1	5.6	1.0	1.4	4.2	1.1	1.6															
10	22.5	0.8	0.8	16.3	0.9	1.1	11.5	0.9	1.4	8.9	1.0	1.7	7.0	1.0	2.0	5.5	1.2	2.4	4.0	1.4	2.6						
15	33.7	0.8	0.8	24.3	0.9	1.1	17.4	0.9	1.4	13.7	1.0	1.7	10.7	1.0	2.1	8.5	1.1	2.4	6.8	1.2	2.8	5.4	1.3	3.2			
20	45.0	0.8	0.8	32.4	0.9	1.1	23.2	0.9	1.4	18.2	1.0	1.7	14.5	1.0	2.1	11.5	1.1	2.5	9.3	1.1	2.8	7.5	1.2	3.2	6.1	1.4	3.7
25	56.2	0.8	0.8	40.5	0.9	1.1	28.9	0.9	1.4	22.8	1.0	1.7	18.1	1.0	2.1	14.6	1.1	2.4	11.7	1.1	2.8	9.6	1.2	3.3	7.8	1.3	3.7
30	67.4	0.8	0.8	48.7	0.9	1.1	34.7	0.9	1.4	27.3	1.0	1.7	21.7	1.0	2.1	17.5	1.1	2.4	14.1	1.1	2.8	11.6	1.2	3.3	9.5	1.3	3.7
35	78.7	0.8	0.8	56.8	0.9	1.1	40.5	0.9	1.4	31.8	1.0	1.7	25.3	1.0	2.1	20.4	1.0	2.5	16.7	1.1	2.8	13.6	1.2	3.3	11.2	1.3	3.7
40	89.9	0.8	0.8	64.9	0.9	1.1	46.3	0.9	1.4	36.4	1.0	1.7	28.8	1.0	2.1	23.3	1.0	2.5	19.1	1.1	2.8	15.6	1.2	3.3	12.9	1.2	3.7
45	101.1	0.8	0.8	73.0	0.9	1.1	52.1	0.9	1.4	40.9	1.0	1.7	32.4	1.0	2.1	26.2	1.0	2.5	21.5	1.1	2.8	17.7	1.2	3.3	14.6	1.2	3.7
50	112.4	0.8	0.8	81.1	0.9	1.1	57.9	0.9	1.4	45.5	1.0	1.7	36.0	1.0	2.1	29.1	1.0	2.5	23.9	1.1	2.8	19.7	1.2	3.3	16.2	1.2	3.7
55	123.6	0.8	0.8	89.2	0.9	1.1	63.6	0.9	1.4	50.0	1.0	1.7	39.6	1.0	2.1	32.0	1.0	2.5	26.2	1.1	2.8	21.7	1.2	3.3	18.0	1.2	3.8
60	134.8	0.8	0.8	97.3	0.9	1.1	69.4	0.9	1.4	54.5	1.0	1.7	43.2	1.0	2.1	34.9	1.0	2.5	28.6	1.1	2.8	23.6	1.2	3.3	19.7	1.2	3.8
65	146.1	0.8	0.8	105.4	0.9	1.1	75.2	0.9	1.4	59.1	1.0	1.7	46.8	1.0	2.1	37.8	1.0	2.5	31.0	1.1	2.8	25.6	1.2	3.3	21.3	1.2	3.8
70	157.3	0.8	0.8	113.5	0.9	1.1	81.0	0.9	1.4	63.6	1.0	1.7	50.4	1.0	2.1	40.7	1.0	2.5	33.4	1.1	2.8	27.5	1.2	3.3	22.9	1.2	3.8
75	168.6	0.8	0.8	121.6	0.9	1.1	86.8	0.9	1.4	68.2	1.0	1.7	54.0	1.0	2.1	43.6	1.0	2.5	35.8	1.1	2.8	29.4	1.2	3.3	24.5	1.2	3.8
80	179.8	0.8	0.8	129.7	0.9	1.1	92.6	0.9	1.4	72.7	0.9	1.7	57.6	1.0	2.1	46.5	1.0	2.5	38.1	1.1	2.8	31.4	1.2	3.3	26.2	1.2	3.8
85	191.0	0.8	0.8	137.8	0.9	1.1	98.3	0.9	1.4	77.3	0.9	1.7	61.2	1.0	2.1	49.4	1.0	2.5	40.5	1.1	2.8	33.3	1.2	3.3	27.8	1.2	3.8
90	202.3	0.8	0.8	145.9	0.9	1.1	104.1	0.9	1.4	81.8	0.9	1.7	64.9	1.0	2.1	52.3	1.0	2.5	42.9	1.1	2.8	35.3	1.2	3.3	29.4	1.2	3.8
95	213.5	0.8	0.8	154.0	0.9	1.1	109.9	0.9	1.4	86.3	0.9	1.7	68.5	1.0	2.1	55.2	1.0	2.5	45.3	1.1	2.8	37.2	1.2	3.3	31.1	1.2	3.8
100	224.7	0.8	0.8	162.1	0.9	1.1	115.7	0.9	1.4	90.9	0.9	1.7	72.1	1.0	2.1	58.1	1.0	2.5	47.7	1.1	2.8	39.2	1.2	3.3	32.7	1.2	3.8
105	236.0	0.8	0.8	170.2	0.9	1.1	121.5	0.9	1.4	95.4	0.9	1.7	75.7	1.0	2.1	61.0	1.0	2.5	50.0	1.1	2.8	41.1	1.2	3.3	34.3	1.2	3.8
110	247.2	0.8	0.8	178.3	0.9	1.1	127.3	0.9	1.4	100.0	0.9	1.7	79.3	1.0	2.1	64.0	1.0	2.5	52.4	1.1	2.8	43.1	1.2	3.3	36.0	1.2	3.8
115	258.5	0.8	0.8	186.4	0.9	1.1	133.0	0.9	1.4	104.5	0.9	1.7	82.9	1.0	2.1	66.9	1.0	2.5	54.8	1.1	2.8	45.0	1.2	3.3	37.6	1.2	3.8
120	269.7	0.8	0.8	194.6	0.9	1.1	138.8	0.9	1.4	109.1	0.9	1.7	86.5	1.0	2.1	69.8	1.0	2.5	57.2	1.1	2.8	47.0	1.2	3.3	39.2	1.2	3.8
125	280.9	0.8	0.8	202.7	0.9	1.1	144.6	0.9	1.4	113.6	0.9	1.7	90.1	1.0	2.1	72.7	1.0	2.5	59.6	1.1	2.8	48.9	1.2	3.3	40.9	1.2	3.8
130	292.2	0.8	0.8	210.8	0.9	1.1	150.4	0.9	1.4	118.2	0.9	1.7	93.7	1.0	2.1	75.6	1.0	2.5	61.9	1.1	2.8	50.9	1.2	3.3	42.5	1.2	3.8
135	303.4	0.8	0.8	218.9	0.9	1.1	156.2	0.9	1.4	122.7	0.9	1.7	97.3	1.0	2.1	78.5	1.0	2.5	64.3	1.1	2.8	52.9	1.2	3.3	44.1	1.2	3.8
140	314.6	0.8	0.8	227.0	0.9	1.1	162.0	0.9	1.4	127.2	0.9	1.7	100.9	1.0	2.1	81.4	1.0	2.5	66.7	1.1	2.8	54.8	1.2	3.3	45.8	1.2	3.8
145	325.9	0.8	0.8	235.1	0.9	1.1	167.8	0.9	1.4	131.8	0.9	1.7	104.5	1.0	2.1	84.3	1.0	2.5	69.1	1.1	2.8	56.8	1.2	3.3	47.4	1.2	3.8
150	337.1	0.8	0.8	243.2	0.9	1.1	173.5	0.9	1.4	136.3	0.9	1.7	108.1	1.0	2.1	87.2	1.0	2.5	71.5	1.1	2.8	58.7	1.2	3.3	49.0	1.2	3.8

PARABOLIC WATERWAY DESIGN
(RETARDANCE "D" AND "B")

Design examples

Parabolic vegetated waterways

A vegetated waterway must be able to carry the design flow and resist erosion. When the grass is long and unmowed, the velocity will be at a minimum and is represented by V_2 in the design tables. Erosion occurs when the grass is short and the velocity is high (V_1 from the tables). A design using the tables results in a channel with adequate capacity when the grass is long and thick, that resists erosion when mowed and that has adequate freeboard during the design flow.

To use the tables, first determine the peak rate of runoff from the design storm (Q in cfs), field verify the channel slope and select the desired grass liner. The permissible velocity (V_1) is based on the liner. Using the required capacity (Q) and the channel slope, with the permissible velocity (V_1), you can determine the top width (T in feet) and the depth (D in feet) for the correct parabolic section.

Design problem 1

Design a parabolic waterway on erosion resistant soils planted in redtop, with a channel slope of 2% and a peak runoff of 20 cfs.

Solution

Using table 2 to determine the permissible velocity of redtop as 3.5 ft/sec and given Q as 20 cfs, look up T and D from table 4a for a 2% slope and "C" retardance (from table 3 for redtop).

T = 9.4 feet, D = 1.1 feet

The design engineer will need to determine the reduction in volume after flows pass through the swale. This reduction is a function of the dynamic percolation rate, the rain duration, the volume of runoff coming to the swale and the area of the swale. The dynamic infiltration rate is typically assumed to be approximately half of the static infiltration rate measured by an in-field double ring infiltrometer test. The following equations assume the swale was designed for infiltration and that it is neither too steep nor too short (Pitt, 1989).

The ratio of the infiltration volume over the runoff volume should be a fraction less than one for the rainfall event used in the design. If the ratio is greater than one, the swale is larger than it needs to be for that rain event; that is, more is infiltrating than is coming in. Before calculating the volume reduction, this fraction must equal one or less (use one if the ratio is greater than one). The ratio (A) of infiltration volume over runoff volume is a result of the following dimensions:

$$A = \frac{\text{infiltration rate (ft/hr) X swale density (ft/acre) X swale width (ft) X basin area (acres) X runoff duration (hr)}}{\text{runoff volume (ft}^3\text{)}}$$

The infiltration rate is the dynamic percolation rate as described earlier. The swale density is the feet of swale per acre of drainage area and should be determined on a case-by-case basis. Some swale density values observed by Pitt (1989) follow.

Land use	Swale density (ft/acre)
Low density residential	160
Medium density residential	350
Shopping centers	280
Industrial	125

The swale width is the wetted width, and the basin area is the area served by swales. Using techniques described in the hydrology chapter of this manual, runoff duration is equal to 0.9 + (0.98) x t when t is the duration of the precipitation event (hours).

A second calculation is the ratio of the area served by the swale over the total drainage basin (B).

$$B = \frac{\text{area served by swales (acres)}}{\text{area of the drainage basin (acres)}}$$

A X B = C the study area runoff reduction due to the grassed swale (calculated as a fraction).

The runoff volume multiplied by one minus this reduction fraction (1-C) equals the runoff volume after drainage controls (swales).

Design problem 2

The runoff volume from a 50-acre, medium-density residential area for a 4-hour rain event is equal to 190,000 ft^3. The in-field double ring infiltrometer test indicates an infiltration rate of 3.0 in/hr for the soils in the area. Only 25 acres of the total area will be served by swales. The swale dimensions will be the same as in the previous example (top width equals 9.4 feet). What is the runoff volume after swales?

Solution

1. The dynamic infiltration rate is assumed to be ½ the measured value or 1.5 in/hr.
2. The wetted width (p) using the calculation in figure 2 for a parabolic channel is 9.74 feet.
3. The runoff duration is equal to 0.9 + .98(4) or 4.8 hours.
4. The infiltration volume over the runoff volume equals:

$$\frac{(1.5\ in/hr)(350\ ft/ac.)(9.74\ ft.)(25\ ac.)(4.8\ hr)(1 ft/12 in)}{(190000\ ft^3)} = 0.27$$

5. The area served by swales divided by the total area equals

   25ac./50 ac. = 0.5
6. The expected reduction in flow as a result of the swales is

(.27)(0.5) = 0.135, or 13.5% reduction.

7. The remaining runoff volume after swales is
   190,000 ft^3) (1-.135) = 164,350 ft^3.

Construction guidelines

Plans and specifications for construction must include the swale location, alignment, grade, depth, width, seeding specification and dates, underdrains (if applicable), inlet and outlet structures, schedule for installation and inspection and maintenance requirements.

Site preparation consists of excavation, filling, shaping and grading. Construction site runoff should be diverted around the swale, and upland slopes should be stabilized prior to start-up of the swale to protect water quality and reduce the potential for early clogging. The site should be stripped of unsuitable material and areas smoothed by equipment should be scarified. Care must be taken if fill material is required in areas where unsuitable material was removed. Compaction of an infiltrative surface must be avoided. Heavy equipment is discouraged and equipment with oversized tires is preferred.

Soils should be tilled prior to seeding or sodding. Locating the swale in a sunny location over soils of sufficient depth and texture is essential if a healthy, vigorous grass mat is to develop. Grasses in a swale should be selected for their high stem density, drought and salt tolerance, well-branched top growth, nonbunching characteristics, root systems that can withstand temporary flooding, stems that can resist flattening and aggressive growth. Flow should be kept out of the swale until the vegetation is well established. Seeding should include the use of lime, fertilizer, mulch and tackifiers to hold down the seed until it germinates.

Check dams

Selection of check dams and their proper installation may determine the channel's stability and the swale's effectiveness in storing flows. Low-head, ported or notched check dams at heights less than 12 inches are preferred. Earth and stone check dams require more maintenance and do not last as long. Stone piled downstream of the dam will prevent downstream scour. Construction of a sediment trap or vegetative filter strip ahead of the swale provides additional protection against sediment build-up.

Maintenance

A detailed operation and maintenance manual for the specific swales should be provided to the responsible party. The primary maintenance responsibility of a grassed swale is care of the vegetative liner. Vegetative liners have intensive maintenance requirements. Establishment of sod or seed requires regular attention until the mat is dense and mature. Pesticides and fertilizer should be used in moderation, and only if important in establishing or maintaining a dense vegetation.

Mowing is necessary to encourage growth but must be done at the correct height for the swale's operating depth. Grass should be maintained at a minimum height of 6 inches; more importantly, grass must be maintained at a height above the operating depth for the

1.5-inch rain. Depending on the natural height of the selected grasses, mowing may be infrequent or unnecessary.

It is very important to inspect for channelization or undesirable woody vegetation. Because of the slow design flow velocities of swales designed primarily for water quality improvement and infiltration, sediment may accumulate in the bottom. Sediment removal may be necessary, but take care to minimize serious disturbance of the vegetation. After sediment is removed, reseed bare spots immediately.

Homeowners or homeowners' associations have sometimes been expected to maintain the grass. However, homeowners may mow at varying heights (since most do not have a sickle-bar type mower to maintain a 6-inch minimum height) or too short, which damages the grass mat. For maintenance consistent with the design and purpose of the swale, mowing and other maintenance responsibilities should stay with the local government.

Inspections should occur seasonally and after major storms. In addition to looking for sedimentation, the maintenance crew should look for bypassing around check dams. Channels and low spots should be regraded and seeded. (If a swale needs to come on line in a short amount of time, use sod rather than seed.)

Crews should also check for nuisance conditions such as mosquitoes, weeds, woody growth and trash dumping which can occur in a relatively short period of time. Post signs to inform local residents of the swale's purpose and to discourage dumping of leaves or parking on the edge of the swale. Curb blocks installed an appropriate distance from the swale will discourage parking. Swales along highways or in median strips are subjected to salting, so the vegetation should be salt tolerant. If salt is a problem and a vigorous grass mat has not developed, the area may need to be stripped and a different seed mixture used.

Swale sites generally do not have a high habitat potential. If wildlife habitat is desired and space is available, a no-mow buffer strip around the swale of 10-12 feet can serve as habitat and improve swale performance. Maintenance requirements for this area are minimal, but take care to discourage undesirable plants in the buffer strip from invading the swale.

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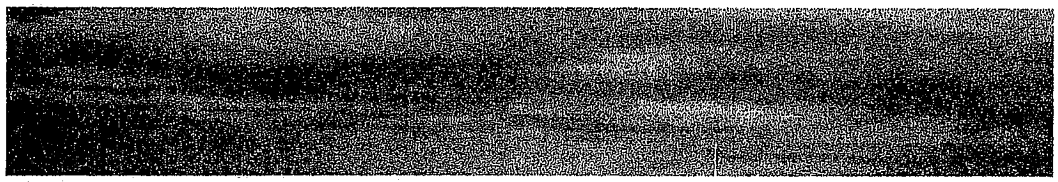
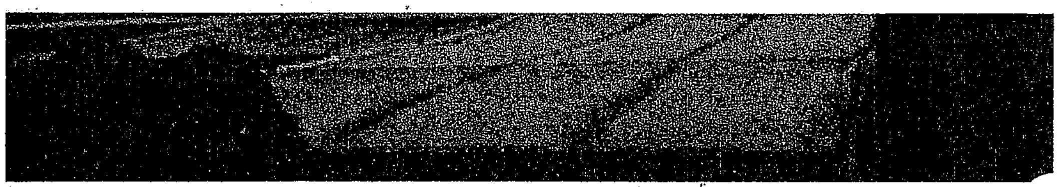
The Wisconsin Storm Water Manual: Grassed Swales (G3691-7)

EFFECTIVENESS OF STREET SWEEPING FOR STORMWATER POLLUTION CONTROL

TECHNICAL REPORT
Report 99/8
December 1999

T.A. Walker and T.H.F. Wong





COOPERATIVE RESEARCH CENTRE FOR
CATCHMENT HYDROLOGY

Effectiveness of Street Sweeping for Stormwater Pollution Control

T.A. Walker and T.H.F. Wong

Cooperative Research Centre for Catchment Hydrology

December, 1999

Preface

This report investigates the effectiveness of street sweeping as a stormwater pollution source control measure. The Cooperative Research Centre for Catchment Hydrology (CRCCH) Project U1 (Gross pollutant management and urban pollution control ponds) focuses on ways to improve the quality of stormwater runoff. The project covered means to reduce gross pollutants both before and after they entered the piped stormwater drainage system. This report describes a scoping study to assess the efficiency of Australian street sweeping practices in the removal of pollutants from street surfaces. This study has provided information on the effectiveness of street sweeping, currently practiced, in the collection of pollutants across the range of particle sizes representative of a street surface load.

It is a pleasure to acknowledge the contribution of Tracey Walker and Tony Wong to the Urban Hydrology Program. This work has provided important insights into the limited role street sweeping plays in improving stormwater quality.

Tom McMahon
Program Leader, Urban Hydrology
Cooperative Research Centre for Catchment Hydrology

Executive Summary

Street cleansing is a common (and expensive) practice undertaken by most urban municipalities with annual expenditure by a municipality often exceeding one million dollars. Street sweeping, essentially the operation of large trucks for cleaning street surfaces, is primarily performed for aesthetic purposes. It is, often perceived to lead to improvements in the environmental conditions of urban waterways by preventing pollutants deposited on street surfaces from reaching the stormwater system. There is, however, little available evidence to quantify the extent to which street sweeping can improve stormwater quality. This report investigates the effectiveness of street sweeping for stormwater quality improvement.

The effectiveness of street sweeping for stormwater pollution control is examined for two types of pollutants, gross pollutants (> 5 mm) and sediment (including associated pollutants). The research literature on street cleaning indicates a general dearth of studies that address the issues of gross pollutant management. Most studies predominantly examine the effectiveness of street sweeping for sediment and associated contaminant removal. This study looks at the effectiveness of street sweeping for gross pollutants using the results of Australian field studies, while sediment and other suspended solid removal is investigated with interpretation of results from overseas studies.

Experimental studies overseas found street sweeping to be highly effective in the removal of large solids greater than 2 millimetres under test conditions. However, field conditions are expected to significantly reduce the efficiency of solid removal because of limitations with sweeper access to source areas (mainly due to street design and car parking), sweeping mechanisms used and operator skills. Field studies undertaken by the Cooperative Research Centre for Catchment Hydrology (CRCCH) in Australia found significant stormwater gross pollutant loads generated from source areas in spite of a daily street sweeping regime.

An earlier CRCCH study, involving analysis of gross pollutant loads from a 50 hectare urban catchment of mixed residential, commercial and industrial land-use, found a clear relationship between the gross pollutant load in the stormwater system and the magnitude of the storm event. The shapes of the curves relating gross pollutant load to event rainfall and runoff were found to be monotonically increasing and representable by a logarithmic function. The shape of these curves suggests that the limiting mechanism affecting the amount of gross pollutants entering the stormwater system is rainfall dependent (ie. the available energy to re-mobilise and transport deposited gross pollutants on street surfaces) rather than being source limiting (ie. the amount of available gross pollutants deposited on street surfaces).

Overseas studies indicate that street sweeping is relatively ineffective at reducing the street surface load of fine particles (below 125 μm). The particle size distribution of suspended solids conveyed in stormwater in Australian conditions typically range from 1 μm to 400 μm with approximately 70% of the particles smaller than 125 μm. Therefore, street sweeping as it is currently practiced cannot be expected to be effective in the reduction of suspended solids and associated trace metals and nutrient concentrations in stormwater.

The study concludes that the performance of street sweeping for stormwater pollutant control is limited and must be accompanied by structural pollutant treatment measures to effectively reduce the discharge of gross and sediment associated pollutants in stormwater. The incremental benefits in increasing the frequency of street sweeping beyond what is required to meet street aesthetic criterion is expected to be small in relation to water quality improvements. As a result, there seems little benefit in conducting an in-depth field-based study into the effectiveness of street sweeping for stormwater pollution control.

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1 Introduction

This report presents the findings of an investigation on the effectiveness of current Australian street sweeping practices in the collection of pollutants across the typical range of particle sizes found on street surfaces. The study was initiated to define and scope a further more-detailed field-based study to quantify the effectiveness of current street sweeping practices as an at-source stormwater pollution management measure. The term street sweeping is used here to describe essentially the operation of large trucks to remove deposited litter and debris from the kerb and channel of major roadways, streets, and carparks. The study examines the effectiveness of street sweeping practices to remove pollutants of two types:- (i) gross pollutant and litter removal and (ii) sediment and associated contaminant removal.

Over the past decade there has been an increase in the management of urban stormwater to protect urban waterways and receiving waters. These initiatives have, in part, resulted from community awareness of environmental impacts of urban stormwater pollution and their expectation that urban aquatic ecosystems should be protected from further environmental degradation.

Pollutants generated from urban land-use activities are transported by stormwater to urban receiving waters. Pollutants washed off street surfaces include gross pollutants, sediment and associated metals, nutrients, hydrocarbons and dissolved pollutants. Increased volumes of stormwater runoff and discharge rates resulting from increased impervious surface areas and hydraulically efficient drainage infrastructure throughout urban catchments have meant that the transport of urban pollutants to receiving waters is particularly efficient.

Most urban metropolitan councils perform cleansing of streets and similar impervious surfaces. This is commonly for the purpose of controlling gross pollutants, particularly litter, to maintain a level of street cleanliness and aesthetic quality. The focus on environmental issues is growing and local authorities are now considering street sweeping as a beneficial at-source method for reducing the amount of street borne pollutants entering the stormwater system. The actual contribution of street sweeping to the abatement of stormwater pollution is however not well understood. The objectives of street sweeping for street aesthetics and stormwater pollution control are very different, with the former placing particular emphasis on the visual impact of environmental pollution while the latter encompasses a much wider range of pollutant types and sizes. Despite street sweeping being widely considered an at-source stormwater pollution control method its effectiveness is unknown.

This report undertakes an interpretation of relevant street sweeping literature, research and survey results. The background to street sweeping operations, focusing on the effectiveness of sweeping for removal of street surface pollutants, is established in Section 2. The methodology undertaken for this investigation is discussed in Section 3. Results from a survey of 21 Melbourne Metropolitan councils on street sweeping practices are assessed in Section 4, to establish an understanding of current operations, target pollutants and sweeping frequencies. The different types of street sweeping mechanisms and their measured effectiveness are examined in Section 5. Pollutant types found on street surfaces are reviewed in Section 6, including an analysis of Australian sediment characteristics to assess the influence of street sweeping practices on fine particulates and associated contaminants.

Inter-event dry periods can influence street sweeping effectiveness and these are determined using Australian rainfall statistics in Section 7, and compared with current sweeping frequency and timing information. Section 8 examines field data to determine gross pollutant load generation and the influence of catchment land-use and associated sweeping frequency on pollutant load. The impact street sweeping has on gross pollutant loads entering the stormwater drainage system is discussed in Section 9, highlighting important issues affecting current sweeping efficiencies. Section 10 concludes with a summary of specific observations from each of the sections of the report from which the effectiveness of street sweeping as a stormwater pollution control method is assessed.

2 Background

2.1 Street Sweeping Pollutant Removal Monitoring

The role and usefulness of street sweepers to control street surface pollutants was first investigated in the late 1950's and early 1960's by the United States Environmental Protection Agency (US-EPA) and its associated researchers. Many of the US-EPA's National Urban Runoff Program (NURP) studies measured the efficiency of street sweeping as a stormwater pollution control method with particular emphasis placed on sediment and sediment-bound contaminants.

Since the late 70's studies have measured street sweeping effectiveness in terms of the reduction in end-of-pipe runoff pollution concentrations and loads rather than assessing the effectiveness of specific equipment. Sartor and Boyd (1972) found sweeping schedules based on a seven day cycle to be almost totally ineffective while daily sweeping was shown to potentially have a high level of pollutant removal for larger sized pollutants typical of street surface material (Sartor and Gaboury, 1984). Pitt and Shawley (1982) and Bannerrnan et al. (1983) concluded that only minor benefits to stormwater quality are provided by street sweeping practices. However, Terstrierp et al. (1982) and Pitt and Bissonette, (1984) demonstrated that street sweeping collects significant amounts of particles, for select particle size ranges, from street surfaces. The overall conclusion reached by the US-EPA, was that, as a water quality best management practice, street sweeping did not appear to be effective at reducing end-of-pipe urban runoff pollutant loads.

Subsequent investigations into the effectiveness of street sweeper mechanisms for water quality improvement report findings that vary to those presented in the conclusions of the earlier NURP studies. Alter (1995) and Sutherland and Jelen (1996b) assert that the NURP studies concluded that street sweeping is largely ineffective, because the sweepers used at the time of these studies were not able to effectively remove very fine accumulated sediments which are often highly contaminated. Sutherland and Jelen (1996a) suggest that street sweeping can significantly reduce pollutant washoff from urban streets due to the improved efficiencies of newer technologies now employed to conduct street sweeping in some American states. Their investigations showed that when street sweeping mechanisms and programs are designed to remove finer particles (ie. small-micron surface cleaners or tandem sweeping) it can benefit stormwater runoff quality.

2.2 Modelling Sweeper Pollutant Removal Efficiencies

Sweeping technologies with the ability to effectively remove accumulated sediments, including fine particles, may significantly increase the efficiency of sweeping for the removal of a variety of stormwater pollutants. Sutherland and Jelen (1993) described the use of a calibrated version of the Simplified Particle Transport Model (SIMPTM) as being able to accurately simulate the complicated interaction of accumulation, washoff, and street sweeper removal that occurs over a time period. For varying street sweeping operations Sutherland and Jelen (1997) employed the SIMPTM to predict the average annual expected reduction in total suspended solids (TSS) at two sites in Portland, Oregon. Sweepers used in their simulations included the NURP era broom sweeper, a mechanical broom sweeper, a tandem operation involving a mechanical broom followed by a vacuum sweeper and a newer technology, the small-micron sweeper. The predicted reductions in TSS showed that all of the newer street sweeping technologies are significantly more effective than the NURP era broom sweeper. It was further concluded that new street sweeping technologies designed for effective removal of fine particles, are capable of removing significant sediment loads and associated pollutants from urban street surfaces.

In a further study Sutherland and Jelen (1998) compared the new small-micron street sweeping technology to wet vaults, a widely used stormwater quality treatment method. The ability of the small-micron street sweeper to achieve significant reductions in urban pollutant washoff led Sutherland and Jelen to consider it an effective Best Management Practice (BMP) for stormwater pollution control.

2.3. Factors Influencing Street Sweeping Effectiveness

The pollutant reduction effectiveness of any street sweeping operation is dependent on the equipment used and the environmental and geographic conditions (eg. wind and presence of parked vehicles). Unless other influential factors (such as street parking) are addressed, the efficiency of individual sweeping mechanisms can be a relatively insignificant factor in the overall effectiveness of street sweeping operations. It is anticipated that the effectiveness of street sweeping programs depend more on factors such as land-use activities, the inter-event dry period, street sweeping frequency and timing, access to source areas and sweeper operation than the actual street sweeping mechanism. These factors all influence the deposition, accumulation and removal rates of pollutants on street surfaces. Physical features such as the degree of catchment imperviousness and the hydraulic characteristics of street surfaces can also influence the effectiveness of street sweeping. These factors require consideration before a thorough assessment of street sweeping efficiency for stormwater pollution control can be achieved.

3 Methodology

This study assesses the effectiveness of street sweeping for stormwater pollution control by:

- reviewing previous studies on sweeper performances and street pollutant characteristics,
- reviewing objectives for street sweeping operations (eg. aesthetic),
- considering rainfall distributions with street sweeping frequency and timing to investigate likely sweeper performance,
- examining field data from an earlier CRC study and others on gross pollutants,
- investigating the potential effects of changing street sweeping regimes on the gross pollutant loads in stormwater.

This study interprets available Australian and overseas field data on the measured efficiencies of street sweeping and street surface sediments. Various studies describing the particle size distribution of sediment loads were also collated to provide an insight into the particle size distribution pattern of suspended solids typical of street surface runoff. Some significant overseas studies on the partitioning of sediment sizes and the contaminant associations (eg. metals and nutrients) with each particle size partition were used to assess the pollutants likely to be discharged into the stormwater system from street surfaces. Information regarding street sweeping efficiencies and sediment contaminant associations from these studies are combined with data on Australian stormwater suspended solids characteristics to enable an assessment of street sweeping practices on removal of fine particulate associated pollutants.

A survey of street sweeping practices amongst municipalities in Melbourne was carried out to examine current sweeping objectives, procedures and mechanisms in these municipalities. This survey was also used to determine the perceived effectiveness of street sweeping in maintaining a certain standard of street aesthetics. Australian rainfall distributions were then examined and used to assess typical statistics of inter-event dry periods for Melbourne and other major capital cities in Australia. Melbourne inter-event periods were compared to the surveyed results of typical sweeping frequency and timing to investigate likely sweeper performance. This information facilitates a "hydrological basis" for selecting a street sweeping frequency that would optimise gross pollutant removal.

The study also examines data obtained from field studies previously undertaken by the CRC for Catchment Hydrology and others to investigate the effectiveness of street sweeping on litter and gross pollutant removal. Gross pollutant load data gathered at 192 side entry pit traps (SEPTs - baskets fitted into roadside stormwater entry pits) in the suburb of Coburg in Melbourne by Allison et al. (1998) were grouped according to the street sweeping frequencies in their respective streets. Similar data are available at two further study catchments in the suburbs of Carnegie and McKinnon in Melbourne (Hall and Phillips, 1997). The load data captured by the SEPTs during a typical street sweeping program are used to evaluate the amount of gross pollutants typically entering the stormwater system under normal Melbourne street sweeping frequencies and conditions. While it was not possible to compute a measure of pollutant removal efficiency owing to an inability to account for pollutants by-passing the SEPTs, the data nevertheless provided an insight on what might be the expected gross pollutant export load from streets that are swept at regular intervals.

4 Melbourne Street Sweeping Practices

4.1 Street Sweeping Operations

The responsibility of keeping urban streets clean, commonly by sweeping road surfaces with large vacuum trucks is an operation carried out by local government. A survey of 21 Melbourne metropolitan councils was performed to determine the motivation for the large expenditure on street cleaning. The results indicated that street sweeping is primarily undertaken for aesthetic purposes in response to community expectations. Table 4.1 summarises the street sweeping practices of 21 municipalities in Melbourne.

4.2 Target Pollutants

Street cleansing programs are generally designed to concentrate on collecting human derived litter to address the obvious visual impacts. However, during autumn, organic matter becomes a focus and the sweeping frequency is altered to reduce the safety hazard associated with decomposing leaf litter on street surfaces and to reduce drain blockages. Street surface sediment collection was not identified as a major issue when designing street sweeping programs.

Street cleansing programs involve what is often termed 'building line to building line' cleansing, incorporating footpath cleaning, and the standard kerb and channel street sweeping where it is apparent a large proportion of litter accumulates. This requires a combination of cleansing methods and equipment for the successful removal of such pollutants. Australian streets are cleaned customarily with large truck mechanical broom and vacuum systems. However, it is becoming common practice to operate smaller broom and vacuum sweepers designed for cleansing areas inaccessible to the traditional larger plants. The most commonly used sweepers are the regenerative air model, for both large truck and small plant systems.

4.3 Contracts and Sweeping Frequency

Under new competitive tendering legislation, the bidding process for street cleansing contracts establishes a requirement for operators to become very competitive. Contractor performance is measured against output based specifications set by the council. This means the council stipulates a set of cleanliness requirements they wish to achieve with a street cleansing program but not the frequency or operation methods used. Street sweeping practices therefore differ considerably between Melbourne metropolitan councils. Street sweeping frequencies can range from every two weeks to every six weeks in residential areas and from daily to every two weeks in commercial areas. Shopping centres and commercial areas are swept more frequently, typically ranging from once or twice a day in busy areas and once or twice a week in less popular areas. Street sweeping frequencies for residential areas range from once a week for highly populated areas to every six weeks in less populated areas.

Table 4.1 Street Sweeping Practices for Melbourne Municipalities

COUNCIL	PURPOSE	TARGET POLLUTANT	CONTRACT	FREQUENCY		SWEEPING MECHANISM	COUNCIL PERSPECTIVE
				Commercial	Residential		
Bayside:							
Hobsons Bay	Aesthetic	Litter / Leaves	Internal (3-5yrs)	1 day	4 weeks	Regenerative	Effective
Port Phillip	H&S / SW / CD	Litter / Leaves	Internal (3-5yrs)	1 day	2 weeks	Regenerative	Effective
Bayside	SW / aesthetics	Litter / Leaves	Internal (3-5yrs)	1 day	3 weeks	Regenerative	Effective
Kingston	SW / aesthetics	Litter / Leaves	External (3-5yrs)	1 day	5 weeks	Regenerative	Effective
Inner City:							
Banyule	Amenity / SW	Litter / Leaves	Internal (3-5yrs)	2 weeks	5 weeks	Regenerative	Effective
Boroondara	Aesthetics / H&S / SW	Litter / Leaves	Internal (3-5yrs)	3-7 days	4 weeks	Regenerative	Effective
Glen Eira	CD	Litter / Leaves	External (3-5yrs)	1-3 days	4 weeks	Regenerative	Not Effective
Manningham	Amenity / SW / CD	Litter / Leaves	Internal (3-5yrs)	1 day	6 weeks	Regenerative	Effective
Whitehorse	Aesthetics / SW	Litter / Leaves	Internal (3-5yrs)	1 day	3 weeks	Regenerative	Effective
Stonnington	Amenity / Aesthetics	Litter / Leaves	Internal (3-5yrs)	1 day	1-2 weeks	Regenerative	Effective
Moonee Valley	SW	Litter / Leaves	Internal (3-5yrs)	1 day	6 weeks	Regenerative	Effective
Melbourne City	CD / amenity	Litter / Leaves	External (3yrs)	1 day	2 weeks	Regenerative	Effective
Maryibynong	CD / aesthetics	Litter / Leaves	Internal (3-5yrs)	1 day	2 weeks	Regenerative	Effective
Monash	Aesthetic / CD / SW	Litter	Internal (3-5yrs)	1 day	6 weeks	Regenerative	Not Effective
Moreland	CD / aesthetics / SW	Litter / Leaves	Internal (3-5yrs)	1 day	2 weeks	Regenerative	Effective
Outer City:							
Brimbank	SW / CD	Litter / Leaves	Internal (3-5yrs)	1 day	5 weeks	Regenerative	Effective
Hume	Amenity / SW	Litter	Internal (3-5yrs)	1 day	4 weeks	Regenerative	Effective
Greater Dandenong	CD / amenity	Litter / Leaves	Internal (3yrs)	1 day	17 days	Regenerative	Effective
Knox City	SW / CD	Litter / Leaves	Internal (3-5yrs)	2 days	5 weeks	Regenerative	Effective
Moroondah	CD / amenity / SW	Litter	Internal (3-5yrs)	1 day	21 days	Regenerative	Effective
Nillumbik	Aesthetic / SW	Litter / Leaves	Internal (3yrs)	1-2 weeks	4 weeks	Regenerative	Effective

Note: Councils not listed were conducting tender negotiations for street sweeping practices during the time of the survey.
H & S = Health and Safety
SW = Stormwater Quality
CD = Community Demand

4.4 Council Perspective of Effectiveness

All but two councils indicated that street sweeping as it is currently practiced was an effective way of collecting litter. Numerous councils stated that street sweeping aided in the prevention of litter entering the stormwater system and therefore reduced the occurrence of stormwater pollution and drain blockage but had no data to validate these observations. Several councils regarded street sweeping as effective only when practiced in conjunction with other source pollution control methods such as bins, side entry pit traps and other gross pollutant traps.

Overall the survey indicated a general satisfaction with the effectiveness of street sweeping in collecting human derived litter and organic matter (gross pollutants) for aesthetic objectives. However, there is little quantitative information for councils to assess the effectiveness of street sweeping practices on stormwater pollution reduction. Throughout the literature there are many suggestions that street sweeping can have an effect on stormwater quality although the degree to which this practice is effective is unknown.

The assessment of the effectiveness of street sweeping in stormwater pollution control rather than just aesthetic requirements will need a detailed analysis of the following major influencing factors.

- street sweeping mechanism
- pollutant types (from sediment and associated contaminants to gross pollutants)
- sweeping frequency & timing
- pollutant load wash-off characteristics

Each one of these factors is examined in detail in the following sections of this report.

5 Street Sweeping Mechanisms

5.1 Types of Sweeping Mechanisms

Types of street sweeping mechanisms commonly utilised in Australian practice include:

1. Mechanical broom sweepers involving a number of rotating brushes sweeping litter into a collection chamber;
2. Mechanical broom and vacuum systems involving the combination of rotating brushes and a vacuum to remove street litter;
3. Regenerative air sweepers which are like mechanical vacuum sweepers but use recirculated air to blast the pavement, dislodging litter before it is swept by rotating brushes towards a vacuum for pick-up. This sweeper also uses water sprays for dust suppression,
4. Small-micron surface sweepers which combine rotating brooms enclosed in a powerful vacuum head in a single unit, performing a dry sweeping/vacuuming operation. A powerful fan pulls debris and air into a containment chamber before the air is finally passed through a series of filters to capture small micron material.

5.2 Sweeper Effectiveness

Pitt and Bissonnette (1984) found following a period of street sweeping trials that street sweeping equipment was unable to remove particles from the street surface unless the loadings were greater than a certain threshold amount. This value was found to be three times higher for a mechanical broom cleaner, most referred to in the US-EPA's NURP studies, compared to the regenerative air street sweeper trialed for a comparison in a study by Pitt and Bissonnette (1984). The study found the regenerative air vacuum sweeper to exhibit a substantially better performance than the regular mechanical street sweeper, especially for the smaller particle sizes. Such findings have progressively led to the mechanical broom method being replaced by the vacuum system method for street sweeping practices. The removal effectiveness data for the smallest particle sizes (less than 125 µm) between the two methods of street sweeping was however found to be inconclusive.

The regenerative air vacuum sweeper (Figure 5.1) is a common mechanism used for street sweeping in Australia. The recirculating air cycle tends to improve the effectiveness of sweepers for the removal of heavy debris but is less effective for removing fine sediment. The air blast is able to dislodge heavier

Figure 5.1 Australian streets are cleaned with large truck vacuum sweepers

materials and propel them into the vacuum airflow however finer materials often remain uncollected (Pitt and Bisonnette,1984). Fine particles may become airborne as a result of the air blast and take some time to settle back onto the road surface or may be left behind on the street surface.

The most recent technology to be employed for street sweeping is a highly effective, vacuum-assisted dry sweeper (the small-micron surface sweeper) originally developed and manufactured by Enviro Whirl Technologies Inc in the United States of America. The sweeper was originally developed for the containment of spilled coal dust along railway tracks. This system is reported to be extremely effective in removing fine street surface sediments and preventing their escape into the air by filtering air emissions down to sizes as small as 4 µm. Sutherland and Jelen (1997) described this system as having an advanced ability, when compared to other sweeping mechanisms, to remove a broad range of particles from road surfaces down to sub micron particulates. The small-micron surface cleaning technology has been shown by Sutherland and Jelen (1997) to have total removal efficiencies ranging from 70% for particles less than 63 µm up to 96% for street surface pollutants larger than 6370 µm.

Despite there being new street sweeping technologies reported to be more efficient, most municipalities and private street sweeping companies in Australia continue to use the mechanical broom and regenerative air vacuum street sweepers. This is because of the high capital costs of newer technologies and their limited availability on the Australian market.

Street Sweeping Mechanism:

- Mechanical and regenerative air street sweeping equipment requires a minimum threshold load of sediment on the street surface before they become effective.
- The threshold load can be three times higher for the mechanical sweeper compared to the regenerative air system.
- Overall the regenerative air sweeper exhibits a substantially better performance than the regular mechanical sweeper.
- Street sweeping technology is developing and improving to remove finer street surface particles for a variety of street surface loads.

6 Pollutant Types

The effectiveness of street sweeping to remove pollutants, across the typical range of particle sizes found on street surfaces, has not yet been successfully quantified for Australian conditions. The examination of street sweeping effectiveness in the present study focuses on two pollutant types:- (i) gross pollutants and litter and (ii) sediment and associated contaminants. Gross pollutants have been defined as any solids that are retained by a 5 mm mesh screen by Allison et al. (1998) and this definition is adopted here. Solids washed off street surfaces which are smaller than 5 mm and not considered to be gross pollutants include a proportion of litter and organic matter but are predominantly sediment particles, typically between the course sand to fine silt range, and sediment associated contaminants.

6.1 Gross Pollutants

Allison et al. (1997a) undertook an investigation into the types of gross pollutants derived from an urban catchment. The study found typical urban gross pollutants transported by stormwater to include litter (predominantly paper and plastics) and vegetation (leaves and twigs) as shown in Figure 6.1. Organic matter comprised the largest proportion by mass of the collected gross pollutants and therefore should be a major consideration in street cleaning programs. The data was based on field monitoring of gross pollutants retained in a Continuous Deflective Separation (CDS) unit treating a catchment area of 50 hectares in Coburg, an inner city suburb of Melbourne.

Only a small number of investigations have examined street sweeping effectiveness on gross pollutant removal. Nilson et al. (1997) conducted an investigation into source control of gross pollutants in Adelaide and attempted to assess the efficiency of street sweeping for gross pollutant removal in stormwater. This study sought to quantify the amount of gross pollutants entering the drainage network in three similar streets swept at different intervals. Catch baskets in side entry pits were used to collect gross pollutants which were not otherwise collected by the sweeper for a street swept every day, once a week, and not at all. Trapped pollutants in these

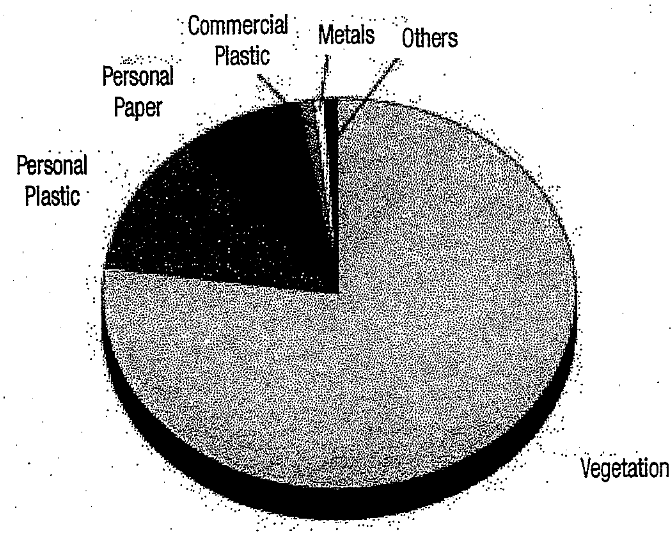

Figure 6.1 Composition of Gross Pollutants by Mass (Allison et al., 1998)

baskets were removed and quantified weekly during the study.

The results of the study by Nilson et al. (1997) show little correlation between the frequency of sweeping, rainfall or wind-run in the catchment with the gross pollutant load collected in the catch baskets. The study provided little conclusive information on the effectiveness of street sweeping with respect to gross pollutants. The study found that typically, a significant amount of gross pollutants were mobilised into the stormwater system from the street during bursts of rain, wind or both, irrespective of the nature of the street sweeping program implemented. These results suggest the amount of gross pollutants or street surface load does not limit the amount transported into the stormwater system regardless of the street sweeping frequency.

The observed composition of the gross pollutant material collected by Nilson et al. (1997) was consistent with other studies conducted by Sartor and Boyd (1972), O'Brien (1994) and Allison and Chiew (1995), where gross pollutant loads measured in dry mass comprised approximately 70-90% organic matter, and 10-30% litter.

Broad-based investigations into street sweeping conducted by the US-EPA suggest that street sweeping efficiency increases with particle size. Sartor and Boyd (1972) found sweeper efficiency to be nearly 80% for the collection of particles greater than 2 millimetres under 'test' conditions (ie. sweeping more frequently than the occurrence of rainfall events and effective use of parking restrictions). Ideal street cleaning conditions are unlikely to occur during normal street sweeping operations, and sweeper efficiencies for collecting gross pollutants would be expected to be considerably lower than the recorded 80% despite any improvements gained through refinements of equipment since the study. In practice, the effectiveness of street sweeping for gross pollutant removal is influenced by a number of factors including: access to the street load, operator skills and sweeping speed, sweeping mechanism, time of day sweeping is conducted and weather conditions.

Gross Pollutants:

- Typical urban gross pollutants transported by stormwater include litter (predominantly paper and plastics) and vegetation (leaves and twigs).
- Significant amounts of gross pollutants are mobilised into the stormwater system during bursts of rain, wind or both.
- There is little correlation between the frequency of sweeping and the transport of gross pollutants into the stormwater system.
- Street sweeping efficiency increases with particle size.
- Sweeper efficiency can be up to nearly 80% for particles greater than 2 millimetres under 'test' conditions (ie. Sweeping more frequently than the occurrence of rainfall events and effective use of parking restrictions).

6.2 Sediment and Other Suspended Solids

Street sweeping performance for smaller street surface particles depends considerably on the type of street sweeper used and also conditions such as the character of the street surface (texture, condition and type), street dirt characteristics (loadings and particle sizes), and other environmental factors (Pitt and Bissonnette, 1984).

Sartor and Boyd (1972) found the removal efficiencies of sediment by conventional street sweepers to be dependent upon the particle size range of the street surface loads as shown in Figure 6.2. Mechanical sweeper efficiency was found to be generally low for fine material. This finding was supported by two further studies conducted by Bender and Terstriep (1984) and Pitt and Bissonnette (1984), who reported that the proportion of the total street load smaller than 300 μm was less affected by street sweeping. Pitt and Bissonnette (1984) also demonstrated that no effective removal was evident for street dirt particles smaller than about 125 μm for the regenerative air sweeper.

Mechanical broom sweepers are found to be effective at collecting larger particles but less effective than regenerative-air vacuum sweepers in removing the smaller particles (Pitt and Shawley, 1982). The regenerative air vacuum sweeper, although regarded as more effective at collecting smaller particle sizes does not successfully control or remove fine particles.

Problems are encountered with water-based dust suppression methods as they tend to resuspend the small micron particles and their associated attached pollutants, forming a slurry which either fills the cracks in the pavement or is discharged into the stormwater system. Similarly, fine particles can easily escape collection when they are re-mobilised into the air by the pavement blast used by the regenerative air sweeper to dislodge larger materials.

Studies by Pitt and Sutherland (1982) indicated that a significant proportion of the larger dirt particle sizes picked up by street sweepers are not easily transported by rain and that removal of these particles tends to expose the smaller sheltered particles. These smaller particles exposed by street sweeping are then more readily mobilised and transported into the stormwater drainage system during rainfall events. The small-micron surface sweeper sweeps dry, with no water being used, and thus overcomes problems associated with resuspension of fine particulates and associated pollutants by dust suppression sprays. These machines utilise strong vacuums in combination with uniquely-designed main and gutter brooms. The air filtration system, enables smaller particles to be removed from the street surface with the return of clean air to the atmosphere (ie. filters particles down to 2.9 microns). This relatively new technology is regarded to be a high-efficiency sweeper (Sutherland et al., 1998).

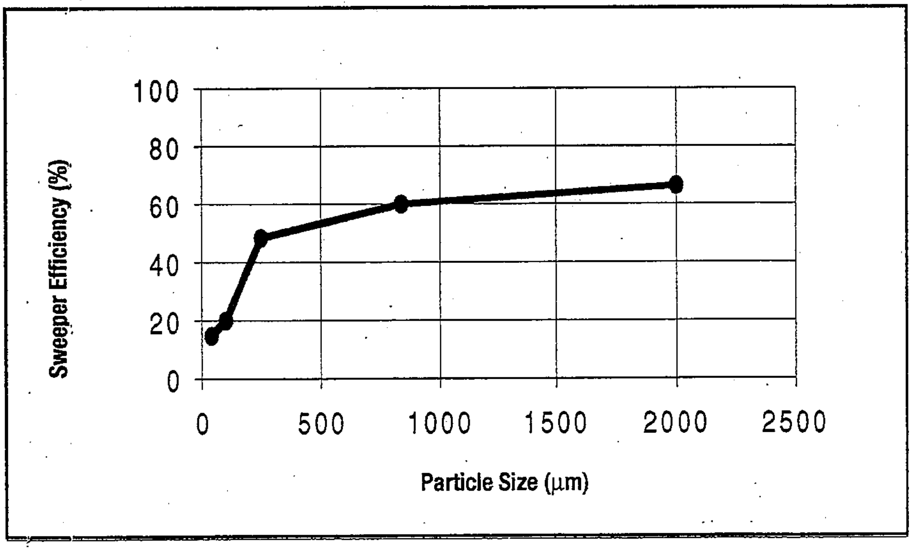

Figure 6.2 Street sweeping efficiency as a function of particle size (Sartor and Boyd, 1972)

The removal performance of street sweepers for sediment has been often determined from sampling accumulated street dirt before and after sweeping has been conducted. Initial street surface conditions are established and the street swept at a specified speed of 7-8 kilometres per hour before it is sampled to establish the residual condition. The difference between initial and residual loadings by specific particle size defines the removal performance of street sweeping operations. It was concluded from this method that sweeping removes little, if any, material below a certain threshold. This threshold load was found to vary by particle size range. A series of mathematical equations developed by Pitt (1979) to describe this removal performance have been recently calibrated and employed by Sutherland and Jelen (1996a and 1997) to evaluate and compare the removal performance of numerous street sweeping technologies.

Sutherland and Jelen (1997), using their Simplified Particle Transport Model, tested the removal performance of the small-micron sweeper, along with a regenerative air vacuum sweeper, a mechanical broom sweeper, and a tandem operation that involved a single pass by a mechanical broom followed by a vacuum sweeper. The small-micron sweeper was shown to be the most efficient, with average total removal efficiencies of 70% for particles less than 63 µm and between 77% and 96% for particle sizes ranging from 125 µm to larger than 6370 µm. The small-micron sweeper demonstrated an ability to efficiently remove particles without any threshold level unlike the other sweepers tested. The regenerative air sweeper was shown to be the second most efficient with overall removal efficiencies calculated to range from 32% for less than 63 µm range to 100% for larger particles between 600 and 2000 µm. However, the removal efficiency of the regenerative air sweeper for particles between 250 and 2000 µm can drop to zero, due to the necessity of large threshold loads for particles within this size range. The tandem operation and mechanical broom sweeper were found to be the least efficient despite some recorded high efficiencies. This can be mainly attributed to the high threshold loads required by these operations before any significant sediment removal is recorded.

6.3 Contaminants Associated with Sediment

It is well recognised that a significant amount of metals and nutrients are transported as sediment-bound contaminants. Many investigations have found the concentration of sediment-bound contaminants to vary with particle size, with high concentrations of contaminants attached to the finer particles (Sartor & Gaboury 1984, Sartor & Boyd 1972). Hvitved-Jacobsen et al. (1991, 1994) investigated road runoff pollutant characteristics and found 60-80% of phosphorous, 30-40% of zinc, 70-80% of lead, 30-40% copper and about 55% of total nitrogen in road

Sediment and Other Suspended Solids:

- The removal efficiency of sediment and other fine organic particles by conventional street sweepers was found to be dependent upon a threshold level of load on the surface and the particle size range of the surface loads.
- Material smaller than 300 µm was less affected by street sweeping.
- No effective removal (>50% removal efficiency) was evident for particle sizes smaller than 125 µm for conventional street sweepers (excluding the new small-micron surface cleaning technology).

runoff to be associated with particulates. While most particulate matter found on street surfaces is in the fractions of sand and gravel. Approximately 6% of particles are in the silt and clay soil size and they were found to contain over half the phosphorous and some 25 percent of other pollutants, as indicated in Table 6.1, adapted by Shaver (1996) from results of Sartor et al. (1974).

Many other investigations have found the concentrations of sediment-bound contaminants in street dirt to be associated with the fine particle size fraction. Pitt & Amy (1973), NCDNRCD (1993) and Woodward-Clyde (1994) have all shown that higher concentrations of pollutants such as heavy metals are associated with the smallest particle size fractions of urban dust and dirt. These data indicate that almost half of the heavy metals (represented by copper, lead and zinc) found on street sediments are associated with particles of 60 to 200 µm in size and 75% are associated with particles finer than 500 µm in size. Dempsey et al. (1993) undertook an analysis of particle size distributions for urban dust and dirt, and partitioning of contaminants into a number of size fractions to determine the concentrations of contaminants in each particle size range. Results show the highest recorded concentrations of Cu, Zn and TP to be associated with sand particles between 74 and 250 µm in size.

Colwill et al. (1984) found 70% of oil and approximately 85% of polycyclic aromatic hydrocarbon (PAH) to be associated with solids in the stormwater. That study demonstrated that over a period of dry weather conditions, increasing proportions of oil become solid associated where the highest oil content was found in sediments of 200 to 400 µm in size.

Sansalone et al. (1997), Fergusson and Ryan (1984), Baker (1980) and Wilber and Hunter (1979) all reported that heavy metal concentrations increase with decreasing particle size. Results presented by Sansalone et al. (1997) from particle size distribution and metal analysis indicate that zinc, copper and lead concentrations increase with decreasing particle size or, equivalently, increasing specific surface area. The absorption of contaminants to particles is often regarded as being directly related to the surface area per unit mass available for ion absorption. Measured specific surface area results presented by Sansalone et al. (1997) indicated that the assumption of smooth spherical particles to estimate available surface area

Table 6.1 Percentage of Street Pollutants in Various Particle Size Ranges

	Particle Size (µm)					
Pollutant	**<43**	**43 - 104**	**104 - 246**	**246 - 840**	**840 - 2000**	**>2000**
Total Solids	5.9	9.7	27.8	24.6	7.6	24.4
Volitile Solids	25.6	17.9	16.1	12.0	17.4	11.0
COD	22.7	45.0	12.4	13.0	4.5	2.4
BOD	24.3	17.3	15.2	15.7	20.1	7.4
TKN	18.7	19.6	20.2	20.0	11.6	9.9
Phosphates	56.2	29.6	6.4	6.9	0.9	0.0
All Toxic Metals	27.8	-	23.5	14.9	17.5	16.3

(Source: Shaver; 1990; adapted from Sartor, Boyd, and Agardy, 1974) grossly underestimated the actual available surface area of particulates transported in stormwater. Specific surface area values were found to deviate from the monotonic pattern expected for spherical particles. Particles in the mid-range to coarser end (100 to 1000 µm) of the distribution were shown to contribute a larger surface area than would normally be expected.

The sediment binding behaviour of other toxicants such as polychlorinated biphenyls (PCB's) and polycyclic aromatic hyrdrocarbons (PAH's) is different to that of heavy metals. Schorer (1997) reported PCB's and PAH's to have no correlation with particle size distribution or surface area but rather with the abundance of organic material. Results indicated that the organic material content in different particle size fractions was bimodally distributed with maximum measurements recorded for fine silt (2 - 6.3 µm) and fine sand fractions (63 - 200 µm). Concentrations of PAH's would therefore be expected to be attached to these particle size fractions.

A substantial database, identifying particle size distributions and other parameters that relate to reactivity and mobility of contaminants, has resulted from data collected by a number of US-EPA studies. However, to date only limited information regarding the physical and chemical characteristics of urban stormwater runoff are available for Australian conditions. Results from an investigation by Mann and Hammerschmid (1989) on urban runoff from two catchments in the Hawkesbury/Nepean basin indicated the existence of high correlations between total suspended solids (TSS) with total phosphorus (TP), total kjeldahl nitrogen (TKN) and chemical oxygen demand (COD). Ball et al. (1995) found that TSS and TP show similar characteristics and correlations to other overseas studies.

In relation to street sweeper effectiveness, the association of pollutants with sediment, particularly the finer fractions, would suggest street sweeping needs to remove these particles in order to provide effective stormwater pollution control. However, street sweeping has to date been found to be generally effective only for material larger than 300 µm (see section 6.2).

Contaminants Associated with Sediment:

- Significant amounts of metals and nutrients are transported as sediment-bound contaminants.
- Most of the total mass of contaminants is associated with the fine particles.
- Conventional street sweeping is generally ineffective at removing particles smaller than 300 µm and therefore will not effectively reduce the export of sediment-bound contaminants such as nutrients, metals and PAHs.

6.4 Australian Conditions

Various studies undertaken by the US-EPA found the major constituents in street dirt to be consistently inorganic, mineral-like matter, similar to common sand and silt. This could be due to the fact that many of the US-EPA studies were conducted in cities where applications of screened sands are made to road surfaces. Street surface particulate matter has been described as having particle sizes ranging from about 3000 to 74 µm and less (Sartor and Gaboury, 1984).

A collation of reported particle size distribution curves for solids found on street surfaces and in street surface and highway runoff is shown in Figure 6.3. The collection of 20 particle size distribution curves presented in Figure 6.3 are derived from sampling solids from street surfaces and suspended sediment collected in road runoff from a number of overseas and Australian catchments.

It is evident from Figure 6.3 that despite the overseas data being collected from a variety of sources, locations and by various methods, they show a consistent distribution ranging from approximately 10 µm to approximately 10,000 µm. The particle size distributions derived from sampled road runoff from two Australian sites, one as part of an ongoing CRC project and the other by Ball and Abustan (1995), are also presented and appear to fall outside the range of the particle size distribution curves of the overseas catchments. The Australian data range from 2 µm to approximately 500 µm. There may be a number of possible explanations for this observed finer particle size distribution including differences in sampling and analysis techniques. However, it should be noted that the particle size distributions derived from overseas catchments were based on a variety of sampling and analysis techniques. The upper particle size limit can influence the position of the derived particle size distribution curve. Adjustments (Lloyd and Wong, 1999) to the overseas data to eliminate particles larger than 600 µm, to allow a common basis for comparison of these curves, still showed the Australian data sets to exhibit finer particle size characteristics. The significantly different particle size distribution of the Australian catchments may indicate fundamental differences in catchment characteristics.

The Australian sampled road runoff data displays a significantly finer particle size distribution, with a greater percentage of particles less than 125 µm (up to 70%). Although only based on sampling at two sites, the inefficiencies of street sweeping in removing particles less than 125 µm would result in little reduction of up to 70% of the particles found in runoff in these Australian catchments. The difficulty for Australian street sweeping is the fine nature of the sediment found on roads. Up to 70% of particles found on street surfaces are less than 125 µm compared to 20% for overseas road runoff data. The inefficiencies of street sweeping in the reduction of sediment-bound pollutants entering the stormwater system is therefore expected to have more severe implications under typical Australian conditions.

Removal of Sediment and Associated Contaminant:

- Limited sampling of sediment in street runoff in Australia indicates that 70% of particles are less than 125 µm compared to 20% for overseas data.
- The fine sediments found on Australian streets would suggest that conventional street sweeping will have a minimal effect on sediments and associated contaminants reaching stormwater systems.

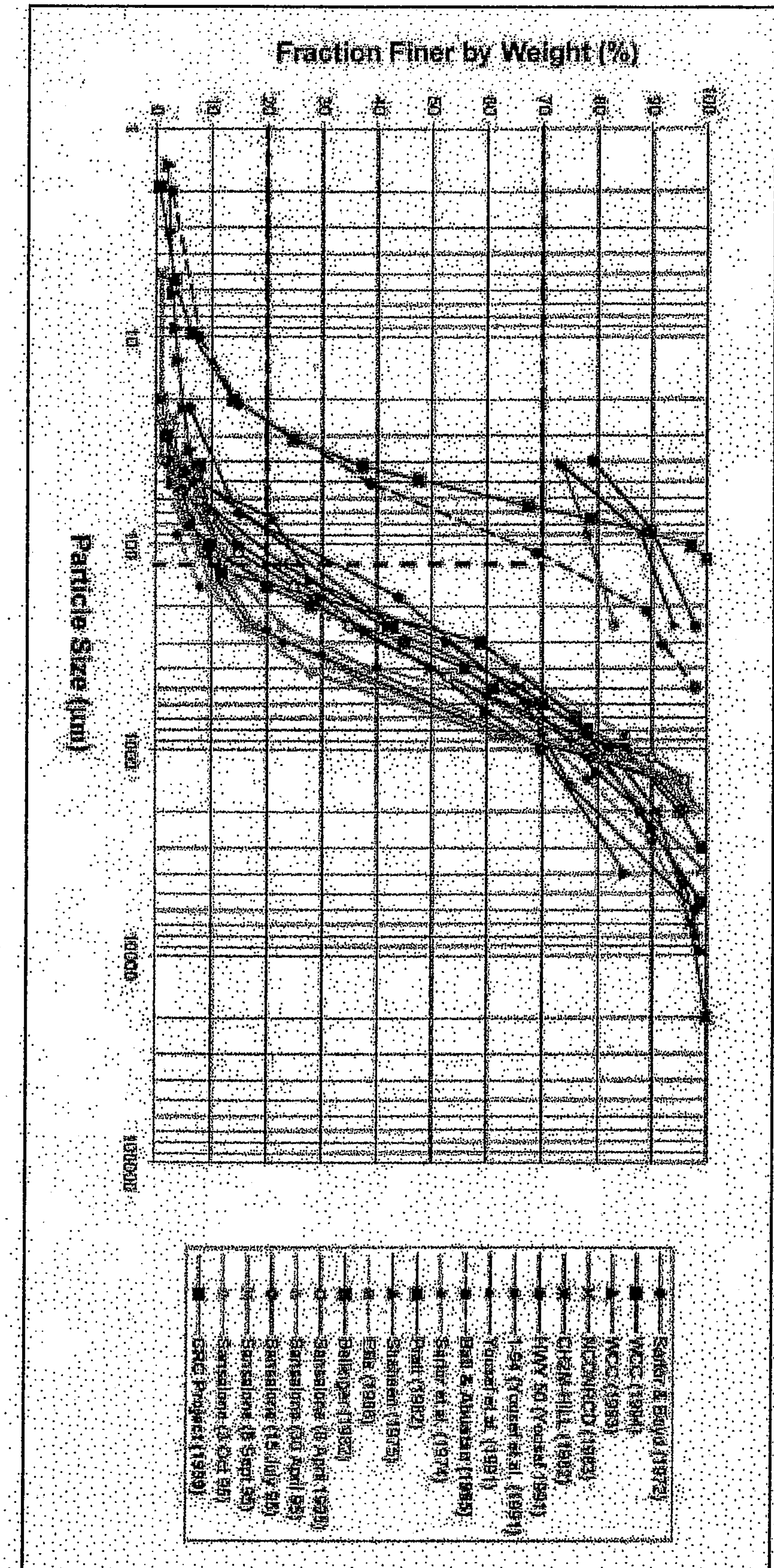

Figure 6.3 Particle Size Distribution of Suspended Solids in Road Runoff

7 Street Sweeping Frequency And Timing

7.1 Sweeping Frequency and Rainfall Patterns

Sartor and Gaboury (1984) concluded that the dominant influence on the effectiveness of street sweeping appears to be time intervals, ie. the relationship between the average interval between storm events (a function of local meteorological conditions) and the frequency at which streets are swept. Street sweeping operations are typically programmed for a fixed interval (eg. swept once per week). If the average time between rainfall events is much less than the sweeping interval, then much of the street surface load could be washed away by storm runoff, hence, making street sweeping relatively ineffective. In this context, analysis of rainfall statistics is important in the design of street sweeping programs to ensure street sweeping is compatible with the frequency of storm events and therefore optimise the effectiveness of street sweeping for removal of stormwater pollutants.

Generally street sweeping frequencies are determined according to land-use. Street sweeping frequencies, practiced by Melbourne metropolitan municipalities, generally range between daily sweeping for busy commercial areas and every six weeks for residential areas. The sweeping frequency in the CBD of Melbourne could however involve numerous sweeps throughout the day. Councils ordinarily stipulate sweeping specifications for the purpose of meeting community demands for aesthetic quality and amenity improvement. The inter-event dry period between storms is not often a factor considered when street sweeping programs are formulated. However, if municipalities are willing to incorporate stormwater management objectives into street sweeping programs, the occurrence of rainfall events should become a significant design factor.

The minimisation of pollutant washoff, particularly fine particulates and associated contaminants, from street surfaces requires compatibility of street sweeping frequency and timing with rainfall characteristics and the daily activities in the catchment. Fine particulates and associated contaminants are often mobilised with even the smallest amount of runoff while gross pollutants often require a minimum runoff rate to be reached before they are mobilised. In areas which are not swept daily, the selected street sweeping frequency should ideally reflect the relationship with the inter-event dry period (time between storm events) typical of the catchment. For those catchments currently on a daily street sweeping regime, the time of day when street sweeping is conducted should be selected to limit the period in which the pollutants deposited on street surfaces are exposed to the risk or likelihood of wash-off associated with a storm event.

7.2 Inter-Event Dry Period

It can be assumed that the majority of pollutants transported into the stormwater system occur during rainfall event periods. Therefore if the street cleaning frequency is longer than the average inter-event dry period it can be expected that the accumulated pollutants, on road surfaces, will have a higher likelihood of being washed into the stormwater system before being collected by the street sweeper.

Melbourne rainfall was characterised from analysis of rainfall over a 105 year period by Wong (1996). The analysis identified storm events as having a thirty minute minimum storm duration. A six hour minimum period of no rainfall to define the conclusion of a rainfall event. Using this definition for a storm event, the analysis found the mean period between storms in Melbourne to be 62.4 hours (2.6 days) with a standard deviation of 76.8 hours (3.2 days). There is an apparent trend in Melbourne of longer periods between storms in summer months, with a maximum mean period of 108 hours (4.5 days) in February and a minimum mean period of 45 hours (1.9 days) in August as shown in Figure 7.1. Wong (1996) also carried out an analysis of the rainfall data for a number of major cities in Australia, and the statistics according to their respective months are presented in Table 7.1. The influence of seasonality on the period between storms for the cities is shown in Figure 7.2.

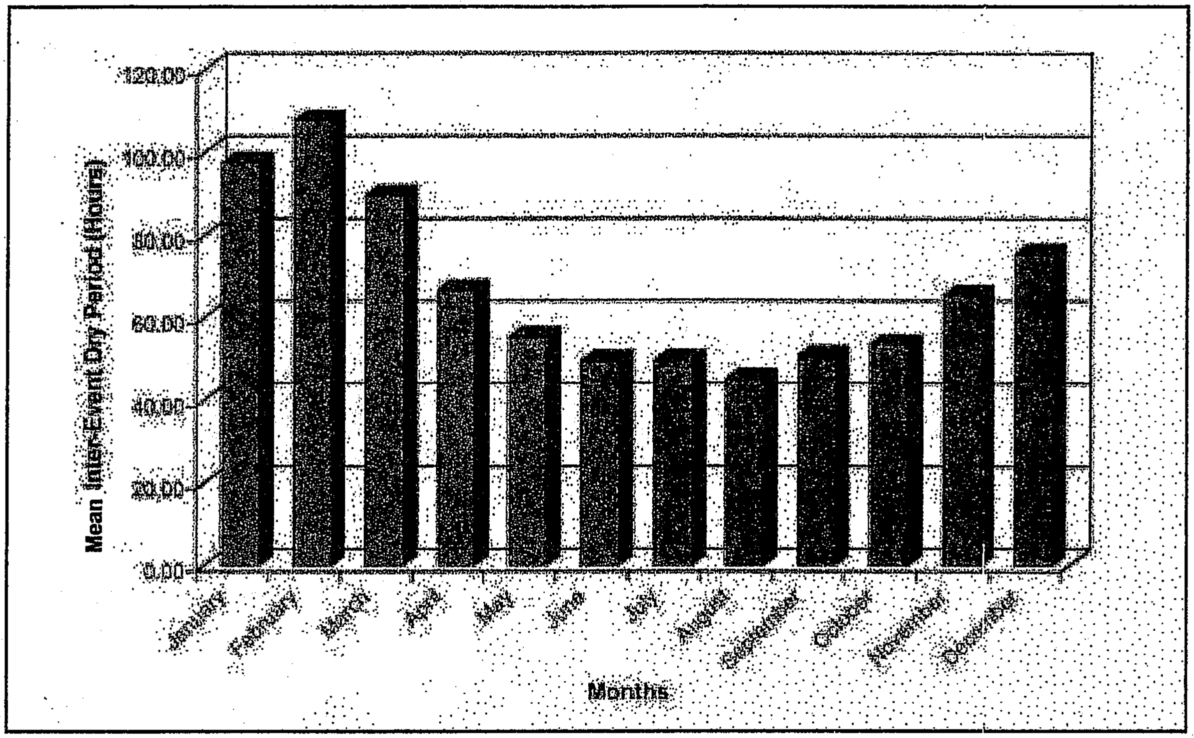

Figure 7.1 Melbourne Mean Monthly Inter-Event Dry Period

Table 7.1 Mean Inter-Event dry Periods (Hours).

CITIES	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
Adelaide	165.93	189.42	156.52	94.81	61.07	51.16
Brisbane	65.39	57.28	58.08	74.48	93.68	111.03
Darwin	33.02	32.10	41.40	116.14	130.32	561.14
Hobart	72.33	83.26	74.79	60.86	56.24	50.69
Melbourne	97.38	107.55	89.56	66.68	55.21	49.46
Perth	250.70	238.29	200.54	89.21	58.02	39.91
Sydney	70.30	64.68	66.58	69.27	70.19	73.36

CITIES	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
Adelaide	44.02	44.45	54.94	69.63	93.96	128.95
Brisbane	133.87	141.20	126.21	90.91	81.91	72.38
Darwin	416.95	240.36	217.41	120.79	62.21	58.72
Hobart	47.94	46.93	50.47	47.26	49.03	59.92
Melbourne	49.57	45.01	50.63	53.39	65.32	75.32
Perth	39.96	53.79	62.20	88.16	141.96	193.17
Sydney	91.48	98.50	97.78	77.87	68.92	76.31

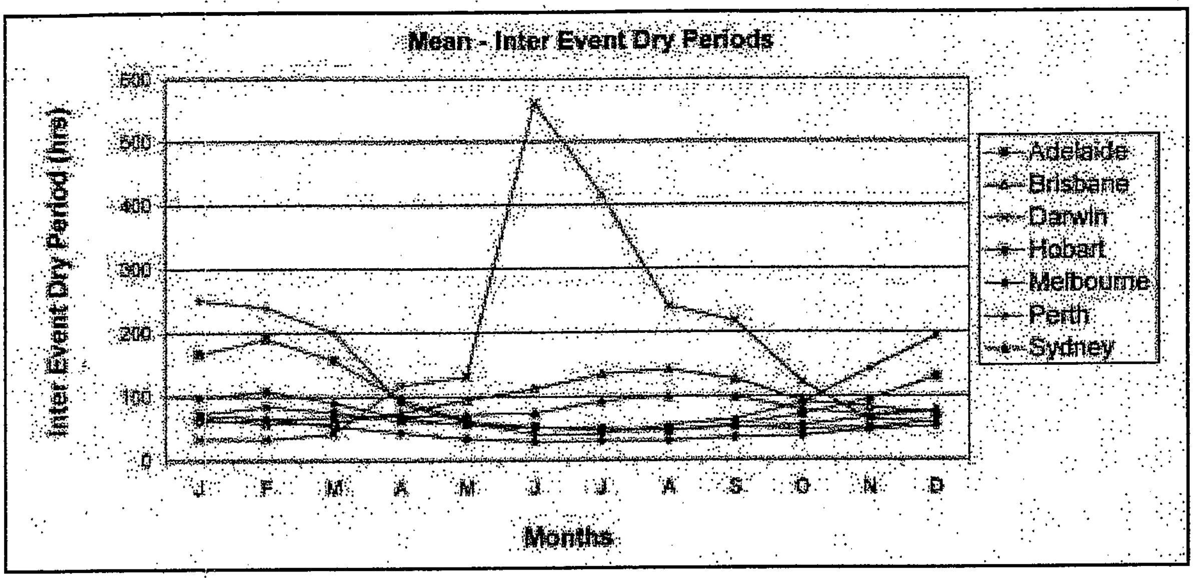

Figure 7.2 Mean Inter-Event Periods for Australian Cities

Of the cities analysed, Darwin shows the most inter-event dry period variability between seasons, ranging between 32 hours (1.3 days) and 561 hours (23.4 days), with the longer periods, unlike Melbourne, occurring during the winter months. The variable nature of inter-event dry periods, both between seasons and capital cities highlights the importance of street sweeping program design being specific to location and flexible to accommodate for season variability.

Based on consideration of typical inter-event dry periods, one would question the effectiveness of current Australian street sweeping practices in effectively preventing pollutants entering the stormwater system if the street sweeping frequency, designed for aesthetic objectives, is significantly lower than the frequency of storm events. If streets are only swept every six weeks then it is likely that storm events occurring within this period will flush a large proportion of the accumulated pollutants into stormwater drains before sweeping has the opportunity to collect it. In the case of gross pollutants, Allison et al. (1998) suggested a minimum rainfall amount before there is sufficient runoff to re-mobilise these larger size pollutants. As a gross pollutant export control, sweeping frequency equivalent to approximately three times the mean inter-event period appears to be appropriate (see Section 8.1).

Sweeping Frequency and Rainfall Patterns:

- The variable nature of inter-event dry periods, both in terms of seasonal variation and dependence on climatic locations, highlights the importance of street sweeping program designs which are specific to location and flexible to accommodate the local meteorological conditions and seasonal variability.
- It is anticipated that if street sweeping occurs at a longer interval than the inter-event dry period of the catchment, street surface pollutants will have a much higher likelihood of being flushed into the stormwater system before being collected by the street sweeper.

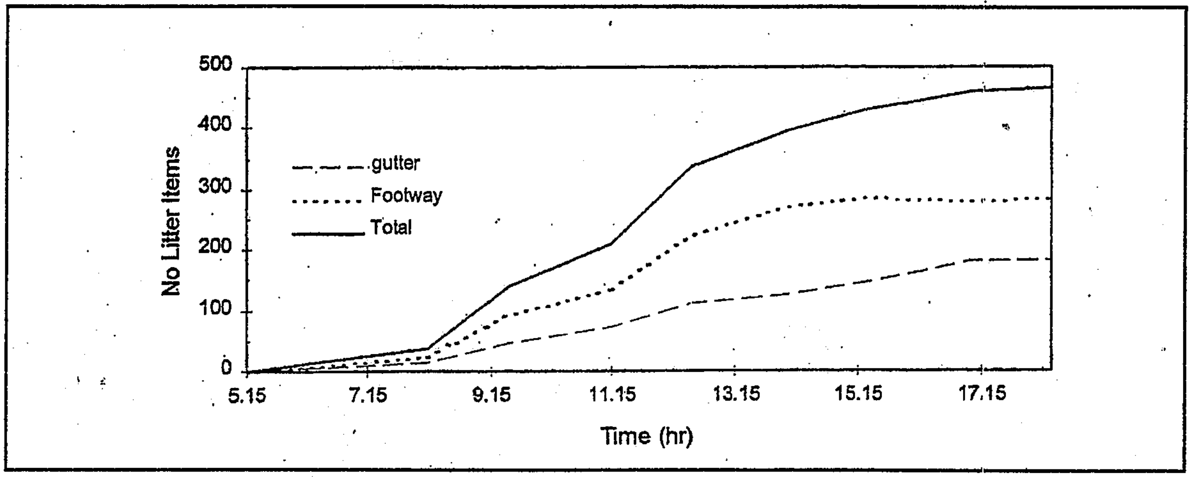

Figure 7.3 Daily Litter Generation (Hall and Phillips., 1997)

7.3 Street Sweeping Timing

Analysis of street and footpath litter accumulation along a 280 m section of strip shopping centre in the Melbourne suburb of Carnegie during a typical business day was conducted by Hall and Phillips (1997). This commercial land-use area is subject to typical street sweeping operations carried out daily by the Glen Eira municipality. Detailed recording of the gross pollutant load generated over a day from 5:15 to 18:30 commenced immediately after street sweeping and footpath cleaning and concluded when trade had effectively ended. The data indicates that the rate of accumulation of litter is highest between the times of 8:00 and 17:00 with litter accumulation effectively ending around 17:00 hours in the evening (see Figure 7.3).

The data plotted in Figure 7.3 suggest that the time of day a rainfall event occurs can alter the amount of litter available for re-mobilisation to the stormwater system. The time of day at which street sweeping is practiced is expected to have an effect on the amount of litter entering the stormwater system due to the exposure time of deposited pollutants to wash-off processes. Street sweeping is most commonly conducted in the early morning leaving the accumulated pollutants, especially litter from the day before, to a longer exposure period and the likelihood of over night rainfall events capable of flushing them into the stormwater system.

The study by Hall and Phillips (1997) also involved comparing accumulated litter items from street surfaces and side entry pit traps (SEPTs) in drains following rainfall events. The Carnegie urban catchment was monitored over a seven day period, and litter material was measured from bins, footpaths, street surfaces and SEPTs located in stormwater drain inlets. Footpath litter items were not considered when determining the effect of rainfall due to their surfaces being sheltered from rainfall and associated washoff mechanisms. When only street material is considered, up to 77% of the calculated street items entered the stormwater system during rainfall events. These data suggest that street washoff is the principal mechanism for transport of gross pollutants into the stormwater system.

Street Sweeping Timing:

- Recorded gross pollutant load generation over a typical day indicates that the accumulation of litter in a shopping strip begins at 8:00 and effectively ends around 17:00 hours.
- Early morning street sweeping allows the exposure of deposited street surface litter items to a higher likelihood of being transported into the stormwater drainage system.

8 Gross Pollutant Wash-Off Characteristics

8.1 Gross Pollutant Load Generation

The study by Allison et al. (1998) showed that stormwater runoff is the principal means by which gross pollutants are transported to the stormwater system. Ten storm events (larger than 3 mm of rainfall) and their transported gross pollutant loads in the Melbourne suburb of Coburg were monitored using the CDS unit from May to August 1996 (Allison et al., 1998). Monitoring was carried out in a 50 hectare catchment and the amount of gross pollutants transported during each of the 10 events was found to be correlated with the event rainfall depth as shown in Figure 8.1. A similarly high correlation between the gross pollutant load retained in the CDS unit and event runoff was also obtained as shown in Figure 8.2.

According to the fitted relationship between the wet gross pollutant load generated and the depth of rainfall (see Figure 8.1), events of less than 3.7 mm may be considered to be insufficient for re-mobilisation and transport of deposited street surface loads. The corresponding threshold for runoff (see Figure 8.2) is 0.70 mm. The fitted relationships between gross pollutant wet load and event rainfall depth or runoff show a trend of increasing gross pollutant load with increasing rainfall or runoff. Although the curves are monotonically increasing, the rate of increase in gross pollutant loads decreases with rainfall and runoff indicating a possible upper limit of gross pollutant load transported into the stormwater system during large rainfall or runoff events. The fitted curves in Figure 8.1 and 8.2 may be interpreted as indicating that the limiting mechanism for stormwater gross pollutant transport, in the majority of cases, is not the supply of gross pollutants but rather the processes (ie. the stormwater runoff rates and velocities) influencing the mobilisation and transport of these pollutants.

If the mobilisation and transportation of gross pollutants from the street surface depends on a rainfall depth greater than 3.7 mm, it is likely that the inter-event dry period for gross pollutant transporting storm events, in Melbourne will be longer than the calculated 2.6 days for all recorded storm events. Analysis of the cumulative frequency distribution of event rainfall depth for Melbourne over a 105 year record is presented in Figure 8.3. The analysis shows that approximately 35% of all recorded rainfall events are greater than 3.7 mm giving an average inter-event dry period of 178 hours (7.4 days) for gross pollutant transporting storm events.

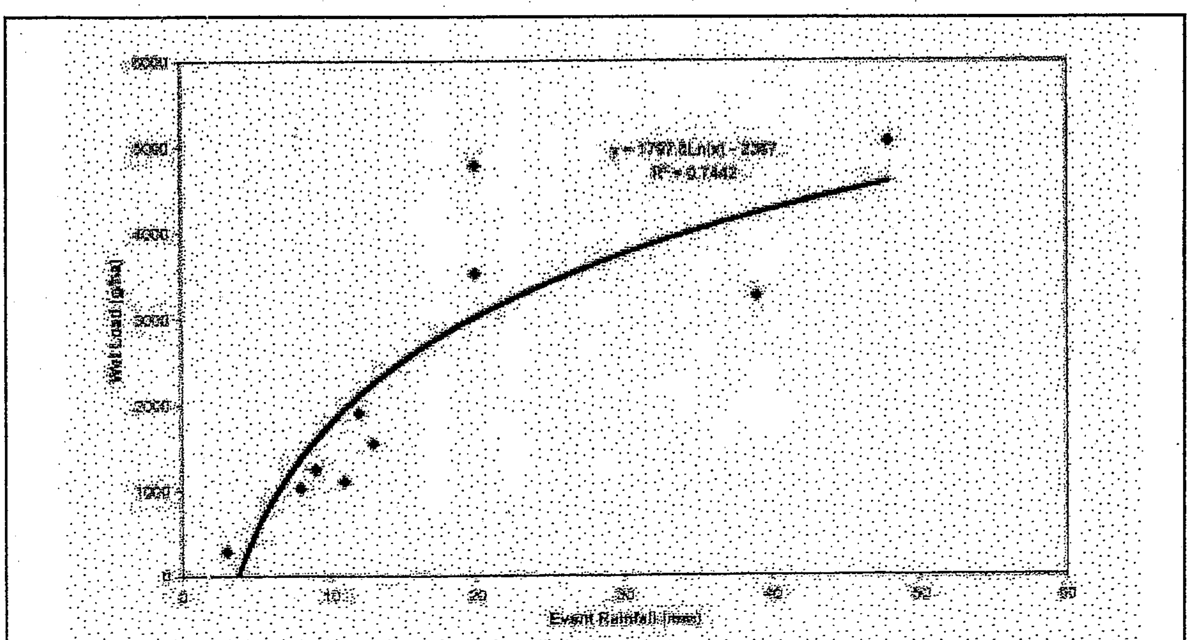

Figure 8.1 Gross Pollutant Wet Loads v's Rainfall (after Allison et al., 1998)

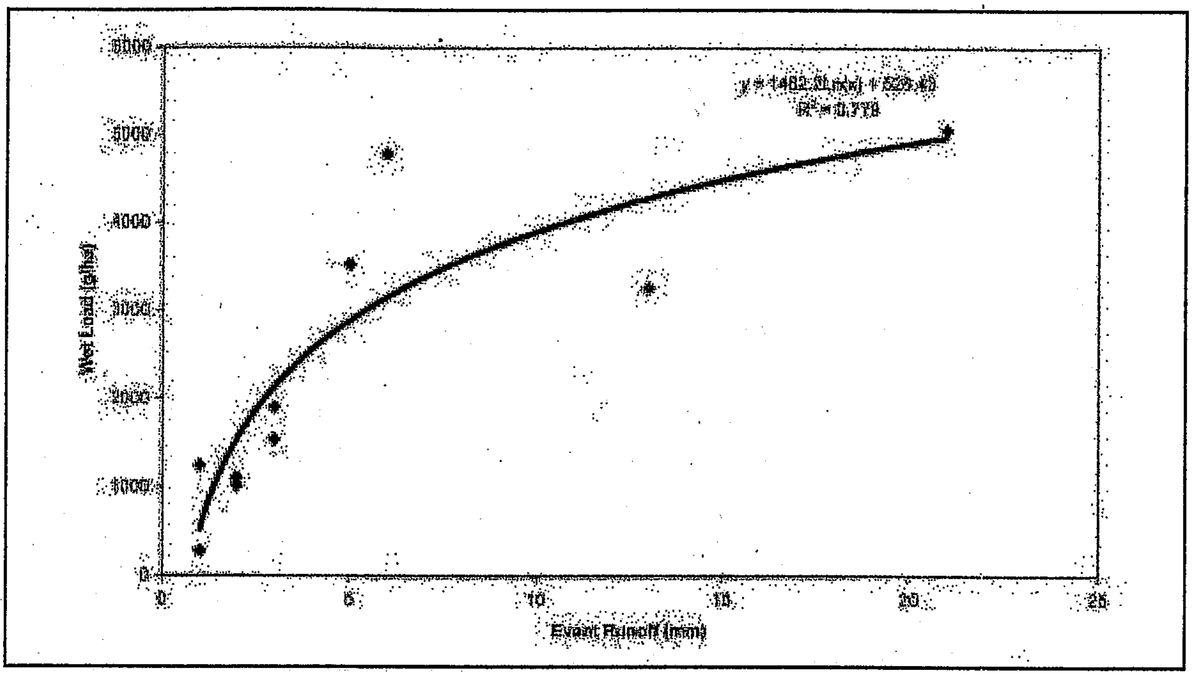

Figure 8.2 Gross Pollutant Wet Loads v's Runoff (after Allison et al., 1998)

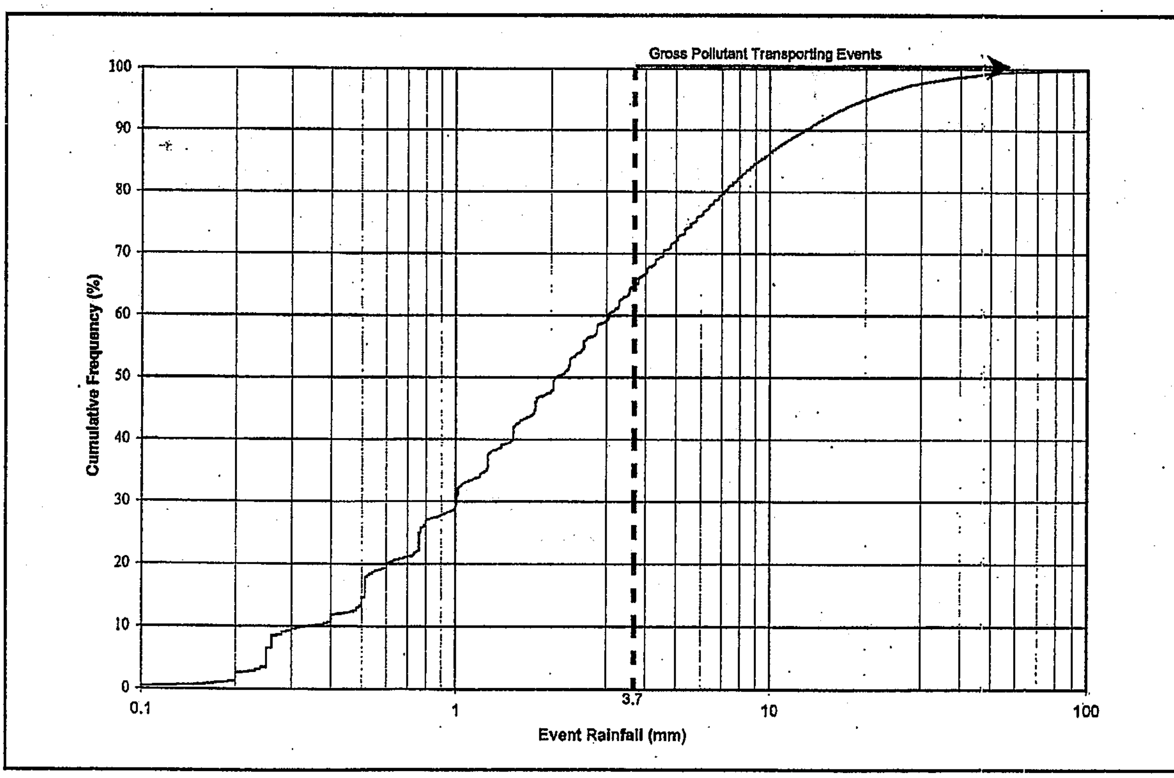

Figure 8.3 Cumulative Probability Distribution of Event Rainfall Depth for Melbourne

The Coburg gross pollutant wet load data have incorporated the effect of Moreland City Council's street sweeping practices which range from daily to fortnightly, depending on land-use. How exactly any alterations made to the street sweeping frequency would affect the gross pollutant load in stormwater (see Figure 8.2) is not known and cannot be ascertained from the data collected. However, it is possible for some inference of the effectiveness of street sweeping in limiting the export of gross pollutants from street surfaces to the stormwater system to be made, and this will be discussed in Section 9.2.

Despite rainfall wash-off being the dominant factor transporting gross pollutants from street surfaces, litter can also reach the stormwater system during dry weather periods. The litter monitoring study, conducted by Hall and Phillips (1997), in the Carnegie commercial catchment indicated that during dry days numerous gross pollutant items are transported into the stormwater system by factors other than stormwater runoff (eg. wind or direct dumping). That study focused on measuring the number of litter items as well as material composition collected daily over seven days, from identified catchment pollutant sources. SEPTs were placed in drain entry pits located in the study area to determine the number of litter items reaching the stormwater system from the identified catchment pollutant sources (including bins, footpaths and street surfaces). The results showed that up to 78 items of litter in total (per day) were collected in SEPTs during periods without rainfall. A substantial amount of the material trapped during recorded dry days were lighter items (polystyrene) although numerous heavier items were also found, indicating possible direct littering rather than wind blown transportation of street surface pollutants.

Gross Pollutant Load Generation:

- Data collected in the Coburg catchment indicated washoff of gross pollutants becomes significant for storm events greater than 3.7 mm of rainfall depth or 0.70 mm of runoff.
- The limiting mechanism affecting the transport of gross pollutants in the majority of cases appears to be re-mobilisation and transport processes (ie. stormwater runoff rates and velocities) and not the supply of gross pollutants.
- Approximately 35% of all recorded rainfall events in Melbourne are greater than 3.7 mm giving an average inter-event dry period of 178 hours (7.4 days) for gross pollutant transporting storm events.

8.2 Influence of Catchment Land-use

As part of the same project, Allison et al. (1997b) investigated the effectiveness of side entry pit traps (SEPT's) by monitoring 192 SEPTs installed in all publicly owned side entry pits of the 50 hectare Coburg catchment as shown in Figure 8.4. The study aimed to assess the effectiveness of SEPTs by using a CDS unit located at the outlet of the catchment to collect any gross pollutants which may pass the SEPTs. The SEPTs were monitored from 2 August 96 to 15 November 96. During these four months, the traps were cleaned out on four separate occasions. For each of these clean-outs the total SEPT load (wet & dry) for each trap was calculated. Gross pollutant load data from that study are used for further analysis in this study.

SEPT gross pollutant wet load data were grouped according to the practiced street sweeping regime defined by catchment land-use. Figure 8.5 displays the three identified land-use sub-catchments in the Coburg catchment (50ha) as the daily swept South East (SE) commercial sub-catchment (13ha), the fortnightly swept North West (NW) & South West (SW) residential sub-catchments (24.5ha) and the daily / fortnightly swept North East (NE) mixed land-use sub-catchment (12.5ha).

The total SEPT gross pollutant wet loads were calculated and categorised according to street sweeping regime, defined by the three sub-catchment land-use types and are presented in Table 8.1. The days between clean outs, total rainfall between clean outs and the number of storm events, are also presented in Table 8.1. For the purpose of this analysis a storm event was identified as a storm that had the potential to re-mobilise deposited solids from the road surfaces and is described as a gross pollutant transporting event (ie. greater than 3.7 mm after Allison et al., 1997b). The SEPT wet loads have been normalised into a load (g) per unit catchment area (ha) to enable gross pollutant loads from the sub-catchments to be compared.

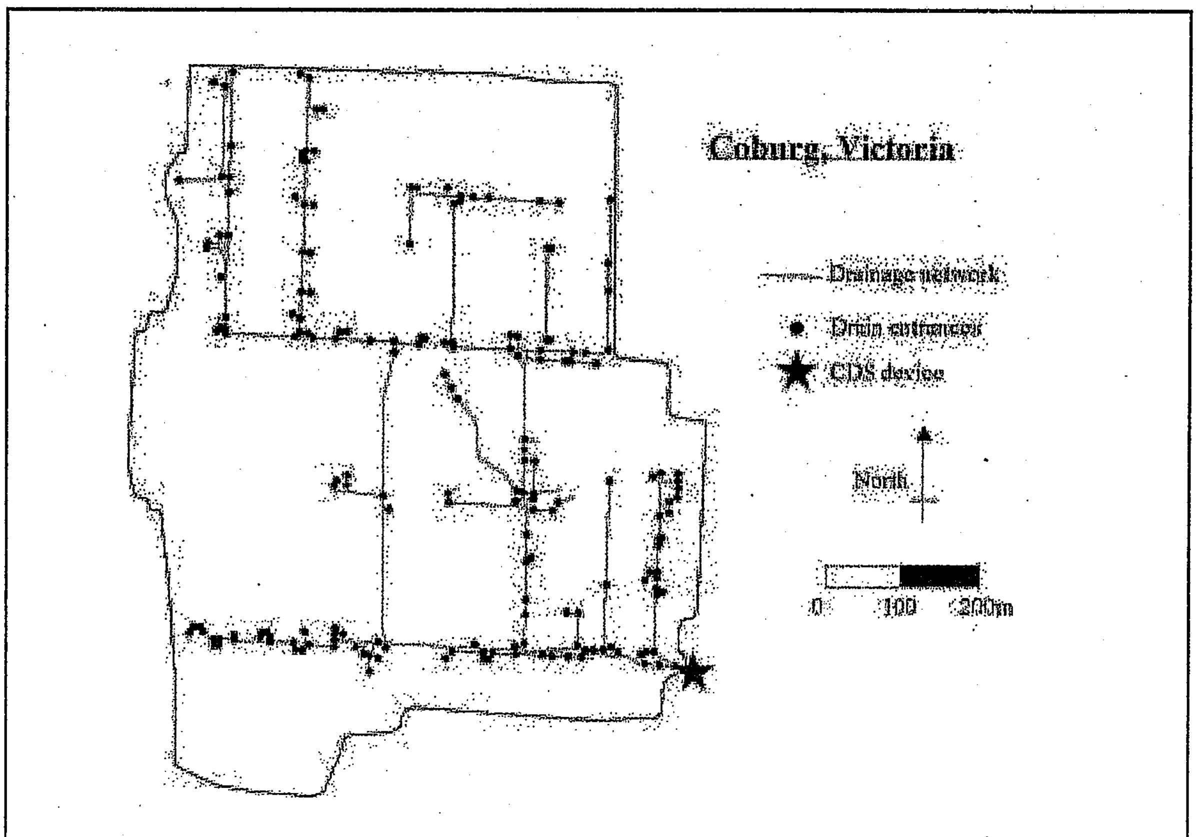

Figure 8.4 SEPT installations in the experimental 50ha Coburg Catchment (source Allison, 1998)

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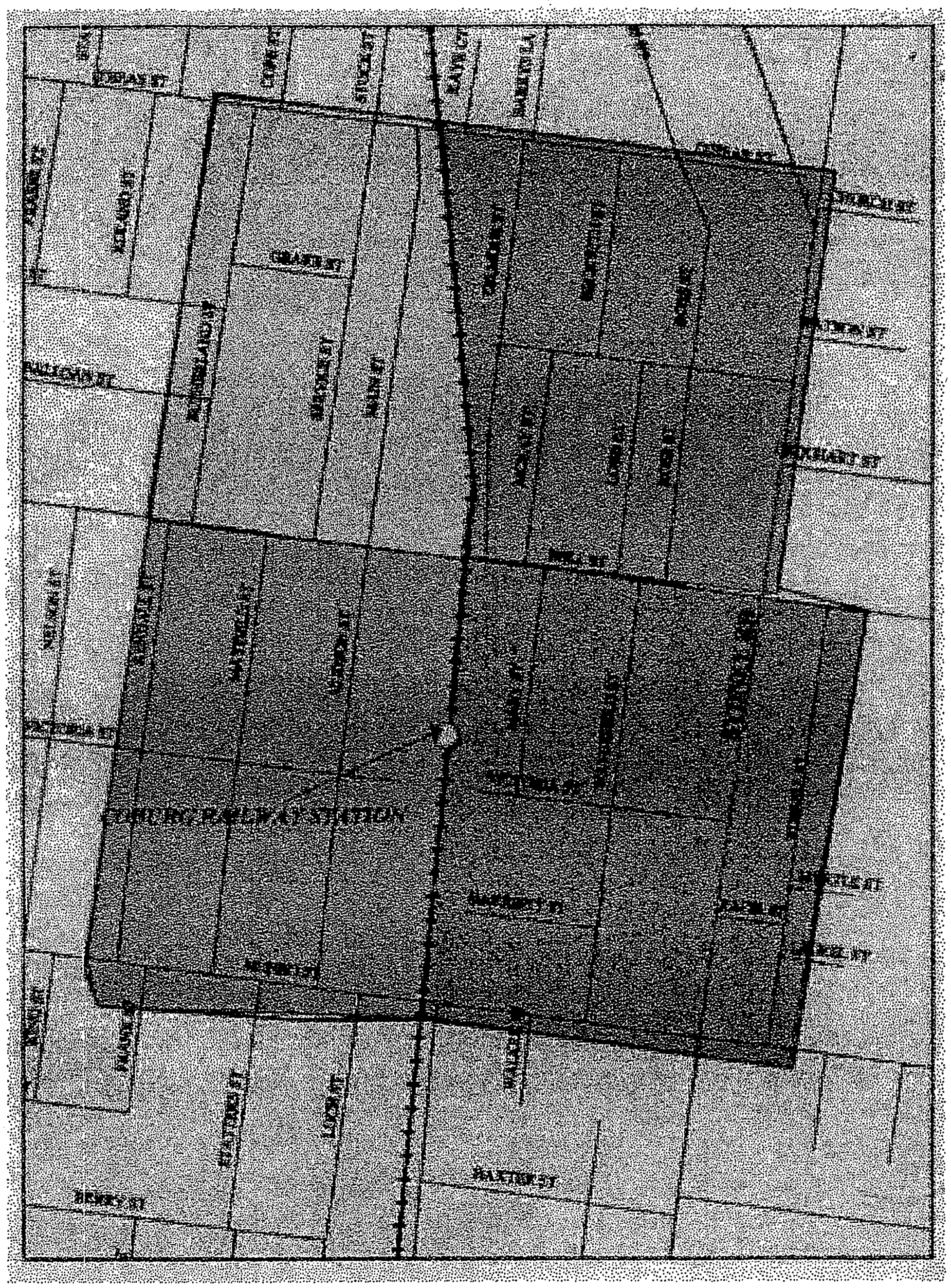

Figure 8.5 Land-use Sub-catchments in the 50ha Coburg Catchment
(source Moreland City Council and Merri Creek Management Committee, 1997)

Table 8.1 Event Rainfall and Related SEPT Total Gross Pollutant Wet Loads

Clean-out Date	Days between clean-outs	Total Rainfall (mm)	Storm Events (>3.7mm)	Single Event Rainfall (mm)	Event Rainfall (mm)	Commercial Wet Load (g/ha)	Residential Wet Load (g/ha)	Mixed Wet Load (g/ha)
29-Aug-96	27	55	5	(6.4) (10) (5) (15) (12)	48	5000	2408	1760
30-Sep-96	32	74	6	(11) (12.3) (16.4) (4.4) (9.4) (11.5)	65	20154	10041	6880
15-Oct-96	15	25	2	(8.2) (14)	22	6462	3143	1840
15-Nov-96	31	47	2	(7) (35.4)	42	6538	5878	1920

As indicated in Table 8.1, calculated total SEPT wet loads ranged from 1.8 kg/ha for the mixed land-use sub-catchment to as much as 20.2 kg/ha for the commercial sub-catchment. Figure 8.6 displays the comparison between land-use and total SEPT wet load, indicating commercial land-use contributes larger loads of gross pollutants per hectare compared to residential and mixed land-use catchments. This is in spite of daily street sweeping in the commercial sub-catchment compared to once every two weeks in residential and mixed land-use areas. Three of the four clean outs showed the ratio of gross pollutant load generation between the commercial and residential areas to be approximately 2.0. There was however, one clean out, that of the 15 November 96 which gave a significantly lower ratio of 1.1. It is interesting to note that the gross pollutant load generated from the mixed land-use was the lowest in all the four clean outs.

Many factors other than land-use contribute to the differences observed in the amount of gross pollutants exported from the different areas, including wind, traffic volume, topography, population density, community awareness and importantly the hydrologic conveyance system. Hydrologic conveyance factors which can influence gross pollutant export include the number of side entry pits in the stormwater system (ie. the average distance to entry pits from within the catchment), the degree of catchment area imperviousness and the extent of "supplementary areas" (defined as pervious areas over which runoff from impervious areas needs to traverse when discharging towards the stormwater drainage system) in these sub-catchments. Catchment topography, average distance along roadside kerbs and the extent of supplementary areas influence the required energy to re-mobilise and convey deposited gross pollutants to the stormwater system. The fraction imperviousness of the catchment influences the magnitude of the runoff from the catchment which in turn determines the energy available for re-mobilisation and transport of deposited gross pollutants in the catchment.

The results presented in Figure 8.6 are consistent with results from a separate study by Allison undertaken during 1995 to investigate the transport of gross pollutants from different land-uses within a 150 hectare catchment in Coburg. Gross pollutant loads from two storm events (27 January 95 and 31 May 95) were monitored at three locations representing mixed commercial/residential, residential and light industrial land-uses as shown in Figure 8.7 (Allison et al., 1998). On commencement of storm runoff, specifically designed gross pollutant samplers (Essery, 1994) were lowered, at varying time intervals, into the flow and used for gross pollutant sampling as illustrated in Figure 8.8.

Gross pollutant loads from the two storm events monitored for each land-use area are presented as dry mass per hectare of catchment area in Table 8.2. The computed unit area dry loads for the different land-uses were compared against the weighted average dry load for the three combined sub-catchments. These data indicate that commercial land-use catchments generate approximately twice the amount of gross pollutants compared to residential land-use and as much as three times the amount generated from light industrial land-use catchments.

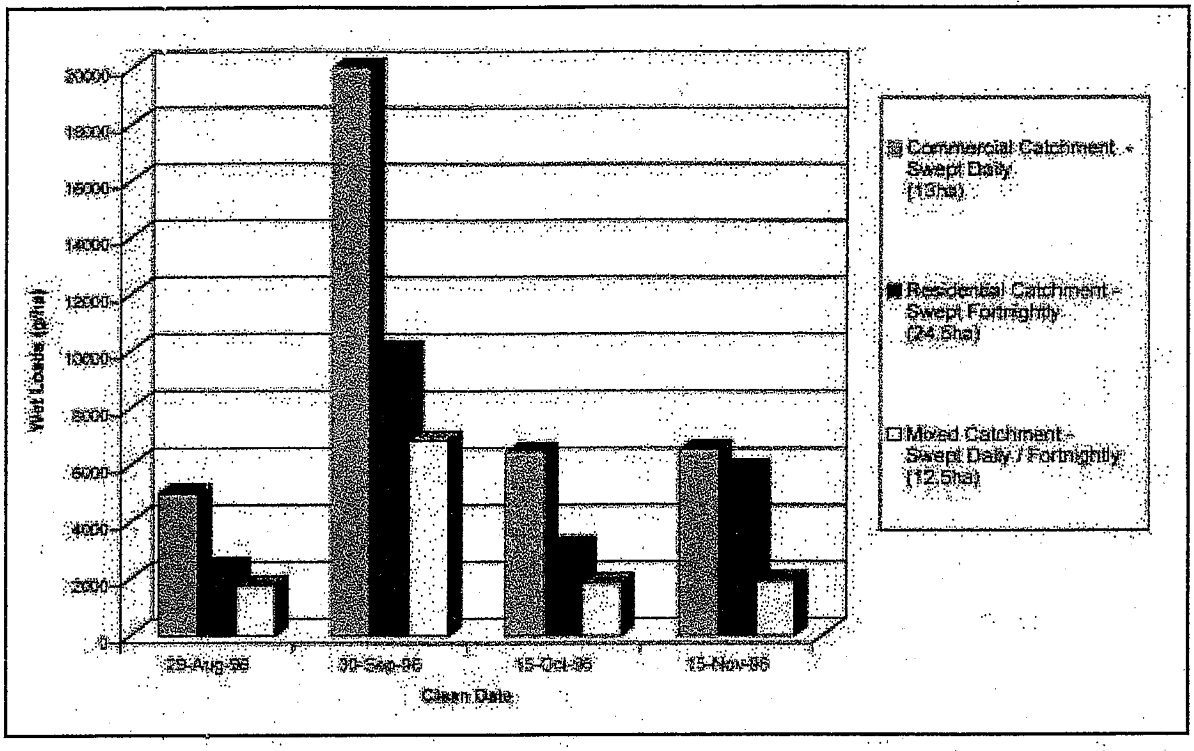

Figure 8.6 SEPT Wet Loads for Different Land use Catchment in Coburg.

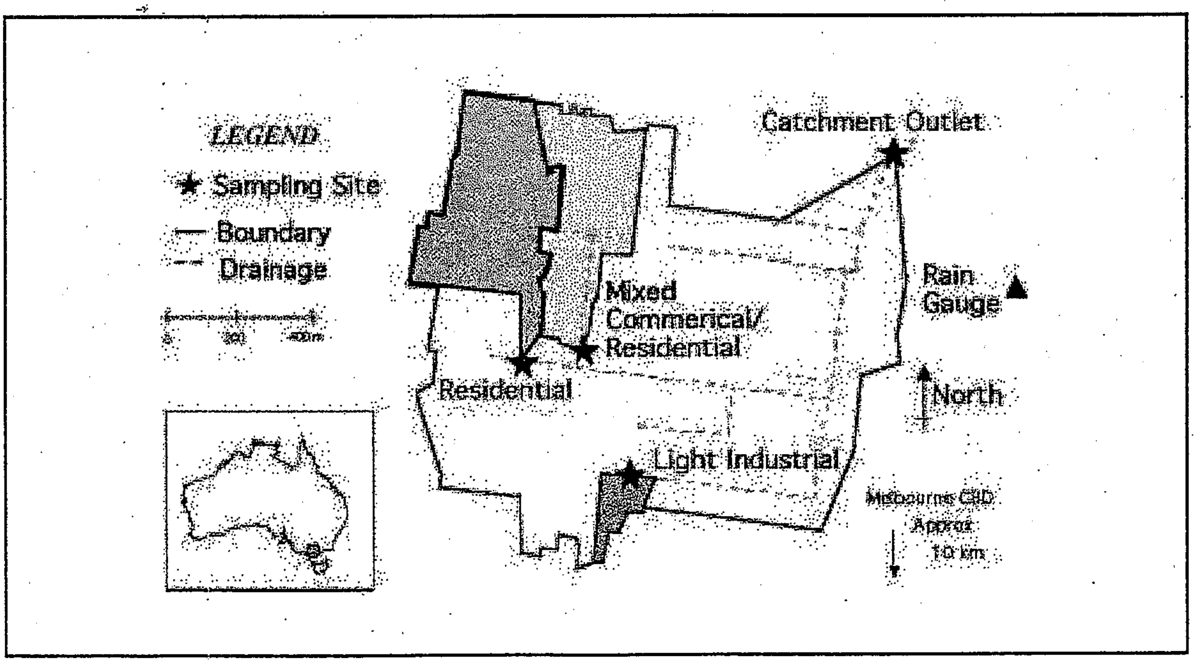

Figure 8.7 Coburg Land-use Monitoring Areas in the 150 ha Coburg Catchment
(source Allison et al. 1998)

Table 8.2 Gross Pollutant Dry Mass Loads and Weighted Averages (after Allison et al., 1998)

Land Use	Area (ha)	Total dry load per unit area		
		27-Jan-95 (g/ha)	31-May-95 (g/ha)	Value / Weighted Average
Commercial	9.5	423	747	1.6
Residential	26.5	292	308	0.8
Light Industrial	2.5	242	63	0.5
Total	38.5			
Weighted Average		321	400	

Allison (1997b) noted that material often blinded the SEPT basket pores, leading to overflows from the baskets and thus a reduction in trapping efficiencies. The field study into the efficiency of SEPTs, found the trapping efficiency of SEPTs to be between 60% and 70% (Allison et al. 1998). The SEPT total wet loads given in Table 8.1 can thus be assumed to be an under estimation of gross pollutant loads generated from the respective sub-catchments.

The gross pollutant loads for three of the four SEPT clean-outs (see Figure 8.6) show similar relative contributions from the different land-use catchments as that derived from the study by Allison (1998) and summarised in Table 8.2. The commercial catchment was found to have generated the most load of gross pollutants on each of the clean out dates in spite of daily street sweeping. As noted earlier, the ratio of commercial to residential land-use gross pollutant load from three of the four clean out dates is approximately 2.0 except for the data from the clean out of 15 November 96. The gross pollutant load transported from the commercial area preceding the clean out of the 15 November 96 was found to be significantly lower than expected when compared to corresponding data from the residential area.

The gross pollutant load from the clean-out of 15 November 1996 was transported by two gross pollutant transporting storm events (ie.<3.7 mm), one with an event rainfall of 6.8 mm and the other 35.4 mm.

Figure 8.8 Sampling Gross Pollutants from Different Land-use Sub-catchments in Coburg (source Allison et al, 1998)

The lower than expected gross pollutant load from the commercial area in this clean-out may be related to a possible "supply limiting condition" during the large 35.4 mm storm event (a trend not apparent in the fortnightly swept, residential catchment). This notion is explored in Section 9.3.

Influence of Catchment Land-use:

- The fraction imperviousness of a catchment influences the runoff during storm events which influence the available energy for mobilisation of deposited gross pollutants.
- Commercial land-uses contribute larger loads of gross pollutants despite more intensive street sweeping frequencies.
- Relative gross pollutant loads generated from different land-uses show that commercial areas produce approximately twice the amount of gross pollutants than residential and three times as much as light industrial, despite a daily street sweeping regime in the commercial area compared to fortnightly in the residential and industrial areas.
- A number of transport factors are thought to also influence gross pollutant loads from different land-uses. Some of these factors include:-
  - Number of entrances to the stormwater system,
  - Fraction of catchment imperviousness,
  - Extent of pervious area over which runoff needs to traverse towards the stormwater drainage system.

9 Discussion

9.1 Gross Pollutant Load and Rainfall Depth Relationship

The relationships between the gross pollutant load and rainfall depth (Figure 8.1) and runoff (Figure 8.2) derived from the Coburg data incorporate the effect of a typical Melbourne municipal street sweeping program, ranging in frequency from daily to fortnightly sweeping depending on catchment land-use. The relationships clearly show a trend of increasing gross pollutant load to the stormwater system with increasing rainfall or runoff, indicating that the limiting mechanism for stormwater gross pollutant transport in the majority of cases is stormwater runoff rates and velocities. While the curves are monotonically increasing, the rate of increase in gross pollutant loads entering the stormwater system decreases with rainfall and runoff indicating a possible upper limit of gross pollutant load transported into the stormwater system at relatively high rainfall depths or runoff. This possible upper limit of gross pollutant load may reflect the gross pollutant load deposited on street surfaces which is available for re-mobilisation into the stormwater system. A modification of the street sweeping frequency could potentially adjust this upper limit value, thereby altering the shape of the gross pollutant export curve as conceptualised in Figure 9.1.

9.2 Impact of Street Sweeping on Gross Pollutant Loads

It is not known how exactly any further alterations made to the street sweeping frequency will affect the gross pollutant export curve. Nevertheless the illustration in Figure 9.1 postulates that if street sweeping effort were reduced it can be expected that the gross pollutant load will increase, initially for those events with large rainfall depths. Further reduction in street sweeping frequency will ultimately lead to the increase of gross pollutants in stormwater systems becoming evident for even smaller storm events. Similarly, by increasing street sweeping effort, the reduction in gross pollutant load would essentially be confined to events of large rainfall depths. Figure 9.1 postulates that in most gross pollutant export events, the export load is defined by the size of the storm event rather than the available pollutant surface load.

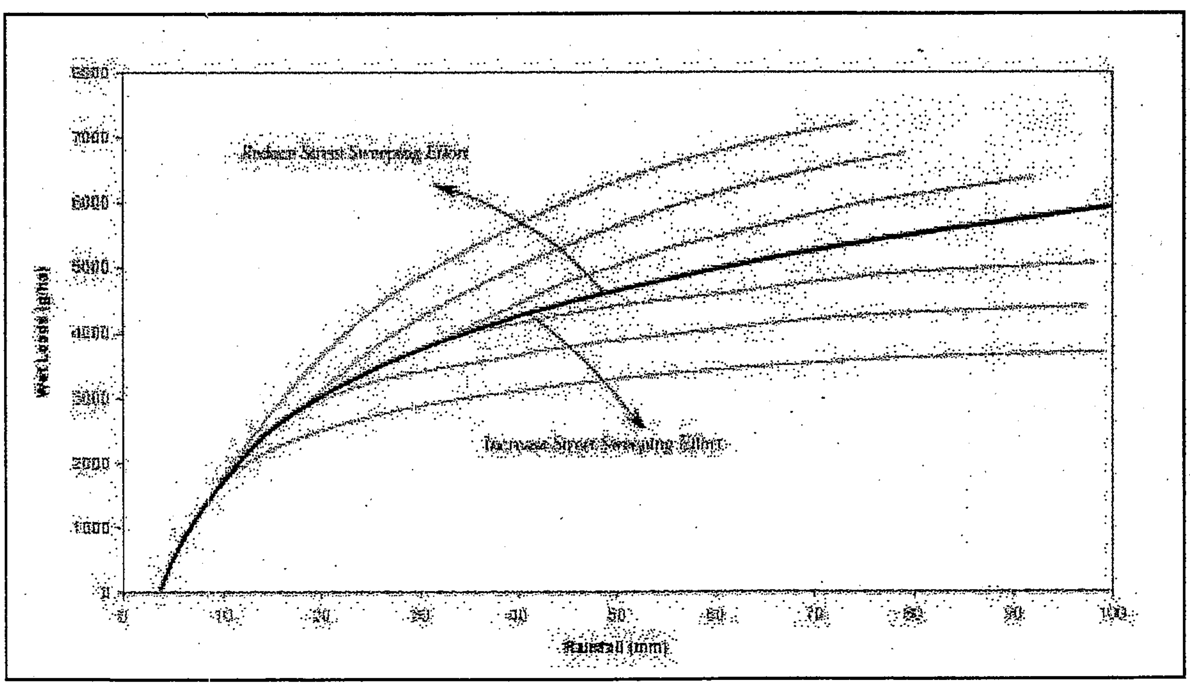

Figure 9.1 Hypothetical Gross Pollutant Load and Street Sweeping Effort

9.3 Supply Limiting Condition

The lower than expected gross pollutant load from the commercial area for the clean-out of the 15 November 96 noted in Table 8.1 of the previous section of this report may be explained by a possible "supply limiting condition" occurring during the large 35.4 mm storm event. It is possible that during this large event the available gross pollutants in the catchment have been substantially removed from the street surface and mobilised into the stormwater system, a trend not apparent in the fortnightly swept, residential catchment.

Based on the results of this investigation, it is postulated that a source limiting storm condition may have occurred during the 35 mm storm event. Storm events greater than 35 mm occur less than 3% of the time in Melbourne (see Figure 8.3) indicating that the occurrence of such a gross pollutant supply limiting condition would be very rare. This may have important implications for assessing the effectiveness of street sweeping. The incremental benefits of increasing the present street sweeping effort in the Coburg catchment (from the daily frequency of the commercial areas and fortnightly frequency in the residential areas) are expected to be low. The limiting factor affecting the transport of gross pollutants in the majority of cases appears not to be the supply of gross pollutants but instead the pollutant mobilisation and transport processes (ie. rainfall patterns and depths, runoff rates and velocities).

9.4 Street Sweeping Efficiency Issues

The use of new street sweeping technologies may contribute to reducing pollutant loads in the stormwater system as advocated by Sutherland and Jelen (1997). Taking into account influencing factors such as the inter-event dry period and catchment characteristics may enable the frequency and timing of street sweeping operations to be redesigned to meet specified stormwater improvement objectives for specific conditions. Street sweeping frequencies that are equivalent to three times the mean inter-event period (approximately 8 days for Melbourne) is considered to be appropriate as approximately 35% of storm events are considered to be gross pollutant transporting events. Also, conducting street sweeping at a time of day which enables the collection of pollutants when the rate of load acummulation of street surface has reached its highest would reduce the time pollutants are potentially exposed to the likelihood of rainfall events.

Factors contributing to inefficiencies in street sweeping are not confined to rainfall patterns (affecting the build-up and wash-off processes), frequency and timing of sweeping, size of pollutants and the sweeper mechanism. Street sweeping inefficiencies are further exacerbated by everyday practice limitations. Significant practice limitations associated with street sweeping include the inability of sweepers to access the street surface load due to parked vehicles (see Figure 9.2), inappropriate street design, poor road surface conditions and operator speed. Street sweeping program specifications must address these influencing factors as well as improving sweeper mechanisms before stormwater quality improvements may be realised from street sweeping practices.

The principle objective of street sweeping in meeting community demand for a standard of street cleanliness, and the perceived success of sweeping to fulfil this objective makes street sweeping an important municipal operation. However, there is little evidence to suggest significant incremental benefits in stormwater quality, particularly the removal of contaminants associated with the fine particulates, can be gained with increased street sweeping frequency.

The use of new street sweeping equipment may lead to increased effectiveness particularly for gross pollutants and coarse to medium sized sediment. There are however other operational limitations which will reduce the actual effectiveness of street sweeping from that determined under controlled test conditions. Furthermore, the use of new equipment will need to be associated with a street sweeping frequency that matches the catchment meteorological characteristics. Their cost effectiveness will need to be evaluated against the cost of installing and maintaining end-of-pipe or in-transit gross pollutant traps.

Figure 9.2 Street sweeping pollutant removal effectiveness is limited by parked cars

10 Conclusions

This study has investigated the effectiveness of street sweeping for stormwater quality improvement. A number of factors are identified as influencing the effectiveness of street sweeping for the collection of street surface pollutants for stormwater pollution control rather than just aesthetic requirements. These factors include street sweeping mechanism, pollutant type, sweeping frequency and timing and also pollutant wash-off characteristics.

The most important conclusion from this study is that current Australian street sweeping practices are generally ineffective as an at source stormwater pollution control measure. Current street sweeping practices are found to be not only ineffective for the reduction of fine sediment and sediment-bound contaminants but also for larger gross pollutants capable of entering the stormwater system. Current Australian street sweeping mechanisms and practices are therefore regarded as providing very little benefit for stormwater quality improvements, due to inefficiencies at reducing a variety of pollutants from entering the stormwater system over a range of conditions. Street sweeping should be therefore accompanied by structural pollutant treatment measures to effectively reduce the discharge of gross and sediment associated pollutants in stormwater.

Increasing the frequency of current street sweeping practices beyond what is required to meet aesthetic objectives is not expected to yield substantial incremental benefits in relation to receiving water quality improvements. There seems little benefit in conducting detailed field monitoring investigations into quantifying the effectiveness of street sweeping as a stormwater pollution control measure for current Australian street sweeping mechanisms or operations. Other specific observations from this study are listed below.

Sweeping Mechanisms

- Mechanical and regenerative air street sweeping equipment requires a minium threshold load of sediment on the street surface before they become effective.
- The threshold load can be three times higher for the mechanical sweeper compared to the regenerative air system.
- Overall the regenerative air sweeper exhibits a substantially better performance than the regular mechanical sweeper.
- Street sweeping technology is developing and improving to remove finer street surface particles for a variety of street surface loads.

Gross Pollutants

- Significant amounts of gross pollutants are mobilised into the stormwater system during bursts of rain, wind or both.
- There is little correlation between the frequency of sweeping and the transport of gross pollutants into the stormwater system.
- Street sweeping efficiency increases with particle size.
- Sweeper efficiency can be up to nearly 80% for particles greater than 2 millimetres under 'test' conditions (ie. sweeping more frequently than the occurrence of rainfall events and effective use of parking restrictions).

Sediment and Other Suspended Solids

- The removal efficiency of sediment and other fine organic particles by conventional street sweepers was found to be dependent upon a threshold level of load on the surface and the particle size range of the surface loads.
- Material smaller than 300 µm was less affected by street sweeping.
- No effective removal (>50% removal efficiency) was evident for particle sizes smaller than 125 µm for conventional street sweepers (excluding the new small-micron surface cleaning technology).

Contaminants Associated with Sediment

- Significant amounts of metals and nutrients are transported as sediment-bound contaminants.
- Most of the total mass of contaminants is associated with the fine particles.
- Conventional street sweeping is generally ineffective at removing particles smaller that 300 µm and therefore will not effectively reduce the export of sediment-bound contaminants such as nutrients, metals and PAHs.

Removal of Sediment and Associated Contaminant

- Limited sampling of sediment in street runoff in Australia indicates that 70% of particles are less than 125µm compared to 20% for overseas data.
- The fine sediments found on Australian streets would suggest that conventional street sweeping will have a minimal effect on sediments and associated contaminants reaching stormwater systems.

Street Sweeping Frequency

- The variable nature of inter-event dry periods, both in terms of seasonal variation and dependence on climatic locations, highlights the importance of street sweeping program design which are specific to location and flexible to accommodate the local meteorological conditions and seasonal variability.
- It is anticipated that if street sweeping occurs at a longer interval than the inter-event dry period of the catchment, street surface pollutants will have a much higher likelihood of being flushed into the stormwater system before being collected by the street sweeper.

Street Sweeping Timing

- Recorded gross pollutant load generation over a typical day indicates that the accumulation of litter in a shopping strip begins at 8:00 am and effectively ends around 5:00 pm.
- Early morning street sweeping allows the exposure of deposited street surface litter items to a higher likelihood of being transported into the stormwater drainage system.

Gross Pollutant Load Generation

- Data collected in the Coburg catchment indicated washoff of gross pollutants becomes significant for storm events greater than 3.7 mm of rainfall depth and 0.70 mm of runoff.
- The limiting mechanism affecting the transport of gross pollutants in the majority of cases appears to be re-mobilisation and transport processes (ie. stormwater runoff rates and velocities) and not the supply of gross pollutants.
- Approximately 35% of all recorded rainfall events in Melbourne are greater than 3.7 mm giving an average inter-event dry period of 178 hours (7.4 days) for gross pollutant transporting storm events.

Influence of Catchment Land-use

- The fraction imperviousness of a catchment influences the runoff during storm events which influence the available energy for mobilisation of deposited gross pollutants.
- Commercial land-uses contribute larger loads of gross pollutants despite more intensive street sweeping frequencies.
- Relative gross pollutant loads generated from different land-uses show that commercial areas produce approximately twice the amount of gross pollutants than residential and three times as much as light industrial, despite a daily street sweeping regime in the commercial area compared to fortnightly in the residential and industrial areas.
- A number of transport factors are thought to also influence gross pollutant loads from different land-uses. Some of these factors include:-
  - number of entrances to the stormwater system,
  - fraction of catchment imperviousness,
  - extent of pervious area over which runoff needs to traverse towards the stormwater drainage system.

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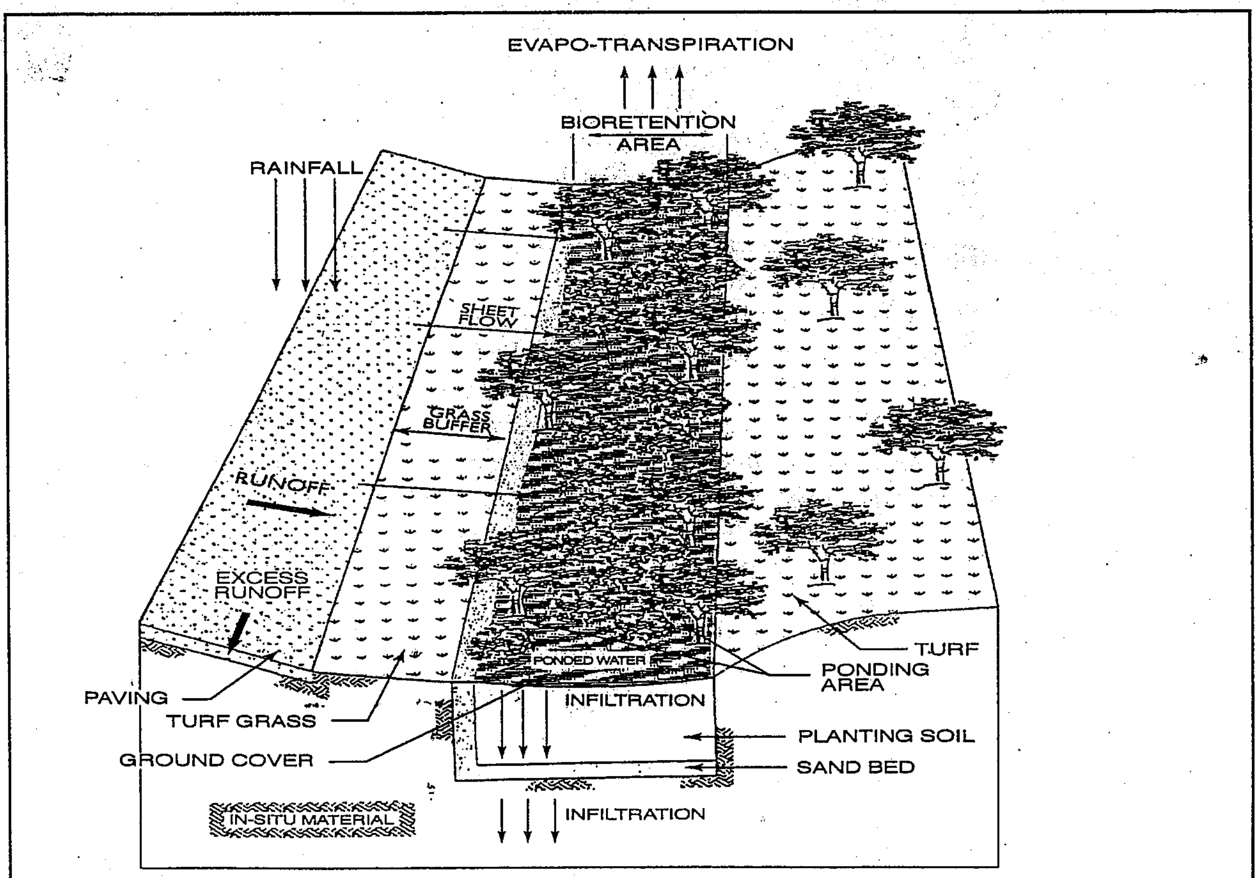
EPA

Storm Water Technology Fact Sheet
Bioretention

DESCRIPTION

Bioretention is a best management practice (BMP) developed in the early 1990's by the Prince George's County, MD, Department of Environmental Resources (PGDER). Bioretention utilizes soils and both woody and herbaceous plants to remove pollutants from storm water runoff. As shown in Figure 1, runoff is conveyed as sheet flow to the treatment area, which consists of a grass buffer strip, sand bed, ponding area, organic layer or mulch layer, planting soil, and plants. Runoff passes first over or through a sand bed, which slows the runoff's velocity, distributes it evenly along the length of the ponding area, which consists of a surface organic layer and/or ground cover and the underlying planting soil. The ponding area is graded, its center depressed. Water is ponded to a depth of 15 centimeters (6 inches) and gradually infiltrates the bioretention area or is



Source: PGDER, 1993.

FIGURE 1 BIORETENTION AREA

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evapotranspired. The bioretention area is graded to divert excess runoff away from itself. Stored water in the bioretention area planting soil exfiltrates over a period of days into the underlying soils.

The basic bioretention design shown in Figure 1 can be modified to accommodate more specific needs. The City of Alexandria, VA, has modified the bioretention BMP design to include an underdrain within the sand bed to collect the infiltrated water and discharge it to a downstream sewer system. This modification was required because impervious subsoils and marine clays prevented complete infiltration in the soil system. This modified design makes the bioretention area act more as a filter that discharges treated water than as an infiltration device. Design modifications are also being reviewed that will potentially include both aerobic and anaerobic zones in the treatment area. The anaerobic zone will promote denitrification.

APPLICABILITY

Bioretention typically treats storm water that has run over impervious surfaces at commercial, residential, and industrial areas. For example, bioretention is an ideal storm water management BMP for median strips, parking lot islands, and swales. These areas can be designed or modified so that runoff is either diverted directly into the bioretention area or conveyed into the bioretention area by a curb and gutter collection system. Bioretention is usually best used upland from inlets that receive sheet flow from graded areas and at areas that will be excavated. The site must be graded in a manner that minimizes erosive conditions as sheet flow is conveyed to the treatment area, maximizing treatment effectiveness. Construction of bioretention areas is best suited to sites where grading or excavation will occur in any case so that the bioretention area can be readily incorporated into the site plan without further environmental damage. Bioretention should be used in stabilized drainage areas to minimize sediment loading in the treatment area. As with all BMPs, a maintenance plan must be developed.

Bioretention has been used as a storm water BMP since 1992. In addition to Prince George's County and Alexandria, bioretention has been used successfully at urban and suburban areas in Montgomery County, MD; Baltimore County, MD; Chesterfield County, VA; Prince William County, VA; Smith Mountain Lake State Park, VA; and Cary, NC.

ADVANTAGES AND DISADVANTAGES

Bioretention is not an appropriate BMP at locations where the water table is within 1.8 meters (6 feet) of the ground surface and where the surrounding soil stratum is unstable. In cold climates the soil may freeze, preventing runoff from infiltrating into the planting soil. The BMP is also not recommended for areas with slopes greater than 20 percent, or where mature tree removal would be required. Clogging may be a problem, particularly if the BMP receives runoff with high sediment loads.

Bioretention provides storm water treatment that enhances the quality of downstream water bodies. Runoff is temporarily stored in the BMP and released over a period of four days to the receiving water. The BMP is also able to provide shade and wind breaks, absorb noise, and improve an area's landscape.

DESIGN CRITERIA

Design details have been specified by the Prince George's County DER in a document entitled *Design Manual for the Use of Bioretention in Storm Water Management* (PGDER, 1993). The specifications were developed after extensive research on soil adsorption capacities and rates, water balance, plant pollutant removal potential, plant adsorption capacities and rates, and maintenance requirements. A case study was performed using the specifications at three commercial sites and one residential site in Prince George's County, Maryland.

Each of the components of the bioretention area is designed to perform a specific function. The grass buffer strip reduces incoming runoff velocity and filters particulates from the runoff. The sand bed also reduces the velocity, filters particulates, and spreads flow over the length of the bioretention area. Aeration and drainage of the planting soil are provided by the 0.5 meter (18 inch) deep sand bed. The ponding area provides a temporary storage location for runoff prior to its evaporation or infiltration. Some particulates not filtered out by the grass filter strip or the sand bed settle within the ponding area.

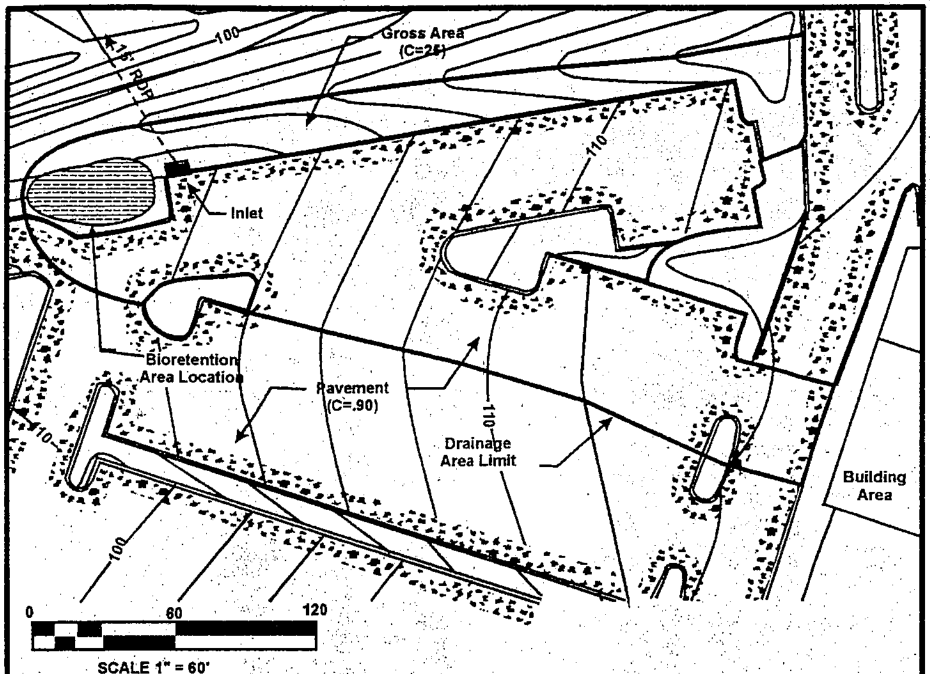
The organic or mulch layer also filters pollutants and provides an environment conducive to the growth of microorganisms, which degrade petroleum-based products and other organic material. This layer acts in a similar way to the leaf litter in a forest and prevents the erosion and drying of underlying soils. Planted ground cover reduces the potential for erosion as well, slightly more effectively than mulch. The maximum sheet flow velocity prior to erosive conditions is 0.3 meters per second (1 foot per second) for planted ground cover and 0.9 meters per second (3 feet per second) for mulch.

The clay in the planting soil provides adsorption sites for hydrocarbons, heavy metals, nutrients and other pollutants. Storm water storage is also provided by the voids in the planting soil. The stored water and nutrients in the water and soil are then available to the plants for uptake.

The layout of the bioretention area is determined after site constraints such as location of utilities, underlying soils, existing vegetation, and drainage are considered. Sites with loamy sand soils are especially appropriate for bioretention because the excavated soil can be backfilled and used as the planting soil, thus eliminating the cost of importing planting soil. An unstable surrounding soil stratum (e.g., Marlboro Clay) and soils with a clay content greater than 25 percent may preclude the use of bioretention, as would a site with slopes greater than 20 percent or a site with mature trees that would be removed during construction of the BMP. Bioretention can be designed to be off-line or on-line of the existing drainage system. The "first flush" of runoff is diverted to the off-line system. The first flush of runoff is the initial runoff volume that typically contains higher pollutant concentrations than those in the extended runoff period. On-line systems capture the first flush but that volume of water will likely be washed out by subsequent runoff resulting in a release of the captured pollutants. The size of the drainage area for one bioretention area should be between 0.1 and 0.4 hectares (0.25 and 1.0 acres). Multiple bioretention areas may be required for larger drainage areas. The maximum drainage area for one bioretention area is determined by the amount of sheet flow generated by a 10-year storm. Flows greater than 141 liters per second (5 cubic feet per second) may potentially erode stabilized areas. In Maryland, such a flow generally occurs with a 10-year storm at one-acre commercial or residential sites. The designer should determine the potential for erosive conditions at the site.

The size of the bioretention area is a function of the drainage area and the runoff generated from the area. The size should be 5 to 7 percent of the drainage area multiplied by the rational method runoff coefficient, "c," determined for the site. The 5 percent specification applies to a bioretention area that includes a sand bed; 7 percent to an area without one. An example of sizing a facility is shown in Figure 2. For this discussion, sizing specifications are based on 1.3 to 1.8 centimeters (0.5 to 0.7 inches) of precipitation over a 6-hour period (the mean storm event for the Baltimore-Washington area), infiltrating into the bioretention area. Other areas with different mean storm events will need to account for the difference in the design of the BMP. Recommended minimum dimensions of the bioretention area are 4.6 meters (15 feet) wide by 12.2 meters (40 feet) in length. The minimum width allows enough space for a dense, randomly-distributed area of trees and shrubs to become established that replicates a natural forest and creates a microclimate. This enables the bioretention area to tolerate the effects of heat stress, acid rain, runoff pollutants, and insect and disease infestations which landscaped areas in urban settings typically are unable to tolerate. The preferred width is 7.6 meters (25 feet), with a length of twice the width. Any facilities wider than 6.1 meters (20 feet) should be twice as long as they are wide. This length requirement promotes the distribution of flow and decreases the chances of concentrated flow.

The maximum recommended ponding depth of the bioretention area is 15 centimeters (6 inches). This



PLAN VIEW

BIORETENTION AREA
SIZING COMPUTATION

DEVELOPMENT	AREA SQ. FT.	"C" FACTOR	C X AREA
PAVEMENT	23,800	0.90	21,400
GRASS	10,100	0.25	2,500
TOTALS	33,900		23,900

BIOTENTION AREA SIZE

1. With Sand Bed (5% Sum of C x Area)
   = 05 x 23,900 = 1,195 OR SAY 1,200 sq. ft.
2. Without Sand Bed (7% Sum of C x Area)
   = 07 x 23,900 = 1,1673 OR SAY 1,700 sq. ft.

* SEE CHAPTER IV. PRINCE GEORGES COUNTYSTORMWATER MANAGEMENT MANUAL

Source: PGDER, 1993.

FIGURE 2 BIORETENTION AREA SIZING

depth provides for adequate storage and prevents water from standing for excessive periods of time. Because of some plants' water intolerance, water left to stand for longer than four days restricts the type of plants that can be used. Further, mosquitoes and other insects may start to breed if water is standing for longer than four days.

The appropriate planting soil should be backfilled into the excavated bioretention area. Planting soils should be sandy loam, loamy sand, or loam texture with a clay content ranging from 10 to 25 percent. The soil should have infiltration rates greater than 1.25 centimeters (0.5 inches) per hour, which is typical of sandy loams, loamy sands, or loams. Silt loams and clay loams generally have rates of less than 0.68 centimeters (0.27 inches) per hour. The pH of the soil should be between 5.5 and 6.5. Within this pH range, pollutants (e.g., organic nitrogen and phosphorus) can be adsorbed by the soil and microbial activity can flourish. Other requirements for the planting soil are a 1.5 to 3 percent organic content and a maximum 500 ppm concentration of soluble salts. In addition, criteria for magnesium, phosphorus, and potassium are 39.2 kilograms per acre (35 pounds per acre), 112 kilograms per acre (100 pounds per acre), and 95.2 kilograms per acre (85 pounds per acre), respectively. Soil tests should be performed for every 382 cubic meters (500 cubic yards) of planting soil, with the exception of pH and organic content tests, which are required only once per bioretention area.

Planting soil should be 10.1 centimeters (4 inches) deeper than the bottom of the largest root ball and 1.2 meters (4 feet) altogether. This depth will provide adequate soil for the plants' root systems to become established and prevent plant damage due to severe wind. A soil depth of 1.2 meters (4 feet) also provides adequate moisture capacity. To obtain the recommended depth, most sites will require excavation. Planting soil depths of greater than 1.2 meters (4 feet) may require additional construction practices (e.g., shoring measures). Planting soil should be placed in 18 inches or greater lifts and lightly compacted until the desired depth is reached. The bioretention area should be vegetated to resemble a terrestrial forest community ecosystem, which is dominated by understory trees (high canopy trees may be destroyed during maintenance) and has discrete soil zones as well as a mature canopy and a distinct sub-canopy of understory trees, a shrub layer, and herbaceous ground covers. Three species each of both trees and shrubs are recommended to be planted at a rate of 2500 trees and shrubs per hectare (1000 per acre). For example, a 4.6 meter (15 foot) by 12.2 meter (40 foot) bioretention area (55.75 square meters or 600 square feet) would require 14 trees and shrubs. The shrub-to-tree ratio should be 2:1 to 3:1. On average, the trees should be spaced 3.65 meters (12 feet) apart and the shrubs should be spaced 2.4 meters (8 feet) apart. In the metropolitan Washington, D.C., area, trees and shrubs should be planted from mid-March through the end of June or from mid-September through mid-November. Planting periods in other areas of the U.S. will vary. Vegetation should be watered at the end of each day for fourteen days following its planting.

Native species that are tolerant to pollutant loads and varying wet and dry conditions should be used in the bioretention area. These species can be determined from several published sources, including *Native Trees, Shrubs, and Vines for Urban and Rural America* (Hightshoe, 1988). The designer should assess aesthetics, site layout, and maintenance requirements when selecting plant species. Adjacent non-native invasive species should be identified and the designer should take measures (e.g., provide a soil breach) to eliminate the threat of these species invading the bioretention area. Regional landscaping manuals should be consulted to ensure that the planting of the bioretention area meets the landscaping requirements established by the local authorities.

The optimal placement of vegetation within the bioretention area should be evaluated by the designers. Plants should be placed at irregular intervals to replicate a natural forest. Shade and shelter from the wind will be provided to the bioretention area if the designer places the trees on the perimeter of the area. Trees and shrubs can be sheltered from damaging flows if they are placed away from the path of the incoming runoff. Species that are more tolerant to cold winds (e.g., evergreens) should be placed in windier areas of the site.

After the trees and shrubs are placed, the ground cover and/or mulch should be established. Ground cover such as grasses or legumes can be planted during the spring of the year. Mulch should be placed immediately after trees and shrubs are planted. Five to 7.6 cm (2 to 3 inches) of commercially-available fine shredded hardwood mulch or shredded hardwood chips should be applied to the bioretention area to protect from erosion. Mulch depths should be kept below 7.6 centimeters (3 inches) because more would interfere with the cycling of carbon dioxide and oxygen between the soil and the atmosphere. The mulch should be aged for at least six months (one year is optimal), and applied uniformly over the site.

PERFORMANCE

Bioretention removes storm water pollutants through physical and biological processes, including adsorption, filtration, plant uptake, microbial activity, decomposition, sedimentation and volatilization. Adsorption is the process whereby particulate pollutants attach to soil (e.g., clay) or vegetation surfaces. Adequate contact time between the surface and pollutant must be provided for in the design of the system for this removal process to occur. Therefore, the infiltration rate of the soils must not exceed those specified in the design criteria or pollutant removal may decrease. Pollutants removed by adsorption include metals, phosphorus, and some hydrocarbons. Filtration occurs as runoff passes through the bioretention area media, such as the sand bed, ground cover and planting soil. The media trap particulate matter and allow water to pass through. The filtering effectiveness of the bioretention area may decrease over time. Common particulates removed from storm water include particulate organic matter, phosphorus, and suspended solids. Biological processes that occur in wetlands result in pollutant uptake by plants and microorganisms in the soil. Plant growth is sustained by the uptake of nutrients from the soils, with woody plants locking up these nutrients through the seasons. Microbial activity within the soil also contributes to the removal of nitrogen and organic matter. Nitrogen is removed by nitrifying and denitrifying bacteria, while aerobic bacteria are responsible for the decomposition of the organic matter (e.g., petroleum). Microbial processes require oxygen and can result in depleted oxygen levels if the bioretention area is not adequately aerated.

Sedimentation occurs in the swale or ponding area as the velocity slows and solids fall out of suspension.

Volatilization also plays a role in pollutant removal. Pollutants such as oils and hydrocarbons can be removed from the wetland via evaporation or by aerosol formation under windy conditions. The removal effectiveness of bioretention has been studied during field and laboratory studies conducted by the University of Maryland (Davis et al, 1998). During these experiments, synthetic storm water runoff was pumped through several laboratory and field bioretention areas to simulate typical storm events in Prince George's County, MD. Removal rates for heavy metals an nutrients are shown in Table 1. As shown, the BMP removed between 93 and 98 percent of metals, between 68 and 80 percent of TKN and between 70 and 83 percent of total phosphorus. For all of the pollutants analyzed, results of the laboratory study were similar to those of field experiments. Doubling or halving the influent pollutant levels had little effect on the effluent pollutants levels (Davis et al, 1998). For other parameters, results from the performance studies for infiltration BMPs, which are similar to bioretention, can be used to estimate bioretention's performance. These removal rates are also shown in Table 1. As shown, the BMP could potentially achieve greater than 90 percent removal rates for total suspended solids, organics, and bacteria. The microbial activity and plant uptake occurring in the bioretention area will likely result in higher removal rates than those determined for infiltration BMPs.

TABLE 1 LABORATORY AND ESTIMATED BIORETENTION

Pollutant	Removal Rate
Total Phosphorus	70%-83% [1]
Metals (Cu, Zn, Pb)	93%-98% [1]
TKN	68%-80% [1]
Total Suspended Solids	90% [2]
Organics	90% [2]
Bacteria	90% [2]

Source: [1]Davis et al. (1998)
[2]PGDER (1993)

OPERATION AND MAINTENANCE

Recommended maintenance for a bioretention area includes inspection and repair or replacement of the treatment area components. Trees and shrubs should be inspected twice per year to evaluate their health and remove any dead or severely diseased vegetation. Diseased vegetation should be treated as necessary using preventative and low-toxic measures to the extent possible. Pruning and weeding may also be necessary to maintain the treatment area's appearance. Mulch replacement is recommended when erosion is evident or when the site begins to look unattractive. Spot mulching may be adequate when there are random void areas; however, once every two to three years the entire area may require mulch replacement. This should be done during the spring. The old mulch should be removed before the new mulch is distributed. Old mulch should be disposed of properly.

The application of an alkaline product, such as limestone, is recommended one to two times per year to counteract soil acidity resulting from slightly acidic precipitation and runoff. Before the limestone is applied, the soils and organic layer should be tested to determine the pH and therefore the quantity of limestone required. When levels of pollutants reach toxic levels which impair plant growth and the effectiveness of the BMP, soil replacement may be required (PGDER, 1993).

COSTS

Construction cost estimates for a bioretention area are slightly greater than those for the required landscaping for a new development. Recently-constructed 37.16 square meter (400 square foot) bioretention areas in Prince George's County, MD cost approximately $500. These units are rather small and their cost is low. The cost estimate includes the cost for excavating 0.6 to 1 meters (2 to 3 feet) and vegetating the site with 1 to 2 trees and 3 to 5 shrubs. The estimate does not include the cost for the planting soil, which increases the cost for a bioretention area. Retrofitting a site typically costs more, averaging $6,500 per bioretention area. The higher costs are attributed to the demolition of existing concrete, asphalt, and existing structures and the replacement of fill material with planting soil. The costs of retrofitting a commercial site in Maryland (Kettering Development) with 15 bioretention areas were estimated at $111,600.

The use of bioretention can decrease the cost for storm water conveyance systems at a site. A medical office building in Maryland was able to reduce the required amount of storm drain pipe from 243.8 meters (800 feet) to 70.1 meters (230 feet) with the use of bioretention. The drainage pipe costs were reduced by $24,000, or 50 percent of the total drainage cost for the site (PGDER, 1993). Landscaping costs that would be required at a development regardless of the installation of the bioretention area should also be considered when determining the net cost of the BMP.

The operation and maintenance costs for a bioretention facility will be comparable to those of typical landscaping required for a site. Costs beyond the normal landscaping fees will include the cost for testing the soils and may include costs for a sand bed and planting soil.

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Storm Water Management Fact Sheet
Spill Prevention Planning

DESCRIPTION

Spill prevention is prudent both economically and environmentally, because spills increase operating costs and lower productivity. An important tool in preventing spills is a Spill Prevention Plan. A Spill Prevention Plan specifies materials handling procedures and storage requirements and identifies spill cleanup procedures for areas and processes in which spills may potentially occur. The plan standardizes process operating procedures and employee training in an effort to minimize accidental pollutant releases that could contaminate storm water runoff.

Spill prevention should be part of a comprehensive Best Management Practice program to prevent runoff contamination. This program should also include storm water contamination assessment, flow diversion, record keeping, internal reporting, employee training, and preventive maintenance.

Typically, most businesses and public agencies that generate hazardous waste and/or produce, transport, or store petroleum products are required by State and federal law to prepare spill control and cleanup plans. Therefore, a Spill Prevention and Response Plan may have already been developed as a result of other environmental regulatory requirements. Existing plans should be re-evaluated and revised to address storm water management issues.

APPLICABILITY

A Spill Prevention Plan is applicable to facilities that transport, transfer, and/or store hazardous materials, petroleum products, or fertilizers that can contaminate storm water runoff. An important part of an effective Spill Prevention Plan is establishing a method for quick notification of the appropriate emergency response teams in the event of a spill. In some plants, each area or process may have a separate team leader and/or response team. Figure 1 illustrates a sample spill prevention team roster that can help in quick identification of Spill Prevention team leaders and their responsibilities.

ADVANTAGES AND DISADVANTAGES

The advantages of an effective Spill Prevention Plan include reducing storm water contamination and maintaining the water quality of the receiving water. Spill Prevention Plans are often good ways of standardizing procedures and employee training to decrease the likelihood of spills.

Spill Prevention Planning can be limited by the following:

- Lack of employee motivation to implement the plan.
- Lack of commitment from senior management.
- Key individuals identified in the Spill Prevention Plan may not be properly trained in the areas of spill prevention, response, and cleanup.

KEY PROGRAM COMPONENTS

Before preparing a Spill Prevention Plan, a facility should do the following:

POLLUTION PREVENTION TEAM MEMBER ROSTER	Worksheet Completed by: __________ Title: __________ Date: __________

Leader: __________ Title: __________

Office Phone: __________

Responsibilities:

____

____

Members:

(1) __________ Title: __________

Office Phone: __________

Responsibilities:

____

____

(2) __________ Title: __________

Office Phone: __________

Responsibilities:

____

____

(3) __________ Title: __________

Office Phone: __________

Responsibilities:

____

____

Source: EPA, 1992.

FIGURE 1 SAMPLE SPILL PREVENTION TEAM ROSTER

- Conduct a materials inventory throughout the facility.
- Evaluate past spills and leaks.
- Identify non-storm water discharges and non-approved connections to storm water.
- Collect and evaluate storm water.
- Summarize the findings of this assessment.

Once these tasks have been accomplished, the facility should prepare its Spill Prevention Plan. The plan should include:

- A description of the facility, including the owner's name and address, the nature of the facility activity, and the general types of chemicals used in the facility.

- A site plan showing the locations of chemical storage areas, storm drains, tributary drainage areas with drainage arrows, all surface water bodies on or next to the site, and any devices to stop spills from leaving the site (i.e., collection basins). Spill prevention devices should also have a description written on the map. Table 1 contains a list of features that should be indicated on the site map.

- Notification procedures to be used in the event of a spill. These should include phone numbers of key personnel and appropriate regulatory agencies, such as local Pollution Control Agencies and the local Sewer Authority.

- Specific instructions regarding cleanup procedures.

- A single designated person who has overall responsibility for spill response. Key personnel should be trained in the use of this plan, and all employees should have basic knowledge of spill control procedures.

A summary of the plan should be written and posted at appropriate points in the building (i.e., meeting rooms, cafeteria, and areas with a high spill potential). The summary should identify the spill cleanup coordinators, location of cleanup kits, and phone numbers of regulatory agencies to be contacted in the event of a spill.

Implementing the Spill Prevention Plan should include the following:

- Spill cleanups should begin immediately. No emulsifier or dispersant should be used.

- In fueling areas, absorbent should be packaged in small bags for convenient use and small drums should be available for storage. Absorbent materials should not be washed down the floor drain or into the storm sewer.

- Emergency spill containment and cleanup kits should be located at the facility site. The contents of the kit should be appropriate to the type and quantities of chemical or goods stored at the facility.

Some structural methods to consider when developing a Spill Prevention Plan include:

- **Containment diking**--Containment dikes are temporary or permanent earth or concrete berms or retaining walls that are designed to hold spills. Diking can be used at any industrial facility, but is most common for controlling large spills or releases from liquid storage and transfer areas. Diking can provide one of the best protective measures against the contamination of storm water because it surrounds the area of concern and keeps spilled materials separated from the storm water outside of the diked area.

- **Curbing**--Similar to containment diking, a curb is a barrier that surrounds an area of concern. Unlike diking, curbing is unable to contain large spills and is usually implemented on a small-scale basis. However, curbing is common at many facilities and in small areas where liquids are handled and transferred.

Collection basins--Collection basins are permanent structures in which large spills or contaminated storm water is contained and stored before cleanup or treatment. Collection basins are designed to receive spills, leaks, etc., and to prevent pollutants from being released into the environment. Unlike containment dikes, collection basins can receive and contain materials from many locations across a facility.

TABLE 1 CRITERIA FOR DESIGNING A SITE MAP

DEVELOPING A SITE MAP	Worksheet Completed by: ______________ Title: ______________ Date: ______________
Instructions: Draw a map of your site including a footprint of all buildings, structures, paved areas, and parking lots. The information below describes additional elements.	

- All outfalls and storm water discharges
- Drainage areas of each storm water outfall
- Structural storm water pollution control measures, such as:
  - -Flow diversion structures
  - -Retention/detention ponds
  - -Vegetative swales
- Name of receiving waters (or if through a Municipal Separate Sewer System)
- Locations of past spills and leaks
- Locations of high-risk, waste-generating areas and activities common sites such as:
  - -Fueling stations
  - -Vehicle/equipment washing and maintenance areas
  - -Area for unloading/loading materials
  - -Above-ground tanks for liquid storage
  - -Industrial waste management areas (landfills, waste piles, treatment plants, disposal areas)
  - -Outside storage areas for raw materials, by-products, and finished products
  - -Outside manufacturing areas
  - -Other areas of concern (specify: ______________________)

Source: EPA, 1992.

In addition to preventing the release of the substance to surface waters, any spilled substances must be cleaned up and disposed to protect plant personnel from potential health and fire hazards. Methods of cleanup, recovery, treatment, or disposal include:

- Physical. Physical methods for the cleanup of dry chemicals include the use of brooms, shovels, sweepers, or plows.
- Mechanical. Mechanical methods include the use of vacuum cleaning systems and pumps.
- Chemical. Chemical cleanups of material can be achieved with the use of sorbents, gels, and foams. Sorbents are compounds that immobilize materials by surface absorption or adsorption in the sorbent bulk. Gelling agents interact with the spilled

chemical(s) by concentrating and congealing to form a rigid or viscous material more conducive to a mechanical cleanup. Foams are mixtures of air and aqueous solutions of proteins and surfactant-based foaming agents. The primary purpose of foams is to reduce the vapor concentration above the spill surface, thereby controlling the rate of evaporation.

IMPLEMENTATION

Past experience has shown that the biggest obstacle to an effective Spill Prevention Plan is its implementation. Qualitatively, implementation of a well prepared Spill Prevention Plan should significantly decrease contamination of storm water runoff.

A facility Spill Prevention Plan should be reviewed at least annually and following any spills to evaluate the Spill Prevention Plan's level of success and how it can be improved. The plan should also be reviewed when a new material is introduced to any of the facility's processes.

COSTS

If a facility already has a Spill Control and Cleanup Plan in place, modification to address storm water contamination concerns will require minimal cost. If a facility will be developing a Spill Prevention Plan for the first time, the initial cost will depend on the type of material at the facility, the facility size, and other related parameters. Costs for structural containment devices will also need to be identified for each facility.

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United States Environmental Protection Agency | Office of Water Washington, D.C. | EPA 832-F-99-024 September 1999

Storm Water Management Fact Sheet

Storm Water Contamination Assessment

DESCRIPTION

A Storm Water Contamination Assessment (SWCA) reviews a facility and/or a site to find materials or practices that may contaminate storm water. This assessment helps target the most important pollutant sources for correction or prevention.

A SWCA program is closely related to other BMPs, such as materials inventory, non-storm water discharges, record keeping, and visual inspections.

APPLICABILITY

An SWCA program is applicable to any industrial facility which contains areas, activities, or materials which may contribute pollutants to storm water runoff from the total site. An assessment for storm water purposes may also be applicable in situations where a formal site assessment for hazardous waste purposes is being performed.

ADVANTAGES AND DISADVANTAGES

A comprehensive SWCA program can eliminate pollution sources that can impair receiving water quality. However, there are limitations associated with a contamination assessment program, including:

- Assessments need to be performed by qualified personnel.
- Assessments are useful only if there is corporate commitment to reduce any contamination sources discovered.
- Assessments need to be periodically updated.

KEY PROGRAM COMPONENTS

A SWCA program should include:

- Assessing potential pollutant sources and associated high risk activities such as loading and unloading operations, outdoor storage activities, outdoor manufacturing or processing activities, dust- or particulate-generating activities, and on-site waste disposal practices.
- Determining which of these sources pose the greatest risks of polluting storm water runoff from the site.
- Selecting other cost-effective BMPs to prevent or control pollution from the high-risk sources at the site.

IMPLEMENTATION

In addition to identifying problems within the storm sewer system, it is even more important to prevent problems from developing at all, and to provide an environment in which future problems can be avoided. Thus, an effective storm water assessment program should include follow-up activities including:

- Educating the public about the consequences of misusing storm sewers.
- Pretreating industrial storm water or disconnecting commercial and industrial storm water entries into the storm drainage system.
- Tackling the problem of widespread septic system failure.

- Disconnecting direct sanitary sewerage connections from the storm sewer system.
- Rehabilitating storm or sanitary sewers to abate infiltration by contaminated water.
- Developing zoning and other ordinances.

In some communities that are assumed to have separate sanitary and storm sewer systems, the storm sewer system may actually act as a combined sewer system. In these cases, the community may consider designating the storm sewer system a combined sewer and treating the discharge.

A SWCA program and the related correction program need to be periodically updated, based on their effectiveness and on the introduction of new raw materials or changes in processes at the site.

Because the results and performance of a SWCA program depend on the severity of the risks uncovered and the corrective actions taken, it is difficult to quantify the water quality benefits of a risk assessment program. Clearly, however, a program that identifies potential pollution sources and corrects them will improve water quality.

COSTS

Costs for the initial assessment may be high. However, by pinpointing high risk areas, a risk assessment may reduce overall costs associated with a complete BMP implementation program. The costs associated with a risk assessment program for storm water are small when compared with those of an overall hazardous waste site assessment.

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Storm Water Management Fact Sheet

Non-Storm Water Discharges to Storm Sewers

DESCRIPTION

Identifying and eliminating non-storm water discharges to storm sewers is an important and very cost-effective Best Management Practice (BMP) for improving runoff water quality. Non-storm water discharges can include discharges of process water, air conditioner condensate, non-contact cooling water, vehicle wash water, or sanitary wastes, and are typically the result of unauthorized connections of sanitary or process wastewater drains to storm sewers. These connections are common, yet often go undetected. Typically these discharges are significant sources of pollutants, and, unless regulated by an NPDES permit, they are also illegal.

Environmental impact evaluations have shown that the elimination of non-storm water discharges is an effective BMP, because such discharges may contain a significant loading of pollutants.

Several studies exist on the contents of non-storm water discharges. Pitt and Shawley (1982) reported that non-storm water discharges were found to contribute substantial quantities of a variety of pollutants, even though the individual concentrations of each pollutant were not high. During extended periods of base flow conditions, the lower concentration was offset, leading to a substantial loading of pollutants. Gartner, Lee and Associates, Ltd. (1983) conducted an extensive survey of non-storm water discharges in the Humber River watershed (Toronto). Out of 625 outfalls, about 10 percent were considered significant pollutant sources. Further investigations identified many industrial and sanitary non-storm water discharges into the storm drainage system.

Sources found in industrial areas included liquid dripping from animal hides stored in tannery yards, and washdowns of storage yards at meat packing facilities. Therefore, it is anticipated that elimination of non-storm water discharges will be a highly effective BMP.

Identifying and eliminating non-storm water discharges has rarely been done at industrial facilities. Part of the problem is education: many facility operators are unaware of what constitutes a non-storm water discharge and what the potential environmental impacts of these discharges are. Compliance with NPDES permit requirements for the presence of non-storm water discharges will greatly improve the implementation of this BMP.

APPLICABILITY

Almost every industrial facility that has not been tested or evaluated for the presence of potential non-storm water discharges should be so evaluated. Typically NPDES permit certification includes:

- Identification of potential non-storm water discharges.
- Results of a site evaluation for the presence of non-storm water discharges.
- The evaluation criteria or test method used.
- The date of testing and/or evaluation.
- The on-site drainage points that were directly observed during the test and/or evaluation.

This certification must be signed in accordance for the facility's NPDES storm water permit. A sample certification form is shown in Figure 1.

ADVANTAGES AND DISADVANTAGES

Identifying and eliminating non-storm water discharges can be an easy and cost-effective method for preventing runoff contamination and pollution of receiving water bodies. However, identifying these discharges may be problematic. Possible problems in identifying non-storm water discharges include:

- A non-storm water discharge may not occur on the date of the test or evaluation.
- The method used to test or evaluate the discharge may not be applicable to the situation.
- A lack of available data on the location of storm drains and sanitary sewers, especially in older industrial facilities, may make identifying an illicit connection difficult.

KEY PROGRAM COMPONENTS

Key program criteria include identifying and locating non-storm water entries into storm drainage and investigating their sources.

For any effective investigation of pollution within a storm water system, all pollutant sources must be included. For many pollutants, storm water may contribute the smaller portion of the total pollutant mass discharge from a storm drainage system. In addition to conventional storm water runoff associated with rainfall, pollutant sources may include dry-weather entries occurring during both warm and cold months and snowmelt runoff. Consequently, much less pollution reduction benefit will occur if only storm water is considered in a control plan for controlling storm drainage discharges.

The investigations may also identify illicit point source outfalls that do not carry storm water. Obviously, these outfalls also need to be controlled and permitted. Figure 1 can be used as a sample worksheet to report non-storm water discharges.

There are four primary methods for investigating non-storm water discharges.

Visual Inspection

The simplest method for detecting non-storm water connections in the storm water collection system is to observe all discharge points during periods of dry weather. Key parameters to look for are the presence of stains, smudges, odors, and other abnormal conditions.

Sanitary and Storm Sewer Map Review

A review of a plant schematic is another simple way to determine if there are any unauthorized connections to the storm water collection system. A sanitary or storm sewer map, or plant schematic, is a map of pipes and drainage systems used to carry

NON-STORM WATER DISCHARGE ASSESSMENT AND CERTIFICATION			Worksheet Completed By: ______ Title: ______ Date: ______ Signature: ______		
Date of Test or Evaluation	Outfall Directly Observed During the Test (Identify as indicated on the site map)	Method Used to Test or Evaluate Discharge	Describe Results from Test for the Presence of Non-Storm Water Discharge	Identify Potential Significant Sources	Name of Person Who Conducted the Test or Evaluation

Source: U. S. EPA, 1992.

FIGURE 1 SAMPLE WORKSHEET FOR RECORDING NON-STORM WATER DISCHARGES

process wastewater, non-contact cooling water, and sanitary wastes. These maps (especially as-built plans) should be reviewed to verify that there are no unauthorized connections. However, a common problem at many sites is that they often do not have accurate or current schematics.

Dye Testing

Another method for detecting improper connections to the storm water collection system is dye testing. A dye test can be performed by simply releasing a dye (either pellet or powder) into either the sanitary or process wastewater system. Discharge points from the storm water collection system are then examined for color change.

Sampling and Chemical Analysis

Sewer mapping and visual inspection are also helpful in identifying locations for sampling. Chemical tests are needed to supplement the visual or physical inspections. Chemical tests can help quantify the approximate components of the discharge mixture at the outfall or discharge point. Samples should be collected, stored, and analyzed in accordance with standard quality assurance and quality control (QA/QC) procedures. Statistical analysis of the chemical test results can be used to estimate the relative magnitudes of the various flow sources. In most cases, non-storm water discharges are made up of many separate sources of flow, such as leaking domestic water systems, sanitary discharges, ground water infiltration, automobile washwater, etc. Key parameters that can be helpful in identifying the source of the non-storm water flows include biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), specific conductivity, temperature, fluoride, hardness, ammonia, ammonium, potassium, surfactant fluorescence, pH, total available chlorine, and toxicity screening. It may be possible to identify the source of the non-storm water discharge by examining the flow for specific chemicals.

Just as high levels of pathogenic bacteria are usually associated with a discharge from a sanitary waste water source, the presence of certain chemicals is generally associated with specific industries. Table 1, includes a listing of various chemicals that may be associated with a variety of activities.

IMPLEMENTATION

Identification of non-storm water discharges should be part of every facility's maintenance program. Facilities should conduct annual inspections for non-storm water discharges, even if previous tests have found no such discharges. New processes, building additions, or other plant changes may have brought about unauthorized connections to the storm water conveyance system.

COSTS

The above methods are mostly time-intensive; therefore, the cost is dependent on the level of effort employed, and on the level of expertise. Visual inspections are the least expensive of the three. Dye testing may be more cost effective for buildings that do not have current schematics of their sanitary and storm sewer systems. The cost of disconnecting illicit discharges from the storm water system will vary depending on the type and location of the connection.

The full use of all of the applicable procedures is most likely necessary to identify all pollutant sources. For example, attempting to reduce costs by examining only a certain class of outfalls, or using inappropriate testing procedures, will significantly reduce the utility of the testing program and result in inaccurate conclusions.

REFERENCES

1. California Environmental Protection Agency, Draft, 1992. *Staff Proposal for Modification to Water Quality Order No. 91-13 DWQ Waste Discharge Requirements for Discharges of Storm Water Associated with Industrial Activities*.

2. Gartner, Lee and Associates, Ltd., 1983. *Toronto Area Watershed Management Strategy Study, Technical Report No. 1, Humber River and Tributary Dry Weather Outfall Study*. Ontario Ministry of the Environment, Toronto, Ontario.

TABLE 1 CHEMICALS COMMONLY FOUND IN INDUSTRIAL DISCHARGES

Chemical	Industries
Acetic Acid	Acetate rayon, pickle and beetroot manufacture
Alkalis	Cotton and straw kiering, cotton manufacture
Ammonia	Gas and coke manufacture, chemical manufacture
Arsenic	Sheep-dipping, felt mongering
Chlorine	Laundries, paper mills, textile bleaching
Chromium	Plating, chrome tanning, aluminum anodizing
Cadmium	Plating
Citric Acid	Soft drinks and citrus fruit processing
Copper	Plating, pickling, rayon manufacture
Cyanides	Plating, metal cleaning, case-hardening, gas manufacture
Fats, Oils	Wool scouring, laundries, textiles, old refineries
Fluorides	Gas and coke manufacture, chemical manufacture, fertilizer plants,
Formalin	Manufacture of synthetic resins and penicillin
Hydrocarbons	Petrochemical and rubber factories
Hydrogen Peroxide	Textile bleaching, rocket motor testing
Lead	Battery manufacture, lead mining, paint manufacture, gasoline
Metcaptins	Oil refining, pulp mills
Mineral Acids	Chemical manufacture, mines, iron and copper pickling, brewing, textiles
Nickel	Plating
Nitro Compounds	Explosives and chemical works
Organic Acids	Distilleries and fermentation plants
Phenols	Gas and coke manufacture, synthetic resin manufacture, textiles,
Silver	Plating and photography
Starch	Food, textile, wallpaper manufacture
Sugars	Dairies, foods, sugar refining, preserves, wood process
Sulfides	Textiles, tanneries, gas manufacture, rayon manufacture
Sulfites	Wood process, vicose manufacture, bleaching
Tannic Acid	Tanning, sawmills
Tartaric Acid	Dyeing, wine, leather, and chemical manufacture
Zinc	Galvanizing, plating, viscose manufacture, rubber process

Source: Pitt *et al.*, 1992.

3. Pitt, R. and G. Shawley, 1982. *A Demonstration of Non-Point Pollution Management on Castro Valley Creek*, Alameda County Flood Control District (Hayward, California) and U.S. EPA, Washington, DC.

4. Pitt, R., D. Barbe, D. Adrian, and R. Field, 1992. *Investigation of Inappropriate Pollution Entries Into Storm Drainage Systems -- A Users Guide*, U.S. EPA, Edison, New Jersey.

5. Pitt, R., and R. Field, 1992. Non-Storm Water Discharges into Storm Drainage Systems. NTIS Report No. PB92-158559.

6. U.S. EPA, 1992. *Storm Water Management For Industrial Activities: Developing Pollution Prevention Plans and Best Management Practice.* EPA 833-R-92-006.

7. Washington State Department of Ecology, February, 1992. *Storm Water Management Manual for the Puget Sound Basin.*

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United States Environmental Protection Agency | Office of Water Washington, D.C. | EPA 832-F-99-021 September 1999

Storm Water Management Fact Sheet
Materials Inventory

DESCRIPTION

A materials inventory system involves the identification of all sources and quantities of "significant" materials that may be exposed to direct precipitation or storm water runoff at a particular site. "Significant" materials are substances related to industrial activities such as process chemicals, raw materials, fuels, pesticides, and fertilizers. When these substances are exposed to direct precipitation or storm water runoff, they may be carried to a receiving water body. Therefore, identification of these materials helps to determine sources of potential contamination and is the first step in pollution control.

APPLICABILITY

A materials inventory system is appropriate at most industrial facilities. Inventory of exposed materials should be part of a baseline administrative program and is directly related to both record keeping and visual inspection Best Management Practices.

ADVANTAGES AND DISADVANTAGES

Since the program is intended to prevent pollution before it occurs, it is not possible to quantify water quality benefits to receiving waters of a materials inventory program. However, it is anticipated that an effective materials inventory program will improve the quality of storm water discharges.

Limitations of a materials inventory system include:

- It is an on-going process that continually needs updating.
- Qualified personnel are required to perform the materials inventory from a storm water perspective.

KEY PROGRAM COMPONENTS

Most facilities already have in place a materials inventory system, but this system is not generally followed from a storm water contamination viewpoint. Adding storm water considerations into an existing inventory should require only minimal effort. When discussing a material inventory it is very important to be aware of Material Safety Data Sheets (MSDS). Currently the United States Government has created a Hazard Communication standard, which requires all firms manufacturing and/or distributing chemicals within the United States to prepare MSDSs for those chemicals and distribute them to their customers.

Keeping an up-to-date inventory of all materials (hazardous and non-hazardous) on the site will help to track how materials are stored and handled on site, and identify which materials and activities pose the greatest risk to the environment. The following instructions explain the basic steps in completing a materials inventory:

- Identify all chemical substances present in the work place. Walk through the facility and review the purchase orders for the previous year. List all chemical substances used in the work place and then obtain the material safety data sheet (MSDS) for each.
- Label all containers to show the name and type of substance, stock number, expiration date, health hazards, suggestions for

handling, and first aid information. This information is found on the MSDS. Unlabeled chemicals and chemicals with deteriorated labels are often disposed of improperly or unnecessarily.

- Clearly mark on the inventory those hazardous materials that require specific handling, storage, use, and disposal considerations.

An example Materials Inventory Worksheet is provided in Figure 1. Based on your materials inventory, describe the significant materials that were exposed to storm water during the past three years or are currently exposed.

Other BMPs should then be evaluated and implemented to prevent exposure of these materials to storm water or them before discharge. Figure 2 illustrates a sample worksheet for evaluating exposed materials.

IMPLEMENTATION

The key to a proper materials inventory system is continual updating of records. Maintaining an up-to-date materials inventory is an efficient way to identify what materials are handled on-site and whether they contribute to storm water contamination problems.

COSTS

Typically, the major cost of implementing a materials inventory system is the time required to adapt an existing program to emphasize storm water quality. The incremental cost is usually small.

Costs of the program are often offset by cost savings in other areas. Improved material tracking and inventory practices, such as instituting a shelf life program, can reduce the waste resulting from the overstocking and disposal of outdated materials. Careful tracking of all materials ordered may also result in more efficient materials use.

MATERIAL INVENTORY				Worksheet Completed by: ______ Title: ______ Date: ______				
Instructions: List all materials used, stored, or produced on site. Assess and evaluate these materials for their potential to contribute pollutants to storm water runoff. Also complete Worksheet 3A if the material has been exposed during the last three years.								
		Quantity (units)					Past Significant Spill or Leak	
Material	Purpose / Location	Used	Produced	Stored	Quantity exposed during last 3 years	Likelihood of contact with storm water. If yes, describe reason	Yes	No

Source: U. S. EPA, 1992.

FIGURE 1 SAMPLE MATERIAL INVENTORY

<table>
<tr><td colspan="4">DESCRIPTION OF EXPOSED SIGNIFICANT MATERIAL</td><td colspan="2">Worksheet Completed by: ______
Title: ______
Date: ______</td></tr>
<tr><td colspan="6">Instructions: Based on your material inventory, describe the significant materials that were exposed to storm water during the past three years or are currently exposed. For the definition of "significant materials" see Appendix B of the manual.</td></tr>
<tr><td>Description of Exposed Significant Material</td><td>Period of Exposure</td><td>Quantity Exposed (units)</td><td>Location (as indicated on the site map)</td><td>Method of Storage or Disposal (e.g., pile, drum, tank)</td><td>Description of Material Management Practice (e.g., pile covered, drum sealed)</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Source: U. S. EPA, 1992.

FIGURE 2 EXPOSED MATERIAL WORKSHEET

REFERENCES

1. U.S. EPA, 1992. *NPDES Best Management Practices Guidance Document.*

2. U.S. EPA, 1992. *Stormwater Management for Industrial Activities: Developing Pollution Prevention Plans and Best Management Practices.* EPA 832-R-92-006.

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United States Environmental Protection Agency | Office of Water Washington, D.C. | EPA 832-F-99-020 September 1999

Storm Water Management Fact Sheet
Internal Reporting

DESCRIPTION

Internal reporting provides a framework for "chain-of-command" reporting of storm water management issues. Typically, a facility develops a Storm Water Pollution Prevention Team (SWPPT) concept for implementing, maintaining, and revising the facility's Storm Water Pollution Prevention Plan (SWPPP). The purpose of identifying a SWPPT is to clarify the chain of responsibility for storm water pollution prevention issues and to provide a point of contact for personnel outside the facility who need to discuss the SWPPP.

APPLICABILITY

The U.S. EPA first identified internal reporting as a BMP in the late 1970s. Currently, internal reporting has evolved into the development of a SWPPT for facilities implementing a SWPPP as part of their NPDES storm water discharge permit. This SWPPT concept is a new and innovative part of the SWPPP.

ADVANTAGES AND DISADVANTAGES

Internal reporting is an essential part of any good record keeping program. When properly implemented, an internal reporting program can clearly define individual's roles and responsibilities for implementing and maintaining the SWPP, thereby making it easier to prevent and contain potential storm water contamination.

Limitations involved in developing an internal reporting system are:

- Corporate commitment in designating appropriate funds may be lacking.
- Inadequate staff hours may be available for proper implementation.
- Low motivation from SWPPT members could inhibit the transfer of key storm water pollution information.

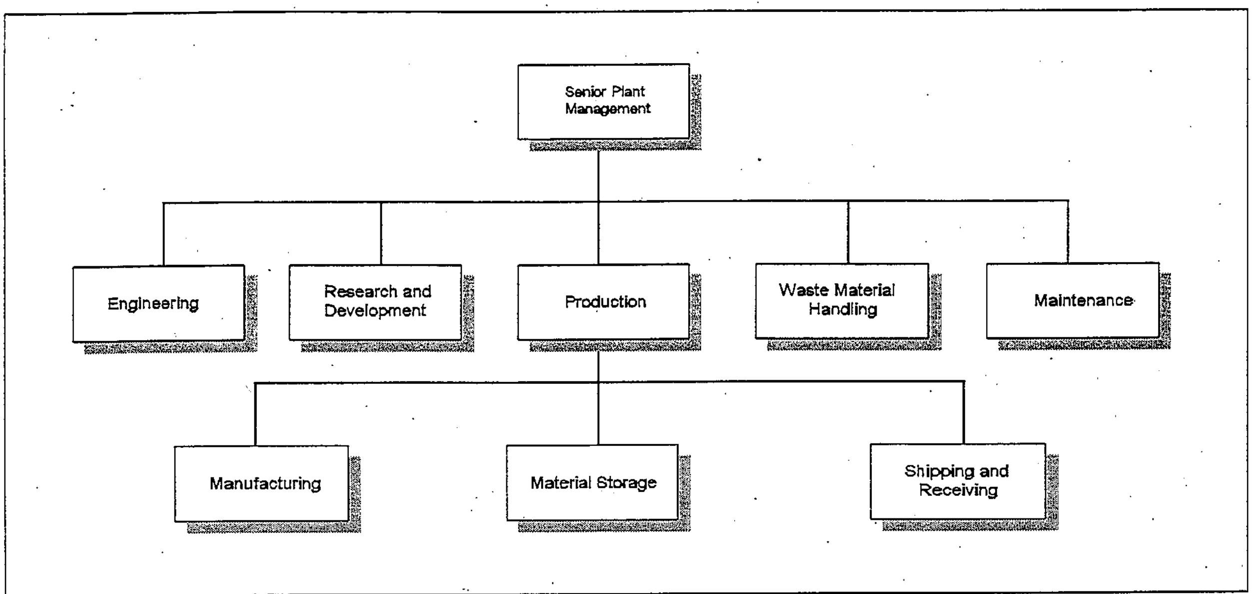
KEY PROGRAM COMPONENTS

When establishing an internal reporting structure, it is important to select appropriate personnel at all levels to serve on the team. Both team and individual responsibilities should be designated with clear goals defined for proper storm water management. Internal reporting should be tied to other baseline BMPs, such as employee training, individual inspections, and record keeping to ensure proper implementation. Figure 1 illustrates an example SWPPT organization chart.

IMPLEMENTATION

The key to implementing internal reporting as a BMP is to establish a qualified SWPPT. When setting up a SWPPP, it is important to identify key people on-site who are most familiar with the facility and its operations and who can also provide adequate structure and direction to the facility's entire storm water management program.

The performance and effectiveness of a facility's internal reporting system is highly variable and dependent upon several factors. Key factors include:



Source: U. S. EPA, 1992.

FIGURE 1 EXAMPLE OF A SWPPT ORGANIZATION CHART

- Commitment of senior management.
- Sufficient time and financial resources.
- Quality of implementation.
- Background and experience of the SWPPT.

To ensure that an internal reporting system remains effective, the person or team responsible for maintaining the SWPPP must be aware of any changes in plant operations or with key team members to determine if modifications must be made in the overall execution of the SWPPP.

COSTS

Costs associated with implementing an internal reporting system are those associated with additional staff hours and related overhead costs. Annual costs can be estimated using the example shown in Table 1. Table 2 can be used as a worksheet to calculate the estimated costs for an internal record keeping program.

REFERENCES

1. U.S. EPA, 1981. *NPDES BMP Guidance Document.*
2. U.S. EPA, 1992. *Storm Water Management for Industrial Activities: Developing Pollution Prevention Plans and Best Management Practices.* EPA 832-R-92-006.

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TABLE 1 EXAMPLE OF ANNUAL INTERNAL REPORTING COSTS

Title	Quantity		Average Hourly Rate ($)		Overhead* Multiplier		Estimated Yearly Hours on SW Training		Estimated Annual Cost ($)
Stormwater Engineer	1	x	15	x	2.0	x	20	=	600
Plant Management	5	x	20	x	2.0	x	10	=	2,000
Plant Employees	100	x	10	x	2.0	x	5	=	10,000
					Total Estimated Annual Cost				**$12,600**

*Note: Defined as a multiplier (typically between 1 and 3) that takes into account those costs associated with payroll expenses, building expenses, etc.

Source: U.S. EPA, 1992.

TABLE 2 EXAMPLE OF ANNUAL INTERNAL REPORTING COST WORKSHEET

Title	Quantity		Average Hourly Rate ($)		Overhead Multiplier		Estimated Yearly Hours on SW Training		Estimated Annual cost($)
________	____	x	______	x	______	x	________	=	______ (A)
________	____	x	______	x	______	x	________	=	______ (B)
________	____	x	______	x	______	x	________	=	______ (C)
________	____	x	______	x	______	x	________	=	______ (D)
			Total Estimated Annual Reporting Cost ______						**(Sum of A+B+C+D)**

Source: U.S. EPA, 1992.

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United States Environmental Protection Agency | Office of Water Washington, D.C. | 832-F-99-046 September 1999

Storm Water Management Fact Sheet
Visual Inspection

DESCRIPTION

Visual inspection is a Best Management Practice (BMP) in which members of a Storm Water Pollution Prevention Team visually examine material storage and outdoor processing areas, the storm water discharges from such areas, and the environment in the vicinity of the discharges, to identify contaminated runoff and its possible sources.

In a visual inspection, storm water runoff may be examined for the presence of floating and suspended materials, oil and grease, discoloration, turbidity, odor, or foam; and storage areas may be inspected for leaks from containers, discolorations on the storage area floor, or other indications of a potential for pollutants to contaminate storm water runoff.

Visual inspections may indicate the need to modify a facility to reduce the risk of contaminating runoff.

APPLICABILITY

The U.S. EPA has recognized visual inspection as a baseline BMP for over 10 years. Its implementation, however, has been sporadic. Implementation may increase as more facilities develop Storm Water Pollution Prevention Plans. Implementation may also increase as facility management recognizes visual inspection to be effective both in protecting water quality and in reducing costs.

ADVANTAGES AND DISADVANTAGES

Visual inspections are an effective way to identify a variety of problems. Correcting these problems can improve the water quality of the receiving water.

Limitations associated with visual inspections include the following:

- Visual inspections are effective only for those areas clearly visible to the human eye.
- The inspections need to be performed by qualified personnel.
- To be effective, inspections must be carried out routinely. This requires a corporate commitment to implementing them.
- Inspectors need to be properly motivated to perform a thorough visual inspection.

KEY PROGRAM COMPONENTS

Visual inspections for signs of storm water contamination should be performed routinely. Flows should be observed during dry periods to determine the presence of any stains, sludge, odors, and other abnormal conditions.

Visual inspections should also be made at all storm water discharge outlet locations during the first hour of a storm event, once runoff has reached its maximum flow rate. Inspectors should examine the discharge for the presence of floating and suspended materials, oil and grease, discoloration, turbidity, foam, or odor.

Inspection frequency interval may be determined by the storm water discharge permit, by storm frequency, or by the potential risk from the site. Inspections should be made at least once a month in areas with frequent storms; inspections may be less frequent where storms are less frequent. Finally, inspection frequency may be based in part on the history of previous spills and leaks. Experienced personnel should evaluate the causes of previous accidents, assess the risks for future accidents, and determine an inspection schedule based on these risks.

Proper records of inspection results must be kept. The record for each inspection should include the date of the inspection, the names of the personnel who performed the inspection, and their observations.

Visual inspections of a facility should focus on the following key areas:

- Storage facilities.
- Transfer pipelines.
- Loading and unloading areas.
- Pipes, pumps, valves, and fittings.
- Tanks (including internal and external inspection of the tank for corrosion and inspection of its support or foundation for deterioration).
- Primary or secondary containment facilities.
- Shipping containers.

In addition, a visual inspection should include assessing the integrity of the storm water collection system; checking for leaks, seepage, and overflows from sludge and waste disposal sites; and ensuring that dry chemicals and dust from industrial areas is not exposed to wind or other elements that may move them into the runoff.

IMPLEMENTATION

A visual inspection BMP program should be incorporated into every storm water discharger's record keeping and internal reporting structure.

Outfall flow rates and the presence of oil sheens, floatables, coarse solids, color, and odors will probably be the most useful indicators of potential problems. Specific parameters to look for in completing a visual inspection include the following:

- Odor: Discharge odors can vary widely. Some may indicate the source of contamination. Industrial discharges may smell like a particular spoiled product, oil, gasoline, a specific chemical, or a solvent. For example, the decomposition of organic wastes in a discharge will release sulfide compounds, creating an intense smell of rotten eggs. Significant sanitary wastewater contributions will also cause pronounced and distinctive odors.

- Color: Color may indicate inappropriate discharges, especially from industrial sources. Industrial discharges may be any color. Dark colors, such as brown, gray, or black, are most common. For instance, flow contaminated by meat processing industries is usually a deep reddish-brown. Paper mill wastes (plating-mill wastes) are often yellow. Wash water from cement and stone working plants can cause cloudy discharges. Contamination from industrial areas may come from process waters (slug or continuous discharges); from equipment and work area wash water discharged to floor drains; or from spills washed into storm drains.

- Turbidity: Turbidity is often affected by the degree of gross contamination. Industrial flows can be cloudy (moderately turbid) or opaque (highly turbid). Undiluted industrial discharges, such as those coming from continual flow sources or intermittent spills, are often highly turbid. Sanitary wastewater is also often cloudy in nature.

- Floatable matter: A contaminated flow may also contain floatable solids or liquids. Identifying floatables can aid in finding the source of the contamination, because these substances are usually direct products or byproducts of the manufacturing process or the sanitary system. Examples of floatables of industrial origin are animal fats, spoiled food products, oils, plant parts, solvents, sawdust, foams, packing materials, and fuel.

- Deposits and Stains: Deposits and stains (residues) are any type of coating that remains after a non-storm water discharge has ceased. Deposits or stains usually are of a dark color and usually cover the area surrounding the storm water discharge. They often contain fragments of floatable substances, and, at times, take the form of a crystalline or amorphous powder. For example, contamination from leather tanneries often produces grayish-black deposits containing fragments of animal flesh and hair. Another characteristic example is the coating of white crystalline powder formed on sewer outfalls by nitrogenous fertilizer wastes.

- Vegetation: Storm water discharges often affect surrounding vegetation. Industrial pollutants often cause a substantial alteration in the chemical composition and pH of the discharge water, which can affect plant growth even when the source of contamination is intermittent. For example, nutrients from various food product wastes increase plant growth. In contrast, the discharge of chemical dyes and inorganic pigments from textile mills may decrease vegetation, as these discharges are often very acidic. In either case, even when the pollution source is gone, the vegetation surrounding the discharge will continue to show the effects of the contamination.

  In order to accurately judge if the vegetation surrounding a discharge is normal, the observer must take into account recent weather conditions, as well as the time of year. Increased or inhibited plant growth near storm water discharges, as well as dead and decaying plants, is often a sign of pollution. However, it is important to distinguish whether plant damage is caused by contamination or by the physical effects of increased flows, such as scour. This can be done by chemically analyzing the flow or by confirming its source through additional visual inspections.

- Structural Damage: Structural damage is also a sign of industrial discharge contamination. Cracked or deteriorated concrete or peeling surface paint at an outfall usually indicates the presence of severely contaminated discharges. Contaminants causing this type of damage are usually very acidic or basic and are usually of industrial origin. For instance, discharges from primary metal industries may cause structural damage because their batch dumps are highly acidic.

The effectiveness visual inspections in reducing storm water runoff contamination is highly variable and dependent upon site-specific parameters. These factors include inspectors' motivation level, the types of industrial activity occurring at the facility, and the facility's maintenance procedures. Because familiarity with facility operations is essential in performing effective visual inspections, the inspections should be assigned to qualified staff such as maintenance personnel or environmental engineers. Figure 1 provides a sample visual evaluation worksheet that can be used to record the results of the inspections.

COSTS

Costs for performing the visual inspection BMP are minimal and consist of direct labor and overhead costs for staff hours spent on training, planning inspections, inspecting, and completing follow up activities. Annual costs can be estimated using the example in Table 1. Figure 2 can be used as a worksheet to calculate the estimated annual cost for implementing a visual inspection program.

Outfall # ______________ Photograph # ______________ Date: ______________

Location: ____

Weather: air temp.: ________ °C rain: Y N sunny cloudy

Outfall flow rate estimate: ______ L/sec

Known industrial or commercial uses in drainage area? Y N

Describe: ____

PHYSICAL OBSERVATIONS

Odor: none sewage sulfide oil gas rancid-sour other: __________

Color: none yellow brown green gray other: __________

Turbidity: none cloudy opaque

Floatables: none petroleum sheen sewage other: __________ (collect sample)

Deposits/stains: none sediment oily describe: __________ (collect sample)

Vegetation conditions: normal excessive growth inhibited growth

extent: ____

Damage to outfall structures:

identify structure: ______________________________

damage: none / concrete cracking / concrete spalling / peeling paint / corrosion

other damage: ______________________________

extent: ____

Source: Pitt, et. al, 1992.

FIGURE 1 VISUAL INSPECTION WORKSHEET

REFERENCES

1. California Environmental Protection Agency, 1992. Staff Proposal for Modification to Water Quality Order No. 91-13 DWQ Waste Discharge Requirements for Dischargers of Storm Water Associated with Industrial Activities, Draft Wording, Monitoring Program and Reporting Requirements.

2. Pitt R., D. Barbe, D. Adrian, and R. Field, 1992. *Investigation of Inappropriate Pollutant Entries into Storm Drainage Systems-A Users Guide*. U.S. EPA, Edison, NJ.

3. U.S. EPA, 1981. *NPDES BMP Guidance Document*.

4. U.S. EPA. Pre-print, 1992. *Storm Water Management for Industrial Activities: Developing Pollution Prevention Plans and Best Management Practices*. EPA 832-R-92-006.

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TABLE 1 EXAMPLE OF VISUAL INSPECTION PROGRAM COSTS

Title	Quantity		Average Hourly Rate ($)		Overhead* Multiplier		Estimated Yearly Hours on SW Training		Estimated Annual Cost ($)
Storm Water Engineer	1	x	15	x	2.0	x	20	=	600
Plant Management	5	x	20	x	2.0	x	10	=	2,000
Plant Employees	100	x	10	x	2.0	x	5	=	10,000
					TOTAL ESTIMATED ANNUAL COST				**$12,600**

*Note: Defined as a multiplier (typically ranging between 1 and 3) that takes into account those costs associated with payroll expenses, building expenses, etc.

Source: U.S. EPA, 1992.

Title	Quantity		Average Hourly Rate ($)		Overhead Multiplier		Estimated Yearly Hours on SW Training		Estimated Annual Cost($)
______	______	x	______	x	______	x	______	=	______ (A)
______	______	x	______	x	______	x	______	=	______ (B)
______	______	x	______	x	______	x	______	=	______ (C)
______	______	x	______	x	______	x	______	=	______ (D)

Source: U.S. EPA, 1992.

FIGURE 2 SAMPLE INSPECTION PROGRAM COST WORKSHEET

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United States Environmental Protection Agency
Office of Water Washington, D.C.
EPA 832-F-99-010 September 1999

Storm Water Management Fact Sheet
Employee Training

DESCRIPTION

In-house employee training programs are established to teach employees about storm water management, potential sources of contaminants, and Best Management Practices (BMPs). Employee training programs should instill all personnel with a thorough understanding of their Storm Water Pollution Prevention Plan (SWPPP), including BMPs, processes and materials they are working with, safety hazards, practices for preventing discharges, and procedures for responding quickly and properly to toxic and hazardous material incidents.

APPLICABILITY

Typically, most industrial facilities have employee training programs. Usually these address such areas as health and safety training and fire protection. Training on storm water management and BMPs can be incorporated into these programs.

Employees can be taught through 1) posters, employee meetings, courses, and bulletin boards about storm water management, potential contaminant sources, and prevention of contamination in surface water runoff, and 2) field training programs that show areas of potential storm water contamination and associated pollutants, followed by a discussion of site-specific BMPs by trained personnel.

ADVANTAGES AND DISADVANTAGES

Advantages of an employee training program are that the program can be a low-cost and easily implementable storm water management BMP. The program can be standardized and repeated as necessary, both to train new employees and to keep its objectives fresh in the minds of more senior employees. A training program is also flexible and can be adapted as a facility's storm water management needs change over time.

Obstacles to an employee training program include:

- Lack of commitment from senior management.
- Lack of employee motivation.
- Lack of incentive to become involved in BMP implementation.

KEY PROGRAM COMPONENTS

Specific design criteria for implementing an employee training program include:

- Ensuring strong commitment and periodic input from senior management.
- Communicating frequently to ensure adequate understanding of SWPPP goals and objectives.
- Utilizing experience from past spills to prevent future spills.
- Making employees aware of BMP monitoring and spill reporting procedures.
- Developing operating manuals and standard procedures.

- Implementing spill drills.

IMPLEMENTATION

An employee training program should be an on-going, yearly process. Meetings about SWPPPs should be held at least annually, possibly in conjunction with other training programs. Figure 1 illustrates a sample employee training worksheet. Worksheets such as these can be used to plan and track employee training programs. Program performance depends on employees' participation and on senior management's commitment to reducing point and nonpoint sources of pollution; therefore, performance will vary among facilities. To be effective these programs need senior management's support

COSTS

Costs for implementing an employee training program are highly variable. Most storm water training program costs will be directly related to labor and associated overhead costs. Trainers can reduce costs by using free educational materials available on the subject of storm water quality.

Figure 2 can be used to estimate the annual costs for an in-house training program. Table 1 provides an example of how this worksheet can be used to estimate annual costs.

REFERENCES

1. U.S. EPA, 1979. *NPDES BMP Guidance Document.*

2. U.S. EPA, Pre-print, 1992. *Stormwater Management for Industrial Activities: Developing Pollution Prevention Plans and Best Management Practices*. EPA 832-R-92-006.

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EMPLOYEE TRAINING	Worksheet Completed by: ______ Title: ______ Date: ______

Instructions: Describe the employee training program for your facility below. The program should, at a minimum, address spill prevention and response, good housekeeping, and material management practices. Provide a schedule for the training program and list the employees who attend the training sessions.

Training Topics	Brief Description of Training Program/Materials (e.g., film, newsletter, course)	Schedule for Training (list dates)	Participants
Spill Prevention and Response			
Good Housekeeping			
Material Management Practices			
Other Topics			

Source: U. S. EPA, 1992.

FIGURE 1 SAMPLE WORKSHEET FOR TRACKING EMPLOYEE TRAINING

TABLE 1 EXAMPLE OF ANNUAL EMPLOYEE TRAINING COSTS

Title	Number		Average Hourly Rate ($)		Overhead* Multiplier		Estimated Yearly Hours on SW Training		Estimated Annual Cost ($)
Stormwater Engineer	1	x	15	x	2.0	x	20	=	600
Plant Management	5	x	20	x	2.0	x	10	=	2,000
Plant Employees	100	x	10	x	2.0	x	5	=	10,000
							Total Estimated Annual Cost $12,600		

*Note: Defined as a multiplier (typically ranging between 1 and 3) that takes into account those costs associated with costs other than salary of employing a person, expenses, etc

Title	Number		Average Hourly Rate ($)		Overhead Multiplier		Estimated Yearly Hours on SW Training		Estimated Annual Cost ($)	
______	______	x	______	x	______	x	______	=	______	(A)
______	______	x	______	x	______	x	______	=	______	(B)
______	______	x	______	x	______	x	______	=	______	(C)
______	______	x	______	x	______	x	______	=	______	(D)
							Total Estimated Annual Cost (Sum of A+B+C+D)		______	

Source: U.S. EPA, 1992.

FIGURE 2 SAMPLE ANNUAL TRAINING COST WORKSHEET

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Storm Water Management Fact Sheet
Coverings

DESCRIPTION

Covering is the partial or total enclosure of raw materials, byproducts, finished products, containers, equipment, process operations, and material storage areas that, when exposed to rain and/or runoff, could contaminate storm water. Tarpaulins, plastic sheeting, roofs, buildings, and other enclosures are examples of temporary or permanent coverings that are effective in preventing storm water contamination. The most prominent advantage of covering is that it is inexpensive in comparison to other BMPs.

APPLICABILITY

A review of numerous NPDES group applications indicates that covering is a commonly implemented BMP. As more facilities identify potential sources of storm water contamination, the use of coverings will increase significantly due to their effectiveness from a performance and cost perspective.

Covering is appropriate for loading/unloading areas, raw material, byproduct, and final product outdoor storage areas, fueling and vehicle maintenance areas, and other high risk areas.

ADVANTAGES AND DISADVANTAGES

Covering is a simple and effective storm water management BMP. Its advantages relative to other storm water management BMPs include its comparative ease of implementation, its potential low cost, and its widespread applicability.

Disadvantages associated with covering as a BMP include:

- Temporary covering methods, such as plastic sheeting, can become torn or ripped, exposing the contaminant to precipitation and/or storm water runoff.
- Costs may prohibit the building of complete enclosures.
- Health or safety problems may develop with enclosures built over certain materials or activities.
- Coverings require frequent inspection.
- A structure with only a roof may not keep out all precipitation.

The impact from a covered area depends on the degree of complexity in the covering design. Simple plastic sheeting can possibly create a storm water diversion, and allow for disposal of uncontaminated water to a storm sewer. An appropriate structure with a permanent roof may be less effective, if the material inside is not sufficiently protected from contact with runoff. An enclosed structure may need to have internal drainage. However, if the stored material is considered hazardous, it must not be connected to the storm sewer. Depending on the site's NPDES permit, connection to a sanitary sewer may also be unsuitable. The internal drains would then need to be connected to some suitable containment area for later pretreatment and disposal.

IMPLEMENTATION

When implementing a program to cover materials to reduce their exposure to runoff, one must first choose the proper covering. When deciding on a covering, it is necessary to evaluate the integrity and durability of the covering, as well as its compatibility with the material or activity being covered.

Covering alone may not protect exposed materials from storm water contact. Placing material on an elevated impermeable surface or building curbing around the outside of the materials may be required to prevent contact with storm water runoff from adjacent areas. If the program calls for a material to be enclosed, the designer should consider materials access, handling, and transfer during the design of the enclosure. Materials that pose environmental and/or safety dangers because they are radioactive, pathogenic, flammable, explosive, or reactive, require special ventilation and temperature design considerations.

In addition to properly designing an enclosure or cover, practicing proper materials management within an enclosure or underneath a covered area is essential. For example, floor drainage within an enclosure should be properly designed and connected to a sanitary sewer. The local publicly owned treatment works should be consulted to determine if there are any pretreatment requirements, restrictions, or compatibility problems prior to discharge of the storm water.

Based on data currently available, it is difficult to quantify the mitigation of runoff contamination when covering is used. However, significant runoff water quality benefits are expected by simply reducing the contact between potential contaminants and precipitation or storm water runoff. One source has estimated that 80 percent of the environmental damage from de-icing chemicals is caused by inadequate storage facilities.

Inspecting coverings must be part of an overall preventive maintenance program. Maintenance involves frequent inspection of the covering for rips, holes, and general wear.

COSTS

Covering costs vary in proportion to the degree of protection desired, and the required life span. The most inexpensive covering is plastic sheeting, but it is not suitable where a high degree of protection is desired for a long period. An enclosed building is the most expensive type of covering when materials for the structure, lighting, and ventilation are considered, but it offers the highest degree of protection for the longest period.

REFERENCES

1. Minnesota Pollution Control Agency, 1989. *Protecting the Water Quality in Urban Areas.*

2. U.S. EPA, 1992. *Summary Guidance: Storm Water Management for Industrial Activities: Developing Pollution Prevention Plans and Best Management Practice.* EPA 833-R92-002, U.S. EPA, Washington, DC.

3. Washington State Department of Ecology, 1992. *Storm Water Management Manual for Puget Sound.*

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United States Environmental Protection Agency | Office of Water Washington, D.C. | 832-F-99-005 September 1999

Storm Water Management Fact Sheet
Record Keeping

DESCRIPTION

Keeping records of spills, leaks, and other discharges can help a facility run more efficiently and cleanly. Records of past spills contain useful information for improving Best Management Practices (BMPs) to prevent future spills. Typical items that should be recorded include the results of routine inspections, and reported spills, leaks, or other discharges.

Records should include:

- The date, exact place, and time of material inventories, site inspections, sampling observations, etc.
- Names of inspector(s) and sampler(s).
- Analytical information, including the date(s) and time(s) analyses were performed or initiated, the analysts' names, analytical techniques or methods used, analytical results, and quality assurance/quality control results of such analyses.
- The date, time, exact location, and a complete characterization of significant observations, including spills or leaks.
- Notes indicating the reasons for any exceptions to standard record keeping procedures.
- All calibration and maintenance records of instruments used in storm water monitoring.
- All original strip chart recordings for continuous monitoring equipment.
- Records of any non storm water discharges.

Figure 1 shows a sample worksheet for tracking spills and leaks.

Record keeping is usually coordinated with internal reporting and other BMPs, and is often integrated into the development of a facility's Storm Water Pollution Prevention Plan (SWPPP) as part of the facility's NPDES storm water discharge permit.

APPLICABILITY

Records keeping is a basic business practice and is applicable to all facilities. If a separate record keeping system for tracking BMPs, monitoring results, etc., is not currently in place at a facility, existing record keeping structures can be easily adapted to incorporate this data. An ideal tool for implementation is the record keeping procedures laid out in an SWPPP.

ADVANTAGES AND DISADVANTAGES

Record keeping is a simple, easily implemented, and cost effective management tool. Complete, well-organized records can help ensure proper maintenance of facilities and equipment and can aid in determining the causes of spills and leaks; thus, record keeping can protect water quality by helping to prevent future leaks and spills.

Limitations of a record keeping system may including the following:

- Records must be updated regularly.
- Personnel completing and maintaining records must be trained to update records correctly.
- The records need to be readily accessible.
- Records containing any confidential information must be secured.

IMPLEMENTATION

The key to maintaining records is continual updating. Ensure that new information, such as analytical results, is added to existing inspection records or spill reports as it becomes available. In addition, update records if there are changes to the number and location of discharge points, principal products, or raw material storage procedures. Maintain records for least five years from the date of sample observation, measurement, or spill report. Some simple techniques used to accurately document and report results include:

- Field notebooks.
- Timed and dated photographs.
- Videotapes.
- Drawings and maps.
- Computer spreadsheets and database programs.

COSTS

Costs are those associated with staff hours used to develop and implement a record keeping system, costs for analyzing samples, and company overhead costs. Figure 2 is a sample worksheet that can be used to determine annual record keeping costs. Table 1 is an example of a completed record keeping costs sheet.

REFERENCES

1. California Environmental Protection Agency, August 17, 1992. Staff Proposal for Modification to Water Quality Order No. 91-13 DWQ Waste Discharge Requirements for Dischargers of Storm Water Associated with Industrial Activities, Draft Wording, Monitoring Program and Reporting Requirements.

2. U.S. EPA, 1981. *NPDES BMP Guidance Document*.

3. U.S. EPA, Pre-print, 1992. *Storm Water Management for Industrial Activities: Developing Pollution Prevention Plans and Best Management Practices*. EPA 832-R-92-006.

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LIST OF SIGNIFICANT SPILLS AND LEAKS	Worksheet Completed by: ____________ Title: ____________ Date: ____________

Directions: Record below all significant spills and significant leaks of toxic or hazardous pollutant that have occurred at the facility in the three years prior to the effective date of the permit.

Definitions: Significant spills include, but are not limited to, releases of oil or hazardous substances in excess of reportable quantities.

1st Year Prior										
				Description				Response Procedure		
Date (mo/day/yr)	Spill	Leak	Location (as indicated on site map)	Type of Material	Quantity	Source, If Known	Reason	Amount of Material Recovered	Material No Longer Exposed to Storm Water (True / False)	Preventive Measure Taken

2nd Year Prior										
				Description				Response Procedure		
Date (mo/day/yr)	Spill	Leak	Location (as indicated on site map)	Type of Material	Quantity	Source, If Known	Reason	Amount of Material Recovered	Material No Longer Exposed to Storm Water (True / False)	Preventive Measure Taken

3rd Year Prior										
				Description				Response Procedure		
Date (mo/day/yr)	Spill	Leak	Location (as indicated on site map)	Type of Material	Quantity	Source, If Known	Reason	Amount of Material Recovered	Material No Longer Exposed to Storm Water (True / False)	Preventive Measure Taken

Source: U.S. EPA, 1992.

FIGURE 1 SAMPLE WORKS… ET FOR TRACKING SPILLS AND LEAKS

Title	Quantity		Average Hourly Rate ($)		Overhead Multiplier		Estimated Yearly Hours on SW Training		Estimated Annual Cost($)
______	______	x	______	x	______	x	______	=	______ (A)
______	______	x	______	x	______	x	______	=	______ (B)
______	______	x	______	x	______	x	______	=	______ (C)
______	______	x	______	x	______	x	______	=	______ (D)

Total Estimated Annual Reporting Cost ______

(Sum of A+B+C+D)

Source: U.S. EPA, 1992.

FIGURE 2 SAMPLE ANNUAL RECORD KEEPING COST WORKSHEET

TABLE 1 EXAMPLE OF ANNUAL RECORD KEEPING COSTS

Title	Quantity		Average Hourly Rate ($)		Overhead* Multiplier		Estimated Yearly Hours on SW Training		Estimated Annual Cost ($)
Storm Water Engineer	1	x	15	x	2.0	x	20	=	600
Plant Management	5	x	20	x	2.0	x	10	=	2,000
Plant Employees	100	x	10	x	2.0	x	5	=	10,000
							Total Estimated Annual Cost:		$12,600

*Note: Defined as a multiplier (typically ranging between 1 and 3) that takes into account those costs associated with payroll expenses, etc

Source: U.S. EPA, 1992.

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United States Environmental Protection Agency
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832-F-99-004
September 1999

Storm Water O&M Fact Sheet
Preventive Maintenance

DESCRIPTION

Preventive maintenance involves the regular inspection, testing, and replacement or repair of equipment and operational systems. As a storm water best management practice (BMP), preventive maintenance should be used to monitor systems built to control storm water. These systems should be inspected to uncover cracks, leaks, and other conditions that could cause breakdowns or failures of storm water mitigation structures and equipment, which, in turn, could result in discharges of chemicals to surface waters either by direct overland flow or through storm drainage systems. A preventive maintenance program can prevent breakdowns and failures through adjustment, repair, or replacement of equipment before a major breakdown or failure occurs.

Typically, a preventive maintenance program should include inspections of catch basins, storm water detention areas, and water quality treatment systems. Without adequate maintenance, sediment and debris can quickly clog storm drainage facilities and render them useless.

APPLICABILITY

Preventive maintenance procedures and activities are applicable to almost all industrial facilities. This concept should be a part of a general good housekeeping program designed to maintain a clean and orderly work environment. Often the most effective first step towards preventing storm water pollution from industrial sites is to improve the facility's preventive maintenance and general good housekeeping methods.

For many facilities, preventive maintenance to protect water quality is simply an extension of current plant preventive maintenance programs. Most plants already have preventive maintenance programs that provide some degree of environmental protection. Such programs could be expanded to include storm water considerations.

ADVANTAGES AND DISADVANTAGES

Preventive maintenance takes a proactive approach to storm water management and seeks to prevent problems before they occur. A preventive maintenance program can improve water quality by controlling pollutant discharges to surface water that would result from spills and leaks. Preventive maintenance programs can also save a facility money by reducing the likelihood of having a system breakdown and also by reducing the likelihood of funding costly cleanup projects. In addition, a preventive maintenance program can be an effective community relations tool.

The primary limitations of implementing a preventive maintenance program include:

- Cost.
- Availability of trained preventive maintenance staff technicians.
- Management direction and staff motivation in expanding the preventive maintenance program to include storm water considerations.

KEY PROGRAM COMPONENTS

Elements of a good preventive maintenance program should include the following:

- Identification of equipment or systems that may malfunction and cause spills or leaks, or may otherwise contaminate storm water runoff. Typical equipment to be inspected inspected includes pipes, pumps, storage tanks and bins, pressure vessels, pressure release valves, process and material handling equipment, and storm water management devices.
- Establishment of schedules and procedures for routine inspections.
- Periodic testing of plant equipment for structural soundness.
- Prompt repair or replacement of defective equipment found during inspection and testing.
- Maintenance of a supply of spare parts for equipment that needs frequent repairs.
- Use of an organized record-keeping system to schedule tests and document inspections.
- Commitment to ensure that records are complete and detailed, and that they record test results and follow-up actions. Preventive maintenance inspection records should be kept with other visual inspection records.

IMPLEMENTATION

The key to properly implementing and tracking a preventive maintenance program is through the continual updating of maintenance records. Update records immediately after performing preventive maintenance or repairing an item and review them annually to evaluate the overall effectiveness of the program. Then refine the preventive maintenance procedures as necessary.

No quantitative data on the effectiveness of preventive maintenance as a BMP is available. However, it is intuitively clear that an effective preventive maintenance program will result in improved storm water discharge quality.

COSTS

The major cost of implementing a preventive maintenance program on storm water quality is the staff time required to administer the program. Typically, this is a small incremental increase if a preventive maintenance program already exists at the facility.

REFERENCES

1. U.S. EPA, June, 1981. *NPDES Best Management Practice Guidance Document.*

2. U.S. EPA, Pre-print, July 1992. *Storm Water Management for Industrial Activities: Developing Pollution Prevention Plans and Best Management Practices.* EPA 832-R-92-006.

3. Washington State Department of Ecology, February 1992. *Storm Water Management Manual for Puget Sound.*

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Storm Water Program

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A Wet Pond as a Storm Water Runoff BMP—Case Study

Presented at:

Department of Environmental Resources Engineering, Humboldt State University, Arcata, California, 1999.

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A Wet Pond as a Storm Water Runoff BMP – Case Study

Scott M. Taylor[1]
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ABSTRACT

The California Department of Transportation (Caltrans) has initiated a five-year study in San Diego to examine the benefits, technical feasibility, costs, and operation and maintenance requirements of using a wet pond to treat storm water runoff from an existing freeway. The purpose of this program is to study the opportunities and constraints, relative to siting, design, construction, operation and maintenance, associated with retrofitting highways with this type of stormwater Best Management Practice (BMP) and to evaluate the efficiency of the device for removing pollutants of concern. Automated monitoring stations have been installed at the site upstream and downstream of the BMP. Constituents monitored in the runoff include: suspended solids (e.g., sediment), metals, nutrients, and organics (e.g., gasoline). Vectors (i.e., mosquitoes), vegetation, and protected and endangered species are also being monitored. A comprehensive operation and maintenance program is in place to ensure the BMP operates at peak performance. Construction and maintenance costs are being documented. Over the past three years, the project has been sited, designed, constructed and monitored (for the first year). Even though pollution-removal data are not yet available, Caltrans' experience indicates that there are substantial challenges in retrofitting wet pond BMP technology into transportation infrastructure.

INTRODUCTION

A wet pond is being tested as part of the Caltrans Best Management Practice (BMP) Retrofit Pilot Studies, which is also testing 11 other types of structural BMPs (i.e., treatment devices) at 38 different installations. The pond is located in the southeast corner of the intersection of La Costa Ave. and I-5 in San Diego County. It is currently in its first year of operation. Five aspects of this wet pond case study are discussed here -- siting, design, construction, operations and maintenance, and efficiency evaluation. Constraints, problems, and solutions of the siting, design, and construction are presented along with the and the study design for the operation, maintenance, and efficiency evaluations.

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The wet pond has a permanent pool of water that is fed by a nearby urban dry-weather flow. The pond is designed with additional storage capacity to capture storm water runoff from the 1 year, 24-hour event, which is diverted to the pond from the nearby freeway. During a rainfall event, storm water flows into the pond, where it inundates the surrounding vegetation. Vegetation in and around the basin provide for enhanced solids removal. The vegetation also provides a structure for an active microbial community that is expected to improve the uptake of dissolved pollutants. The co-mingled water is discharged until the water level returns to the level of the permanent pool. The permanent pool is divided into two sections by a gabion wall. The forebay is to concentrate sediment capture in one area for ease of maintenance, and allows less intrusive maintenance for the main pool. An impermeable lining is buried at below the invert of the wet pond to maintain the permanent pool of water and circulation by minimizing infiltration losses. An emergency spillway is incorporated into the design for high flow conditions.

PROJECT SITING

The site selection process began with a reconnaissance of Caltrans highways and freeways in San Diego County. Site evaluations included an initial feasibility investigation, followed by a more detailed site investigation.

A feasibility investigation was performed to determine the locations of surplus areas owned by Caltrans along freeway and highway interchanges, and on- and off-ramps. The feasibility investigation started by reviewing topographic maps to ensure that identified sites were located at or near the low point of the associated highway drainage. Candidate sites from the feasibility phase were further investigated to determine available site area, estimated tributary watershed and the availability of a perennial water source for the permanent pool. Adequacy of the site was determined by estimating the required basin surface area (a function of tributary area, 0.5 percent was used), including safety setback limits required by Caltrans. If these criteria were satisfied, further site investigation was completed, such as reviews of geotechnical conditions and Caltrans grading and drainage plans. Safety concerns dictated several siting criteria, including the reservation of a 9.1 m (30-foot) clear recovery zone (for motorist safety) around the perimeter of the basin. In addition, the basin must be protected by guardrail behind the edge of shoulder.

Finally, the site information was evaluated using a weighted decision matrix. Each site was evaluated and compared with respect to several different criteria. The criteria were weighted according to their importance and relevance to the site selection process. The most important criteria were:

- Sufficient area (without substantial improvement);
- location away from building foundations and highway pavement;
- proximity to receiving waters;
- ease of maintenance access;
- availability of a perennial water source.

Each site scored 1 to 10 with respect to each criterion. The site's total score was the sum of the individual scores, multiplied by the weighting factors associated with that criterion.

BMP DESIGN

The design storm used for the wet pond is the estimated 1-year, 24-hour storm event. At the La Costa Ave. site in San Diego, this rainfall is calculated to be 3.40 cm (1.34 in.). The computed time of concentration for the site is 22.3 minutes for the 1.7 ha (4.2 acre) tributary watershed.

The basin side slope ratio varies between 1:3 and 1:6. The design residence time is 24-hours for the 1-year storm frequency. The average permanent pool depth is 0.7 m (2.3 feet). The water quality pool depth is 0.19 m (0.63 feet) with a volume of 777 m^3 (0.63 acre-feet).

The ratio for permanent pool to the water quality capture volume is 3:1 per the following relationship (Young, 1996):

$$V_{PP} = 3 \times (V_{WQ})$$

where: V_{PP} = permanent pool volume
V_{WQ} = 1-yr, 24-hr water quality capture volume

The outlet structure controls the discharge rate by way of an orifice to achieve the desired detention time. An overflow weir at the outlet structure is designed to pass larger, but less frequent, discharges. A spillway discharges storm events significantly greater than the 1-yr design volume; however, the basin is designed as an off-line device, thus limiting surcharge flows. Runoff volumes up to the design storm are directed to the basin; discharge volumes in excess of the 1-yr, 24-hr storm bypass the facility through the existing storm drain system.

PROJECT CONSTRUCTION

The construction of the wet pond was awarded to the low bidder, according to an accelerated Caltrans plans, specifications and estimates (PS&E) delivery process. Seven bids were submitted, and the contract was awarded to the second low bidder for an amount of $602,158, 7% under the engineer's estimate of $648,810. (The low bid was withdrawn prior to award.) The entire process from contract advertisement to start of construction took 24 calendar days.

Construction for the site began on April 5, 1999 and was completed 45 working days later on June 25, 1999. During construction, eight Construction Change Orders (CCOs) were issued at a total cost of $50,461. The CCOs were issued for additional traffic handling, the disposal of material cleaned from the adjacent receiving channel, changes to the irrigation system and adjacent highway lighting, construction of a small retaining wall (for the maintenance road), and miscellaneous site modifications.

Vegetation for the wet basin was procured through a separate contract and shipped to the contractor as state-supplied material. The initial planting occurred between June 1 and June 25 in three different zones: 1) permanent pool perimeter, 2) zone of inundation and 3) upland area. The plant materials, which were selected by a wetland biologist, differed somewhat by zone, although species native to southern California were used throughout. Irrigation was used for plant establishment only, and was discontinued about 8 months after planting.

OPERATION AND MAINTENANCE

Operation and maintenance of the wet pond consists of vegetation management for vector control, surveying for sensitive or endangered species, periodic clean up and inspection, and vector monitoring and abatement. Each is discussed below.

Vegetation management is a balance between maintaining a dense plant cover for to enhance sedimentation and maintaining open water to enhance vector abatement. Currently, the vegetation management strategy is to minimize disturbance of the wet pond, while maintaining the efficacy of mosquito fish (*Gambusia*). When the density of plant stalks becomes too great, the fish cannot get to all of the mosquito larvae. Chemical controls also require a certain amount of open water so the chemical can penetrate to the larvae. Plant density is assessed quarterly. As of April 2000, the cattails are dominating the zone of inundation. The cattails are up to 12 feet tall and some are beginning to fall over.

Any maintenance action must be preceded by a bioassessment to determine if any sensitive or endangered species are utilizing the wet pond. Assessments at the wet pond include surveying for migrating birds during the breeding season. Sensitive or endangered species utilizing the wet pond will probably preclude maintenance necessary for vector abatement and for water treatment. Activities, such as sediment and vegetation removal, could be restricted to prevent accidental takings of sensitive species. Access to the site could also be restricted to avoid disturbing nesting birds. As a result, the bioassessments have two goals. The first is two determine the likelihood that a wet pond will attract sensitive species. A treatment device that attracts sensitive species more than a comparable alternative will not be seen as the most desirable storm water treatment technology for other locations. The second goal is to identify protected species so that maintenance crews and the U.S. Fish and Wildlife Service can be notified.

Periodic inspection and clean up include sediment removal, erosion and structural maintenance, and monthly removal of graffiti, trash, debris, and other material that could clog the outlet works. Sediment accumulation is measured monthly. Sediment is removed from the forebay when the depth of accumulated sediment exceeds 5.1 cm (2 inches), and from the main pond when the depth exceeds 10.2 cm (4 inches). Erosion control and structural repairs occur as needed. After storm events the 24-hour drawdown time to the permanent pool elevation is verified, and if the time is exceeded, further maintenance action to restore the design drawdown time is coordinated with the design engineer.

Monitoring and controlling vectors is being conducted by a team consisting of the County of San Diego Department of Public Health, the California Department of Health Services (DHS), and University of California, Riverside, Department of Entomology. San Diego County monitors the wet pond weekly for vector occurrence and treats the pond as needed. To date, the *Gambusia* have been sufficient to control mosquitoes. DHS collects additional information that affects vector production during bi-weekly surveys (weekly during summer months). Information such as water temperature and vegetation type is recorded in a project database. DHS will compare the vector production of the wet basin with the production of the other types of BMPs being studied in the Caltrans Retrofit Pilot Program. U.C. Riverside is conducting weekly adult mosquito surveys at the wet pond, and at a nearby sand filter and infiltration basin being operated as part of the retrofit program. The three sites are far enough apart that the mosquito capture can be compared between the sites. Both gravid (egg-laying) and host-seeking mosquitoes are collected. The results of the study will help determine the relative attractiveness of the wet pond as mosquito habitat.

EFFICIENCY EVALUATION

The efficiency of the wet pond to remove pollutants will be evaluated by comparing the load going into the pond during a storm event to the load leaving the pond. Up to eight storms over two years will be analyzed. The sampling procedures follow the protocols established for Caltrans statewide stormwater monitoring efforts (LWA, 1997). The monitoring program consists of empirical observations, flow-weighted composite samples on the stormwater influent and effluent, and samples of the baseline dry weather flows.

Empirical observations made during monitored storm events are shown in Table 1. In addition, monitoring equipment is thoroughly checked before and during each monitored storm event to ensure successful data collection.

Table 1 Empirical Monitoring Observations

Type of Observation	Items Observed
Meteorological characteristics	Present wind conditions, cloud cover, and rainfall intensity and distribution.
Hydrologic and hydraulic characteristics	Flow condition at influent and effluent, emergency overflows, facility bypass, maximum water depth, and drain time
Influent and effluent water quality appearance	Evidence of erosion, flow restriction, odor, floating material, oil, grease, color, and turbidity

Type of Observation	Items Observed
Solids deposition	Where and what type of solids have accumulated in the wet pond.
Erosion observations	Location, total area affected, and depth of erosion throughout the wet pond.
Vegetation observations	Vegetation coverage and type for the side slopes and invert.
Vector observations	Occurrence of mosquitoes, blackflys, cockroaches, and rats.

Flow-weighted composite samples are collected at the influent and effluent of the wet pond. The parameters being analyzed include certain conventional pollutants (pH, specific conductance, hardness, TSS), nutrients (nitrate-N, TKN, Total-P), total and dissolved metals (copper, lead, zinc), bacteria (fecal coliform), and organics (TRPH-gas, diesel, oil). The dry weather base flow is shut off during storm events. Although the contribution of base flow less than 18.9 liters per minute (5 gpm) and the runoff from a storm event can be over 3,785 liters per minute (1000 gpm) or higher, the baseline flow is shut off to eliminate interference in determining the efficiency of the device as a storm water treatment technology.

Flow-weighted composite samples for the dry weather flow are taken monthly. The data from these samples are used to estimate pollutant concentrations in the wet pond prior to the storm event. This information is expected to be useful in interpreting the pond's performance data. All water quality data collected is reported according to the Caltrans Data Reporting Protocols (1999).

DISCUSSION

Siting a wet pond for treatment of storm water in an arid climate is challenging due to the lack of a perennial water source. Safety is also a special concern because the device incorporates a permanent pool. A setback zone and guardrail are required for highway environments.

Finding sufficient site area for this kind of facility may be difficult. The pond in this project has an area of 0.25 ha (0.62 acres) to serve a tributary area of only 1.7 ha (4.2 acres). Sizing in this case was based on Caltrans' 1-year, 24-hour storm event.

There are several good references offering guidance for designing pond facilities. For sites with a relatively small tributary area, the outlet orifice must be relatively small to achieve the desired residence time. At this site, the outlet orifice is 7.62 cm (3 inches). No clogging problems have arisen to date. A smaller orifice may, however, require more maintenance.

It is imperative to include a plant establishment period in the construction contract to ensure that the plant stock is healthy and has a good survival rate. The plant material for this project required some replacement due to either poor quality of material from the nursery, or improper planting procedures during installation.

Operation and maintenance procedures for a wet pond are greatly affected by vector control needs and the possible occurrence of sensitive or endangered species. Other storm water treatment devices that have similar treatment effectiveness but are less attractive to sensitive species and vectors should be considered as more practicable BMPs. Monitoring of the wet pond will provide the data necessary to compare its water quality performance with the performance of other technologies.

REFERENCES

Caltrans Storm Water Management Program, 1999, *1998-99 Data-Reporting Protocols*, California Department of Transportation, Environmental Program, Sacramento, CA

Larry Walker Associates, 1997, *Guidance Manual: Stormwater Monitoring Protocols*, California Department of Transportation, Environmental Program, Sacramento, CA

Young, G.K., et al., 1996, *Evaluation and Management of Highway Runoff Water Quality*, Publication No. FHWA-PD-96-032, U.S. Department of Transportation, Federal Highway Administration, Office of Environment and Planning.

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Mosquitoes Associated with Stormwater Detention/ Retention Areas[1]

G. F. O'Meara[2]

Water Quality and Supply

Florida's extensive drainage and flood control systems have eliminated many wetland areas that provided suitable aquatic habitats for a variety of mosquito species. However, the diversion of storm water to coastal marine systems via canals has dumped pollutants into our estuarine systems, and it has also greatly diminished the amount of storm water that enters recharge areas for replenishing the aquifer. To alleviate these water quality and supply problems, various types of storm water detention/retention area are being incorporated into all new commercial and residential developments. Some established developments have also been retrofitted with storm water retention or detention systems. The widespread use of these storm water systems may lead to increased mosquito production, unless adequate precautions are taken.

Storm Water Detention and Retention Systems

Most storm water detention ponds are semi-permanent aquatic systems that dry out only under drought conditions. Often, during the rainy season the water levels in these ponds remain at or near the outflow structures. Under these conditions, storm water entering a detention area displaces an equivalent amount of water that usually overflows to an adjacent man-made or natural drainage system. The detention pond acts as a sink or trap where pollutants picked up by the initial surge of storm water settle out before leaving the detention pond. These ponds are usually referred to as "wet-detention systems."

By contrast, retention areas are designed to hold storm water until the effects of percolation and evapotranspiration return the area to its normal dry state. Regulations concerning the design and construction of retention areas stipulate that storm water inflow must be dissipated within 72 hours so that a new volume can be accommodated. Since these storm water areas are designed to dry out rapidly, they are usually called "dry-retention systems."

Mosquito Production

Detention ponds for holding storm water runoffs usually do not produce mosquitoes in sufficient numbers to cause a problem. Exceptions may occur when ponds become nearly dry due to a lack of rainfall. Under these conditions wastewater *Culex* may invade the system. A similar type of invasion can occur in detention ponds that receive both storm and wastewater. Wide fluctuations in water levels, especially when they are frequent events, may make the detention system a suitable habitat for floodwater mosquitoes, such as *Aedes vexans* and *Psorophora columbiae*. Floating and

1. This document is ENY-627, one of a series of the Entomology and Nematology Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Publication date: March 1993. Revised: September 1997. Please visit the FAIRS Web site at **http://hammock.ifas.ufl.edu.**
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rooted aquatic plants may foster the growth of populations of *Mansonia dyari*, *M. titillans* and *Coquillettidia perturbans*.

Although storm water entering retention systems is supposed to percolate into the ground within 72 hours, retention areas often remain wet for longer periods. Floodwater mosquitoes are normally the first to appear in retention areas. Later in the rainy season, it is not uncommon to find *Culex*, especially if grass cuttings have been accumulating in these areas. Overall, abundant populations of pest and disease-vectoring mosquitoes are much more frequently associated with retention systems than they are with detention systems. Moreover, it is much easier to achieve long-term mosquito abatement in detention ponds than it is in retention areas. Retention systems tend to be more effective for recharging the aquifer and for improving water quality than are detention systems. Therefore, water management experts often recommend the installation of retention systems for new developments. The use of detention with filtration is generally not recommended because it is often difficult to properly design, construct and maintain such a system.

Mosquito Control Considerations

Local mosquito control programs should be actively involved in the planning and approval stages for all new storm water management schemes. Try to avoid the placement of retention systems in areas where they are likely to remain wet for a period long enough for mosquito development. If retention areas must be placed at these sites, then a dual retention/ detention system might be the best approach for both storm water management and mosquito abatement. With proper design and construction, excess water in the retention part of the system can be sent to the detention pond, thus lessening the chances for mosquito production.

Detention ponds should receive only storm water. Treated wastewater from package plants should be placed in separate holding ponds. Banks on detention ponds should be steep, but not too steep to hinder mowing and other maintenance activities. Deeper ponds are preferable to shallow ones. Inlets and outlets should be constructed so that there are erosion protectors. Adequate vegetation should be maintained on the banks to prevent erosion.

Growth of aquatic vegetation should be restricted to the periphery of detention ponds. Property owners should be responsible for weed control in their ponds. City or county governments should have ordinances that require owners of detention ponds to follow proper maintenance procedures. The presence of a mechanical aerator, such as a fountain in the middle of the pond, often makes the site more attractive, deters the growth of unwanted vegetation, and makes the habitat more suitable for fish.

The bottoms of retention areas should be free of depressions where water might accumulate and remain for periods sufficient to allow mosquito production. Mowing and other maintenance operations should be done without producing ruts. Grass cutting and other types of debris should be removed from retention areas. Long-term responsibilities for proper maintenance of retention areas should be clearly stipulated in city or county ordinances.

Once a retention system has been installed at an inappropriate location (e.g. on a site where the water table is too close to the surface), not much can be done to change the situation without eliminating the system. Under these conditions, mosquitoes must be controlled with larvicides. For a larvicide operation to be effective, it must be supported with a quality inspection program. The widespread occurrence of potential mosquito breeding sites in retention areas greatly increases the costs and man-power needs of inspection programs. Perhaps, through educational programs directed at the general public, we could generate more service request for the control of mosquito larvae and fewer for adult mosquito control.

Wet Detention Basin
(No.)
Code 1001

Wisconsin Department of Natural Resources
Conservation Practice Standard

I. Definition

A permanent pool of water with designed dimensions, inlets, outlets and storage capacity, constructed to collect, detain, treat and release stormwater runoff.

II. Purposes - Primary reasons for which the practice is applied. Each purpose identifies a resource problem the practice can be specifically designed to treat.

The primary purposes of this practice are to control water pollution and peak flow.

III. Conditions Where Practice Applies - Land uses and site conditions that affect the suitability or function of the practice.

This practice applies to urban, construction, and agricultural sites where runoff pollution due to suspended solids loading and attached pollutants is a concern. It also applies where increased runoff from urbanization or land use change is a concern. Site conditions must allow for runoff to be directed into the basin and a permanent pool of water to be maintained.
This practice does not apply to wetland restorations, animal lot runoff control, infiltration basins, or dry detention basins. It also does not apply to sites with high concentrations of toxic materials, or other regulated materials contained in the runoff.
This practice may not apply to all flood control, floodplain management and other flooding issues. Modifications to the peak flow criteria or additional analysis of the potential flooding issues may be needed.

IV. Federal, State and Local Laws

The design, construction, and maintenance of wet detention basins shall comply with all federal, state and local laws, rules or regulations. The owner/operator is responsible for securing required permits. This standard does not contain the text of any federal, state or local laws governing wet detention basins.

The location and use of wet detention basins may be limited by regulations relating to navigable waters (Ch. 30, Stats.), floodplains, wetlands, buildings, wells and other structures, or land uses, such as waste disposal sites and airports. The basin embankment may also be regulated as a dam under Ch. 31 Stats. and further restricted under NR 333, Wis. Adm. Code which includes regulations for embankment heights and storage capacities.

V. Criteria - Allowable limits for design parameters, acceptable installation processes, or performance requirements to accomplish one or more identified purposes.

A. General The following minimum criteria shall apply to all wet detention basin designs used for the purposes stated in section II of this standard. Use more restrictive criteria as needed to fit the conditions found in the site assessment.

1. **Site Assessment** - A site assessment shall be conducted and documented to determine the physical site characteristics that will affect the placement, design, construction, and maintenance of the basin. The site assessment shall identify characteristics such as ground slopes, soil types, soil conditions, *bedrock*[1], sinkholes, drainage patterns, runoff constituents, proximity to regulated structures, natural resources, and specific land uses. The site assessment shall include the following:

   a. A 2 foot contour map drawn to scale showing location and elevations for the basin area, soil borings and test pits, buildings and other structures, property lines, wells, wetlands, 100 yr.

[1] Words in the standard that are shown in italics are described in IX. Definitions. The words are italicized the first time they are used in the text.

floodplains, surface drains, navigable streams, known drain tile, roads and overhead or buried utilities.

b. Soil logging of the site shall be to a depth at least 3 ft. below the proposed design bottom of the basin and include information on the texture, color, odor, structure, water table indicators, and distance to and type of bedrock, if encountered.

2. **Water Pollution Control** - A minimum of 80% of the total suspended solids load shall be removed from the runoff volume generated by the drainage area on an average annual basis. The following criteria meet this requirement:

a. **Permanent Pool** - All basins shall be designed to include a permanent pool of water consisting of a sediment forebay and main pool. (See fig. 1 and fig. 2)

(1) The minimum surface area of the permanent pool shall be based on the total drainage area to the basin or it shall be 10,000 sq. ft., whichever is greater. Table 1 or an *approved model* shall be used. Values shall be prorated for mixed land uses.

(2) A sediment forebay shall be located at the inlet to trap large particles such as road sand. The storage volume of the sediment forebay shall be consistent with the maintenance plan, with a goal of 5-15% of the permanent pool surface area. The sediment forebay shall be a minimum depth of 3 ft. plus the depth for sediment storage.

(3) The length to width ratio of the flow path shall be maximized with a goal of 3:1 or greater. The flow path is considered the general direction of water flow within the basin including the permanent pool and forebay.

(4) A safety shelf shall extend a minimum of 8 ft. from the edge of the permanent pool, with a slope of 10h:1v or flatter. The maximum depth of water over the shelf shall be 1.5 ft.

(5) Excluding the safety shelf and sediment storage, the average water depth of the permanent pool shall be a minimum of 3 ft.

(6) A minimum of 2 ft. shall be added for sediment storage.

(7) For basins greater than 20,000 sq. ft., 50% of the total surface area of the permanent pool shall be a minimum of 5 ft. deep. For basins less than 20,000 sq. ft., maximize the area of 5 ft. depth.

(8) All side slopes below the safety shelf shall be 2h:1v or flatter as required to maintain soil stability.

Table 1 - Calculation of Minimum Permanent Pool Surface Area.[1]

Land Use/Description/Management[2]	Total Impervious (%)[3]	Minimum Surface Area of the Permanent Pool (% of Watershed Area)	
Residential			
• < 2.0 units/acre (>1/2 acre lots)	8 - 28	0.7	
• 2.0 - 6.0 units/acre	>28 -41	0.8	
• > 6.0 units/acre (high density)	>41 - 68	1.0	
Office Park/Institutional/Warehouse[4]			
(Non-retail related business, multi-storied buildings,	<60	1.6	
usually more lawn/landscaping not heavily traveled, no	60-80	1.8	
outdoor storage/manufacturing	>80	2.0	
Commercial/Manufacturing/Storage[5]			
(Large heavily used outdoor parking areas, material	<60	1.8	
storage or manufacturing operations)	60-80	2.1	
	>80	2.4	
Parks/Open Space/Woodland/Cemeteries	0-12	0.6	
Highways/Freeways			
(Includes right-of-way area)			
• Typically grass banks/conveyance	<60	1.4	
• Mixture of grass and curb/gutter	60-90	2.1	
• Typically curb/gutter conveyance	>90	2.8	
Cropland (Cropland that is draining to the basin)			
Dominant Surface Soil Texture[6]		Erosion < *Tolerable*	Erosion > Tolerable
- S, LS		0.6	0.9
- SC, SCL, SL, L, SiL, Si		1.6	2.4
- C, CL, SiCL, SiC		2.0	3.0

[1] Multiply the value listed by the watershed area within the category to determine the minimum pond surface area. Prorate for drainage areas with multiple categories due to different land use, management, percent impervious, soil texture, or erosion rates. For example, a 50 acre (residential, 50% imperviousness) x 0.01 (1% of watershed from table) = 0.5 acre + 50 acres (office park, 85% imperviousness) x 0.02 (2% of watershed) = 1.0 acre. Therefore 0.5 acre + 1.0 acre = 1.5 acres for the minimum surface area of the permanent pool.

[2] For offsite areas draining to the proposed land use, refer to local municipalities for planned land use and possible institutional arrangements as a regional stormwater plan.

[3] Impervious surfaces include rooftops, parking lots, roads, and similar hard surfaces, including gravel driveways/parking areas. Roofs are assumed to be pitched and half connected (or draining directly) to the storm sewer system. The other half is assumed to drain onto a vegetated area. Paved parking and storage areas are assumed to be all connected. Sidewalks and driveways are only half connected.

[4] Category includes insurance offices, government buildings, company headquarters, schools, hospitals, and churches.

[5] Category includes shopping centers, strip malls, power plants, steel mills, cement plants, lumber yards, auto salvage yards, grain elevators, oil tank farms, coal and salt storage areas, slaughter houses, and other outdoor storage or parking areas.

[6] S=Sand, Si=Silt, C=Clay, L=Loam (USDA Textural Soil Classification System)

b. **Extended Detention Volume** - Volume above permanent pool that is released slowly. (see fig. 1 and 2)

(1) Extended detention volume shall be the runoff volume produced by a 1-yr., 24-hr. design storm or as computed by an approved model. The 1-yr., 24-hr rainfall data for Wisconsin is shown in Table 4. The relationship of runoff to precipitation is shown in Table 5. For curve number determination see Chapter 2, Natural Resources Conservation Service, Technical Release 55 (TR-55). Use the post development curve number.

(2) Outlet design shall allow for the release of the extended detention volume over a period of 24 hr. or greater.

3. **Peak Flow Control** - Peak flow control shall be designed to maintain stable downstream conveyance systems and comply with local ordinances or conform with regional stormwater plans where they are more restrictive than this standard. At a minimum:

a. Outflow shall not exceed pre-development peak flows for both the 2-yr. and 10-yr., 24-hr design storms.

b. All runoff and flow calculations required for peak flow design of this practice shall use a hydrograph-producing method such as TR-55.

c. When pre-development land cover is cropland, use the runoff curve numbers in Table 2. For all other pre-development land covers, use runoff curve numbers from TR - 55 assuming "good hydrologic conditions." For post-development calculations use runoff curve numbers based on actual conditions.

Table 2 - Maximum Pre-Development Runoff Curve Numbers for Cropland Areas

Hydrologic Soil Group	A	B	C	D
Runoff Curve Number	55	68	77	80

4. **Inflow Points** – All inlets shall be designed to prevent erosion during peak flows produced by the 10-yr., 24-hr. design storm. Any rock rip-rap or other channel liners shall extend a minimum of 1.5 vertical ft. below the permanent pool elevation.

5. **Outlets** –All outlet designs shall incorporate preventive measures for ice damage, trash accumulation, and erosion at the outfall.

6. **Emergency Spillway** – All basins shall have an emergency spillway. The spillway shall be designed to safely pass peak flows produced by a 100-yr., 24-hour design storm routed through the basin without damage to the structure. The flow routing calculations shall start at the permanent pool elevation.

7. **Freeboard** – The basin design shall ensure the top of embankment, after settling, is a minimum of 1 vertical foot above the flow depth in the emergency spillway required to safely pass the routed 100-yr., 24-hr. storm.

8. **Side Slopes** – All interior side slopes above the safety shelf shall be 4h:1v or flatter.

9. **Bedrock** – If bedrock is encountered within 2 ft. of the bottom of the pond, special precautions shall be taken, as needed, to minimize movement of pollutants to groundwater.

10. **Earthen Embankments** - Earthen embankments (see fig. 2) shall be designed to address potential risk and structural integrity issues such as seepage and saturation. All constructed earthen embankments shall meet the following criteria.

a. The base of the embankment shall be stripped of all vegetation, stumps, topsoil and other matter. Stripping shall be a minimum of 6 in.

b. For embankments where the permanent pool is ponded 3 ft. or more against the embankment, there shall be a core trench or key-way along the centerline of the embankment up to the permanent pool elevation. The core trench or key-way shall be a minimum of 2 ft. deep and 8 ft. wide with a side slope of 1:1 or flatter.

c. All embankments shall be constructed with non-organic soils and compacted to 90% standard proctor according to the procedures outlined in ASTM D-698 or by using compaction requirements of USDA Natural Resource Conservation Service, Wisconsin Construction Specification 3. No tree stumps, or other organic material shall be buried in the embankment. The constructed embankment height shall be increased by a minimum of 5% to account for settling.

d. Any pipes extending through the embankment shall be bedded and backfilled with embankment or equivalent soils. The bedding and backfill shall be compacted in lifts and to the same standard as the original embankment. Excavation through a completed embankment shall have a minimum side slope of 1:1 or flatter.
e. Measures shall be taken to minimize seepage along any conduit buried in the embankment. Measures such as anti-seep collars or sand diaphragms are acceptable.
f. Downstream side slopes shall be 3h:1v or flatter.
g. Minimum embankment top width shall be 10 ft.

11. **Topsoil and Seeding** - Topsoil shall be spread on all disturbed areas, except for elevations below the safety shelf, as areas are completed. Minimum depth of topsoil spread shall be 4 in. Seed all areas above safety shelf.
12. **Operation and Maintenance** - An operation and maintenance plan shall be developed that is consistent with the purposes of this practice, its intended life, safety requirements and the criteria for its design.

    The plan shall address the responsible party for operation, maintenance, and documentation of the plan. At a minimum, the plan shall also include details on inspecting sediment depths, frequency of sediment removal, disposal locations for sediment, inlet and outlet maintenance, keeping embankments clear of woody vegetation, and providing access to perform the operation and maintenance activities.

B. Construction Site. A wet detention basin, designed to meet the minimum criteria in section V. A. will also meet the criteria for construction sites if the following criteria are followed.

1. The minimum permanent pool area shall be the larger of 1.5% of the disturbed area, or the permanent pool size as specified in Table 1.
2. If a minimum of 2 vertical feet of sediment storage is not available after construction and site stabilization, all excess sediment must be removed and disposed in accordance with the operation and maintenance plan. After the site is stabilized, the minimum permanent pool depth must meet the requirements of V. A. 2. a.

C. Agricultural. A wet detention basin, designed to meet the minimum criteria in V. A. will also meet the criteria for the control of pollution from agricultural watersheds if the following additional criteria and exceptions are followed.

1. A permanently vegetated buffer extending a minimum of 75 ft. beyond the designed permanent pool elevation is required around the entire basin.
2. The peak outflow for the 10-yr., 24-hr. design storm shall not exceed the peak inflow for the 2-yr., 24-hr. design storm.
3. If the permanent pool is ponded 3 ft. or more against the basin embankment, the embankment and spillway design shall meet the criteria in Engineering Standard 378 - Pond, NRCS Field Office Technical Guide (FOTG) Section IV.
4. The sediment forebay (V. A. 2. a. (2)) is not required.
5. Livestock shall be excluded from the pool, embankment, outlet, and buffer areas.

VI. Considerations.

Additional recommendations relating to design which may enhance the use of, or avoid problems with, this practice.

A. **General.** Consider the following items for all applications of this standard:

1. Additional conservation practices should be considered if the receiving water body is sensitive to temperature fluctuations, oxygen depletion, excess toxins or nutrients.
2. Consider providing additional length to the safety shelf, above or below the wet pool elevation, to enhance safety.
3. The use of liners should be evaluated for maintaining permanent pool levels and reducing potential groundwater contamination.
4. To prevent damage or failure due to ice, all risers extending above the pond surface should be incorporated into the basin embankment.
5. The use of underwater outlets should be considered to minimize ice damage, accumulation of floating trash or vortex control.

6. When designing basins in series (along same flow path), consider the impacts on sediment removal efficiency, flow routing, and safety.
7. Minimum watershed size and land cover should be considered to ensure adequate runoff volumes to maintain a permanent pool. For supplementing low runoff periods, consider the installation of a well to maintain the permanent pool level.
8. Aesthetics of the pond should be considered in designing the shape and specifying landscape practices.
9. If downstream flood management or bank erosion is a concern, a watershed study should be conducted to determine the most appropriate location and design of stormwater management structures.
10. For elongated pools in the direction of prevailing winds, consider reinforcing banks, extending the safety shelf, or other measures to prevent erosion of embankment due to wave action.
11. Consider the potential impacts on downstream channels, farming practices, or other land uses if the wet detention basin may create or alter base flows.
12. To prevent failure, earthen emergency spillways should not be constructed over fill material.
13. All flow channels draining to the basin should be stable to minimize sediment delivery to the basin.
14. The use of baffles may be used to artificially lengthen the flow path in the basin.
15. Consider aerators to maintain aerobic conditions.

B. **Urban Applications.** Consider the following items when applying this standard to urban areas:

1. Consider including volume reduction practices in the design to reduce the potential downstream impacts of larger runoff volumes with increased development.
2. Consider using flow splitters before the basin inlet to provide treatment of the first flush from urban areas.
3. Consider safety issues such as signage, flotation devices and special landscaping to deter entry by people.
4. Consider the effects of construction site compaction and the use of deep tilling to increase soil infiltration. Consider raising the hydrologic soil group used in calculating post-development runoff to calculate a more representative runoff volume due to compaction.
5. Consider vegetative buffer strips along drainage ways leading to the detention basin to help filter pollutants in urban runoff.

C. **Construction Site Applications.** Consider the following items when applying this standard to construction sites:

1. Consider providing extra sediment storage depth for structures that will serve as permanent stormwater management practices. This could eliminate the need for sediment removal after site stabilization.
2. The entire drainage area, and all of the basin side slopes, should be thoroughly stabilized with a vegetative cover prior to conversion to a permanent pond.
3. Consider construction sequencing to minimize the amount of land opening during construction.

D. **Agricultural Applications.** Consider the following items when applying this standard to an agricultural setting:

1. Consider installing a sediment forebay to minimize maintenance needs for the entire basin, especially if coarse surface soils are present in the watershed.
2. Consider vegetative buffer strips between cropland and drainage ways leading to the detention basin to help filter agricultural pollutants. See Standard 393 - Riparian Vegetative Buffer, NRCS FOTG Section IV.
3. To enhance use by wildlife, consider enlarging the pond surface area, flattening slopes below the water surface, creating irregular edges and planting native species in and around the pond. See Chapter 11 - Ponds and Reservoirs, NRCS Engineering Field Manual.

4. Consider using the basin as an outfall for subsurface drains from upstream agricultural lands.
5. All concentrated flow channels entering the basin from drainage areas as large or larger than those listed in the middle column of Table 3 should be vegetated adequately to carry the 10 yr. storm. See Standard 412 - Grassed Waterway, NRCS FOTG Section IV and to Chapter 7 - Grassed Waterways, USDA-NRCS Engineering Field Manual.
6. All concentrated flow channels entering the basin from drainage areas in the range shown in the right hand column of Table 3 should be vegetated 200 ft. up the channel from the permanent pool. Vegetation should be adequate to carry the 10 yr. storm.
7. Consider measures to minimize sheet and rill erosion in the entire drainage area.

Table 3 - Drainage areas for vegetation of concentrated flow channels

Hydrologic Soil Group	Drainage Area for vegetated channels, ac	Drainage Area for 200 ft. of vegetation up the channels, ac
A	100	20 to 99
A/B	40	15 to 39
B	25	10 to 24
B/C	15	7 to 14
C, D	10	5 to 9

E. **Operation and Maintenance Considerations for All Applications** -The maintenance plan should address weed or algae growth and removal, insect and wildlife control and any landscaping practices. Outlet designs should consider having the ability to dewater the pond to ease future maintenance. To prevent nuisance from geese, consider not mowing around the pond perimeter. To maximize safety and pollutant removal, allow plant growth along the safety shelf.

VII. Plans and Specifications

Plans and specifications shall be prepared in accordance with the criteria of this standard and shall describe the requirements for applying the practice to achieve its intended use. Plans shall specify the materials, construction processes, location, size and elevations of all components of the practice to allow for certification of construction upon completion.

VIII. References

Center for Watershed Protection, *Stormwater BMP Design Supplement for Cold Climates*, Draft Review Document, August 1997.

United States Department of Agriculture, Natural Resources Conservation Service, *Ponds – planning, Design, Construction*, Agriculture Handbook 590, Revised September 1997.

United States Department of Agriculture - Natural Resources Conservation Service, *Wisconsin Field Office Technical Guide, Section IV.*

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United States Department of Commerce - Weather Bureau, *Rainfall Frequency Atlas of the United States, Technical Paper 40.*

Wisconsin Department of Natural Resources - Bureau of Water Resources Management, *Wisconsin Construction Site Best Management Practice Handbook*, Publication WP-222 93 REV, April 1994.

Wisconsin Department of Natural Resources - Bureau of Water Resources Management, *The Wisconsin Stormwater Manual Part One: Overview*, Publication WR-349-94.

IX. Definitions

Approved Model(V. A. 2. b. (1), V. A. 2. c. (1)) - A computer model that is used to predict pollutant loads from urban lands and has been approved by the applicable regulatory authorities. SLAMM and P8 are examples of models which may be used to verify that a detention pond design meets the minimum criterion of 80% reduction of suspended solids.

Bedrock (V. A. 1., V. A. 1. b., V. A. 2. a.) - Consolidated rock material and weathered in-place material with > 50%, by volume, larger than 2 mm in size.

Tolerable (Table 1) - The tolerable level ("T") of erosion that could occur without losing long term productivity as farmland. T values are assigned for each soil type and are found in Section 1 of the NRCS FOTG. Erosion rates are estimated using industry standard formulas such as the Revised Universal Soil Loss Equation.

Table 4 - Rainfall for Wisconsin Counties for a 1 - year, 24 - hour Rainfall[1]	
Inches of Rainfall	County
2.1 in.	Door, Florence, Forest, Kewaunee, Marinette, Oconto, Vilas
2.2 in.	Ashland, Bayfield, Brown, Calumet, Douglas, Iron, Langlade, Lincoln, Manitowoc, Menominee, Oneida, Outagamie, Price, Shawano, Sheboygan
2.3 in.	Barron, Burnett, Dodge, Fond du Lac, Green Lake, Marathon, Milwaukee, Ozaukee, Portage, Racine, Rusk, Sawyer, Taylor, Washburn, Washington, Waukesha, Waupaca, Waushara, Winnebago, Wood
2.4 in.	Adams, Chippewa, Clark, Columbia, Dane, Dunn, Eau Claire, Jackson, Jefferson, Juneau, Kenosha, Marquette, Pepin, Pierce, Polk, Rock, St. Croix, Walworth
2.5 in.	Buffalo, Green, Iowa, La Crosse, Monroe, Richland, Sauk, Trempealeau, Vernon
2.6 in.	Crawford, Grant, Lafayette

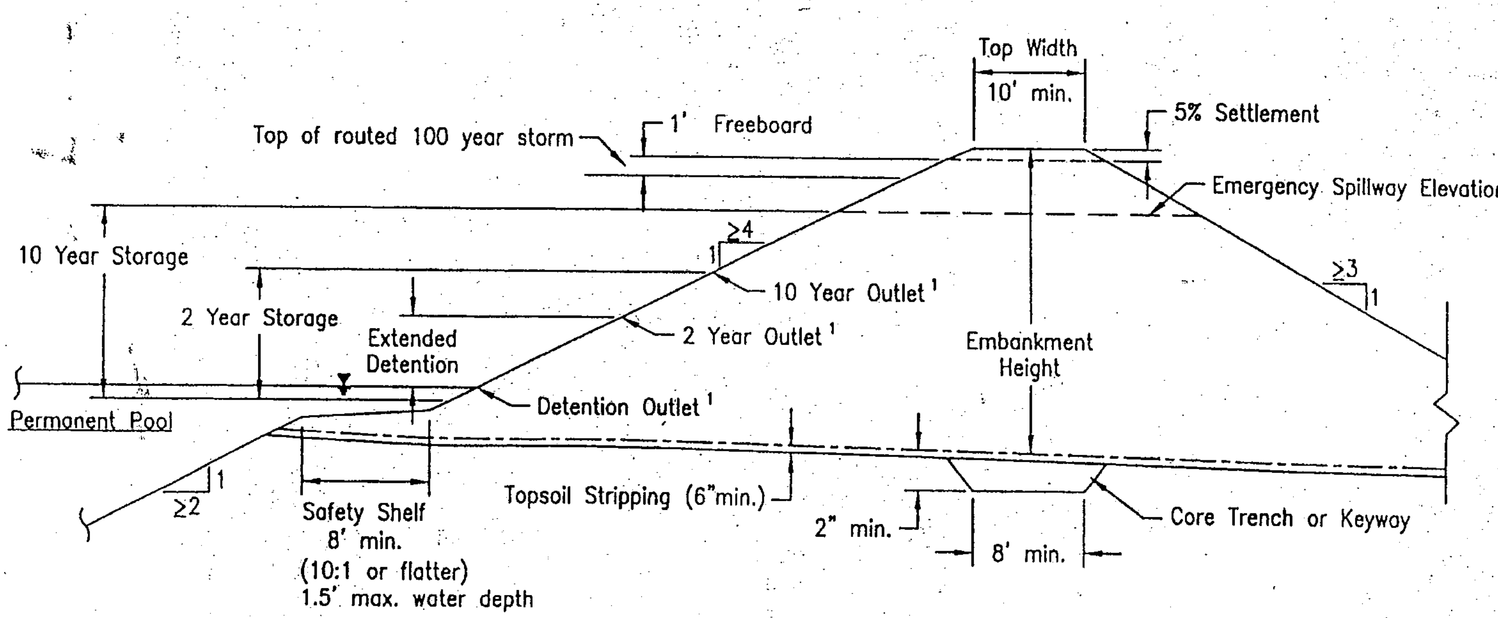
[1]TP - 40 - Rainfall Frequency Atlas of the United States, U.S. Department of Commerce Weather Bureau.

Table 5 - Runoff for Selected Curve Numbers and Rainfall Amounts[1]

	Runoff Depth in Inches for Curve Number of:										
Rainfall (inches)	50	55	60	65	70	75	80	85	90	95	98
2.1 in.	.00	.02	.08	.17	.28	.43	.63	.88	1.18	1.58	1.87
2.2 in.	.01	.04	.10	.20	.33	.49	.69	.95	1.27	1.67	1.97
2.3 in.	.01	.06	.13	.24	.37	.54.	.76	1.03	1.35	1.77	2.07
2.4 in.	.02	.07	.15	.27	.42	.60	.82	1.10	1.44	1.86	2.17
2.5 in.	.02	.08	.17	.30	.46	.65	.89	1.18	1.53	1.96	2.27
2.6 in.	.03	.10	.20	.34	.51	.71	.96	1.26	1.62	2.06	2.37

[1]NRCS TR-55

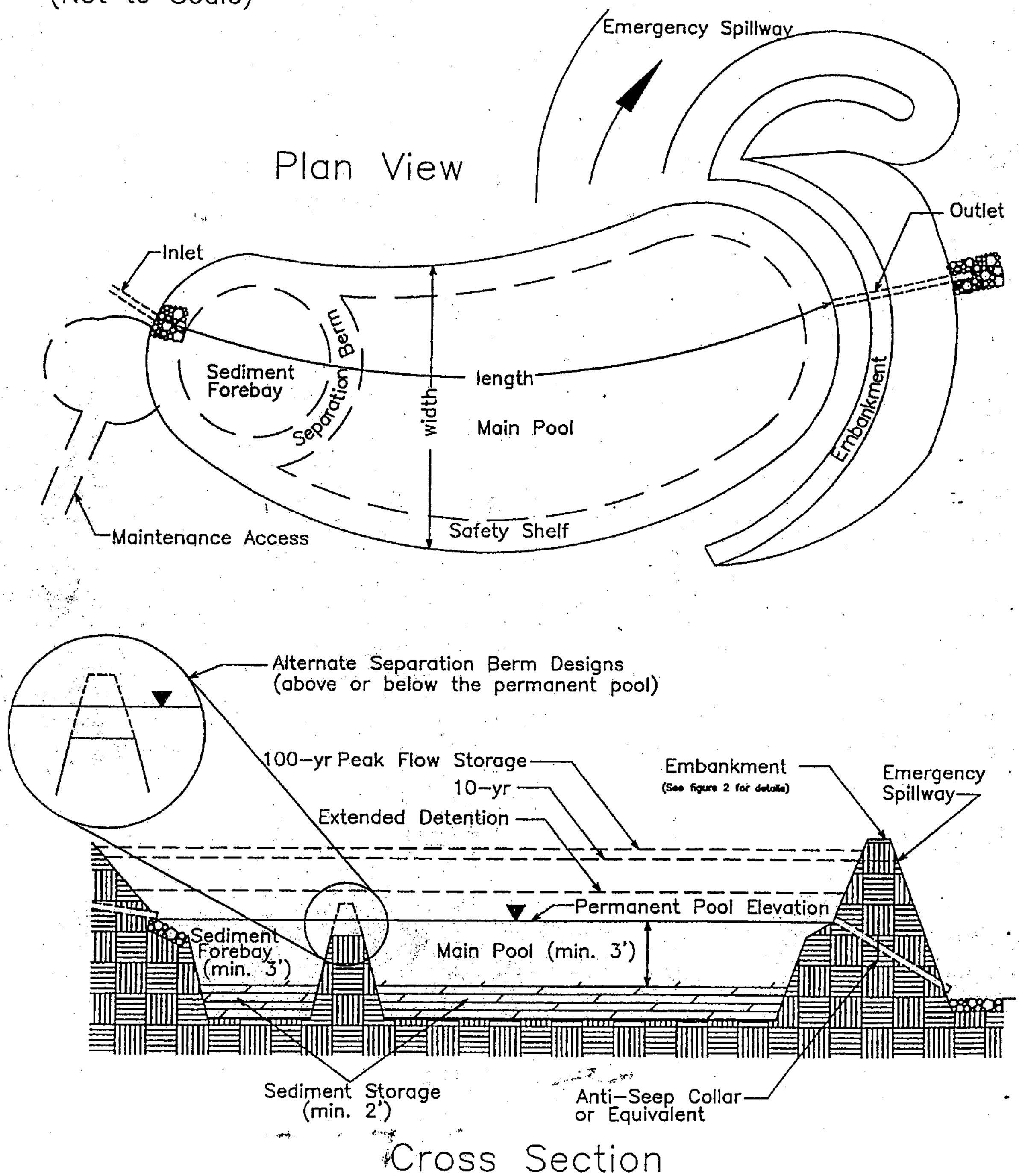
Figure 2: Typical Embankment Cross Section for Wet Detention Basin (Not to Scale)



1. These are conceptual outlet locations to indicate the need to have different outlets for different purposes. Numerous outlet designs will meet the criteria of the standard.

Figure 1: Conceptual Wet Detention Basin

(Not to Scale)



Mosquitoes and Stormwater Management

Water Quality and Supply

Extensive drainage and flood control systems have eliminated many wetland areas that provided suitable aquatic habitats for a variety of mosquito species. However, the diversion of stormwater to coastal marine systems via canals has dumped pollutants into our estuarine systems, and it has also greatly diminished the amount of storm water that enters recharge areas for replenishing the aquifer.

To alleviate these water quality and supply problems, various types of stormwater detention/retention areas are being incorporated into all new commercial and residential developments. Some established developments have also been retrofitted with stormwater retention or detention systems. The widespread use of these stormwater systems may lead to increased mosquito production, unless adequate precautions are taken.

Stormwater Detention/Retention Systems

Most stormwater detention ponds are semi-permanent aquatic systems that dry out only under drought conditions. Often during the rainy season, the water levels in these ponds remain at or near the outflow structures. Under these conditions, stormwater entering a detention area displaces an equivalent amount of water that usually overflows to an adjacent man-made or natural drainage system. The detention pond acts as a sink or trap where pollutants picked up by the initial surge of stormwater settle out before leaving the detention pond. These ponds are usually referred to as wet-detention systems.

By contrast, retention areas are designed to hold stormwater until the effects of percolation and evapotranspiration return the area to its normal dry state. Regulations concerning the design and construction of retention areas stipulate that stormwater inflow must dissipate within 72 hours so that a new volume can be

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accommodated. Since these stormwater areas are designed to dry out rapidly, they are usually called dry-retention systems.

Mosquito Production

Detention ponds for holding stormwater runoffs usually do not produce mosquitoes in sufficient numbers to cause a problem. Exceptions may occur when ponds becomes nearly dry due to a lack of rainfall. Under these conditions, wastewater *Culex* may invade the system. A similar type of invasion can occur in detention ponds that receive both storm and wastewater.

Wide fluctuations in water levels, especially when they are frequent events, may make the detention system a suitable habitat for flood-water mosquitoes such as *Aedes vexans* and *Psorophora columbiae*. Floating and rooted aquatic plants may foster the growth of populations of *Mansonia dyari*, *M. titillans* and *Coquillettidia perturbans*.

Although stormwater entering retention systems is supposed to percolate into the ground within 72 hours, retention areas often remain wet for longer periods. Floodwater mosquitoes are normally the first to appear in retention areas. Later in the rainy season, it is not uncommon to find *Culex*, especially if grass cuttings have been accumulating in these areas.

Mosquito Control Considerations

Local mosquito control programs should be actively involved in the planning and approval stages for all new stormwater management schemes. Try to avoid the placement of retention systems in areas where they are likely to remain wet for a period long enough for mosquito development. If retention areas must be placed at these sites, then a dual retention/detention system might be the best approach for both stormwater management and mosquito abatement. With proper design and construction, excess water in the retention part of the system can be sent to the detention pond, thus lessening the chances for mosquito production.

Detention ponds should receive only stormwater. Treated wastewater from package plants should be placed in separate holding ponds. Banks on detention ponds should be steep, but not too steep to hinder mowing and other maintenance activities. Deeper ponds are preferable to shallow ones. Inlets and outlets should be constructed with erosion protectors. Adequate vegetation should be maintained on the banks to prevent erosion.

Growth of aquatic vegetation should be restricted to the periphery of detention ponds. Property owners should be responsible for weed control in their ponds. City or county governments should have ordinances that require owners of detention ponds to follow proper maintenance procedures. The presence of a mechanical aerator, such as a fountain in the middle of the pond, often makes the site more attractive, deters the growth of unwanted vegetation, and makes the habitat more suitable for fish.

The bottoms of retention areas should be free of depressions where water might accumulate and remain for periods sufficient to allow mosquito production. Mowing and other maintenance operations should be done without producing ruts. Grass cuttings and other types of debris should be removed from retention areas. Long-term responsibilities for proper maintenance of retention areas should be clearly stipulated in city or county ordinances.

Once a retention system has been installed at an inappropriate location (e.g., on a site where the water table is too close to the surface), not much can be done to change the situation without eliminating the system. Under these conditions, mosquitoes must be controlled with larvicides. For a larvicide operation to be effective, it must be supported with a quality inspection program. The widespread occurrence of potential mosquito breeding sites in retention areas greatly increases the costs and manpower needs of the program. The widespread occurrences of potential mosquito breeding sites in retention areas greatly increases the costs and manpower needs of inspection programs. Perhaps through educational programs directed at the general public, we could generate more service requests for the control of mosquito larvae and fewer for adult mosquito control.

POTENTIAL EFFECTIVENESS OF DETENTION POLICIES

Ben Urbonas[1] and Mark W. Glidden[2]

INTRODUCTION

Urbanization is a continuing phenomenon in the United States. Grasslands, farmlands, forests, swamps, etc. are being continually changed to residential subdivisions, commercial and industrial complexes, roads and streets, parking lots, shopping centers, and so on. One of the side effects of urbanization with which engineers and planners must deal with is the increase of peak flows and volumes of runoff from rainstorm events. As a result, the urban drainage and flood control systems must be designed to accommodate the peak flows from a variety of storms that may occur.

The approach to drainage until the early 1980's relied on swales, curb and gutter, inlets, storm sewers, and channels to carry away flow as quickly as possible. This approach has in recent years been modified by the introduction of detention storage to hold back runoff and to release it downstream at controlled rates. The concept apparently has considerable appeal since it has been widely embraced throughout the United States, Canada and many other countries throughout the world.

One approach to detention is the use of regional detention or retention facilities. Another approach to detention is to require developers to provide detention as a part of the development process. Such lion-site" detention facilities can take many forms in terms of size, shape, and location.

Although the concept of detention storage has been widely accepted, the questions regarding its effectiveness in managing stormwater runoff persist. It is easy to study the hydrologic effectiveness of individual detention sites. It is also relatively easy to assess the effectiveness of large, publicly owned, regional detention facilities. It is another matter to study and quantify the effectiveness of a system of detention ponds, particularly if they occur randomly as to time of construction and in their location. The effectiveness of on-site detention is also affected by design criteria, which varies from one other regions.

BACKGROUND

The basic policy that most frequently guides the development of stormwater detention ordinances and design standards is the control of stormwater runoff peak discharges from a development. The peak flow, after development, is required not to exceed what would have occurred from the same storm under conditions existing prior to development (1). In the Denver area, the most commonly used policy among the various local general-purpose governments is to limit the 100-year peak flow after development to the pre-develop 100-year peak flow. However, there are several communities that require control of two recurrence frequencies such as 2-year and 100-year, 5-year and 100-year or 10-year and 100-year events.

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[2] Project Manager, Wright Water Engineers, Inc., Denver, Colorado.

McCuen (1974) published reported the results of his modeling effort utilizing 17 sub-watersheds and two systems of detention storage. In one system he modeled 12 ponds and in another he modeled 17 ponds. He modeled ten storm events at the Gray Haven Watershed to calibrate a "linked-process hydrograph simulation model" before adding the detention ponds to the system. The modeled watershed consisted of 23.3 acres of which 52 percent was impervious. Although the article did not describe the design of individual detention facilities, McCuen reported that the 17 sub-watershed scenarios had a total of 22,000 cubic feet of storage. On the basis of his modeling results he suggested that,

> "(1) That the "individual -size" approach to stormwater detention may actually create flooding problems than reduce the hydrologic impact of urbanization; and (2) that a regional approach to urban stormwater management may be more effective than the 'individual -site' approach."

Hardt and Burges (1976) report on their investigation of detention effects from an hypothetical 2000 acre watershed. Their investigation, utilizing SCS runoff model and a kinematic channel routing technique, was limited to three sub-watersheds; nevertheless it was one of the earlier attempts to look at the effects of detention systems. Their findings can be summarized in the following quote from their report:

> "Restricting the outflow from a retention facility to level less than the undeveloped rate could achieve a composite peak flow rate that would equal the pre-urbanization flow but would run for a much greater duration at that rate. The increased flow duration would have potentially undesirable effects on the channel system."

Lindsey and Crawford (1974) suggested the use of continuous simulation models in urban hydrology. Although this suggestion has considerable merit, it suffers from the fact that continuous record of rainfall is often not available. When it is, the cost of such modeling can be very expensive, and that the majority of design practitioners are not prepared to use continuous long term modeling in the design of stormwater detention facilities.

Walesh (1976 and 1979) suggested a technique to reduce a continuous hyetograph record to a reasonable number of discrete hyetographs that represent desired recurrence frequency storms. These representative recorded hyetographs can then be used to design stormwater management facilities, including detention. The reason for suggesting continuous simulation or the use of representative recorded hyetographs stems from the questioning of the validity of using a design storm by McPherson (1977), Marsalek (1978) and Sieker (1978). This design storm controversy has not been resolved, however, the authors believe that there are definite applications, particularly where non-point source water quality is being considered, in which continuous simulation or quasi-continuous simulation should be used whenever rainfall data is available. On the other hand, the authors believe that the design of basic storm sewer systems, channels, and detention ponds can be accomplished with reasonable accuracy using properly developed design storms.

Urbonas (1979), based on hydrologic studies in Denver, Colorado expressed the following opinion:

> "It is possible to develop design storms that reasonably duplicate the peak flows from small urban basins at various recurrence intervals. However, this requires substantial rainfall-runoff data to permit calibration of computer models, long term simulation of runoff using recorded rainstorms and statistical analysis of simulated peaks and volumes."

Such design storms need to be developed for each locale, using representative rainfall-runoff data. Once developed, they can be used with confidence that the designs for the region will be reasonably accurate and responsive to the stormwater management needs of the region.

POLICY AND POTENTIAL EFFECTIVENESS

The objective of the Denver study reported herein was to assess the "potential effectiveness" of on-site detention by estimating how much on-site detention can reduce the peak flows along major drainageways. As stated earlier, many local governments require on-site detention; however, little work has been done to assess the effectiveness of on-site detention in controlling flows along major drainageways. The primary interest of the Urban Drainage and Flood Control District (District) is in the flooding along the "major drainageways". Thus, it was logical for the District to investigate the potential effectiveness of on-site detention policies in controlling flood levels along such drainageways.

Denver Area Setting

The Denver metropolitan area is located on the Colorado high plains immediately east of the Rocky Mountains at an elevation of 5,280 feet (1.600 m). Because it receives 15-inches (380 mm) of precipitation annually, it is considered to have a semiarid climate. Rainstorms in the spring and early fall often have an "upslope" character where easterly flow of moisture settles against the mountains. These types of rainstorms can have a duration that exceeds 6-hours and, although they may drop relatively large amounts of total precipitation, they are not very intense and are not normally associated with major urban flooding problems along major drainageways. In late spring and throughout the summer, the rainstorms often result from convective or frontal stimulated convective action. These type of storms are often less than 1- or 2-hours in duration; however, they can produce brief periods of high rainfall intensities.

Experience and rainfall/runoff data in the Denver area show that very little, if any, runoff occurs from low intensity storms such as "upslope" type storms and from the lesser convective storms when the land is not urbanized. As the land develops, streets, curbs and gutters, and storm drainage facilities are installed and runoff occurs from even very small rainstorms.

The terrain in the Denver area is rolling with moderate to steep slopes. Much of the area has high clay content with tight surface soils; however, there are also areas that have very free draining sandy soils. The native vegetation consists of dry land range grasses, which in some cases were replaced in the past by dry wheat or irrigated crops and are now being replaced by Kentucky Blue Grass as the area urbanizes. Since most of the land in new developments has residential land use, the detention study concentrated on an ultimate land use mix consisting of mostly residential with some light commercial.

A study conducted by the District used an actual Denver area watershed as a study basin. The study watershed had an area of 7.85 square miles, a watershed length of 6.4 miles with an average watershed slope of 0.015. Its shape and drainage pattern is shown on Figure 1 and it was estimated that 1.9 percent of its area was impervious before land development began. After full development, the watershed area is projected to be 38 percent impervious.

Runoff was modeled using 2-hour design storms for the 2-, 10-, and 100-year recurrence frequencies. These design storms were developed for the Denver area using the rainfall-runoff data collected by USGS since 1970 and the long term Denver Raingage record collected since 1896. Modeling was done using stationary storms and storms that moved across the watershed at six miles per hour upstream and downstream. In addition, runoff was modeled using three recorded rainstorms under the stationary and moving storm scenarios. Although the runoff results reported in this paper are for the stationary design storm scenarios, the effects of stormwater detention on each storm scenario were found to be similar. Namely, if a reduction in peak flow was calculated with detention for the stationary storm scenario, then a similar reduction was also observed for the a moving storm scenario when compared against the undetained moving storm condition.

Because the modeling was for a 7.85 square mile watershed, conclusions of this study should not be extrapolated much beyond 10 square mile watersheds. This seems like a severe limitation; however, many of the observed rainstorms in the semi-arid climates have a rather limited footprint where the intense rainfall occurs. Thus, controlling runoff from a 10 square mile or lesser watersheds may be very beneficial for flood control purposes in semi-arid climates.

The study watershed was subdivided into 56 sub-catchments and 52 channel segments. After calibration, runoff was modeled using the various storm scenarios for the undeveloped and the urbanized land use conditions. The model was then modified to include 28 randomly located detention ponds. The ponds intercepted 91 percent of the total area with runoff from 9 percent of the area being undetained. Each pond was sized on the basis of the hydrographs calculated for the pre and post-developed conditions. The control volume was estimated using a process illustrated in Figure 2, where the control volume was assumed to be equal to the cross-hatched portion of the runoff hydrograph.

The hydraulic characteristics of each pond's outlet were designed assuming that the outlet functioned as an orifice until the design control volume was filled. At that point the ponds were assumed to overflow and a broad-crested weir controlled the overflow. On the basis of trends observed in several individual designs, the outlet discharge versus storage volume relationship was reduced to a non-dimensional form for all ponds. This expedited the design of a large number of ponds under a variety of desired control conditions.

Figures 3 and 4 illustrate the design characteristics used for the 28 ponds in the model. In Figure 3 *h* represents the peak flow from an undeveloped sub-basin, Q_d represents the peak flow from a developed sub-basin, and V_T represents the design control volume of the pond. In Figure 4, Q_h and Q, represent the historic and developed 100-year storm peak flows, V_T represents the 100-year control volume, and Q_i and V_i represent the historic peak flow and the required control volume for the 10-year storm.

While the pond is operating within orifice control, Equation 1 can express the discharge:

$$Q = C A (2gh)^{0.5} \tag{1}$$

In which, Q = discharge-ft^3 /sec
A = area of orifice-ft^2
h = water surface height above orifice-ft
g = acceleration of gravity - 32.2 ft/sec^2
C = discharge coefficient

Equation I can be expressed for any given C and A as

$$Q = C h^{0.5} \tag{2}$$

For the individual ponds designed in the study, it was observed that the pond volume could be reasonably estimated by a power function of depth, which, after rearrangement was expressed as

$$h = C V^{0.92} \tag{3}$$

In which, V = pond volume at any stage height
C_2 = constant

Combining equations 2 and 3 gave

$$Q = KV^{0.46} \tag{4}$$

In which, $K = C_1 C_2^{0.5}$ (i.e. a constant).

To facilitate a large number of pond designs, the volume-discharge relationship was made non-dimensional by dividing the outflow by the discharge required at the full control volume and the volume by the full control volume. Equation 5 gives the non-dimensional relationship, while the pond is operating within the maximum control volume.

$$\frac{Q}{Q_T} = K\left(\frac{V}{V_T}\right)^{0.46} \tag{5}$$

In which V_T = detention pond control volume V_T.

Q_T = discharge desired at control volume V_T

The non-dimensional volume-discharge relationship for the entire range of pond operation is illustrated in Figures 3 and 4.

Results and Observations

Many of the results of the District's random detention study can be found in the Masters of Science Thesis by Mark Glidden (1981). A series of five figures (i.e., Figures 5, 6, 7, 8, and 9) summarize the generalized trends that were identified by the study. Each figure relates the size of the watershed to the non-dimensional peak flow. The non-dimensional peak flow was obtained by dividing the actual peak flow by its respective flow from the undeveloped watershed. Therefore, a value of "one" on the ordinate represents no change from the undeveloped condition and a value of "two" represent an increase in peak flows by a factor of two from the undeveloped condition. Figure 5 shows the estimated trends in peak flows along the major drainageways without on-site detention and Figures 6 through 9 show the trends when different on-site detention designs are used.

Figures 6 through 9 reveal the following trends for the soil and meteorological conditions modeled by the District's study:

1. The 2-year random detention pond design was effective in controlling the 2-year peak flows at individual pond sites only. As the number of ponds increased with an increasing tributary area, the 2-year design rapidly diminished in effectiveness. This trend is attributed to the fact that the 2-year storm volume increased many fold after development and, although the peaks were controlled at the individual sites, the resulting flat peaked outlet hydrographs from the ponds added directly as the flows progressed downstream. In contrast, prior to development the individual tributary hydrographs had small volumes and were out of phase with each other. The 2-year design somewhat reduced the 10-year and the 100-year storm runoff peaks when compared to the undetained condition.
2. The 10-year random detention pond designs were relatively effective in limiting runoff peaks along the major drainageways from the 10-year storms and were also somewhat effective in reducing the 100-year storm peaks. It was virtually ineffective in controlling the 2-year design storm runoff peaks.

3. The 100-year design was effective in controlling the 100-year peaks but was virtually ineffective in controlling the 2- and 10-year storms.

4. The combination 10- and 100-year control design was effective in controlling the 10- and 100-year storm runoff, but was ineffective in controlling the 2-year storm runoff peaks. The two-frequency control design looked to be more effective in controlling the two design storms than the individual 10- or 100-year frequency designs were in controlling their respective individual recurrence runoff peaks.

The results of the District's study seem to verify some of the conclusions of Hard and Burges (1976). The one surprise, although predictable, was that the 2-year design was not very effective in controlling peak flows along the major drainageways from the smaller storms. It may be that McCuen's (1974) study, since it' utilized recorded data, was limited to such smaller storms. It does not mean that the 2-year design is ineffective for individual sites and may be more effective than the study results indicate if the spatial distributions of the smaller storms are considered. Additional work is needed to quantify realistic spatial storm patterns before the 2-year detention design effectiveness can be judged.

SIMPLIFIED CRITERIA EFFECTIVENESS

General

As a follow-up to the study of the "potential effectiveness" of detention policies for the Denver area, the District investigated the possibility of using simplified detention design criteria. Of great concern to designers is that simplified detention requirements take away the "creativity" in design and may result in detention sizing that is inappropriate for an individual site. These concerns are very valid. On the other hand, simple regional detention sizing requirements do offer advantages to the developer, the design engineer and the local government official that has to review large numbers of designs. Although simplified detention requirements may not permit "optimization" for each on-site detention facility, they offer the advantages of simplicity, uniformity and, from land developer's perspective, equal treatment. In other words, all developments know early on what the detention volumes and areas will have to be. It is also clear to everyone that all similar developments will be treated the same way. For these reasons, regional simple detention design criteria deserve to be considered by stormwater management professionals. A decision if they should be promulgated or rejected should then be made based on each community's needs, capabilities and political factors.

Preliminary Control Equations

Scrutinizing the "runoff vs. area" results of the earlier modeling effort revealed, two simplified trends for undeveloped runoff and detention control volume (see Equations 6, 7, 8, and 9):

$$V_{10} = (1.35\,I + 2.70)\,(A/1000) \quad (6)$$

$$Q_{10} = 0.4\,A \quad (7)$$

$$V_{100} = (2.07\,I + 4.04)\,(A/1000) \quad (8)$$

$$Q_{100} = 1.25\,A \quad (9)$$

In which, V_{10} = Volume needed to control a 10-year storm in acre-feet

V_{100} = Volume needed to control a 100-year storm in acre-feet

Q10 = Average 10-year peak flow rate from undeveloped sub-basin in cubic feet per second

Q100 = Average 100-year peak flow rate from undeveloped sub-basin in cubic feet per second

A = Tributary basin area in acres

I = Tributary basin imperviousness in percent

Equations 6 through 9 were used to size all of the 28 detention ponds in the study model for the 10-and 100-year storm runoff controls. These relationships provided pond designs that did not control the peak flows along major drainageways as well as the individually designed ponds during the earlier investigation.

Final Control Equations

After three trials, a set of simplified design equations (see Equations 10, 11, 12, and 13) were developed that produced peak flow trends along major drainageways similar to the ones obtained using the rigorous analysis of each detention site.

$$V10 = (0.95\,I - 1.90)\,(A/1000) \quad (10)$$

$$Q10 = 0.24\,A \quad (11)$$

$$V100 = (1.78\,I - 0.002\,I^2 - 3.56)\,(A/1000) \quad (12)$$

$$Q100 = 1.0A \quad (13)$$

OBSERVATIONS

The peak flow results obtained with detention ponds sized using equations 10 through 13 were reduced to a non-dimensional form and are depicted in Figures 10, 11, 12, 13, 14, and 15. These figures reveal the following trends:

1. The 10-year and 100-year designs based on Equation 10 through 13 controlled the peak flows along the major drainageways almost as well as the rigorous individual design scenarios.
2. The 10-year simplified design was less effective in controlling the 100-year peak storm flows than the rigorous 10-year design scenario.
3. The 100-year simplified design was more effective in controlling the 10-year peak storm flows than the rigorous 100-year design scenario.
4. The combined 10-year and 100-year simplified design was equivalent to the rigorous combined 10-year and 100-year in controlling both recurrence storm flow peaks.

Although the peak flow trends along the major drainageways were duplicated very well by the simplified design equations, there were a number of ponds in the system that overflowed. All ponds have the potential for overflowing since a storm larger than it was designed to control can and will occur. Thus, an infrequent overflow, by itself should not constitute a faulty design. It is up to the designer to insure that when an overflow occurs, property damages are not increased. Namely, a safe overflow path, free of structures, has to be provided for every detention pond regardless of control frequency design.

As a further comparison, Table 1 illustrates the differences in watershed detention storage requirements between the rigorous design approach and the simplified one. The comparison shows a trend towards less basin wide storage volume using the simplified approach as tested by the District.

Table 1. Comparison of Required Unit Volume Using Rigorous vs. Simplified Designs

		Unit Volume For 100-yr. Control (Acre-Feet/Acre)	
Percent Impervious	Rigorous	Simplified	% Difference
20	0.037	0.032	- 13
40	0.079	0.064	- 19
80	0.162	0.126	- 22
100	0.203	0.154	- 24

DESIGN ACCURACY AND EFFECTIVENESS

The topic of design accuracy was indirectly touched upon by the earlier discussion of the design storm concept. The possible citations concerning urban design storms are numerous and have been tabulated by the Design Storm Task Committee of the Urban Water Resources Research Council into an Annotated Bibliography (ASCE, 1983) which can be obtained upon request from ASCE. The mere fact that design storms or their substitutes are used as input in the sizing of detention basins, leaves a lot of room for argument as to the design accuracy or detention pond effectiveness. Although the questioning has merit and should not stop if technology is to move forward, it should not paralyze the designer into an endless analysis process. In the author's opinion, it is important that the designer recognizes the limitations in the accuracy of the rainfall input and move forward to design what are considered reasonably sized facilities in line with current state-of-the-art technology and practice.

Unlike many other fields of engineering, the statistics of hydrologic data have very wide bounds of design confidence. As an example, a USGS (1980) document provides regression equations and techniques for estimating flood peaks, volumes, and hydrographs on small streams in South Dakota. The range in the standard error of estimate is as much as +152 and -60 percent for the flood peaks and +136 and -58 percent for the runoff volumes. Such uncertainties, as an example, in structural analysis would be considered intolerable and would be dealt with through the use of very large safety factors. On the other hand, drainage and flood control engineers work with these kind of uncertainties all the time whether they know it or not. Thus, whenever we discuss accuracy or effectiveness, we need to remind ourselves of the randomness of the physical phenomenon which is involved, and the fact that the data that was used in developing all of the commonly available surface runoff calculating techniques is broadly scattered.

INSTITUTIONAL CONSTRAINTS

In their discussion, Jones and Jones (1982) point out that many communities mandated misuse of detention ponding with resultant waste of land and economic resources. They encourage communities to avoid arbitrary specification of single recurrence probability in their ordinances. Instead community's need to reexamine their selected design basis and attempt to arrive at a design basis that is demonstrably cost-effective. Too often either the extreme rare event or the small frequent event are the basis for local requirement, which, when applied uniformly and without regard to the effects downstream, can lead to either local drainage and erosion problems or to flooding problems. They went on to say,

> "It follows that design of detention pond outlet works often should have a multi-probability basis: (a) for frequent low flow conditions; (b) for the detention design discharge condition; and (c) for the extreme runoff (emergency spillway) condition."

The District's study revealed that even though the smaller storms may be the pond design criteria, the increased runoff volume resulting from urbanization virtually precludes design of on-site ponds that can effectively control peak flows along downstream drainageways. This mandates that downstream drainage facilities cannot arbitrarily be sized to accommodate flow from historic or undeveloped watershed only on the basis of "on-site" detention policy. It is incumbent on communities to also examine the detention requirements for each site, when detention is required, to insure that pond releases will not create hazards or damages to downstream properties. Requiring on-site detention is not an assurance that the drainage needs of the community and of the new development are satisfied. Communities and developers need to recognize that detention, when used, is only one element of a total formalized (or natural) drainage system and cannot be treated haphazardly. Thus, institutional arrangements in communities are just as important as sound design practices. In other words, communities need an institutional structure that insures sound design, and that the required detention ponds fit the system and are not used just to pacify local regulatory requirements.

Beyond this, an institutional structure is needed to insure that detention ponds are properly constructed and maintained for as long as they are a part of the community's drainage system. Assessing the potential hydraulic effectiveness of a detention ordinance or policy is like trying to weigh candy with only one-half of a balance scale. Even though the product looks attractive, it is not possible to know how much there is of it. If there is an emerging theme among the stormwater management professionals, it is that more often than not such institutional structures are not in place, are inadequate, or are under funded. Thus, the true effectiveness of detention systems or policies cannot be assessed without knowledge of how policy requirements translate into physical facilities and how these facilities will continue to function over the many years they are expected to operate.

CONCLUSIONS

The effectiveness of on-site detention ponds was addressed from the quantity and institutional aspects. The model study of random on-site detention in one Denver area watershed has indicated the following:

1) When ponds are designed to control the peak flow from a single recurrence event, the effectiveness of the system in controlling flow rates along major drainageways is limited only to that single design event.

2) Ponds designed to control peak flows of two separate recurrence frequency events appear to be effective in controlling flow rates along major drainageways for a range of flows and also appear to be more effective in controlling the two individual design events.

3) Designs intended to control frequent events (e.g., 2-years) are effective in controlling the frequent event immediately downstream of each pond only. Control of frequent events appears to be less and less effective along the major drainageways as more and more ponds contribute to the system.

4) It appears feasible to develop simplified regional on-site detention sizing requirements. Ponds sized using such requirements have the potential of controlling peak flow rates along major drainageways just as effectively as ponds sized using rigorous, flood routed, design procedures. Finally, the effectiveness of random on-site detention policies is also constrained by the institutional structure that can insure adequate design, proper construction and long term operation and maintenance of detention facilities. Without knowing how effective the institutional structure is in providing and maintaining adequate facilities, we need to view the foregoing conclusions as representing Only the "potential effectiveness" of detention policies. The assessment of the actual effectiveness of random on-site detention will require studies beyond those conducted to date.

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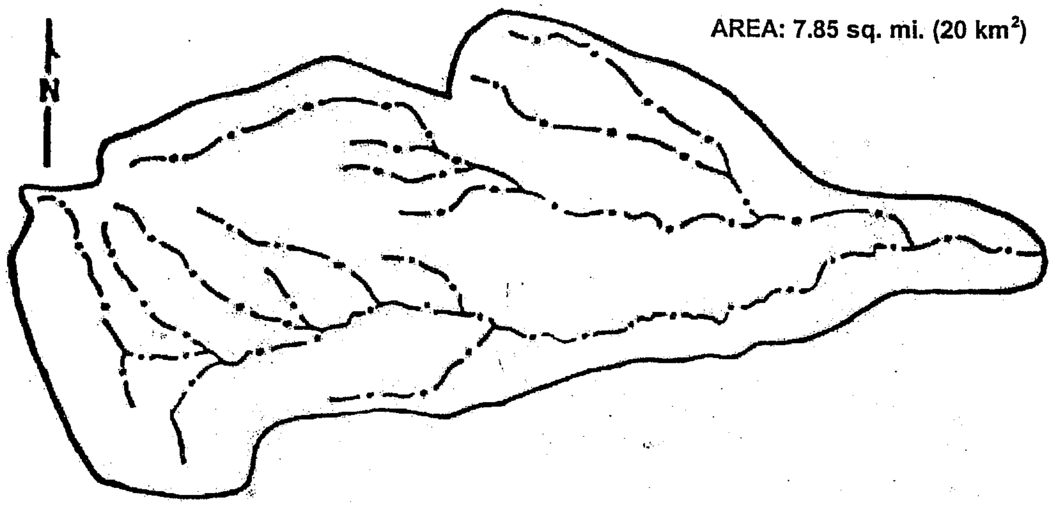


Figure 1. Study Catchment

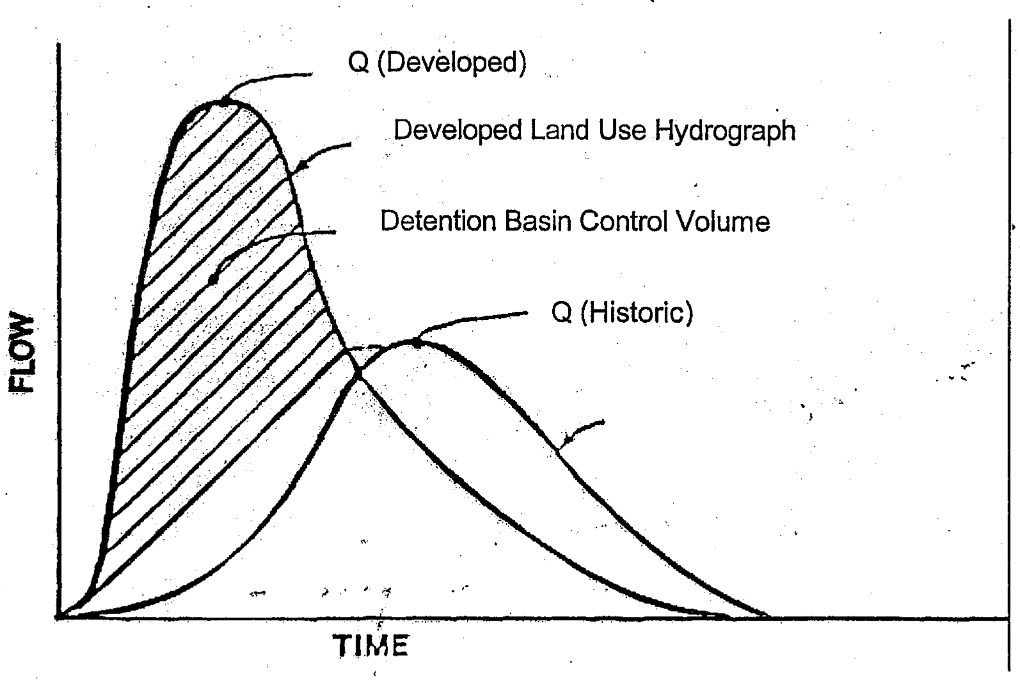


Figure 2. Determination of a Detention Pond Volume.

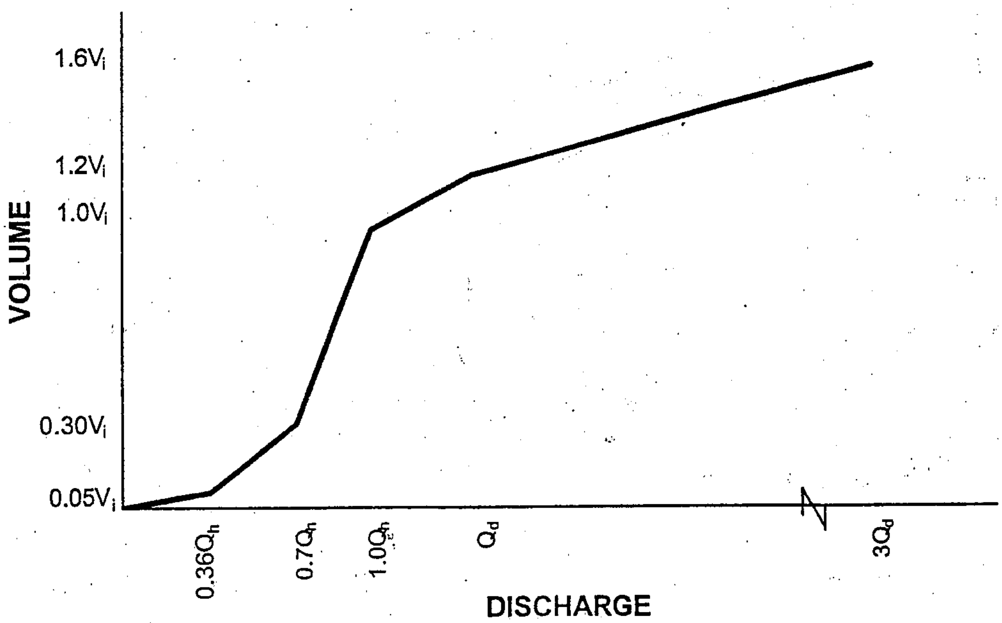


Figure 3. Volume vs. Discharge: 2-, 10- and 100-year Designs of Detention Basins.

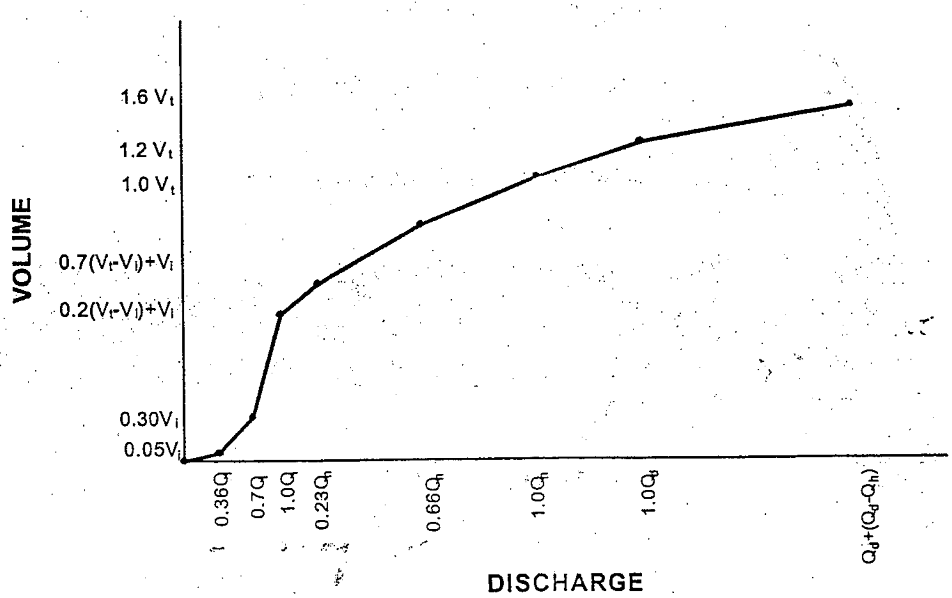


Figure 4. Volume vs. Discharge: 10- & 100-year Combination Designs of Detention Basins.

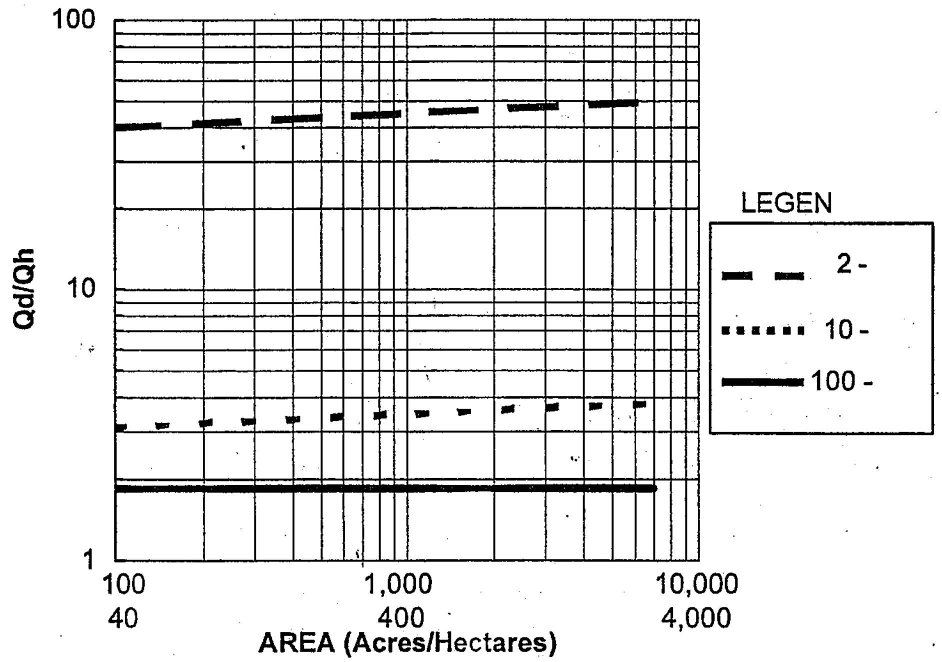


Figure 5. Urban Runoff Trends – Fully Urbanized Watershed Without Detention

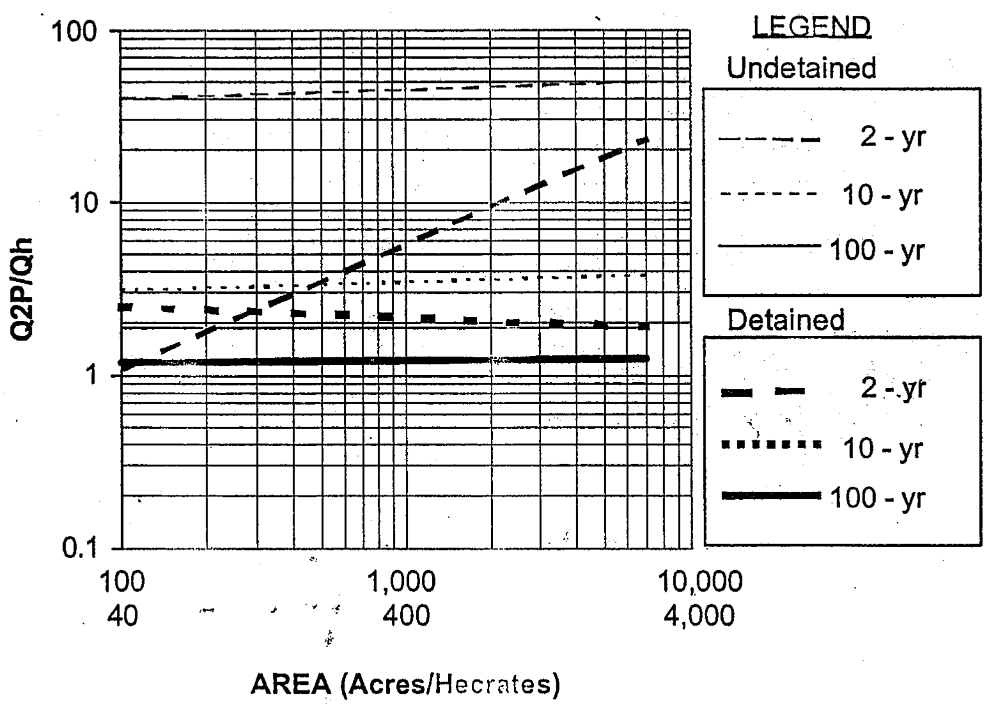


Figure 6. Effectiveness of 2-year Peak Flow Detention Design

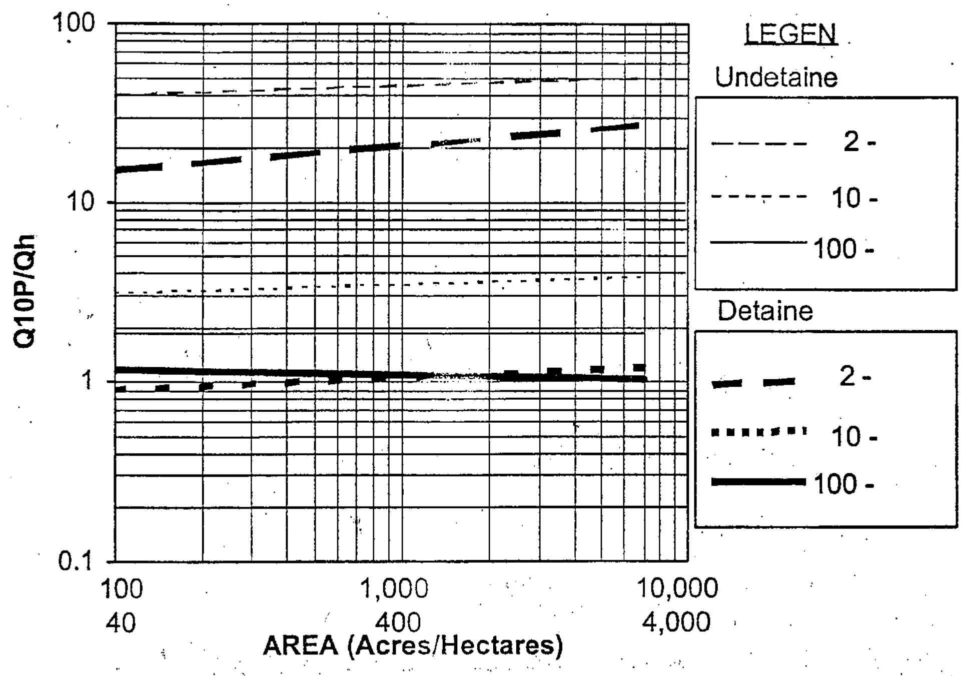


Figure 7. Effectiveness of 10-year Peak Flow Detention Design

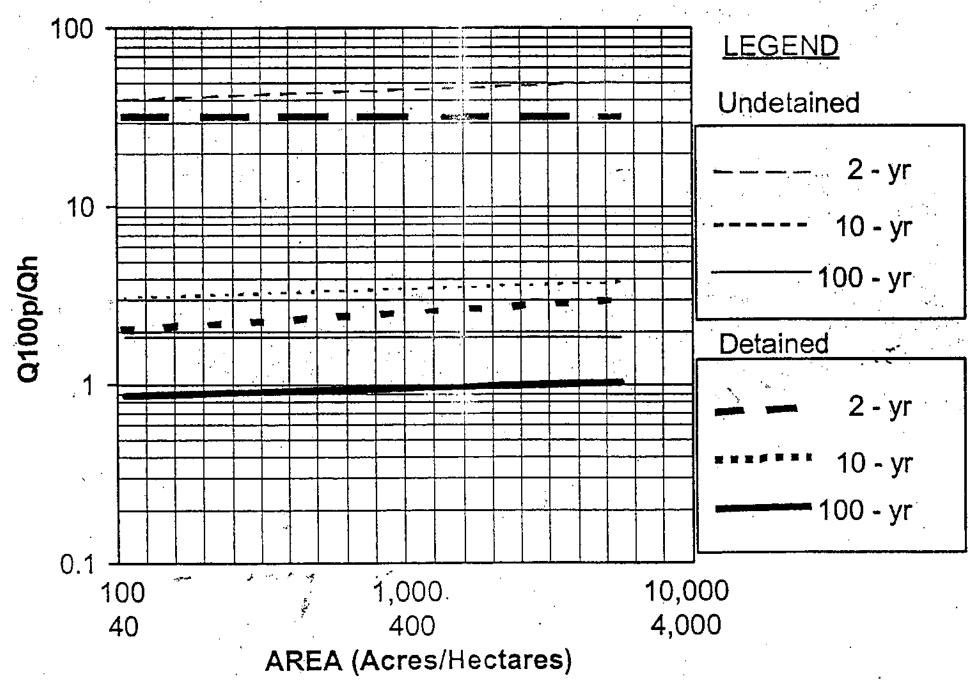


Figure 8. Effectiveness of 100-year Peak Flow Detention Design

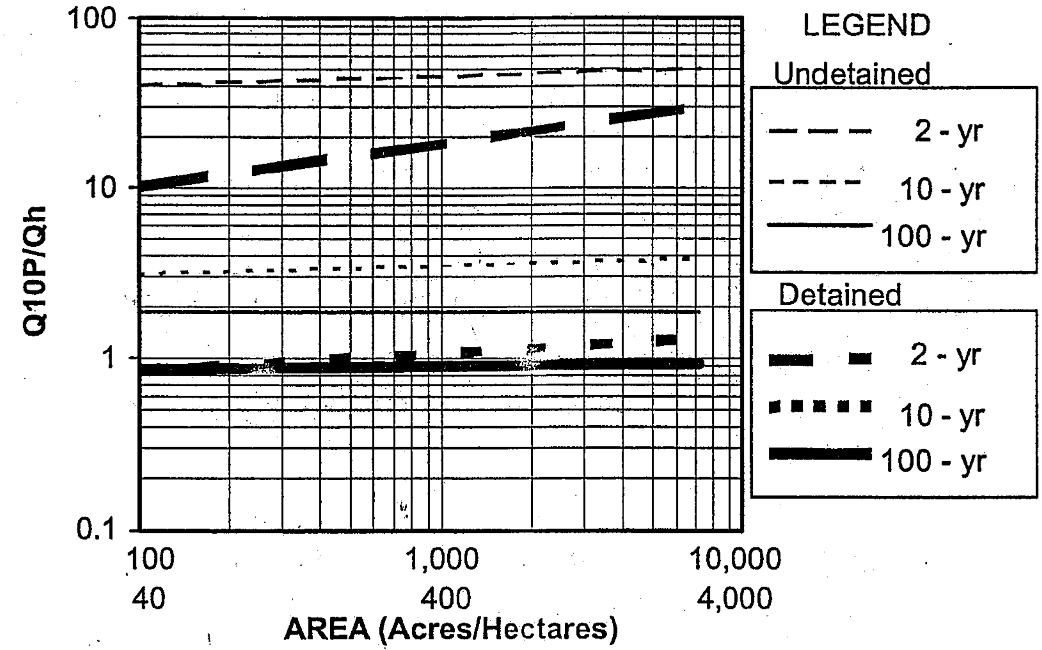


Figure 9. Effectiveness of 10- & 100-year Peak Flow Detention Design

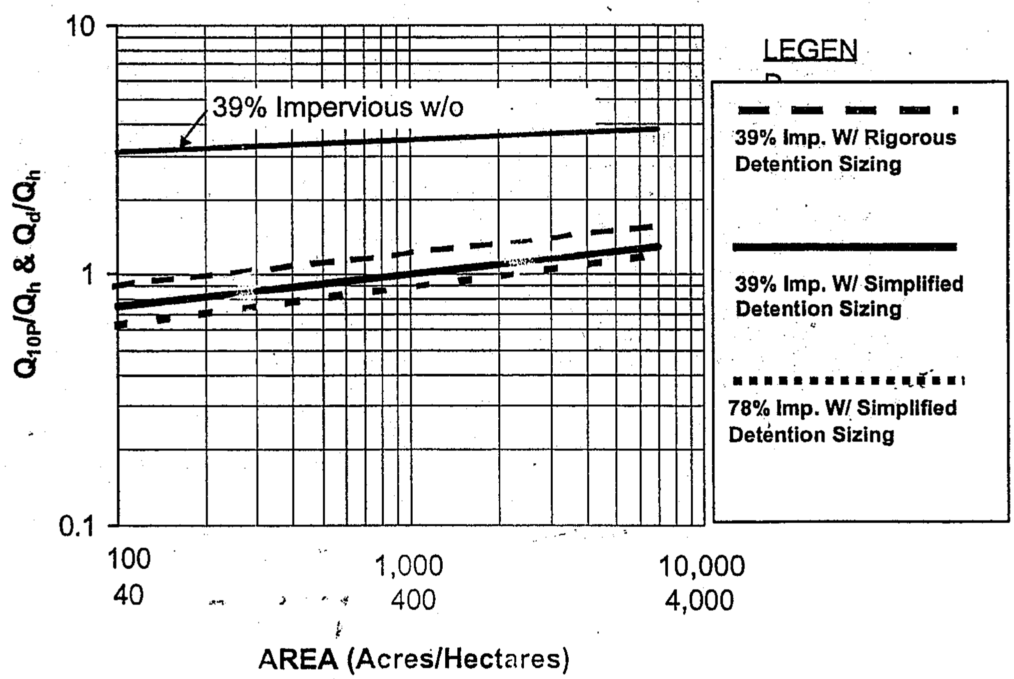


Figure 10. Effects of 10-year Simplified Detention Sizing on 10-year Runoff Peak Flows.

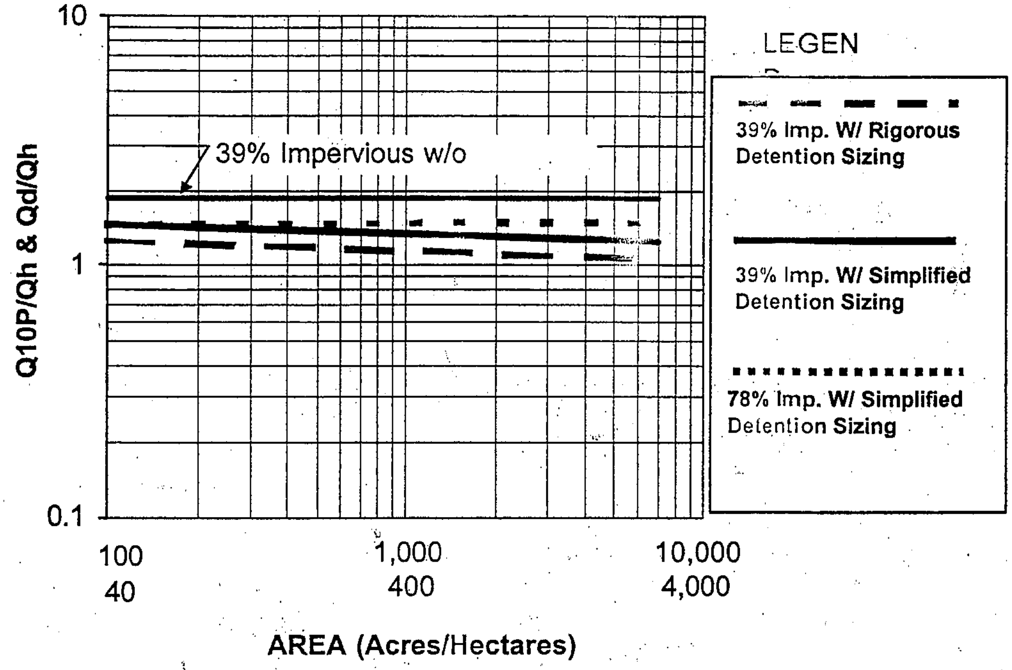


Figure 11. Effects of 10-year Simplified Detention Sizing on 100-year Runoff Peak Flows.

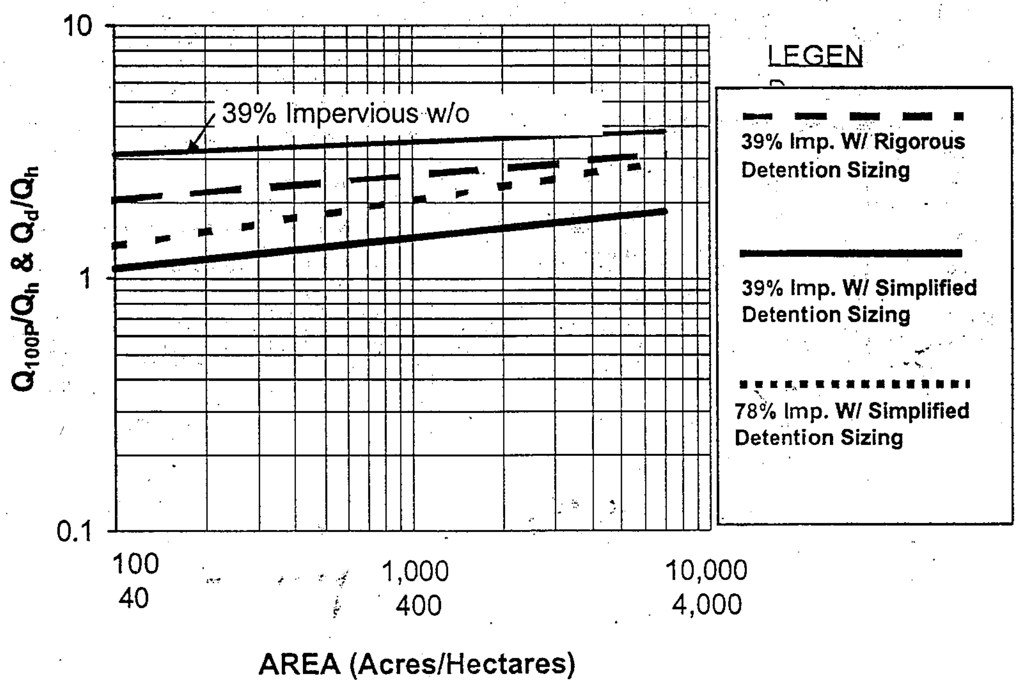


Figure 12. Effects of 100-year Simplified Detention Sizing on 10-year Runoff Peak Flows.

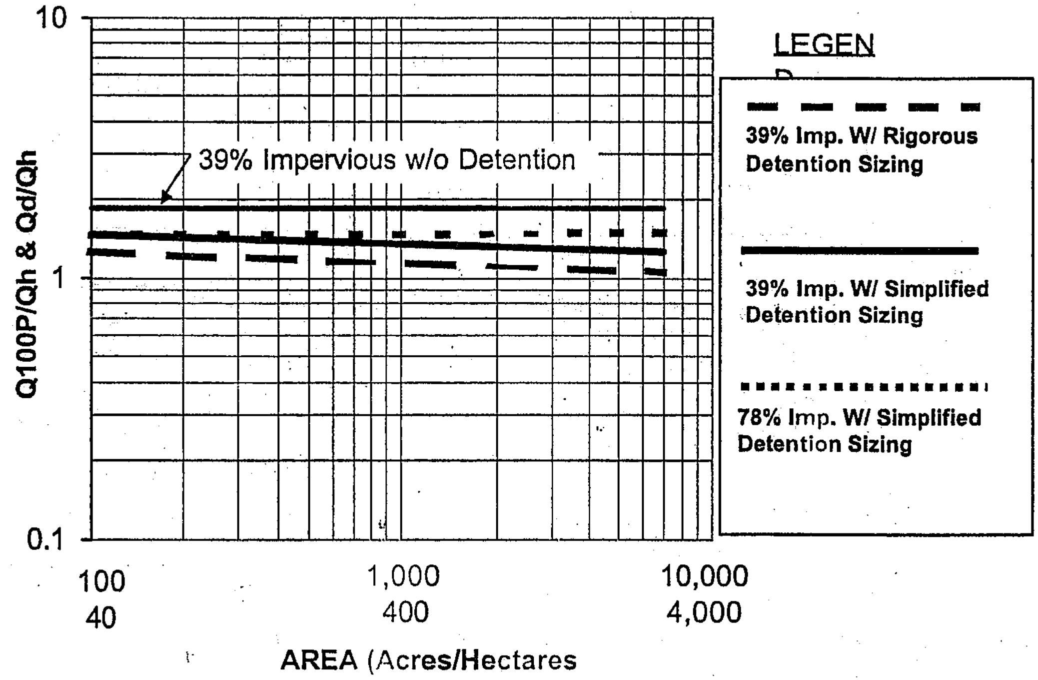


Figure 13. Effects of 100-year Simplified Detention Sizing on 100-year Runoff Peak Flows.

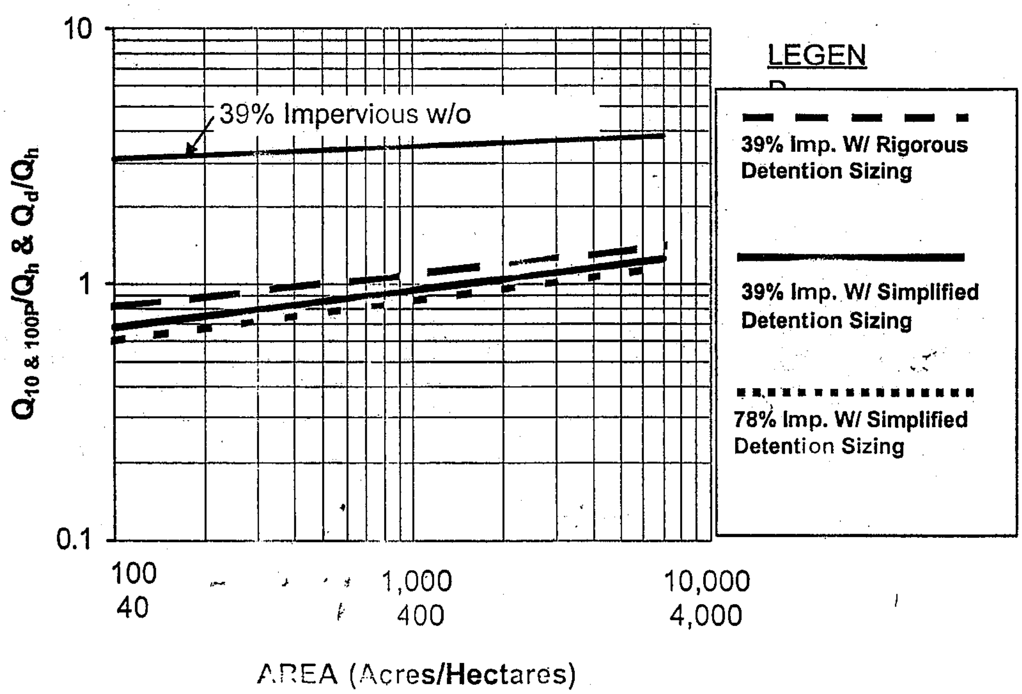


Figure 14. Effects of a Combined 10- & 100-year Simplified Detention Sizing on 10-year Peaks.

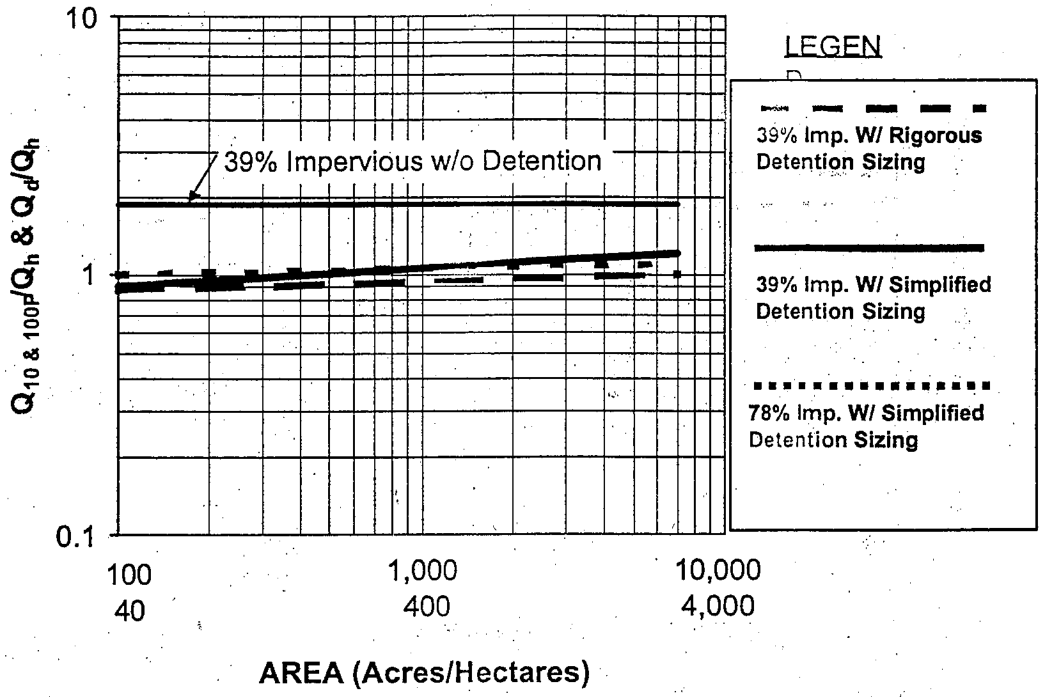


Figure 15. Effects of a Combined 10- & 100-year Simplified Detention Sizing on 100-year Peaks.

TAKING THE BITE

OUT OF

MOSQUITOES

Information leaflet to help get through the mosquito season

Prepared by:
Regional District of North Okanagan
Phone: (250) 545-5368
Web: www.nord.bc.ca

Find out more:
Please call the Public Health hotline at **1-866-300-0520** or visit their website at http://www.interiorhealth.ca (Click on "Your Health" and enter "West Nile Virus". Another source of information is the BC Centre for Disease Control website at http://www.bccdc.org

A001178

THE LIFE OF A MOSQUITO

There are approximately 75 species of mosquitoes recorded in Canada but not all species suck blood or are considered a nuisance. Mosquitoes may be encountered during both days and nights and from early spring until late summer/early fall.

Any natural or artificial area that can hold water for about a week or more--virtually all types of standing water, can be a potential breeding site for mosquitoes. Some typical sites are:

- Margins of lakes, ponds, streams
- Ditches, vehicle and animal ruts
- Pasture, woodlot and rock pools
- Gutters, barrels, tires, cans, birdbaths, boats
- Culverts, open wells, tree holes, catch basins, ornamental and wading pools
- Snow-melt or summer rain pools

The larval and pupal stages of all known species require **standing** water in which to develop. Mosquito eggs may remain dormant and will hatch only when a pool of water is formed. Once the larvae and pupae have developed, the adult mosquito emerges at the water surface and soon flies off to mate.

Larvae of most mosquitoes feed on plant material in the water. The male and female adult mosquito feed on plant nectar but only the **female adult** mosquito sucks blood which she needs in order to lay eggs.

Temperature, humidity and wind all affect the breeding and activity habits of mosquitoes. Because they are sensitive to hot, dry weather, most mosquitoes like to rest in cool, moist locations during the day.

CONTROLLING MOSQUITOES

Source Reduction:

Some examples of how to remove potential mosquito breeding sites are:

- **Many small temporary pools can be drained or filled in:** *eg. fill in animal and vehicle ruts, regrade low field areas to eliminate pooling, provide ditching to drain low areas*
- **Eliminate artificial breeding containers:** *eg. Clean gutters, empty tires, fill tree holes with sand or concrete, change bird-bath water weekly, cover rain barrels, drain or cover small plastic pools, avoid ponding on swimming pool covers and maintain pool water quality*
- **Alter breeding sites:** *eg. scrape out sediment in ditches, keep vegetation around ponds and ditches mowed, provide steep sloped gravel, rock or sandy shorelines around ponds, incorporate smaller floodwater habitats into larger wetland habitats,* **Reconsider landscaping plan:** *eg. consider the mosquito habitats created when wetlands, storm water retention ponds, sewage lagoons, or ornamental ponds are integrated into landscape or neighborhood designs*

Source Exclusion:

To control mosquitoes:

- Use mosquito screening on doors and windows to keep mosquitoes out.
- Use mosquito screening or lids to cover small ornamental ponds, plastic pools, rain barrels, and other small water holding area

Biological, Mechanical and Chemical Controls:

Although mosquitoes are affected by a wide variety of natural enemies, these enemies do little to keep mosquitoes at tolerable levels.

- **Introduce fish:** *fish can be introduced into contained ornamental ponds* ***but must not be introduced into waters that drain into natural wetlands, ponds, lakes, streams, etc***
- **Use of Bti (Bacillus thuringiensis israelensis):** *Bti is a naturally occurring bacteria. It has a very specific mode of action against mosquito and black fly larvae, midge and fungus gnats, but virtually no adverse effect to mammals, fish or other wildlife. Bti is introduced into standing water when mosquito larvae are present.*
- **Use of Insecticides:** *certain insecticides such as Malathion, Propoxur, Pyrethrins, Methoxychlor and Dichlorvos are registered for use in Canada as a spray and/or fog to control adult mosquitoes. Generally, these are used as a last resort when mosquitoes have become a nuisance or when larviciding programs have not worked adequately. Malathion is also registered for use in standing water to control larvae.*
- **Other Controls:** *mechanical and other controls are used against the adult stage of the mosquito. These include such things as aromatic repellents, electric grids, incense coils, aromatic plants and ultrasonic emitters, all of which generally have very little effect against the mosquito.*

Personal Protection:

There are times when we cannot avoid coming into contact with mosquitoes. There are some things we can do to minimize our discomfort.

- **Avoid places** where mosquito densities are high
- **Avoid being outside** at times of day when mosquitoes are most active (calm, warm, humid evenings)
- **Limit exposed skin** by wearing a hat or head net, long trousers and a long-sleeved shirt
- **Use of a personal repellant**: most repellents contain DEET (N,N-diethyl-meta-toluamide) in concentrations usually between 10 and 30%. The higher the concentration, the longer the duration of protection for a single application. Strong winds, high temperatures, high humidity, and amount of sweating will generally decrease the duration of protection. DEET can be an irritant to some people and can also damage synthetic materials such as rayon, nylon or certain plastics. DEET should not be used on children under 6 months of age. Check the label for more detailed information or ask your family physician for assistance.
- **Alternatives to DEET**: there are few, if any, alternatives to DEET. Products containing oil of lavender or citronella have a very low, short-lived repellent effect against the biting mosquitoes.

For more information about mosquitoes and how to control them, go to www.hc-sc.gc.ca

Transmission of Viruses by Mosquitoes

The objective of this leaflet is to provide some basic information to help people protect themselves from mosquitoes and the potential spread of diseases they carry, particularly the West Nile Virus (WNV), that is transmitted between a **reservoir species (birds), host (humans), by a vector (mosquitoes).**

Wild birds are the main reservoir species for West Nile Virus. When mosquitoes feed on infected birds, they acquire the virus and can then spread it to other birds (mainly crows and blue jays) and then to mammals (horses, cats, bats, chipmunks, skunks, squirrels and domestic rabbits) as well as humans.

WNV is not transmitted from one person to another or from birds directly to people. Infected birds may serve to spread the virus from one geographic area to another.

WNV is spread to humans by the bite of a mosquito. Most people (80%) who are infected with the virus show no ill signs. However, WNV can produce flu-like symptoms (20% of cases), or can cause **encephalitis** (inflammation of the brain) or **meningitis** (inflammation of the lining of the brain and spinal cord) in less than 1% of the cases. WNV is closely related to the viruses that cause the St. Louis Encephalitis and Japanese Encephalitis

Where WNV has been confirmed In Canada, transmission from mosquitoes to humans is more likely to occur during the mid-to late-summer period until the end of the first severe frost.

Stormwater Management and West Nile Virus

Introduction

As a result of increased public awareness and concern regarding the risks associated with West Nile virus (WNV), the Pennsylvania Department of Environmental Protection (DEP) has been receiving inquiries concerning the potential for stormwater retention devices to serve as breeding areas for mosquitoes. This factsheet was developed in response to these inquiries and to serve as a source of information for Pennsylvania residents and developers.

What is WNV?

West Nile virus is a mosquito-borne disease that can cause encephalitis, or a brain infection. Mosquitoes acquire the virus from birds and pass it on to other birds, animals and people. In 1999, West Nile virus first appeared in New York. For the first time, in the summer of 2000, Pennsylvania found the virus in mosquitoes, birds and a horse.

Mosquitoes spread this virus after they feed on infected birds and then bite people, other birds and animals. It is not spread by person-to-person contact and there is no evidence that people can get the virus by handling infected animals. West Nile virus cases occur primarily in the late summer or early Fall, although the mosquito season is April through October.

How do people get WNV encephalitis?

People become infected with WNV after being bitten by an infected mosquito. There is no evidence that people can transmit the virus to other animals, birds, or people.

Are stormwater catch basins significant breeding areas for WNV mosquito vectors?

Catch basins can be important breeding areas for mosquitoes in the genus *Culex*. Many storm drain systems are designed to quickly direct water from impervious surfaces to nearby streams. Sometimes these systems can become clogged with debris, which can lead to standing water and mosquito breeding. Malfunctioning systems should be reported to local authorities for repair. Older catch basins were designed to trap debris and hold a small portion of the storm water after a rainfall event. These catch basins are a significant source of mosquito breeding and need to be treated for mosquito larvae on a regular basis. Some counties actively treat catch basins with mosquito larvicides to prevent mosquito breeding.

Are residential stormwater retention basins significant breeding areas for WNV mosquito vectors?

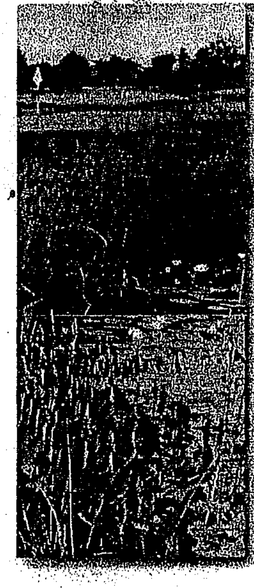
Most residential stormwater retention basins are designed to drain in less than four days, which prevents mosquito larvae from completing their development. Mosquitoes need at least four days of larval development to reach adulthood during the summer. Storm water retention basins that contain water for more than a few days following a rain event should be reported to your county West Nile coordinator.

Are stormwater retention wetlands/ponds significant breeding areas for WNV mosquito vectors?

New regulations require that Pennsylvania developers consider water quality concerns as they address storm water issues. Created wetlands/ponds are being developed more frequently because the retain water for longer periods of time than previous designs, allowing more pollutants to be removed before the stormwater is allowed to enter a stream. It is possible for these habitats to harbor mosquito larvae. Mosquito populations are often significantly reduced by the presence of natural predators such as fish and predaceous aquatic insects. When mosquito production is a problem, mosquito larval control should be added to the normal maintenance costs of debris removal, slope maintenance, removal of invasive vegetation, and sediment removal. Larval control is relatively inexpensive and should be performed from June through October to coincide with the peak of the WNV season in Pennsylvania.

Remember……

The County West Nile Coordinator works closely with DEP regional WNV biologists to monitor and control mosquito populations throughout the Commonwealth. Those concerned about WNV are encouraged to visit http://www.westnile.state.pa.us for regular updates on WNV activity within the State. This website also has a list of the County West Nile coordinators who can assist with the monitoring and control of mosquitoes in your area.



Water Quality

Management of Ponds, Wetlands, and Other Water Reservoirs to Minimize Mosquitoes

PURDUE
UNIVERSITY

Brent Ladd
Jane Frankenberger

Agricultural & Biological Engineering Department

Introduction

The recent discovery of West Nile virus in Indiana has directed increased attention to mosquitoes (carriers and transmitters of the disease) and potential means of controlling mosquito populations. Because mosquitoes are known to breed in standing water, many people are raising questions about the role of natural and artificial ponds and wetlands in relation to mosquito populations.

In addition to beautifying the landscape, ponds and wetlands provide important ecosystem services in Indiana such as storm water management, habitat for aquatic life, and ecosystem health and stability. Ponds and wetlands reduce storm water runoff problems by catching and slowing the movement of storm water. They help filter and clean rainfall and runoff water, and increase ground water aquifer recharge. Ponds and wetlands in the landscape provide for diverse flora and fauna, including birds, bats, aquatic insects, fish, and amphibians; all of which feed on mosquitoes. In addition to these positive aspects, ponds and wetlands provide recreational opportunities for many Hoosiers, including fishing, swimming, boating, and hunting.

Although under some circumstances ponds and wetlands can increase mosquito populations, predators of mosquitoes such as fish and other aquatic organisms will usually control mosquito populations if the pond or wetland supports a well-balanced ecosystem. This publication describes problems that make ponds and wetlands especially inviting to mosquitoes and how to develop and promote an ecosystem in your pond or wetland that controls mosquito populations by natural predation.

Management of ponds to minimize mosquitoes

Large & Natural Ponds

A well-functioning pond is characterized by a living ecosystem that includes fish and other aquatic organisms, stable banks with good plant cover, and a diversity of insect and animal life. Such a pond will have water with adequate and stable levels of oxygen, some surface wave action, and possibly a slight greenish tint from the presence of phytoplankton. In balance, phytoplankton provide the base of the aquatic food chain and are essential to

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Key Factors in Ponds that Reduce and Destroy Mosquito Larvae

- Fish and aquatic insects
- Surface wave action
- Disturbance from rainfall

a pond ecosystem. Ecologically stable ponds normally do not produce problem mosquito populations because the natural factors of fish predation and surface wave action tend to kill mosquito larvae. Ponds stocked with fish, such as Large Mouth Bass and Blue Gill, will greatly reduce or eliminate mosquito larvae.

Bats and Purple Martins consume mosquitoes, although field research has shown that they do not have significant effects on mosquito populations.[1,2] However, these species should be encouraged as they help complete a diverse ecosystem. Other birds, aquatic insects, dragonflies, fish, and amphibians all consume mosquitoes and their larvae and together serve as natural mosquito control.

In addition to fish, wave action or water movement on the pond surface is an important factor in reducing mosquito larvae survival rates. Natural ponds and most Indiana farm ponds will have adequate surface water movement and do not require additional aeration. In the case of stagnant ponds lacking water movement, or ponds lacking enough oxygen for fish survival, mechanical aerators can help improve the pond condition.

Ponds receiving excess nutrients can favor algae blooms and submersed aquatic vegetation. This situation can lead to increased mosquito egg laying in these ponds and pools due to excess plant cover, providing the larvae with protection from predators, wave action, and rainfall.[3] Mosquito larvae also feed on organic debris in water. These problem ponds need to be addressed by restoring the ponds with aeration and stocking them with fish. For more information on pond aeration and restoring water movement, contact one of the resource people listed at the end of this publication, or view the following Web publication: http://agpublications.tamu.edu/pubs/efish/370fs.pdf. Avoid the use of fertilizer within at least a 50 foot radius of ponds since this will help prevent excess nutrients from entering the ponds.

Make sure that high quality vegetative buffers are in place around ponds. These will slow or trap sediment, pesticides, and nutrients. Encouraging natural vegetation on the banks and shoreline of larger ponds may provide some adult mosquito habitat, however it also has many benefits for pond quality. Tall vegetation surrounding a pond makes it less attractive to geese. Large numbers of geese can degrade pond water quality and have also been implicated as vectors of West Nile virus.[4] In addition, natural vegetation surrounding large ponds provides habitat for predators of adult mosquitoes and their larvae.

Mosquito Prevention Checklist for Pond Owners

- ☐ Maintain high quality vegetative buffers around the pond.
- ☐ Use top feeding minnows and other fish to reduce or eliminate mosquito larvae.
- ☐ Use aeration to improve stagnant ponds.
- ☐ Prevent excess nutrients and pollutants from entering the pond.
- ☐ Do not spray chemicals or apply fertilizer near, uphill, or upwind from the pond.
- ☐ Prevent livestock from entering the pond and degrading the banks of the pond.
- ☐ Prevent ruts when mowing.
- ☐ Keep grass clippings out of the pond.
- ☐ Encourage patches of natural vegetation at pond edges to provide beneficial wildlife and insect habitat.
- ☐ Avoid shallow ponds and basins without fish or aeration.
- ☐ Employ chemical controls by a certified pesticide applicator only as a last resort.

A balance must be struck between open water and aquatic vegetation. A good rule of thumb is to have 30 percent of the shallow area of the pond in rooted-floating and submersed aquatic vegetation. These aquatic plants provide necessary habitat for fish and other wildlife and should be protected. The side slope of ponds influences the presence of submersed and rooted-floating aquatic plants. For more information on pond side slope and construction see the contact list on page 7 under the section: "Assistance with pond and wetland restoration and management."

Types of Aquatic Vegetation

Emergent

➤ Plants that are rooted in the silt and pond shoreline such as cattails.

Rooted-floating

➤ Plants that are rooted under water in shallow areas and have floating surface vegetation such as waterlily.

Submersed

➤ Plants that have their roots under water in bottom sediments and grow up through the water such as pondweed.

Free-floating

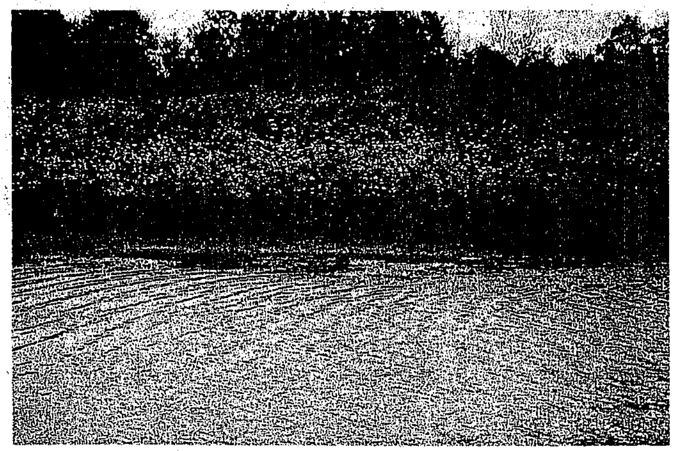
➤ Very small plants that float on the surface such as duckweed.

For information on controlling invasive aquatic plants refer to the following Purdue Extension publications:
Aquatic Plant Management, WS-21,
www.agcom.purdue.edu/AgCom/Pubs/WS/WS_21.pdf
Barley Straw for Algae Control, APM-1-W
www.btny.purdue.edu/Pubs/APM/APM-1-W.pdf
Control of Duckweed and Watermeal, APM-2-W
www.btny.purdue.edu/Pubs/APM/APM-2-W.pdf

Small Backyard Water Gardens and Shallow Ponds

Small or very shallow ponds are prone to mosquito problems if they lack fish, water movement, or have their edges or surfaces completely covered with aquatic plants. If a small pond becomes stagnant restore water movement with a fountain, waterfall, or other aerator and stock the pond with minnows. Top feeding minnows will provide effective mosquito control in small ponds. A small fish that has received a lot of media attention is the Mosquito fish (*Gambusia affinis*). They have been shown to be the most effective fish for mosquito control in ponds not connected to natural waterways.[5,6] However, Mosquito fish do eat and affect habitat resources at varying levels and should not be considered for ponds connected with natural waterways.[7]

As water temperature rises it holds less oxygen. This may have a deleterious effect on fish in small and shallow ponds during summer months. Providing afternoon shade from hot summer sun for small and shallow ponds can improve conditions for fish by helping to keep water temperature from rising beyond the capacity of fish to tolerate. Artificial aeration will also help improve oxygen levels in small ponds. If mosquitoes are a problem, mowing around small backyard or shallow ponds may be necessary in order to eliminate adult mosquito habitat. Clippings from mowed vegetation can cause problems if they end up in the pond since they add excess nutrients and provide additional food and protection for mosquito larvae.[8] Make sure that clippings are prevented from entering the pond. For more information on backyard water gardens view this Web publication http://wildlife.tamu.edu/publications/TAEXPonds/789a.pdf.



Storm Water Ponds and Infiltration Areas

Ponds that have been built specifically for catching and holding storm water have important environmental benefits. When properly designed and managed these storm water ponds and infiltration areas should not become problem mosquito breeding habitat.[8] However, there are conditions under which these areas can encourage mosquitoes. When storm water holding ponds become nearly dry, vector mosquitoes may invade the ponds. Large fluctuations in water levels of storm water ponds can make the system ideal for floodwater mosquitoes. Monitor for mosquito larvae during periods when water levels remain low, or when water levels fluctuate frequently.

Areas designed to infiltrate, rather than hold, storm water can also become potential mosquito breeding areas. If these infiltration areas remain wet for periods longer than 72 hours, floodwater mosquitoes are often the first to invade.[8] If poor management has resulted in grass cuttings or polluted runoff accumulating in these wet areas, vector mosquitoes can be found later in the summer season. Avoid placement of infiltration systems in areas where they are likely to remain wet for longer than 72 hours (e.g. where the water table is close to the surface). Storm water infiltration areas should be free of isolated depressions that could allow water to accumulate for longer periods. Mowing near infiltration areas should be done without producing ruts where water can collect, and grass clippings and debris should be removed regularly.

Use of Chemical Products in Ponds to Control Mosquitoes

Questions arise about the use of chemicals and other products for mosquito control. Due to a higher level of environmental and human health risk compared with natural mosquito control methods, chemical controls should be seen as a last resort. Chemicals for mosquito control are best left to certified pesticide applicators.[9] Before applying chemical controls, you should verify that the mosquito population in question is at risk for transmitting disease. For more information see the Purdue Extension publication *E-52-W, Mosquito Control by Trained Personnel,* www.entm.purdue.edu/Entomology/ext/targets/e-series/EseriesPDF/E-52.pdf.

Wetlands and mosquitoes

Natural Wetlands

Management practices that ensure healthy, functioning aquatic ecosystems are proven long-term and cost-effective strategies for controlling mosquito populations. Contrary to popular belief, natural wetlands can reduce the population of mosquitoes compared with drained or degraded wetland areas. According to the Indiana Department of Natural Resources-Division of Fish & Wildlife, wetland restoration decreases mosquito populations in two ways: by providing healthy habitat for the natural enemies of mosquitoes, and by preventing or reducing flooding in non-wetland areas. The IDNR fact sheet, *Did you know? Healthy wetlands devour mosquitoes* <www.in.gov/dnr/fishwild/publications/inwetcon/

hlywet.pdf>, provides an example of one mosquito control project that documented a reduction of 90 percent in the mosquito population after restoring a 1,500 acre wetland area.[10]

To be certain, all wetlands will have populations of mosquitoes varying with the degree of wetness and air temperature. During drought periods when water in some wetland areas may be reduced to small or shallow pools, mosquitoes can migrate and congregate in these smaller areas of wetness, though populations of flood water mosquitoes overall tend to decrease during drought periods.[11,12] However, in areas where wetlands have been drained, mosquito populations thrive when these former wetland areas become inundated after rain storms.[10] Following rain, intermittent moist muddy or shallow stagnant water combined with an absence of predators of mosquitoes can allow the mosquito population to explode.[10,11,12,13] including disease carrying mosquitoes that breed only in stagnant water.[11] This type of flooding in non-wetland areas occurs more frequently *after* wetlands are drained, and this creates the most serious nuisance mosquito problems in Indiana.[10] The Indiana Departement of Natural Resources recommends restoring these wetland ecosystems.[10] For additional information on wetlands see the Purdue Extension publication *Wetlands and Water Quality, WQ-10* persephone.agcom.purdue.edu/AgCom/Pubs/WQ/WQ-10.html.

Long-term commitment to wetland restoration also saves tax payers money on mosquito control. A study of a 548 acre marsh in 1969 on the U.S. east coast reported spending $16,000 to implement wetland restoration. Since that time the wetland has not needed any maintenance, cleaning, pesticides, or other costs. It was estimated that in a 25 year period since 1969 traditional insecticide methods would have cost $685,000.[10,14,15]

Constructed Wetlands

"Artificial" wetlands are being constructed in Indiana to control and treat storm water and wastewater. Whenever possible, constructed wetlands that treat wastewater should be located away from residential areas and beyond the flight range of local disease carrying mosquitoes. Locating constructed wetlands in open areas where wind can produce waves in the wetland will disrupt mosquito development.

Pollutant traps and sedimentation zones within the wetland should be managed to prevent blockages and pollutant buildup, as blockage can promote stagnant water. Maintaining water movement through the wetland is important for reducing mosquito populations. Riffle zones provide turbulence detrimental to mosquito larvae and also raise oxygen levels in the water.

Aeration systems for large constructed wetlands reduce mosquito larvae by disturbing the water surface, and sprinkler systems can inhibit mosquito egg laying. If constructed wetlands become overvegetated they provide ideal habitat for mosquito larvae due to being protected from predators and from rainfall and wave action. Maintenance of vegetation by harvesting and culling of plants can provide for increased water movement and predator access to mosquito larvae.

Managing water other than ponds and wetlands near the home

Mosquitoes that tend to lay their eggs in human-made reservoirs near residential areas are the primary disease carrying species, and are often referred to as vector mosquitoes.[11,16,17,18,19] More information on vector mosquitoes can be read online at www.entm.purdue.edu/Entomology/ext/targets/e-series/EseriesPDF/E-204.pdf. If you have a mosquito problem around your home, chances are good that they are breeding in your yard.

The number one action that homeowners can take to reduce vector mosquitoes near the home is to eliminate the reservoirs where these mosquitoes often breed.[20] The checklist on page 6, "Water reservoirs other than ponds and wetlands where mosquitoes may breed," provides a general list of these breeding areas. Consider that just one inch of water in an ordinary coffee can may result in as many as 1,000 mosquitoes every seven days. For a photographic chart of the life cycle of a vector mosquito visit the *Mosquito Hygiene Web site* at www.cfe.cornell.edu/erap/WNV/WNVEducDocs/MosqHygienePoster6-02.pdf.

In many cases, simply altering the reservoir will prevent mosquito breeding. For example, turning a wheelbarrow upside down to prevent pooling of stagnant water. In other instances, the reservoir should be eliminated, as in the case of abandoned tires. Regular maintenance is required for some reservoirs, such as keeping rain gutters cleaned of debris, and changing water in bird baths and pet bowls once a week. There are additional problem areas that fall into the jurisdiction of county and city officials, such as storm water drains and ditches. Contact your local health department for information and assistance.

For more information on mosquitoes and their control around the home refer to Purdue Extension publication, *Mosquitoes In and Around the Home, E-26-W*; www.entm.purdue.edu/Entomology/ext/targets/e-series/EseriesPDF/E-26.pdf.

An issue that deserves further inquiry

Ponds, wetlands, and residential environments in relation to mosquitoes are complex issues. This publication presents available information and strategies for pond, wetland, and water reservoir management as a way of helping Indiana residents to minimize mosquito problems. Further studies focusing on the effects of protecting and encouraging natural predators of mosquitoes through ecosystem restoration would shed light on some of these complex issues. Currently, only four percent of natural wetland areas in Indiana remain. As wetland areas are restored, mosquito populations and predator/prey relationships can be monitored. This publication will be updated as knowledge on this issue evolves.

Water reservoirs other than ponds and wetlands where mosquitoes may breed

Check if present	Potential reservoirs	Date problem remedied
☐	Basements with standing water	______
☐	Birdbaths	______
☐	Boats that have not been drained or covered	______
☐	Cans, jars, or other open containers	______
☐	Clogged house roof gutters	______
☐	Culverts with stagnant water	______
☐	Ditches that hold stagnant water	______
☐	Drain outlets from air-conditioners	______
☐	Dripping outdoor faucets	______
☐	Flower pots	______
☐	Leaf-filled drains	______
☐	Leaking pipe joints	______
☐	Livestock water tanks	______
☐	Manure treatment lagoons	______
☐	Old cisterns	______
☐	Ornamental ponds	______
☐	Over-irrigated lawns and fields	______
☐	Saucers under potted plants	______
☐	Septic absorption fields (if soggy)	______
☐	Sewage treatment ponds	______
☐	Standing water in tire ruts and horse or livestock lots	______
☐	Storm water drain systems	______
☐	Street gutters, catch basins at road corners	______
☐	Stumps and tree holes	______
☐	Swimming pool covers	______
☐	Tires (abandoned)	______
☐	Unsealed barrels	______
☐	Wading pools or kiddie pools	______
☐	Water cans, buckets, troughs, pet bowls	______
☐	Wheel barrows or tilt-up carts	______
☐	Wells in old frost pits that flood	______

Assistance with pond and wetland restoration and management

Technical assistance is available from the agencies listed below. Some cost-share funds, as well as payment programs on agricultural lands, may be available for pond and wetland restoration and protection.

- Indiana Department of Natural Resources, Division of Fish and Wildlife, 402 W. Washington St., Rm. W273, Indianapolis, Indiana 46204. Phone: 317-232-4080 www.IN.gov/dnr/fishWild
- Indiana Natural Resources Conservation Service. Call 317-290-3200 for information. www.in.nrcs.usda.gov/
- The Purdue Extension Water Quality Web Site provides information and recommendations on many water quality subjects. www.ces.purdue.edu/waterquality/index.htm.
- Contact Purdue Extension, 1-888-EXT-INFO, and ask for the Aquaculture Specialist's contact information for fish related questions and ask for the Entomology Department for mosquito related questions.
- Jonathon Ferris, Purdue Extension Educator, is an aquaculture expert and can be contacted at 765-529-5002 for pond management questions.

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This publication is dedicated in memory of Chris Bitler, former Newton County Educator and Purdue Extension Water Quality Team member.

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Storm Water Wetlands

Storm Water Management Benefits

Pollutant Reduction

Sediment	■
Phosphorous	■
Nitrogen	■
Metals	■
Pathogens	◘
Floatables*	■
Oil and Grease*	■
Dissolved Pollutants	◘

Runoff Volume Reduction	□
Peak Flow Control	■

Key:
■ Significant Benefit
◘ Partial Benefit
□ Low or Unknown Benefit

*Only if a skimmer is incorporated

Implementation Requirements

Construction Cost	**High**
Maintenance Cost	**Moderate**

1.0 Description

Storm water wetlands are constructed wetlands that incorporate marsh areas and permanent pools to provide enhanced treatment and attenuation of storm water flows. Storm water wetlands differ from storm water ponds in that wetland vegetation is a major element of the overall treatment mechanism as opposed to a supplementary component. It should be noted that this BMP only applies to constructed wetland systems as opposed to natural wetland systems, which are waters of the State and are protected. This section includes three types of storm water wetlands:

- Shallow Wetland
- Extended Detention Shallow Wetland
- Pond/Wetland System.

While storm water wetlands can provide some of the ecological benefits associated with natural wetlands, these benefits are secondary to the function of the system to treat storm water. Storm water wetlands can be very effective at removing pollutants and reducing peak flows of runoff from developed areas. Removal of particulate pollutants in storm water wetlands can occur through a number of mechanisms similar to storm water ponds including sedimentation and filtration by wetland vegetation. Soluble pollutants can also be removed by adsorption to sediments and vegetation, absorption, precipitation, microbial decomposition, and biological processes of aquatic and fringe wetland vegetation. Storm water wetlands are particularly advantageous compared to other BMPs when nitrogen and/or dissolved pollutants are a concern.

The key to maximizing pollutant removal effectiveness in storm water wetlands is maintaining wet conditions adequate to support wetland vegetation. To achieve this, the constructed wetlands must either intercept the groundwater table or must be lined with an impermeable liner and have a watershed large enough to supply storm flows that will maintain wetness even during dry periods.

Storm water wetland systems should be designed to operate on the plug flow principle where incoming water displaces the water retained in the system from the previous storm event. This is accomplished by maximizing length versus width ratios and/or by creating distinct cells along the treatment path. Ideally, the wetland system would be designed to retain the water quality volume (WQV) between storm events. As a result, storms that generate runoff less than the WQV would be entirely retained while only a percentage of the runoff from storms that generate more than the WQV would be retained. The value provided by this process is that a portion of the "new" polluted runoff is retained, and the "old" treated water is discharged from the wetland, thereby allowing extended treatment of the WQV.

Storm water wetlands should be equipped with a sediment forebay or similar form of pretreatment to minimize the discharge of sediment to the primary treatment wetland. High solids loadings to the system will degrade system performance and result in more frequent cleaning, which could result in additional disturbance to the wetland vegetation. A micropool or permanent pool is also often included just prior to the discharge for additional solids removal.

2.0 Design Alternatives

There are several common storm water wetland design variations. The various designs are characterized by the volume of the wetland in the deep pool, high marsh, and low marsh zones, and whether the design allows for detention of small storms above the permanent pool.

a) ***Shallow Wetland:*** Most shallow wetland systems, also referred to as shallow marsh wetlands, consist of aquatic vegetation with a permanent pool ranging from 6 to 18 inches during normal conditions. Shallow wetlands are designed such that flow through the wetlands is conveyed uniformly across the treatment area. While pathways, streams or other varied water depths could enhance the aesthetic or ecosystem value of the wetland, they could also allow short-circuiting through the wetland thereby reducing the overall treatment effectiveness. As a result, providing a uniformly sloped system is required to maximize treatment performance. In order to enhance plug flow conditions across the wetland, individual wetland cells can be constructed and separated by weirs. Figure 11-P2-1 depicts a typical schematic design of a shallow wetland.

b) ***Extended Detention Shallow Wetland:*** Extended detention shallow wetlands provide a greater degree of downstream channel protection as they are designed with more vertical storage capacity. The additional vertical storage volume provides extra runoff detention above the normal pool elevations. Water levels in the extended detention shallow wetland may increase by several feet after a storm event and return gradually to pre-storm elevations within 24 hours of the storm event. The growing area in extended detention shallow wetlands extends from the normal pool elevation to the maximum water surface elevation. Wetland plants that tolerate intermittent flooding and dry periods should be selected for the extended detention area above the shallow marsh elevations. Figure 11-P2-2 depicts a typical schematic design of an extended detention shallow wetland.

c) ***Pond/Wetland Systems:*** Multiple cell systems, such as pond/wetland systems, utilize at least one pond component in conjunction with a shallow marsh component. The first cell is typically a wet pond, which provides pretreatment of the runoff by removing particulate pollutants. The wet pond is also used to reduce the velocity of the runoff entering the system. The shallow marsh then polishes the runoff, particularly for soluble pollutants, prior to discharge. These systems require less space than the shallow marsh systems since more of the water volume is stored in the deep pool which can be designed to reduce peak flows through the system. Because of this system's ability to significantly reduce the velocity and volume of incoming peak flows (i.e., flow equalization or dampening), it can often achieve higher pollutant removal rates than other similarly sized storm water wetland systems. Figure 11-P2-3 depicts a typical schematic design of a pond/wetland system.

3.0 Advantages

a) Efficient at removing both particulate and soluble pollutants. Constructed wetlands are one of the most effective storm water treatment practices for removing soluble pollutants.
b) Capable of providing aesthetic benefits.
c) Capable of providing wildlife habitat with appropriate design elements.
d) Provides ability to attenuate peak runoff flows.

4.0 Limitations

a) More costly than most systems.
b) Requires a relatively large land area that is directly proportional to the size of the contributing drainage area.
c) Very sensitive to the ability to maintain wet conditions especially during extended dry weather when there may be significant evaporative losses. Lined systems require a minimum drainage area in order to maintain a permanent pool, which may become difficult during extended dry periods.
d) May cause thermal impacts to receiving waters and thereby are not recommended to discharge directly to cold water fish habitats.
e) Potential breeding habitat for mosquitoes. Circulating water in the permanent pool and proper pool depths should minimize this problem.
f) Wetland systems with steep side slopes and/or deep wet pools may present a safety issue to nearby pedestrians without adequate protection.

g) Unlined systems that intercept groundwater have potential to impact groundwater quality if dissolved pollutants are present in the runoff. This is important in areas sensitive to groundwater quality.
h) Requires more storage volume (i.e., above permanent pool) to attenuate peak flows.
i) Pollutant removal efficiency can be affected in cold climates due to ice formation on the permanent pool and longer particle settling times associated with higher density water during winter months. However, constructed wetlands can be designed to maintain the primary pollutant removal mechanism of sedimentation.

5.0 Siting Considerations

a) ***Drainage Area:*** Storm water wetlands that utilize a liner system to maintain the desired permanent pool should have a contributing drainage area that is adequate to maintain minimum water levels. Typically, minimum contributing drainage areas are twenty-five acres especially for shallow systems. A water budget for the wetlands should be calculated to ensure that evaporation losses do not exceed inflows during warm weather months.

b) ***Groundwater:*** Unlined basins must intersect the groundwater table in order to maintain the desired permanent pool. This is the desired condition to optimize the establishment of a wet pool. In this case, the elevations of the basin should be established such that typical groundwater elevations (not the high groundwater elevation) are equal to the desired permanent pool elevation. Seasonal variations of groundwater elevations should be considered, which can be very pronounced in low permeability soils.

Liners will be required for these systems where groundwater quality is a critical concern such as GAA classified areas or where the system is upgradient to nearby public or private drinking water wells. This is only a precaution since organic sediments that would accumulate in these systems should capture much of the soluble pollutant load prior to discharge to groundwater.

c) ***Land Uses:*** Land uses will both dictate potential pollutants-of-concern as well as potential safety risks. For those land uses where there is significant potential for soluble pollutants, especially those that are highly susceptible to groundwater transport and contamination such as from petroleum hydrocarbons, the use of a liner is recommended. Some of these risks can be mitigated by using appropriate pretreatment such as an oil/water separator. An impermeable liner may also not be required depending on risk of downstream contamination. With regard to potential safety issues, adjacent residential land uses pose the greatest risks where water hazards must be considered.

d) ***Base Flow:*** A small amount of base flow is desirable to maintain circulation and reduce the potential for low dissolved oxygen levels during late summer as well as mosquito breeding. This base flow can be provided by groundwater infiltrating into either the wetland or the collection system above the pond.

e) *Site Slopes:* Steep on-site slopes may result in the need for a large embankment to be constructed to provide the desired storage volume. Steep slopes may also present design and construction challenges as well as significantly increase the cost of earthwork.

f) *Receiving Waters:* The sensitivity of receiving waters should be evaluated to determine whether the effects of the warmer storm water discharges from the wetland could be detrimental to cold-water fish or other sensitive aquatic species. Consult RIDEM, Fish and Wildlife Division to determine if the storm water wetland is discharging into a cold water habitat.

g) *Flood Zones:* Constructed wetlands should not be located in floodways, floodplains, or tidal lands, especially those that require construction of an embankment, in a manner that will result in flood waters entering the constructed wetland. Floodwaters could flush out stored pollutants or damage pond embankments.

6.0 Design Criteria

Design considerations for storm water wetlands are presented below and summarized in Table 11-P2-1. If the pond also serves to provide a storm water peak flow detention benefit, the design criteria applicable to detention design in the extended detention basin section should be adhered to.

Table 11-P2-1. Design Criteria for Storm Water Wetlands

Parameter	Design Criteria
Setback requirements	• 50 feet from on-site sewage disposal system • 75 feet from private well • 25 feet from property line (this distance may be reduced with proper fencing or landscaping) • 20 feet from any structure • 50 feet from any residential structure • 50 feet from any steep slope below the berm (greater than 15%) • 200 feet from a surface drinking water supply or tributary • 25 feet from a designated CRMC buffer zone
Side Slopes	3:1 maximum or flatter preferred
Length to Width Ratio	3:1 minimum along the flow path between the inlet and outlet; flow length is the length at mid-depth. Mid-depth is (avg. top width+avg. bottom width)/2
Pretreatment Volume	Forebays are highly recommended for storm water wetlands and sized to contain at least 10% of the WQV. Outlet micropools should also be sized to contain 10% of the WQV
Drainage Area	Minimum contributing drainage area is typically 25 acres for lined systems. Ideally, the watershed to wetland surface area ratio should range between 100:1 to 2.

Underlying Soils	Low permeability soils are best (NRCS Hydrologic Soil Group A and B soils require modifications to maintain a permanent pool unless groundwater is intercepted but may also have greater groundwater fluctuations).
Size	The size of the wetland area will be based on desired pollutant removal efficiencies and the depth of water available to store the WQV Suggested guidelines for the ratio of wetland to watershed areas is 0.2 (20%) for shallow marshes and 0.01 (1%) for extended detention shallow wetland systems and pond/wetlands.
Depth	Average water levels in the marsh/wetland areas can vary between 0.5 and 1.5 feet. Maximum water depths will depend on the site topography and the design of the system. Forebays and micropools should typically have a permanent pool depth of between 4 and 6 feet.
Sediment Storage	Sufficient volume shall be provided in the forebay to store a total of two years of sediment. This sediment volume shall be calculated using the Universal Soil Loss Equation as outlined in the Rhode Island Sediment and Erosion Control Handbook. This volume shall not be included in the WQV storage.
Emergency Spillway	An emergency spillway shall be provided for any fill embankment. The spillway shall be designed to at least convey the 100-year storm across a stabilized spillway away from the embankment.
Embankment	• Embankments should be designed with a minimum one foot of freeboard during the 100-year storm. This freeboard can include the emergency spillway, however, at least six inches of freeboard should be provided above the 100-year storm water surface elevation in the spillway. These depths can be lessened for low risk embankments (short and no potential downstream risks). • For embankments with a maximum height greater than five feet, a minimum embankment width of 10 feet should be provided for maintenance access. Smaller widths can be employed for smaller embankments. • Maintenance access shall be provided to the forebay and the basin such that heavy construction equipment can be used to remove sediment. • Fill embankments designed to retain the permanent pool require special attention because of the potential for embankment soils to become saturated.

Source: Adapted from MADEP, 1997 and Schueler, 1992.

6.1 Forebay

A sediment forebay shall be provided for all constructed wetland systems. The purpose of the forebay is to provide pretreatment by settling out coarse sediment particles, which will enhance treatment performance, reduce maintenance, and increase the longevity of a storm water pond. A forebay is a separate cell within the pond formed by a barrier such as an earthen berm, concrete weir, or gabion baskets.

a) The forebay shall be sized to contain at least 10% of the WQV and be of an adequate depth to prevent resuspension of collected sediments during the design storm, often being four to six feet deep. The goal of the forebay is to remove, at a minimum, particles consistent with the size of medium sand. The forebay must also include additional sediment storage volume that may not be used for WQV calculations.

Alternative technologies sized to remove 80% of the total suspended solids load may be used in lieu of a forebay and its storage requirements.

b) The outlet from the forebay should be designed in a manner to prevent erosion of the embankment and primary pool. This outlet can be configured in a number of ways including a culvert, weir, or spillway channel. The outlet should be designed to convey the same design flow proposed to enter the basin. The outlet invert must be elevated in a manner such that 10% of the WQV can be stored below it in addition to the required sediment volume.

c) The forebay should have a minimum length to width ratio of 2:1 and a preferred minimum length to width ratio of 3:1.

d) Direct access for appropriate maintenance equipment should be provided to the forebay and may include a ramp to the bottom if equipment cannot reach all points within the forebay from the top. The forebay can be lined with a concrete pad to allow easy removal of sediment and to minimize the possibility of excavating subsurface soils or undercutting embankments during routine maintenance.

e) A fixed vertical sediment depth marker should be installed in the forebay to measure sediment deposition.

f) A barrier, such as an earthen berm, gabions, or a concrete weir may be used to separate the forebay from the permanent pool. This barrier should be armored as necessary to prevent erosion of the embankment if it is designed to overtop. This armoring could consist of materials such as riprap, pavers, or geosynthetics designed to resist slope erosion. If a channel is used to convey flows from the forebay to the pond, the side slopes of the channel must be armored as well.

g) Sediment storage capacity shall be provided in the forebay as calculated by the Universal Soil Loss Equation in the *Rhode Island Soil Erosion and Sediment Control Handbook.* Adequate volume to store a minimum of two years of sediment storage from the contributing watershed should be incorporated into the forebay.

h) The required surface area of the sedimentation chamber or forebay for full sedimentation design can be determined using the following equation that is based on Camp-Hazen:

$$A_s = -\frac{Q}{W}\ln(1-E)$$

where:

A_s = sedimentation surface area (ft^2)
Q = discharge rate from drainage area (ft^3/s) $= WQV/86{,}400\text{sec}^*$
W = 0.0004 ft/s particle settling velocity recommended for silt
E = sediment removal efficiency (assume 0.9 or 90%)

*(between 25 and 100 percent of the water quality volume can be used for partial sedimentation design)

Therefore, for the purposes of this manual and for evaluating storm water wetland practices in Rhode Island, use

$$A_s = 5{,}750 * Q$$

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6.2 Wetland/Marsh Area

The size of the wetland/marsh area should be based on pollutant influent concentrations, base flow, peak design flow, and desired effluent concentrations. Kadlec and Knight (1996) have developed area-based, first-order wetland design models to predict treatment area requirements. The use of these models is recommended to size the wetland areas. This model is as follows:

General Model:

$J = k\,(C - C^*)$; where: $k = k_{20}\,\theta_k^{(T-20)}$; $C^* = C^*_{20}\,\theta_c^{(T-20)}$

where:

J	=	Removal rate (g/m²/yr)
k	=	First-order, area-based rate constant (m/yr)
k_{20}	=	Rate constant at 20°C (m/yr)
C	=	Pollutant concentration (mg/L)
C^*	=	Irreducible background concentration (mg/L)
C^*_{20}	=	Irreducible background concentration at 20°C (mg/L)
T	=	Temperature, °C
θ_c	=	Temperature coefficient for background concentration
θ_k	=	Temperature coefficient for rate constant

Wetland Area (based on modified plug-flow hydraulics):

$$A = Q / HLR = \frac{Q}{k} \propto \ln \left[\frac{C_2 - C^*}{C_1 - C^*} \right]$$

where:

HLR	=	Hydraulic loading rate (m/yr) (1 m = 3.28 ft)
A	=	Wetland area at normal pool elevation (m²), excluding habitat islands (1 m² = 10.76 ft²)
Q	=	Design inflow rate (m³/yr) (1 m³ = 35.31 ft³)
C_1	=	Inflow concentration (mg/L)
C_2	=	Outflow concentration (mg/L)

Model Parameter Values (at 20°C):

	BOD	TSS	NH_3-N	NO_3+NO_2-N	TN	TP
K_{20}, m/yr	35	1,000	18	35	22	12
θ_k	1.00	1.00	1.04	1.09	1.05	1.00
C_{20}, mg/L	6	$5.1+0.16C_1$	0.0	0.0	1.5	0.02
θ_c	-	1.065	-	-	-	1.00

BOD = biochemical oxygen demand
TSS = total suspended solids
NH_3-N = ammonia nitrogen
NO_3+NO_2-N = nitrate and nitrite nitrogen
TN = total nitrogen
TP = total phosphorous

In order to better simulate plug flow conditions and minimize short-circuiting, individual wetland cells can be constructed along the flow path. Weirs, berms, or shallow marsh areas can be used to form these cells. However, the cells should be designed such that flow is redistributed along the edge of each cell. Weirs constructed at a uniform elevation should be constructed at the front and end of each cell to reduce flow expansion and contraction and maximize treatment area. The treatment area calculated in the equations presented above only apply to the effective area. Forebay, micropool, and wetland area not available due to short circuiting would not apply to the area required herein.

6.3 *Infiltration Design and Water Balance*

The rate of infiltration through the bottom of the wetland can be estimated by using Darcy's law. For most wetlands, the rate of infiltration is relatively constant unless there is a significant change in groundwater elevations. Wetlands act as storage reservoirs, retaining water during precipitation events and releasing it slowly as outlet flow and infiltration. During summer months when evapotranspiration losses are large, pool levels commonly drop episodically below the design operating level and outflow ceases.

Ideally, wetlands should not completely dewater under conditions of normal precipitation. To identify potential problems, a monthly water balance should be analyzed for the proposed wetland. This evaluation should be done on an annual basis. The pool level at the end of each month can be estimated as follows:

$$PL = PL_0 + [BF + (PR \times AW) + (PR \times AD \times RO) - (ET \times AW) - (I \times A)] / A$$

where:
- PL = Pool depth at the end of month (feet)
- PL_0 = Pool depth from the previous month (feet)
- BF = Total monthly flow into the wetland (acre-feet)
- PR = Total monthly precipitation (feet)
- AW = Area of wetland (acres)
- AD = Area of tributary drainage (acres)
- RO = Runoff Coefficient
- ET = Monthly potential evapotranspiration (feet)
- A = Area inundated at depth PL_0 (acres)
- I = Monthly infiltration (feet)

Table 11-P2-2 lists average monthly precipitation and potential evapotranspiration data to be used for water balance calculations in Rhode Island.

Table 11-P2-2. Average Monthly Precipitation and Potential Evapotranspiration for Rhode Island

Month	Precipitation (feet)	Potential Evapotranspiration (feet)
January	0.36	0
February	0.29	0
March	0.37	0.03
April	0.35	0.13
May	0.31	0.25
June	0.28	0.38
July	0.26	0.47
August	0.33	0.42
September	0.31	0.29
October	0.31	0.17
November	0.37	0.08
December	0.35	0.01

Sources: NOAA-EDIS Climatological Data, 2003, T.F. Green Airport, Warwick, RI. Worldwide Bioclimatic Classification System, 2003, Quonset Point, RI.

If the calculated pool depth at the end of the month is greater than the normal pool depth established at the outlet, then outflow will occur during that month. The quantity is not important. In months with a net outflow, the beginning pool depth for the next month will equal the normal pool depth. See the chapter on Storm Water Ponds for an example of a water balance calculation.

In most wetlands, the area that is inundated varies with depth. The normal operating pool depth also may be adjusted seasonally to accommodate changes in the water budget. These factors should be accounted for in the calculation. If the water balance predicts that the wetland will dewater, design modifications can be considered, including:

a) Reducing the infiltration rate by adding a clay layer or synthetic liner
b) Relocating the proposed wetland to increase the contributing drainage area
c) Increasing the normal operating pool level.

Limitations on increasing the normal pool level will be imposed by the need for shallow water habitat to support emergent plant vegetation. Short periods during which the wetland becomes dry may be tolerated in some instances. However, the selection of plants must be tailored to accommodate these adverse conditions and special considerations will be required for the maintenance of the wetland during dry periods.

6.4 Inlet Protection

a) Inlet areas should be stabilized with riprap or other energy dissipation device to ensure that non-erosive conditions exist for the design storm event.
b) The ideal inlet configuration is above the permanent pool, not submerged, since this can result in freezing and upstream damage or flooding as well as minimize tail water conditions.
c) The number of inlets should be minimized, and one inlet is preferable. The inlet should be located at the most hydraulically remote point from the outlet, but in any case should be located in a manner that meets or exceeds desired length to width ratios. One exception would be allowed for minor outlets where less than 10% of the total volume of runoff enters the basin.
d) Inlet areas should be stabilized to ensure that non-erosive conditions exist for the design storm event.

6.5 Outlet Protection

a) The channel immediately below a pond outfall should be designed as necessary to prevent erosion and conform to natural topography. An energy dissipator shall be appropriately designed as necessary to control erosive conditions at the outlet for at least the two-year frequency storm. Allowable velocities shall be based on actual cover and soil conditions. The maximum permissible velocities are as follows:

Table 11-P2-3. Maximum Permissible Velocity (ft/sec)

Soil Texture	Bare Channel	Channel Vegetation Condition		
		Poor	*Fair*	*Good*
Sand, silt, loam, sandy loam, loamy sand, loam and muck	2.0	2.0	2.5	3.5
Silty clay loam, sandy clay loam, clay, clay loam, sandy clay, silty clay	2.5	3.0	4.0	5.0

Source: Engineering Field Manual for Conservation Practices, USDA Soil Conservation Service, 1979.

b) If a pond outlet discharges to a perennial stream or channel with dry weather base flow, tree clearing should be minimized and a forested riparian zone re-established around the cleared areas adjacent to the channel/stream.

c) To convey potential flood flows from the basin, an armored emergency spillway should be provided if a fill embankment is used. The spillway shall be armored with riprap or other alternative that protects subgrade soils from erosion during the design event. The armoring shall also include a filter fabric and gravel filter. The spillway shall extend beyond the toe-of-slope in a manner to prevent scour of the embankment toe.

6.6 Outlet Micropools

a) An outlet micropool shall be provided for each wetland system that has a direct discharge to a surface water or to a subsurface infiltration system. Other wetland systems that utilize level spreaders or discharge overland do not require a micropool. The purpose of the micropool is to remove solids that may have "detached" from the wetland system prior to discharge.

b) The micropool shall be sized to store at least 10% of the WQV with a length to width ratio of 2 to 3:1. A water depth of 4 to 6 feet shall be provided in the micropool below the outlet invert.

6.7 Wetland Liners

a) When the permanent pool does not intercept groundwater at its minimum levels, a liner may be needed to maintain minimum water levels. Liners are also necessary for wetland systems that may present a risk to groundwater quality. Table 11-P2-4 lists recommended specifications for clay and geomembrane liners.

b) When used, at a minimum, the liner should extend across the permanent pool area.

Table 11-P2-4. Storm Water Wetland Liner Specifications

Liner Material	Property	Recommended Specification
Clay	Minimum Thickness	6 to 12 inches
	Permeability	1×10^{-5} cm/sec[1]
	Particle Size	Minimum 15% passing #200 sieve[1]
Geomembrane	Minimum Thickness	30 millimeters
	Material	Ultraviolet resistant, impermeable poly-liner
		Geotextile fabric should be installed on the top and bottom of the geomembrane to protect against puncture, tearing, and abrasion

Source: [1]NYDEC, 2001; all other listed specifications from City of Austin in Washington, 2000 (in Metropolitan Council, 2001).

6.8 Pool Benches

a) For forebay and micropool side slopes steeper than 4:1, provide a flat aquatic bench that extends 10 feet inward from the normal shoreline at a depth of 12-18 inches below the normal pool water surface elevation.

6.9 Maintenance Reduction Features

In addition to regular maintenance activities needed to maintain the function of storm water practices, some design features can be incorporated to ease the maintenance burden of each practice. In constructed wetlands, maintenance reduction features include techniques to reduce the amount of required maintenance, as well as techniques to make regular maintenance activities easier.

a) Outlets should be designed with non-clogging features, such as a weir, or by incorporating trash racks for culverts and orifice openings.
b) When a weir is used, the minimum slot width should be 3 inches.
c) Baffle weirs can prevent ice formation near the outlet by preventing surface ice from blocking the inlet, encouraging the movement of base flow through the system. Baffle weirs are constructed offset from the outlet and extend below normal ice depth.
d) To prevent clogging from ice or floatables, a reverse slope outlet pipe can be used to draw water from below the permanent pool up to the outlet structure. The invert of the pipe drawing from the pool should be at least 18 inches from the bottom to prevent sediment discharge.
e) Riser hoods and reverse slope pipes should draw from at least 12 inches below the low level outlet. This design encourages circulation in the pond, preventing stratification and formation of ice at the outlet. Reverse slope pipes should not be used for off-line ponds.
f) No orifices should be smaller than 6 inches in diameter unless a trash rack is added to prevent clogging.
g) Trash racks should be installed at a shallow angle (80-85 degrees).
h) Outlet structures should be resistant to frost heave and ice action in the pond.

6.10 Landscaping/Vegetation

High pollutant removal efficiencies are dependent on a dense cover of emergent plant vegetation. Actual plant species do not appear to be as important as plant growth habitat. In particular, plants should be used that have high colonization and growth rates, can establish large surface areas that continue through the winter dormant season, have high potential for treating pollutants, and are very robust in flooded environments. Appendix A contains planting guidance for storm water wetlands. Other landscaping criteria include the following:

a) Soils should be modified (e.g., scarified or tilled) to mitigate compaction that occurs during construction around the proposed planting sites.
b) Woody vegetation may not be planted or allowed to grow on the embankment as well as within 25 feet of the toe of the embankment and 25 feet from the principal spillway structure. However, woody vegetation can be planted along excavated banks of the basin as long as maintenance access is allowed.
c) The best depth for establishing wetland plants, either through transplantation or voluntary colonization, is within approximately six inches of the normal pool elevation.

d) Existing trees should be preserved in the area around the wetland during construction. It is desirable to locate forest conservation areas adjacent to ponds and wetlands. To help discourage resident geese populations, the buffer can be planted with trees, shrubs, and native ground covers.
e) Annual mowing of the area around the wetland is only required along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing every other year) or forest.
f) The area of the basin above the pond outlet shall be stabilized with a seed mixture that is tolerant to periodic flooding and is resistant to erosion.

7.0 Construction

a) Avoid soil compaction to promote growth of vegetation.
b) Temporary erosion and sediment controls should be used during construction, and sediment deposited in the wetlands should be removed after construction, but before wetland vegetation is planted.
c) Temporary dewatering may be required if excavation extends below the water table. Appropriate sedimentation controls will be required for any dewatering discharges.
d) Establishment of wetland plantings is critical. As a result, installation should be as directed by a biologist or landscape architect.
e) Upstream areas should be stabilized to the greatest extent practicable prior to planting wetland plants, especially in areas where significant amounts of sediment would collect.
f) Appropriate soil stabilization methods should be used before permanent vegetation is established. Seeding, sodding, and other temporary soil stabilization controls should be implemented in accordance with the *Rhode Island Soil Erosion and Sediment Control Handbook.*

8.0 Inspection and Maintenance

a) Plans for storm water wetlands should identify detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance.
b) The principal outlet should be equipped with a removable trash rack, and generally accessible from dry land.
c) Sediment removal in the forebay and micropool should occur at a minimum of every five years or before the sediment storage capacity has been filled. A permanent sediment marker should be used to check sediment depths.
d) Inspect twice per year for the first three years to evaluate plant sustainability, water levels, slope stability, and the outlet structure.
e) Perform maintenance outside of vegetative growing and wildlife seasons.
f) Harvesting of dead plant material is not required except in cases where high pollutant removal efficiencies, especially for nutrients, are required.
g) Sediment removed during construction can be incorporated into on-site fill areas. After construction, this sediment shall be managed in accordance to RIDEM requirements for street sand.

h) Recommended long-term maintenance activities for constructed wetlands are summarized in Table 11-P2-5.

8.1 Maintenance Access

a) A maintenance right of way or easement should extend to the pond from a vehicular point of access.
b) Maintenance access should be at least 10 feet wide, have a maximum slope of no more than 15%, and be appropriately stabilized to withstand maintenance equipment and vehicles.
c) The maintenance access should extend to the forebay, inlet, emergency spillway, embankment, micropool and outlet where possible.

8.2 Outlet Riser in Embankment

a) The riser should be located within the embankment for maintenance access, safety, and aesthetics.
b) Lockable manhole covers, and manhole steps within easy reach of valves and other controls should provide access to the riser.

8.3 Drain

a) Except where local slopes prohibit this design, each wetland should have a drain pipe that can completely or partially drain the wetland. The drain pipe shall have an elbow or protected intake within the pond to prevent sediment deposition, and a diameter capable of draining the wetland within 24 hours.
b) Care should be exercised during draining to prevent rapid drawdown and minimize downstream discharge of sediments or anoxic water. The approving jurisdiction must be notified before draining.
c) Outlet valve shall be located in the riser.

Table 11-P2-5. Typical Maintenance Activities for Storm Water Wetlands

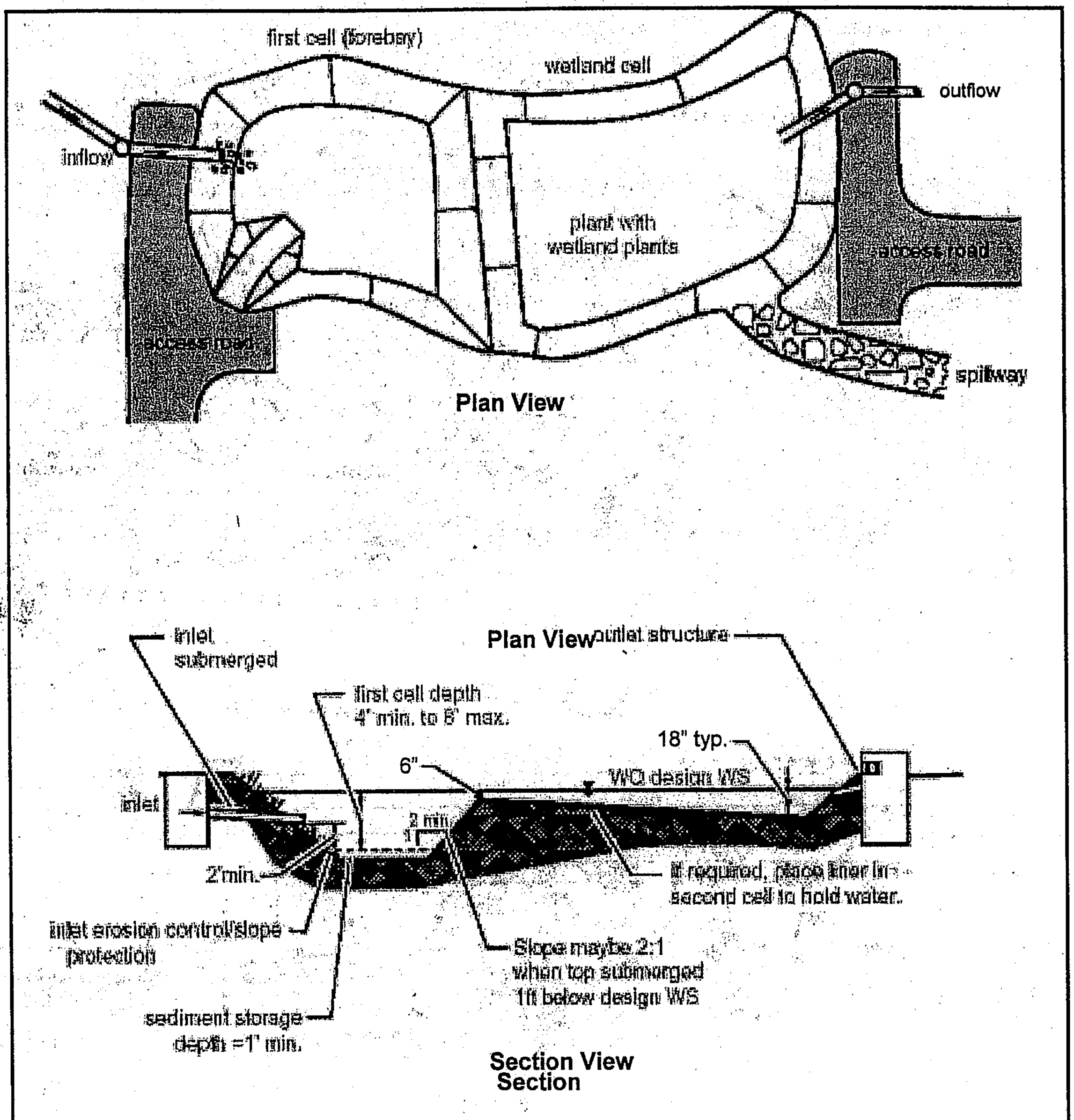
Activity	Schedule
• If necessary, re-plant wetland vegetation to maintain at least 50% surface area coverage in wetland plants after the second and third growing seasons. ☐	As needed
• Inspect for invasive vegetation and remove where possible. • Monitor water levels in the wetlands	Semi-annual inspection
• Inspect for damage to the embankment and inlet/outlet structures. Repair as necessary. • Note signs of hydrocarbon build-up, and deal with appropriately. • Monitor for sediment accumulation in the facility, forebay and micropool. • Examine to ensure that inlet and outlet devices are free of debris and are operational. ☐	Annual inspection
• Repair undercut or eroded areas. ☐	As needed maintenance
• Clean and remove debris from inlet and outlet structures.☐ • Mow side slopes. ☐	Frequent (3-4 times/year) maintenance
• Harvest wetland plants that have been "choked out" by sediment build-up.	Annual maintenance (if needed)
• Removal of sediment from the forebay and micropool. ☐	As needed, minimum 5 year maintenance
• Monitor sediment accumulations, and remove sediment when the wetland volume has become reduced significantly, plants are "choked" with sediment, or the wetland becomes eutrophic. ☐	As needed, typical 20 to 50 year maintenance

Source: WMI, 1997.

9.0 Cost Considerations

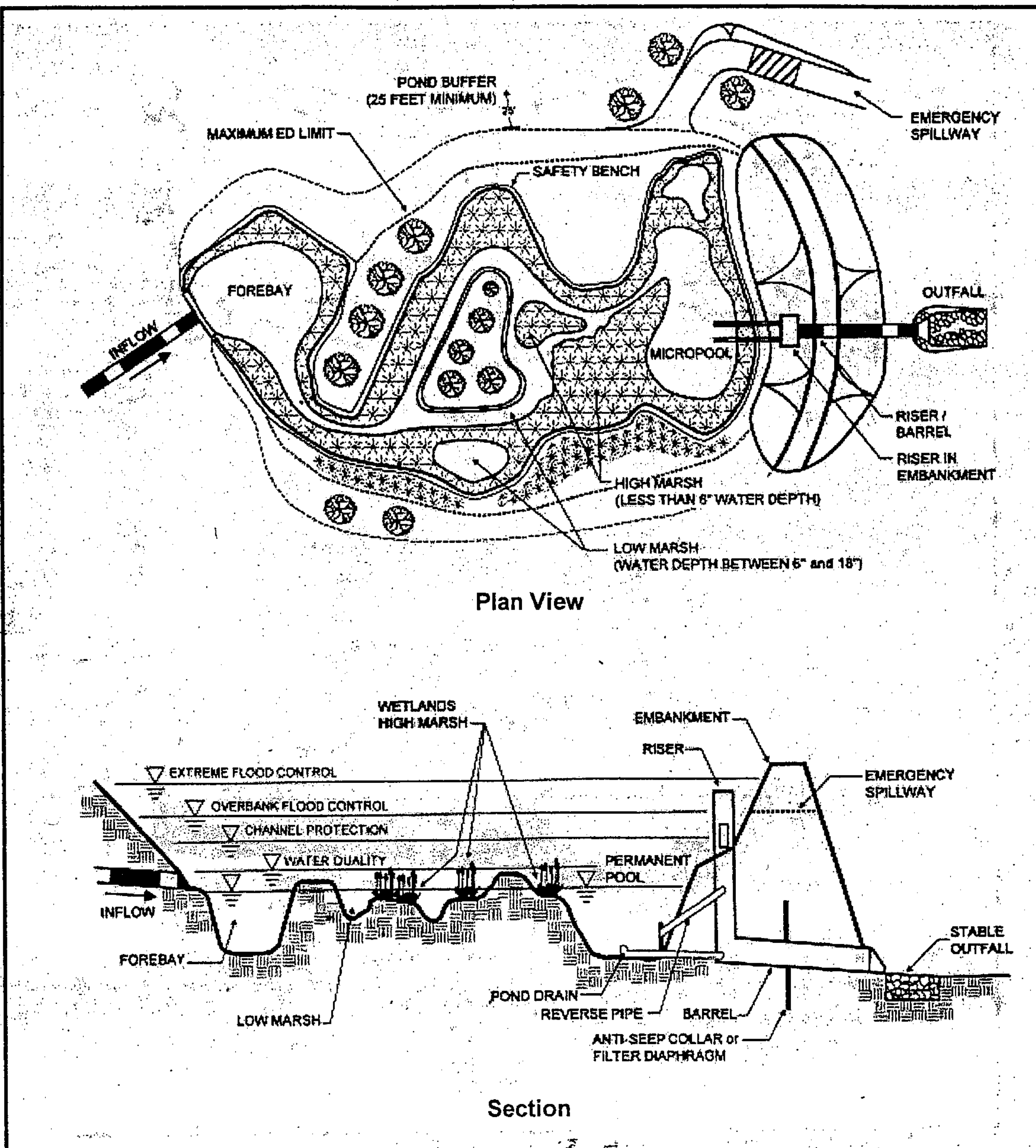
Storm water wetlands are relatively inexpensive storm water treatment practices, but vary widely depending on the complexity of the design or site constraints. The costs of storm water wetlands are generally 25 percent more expensive than storm water ponds of an equivalent volume (Brown and Schueler, 1997). The annual cost of routine maintenance is typically estimated at approximately 3 to 5 percent of the construction cost (EPA Storm Water Wetland Fact Sheet, www.epa.gov/npdes/menuofbmps/menu.htm). Storm water wetlands typically have a design life longer than twenty years.

Figure 11-P2-1. Shallow Wetland



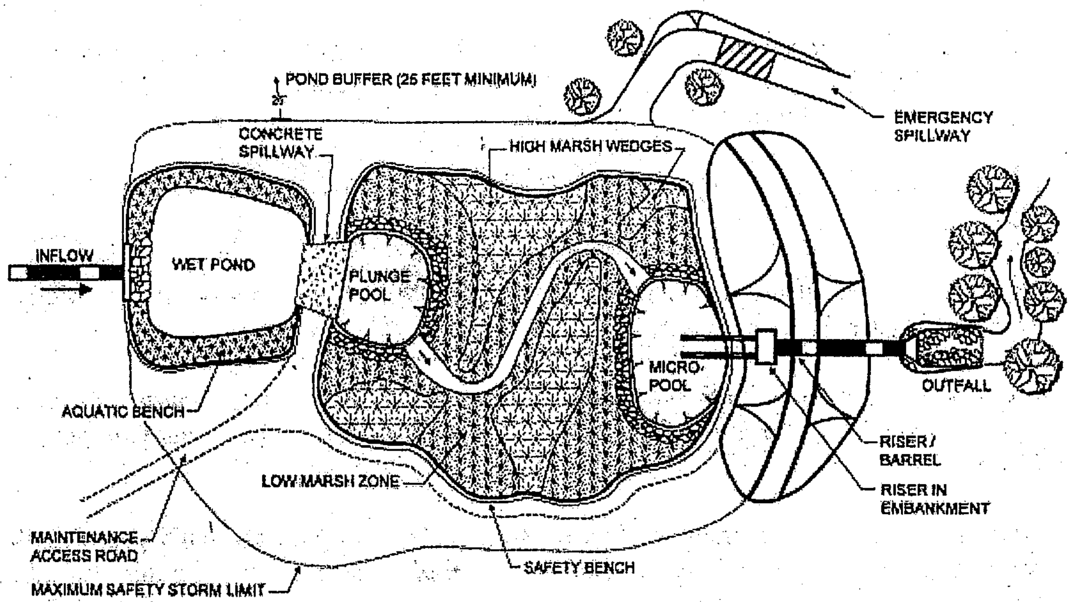
Source: Adapted from King County Department of Natural Resources, 1998.

Figure 11-P2-2. Extended Detention Shallow Wetland

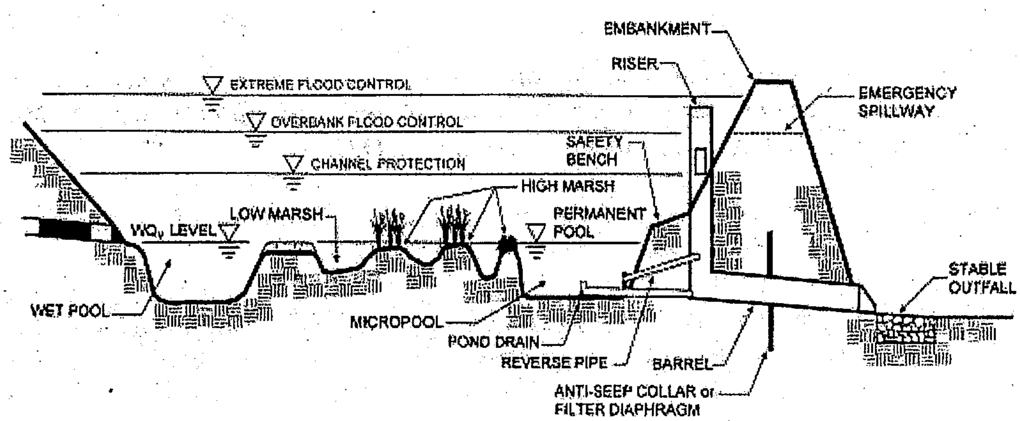


Source: Adapted from NYDEC, 2001.

Figure 11-P2-3. Pond/Wetland System



Plan View



Section

Source: Adapted from NYDEC, 2001.

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Storm Water Ponds

Storm Water Management Benefits

Pollutant Reduction

Sediment	■
Phosphorous	■
Nitrogen	■
Metals	■
Pathogens	◘
Floatables*	■
Oil and Grease*	■
Dissolved Pollutants	◘
Runoff Volume Reduction	◘
Peak Flow Control	■

Key: ■ Significant Benefit ◘ Partial Benefit □ Low or Unknown Benefit

*Only if a skimmer is incorporated

Implementation Requirements

Construction Cost	**Moderate**
Maintenance Cost	**Moderate**

1.0 Description

Storm water ponds are vegetated ponds that retain a permanent pool of water and are constructed to provide both treatment and attenuation of storm water flows. This section addresses four types of storm water ponds:

- Wet Pond
- Micropool Extended Detention Pond
- Wet Extended Detention Pond
- Multiple Pond System.

Through careful design, storm water ponds can be effective at removing urban pollutants. Treatment is primarily achieved by the sedimentation process where suspended particles and pollutants settle to the bottom of the pond. Storm water ponds can also potentially reduce soluble pollutants in storm water discharges by adsorption to sediment, bacterial decomposition, and the biological processes of aquatic and fringe wetland vegetation.

The key to maximizing the pollutant removal effectiveness of storm water ponds is maintaining a permanent pool. To achieve this, wet ponds typically require a large contributing watershed and either an impermeable liner or an elevated water table when a liner is not used. The pool typically operates on the instantaneously mixed reservoir principle where incoming water mixes with the existing pool and undergoes treatment through sedimentation and the other processes. When the existing pool is at or near the pond outlet or when the primary flow path through the pond is highly linear, the pond may act as a plug flow system in which incoming water displaces the permanent pool, which is then discharged from the pond. The value provided by this process is that a portion of the "new," polluted runoff is retained as the "old," treated water is discharged from the pond, thereby allowing extended treatment of the water quality volume (WQV). For example, when sized to store the WQV, a pond system will retain all of the water from storms that generate runoff less than or equal to the WQV and result in a significantly increased period of time available for treatment. For storms that generate runoff greater than the WQV, wet ponds still provide treatment through conventional settling and filtration for the additional runoff volume that is conveyed through the pond. The total pond volume is dependent on the pond design and removal goals but should be greater than or equal to the WQV to ensure a retention time within the pond of at least one day.

When properly designed, the permanent pool reduces the velocity of incoming water to prevent resuspension of particles and promote settling of newly introduced suspended solids. The energy dissipation and treatment properties of the permanent pool are enhanced by aquatic vegetation, which is an essential part of the storm water pond design.

Several design alternatives of storm water ponds exist that can fit a wide range of design conditions. Descriptions of these design alternatives are provided in the following section. However, the greater portion of the WQV that is retained in the permanent pool will result in a greater treatment potential.

2.0 Design Alternatives

Wet ponds typically consist of two general components - a forebay and a permanent wet pool. The forebay provides pretreatment by capturing coarse sediment particles in order to minimize the need to remove the sediments from the primary wet pool. The wet pool serves as the primary treatment mechanism and where much of the retention and detention capacity exists. Wet ponds can be sized for a wide range of watershed sizes, if adequate space exists. For example, a variation on the conventional wet pond, sometimes referred to as a "pocket pond", is intended to serve relatively small drainage areas (between one and five acres). Because of these smaller drainage areas and the resulting lower hydraulic loads of pocket ponds, their outlet structures can be simplified and often do not have safety features such as low level drains. Figure 11-P1-1 depicts a typical schematic design of a conventional wet pond, while Figure 11-P1-2 shows a typical schematic design of a modified wet pond or "pocket pond".

Several adaptations of this basic design have been developed to achieve the specific treatments goals of various watershed or site conditions. These wet pond design variations are described below.

a) *Micropool Extended Detention Pond:* Micropool extended detention ponds are primarily used for peak runoff control and utilize a smaller permanent pool than conventional wet ponds. While micropool extended detention ponds are not as efficient as wet ponds for the removal of pollutants, they should be considered when a large open pool might be undesirable or unacceptable. Undesirable conditions could include thermal impacts to receiving streams from a large open pool, safety and mosquito concerns in residential areas, or where maintaining a large open pool of water would be difficult due to a limited drainage area or deep groundwater.

Micropool extended detention ponds are also beneficial as a storm water retrofit to improve the treatment performance of existing detention basins. Figure 11-P1-3 depicts a typical schematic design of a micropool extended detention pond.

b) *Wet Extended Detention Ponds:* These ponds are very similar to wet ponds with the exception that their design is more focused on attenuating peak runoff flows. As a result, more storage volume is committed to managing peak flows as opposed to maximizing the wet pool depth. The configuration of the outfall structure may also differ from typical wet pond designs to provide additional storage volume above the level of the permanent pool. Figure 11-P1-4 depicts a typical schematic design of a wet extended detention pond.

c) *Multiple Pond System:* Multiple pond systems consist of several wet pools that are constructed in series following a forebay. The advantage of these systems is that they can improve treatment efficiency by better simulating plug flow conditions as compared to a single large wet pool. Also, these systems can reduce overall maintenance needs since more frequent maintenance would be performed within the first pool cells as opposed to the large, primary pool. The disadvantage of these systems is that they typically require more land area to treat the same water quality volume. Figure 11-P1-5 depicts a typical schematic design of a multiple pond system.

The division of storage between the permanent pool and extended detention for each of these design variations is outlined in Table 11-P1-1.

Table 11-P1-1. Water Quality Volume Distribution in Pond Designs

Design Variation	Percent of Water Quality Volume (WQV)	
	Permanent Pool	Extended Detention
Wet Pond	100%	0%
Micropool Extended Detention Pond	20% min.	80% max.
Wet Extended Detention Pond	50% min.	50% max.
Multiple Pond System	50% min.	50% max.

Source: NYDEC, 2001.

3.0 Advantages

a) Can remove both particulate and soluble pollutants. Storm water ponds are one of the most effective storm water treatment practices for removing soluble pollutants.
b) Can provide an aesthetic benefit if open water is desired as part of an overall landscaping plan.
c) May provide wildlife habitat with appropriate design elements.

d) Can be adapted to fit a wide range of sites. Design variations allow this control to be utilized for both small and large drainage areas. Pollutant removal mechanisms make storm water ponds efficient in treatment of pollutants-of-concern from a wide range of land uses.
e) Provides ability to attenuate peak runoff flows.

4.0 Limitations

a) Unlined ponds that intercept groundwater have potential to impact groundwater quality if dissolved pollutants are present in the runoff. This is important in areas sensitive to groundwater quality.
b) Lined ponds require a minimum drainage area in order to maintain a permanent pool. Maintaining a pool may become difficult during extended dry periods.
c) May cause thermal impacts to receiving waters and thereby are not recommended to discharge directly to cold water fish habitats.
d) Requires more storage volume (i.e., above permanent pool) to attenuate peak flows.
e) Potential breeding habitat for mosquitoes if wet pond is not property designed/constructed.
f) Pollutant removal efficiency can be affected in cold climates due to ice formation on the permanent pool and longer particle settling times associated with higher density water during winter months. However, ponds can be designed to maintain the primary pollutant removal mechanism of sedimentation.
g) Ponds with steep side slopes and/or deep wet pools may present a safety issue to nearby pedestrians without adequate protection.

5.0 Siting Considerations

a) ***Drainage Area:*** Storm water ponds that utilize a liner system should have a contributing drainage area that is adequate to maintain minimum water levels. Typically, minimum contributing watersheds for unlined ponds that do not intercept groundwater are twenty-five acres for wet ponds, wet extended detention ponds, and multiple pond systems; ten acres for micropool extended detention ponds; and one to five acres for pocket ponds.

b) ***Groundwater:*** Unlined basins must intersect the groundwater table in order to maintain the desired permanent pool. This is the desired condition to optimize the establishment of a wet pool. In this case, the elevations of the basin should be established such that typical groundwater elevations (not the high groundwater elevation) are equal to the desired permanent pool elevation. Seasonal variations of groundwater elevations should be considered, which can be very pronounced in low permeability soils.

Liners will be required for these systems where groundwater quality is a critical concern such as GAA classified areas or where the system is upgradient to nearby public or private drinking water wells. This is only a precaution since organic sediments that would accumulate in these systems should capture much of the soluble pollutant load prior to discharge to groundwater.

c) ***Land Uses:*** Land uses will both dictate potential pollutants-of-concern as well as potential safety risks. For those land uses where there is significant potential for soluble pollutants, especially those that are highly susceptible to groundwater transport and contamination such as from petroleum hydrocarbons, the use of a liner is recommended. Some of these risks can be mitigated by using appropriate pretreatment such as an oil/water separator. An impermeable liner may also not be required depending on risk of downstream contamination. Consider potential safety issues in all adjacent land uses.

d) ***Base Flow:*** A small amount of baseflow is desirable to maintain circulation and reduce the potential for low dissolved oxygen levels during late summer. This baseflow can be provided by groundwater infiltrating into either the basin or the collection system above the pond.

e) ***Site Slopes:*** Steep on-site slopes may result in the need for a large embankment to be constructed to provide the desired storage volume. Steep slopes may also present design and construction challenges, as well as significantly increase the cost of earthwork.

f) ***Receiving Waters:*** The sensitivity of receiving waters should be evaluated to determine whether the effects of the warmer storm water discharges from the facility could be detrimental to cold water fish or other sensitive aquatic species. Consult RIDEM, Fish and Wildlife Division to determine if the facility is discharging into a cold water habitat.

It should be noted that storm water ponds can discharge bacteria, pathogens, and soluble pollutants. As a result, this practice may not be appropriate where receiving water may be impaired or sensitive to these pollutants-of-concern.

g) ***Flood Zones:*** Ponds should not be located in floodways, and shall not be located in floodways or tidal lands.

h) ***Buffer Zones:*** Facilities shall not be located in regulatory buffer zones.

6.0 Design Criteria

Design considerations for storm water ponds are presented below and summarized in Table 11-P1-2. If the pond also serves to provide a storm water peak flow detention benefit, the design criteria applicable to detention design in the extended detention basin section should be adhered to.

Table 11-P1-2. Design Criteria for Storm Water Ponds

Parameter	Design Criteria
Setback requirements	• 50 feet from on-site sewage disposal systems • 75 feet from private wells • 25 feet from a property line (this distance may be reduced with proper fencing or landscaping) • 20 feet from any structure • 50 feet from any residential structure • 50 feet from any steep slope below the berm (greater than 15%) • 200 feet from a surface drinking water supply or tributary if unlined • 25 feet from a designated CRMC buffer zone
Side Slopes	3:1 maximum or flatter preferred
Length to Width Ratio	3:1 minimum along the flow path between the inlet and outlet; flow length is measured at mid-depth (avg. top width+avg. bottom width)/2
Forebay	Forebays are highly recommended for wet ponds and at a minimum sized to contain 10% of the WQV.
Pond Volume	Minimum total pond volume, including pretreatment volume, shall be equal to or exceed the WQV.
Underlying Soils	Low permeability soils are best. NRCS Hydrologic Soil Group A and B soils require modifications to maintain a permanent pool unless groundwater is intercepted. These types of soils may also have greater groundwater fluctuations.
Depth	• An average permanent pool depth of 3 to 6 feet is recommended and varying depths in the pond are preferred. It should not be greater than 8 feet deep. • The aquatic bench should be 12-18 inches deep.
Sediment Storage	Sufficient volume shall be provided to store a total of ten years of sediment in accordance with the Universal Soil Loss Equation as outlined in Appendix B.
Emergency Spillway	An emergency spillway shall be provided for any fill embankment. The spillway shall be designed to at least convey the 100-year storm across a stabilized spillway away from the embankment.
Embankment	• The embankment needs to be designed with a minimum one foot of freeboard during the 100-year storm. This freeboard can include the emergency spillway, however, at least six inches of freeboard should be provided above the 100-year storm water surface elevation in the spillway. These depths can be lessened for low risk embankments (short and no potential downstream risks). • For embankments with a maximum height greater than five feet, a minimum embankment width of 10 feet should be provided for maintenance access. Smaller widths can be employed for smaller embankments or alternative designs that can be demonstrated to be technically feasible. • Maintenance access shall be provided to the forebay and the structure such that heavy construction equipment can be used to remove sediment.

	• Fill embankments designed to retain the permanent pool require special attention because of the potential for embankment soils to become saturated.

6.1 Forebay

A sediment forebay shall be required to minimize maintenance needs for all wet pond systems. The purpose of the forebay is to provide pretreatment by settling out coarse sediment particles. This will enhance treatment performance, reduce maintenance, and increase the longevity of a storm water pond. A forebay is a separate cell within the pond formed by a barrier such as an earthen berm, concrete weir, or gabion baskets.

a) The forebay shall be sized to contain at least 10% of the WQV and be of an adequate depth to prevent resuspension of collected sediments during the design storm, often being three feet deep. Shallower depths should be evaluated such that flow through velocities do not exceed 2 ft/sec for all design storms. The goal of the forebay is to at least remove particles consistent with the size of medium sand. The forebay storage volume may be used to fulfill the total WQV requirement of this system. The forebay must also include additional sediment storage volume that may not be used for WQV calculations.
b) Alternative technologies sized to remove 80% of the total suspended solids load may be used in lieu of a forebay and its storage requirements.
c) The outlet from the forebay should be designed in a manner to prevent erosion of the embankment and primary pool. This outlet can be configured in a number of ways, such as a culvert, weir, or spillway channel. The outlet should be designed to convey the same design flow proposed to enter the basin. The outlet invert must be elevated in a manner such that 10% of the WQV as well as the required sediment volume can be stored below it.
d) The forebay needs to have a minimum length to width ratio of 2:1 and a preferred minimum length to width ratio of 3:1.
e) Direct access for appropriate maintenance equipment needs to be provided to the forebay and may include a ramp to the bottom of the embankment if equipment cannot reach all points within the forebay from the top of the embankment. The forebay can be lined with a concrete pad to allow easy removal of sediment and to minimize the possibility of excavating subsurface soils or undercutting embankments during routine maintenance.
f) A fixed vertical sediment depth marker should be installed in the forebay to measure sediment deposition.
g) A barrier, such as an earthen berm, gabions, or a concrete weir may be used to separate the forebay from the permanent pool. This barrier should be armored as necessary to prevent erosion of the embankment if it is designed to overtop. This armoring could consist of materials such as riprap, pavers, or geosynthetics designed to resist slope erosion. If a channel is used to convey flows from the forebay to the pond, the side slopes of the channel must be armored as well.
h) Sediment storage capacity shall be provided in the forebay as calculated by the Universal Soil Loss Equation in the *Rhode Island Soil Erosion and Sediment Control Handbook.* Adequate volume to store a minimum of five years of sediment storage from the contributing watershed should be incorporated into the forebay.

i) The required surface area of the sedimentation chamber or forebay for full sedimentation design can be determined using the following equation that is based on Camp-Hazen:

$$A_s = -\frac{Q}{W}\ln(1-E)$$

where:

A_s = sedimentation surface area (ft^2)
Q = discharge rate from drainage area (ft^3/s) = $WQV/86{,}400\,\text{sec}^*$
W = 0.0004 ft/s particle settling velocity recommended for silt
E = sediment removal efficiency (assume 0.9 or 90%)

*(between 25 and 100 percent of the water quality volume can be used for partial sedimentation design)

Therefore, for the purposes of this manual and for evaluating storm water filtering practices in Rhode Island, use

$$A_s = 5{,}750 * WQV$$

6.2 Permanent Pool

Storm water pond design features primarily enhance the removal of pollutants by increasing the residence time of storm water in the pond and providing habitat for aquatic plants.

a) Provide water quality treatment storage to capture the computed WQV from the contributing drainage area in the proposed forebay and permanent pool. This volume shall be strictly the volume available below the pond's lowest free outfall, excluding that volume reserved for sediment storage.
b) The portion of the water quality volume retained is dependant on the specific design selected (see Table 11-P1-1). The more volume that is retained will result in the greater treatment potential provided by this pool. A larger volume should be used to achieve greater pollutant removal when it is necessary to meet specific water quality standards.
c) Water quality storage can be provided in multiple cells. Performance is enhanced when multiple treatment pathways are provided by using multiple cells, longer flow paths, high surface area to volume ratios, complex microtopography, and/or redundant treatment methods (combinations of pool, extended detention, and marsh).
d) Underwater or marsh berms may be incorporated in the design to lengthen the flow path through the pond.
e) Provide variable permenant pool depths of 3 to 6 feet but should not exceed a depth of 8 feet.

6.3 Infiltration Design and Water Balance

The rate of infiltration through the bottom of the pond can be estimated by using Darcy's law. For most ponds, the rate of infiltration is relatively constant unless there is a significant change in groundwater elevations. Storm water ponds act as storage reservoirs, retaining water during precipitation events and releasing it slowly as outlet flow and infiltration.

During summer months when evapotranspiration losses are large, pool levels commonly drop below the design operating level and outflow ceases.

Ideally, ponds should not completely dewater under conditions of normal precipitation. To identify potential problems for ponds that are not connected to groundwater or lined with an impermeable liner. A monthly water balance should be analyzed for the proposed storm water pond. The pool level at the end of each month can be estimated as follows:

$$PL = PL_0 + [BF + (PR \times AW) + (PR \times AD \times RO) - (ET \times AW) - (I \times A)] / A$$

where:
- PL = Pool depth at the end of month (feet)
- PL_0 = Pool depth from the previous month (feet)
- BF = Total monthly base flow into the pond (acre-feet)
- PR = Total monthly precipitation (feet)
- AW = Area of pond (acres)
- AD = Area of tributary drainage (acres)
- RO = Runoff Coefficient
- ET = Monthly potential evapotranspiration (feet)
- A = Area inundated at depth PL_0 (acres)
- I = Monthly infiltration (feet)

Table 11-P1-3 lists average monthly precipitation and potential evapotranspiration data to be used for water balance calculations in Rhode Island.

Table 11-P1-3. Average Monthly Precipitation and Potential Evapotranspiration for Rhode Island

Month	Precipitation (feet)	Potential Evapotranspiration (feet)
January	0.36	0
February	0.29	0
March	0.37	0.03
April	0.35	0.13
May	0.31	0.25
June	0.28	0.38
July	0.26	0.47
August	0.33	0.42
September	0.31	0.29
October	0.31	0.17
November	0.37	0.08
December	0.35	0.01

Sources: NOAA-EDIS Climatological Data, 2003, T.F. Green Airport, Warwick, RI. Worldwide Bioclimatic Classification System, 2003, Quonset Point, RI.

If the calculated pool depth at the end of the month is greater than the normal pool depth established at the outlet, then outflow will occur during that month. The quantity is not important. In months with a net outflow, the beginning pool depth for the next month will equal the normal pool depth.

Example: Given a 0.5 acre storm water pond with a pond depth of 1 foot on May 31st, what is the pond depth should be expected on June 31st?

AD = 5 acres
RO = 0.6
A = 0.25 acres
I = 5 feet
BF = 0 acre-feet

$PL = PL_0 + [BF + (PR \times AW) + (PR \times AD \times RO) - (ET \times AW) - (I \times A)] / A$

PL=1 + [0 + (0.28 x 0.5) + (0.28 x 5 x 0.6) – (0.38 x 0.5) – (5 x 0.25)] / 0.25

PL = -0.84 feet (The standing water in the pond lost a total of 0.84 feet.)*

*The calculated PL may then be used as PL_0 in calculations to determine the water balance for July.

In most storm water ponds, the area that is inundated varies with depth. The normal operating pool depth also may be adjusted seasonally to accommodate changes in the water budget. These factors should be accounted for in the calculation. If the water balance predicts that the wetland will dewater, design modifications can be considered, including:

a) Reducing the infiltration rate by adding a clay layer or synthetic liner
b) Relocating the proposed pond to increase the contributing drainage area
c) Increasing the normal operating pool level.

Limitations on increasing the normal pool level will be imposed by the need for shallow water habitat to support emergent plant vegetation. Short periods during which the pond becomes dry may be tolerated in some instances. However, the selection of plants must be tailored to accommodate these adverse conditions and special considerations will be required for the maintenance of the wetland during dry periods.

6.4 *Extended Detention Volume*

a) Hydrologic routing models based on accepted algorithms (e.g., storage indication method, TR-55, TR-20, HEC-HMS) shall be used to route design storms through the detention basin and determine outlet structure configuration and sizing. All routed storms shall be Type III with a 24- hour duration
b) At a minimum, volume should also be designed to have a drain out time of a minimum of 36 hours for the WQV unless adequate permanent pool storage is provided or Stoke's Law analysis demonstrates 80% TSS removal efficiency during the peak two-year storm flows.
c) The inlet and outlet of the pond should be positioned to minimize short-circuiting. Baffles and internal grading can be used to lengthen the flow path within the pond. A

minimum length-to-width ratio of 3:1 is recommended for all inlets. One exception would be allowed for minor outlets where less than 10% of the total volume of runoff enters the basin.

d) Ideally, the number of inlets should be minimized and placed at the most hydraulically remote points in the basin in order to minimize the potential for short circuiting.

6.5 Stoke's Law Analysis (Alternate TSS Removal Analysis)

Extended detention portions of the pond should be sized to remove 80% of the total suspended solids (TSS) entrained in storm water runoff. The geometry of the structure should be evaluated using Stoke's Law to confirm 80% removal. The purpose of this section is to outline an alternative approach from what is described previously to size a storm water pond.

The Stoke's Law method can be used to determine the percentage of TSS that would settle in an extended detention facility prior to discharging through the facility's outlet. Stoke's Law is defined by the following equations:

$Q = v_0 * A$ where, Q =2-year peak flow rate for particular storm event, cfs
v_0 = reference settling velocity, fps
A = surface area of settling zone, ft^2

And, $V = (g(\rho_s - \rho)d^2)/18\mu$ where, V = settling velocity, fps = 0.04 fps*
where, g = acceleration of gravity, 32.2 ft/sec^2
ρ_s = density of the particle, lb sec^2/ft^4
where, $\rho_s = \gamma d/g = G_s\gamma_w/g = 5.14$ lb sec^2/ft^4
G_s = specific gravity of sand (assume mostly quartz in composition, 2.65)
γ_w = specific weight of water (assume, 62.43 lb/ft^3 at 40°F)
ρ = density of water (assume, 1.94 $lb*sec^2/ft^4$ at 40°F)
d = diameter of spherical particle, (assume, 0.0005 ft)
μ = absolute viscosity of water, (assume, $3.23x10^{-5}$ $lb*sec/ft^2$ at 40°F)

* This value is only appropriate where street sand is the primary source of sediment load. Other land uses will require a separate analysis.

Particles where V is greater than or equal to v_0 will settle from the facility. For the purposes of analyzing the acceptability of a subject structure, this analysis should be based on the following conditions:

a) Peak flow rate shall be the outlet flow rate calculated by routing the 2-year, 24 hour frequency storm through the facility.

b) Settling zone is the area of the structure where mixing is at a minimum and plug flow conditions exist. The zone width is defined by determining the water surface elevation generated by the two-year storm in the structure and is measured between the points that are half way up the structure side slope to that calculated elevation. The length of this zone is the length of the structure excluding the expansion and contraction zones found at the beginning and end respectively. The contraction zone has a 3:1 length to width ratio while the expansion zone has a 4:1 length to width ratio to the settling zone edge unless "spreaders" have been incorporated into the design to eliminate the expansion and contraction zones. (INSERT DIAGRAM BELOW)

c) Water temperature should be assumed to be 40°F.

d) A No. 100 sieve size (0.0005 ft diameter) should be used as the particle size that is evaluated. The analysis should demonstrate that the settling velocity of this particle size is greater than or equal to the reference settling velocity of the structure.

Based on these evaluation criteria, the Stoke's Law analysis can be simplified to the following equation:

$$A = Q / 0.04$$

The settling area of the structure is adequate if it is greater than or equal to the area calculated by this equation.

6.6 Inlet Protection

a) Inlet areas shall be stabilized with riprap or other energy dissipation device to ensure that non-erosive conditions exist.

b) The ideal inlet configuration is above the permanent pool, not submerged, since this can result in freezing and upstream damage or flooding as well as minimize tail water conditions.

6.7 Outlet Protection

a) The channel immediately below a pond outfall should be designed as necessary to prevent erosion and conform to natural topography. An energy dissipater shall be appropriately designed as necessary to control erosive conditions at the outlet for at least the two-year frequency storm by use of a plunge pool or a riprap pad and sized fro peak discharge velocities. Allowable velocities shall be based on actual cover and soil conditions. The maximum permissible velocities are as follows:

Table 11-P1-4. Maximum Permissible Velocity (ft/sec)

Soil Texture	Bare Channel	Channel Vegetation Condition		
		Poor	*Fair*	*Good*
Sand, silt, loam, sandy loam, loamy sand, loam and muck	2.0	2.0	2.5	3.5
Silty clay loam, sandy clay loam, clay, clay loam, sandy clay, silty clay	2.5	3.0	4.0	5.0

Source: Engineering Field Manual for Conservation Practices, USDA Soil Conservation Service, 1979.

b) If a pond outlet discharges to a perennial stream or channel with dry weather base flow, tree clearing should be minimized and a forested riparian zone re-established around the cleared areas adjacent to the channel/stream.

c) To convey potential flood flows from the basin, an armored emergency spillway should be provided if a fill embankment is used. The spillway shall be armored with riprap or other alternative that protects subgrade soils from erosion during the design event. The armoring shall also include a filter fabric and gravel filter. The spillway shall extend beyond the toe-of-slope in a manner to prevent scour of the embankment toe.

6.8 Pond Liners

a) When a pond is located such that the permanent pool does not intercept groundwater at its minimum levels, a liner may be needed to maintain minimum water levels. Pond liners are also necessary for ponds that may present a risk to groundwater quality. Table 11-P1-5 lists recommended specifications for clay and geomembrane liners.

b) When used, at a minimum, the liner should extend across the permanent pool area.

Table 11-P1-5. Liner Specifications

Liner Material	Property	Recommended Specification
Clay	Minimum Thickness	6 to 12 inches
	Permeability	$1x10^{-5}$ cm/sec[1]
	Particle Size	Minimum 15% passing #200 sieve[1]
Geomembrane	Minimum Thickness	30 millimeters
	Material	Ultraviolet resistant, impermeable poly-liner
		Geotextile fabric should be installed on the top and bottom of the geomembrane to protect against puncture, tearing, and abrasion

Source: [1]NYDEC, 2001; all other listed specifications from City of Austin in Washington, 2000 (in Metropolitan Council, 2001).

6.9 Wet Pool Benches

a) For pond side slopes steeper than 4:1, provide a flat aquatic bench that extends 10 feet inward from the normal shoreline at a depth of 12-18 inches below the normal pool water surface elevation.

6.10 Maintenance Reduction Features

In addition to regular maintenance activities needed to maintain the function of storm water practices, some design features can be incorporated to ease the maintenance burden of each practice. In wet ponds, maintenance reduction features include techniques to reduce the amount of maintenance needed, as well as techniques to make regular maintenance activities easier.

a) Ponds should be designed with non-clogging outlets, such as a weir, or by incorporating trash racks for culverts and orifice openings.
b) When a weir is used, the minimum slot width should be 3 inches.
c) Baffle weirs can prevent ice formation near the outlet by preventing surface ice from blocking the inlet, encouraging the movement of base flow through the system. Baffle weirs are constructed offset from the outlet and extend below normal ice depth
d) To prevent clogging from ice or floatables, a reverse slope outlet pipe can be used to draw water from below the permanent pool up to the outlet structure. The invert of the pipe drawing from the pool should be at least 18 inches from the bottom to prevent sediment discharge.
e) No orifice should be less than 6 inches in diameter unless a trash rack is added to prevent clogging.
f) Trash racks should be installed at a shallow angle (80-85 degrees).
g) Alternative methods are to employ a broad crested rectangular, V-notch, or proportional weir, protected by a half-round pipe that extends at least 12 inches below the normal pool level.
h) Riser hoods and reverse slope pipes should draw from at least 6 inches below the typical ice layer. This design encourages circulation in the pond, preventing stratification and formation of ice at the outlet. Reverse slope pipes should not be used for off-line ponds.
i) Outlet structures should be resistant to frost heave and ice action in the pond.

6.11 Landscaping/Vegetation

Landscaping wet ponds not only enhances their aesthetic value but can also be a critical component to the pollutant uptake mechanisms that can be provided in a pond. Wetland plants should be encouraged in a pond design, either along the aquatic bench (fringe wetlands), the safety bench and side slopes, or within shallow areas of the pool.

a) The best depth for establishing wetland plants, either through transplantation or voluntary colonization, is within approximately six inches of the normal pool elevation.
b) Soils should be modified (e.g., scarified or tilled) to mitigate compaction that occurs during construction around the proposed planting sites.
c) Avoid species that require full shade, are susceptible to winterkill, or are prone to wind damage.
d) Woody vegetation shall not be planted or allowed to grow on the embankment as well as within 25 feet of the toe of the embankment and 25 feet from the principal spillway structure. However, woody vegetation can be planted along excavated banks of the basin as long as maintenance access is allowed.
e) Existing trees should be preserved in the area around the pond during construction. To minimize warming of stored water and help discourage resident geese populations, this buffer can be planted with trees, shrubs, and native ground covers.
f) Annual mowing of the pond buffer is only required along maintenance rights-of-way and the embankment.
g) The area of the basin above the pond outlet shall be stabilized with a seed mixture that is tolerant to periodic flooding and is resistant to erosion.

7.0 Construction

a) Avoid soil compaction to promote growth of vegetation.
b) Temporary erosion and sediment controls should be used during construction and sediment deposited in the wet pond should be removed after construction and before landscaping. This pond can be used as a temporary sedimentation basin during construction. If so, it may be desirable to temporarily modify the outlet as a stand pipe during construction in order to better manage sediment loads with lower hydraulic loads during construction.
c) Upstream areas should be stabilized to the greatest extent practicable prior to planting wetland plants, especially in areas where significant amounts of sediment would collect.
d) Appropriate soil stabilization methods should be used before permanent vegetation is established. Seeding, sodding, and other temporary soil stabilization controls should be implemented in accordance with the *Rhode Island Soil Erosion and Sediment Control Handbook.*
e) Temporary dewatering may be required if excavation extends below the water table. Appropriate sedimentation controls will be required for any dewatering discharges.

8.0 Inspection and Maintenance

a) Plans for storm water ponds should identify detailed inspection and maintenance requirements, inspection and maintenance schedules, and those parties responsible for maintenance.
b) The principal outlet should be equipped with a trash rack, and be generally accessible from dry land.
c) Sediment removal in the forebay should occur at a minimum of every five years or after the sediment storage capacity in the forebay capacity has been filled. A permanent sediment marker shall be installed in the forebay to indicate sediment depths and when cleaning is required.
d) A permanent sediment marker shall be installed in the wet pool area to indicate sediment depths and when cleaning is required.
e) Sediment removed from ponds during construction can be incorporated into on-site fill areas. After construction, this sediment shall be managed in accordance to RIDEM requirements for street sand.
f) Recommended maintenance activities for wet ponds are summarized in Table 11-P1-6.

8.1 Maintenance Access

a) A maintenance right of way or easement should extend to the pond from a vehicular point of access.
b) Maintenance access should be at least 10 feet wide, have a maximum slope of no more than 15%, and be appropriately stabilized to withstand maintenance equipment and vehicles.
c) The maintenance access should extend to the forebay, inlet, emergency spillway, embankment, and outlet.

8.2 *Riser in Embankment*

a) The riser must be located within the embankment for maintenance access, safety and aesthetics.

b) Lockable manhole covers and manhole steps within easy reach of valves and other controls should provide access to the riser. If perforated riser pipes are used, the minimum orifice diameter should be 0.5 inches. In addition, the pipe should have a diameter of at least 6 inches.

8.3 *Pond Drain*

a) Except where local slopes prohibit this design, each pond should have a drain pipe that can completely or partially drain the pond. The drain pipe shall have a protected intake within the pond to prevent sediment deposition in the pipe, and a diameter capable of draining the pond within 24 hours. Additional safety features may be required depending on the size of the pipe.

b) Care should be exercised during pond draining to prevent rapid drawdown and minimize downstream discharge of sediments or anoxic water. The approving jurisdiction should be notified prior to draining any pond.

c) The pond drain should be equipped with an adjustable gate valve (typically a handwheel activated knife gate valve).

d) Valves should be located inside of the riser at a point where they can be operated in a safe manner.

e) To prevent vandalism, the handwheel should be chained to a ringbolt, manhole step, or other fixed object.

8.4 *Safety Features*

a) Side slopes to the pond should not exceed 3:1 and should terminate at a safety bench.

b) The principal spillway opening must not permit access by small children, and endwalls above pipe outfalls greater than 48 inches in diameter must be fenced to prevent a hazard.

c) Both the safety bench and the aquatic bench may be landscaped to prevent access to the pool.

d) Warning signs prohibiting swimming and skating should be posted depending on depth.

e) Pond fencing is generally not encouraged, but may be required by some municipalities. The preferred method is to grade the pond to eliminate dropoffs or other safety hazards.

Table 11-P1-6. Typical Maintenance Activities for Storm Water Ponds

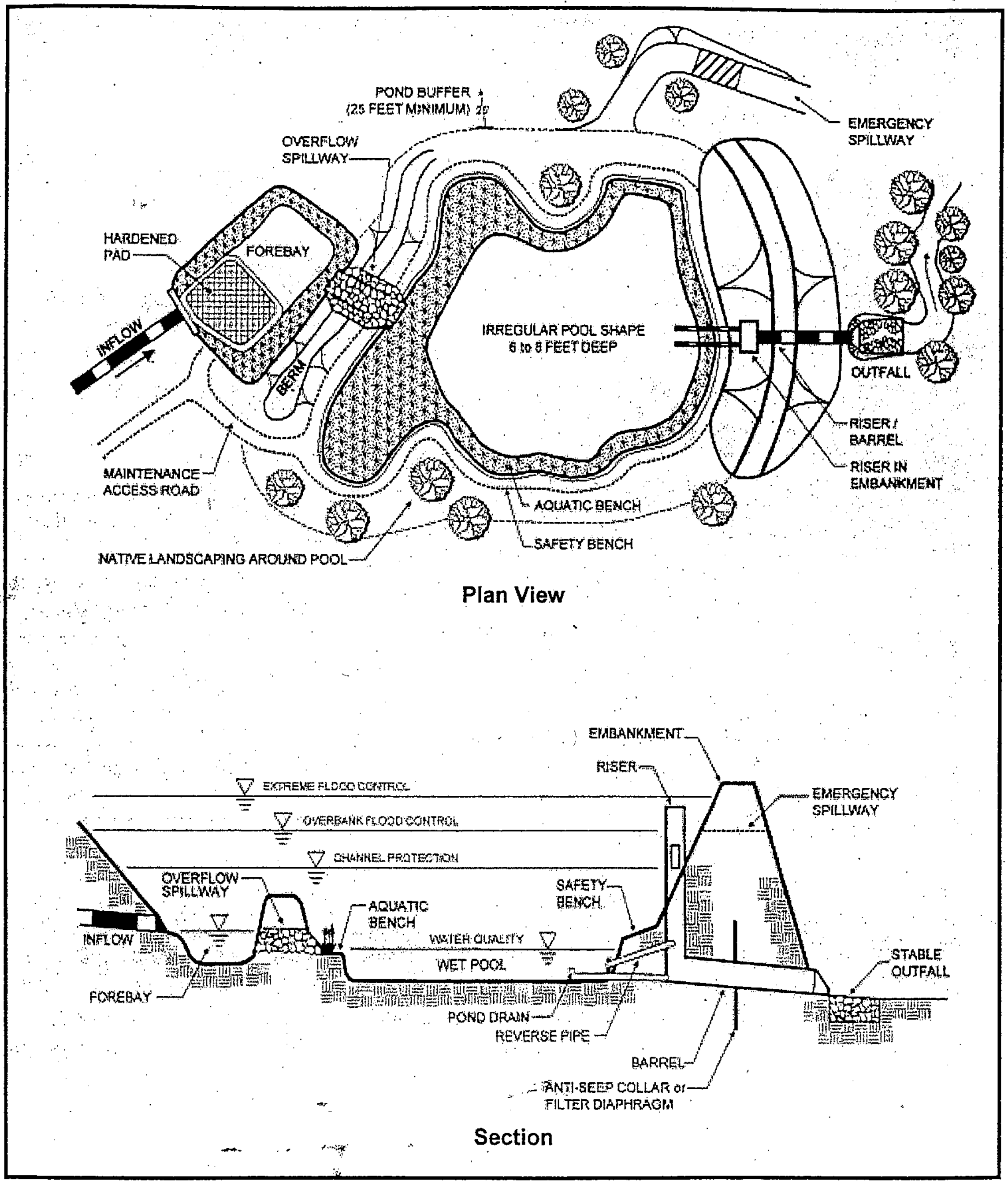
Activity	Schedule
• If wetland components are included, inspect for invasive vegetation.	Semi-annual inspection
• Inspect for damage. • Note signs of hydrocarbon build-up, and remove if detected. • Monitor for sediment accumulation in the facility and forebay. • Examine to ensure that inlet and outlet devices are free of debris and operational.	Annual inspection
• Repair undercut or eroded areas.	As needed maintenance
• Clean and remove debris from inlet and outlet structures. • Mow side slopes. High grass along pond edge will discourage waterfowl from taking up residence.	Monthly maintenance
• Wetland plant management and harvesting. • Drain pond in fall and let frost kill plants, then dredge in spring.	Annual maintenance (if needed)
• Removal of sediment from the forebay.	As needed, typical 10 year maintenance
• Remove sediment when the pool volume has become reduced significantly, or when significant algal growth is observed.	As needed, typical 10 year maintenance; more frequent dredging in developing watersheds with significant sediment loads

Source: Adapted from WMI, 1997.

9.0 Cost Considerations

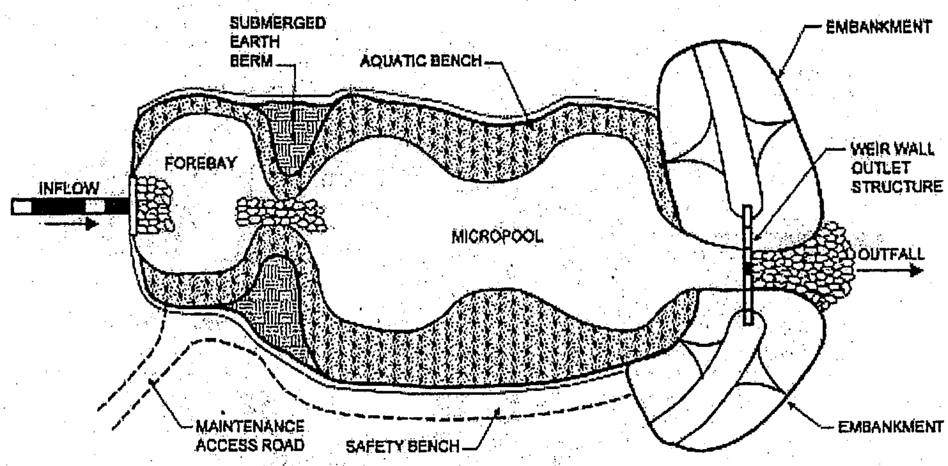
Wet ponds are relatively inexpensive storm water practices, but vary widely depending on the complexity of the design or difficulty of site constraints. The annual cost of routine maintenance is typically estimated at about 3 to 5 percent of the construction cost (EPA Wet Pond Fact Sheet, www.epa.gov/npdes/menuofbmps/menu.htm). Ponds typically have a design life longer than twenty years.

Figure 11-P1-1. Wet Pond

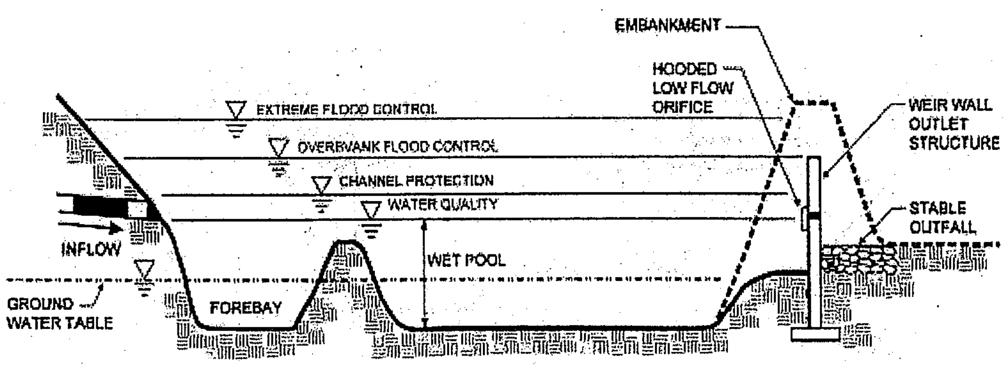


Source: Adapted from NYDEC, 2001.

Figure 11-P1-2. Pocket Pond



Plan View



Section

Source: Adapted from NYDEC, 2001.

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Hancor offers solution to open-air retention pond health risks

As commercial and residential development continues to grow across the country, so does the challenge to manage increased storm water runoff. And now, that challenge is further complicated by the health risks associated with retention ponds, one of the options available to municipalities.

One method used by municipalities to manage storm water runoff is storm water retention ponds. These open-air ponds are inadvertently becoming breeding grounds for mosquitoes. As residential areas continue to multiply, this health issue will have to be addressed by developers and municipal planners.

Phase II of the United States Environmental Protection Agency Storm Water Management Program puts immediate pressure on municipalities to develop comprehensive plans to manage storm water runoff and address issues of paved surface runoff and the concentration of pollutants in runoff.

The public however, is becoming increasingly more concerned with mosquitoes and other health risks associated with retention ponds. Initially, these ponds were built to help control flooding by taking in increased amounts of runoff from paved surfaces.

Retention ponds are often located within residential areas or close to business districts. Besides being unsightly, retention ponds create an ideal habitat for unwanted pests, including insects. And attention is increasingly concentrated on insects with regards to transfer of diseases, such as West Nile Virus, to birds, animals and humans. These open-air ponds also occupy land, which is becoming more and more valuable with the housing market increasing at such a rapid rate.

More than ten years ago, Hancor®, Inc., a Findlay, Ohio based company, developed a safer and more efficient storm water management solution in their LandMax® Storm Water Retention/Detention system. LandMax is a series of high-density polyethylene pipe connected side-by-side in a subsurface structure, something like a massive underground holding tank.

Installed below ground, the system maximizes the amount of land available by providing space for parking lots, playgrounds and other facilities to be built on top, while eliminating safety and health risks associated with retention ponds.

"We recognize that storm water management solutions become more important as construction increases. That's why we developed an effective alternative that provides

Hancor
Technology • Innovation • Solutions

the functionality required for storm water management, while at the same time eliminating health and safety risks," says Steven Anderson, President of Hancor.

"The LandMax system is the safest and most cost-effective option to collect storm water runoff. We know it is less expensive to manage a system that prevents waterway pollution than it is to clean contaminated water. In addition to safety and cost benefits, our LandMax system also conserves water resources and efficiently recharges the ground water table."

Anderson explains that LandMax is an easily assembled quality system that maximizes the amount of usable land. "It guards public health by reducing hazards and safety risks," says Anderson. "The entire system is inaccessible to the public, eliminating the risk of human tampering or chance of accidental injury. The safety management costs of open-air ponds are virtually eliminated, and LandMax offers the additional benefit of a pest-free approach to storm water management."

For more information visit www.hancor.com.

Hancor, Inc. 401 Olive Street, Findlay, Ohio 45840

Water Conservation Information Sheet

How much water will my rain barrel collect?

A formula to remember: 1 inch of rain on a 1000 sq ft roof yields 623 gallons of water. Calculate the yield of your roof by multiplying the square footage of your roof by 623 and divide by 1000.

Depending on roof area - a rain barrel will fill up with as little as 1/10th inch of rain. (based on the fact that 1 inch of rain on 1000 square feet roof area equals about 625 gallons of water). Plants thrive on natural rain water - no chlorine, ammonia, fluoride, or other chemicals added to municipal water systems.

Recognize the importance of stormwater runoff:

A rain barrel will show you the large amounts of stormwater that is shed from impervious surfaces. Consider the cumulative impacts of stormwater runoff in a large drainage basin.

Diversion of rain water from the storm sewers

Typically, rain water runoff is collected in storm sewer systems and released directly into streams. This direct runoff can contribute to flooding in developed areas with a lot of impervious surface. When you collect rain water that would have otherwise entered the storm sewers, you are helping to minimize the amount of storm water that will directly runoff into streams. A rain barrel won't solve the flooding issue by holding back storm water, however it is a good way to help and it gets homeowners thinking about water conservation.

Tips for using your rain barrel

- Do not use collected water for drinking, cooking or bathing.
- Keep the lid secure so children or animals cannot fall into the barrel.
- Disconnect the barrel during the winter to avoid freezing and breaking of the barrel and its valves.
- If a moss killer has been used on the roof let a few rainfalls occur before collecting the roof runoff.
- The screen will prevent mosquitoes from breeding in your barrel.
- Consider joining multiple barrels for additional capacity!

Special note for the winter

Your rain barrel system and all connecting hoses must be drained during freezing weather to avoid damage. In many cases leaving the drain at the bottom of the barrel open to prevent water from remaining in the barrel should work. It is recommended to drain the barrel then, turn it over to get all of the water out and store the barrel with hoses in a protected area.

TIPS FOR SAVING WATER INSIDE THE HOME

Approximately sixty percent of total household water supply is used inside the home in three main areas: the kitchen, the bathroom and the laundry room. Follow these tips to reduce water use indoors:

Make sure all faucets are tightly turned off and not leaking: A leaking faucet could waste up to 4,000 gal/year

Replace old faucets with new water-efficient models or install aerators to reduce flow

In the Kitchen

- Run dishwasher only when full
- Consider water use when purchasing a new dishwasher: New water and energy efficient models use 20% less water
- Defrost food in refrigerator instead of using running water: A running faucet uses about a gallon of water per minute
- Use a dishpan or plug the sink when hand-washing dishes
- Don't prerinse dishes before loading into dishwasher
- Keep a container of water in the refrigerator rather than waiting for cold water from faucet

In the Bathroom

- Install low flow toilets or toilet dams
- Test all toilets regularly for leaks: A leaking toilet could waste up 100 gal/day
- Do not use the toilet as a wastebasket
- Replace old showerheads: Low flow showerheads can save 3 gal/min
- Take shorter showers
- Turn off water when shaving or brushing teeth

In the Laundry

- Run full loads of laundry instead of many small loads
- Consider energy and water efficiency when purchasing new laundry machines: Newer models use 40% less water and can save up to 6000 gal/year

TIPS FOR SAVING WATER OUTSIDE THE HOME

Forty percent of total household water supply is used outside the home. Maryland's water resources are daily sprinkled, squirted, dripped, gushed and often wasted outside the home. Follow these tips to reduce water use outdoors:

Landscape Irrigation

- Install efficient irrigation systems such as drip irrigation, soil soakers, and efficient sprinkler systems
- Set sprinklers for lawn and garden only, don't water the street or sidewalk
- Water the lawn only when the ground is dry and preferably no more than once a week: The amount of water used by a sprinkler in one hour is equal to the daily water needs of a family of four
- Water during the coolest part of the day (preferably morning) and never water on windy days: As much as 30% of water used can be lost to evaporation by watering lawn during midday
- Pull weeds to decrease competition for water
- Increase mowing height to 2-3 inches and apply mulch to both reduce evaporation and prevent weed growth
- Limit grass areas and use trees, shrubs, and other plants that require less water to landscape your yard: Grass turf requires 30-50% more water than shrubs and other groundcover

Other Outdoor Use

- Repair or replace leaking hoses and sprinklers
- Always use an automatic shut-off nozzle on hoses
- Use a broom rather than a hose to clean decks, sidewalks, and other paved areas: 5 minutes of running the hose uses 25 gallons of water
- Collect rainwater for reuse in the garden whenever possible
- Cover pools to prevent evaporation: An average uncovered pool loses about an inch of water a week because of evaporation

This information sheet was developed by the Cumberland County Conservation District for informational purposes only. Information was gathered from multiple sources including websites and other rain barrel programs.

Assessment of best management practice (BMP) effectiveness for reducing toxicity in urban runoff

Jeffrey Brown and Steven Bay

Abstract

To assess the effectiveness of Best Management Practices (BMPs) in southern California for improving water quality impacts related to toxicity, five BMP technologies were evaluated with respect to their ability to reduce contaminant concentrations and toxicity in runoff samples. The BMP technologies included an enhanced stream wetland, constructed sub-surface flow wetland cells, a screening/settlement sump, hydrodynamic devices using Continuous Deflection Separation (CDS) units, and a combination of screening, microfiltration, and UV treatment. BMPs based on wetland systems were able to reduce many of the total and dissolved metals, as well as diazinon, in the runoff samples . Dissolved metals that were not reduced were either too low to expect large reductions, or were below chronic water quality criteria in the inflow. Toxicity for wetlands was rare, and was reduced after treatment. Most of the CDS unit devices were ineffective or inconsistent at reducing metal concentrations or toxicity, and had mixed results with total suspended solids (TSS). In general, the CDS units also had no effect on toxicity. This is not surprising, as the CDS units were designed to remove solids from runoff, yet the fraction usually associated with toxicity is the dissolved phase. The screening/settlement sump was inconsistent in reducing most metals and TSS. Although sample toxicity was often reduced after screening/settlement sump treatment, outflow samples remained highly toxic. The SMURRF site used a combination of treatment processes that consistently reduced concentrations of most total metals and TSS, however few metals were high enough to assess attainment of the chronic criteria. Toxicity for this site was not consistent enough to evaluate reduction.

Introduction

Best Management Practices (BMPs) are used extensively in southern California to reduce contaminants in urban runoff (Caltrans 2004, Strecker *et al.* 2004). The BMPs are extremely varied and may include public education, installation of treatment facilities/devices, the routing of runoff through grassy/wetland habitats, or diversion of runoff to sanitary sewers. Most BMPs that treat urban runoff are designed to reduce or remove trash, nutrients, or toxic constituents associated with particulates. Previous studies have examined the effectiveness of BMPs with regards to contaminant removal in southern California (Caltrans 2004, Strecker *et al.* 2004). For example, the Caltrans 2004 study determined that BMPs that use infiltration or sand filtration technologies were among the most effective for reducing levels of total suspended solids (TSS), total nutrients, and total metals.

In contrast, information regarding changes in toxicity is comparatively limited. Aquatic toxicity has been measured in runoff samples in Ballona Creek, Los Angeles River, Santa Ana River, San Diego Creek, and Chollas Creek (Schiff *et al.* 2003, Bay *et al.* 1997). Because of the many chemical constituents found in runoff, measurements obtained using a routine suite of chemicals alone does not give a complete assessment of changes made by the BMP. However, toxicity measurement can improve the evaluation of BMP effectiveness as this helps to account for unmeasured contaminants. In addition, such measurements incorporate the additive and antagonistic interactions of chemicals as a direct measure of effect. Moreover, many structural BMPs are not capable of reducing the most toxic fraction of runoff, the dissolved phase. Therefore, even when BMPs have been shown to reduce the larger particulates found in runoff, it cannot be assumed that treatment processes are also reducing toxicity. Consequently, direct measurement of toxicity is needed.

The goal of this project was to assess the effectiveness of BMPs in southern California for reducing water quality impacts related to toxicity. Collaborative monitoring programs were established with local research and stormwater management agencies that implement BMPs in the southern California coastal area. Samples of stormwater or dry-weather flow from upstream and downstream of the BMPs were analyzed for toxicity to aquatic life and contaminant concentration associated with runoff toxicity.

Methods

Approach

Seven BMP sites representing five BMP technologies were assessed for their effectiveness to reduce contaminant concentrations and toxicity (Figure 1). The five BMP technologies included wetlands, hydrodynamic devices (e.g., continuous deflection separation (CDS) units), microfiltration, UV treatment, and screening/settlement. Samples were collected both before and after the BMP treatment processes in order to evaluate the effectiveness of each BMP system. Each BMP was assessed for its ability to reduce toxicity and concentrations of pollutants to levels below water quality criteria.

Four to five sampling events were conducted for each site (Table 1). Paired inflow/outflow samples of dry-weather or stormwater runoff were collected between February 2, 2004 and March 10 2005. Two sites were sampled only during storm events, and three sites were sampled only during dry-weather flow. One other site was sampled during both storm and dry-weather events. Finally, two constructed experimental wetland cells were dosed with a mixture of Cu, Zn, and diazinon over a six week period. The wetland cells were dosed because the inflow water for these cells did not contain contaminant concentrations that were sufficient to evaluate removal effectiveness. Time-weighted composite samples were collected at most BMP sites, with multiple grabs collected and composited at two of the sites.

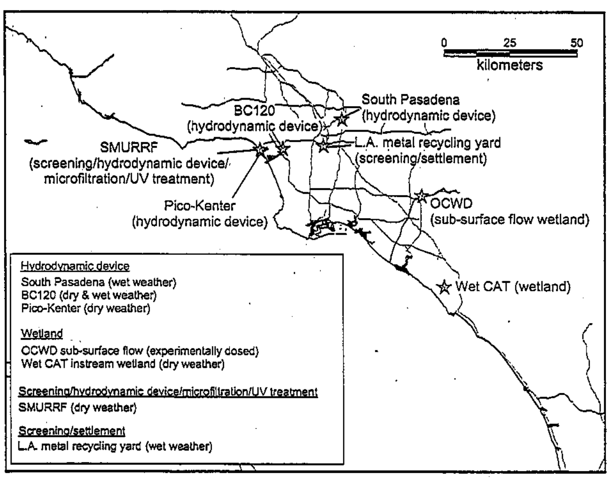

Figure 1. BMP sampling locations. The type of sample collected for this study (dry- or wet-weather) is indicated in the figure legend. Los Angeles and Orange County freeways have been added for reference.

Samples from each site were analyzed for toxicity (echinoderm fertilization test, and *Ceriodaphnia dubia* (*C. dubai*) survival and reproduction test) and metals (Table 2). Most BMP inflow and outflows were also analyzed for organophosphorus pesticides, and a subset were also measured for pyrethroid pesticides, and glyphosate (active ingredient in Roundup™ and Rodeo™). Differences among the constituents analyzed reflect that while most of the data in this study were collected specifically for this investigation, some of the data were obtained through parternship with other monitoring programs that measured fewer parameters. Analytical methods and reporting levels among the analytical laboratories were generally consistent (Table 2).

Technologies evaluated

Wetlands

<u>Wet CAT (wetland)</u>

The Wetland Capture and Treatment network (Wet CAT) was designed to treat low-flow urban runoff from a residential neighborhood in the Aliso Creek watershed. The major processes that reduce contaminants in wetland systems include settling, microbial degradation, and uptake by wetland plants. The Wet Cat site was designed to treat flows of approximately 0.2 cfs, with measured flows at 0.15 cfs in the summer and 0.12 cfs in the fall of 2003. The hydraulic residence time was three days. While there are three distinct wetlands in the Wet CAT network, this study focused on the largest one, known as the West wetland. The West wetland is a 1.4 acre, 0.5-mile long parcel of land on the west side of Alicia Parkway in Laguna Niguel. The West wetland treats 317 acres of exclusively urban runoff. Only dry-weather runoff samples from the Wet CAT site were collected for this study. Samples were collected at the head of the wetland and as the water left the wetland.

<u>OCWD (sub-surface flow constructed wetland)</u>

The other wetland BMP in this study was the Orange County Water Department (OCWD) sub-surface flow (SSF) constructed wetlands, located next

Table 1. Sampling event descriptions for each BMP in this study.

Site	Sampling event	Sample date	Type of sample	Antecedent dry weather period (days)	Flow volume sampled (gallons)
Wet CAT wetland (dry)	1 Inflow	11/17/04	Composite (time weighted)	8	203,773
	1 Outflow	11/18/04	Composite (time weighted)	9	208,167
	2 Inflow	12/15/04	Composite (time weighted)	6	163,815
	2 Outflow	12/16/04	Composite (time weighted)	7	169,486
	3 Inflow	1/19/05	Composite (time weighted)	7	51,534
	3 Outflow	1/20/05	Composite (time weighted)	8	50,673
	4 Inflow	3/9/05	Composite (time weighted)	5	65,559
	4 Outflow	3/10/05	Composite (time weighted)	6	64,347
OCWD sub-surface wetland (experimental dosing)	1	2/3/05	Composite (multiple grabs)	5	Approx. 1,440
	2	2/10/05	Composite (multiple grabs)	12	Approx. 1,440
	3	2/24/05	Composite (multiple grabs)	0	Approx. 1,440
	4	3/3/05	Composite (multiple grabs)	7	Approx. 1,440
	5	3/10/05	Composite (multiple grabs)	6	Approx. 1,440
Pico-Kenter hydrodynamic device (dry)	1	11/18/04	Composite (time weighted)	9	Not measured
	2	12/16/04	Composite (time weighted)	7	Not measured
	3	1/20/05	Composite (time weighted)	8	Not measured
	4	3/10/05	Composite (time weighted)	6	Not measured
BC120 hydrodynamic device (dry)	1	1/19/05	Composite (time weighted)	7	11,176
	2	3/10/05	Composite (time weighted)	6	3,217
BC120 hydrodynamic device (wet)	1	1/26/05	Composite (flow weighted)	14	284,257
	2	2/11/05	Composite (flow weighted)	13	4,911,939
South Pasadena hydrodynamic device (wet)	1	12/5/04	Composite (time weighted)	5	55,475
	2	1/2/05	Composite (time weighted)	1	30,954 (toxicity); 163,113 (chemistry)
	3	1/7/05	Composite (time weighted)	1	20,332 (toxicity); 1,307,639 (chemistry)
	4	1/26/05	Composite (time weighted)	14	12,066 (toxicity); 13,884 (chemistry)
	5	2/11/05	Composite (time weighted)	12	39,677 (toxicity); 304,322 (chemistry)
SMURRF UV/filtration/ hydrodynamic device (dry)	1	11/18/04	Composite (time weighted)	9	201,907
	2	12/16/04	Composite (time weighted)	7	25,900
	3	1/20/05	Composite (time weighted)	8	333,043
	4	3/10/05	Composite (time weighted)	6	234,788
L.A. metal recycling yard screening/settlement (wet)	1	2/2/04	Composite (multiple grabs)	14	4,309
	2	2/18/04	Composite (multiple grabs)	15	27,460
	3	10/26/04	Grab	5	Not measured
	4	2/11/05	Grab	13	Not measured

Table 2. Constituent methods and reporting levels used to analyze runoff samples.

	SMURRF, Pico-Kenter, Wet CAT, BC120		L.A. metal recycling yard		South Pasadena	
Analyte	**Reporting Level**	**Method**	**Reporting Level**	**Method**	**Reporting Level**	**Method**
Total and dissolved metals (µg/L)						
As	0.5	EPA 200.8	0.5	EPA 200.8	1.0	EPA 200.8
Cd	0.2	EPA 200.8	0.2	EPA 200.8	0.25	EPA 200.8
Cr	0.5	EPA 200.8	1.0	EPA 200.8	0.5	EPA 200.8
Cu	0.5	EPA 200.8	1.0	EPA 200.8	0.5	EPA 200.8
Fe	5.0	EPA 200.8	100	EPA 200.7	100	EPA 236.1
Pb	0.5	EPA 200.8	0.5	EPA 200.8	0.5	EPA 200.8
Hg	0.1	EPA 200.8	0.1	EPA 7470A	0.2	EPA 245.1
Ni	0.5	EPA 200.8	1.0	EPA 200.8	1.0	EPA 200.8
Se	0.5	EPA 200.8	1.0	EPA 200.8	1.0	EPA 200.8
Zn	0.5	EPA 200.8	5	EPA 200.8	1.0	EPA 200.8
Organics (µg/L)						
Organophosphate Pesticides	0.01-0.02	EPA 625	Not analyzed		0.01-2.00	EPA 507
Pyrethroids	0.01-0.025	EPA 625	Not analyzed		Not analyzed	
Glyphosate	6	EPA 547	Not analyzed		Not analyzed	

to OCWD's Field Research Laboratory, near Anaheim Lake. These wetlands consist of 1 m tall x 2 m wide x 8 m long cells that are constructed from concrete panels. Each wetland cell is filled with fl" pea gravel. A monoculture of wetland plants (bulrushes, genus Scirpus) are planted in the gravel. The gravel provides an approximate thousand-fold increase in surface area for the growth of bacterial biofilms that increase the rate of contaminant degradation or removal. Within the gravel matrix there are distinct oxygen rich (aerobic) and oxygen free (anaerobic) zones where specific microbial processes take place. Water flows beneath the surface of the gravel matrix. The source water for the wetlands comes from Conrock Basin, which receives wet- and dry-weather flow from the Santa Ana River. The advantages of SSF wetlands are less land area required for a system, the elimination of vector problems, and viable operation in winter. The wetland cells were constructed in 2002.

The OCWD SSF was the only BMP in this study that was experimentally dosed with contaminants. Two replicate wetland cells were used in this study. Each cell was continuously dosed with a mixture of Cu, Zn, and diazinon and monitored over a six week period. The nominal concentrations flowing into each cell were 30 µg/L Cu, 60 µg/L Zn, and 0.4 µg/L diazinon. Concentrations of each contaminant were measured in the influent and effluent from each replicate system over five sampling periods. The samples were also analyzed for toxicity using the sea urchin fertilization test. The flow rate for the source water from Conrock Basin was maintained at 4 L/minute. Two stock solutions (one for Cu and Zn, and one for diazinon) were created and diluted to working solutions on a daily basis. The working solutions were added to each wetland cell on a continuous basis using peristaltic pumps.

The flow rates for the working solutions were maintained at 5 mL/minute. Filters made from montmorillonite clay and granular activated carbon were used to recover any remaining amounts of contaminants from the effluent that were not removed by the wetlands.

Hydrodynamic devices (CDS units)

Three of the BMP sites (Pico-Kenter, BC120, and South Pasadena) used CDS Technologies' Continuous Deflective Separation (CDS) hydrodynamic devices. These devices use a vortex and screening process to remove solids from wet- and dry-weather runoff. The components of a CDS unit consist of a sump, separation chamber (which contains a stationary screen cylinder), and diversion weir. Particles within the diverted treatment flow are retained by a deflective screen and maintained in a circular motion, forcing the particles to the center of the separation chamber, which creates an enhanced swirl concentration of solids (vortex separation) until they settle into the sump.

Pico-Kenter (hydrodynamic device)

The Pico-Kenter CDS unit is located at the end of Pico Boulevard near the beach in Santa Monica and operated by the City of Santa Monica. It receives a mix of runoff from approximately 4,200 acres of western Los Angeles County, which includes commercial, residential, and transportation land uses. The effluent from this CDS unit feeds into the Santa Monica Urban Runoff Recycling Facility (SMURRF; see below).

BC120 (hydrodynamic device)

The BC120 CDS unit is located near Ballona Creek, in Culver City. It receives runoff from approximately 4,077 acres of Culver City and drains into Ballona Creek at Overland Avenue.

South Pasadena (hydrodynamic device)

The South Pasadena CDS unit is located near the intersection of Orange Grove and El Centro, in the City of South Pasadena and operated by the Los Angeles County Department of Public Works (LACDPW). It receives runoff from 6 acres comprised of approximately 70% residential, 20% industrial, and 10% other.

Screening/hydrodynamic device/microfiltration/ UV treatment

SMURRF (Screening/hydrodynamic device/microfiltration/UV treatment)

The Santa Monica Urban Runoff Recycling Facility (SMURRF) treats dry-weather flow using a combination of technologies, including 2-mm² screening, a hydrodynamic device to remove sand and grit, microfiltration to remove turbidity (effluent turbidity <2 ntu), and ultraviolet radiation to kill pathogens (Boyle Engineering Corp. 1999). This system is designed to treat up to 500,000 gallons of runoff per day. Water from this facility is used for City landscaping and government toilets. This BMP site is located adjacent to the Santa Monica Pier and receives runoff from approximately 5,100 acres of commercial, residential, and transportation activities. Most of the runoff treated by SMURRF is first passed through the Pico-Kenter CDS unit. A smaller amount of runoff is received from the Santa Monica pier storm drain.

Screening/settlement

L.A. metal recycling yard (screening/settlement)

The BMP at the L.A. metal recycling yard is an infiltration trench that uses screening and settlement to prevent larger particles from entering the trench. Water from the site flows into a 3 m x 3 m x 0.7 m sump, where settlement of the heavier particles occurs. The water then flows through a screen mesh into the infiltration trench. Samples were collected before the water entered the sump and after it had passed through the screen mesh. Approximately 0.85 acres of the recycling yard is treated by the BMP. This BMP treats runoff that is exclusive to this site and monitored only during wet-weather events.

Sampling methods

Wet CAT, Pico-Kenter, BC120, SMURRF

The samples from the Wet CAT, Pico-Kenter, BC120, and SMURRF sites were collected using similar methods among sites. Samples from each of these sites were collected with American Sigma 900 Max Autosamplers configured with 19-L borosilicate jars. Flow monitors (American Sigma 950 Area Velocity Bubbler Flowmeters) were used at each site, with the exception of Pico-Kenter, where flow meters could not be installed due to the non-ideal configuration. The components of each monitoring system used were calibrated for time and sample-aliquot volume prior to deployment. The autosamplers at these sites collected 200 mL aliquot inflow and outflow samples every 15 minutes for 24 hours. Because the flow at the SMURRF site was intermittent (treatment occurred only when sufficient volume of runoff had accumulated), the autosamplers were triggered by flowmeters only in response to effluent flow. Most of these sites used paired autosamplers to collect the inflow and outflow samples simultaneously. At the Wet CAT site, however, sampling of the outflow was delayed by 24 hours after the start of inflow collection, in an attempt to account for the hydraulic residence time of the wetland.

OCWD SSF

Five sampling events were captured at the OCWD SSF site. At approximately weekly intervals, 2-L composite samples of inflow and outflow samples were collected from each wetland for chemical and toxicity analysis. Three manual grab samples were collected over 24 hours and composited. The flow rate was monitored and adjusted by visual inspection using a sight glass flow meter.

South Pasadena

Five stormwater sampling events were captured at the South Pasadena site. The samples for toxicity testing were collected every 20 minutes and composited usually for 3 hours during the initial part of each storm. The samples for chemical analysis were also collected every 20 minutes and composited, but the sample duration was usually longer, lasting from 3 hours up to 4 days.

L.A. metal recycling yard

Four stormwater sampling events were captured at the L.A. metal recycling yard. Multiple grab samples were collected and composited for the first two events, while single grab samples were collected for the other two events.

Toxicity testing

Dry-weather and wet-weather samples were tested for toxicity using the 7-day *C. dubia* survival and reproduction test (USEPA 1994). All tests were started within 2 days of sample collection. The samples were tested at three concentrations (100%, 50%, and 25% runoff). Ten replicates were included in each test. The test endpoints were percent survival and the number of offspring. A concurrent copper reference toxicant test was conducted with each testing event. Each test included a laboratory control consisting of moderately hard freshwater. A salt blank, consisting of freshwater adjusted to the salinity of the test sample, was included in some of the tests. Test solutions were changed on a daily basis, and the organisms were fed each day. Dissolved oxygen, conductivity, pH, and temperature were measured each day. Alkalinity, hardness, and total ammonia were measured at the beginning of each experiment. Water quality measurements during the test met the test recommended ranges.

The echinoderm fertilization test was also used (USEPA 1995). This test measured toxic effects on sea urchin or sand dollar sperm as a reduction in ability to fertilize eggs. Purple sea urchins (*Strongylocentrotus purpuratus*) were used in the majority of tests, while sand dollars (*Dendraster excentricus*) were used for the November 2004 tests due to the lack of spawning sea urchins. The tests consisted of a 20 minute exposure of sperm to samples of 12.5%, 25%, or 50% runoff that were adjusted to a salinity of 32 g/kg using hypersaline brine. Eggs were then added and 20 minutes allowed for fertilization to occur. The eggs were then preserved and examined later with a microscope to assess the percentage of successful fertilization. Toxic effects were expressed as a reduction in fertilization percentage. The tests were conducted in glass shell vials containing 10 mL of solution at a temperature of 15°C. Four replicates were tested for each sample. Laboratory seawater was included as a control. A concurrent reference toxicity test with Cu was conducted with each testing event.

Chemical analysis

All samples were analyzed for total and dissolved metals. The samples from the SMURRF, Pico-Kenter, WetCAT, and BC120 sites were also analyzed for organophosphate (OP) pesticides, pyrethroid pesticides, and glyphosate. The samples from the South Pasadena and OCWD SSF sites were analyzed for OP pesticides in addition to metals. Variation in the constituents among sites reflects the multiple monitoring programs contributing data. While the samples in this study were analyzed by multiple organizations, the testing procedure and reporting levels were generally consistent (Table 2).

Data analysis

Toxicity

Data from the echinoderm and *C. dubia* tests were evaluated for significant reductions in fertilization, survival, or reproduction using analysis of variance (ANOVA) with Dunnett's test, or Steel's Many-One rank test when assumptions of normality or homoscedasticity were not met. Comparisons were made against the seawater control for the echinoderm fertilization test and against the laboratory dilution water control for the *C. dubia* test. Using this approach, the highest concentration of runoff that did not cause significant toxicity (the no effect concentration; NOEC) was estimated for each inflow and outflow sample.

Median-effect concentrations (LC50 or EC50) were also calculated. These are the concentrations of runoff that caused a 50% reduction in survival (LC50), or reproduction or fertilization (EC50).

Toxicity units were then calculated to compare the magnitude of response. Toxic units (TU) were derived as 100/LC50 or 100/EC50. A TU >1 was considered to be a strong toxic response. Because the highest concentration of runoff sample tested with the echinoderm fertilization test was 50%, the lowest TU that could be calculated was 2. Therefore, absence of toxicity in the 50% sample would be associated with TU <2. The lowest concentration of runoff in the fertilization test was 12.5%. Therefore in cases with extreme toxicity where the EC50 <12.5%, the associated TU would be >8.

Chemistry

A tiered approach was used to evaluate BMP effectiveness. In the first tier of the BMP effectiveness evaluation, the magnitude of the difference in concentrations between inflow and outflow samples was examined. The percent reduction between inflow and outflow contaminant concentrations was calculated for each BMP site as:

$$\frac{Influent - Effluent}{Influent} x(100)$$

For those samples with a ≥10% reduction between inflow and outflow concentrations, the second tier of the BMP effectiveness evaluation, which compared the outflow concentrations to chronic water quality criteria, was used. While water quality criteria are not currently used to assess regulatory compliance of the runoff in this study, these criteria are useful for determining protective levels of concentrations in the inflow and outflow. California Toxics Rule values were used for total Se, as well as for dissolved As, Cd, Cu, Ni, Pb, and Zn; there are no chronic criteria for dissolved Ag, Al, Cr(3+6), Se or Sn. For total Al, chlorpyrifos, and malathion, the national freshwater chronic water quality criteria were used; for diazinon, the California Department of Fish and Game freshwater chronic criterion was used. In cases for which at least two inflow samples exceeded the water quality criterion, the relationship of the outflow concentration to the water quality criterion was examined.

The concept that a 10% reduction between inflow and outflow concentrations is meaningful was derived from measures of analytical variability. Analytical variability was estimated from the relative percent difference (RPD) among sample duplicates that were measured as part of the quality assurance program in this study.

Table 3. Toxicity in inflow and outflow samples from each BMP site. NA = not analyzed. NOEC = No Effect Concentration (the highest concentration of sample tested that did not cause an effect, relative to the control). TU = toxic units.

	Event 1		Event 2		Event 3		Event 4		Event 5	
	NOEC (%)	TU	NOEC (%)	TU	NOEC (%)	TU	NOEC (%)	TU	NOEC (%)	TU
Wet CAT wetland										
Echinoderm fertilization inflow	50	<2	50	<2	<12.5	3.1	<12.5	>8		
Echinoderm fertilization outflow	50	<2	50	<2	50	<2	25	2.2		
C. dubia survival inflow	50	2.4	100	<1	100	<1	100	<1		
C. dubia survival outflow	100	<1	100	<1	100	<1	100	<1		
C. dubia reproduction inflow	NA	NA	NA	NA	NA	NA	100	<1		
C. dubia reproduction outflow	NA	NA	NA	NA	NA	NA	100	<1		
OCWD Wetland cell #1										
Echinoderm fertilization inflow	25	<2	50	<2	50	<2	50	<2	25	<2
Echinoderm fertilization outflow	50	<2	50	<2	50	<2	50	<2	50	<2
OCWD Wetland cell #2										
Echinoderm fertilization inflow	50	<2	50	<2	50	<2	50	<2	50	<2
Echinoderm fertilization outflow	50	<2	50	<2	50	<2	50	<2	50	<2
Pico-Kenter CDS										
Echinoderm fertilization inflow	50	<2	25	1.7	25	<2	<12.5	<2		
Echinoderm fertilization outflow	50	<2	25	2.1	25	2.3	12.5	1.1		
C. dubia survival inflow	100	<1	100	<1	NA	NA	100	<1		
C. dubia survival outflow	100	<1	100	<1	NA	NA	100	<1		
C. dubia reproduction inflow	NA	NA	NA	NA	NA	NA	100	<1		
C. dubia reproduction outflow	NA	NA	NA	NA	NA	NA	100	<1		
BC120 CDS dry-weather										
Echinoderm fertilization inflow	25	2.4	50	<2						
Echinoderm fertilization outflow	12.5	3.0	<12.5	<2						
C. dubia survival inflow	NA	NA	100	<1						
C. dubia survival outflow	NA	NA	100	<1						
C. dubia reproduction inflow	NA	NA	100	<1						
C. dubia reproduction outflow	NA	NA	100	<1						
BC120 CDS wet-weather										
Echinoderm fertilization inflow	<12.5	>8	25	2.6						
Echinoderm fertilization outflow	<12.5	>8	25	2.9						
C. dubia survival inflow	NA	NA	100	<1						
C. dubia survival outflow	NA	NA	100	<1						
C. dubia reproduction inflow	NA	NA	100	<1						
C. dubia reproduction outflow	NA	NA	100	<1						

Table 3. continued

	Event 1		Event 2		Event 3		Event 4		Event 5	
	NOEC (%)	TU	NOEC (%)	TU	NOEC (%)	TU	NOEC (%)	TU	NOEC (%)	TU
South Pasadena CDS										
Echinoderm fertilization inflow	12.5	3.3	<12.5	5.0	<12.5	>8	<12.5	>8	12.5	30.5
Echinoderm fertilization outflow	12.5	3.6	<12.5	7.1	<12.5	>8	<12.5	>8	<12.5	27.5
C. dubia survival inflow	100	<1	100	<1	100	<1	>100	<1	>100	<1
C. dubia survival outflow	100	<1	100	<1	100	<1	>100	<1	>100	<1
C. dubia reproduction inflow	100	<1	100	<1	100	<1	>100	<1	>100	<1
C. dubia reproduction outflow	100	<1	100	<1	100	<1	>100	<1	>100	<1
SMURRF										
Echinoderm fertilization inflow	50	<2	25	2.5	<12.5	1.2	25	<2		
Echinoderm fertilization outflow	6.25	8.7	<12.5	>8	<12.5	>8	25	<2		
C. dubia survival inflow	100	<1	100	<1	100	<1	100	<1		
C. dubia survival outflow	50	1.4	.100	<1	100	<1	100	<1		
C. dubia reproduction inflow	NA	NA	NA	NA	NA	NA	100	<1		
C. dubia reproduction outflow	NA	NA	NA	NA	NA	NA	100	<1		
L.A. metal recycling yard BMP										
Echinoderm fertilization inflow	<12.5	>8	<12.5	>8	12.5	2.5	<12.5	>8		
Echinoderm fertilization outflow	<12.5	>8	12.5	5.4	50	<2	<12.5	>8		
C. dubia survival inflow	<25	>4	100	<1	6.25	16.0	25	2.2		
C. dubia survival outflow	<25	>4	25	2.1	12.5	8.3	50	1.4		
C. dubia reproduction inflow	<25	>4	6.25	9.4	<6.25	7.0	<25	6.7		
C. dubia reproduction outflow	<25	>4	12.5	5.2	12.5	5.7	<25	5.9		

In this study, 120 pairs of laboratory duplicate analyses for metals were analyzed. Most of the pairs had RPD values of <10%, indicating that analytical variability was usually less than 10% for both dissolved and total metals. Therefore, differences of ≥10% for the inflow and outflow metals data were greater than expected for analytical variability, and are probably meaningful. The 10% difference rule was also applied to TSS and pesticides, although these constituents did not have enough duplicate measurements to determine the level of analytical variability.

Results

Changes in toxicity

The two wetland BMPs were effective in reducing toxicity (Table 3). Both the Wet CAT wetland and the OCWD SSF wetland reduced the toxicity in two of the sampling events. The TU of the November inflow sample at the Wet CAT site decreased from 2.4 to <1 with respect to the survival test and from >8 to 2.2 in the March event with respect to the fertilization test. None of the samples at the OCWD SSF site reduced sea urchin fertilization by 50%; therefore, the TU was <2 for all samples. However, significant toxicity in two of the inflow samples was observed. The threshold effect value (NOEC) for the two sampling events improved following treatment from a threshold of 25% for the inflow samples to 50% for the outflow samples (fertilization test).

The *C. dubia* survival and reproduction results for samples from the Wet CAT site were influenced by dissolved salts. While survival and reproduction were consistently low in these samples (0 - 55% survival, 0 offspring), toxicity was usually equivalent to the salt blank that was tested concurrently with the Wet CAT samples. In a previous study, concentrations of dissolved salts associated with conductivity values greater than 1.8 - 2.8 ms caused impairment to *C. dubia* reproduction (Brown and Bay 2003). In the present study, the conductivity values in all Wet CAT samples exceeded this threshold range by a factor of at least two. Toxicity due to other contaminants could only be resolved in the November inflow sample. While the conductivity value was relatively high in this sample, the survival was significantly lower than that found in the salt control. The high salt content did not cause interference with the echinoderm fertilization test, because hypersaline brine was added to the samples to bring the conductivity level up to approximately 54 ms.

In general, the CDS units had no effect on the toxicity (Table 3). Most of the inflow and outflow samples from each of the CDS units were toxic to sea urchin fertilization, with no improvement following treatment. In addition, there was no difference between the wet- and dry-weather samples at BC120 (the only site with both wet- and dry-weather samples) in terms of the effectiveness of toxicity removal.

The toxicity data for the samples from the SMURRF site could not be used to evaluate toxicity removal effectiveness. Although the inflow samples from two of the events were toxic to echinoderm fertilization, reductions in toxicity could not be assessed because of the influence of added chlorine. As part of the treatment process at SMURRF, chlorinated water is used to backflush the screens. Previous studies have shown that the echinoderm test is sensitive to chlorine, with an approximate median effect threshold of 0.02 mg/L (Dinnel *et al.* 1981). In the present study, residual chlorine concentrations in the outflow samples from SMURRF were 12 to 33 times this value in the samples from November, December, and January. The increased toxicity was probably not due to other contaminants, as the other dissolved contaminants analyzed at SMURRF either remained fairly constant or declined between inflow and outflow samples. There was no consistent toxicity to *C. dubia*.

Outflow samples from the screening/settlement device at the L.A. metal recycling yard were usually quite toxic, although toxicity was often slightly lower following treatment (Table 3). This slight decrease was not consistent enough to indicate that the BMP apparatus was able to affect toxicity. For example, *C. dubia* survival improved following treatment for two sampling events (from 16 TU to 8 TU in the October 2004 event, and from 2.2 TU to 1.4 TU in the February 2005 event), however the BMP apparatus appeared to induce toxicity for the February 2004 event (from <1 TU to 2.1 TU following treatment). For the fourth sampling event at this site, toxicity to sea urchin fertilization was high and unaffected by the treatment.

Effectiveness of metals removal

Both wetland BMP systems (Wet CAT and OCWD SSF) showed great potential to reduce concentrations of total and dissolved metals. A consistent reduction in the concentrations of total Cd, Cu, Ni and Zn, and dissolved Al, Cd, Ni and Zn between inflow and outflow samples from the Wet CAT site

Table 4. Range of percent removal of contaminants for each BMP type evaluated in this study. NA = not analyzed. ND = not detected.

	Wetland		Hydrodynamic device (CDS)				Screening / hydrodynamic device / microfiltration / UV treatment	Screening / settlement
Analyte	Wet CAT	OCWD SSF	Pico-Kenter	BC120 (dry)	BC120 (wet)	South Pasadena	SMURRF	LA Metal Recycling Yard
General				Range of % removal				
Dissolved Organic Carbon	0 – 6.7	NA	0 – 10	0, 10	-91, (-4)	NA	6 – 12	-238 – 24
Ammonia	>17 - >88	NA	-60 - 40	-50, 10	-67, 0	-31 – 57	-100 – 64	-108 – 15
Conductivity	-6 – 5	NA	-0.1 – 5	-3, 0.3	-60, (-6)	NA	-1 – 2	-61 – 15
TDS	-5 – 1	NA	-17 – 16	-7, 72	5, ND	-422 – 67	- 6 – 13	-71 – 16
TSS	31 – 90	NA	-300 – 19	50, 73	-97, (-6)	-57 – 97	94 – 99	-179 – 69
Metals								
As (total)	-12 – 12	NA	-64 – 95	-4, 0.5	-26, (-21)	ND	-7 – 12	-214 – 48
Cd (total)	97 – 99	NA	ND	ND	-41, (-3)	ND	ND, 33	-110 – 29
Cr (total)	4 – 25	NA	-91 – (-2)	9, 14	-50, (-32)	-40 – 55	18 – 41	-5.1 – 52
Cu (total)	20 – 29	64 – 94	-84 – 3	13, 26	-46, (-34)	-6 – 26	47 – 59	-16 – 58
Pb (total)	-54 – ND	NA	-1161 – 40	32, 33	-53, (-7)	-49 – 80	79 – 97	-66 – 48
Hg (total)	ND	NA	ND	-14	ND	ND	ND	-135 – 52
Ni (total)	75 – 84	NA	-344 – 2	9, 16	-36, (-30)	-34 – 30	24 – 66	-3.3 – 45
Se (total)	10 – 18	NA	-11 – 8	-6, (-5)	-4, ND	ND	-108 – 2	<(-595) – 3
Zn (total)	64 – 91	75 – 98	-375 – 6	24, 33	-31, (-14)	-26 – 28	52 – 68	-156 – 33
As (dissolved)	-32 – 5	NA	-5 – 5	-1, 0	-35, (-2)	ND	11 – 65	-45 – >59
Cd (dissolved)	65 – 99	NA	ND - 0	ND, 29	25, ND	ND	ND	-602 – 54
Cr (dissolved)	-44 – 20	NA	-8 – 13	2, 6	-247, 1	-104 – 5	-16 – 7	36 – 79
Cu (dissolved)	-27 – 10	53 – 93	-3 – 11	-0.6, 0.4	-82, (-5)	-60 – 19	-38 – 6	2 – 50
Pb (dissolved)	ND	NA	0 – 13	-3, 15	-40, (-0.4)	-51 – 58	ND – 29	-54 – 87
Hg (dissolved)	ND	NA	ND	ND	ND	ND	ND	-35 – 18
Ni (dissolved)	76 – 85	NA	-2 – 8	-6, 0.8	-97, (-3)	-20 – 6	-1 – 11	-47 – 47
Se (dissolved)	0.5 – 14	NA	-16 – 21	-7, 0.8	18, ND	ND	-12 – 2	-452 – 5
Zn (dissolved)	43 – 82	75 – 100	-6 – 17	-10, 29	-42, 18	-33 – (-4)	10 – 34	-2009 – (-57)
Diazinon	ND – >67	-14 – >92	ND	ND, 0	ND, 50	ND, 21	ND	NA

was observed (Tables 4 and 5). For those metals with water quality criteria, the Wet CAT wetland system was very effective at reducing concentrations of dissolved Cd and Ni, and total Al to levels below established thresholds (Table 6). For other dissolved metals, including dissolved Zn, concentrations below the chronic criterion were observed in the inflow samples; therefore, the ability of the Wet CAT system to attain the water quality criterion could not be evaluated (Tables 6 and 7). This system was not able to reduce concentrations of dissolved Cu by more than 10%, however dissolved Cu levels were quite low in the inflow samples (≤11 µg/L) from this site. For the SSF wetlands, concentrations of total and dissolved Cu and Zn were consistently reduced by at least 50% in the outflow samples. This site was also effective at consistently reducing concentrations of dissolved Cu to levels below the chronic criterion. Dissolved Zn levels, while greatly reduced in the outflow samples, never exceeded the chronic criterion in the inflow samples (Table 7).

The BMPs using hydrodynamic devices were generally ineffective at reducing metal concentrations by ≥10%, for metals with chronic water quality criteria. The CDS unit at the BC120 site was able to reduce concentrations of total metals in the dry-weather samples, but water quality criteria for these constituents do not exist. Concentrations of total Al were reduced by >10% in both dry-weather outflow samples from the BC120 site, although the outflow concentrations were never reduced below the chronic criterion. Concentrations of most total metals, including total Al, As, Cd, Cr, Cu, Pb, Ni and Zn, increased in at least one of the wet-weather samples from the BC120 site after treatment (Table 4). Most increases were more than 10%. For example, concentrations of total Cu increased by 46% (from 90 to 131 μg/L) for the first wet-weather event and by 34% (from 26 to 36 μg/L) for the second wet-weather event. Increases in total metals were also observed for at least one sampling event from the Pico-Kenter CDS unit, with concentrations of total As, Cd, Cu, Cr, Ni, Pb, and Zn increasing by more than 50%.

The BMP for the SMURRF site was effective in reducing concentrations of most total metals by 10%, but less effective in reducing concentrations of most dissolved metals (Table 5). The treatment process consistently reduced concentrations of total Al, Cr, Cu, Ni, Pb, and Zn, and dissolved Al and Zn by ≥10%, but was not able to effectively reduce levels of total As and Se or dissolved As, Cr, Cu, and Se. Dissolved metals in the SMURRF site inflow were consistently below chronic water quality criteria; therefore, attainment of the water quality criteria could not be evaluated. However, total Al values were reduced to levels below the chronic criterion.

The screening/settlement apparatus at the L.A. metal recycling yard was usually effective at reducing concentrations of dissolved Cu and Pb by ≥10%. Dissolved Pb was reduced to levels below the chronic criterion half of the time, while dissolved Cu was never reduced below the criterion. This BMP was not effective for reducing any of the other metals with chronic criteria. Dissolved Cr was the only metal constituent without a chronic criterion to be consistently reduced by ≥10%. A consistent increase in concentrations of total and dissolved Cd and dissolved Zn following treatment was observed. Concentrations of total and dissolved Cd increased for three out of the four sampling events, with total Cd levels in the outflow up by as much as 110% (from 9 to 19 μg/L) and dissolved Cd up by as much as 601% (from 0.7 to 5.2 μg/L). Dissolved Zn increased in the outflow for all four sampling events, by as much as 2009% (from 33 to 696 μg/L).

Effectiveness of pesticide removal

Diazinon and malathion were the only pesticides detected in any of the Wet CAT wetland samples. Diazinon was reduced by a factor of >3 in one sample event, and by a factor of 2 in the other event for which this pesticide was detected. Inflow concentrations for the Wet CAT site were insufficient to evaluate attainment of the water quality criterion. Malathion was reduced by a factor of >7 for the only sampling event with detectable amounts of this pesticide. Malathion levels were below the water quality criterion for both the inflow and outflow samples.

The OCWD SSF system was able to reduce diazinon concentrations by >10% for 8 out of 9 sampling events (from 12% to >92%). For one sampling event however, concentrations were similar between the inflow and outflow samples. Only the outflow sample for the first sampling event was below the chronic water quality criterion. The reason for reduction in the effectiveness of diazinon removal after the first event is unclear; however, the most likely explanation is that lack of diazinon in the outflow during the first week was due to inconsistencies in the dosing of the wetlands. The dosing of the metals solution at the OCWD SSF site used a different delivery system and was not affected.

Chlorpyrifos was detected in two of the sampling events for the South Pasadena CDS site. Concentrations of chlorpyrifos were similar between inflow and outflow samples for one of the events, but an apparent 67% increase in chlorpyrifos was observed for the other sampling event. Hence this BMP was not effective in removing this OP pesticide. Pesticides were not detected at any other BMP site with enough frequency to determine reduction effectiveness.

Effectiveness of TSS removal

Numerical water quality criteria do not exist for TSS; consequently, the BMPs in this study were only evaluated for their ability to reduce concentrations of TSS by at least 10%. The Wet CAT wetland was able to reduce TSS for all sampling events captured, presumably because the long residence time allowed sedimentation processes to occur. A previous study found an average TSS reduction of 23% for the Wet CAT site (CH2MHill 2004), which is less than the 74% average reduction observed for this study.

Mixed results for the CDS units were observed. TSS was reduced by >10% in both of the dry-weather samples from BC120 (from 51 to 14 mg/L for the first event and 17 to 8 mg/L for the second event); however, TSS was not reduced in the wet-weather samples from this site (from 204 to 217 mg/L for the

Table 5. Proportion of sampling events with >10% reduction between inflow and outflow samples. NA = not analyzed. ND = not detected.

	Wet CAT (wetland) Dry-weather	OCWD (sub-surface flow wetland) Experimental dosing	Pico-Kenter (CDS) Dry-weather	BC120 (CDS) Dry-weather	BC120 (CDS) Wet-weather	South Pasadena (CDS) Wet-weather	SMURRF (filtration + UV) Dry-weather	L.A. metal recycling yard (grit removal) Wet-weather
Total metals								
Al	3/4	NA	1/4	2/2	0/2	2/4	4/4	2/4
As	1/4	NA	1/4	0/2	0/2	ND	1/4	2/4
Cd	4/4	NA	ND	ND	0/2	ND	1/1	1/4
Cr	3/4	NA	0/4	1/2	0/2	2/5	4/4	1/4
Cu	4/4	5/5 (cell#1 & #2)	0/4	2/2	0/2	2/5	4/4	1/4
Ni	4/4	NA	0/4	1/2	0/2	2/5	4/4	2/4
Pb	0/2	NA	2/4	2/2	0/2	3/5	4/4	2/4
Se	4/4	NA	0/4	0/2	0/1	ND	0/4	0/4
Zn	4/4	5/5 (cell#1 & #2)	0/4	2/2	0/2	3/5	4/4	2/4
Dissolved metals								
Al	4/4	NA	2/4	0/2	0/2	ND	4/4	1/2
As	0/4	NA	0/4	0/2	0/2	ND	0/4	2/3
Cd	4/4	NA	0/1	1/1	1/1	ND	ND	1/4
Cr	2/4	NA	2/4	0/2	0/2	0/4	0/4	4/4
Cu	1/4	5/5 (cell#1 & #2)	1/4	0/2	0/2	1/5	0/4	3/4
Ni	4/4	NA	0/4	0/2	0/2	0/3	1/4	2/4
Pb	0/1	NA	0/2	1/2	0/2	0/3	1/2	3/4
Se	1/4	NA	2/4	0/2	1/1	ND	0/4	0/4
Zn	4/4	5/5 (cell#1 & #2)	1/4	1/2	1/2	0/5	4/4	0/4
Total suspended solids	4/4	NA	2/4	2/2	0/2	3/5	4/4	2/4
Organophosphorus pesticides								
Chlorpyrifos	ND	NA	0/1	ND	ND	1/2	ND	NA
Diazinon	2/2	3/4 (cell#1) 5/5 (cell#2)	ND	0/1	1/1	1/1	ND	NA
Malathion	1/1	NA	ND	ND	ND	ND	1/1	NA
Pyrethroid pesticide	ND	NA	ND	ND	ND	NA	ND	NA
Bifenthrin	ND	NA	ND	0/1	ND	ND	ND	NA
Glyphosate	ND	NA	ND	ND	ND	NA	ND	NA

Table 6. BMP effectiveness with regard to chronic water quality criteria. Denominators indicate the number of inflow samples that exceeded water quality criteria, while numerators indicate the number of outflow samples that met the criteria only after treatment. Instances for which the inflow sample was below the water quality criteria prior to treatment were not counted. NA = not analyzed. * = outflow sample from 1/2/05 met the water quality criterion only because the hardness of the outflow sample increased substantially relative to the inflow sample, thereby increasing the criterion; these samples are not identified as meeting the chronic criteria after treatment in this table.

	Wet CAT (wetland) Dry-weather	OCWD (sub-surface flow wetland) Experimental dosing	Pico-Kenter (CDS) Dry-weather	BC120 (CDS) Dry-weather	BC120 (CDS) Wet-weather	South Pasadena (CDS) Wet-weather	SMURRF (filtration + UV) Dry-weather	L.A. metal recycling yard (grit removal) Wet weather
Total metals								
Al	3/4	NA	0/3	0/2	0/2	0/3	4/4	0/2
Se	0/4	NA	0/1	0/0	0/0	0/0	0/1	0/3
Dissolved metals								
As	0/0	NA	0/0	0/0	0/0	0/0	0/0	0/0
Cd	3/3	NA	0/0	0/0	0/0	0/0	0/0	0/0
Cu	0/0	5/5 (cell#1) 2/2 (cell#2)	1/1	0/2	0/2	0/5	0/0	0/4
Ni	2/2	NA	0/0	0/0	0/0	0/0	0/0	0/1
Pb	0/0	NA	0/0	0/1	0/1	1*/3	0/0	2/4
Zn	0/0	0/0 (cell#1) 0/0 (cell#2)	0/0	0/1	0/2	0*/4	0/0	0/1
OP pesticides								
Chlorpyrifos	0/0	NA	0/0	0/0	0/0	0/2	0/0	NA
Diazinon	0/0	0/4 (cell#1) 1/5 (cell#2)	0/0	0/0	1/1	1/1	0/0	NA

Table 7. Overall effectiveness of BMP treatment. The evaluation of the BMP efficiency used a two-tier approach: tier 1 assessed the ability of the BMP to reduce concentrations by >10%; tier 2 assessed the ability to attain a water quality criterion. The results of the tiered approach were designated as follows. For tier 1, reductions less than 10% were given a "No" designation, while reductions of >10% (for at least 75% of the sampling events) were designated "Yes". Instances of insufficient data to determine consistent reduction (e.g., measurements usually below the reporting level) are indicated by "U" (uncertain). For tier 2, "+" indicates that the BMP reduced the outflow sample concentration to below the chronic criterion, and a "-" indicates the BMP was unable to meet the criterion. A "U" designation was used for tier 2 if concentrations were below the criterion in the inflow, or when there was insufficient data to assess a reduction. A "?" was used when the criterion was met inconsistently. NA = not analyzed.

	Wet CAT (wetland) Dry-weather	OCWD (sub-surface flow wetland) Experimental dosing	Pico-Kenter (CDS) Dry-weather	BC120 (CDS) Dry-weather	BC120 (CDS) Wet-weather	South Pasadena (CDS) Wet-weather	SMURRF (filtration + UV) Dry-weather	L.A. metal recycling yard (grit removal) Wet-weather
Total metals								
Al	Yes/+	NA	No/–	Yes/–	No/–	No/–	Yes/+	No/–
Se	Yes/–	NA	No/U	No/U	U/U	U/U	No/U	No/–
Dissolved metals								
As	No/U	NA	No/U	No/U	No/U	U/U	No/U	No/U
Cd	Yes/+	NA	U/U	U/U	U/U	U/U	U/U	No/U
Cu	No/U	Yes/+	No/U	No/–	No/–	No/–	No/U	Yes/–
Ni	Yes/+	NA	No/U	No/U	No/U	U/U	No/U	No/U
Pb	U/U	NA	U/U	No/U	No/U	No/U	U/U	Yes/?
Zn	Yes/U	Yes/U	No/U	No/U	No/–	No/–	Yes/U	No/–
OP pesticides								
Chlorpyrifos	U/U	NA	U/U	U/U	U/U	No/–	U/U	NA
Diazinon	Yes/U	Yes/–	U/U	U/U	U/U	U/U	U/U	NA

first sampling event and from 80 to 140 mg/L during the second event). TSS reduction was inconsistent in the samples from the Pico-Kenter and South Pasadena sites. Overall, the removal ability of the CDS units in this study did not appear to be related to inflow TSS concentrations, although most inflow TSS levels were <250 mg/L. The greatest TSS reduction (97% removal) was associated with an inflow concentration (868 mg/L) that was much higher than the other initial TSS levels in this study.

The microfiltration process used at the SMURRF site consistently reduced the TSS levels by more than 10%. Removal efficiencies ranged from 94% - 99% TSS removal, with starting concentrations ranging from 8 - 44 mg/L. The screening/settlement process used at the L.A. metal recycling yard was not able to consistently reduce TSS levels. TSS levels were reduced by 25% and 69% from starting concentrations of 320 and 440 mg/L, respectively, for two of the sampling events. However, for one other sampling event, TSS levels were unchanged (1,200 mg/L in both inflow and outflow) after treatment, and for another sampling event, TSS levels increased (from 61 mg/L TSS in the inflow to 170 mg/L in the outflow). Remobilization of particles that had settled out is a possible explanation for this increase.

Reduction in TSS is not a parameter of direct relevance to water column toxicity, as contaminants usually need to be in the dissolved form to produce effects on organisms under laboratory exposure conditions. However, TSS removal does correspond to reductions in particle-associated contaminants, which could have a beneficial impact on sediment toxicity or bioaccumulation from feeding. The study design and analytical methods used in this study were not sufficient to assess potential impacts on sediment toxicity. Different procedures for sample collection and testing are needed to assess the toxicity associated with runoff particles.

Discussion

The wetland BMPs had the best overall combination of toxicity and contaminant reduction. The toxicity was consistently reduced (although not completely removed in all samples from the Wet CAT site) by both wetland systems. In addition, both wetland BMPs were better able to reduce contaminants by at least 10% and better able to meet chronic water quality criteria than the other BMP types in this study (Table 7). Reductions in toxicity and contaminants for the wetland sites is facilitated by major processes such as settling, microbial degradation, and uptake by wetland plants. These processes are enhanced by, and require, the longer residence time in wetlands. The half-mile long stretch of wetland and added berms at the Wet CAT site provide for a three-day hydraulic residence time, while the flow rate through the OCWD sub-surface flow wetland cells is controlled manually.

In general, the hydrodynamic devices (e.g., CDS units) had no effect on toxicity. This is not surprising, as CDS units were designed to remove solids from runoff and exhibited little effect on the dissolved metals in this study; dissolved metals are the forms most likely to cause water column toxicity. Improvements in toxicity for about half of the samples following treatment by the grit removal system at the L.A. metal recycling yard were observed. However despite the improvement, the outflow samples usually remained quite toxic.

Previous investigators have shown that BMPs can have lower percent removal rates when inflow concentrations are low (Caltrans 2004). This issue appears to be particularly relevant for dissolved Cu at the Wet CAT site, as this system was able to reduce the levels of other dissolved metals with greater inflow concentrations. The issue of low inflow concentrations is also a reason to use caution when considering the range of removal efficiencies results in Table 4, because the data in this table do not take into account the inflow concentrations for any of the constituents listed. The lower efficiency for dissolved metals reduction at SMURRF and the Pico-Kenter sites may also be a function of the low inflow concentrations; however, it is more likely that this lower efficiency is due to these BMPs' lack of treatment processes to reduce dissolved metals.

Increases in contaminant concentrations following treatment by some of the BMPs were observed. Concentrations of total and dissolved Cd and dissolved Zn were consistently higher following treatment by the screening/settlement device at the L.A. metal recycling yard, while total metals tended to increase in the wet-weather samples from the CDS unit at the BC120 site and in one of the samples from the Pico-Kenter CDS unit. It is unclear what causes the increase in metal concentrations, but possible explanations include resuspension and remobilization of contaminants that have been collected by the devices (for the particle-bound metals) and oxidation/reduction processes of dissolved phase metals during periods of dry weather.

In order to determine whether or not the increase in metal concentrations by the CDS units was typical of other studies, the chemistry data were compared with the International Stormwater BMP Database. This database contains inflow and outflow data for metals and TSS that has been collected over the past decade from several types of BMPs (Strecker *et al.* 2004); however, this database does not currently include toxicity data. Dissolved Cu and Zn data from the present study were compared to the inflow/outflow 95% prediction interval for hydrodynamic devices from the international database. Most of the data from the CDS units used in this study fell within the prediction interval (Figure 2). However, one of the CDS unit samples (BC120 wet-weather sample) exceeded the upper prediction limit for total Cu, while two samples (one BC120 wet-weather sample, and one Pico-Kenter sample) exceeded the upper prediction limit for total Zn. Therefore, some of the increases in concentration following treatment at these sites was not typical of the performance at other sites with hydrodynamic devices.

The data from all of the BMPs in this study were compared with biofiltration BMPs in the international database. Biofiltration BMPs (which include grass strips and swales) are believed to be one of the most effective types of BMPs currently in use (E. Strecker, personal communication). Comparison to biofiltration BMPs was used to evaluate how the BMPs in this study relate to one of the best available BMP treatment processes.

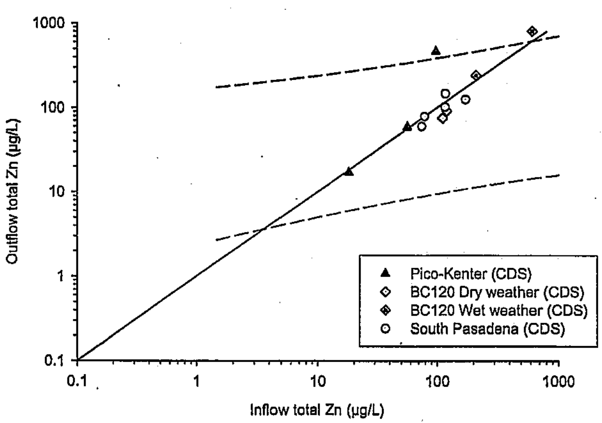

Figure 2. Total zinc concentrations in the inflow and outflow samples from the CDS unit sites. The solid line demonstrates a one-to-one relationship between total zinc concentrations in inflow and outflow samples. The dashed lines represent the upper and lower 95% prediction intervals for hydrodynamic devices in the International Database.

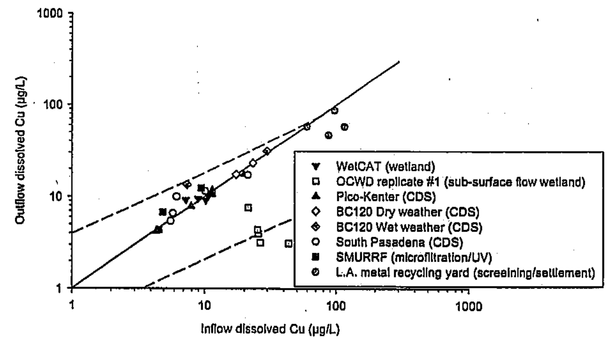

Figure 3. Dissolved copper concentrations in the inflow and outflow samples from each of the BMP study sites. The solid line demonstrates a one-to-one relationship between dissolved copper concentrations in these inflow and outflow samples. The dashed lines represent the upper and lower 95% prediction intervals for the International Database.

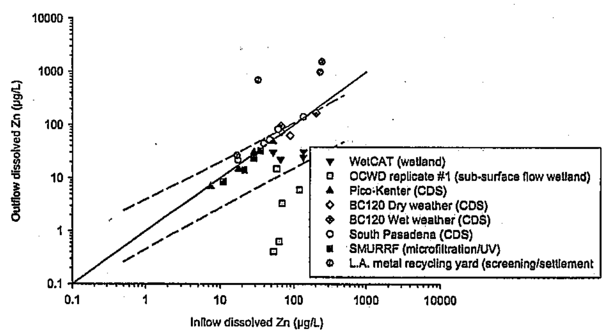

Figure 4. Dissolved zinc concentrations in the inflow and outflow samples from each of the BMP study sites. The solid line demonstrates a one-to-one relationship between dissolved zinc concentrations in the inflow and outflow samples. The dashed lines represent the upper and lower 95% prediction intervals for the International Database.

For dissolved Cu and Zn, most of the data from the present study fell within the prediction limits from the international stormwater database (Figures 3 and 4). However, the OCWD SSF wetland was often at, or below the lower prediction level for both dissolved Cu and Zn, indicating that this BMP performed better than most of the biofiltration BMPs in the international database. Conversely, the grit removal system at the L.A. metal recycling yard usually exceeded the upper prediction level for dissolved Zn, indicating a poorer removal efficiency than the biofiltration BMPs. For TSS, only the data from SMURRF and the Wet CAT sites were below the biofilter lower prediction limit, while the

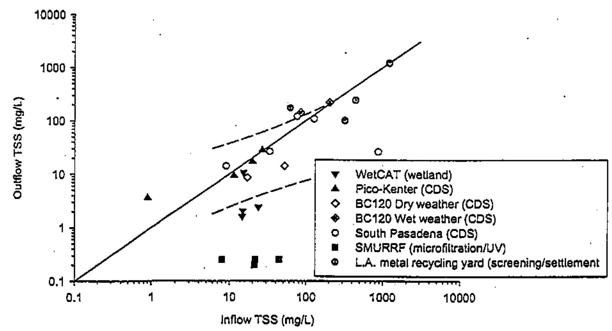

Figure 5. Total suspended solids concentrations in the inflow and outflow samples from each of the BMP study sites. The solid line demonstrates a one-to-one relationship. The dashed lines represent the upper and lower 95% prediction intervals for the International Database.

wet-weather flow from the BC120 site consistently exceeded the upper prediction limit (Figure 5).

This study expands understanding of BMP effectiveness under field conditions in southern California, adding new information for sites that have not been examined previously, and assesses additional constituents of concern for aquatic life protection (e.g., toxicity, OP pesticides) at sites that have been studied before. The assessment of treatment effectiveness described in this study is intended to provide information regarding the technologies examined and not designed to evaluate the suitability of specific BMPs at the study sites. The BMPs included in this study were installed for purposes other than removal of aquatic life toxicity, and the results show that, with the exception of systems that included biological treatment, toxicity removal effectiveness cannot be assumed.

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NOVEMBER 2003 FINAL

Storm Water Monitoring &
Data Management

Discharge Characterization Study Report

CTSW-RT-03-065.51.42

California Department of Transportation

Caltrans

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Executive Summary

The California Department of Transportation ("the Department", or "Caltrans") has completed a comprehensive set of studies designed to characterize stormwater runoff from transportation facilities throughout the state of California. This report includes an overview of the Department's stormwater characterization activities; descriptions of the methods used to produce and evaluate the data; the results of the characterization monitoring and data analysis; and conclusions pertinent to management of stormwater runoff from transportation facilities.

OVERVIEW

Since 1998, the California Department of Transportation has conducted monitoring of runoff from representative transportation facilities throughout California. The key objectives of this characterization monitoring include:

1. Achieve compliance with NPDES Permit requirements;
2. Produce data that are scientifically credible and representative of runoff from the Department's facilities;
3. Provide information that can be useful to the Department in designing effective stormwater management strategies.

In May, 1999, the Department was issued its first statewide NPDES stormwater permit. In response to the requirements of this new permit, the Department initiated in 2000 a three-year Statewide Characterization Study. This comprehensive study was designed to systematically characterize representative sites for each of the Department's major transportation facility types.

In addition to runoff quality monitoring, the Department also implemented monitoring programs to characterize runoff sediment/particle quality, as well as litter studies and runoff toxicity studies. These additional studies are not covered by the current report.

The characterization monitoring data presented in this report include both the results of the three-year statewide study, and the results of other studies conducted prior to or in parallel with the statewide study. In all, over 60,000 data points from over 180 monitoring sites were included in the presentation of monitoring results.

The report includes an in-depth statistical analysis of the factors affecting the quality of runoff from transportation facilities. This statistical analysis is focused on the data from the three-year statewide study, as that data set was designed to be representative of transportation facilities throughout the state, and the data collection was performed using consistent monitoring protocols and data management procedures.

METHODS

To provide for consistent, standardized stormwater data collection and reporting, the Department developed a comprehensive set of monitoring protocols and data management tools. These protocols and tools were designed to ensure the scientific validity and representativeness of the data produced by the Department's monitoring programs. The standard protocols are supported and enforced by a comprehensive data management and quality control program implemented by the Department. Together, these measures enhance the value and usefulness of the Department's monitoring programs, and ensure effective use of taxpayer funds.

The Department's monitoring studies have provided broad geographic coverage throughout the State of California (see Figure 1). Facilities monitored by the Department as part of its discharge characterization activities include:

- Highways
- Maintenance stations
- Park and ride lots
- Rest areas
- Toll plazas
- Weigh stations

In addition to the monitoring conducted at representative, fully operational facilities, additional monitoring and special studies were conducted to address specific issues. For example, highway sites in the Tahoe Basin were monitored for snowmelt runoff quality and for rainfall and snowfall precipitation characteristics, in addition to rainfall runoff. Other specialized studies included microbiological (pathogen indicator) studies, construction site runoff studies, and an in-depth, "first flush" highway runoff study.

The standard list of water quality constituents monitored in the Department's runoff characterization studies includes:

- conventional parameters (pH, temperature, TSS, TDS, conductivity, hardness, TOC, and DOC),
- nutrients (nitrate, TKN, orthophosphate-P, and total P), and
- total and dissolved metals (As, Cd, Cr, Cu, Pb, Ni, and Zn).

Oil and grease and selected herbicides were also included for a subset of specific sites. Other constituents were included in earlier (pre-2000) characterization studies, including selected pesticides and other organic compounds, iron, turbidity, and total and fecal coliform.

The scientifically-valid data gained from the Department's runoff characterization activities may be used to design and evaluate existing and potential new BMPs. The information presented in this report also may be used to assist the Department in assessing the effectiveness of the current stormwater management program, and to provide a foundation for long-term management decision-making.

SUMMARY OF FINDINGS

The major findings of this study are summarized below.

Characterization of Runoff Quality

The quality of stormwater runoff was characterized for each transportation facility type through calculation of summary statistics and data distribution parameters. Statistics were calculated using methods appropriate for data sets that include values below detection ("non-detect data"). The data presented in this report are considered to adequately characterize the quality of runoff from the edge of pavement for highways and other transportation facilities operated by the California Department of Transportation.

Relationships Between Runoff Quality and Other Factors

Multiple Linear Regression (MLR) analysis was employed to assess the factors that influence the quality of runoff from transportation facilities. The results indicated that several environmental and site-specific factors have a significant influence on runoff pollutant concentrations. The effects of AADT, total event rainfall, seasonal cumulative rainfall, and antecedent dry period were statistically significant for nearly all of the constituents evaluated, and were very consistent across pollutant categories. The specific effects of the factors evaluated can be summarized as follows:

- Pollutant concentrations in stormwater runoff increase with higher traffic levels. Sites with higher *AADT* have higher concentrations of nearly every pollutant evaluated.
- As *Cumulative Seasonal Precipitation* increases, pollutant concentrations decrease. This is evidence of pollutant "wash-off" during the wet season, as pollutant concentrations in runoff are highest in the early wet season and tend to decrease thereafter. This effect was consistent for all pollutant categories and constituents.
- Longer *Antecedent Dry Periods* result in higher pollutant concentrations in runoff. This factor provides a measure of the "buildup" of pollutants during dry periods between storms.
- As *Total Event Rainfall* increases, pollutant concentrations tend to decrease; *i.e.*, runoff from larger storms tends to be diluted. This phenomenon is consistent with the interpretation that concentrations tend to be highest in the initial portion of the runoff and are diluted as the storm event continues (i.e., it is consistent with a storm event "first flush" effect).
- *Maximum Rainfall Intensity* was highly correlated with *Event Rainfall* and generally had a similar effect, but was less consistent and significant for fewer constituents.
- Larger *Drainage Areas* tended to result in lower concentrations of a few pollutants for highways, but this effect was not consistent for pollutants at other (non-highway) facilities.

- *Impervious Fraction of the Drainage Area* did not have a consistent effect on pollutant concentrations. Higher imperviousness tended to increase concentrations of some pollutants and decrease others. *Impervious Fraction* had the weakest effect of all the factors evaluated.

Event and Seasonal "First Flush" Effects

The results provide conclusive evidence of both intra-event and seasonal "first flush" effects for conventional parameters, trace metals, and nutrients. The first flush effect results in higher concentrations of pollutants in runoff from the initial phases of a storm and during the early part of the storm season.

In California the lengthy dry season leads to an annual build-up of pollutants on surfaces (such as highways), as evidenced by the positive correlation between runoff pollutant concentrations and antecedent dry period. As the wet season progresses, pollutants are progressively washed off, as evidenced by the negative correlation between cumulative seasonal rainfall and runoff pollutant concentrations. Together these phenomena produce what is known as a "seasonal first flush" effect.

The "event first flush" effect recapitulates the build-up/wash-off phenomena on an event basis, as pollutant concentrations tend to be higher in the earlier stages of rainfall/runoff events. Inferential evidence for this effect is provided by the negative correlation between event rainfall and runoff pollutant concentrations. This finding is corroborated by the preliminary results of a Caltrans "First Flush Characterization Study" designed specifically to answer this question.

Comparisons of Runoff from Different Facility Types

Pollutant concentrations were generally highest in runoff from facilities with higher vehicle traffic. Pollutant concentrations in runoff from lower-traffic facilities (maintenance facilities, park-and-ride lots, vehicle inspection facilities, and rest areas) were generally similar to each other and lower than runoff from highways and toll plazas. This pattern was consistent across the categories of conventional constituents, trace metals, and nutrients. The results for facility types confirm the importance of AADT as a predictor of pollutant concentrations in runoff.

Effect of Local Land Use on Runoff Quality

Pollutant concentrations were generally higher in highway runoff from predominantly agricultural and commercial areas. Pollutant concentrations in highway runoff from residential areas, transportation corridors, and open land use areas were generally similar to each other, and lower than agricultural and commercial land uses. These differences were generally consistent for conventional pollutants, trace metals, and nutrients.

Effect of Geographic Regions on Runoff Quality

Although there were some significant differences, geographic region does not appear to have a consistent, predictable effect on runoff quality, and there was no consistent pattern in the runoff quality from different geographic regions. In general, regions with pollutant concentrations that were significantly higher than average or lower than average tended to be represented by relatively few sites with high or low AADT respectively. These results appear to be more reflective of the effect of AADT on runoff quality than a consistent effect of geographic region.

Trends and Annual Variability

Although there was significant annual variability in runoff quality for most constituents and facilities, there were no consistent patterns or trends in the data over the several years studied. Annual variability typically accounted for less than 10% of the overall variability in runoff quality.

Comparisons with Water Quality Objectives

For the purpose of prioritizing constituents for future pilot monitoring, runoff quality data were compared to California Toxics Rule (CTR) objectives (USEPA 2000) and other receiving water quality objectives considered potentially relevant to stormwater runoff quality. A few parameters exceeded these objectives in a majority of runoff samples. It should be noted that the receiving water quality objectives cited are not intended to apply directly to stormwater runoff discharges, and are used here only in the context of establishing priorities for monitoring. It should also be noted that many constituents monitored do not have relevant water quality objectives. The most notable results of comparisons with the most stringent CTR and other relevant water quality objectives are summarized below.

- Copper, lead, and zinc were estimated to exceed the California Toxics Rule (CTR) objectives for dissolved and total fractions in greater than 50% of samples.
- Based on a relatively small number of samples, diazinon was estimated to exceed the California Department of Fish and Game (CDFG) recommended chronic criterion in 79% of stormwater runoff samples, and chlorpyrifos was estimated to exceed the CDFG recommended chronic criterion in 73% of samples. Neither of these pesticides are routinely applied by the Department to highways or other transportation facilities.

Correlations Between Constituents

Correlations between runoff quality parameters were evaluated to identify relationships that are strong enough for one constituent to serve as a monitoring surrogate for another. Significant correlations were considered to support reduction of the list of standard monitoring constituents.

Correlations were generally strongest within pollutant categories, with few strong correlations between constituents in different categories. Within the conventional parameters, the strongest correlations were observed among parameters associated with dissolved minerals (EC, TDS, and chloride), organic carbon (TOC and DOC), and suspended particulate materials (TSS and turbidity). Within the metals category, total concentrations of most metals were highly correlated, but correlations between total and dissolved concentrations were generally lower, even between total and dissolved concentrations of the same metals. Total petroleum hydrocarbons were generally poorly correlated with all other parameters, but did exhibit a strong correlation between the diesel and heavy oil fractions. Nutrients were generally not strongly correlated within the nutrient category or with other categories (with the odd exception of ammonia and dissolved aluminum). Total and fecal coliform bacteria exhibited no significant correlations within or outside the microbiological category.

Monitoring Constituents

As a means of determining the relative importance of specific constituents for continued monitoring, a multi-tiered approach was used to evaluate the Department's stormwater runoff quality data. The constituents monitored were evaluated with respect to frequency of detection and identification of a transportation-related source for the constituent, as well as comparisons to water quality objectives and correlation with other measured parameters, as summarized above.

The following constituents remain high priorities for monitoring, due to their relatively high levels in runoff and their ongoing usefulness in runoff characterization:

- Copper, lead, and zinc
- Aluminum and iron
- Electrical conductivity, TOC, TSS, pH and temperature

The following constituents receive lower priorities for continued monitoring, due to their relatively low concentrations in runoff, their correlations with other parameters, or the lack of an obvious transportation-related source:

- Arsenic, cadmium, chromium, and nickel
- TDS, ammonia, and nitrite
- Diazinon and chlorpyrifos
- Nitrate, TKN, total phosphorous, and dissolved ortho-phosphate
- Semi-volatile organic compounds, including PAHs
- Pathogen indicator bacteria

Percentage of Metals in the Particulate Fraction

A large proportion of the concentrations of most metals are bound to particulate matter in runoff. Based on data from the Statewide Study for metals with data available for both dissolved and total analyses, lead is present in the highest proportion as particulates (86% on average). Cadmium, chromium, and zinc average between 60-70% in the particulate fraction, and arsenic, copper and nickel average between 50-55% as particulates.

CONCLUSIONS

The extensive monitoring performed by the Department over the past several years, and particularly the recently-completed, three-year Statewide Characterization Study, have provided sufficient data with which to characterize the quality of runoff from Caltrans facilities throughout the State of California, in accordance with the approved Characterization Monitoring Plan (Caltrans, 2002, CTSW-RT-02-004).

The primary environmental factors affecting the quality of edge-of-pavement runoff have been identified and quantified, and major patterns of temporal variability (seasonal and intra-storm) have been characterized. The monitoring conducted to date has focused on runoff from paved surfaces.

AADT is the most important site characteristic in predicting highway runoff quality. Although facility type, geographic region and contributing land use were determined to have some statistically significant effects on runoff quality, these effects are less consistent than AADT.

Pollutant build-up and wash-off are evident in the statistical analysis of the highway runoff quality data, providing support for the concepts of seasonal and event first flush effects.

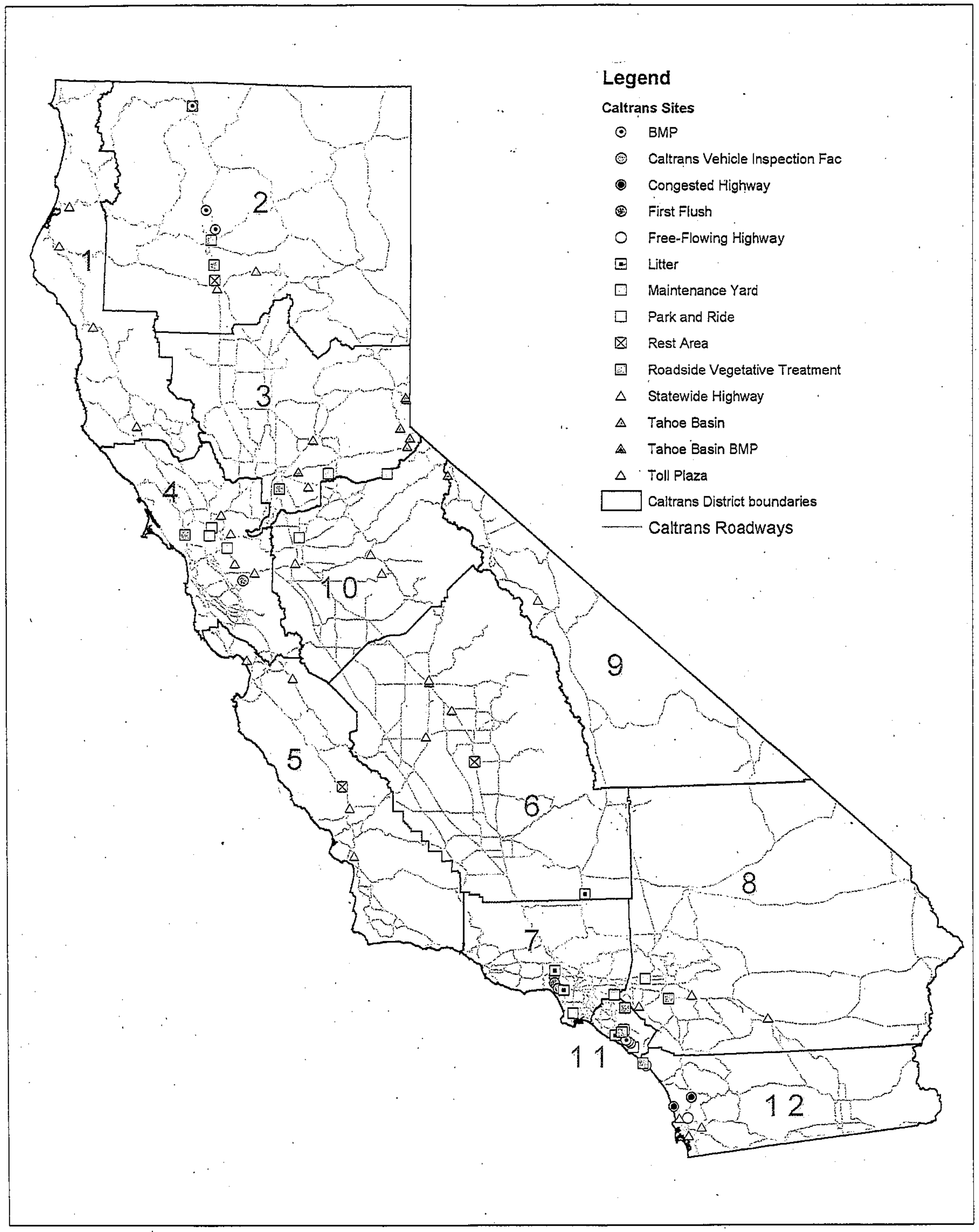


Figure 1 **Stormwater Monitoring Sites**

SECTION 1 INTRODUCTION

The California Department of Transportation (the Department, or Caltrans) has completed a comprehensive study designed to characterize stormwater discharges from transportation facilities throughout the state of California. This report includes a presentation of the methods used to produce and analyze the data, the results of the various monitoring and research studies, and the conclusions derived from those studies.

CALTRANS STORMWATER CHARACTERIZATION

The California Department of Transportation has taken a multi-faceted approach to stormwater quality monitoring. This approach results in data that can be placed into four categories, encompassing a wide range of stormwater quality issues: Runoff Water Quality, Litter Characterization, Sediment/Particle Quality, and Toxicity Studies (Figure 1-1). This comprehensive approach to stormwater runoff monitoring is further described in "Improving Stormwater Monitoring" (Ruby and Kayhanian 2003). The Department's characterization monitoring studies have been specified annually in the *Characterization Monitoring Plan* (Caltrans, 2002; CTSW-RT-02-004).

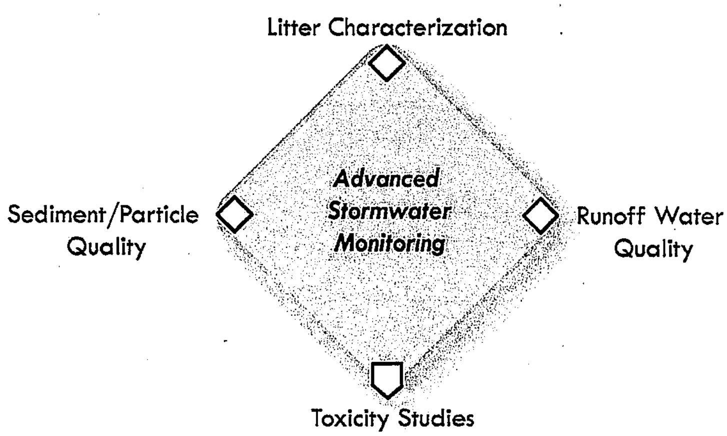


Figure 1-1 Covering the Bases: the Department's Multi-Faceted Approach To Stormwater Quality Monitoring.

Since 1998, the California Department of Transportation has conducted monitoring of runoff from representative transportation facilities throughout California. The key objectives of this characterization monitoring include:

1. Achieve compliance with NPDES Permit requirements;
2. Produce data that are scientifically credible and representative of runoff from the Department's facilities, and can be used to define future monitoring needs;
3. Provide information that can be useful to the Department in designing effective stormwater management strategies.

In May, 1999, the Department was issued its first statewide NPDES stormwater permit. In response to the requirements of this new permit, the Department initiated in 2000 a Statewide Stormwater Runoff Characterization Study. This comprehensive study was designed to systematically characterize, through collection and analysis of representative samples, the quality of stormwater runoff from specific types of transportation facilities. The sites monitored for the Statewide Study were selected to provide representative characterization of the Department's facilities throughout California. Furthermore, this study was conducted to generate sufficient water quality data to satisfy NPDES permit requirements, support research and development needs, provide inputs for load assessment and modeling efforts, provide useful information for watershed planning, and allow for scientifically-sound statistical data quantification.

The data presented and evaluated in this report were gathered principally from The *Caltrans Statewide Stormwater Runoff Characterization Study* (Caltrans, 2003a; CTSW-RT-03-052) . For purposes of general statistical characterization, data from other Department monitoring efforts were also included where appropriate. Stormwater runoff was monitored from over 50 sites in the Statewide Study, representing six different types of facilities: highways, maintenance stations, park and ride lots, rest areas, toll plazas, and vehicle inspection facilities. The study was designed to produce representative data for each facility type nominally over a three-year period, during several storm events annually. The three-year study commenced during the 2000-01 wet season, and was concluded at the end of the 2002-03 wet season (Caltrans, 2003a; CTSW-RT-03-052).

The statewide distribution of monitoring sites covered by this report is illustrated in Figure 1-2.

Monitoring Approach

Data were collected for the statewide characterization study and additional, specialized studies throughout California's geographic and climatic regions, under wide ranges of weather and traffic conditions. Figure 1-3 depicts typical monitoring sites across the state.

Flow can vary significantly throughout a runoff event, and runoff quality is known to vary as well (Stenstrom *et al.* 2001). Flow-proportioned composite samples are therefore considered to be the most representative sampling regimen for runoff monitoring (Kayhanian, 2002). Department monitoring projects generally employ automated monitoring equipment to collect an equal-volume sample (aliquot) for every increment of a pre-set runoff flow volume. Automatic monitoring equipment was used to ensure representative and accurate collection of samples and data (see Section 2 for more detail), including information on flow and rainfall (see photo, Figure 1-4).

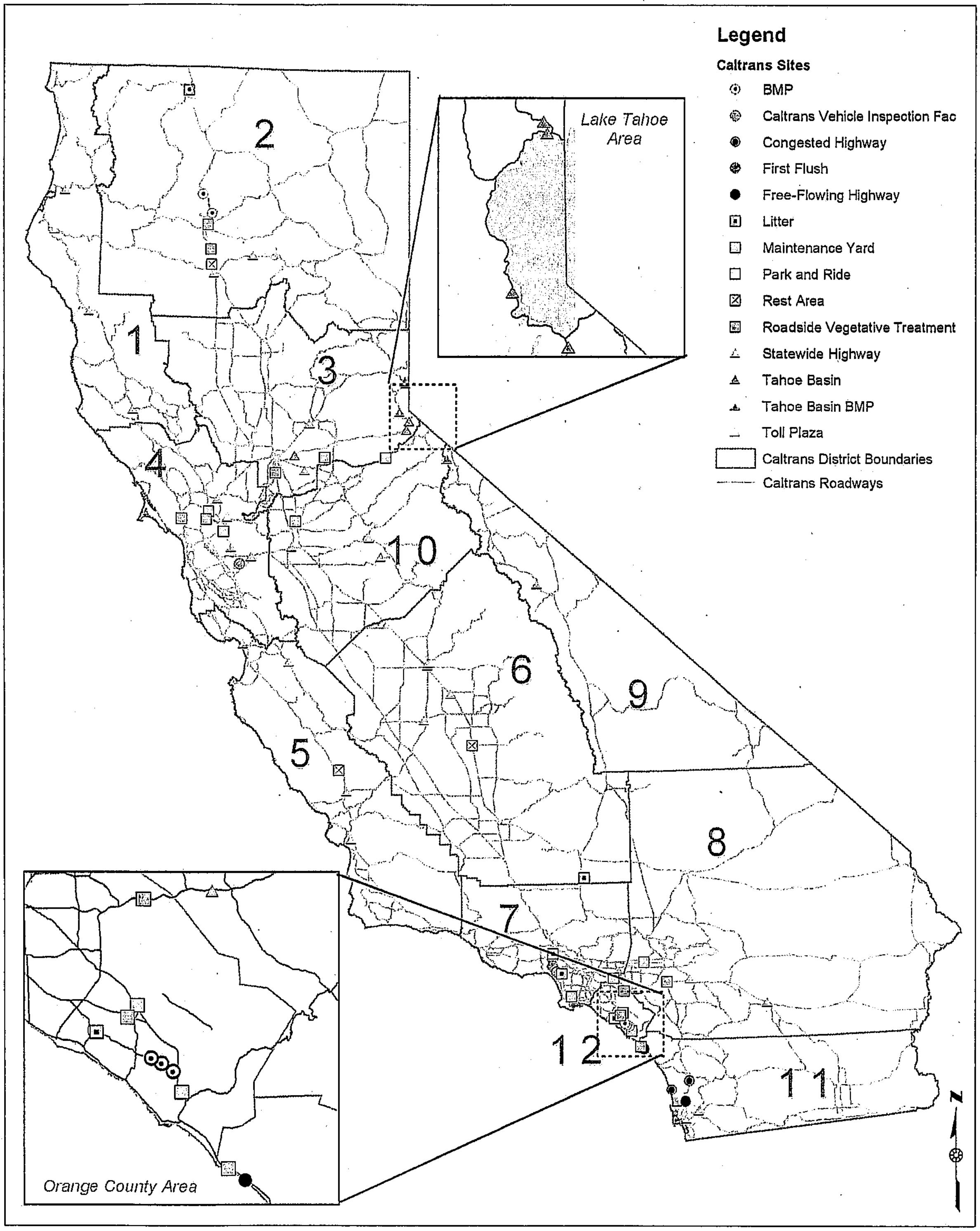
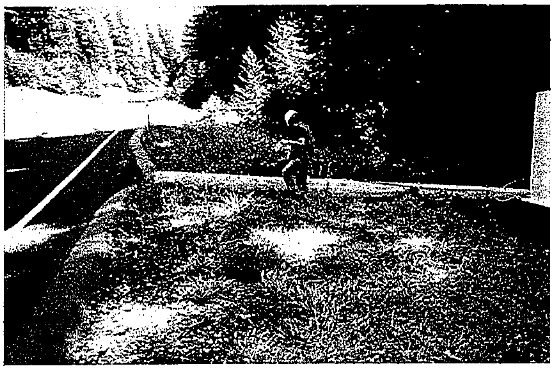
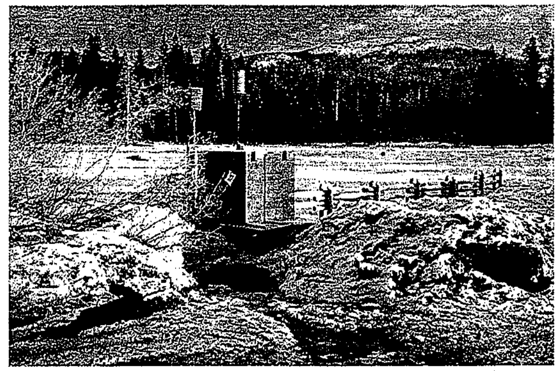


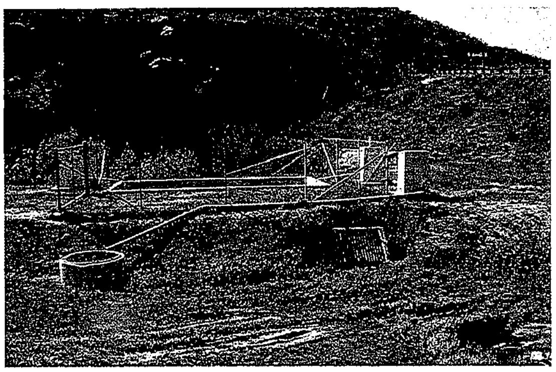
Figure 1-2 Caltrans Monitoring Sites



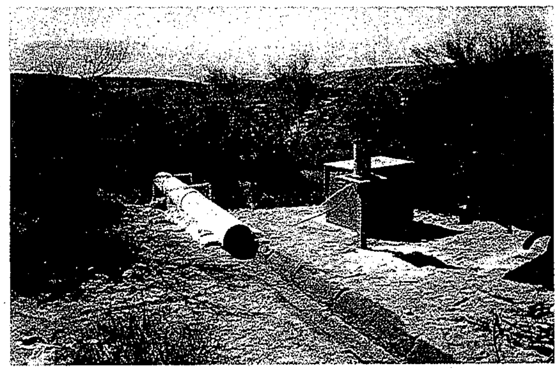
(a) North Coast Region, District 1



(b) Lake Tahoe, District 3



(c) Orange County Region, District 12



(d) Mojave Desert, District 8

Figure 1-3 (a)-(d). Typical monitoring facilities used in the statewide stormwater runoff characterization study

Figure 1-4 **Typical monitoring equipment scenario at enclosed automated monitoring station. Shown are autosampler unit (lower right) and automatic flow meter (top left).**

Comprehensive Program Management and Quality Control

To ensure that the Department's monitoring programs produce credible, verifiable and useful data, the Department has developed a comprehensive set of protocols and tools for stormwater monitoring and data management, which are believed to be unique in the field. These include:

- A set of ***planning documents*** that lay out the projects and their objectives;
- A set of detailed ***monitoring protocols guidance manuals***, covering:
  - Water quality (runoff) monitoring,
  - Sediment/particle monitoring,
  - Litter monitoring,
  - Runoff toxicity studies;
- A complete set of ***data reporting protocols*** for the above data categories to ensure consistency in data formatting;
- A comprehensive ***quality assurance/quality control system***;
- Laboratory ***data validation and error checker software***;
- A ***hydrologic software utility*** that converts rainfall, runoff flow, and sampling data into graphical and tabular summaries depicting sample timing and completeness, allowing assessment of compliance with the Department's criteria for composite sample representativeness;
- A ***relational database*** with a user-friendly, geo-referenced interface and menu-driven querying (Figure 1-5); and
- A ***data analysis software tool*** that allows rapid production of summary statistics for selected data sets and includes statistically-based handling of non-detect data (Figure 1-6).

This set of tools and protocols provides monitoring personnel with the means to plan and implement sound monitoring programs, and to verify and interpret the monitoring data. The data may then be used to help improve stormwater management at transportation facilities throughout California.

The software tools developed for the Department's monitoring programs are assembled in an "Electronic Tool Kit" (Caltrans, 2003b; CTSW-OT-02-002).

The monitoring protocols and data reporting protocols developed for the Department's various stormwater monitoring activities are compiled together in the *Comprehensive Guidance Manual for Stormwater Monitoring* (Caltrans. 2003c; CTSW-RT-03-055.36.19).

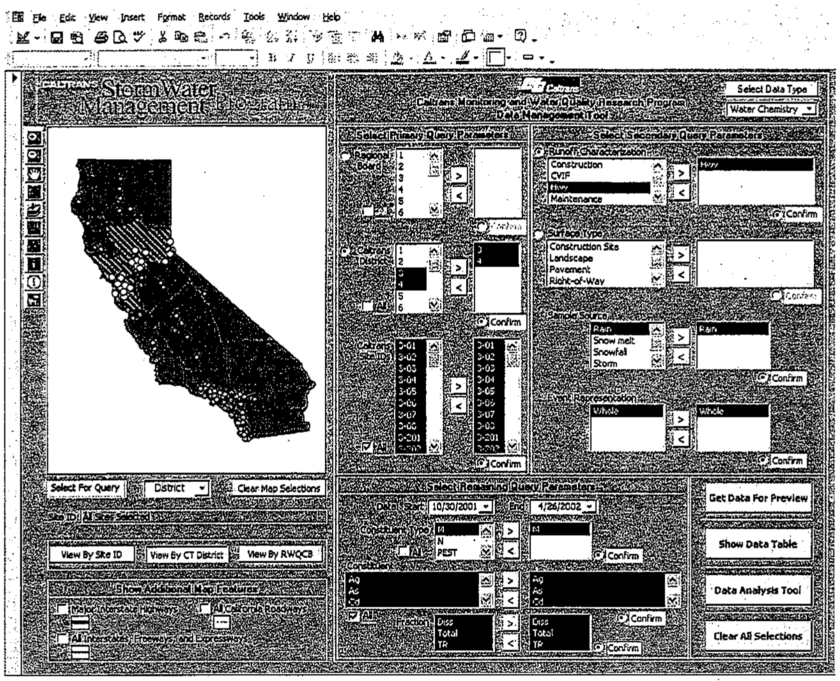


Figure 1-5 Example Screen Shot from Data Management Tool User Interface

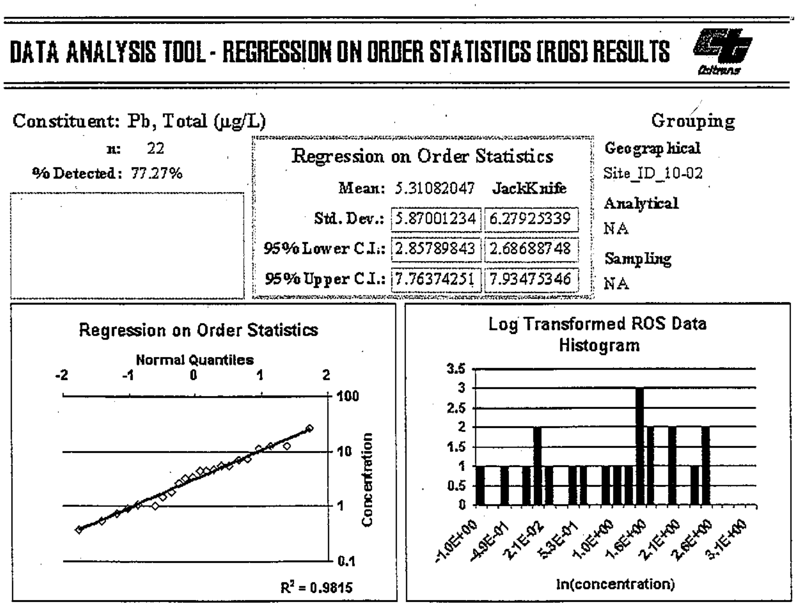


Figure 1-6 Example of Data Analysis Tool Output

CHARACTERIZATION STUDY REPORT OBJECTIVES

This report is designed to address the following objectives, using data generated from the three-year Statewide Stormwater Runoff Characterization Study:

- Quantify the distributional and statistical characteristics of runoff from the different Department facilities.
- Identify relationships between runoff quality and average annual daily traffic (AADT), drainage area, precipitation factors, and antecedent conditions.
- Update Multiple Linear Regression models of stormwater runoff quality produced previously (Kayhanian *et al.*, 2003) using Statewide Study data.
- Identify significant differences in runoff quality from different facility types or from different predominant contributing land uses.
- Determine whether there are significant differences in runoff quality from different geographic regions.
- Determine whether there are significant trends or annual variation in runoff quality.
- Determine whether there are significant seasonal patterns in runoff quality (i.e., a seasonal "first flush" effect).
- Determine whether there are within-storm patterns in runoff quality. Specifically, determine if an intra-event "first flush" effect exists.
- Identify relationships (correlations) between runoff quality parameters. Determine if such relationships can be used to reduce the number of parameters monitored.
- Compare runoff quality to the water quality objectives within the California Toxics Rule and other relevant regulations to prioritize parameters selected for BMP management.

REPORT ORGANIZATION

This report includes:

- an overview of the Department's stormwater monitoring and research program and the objectives of the characterization study report (Section 1);
- descriptions of the methods used to produce and evaluate the characterization monitoring data (Section 2);
- the results of the characterization monitoring and data analysis (Section 3);
- discussion of the results (Section 4); and
- conclusions (Section 5).

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DATA COLLECTION

Data Collection for Stormwater Characterization

Sample Collection

To ensure that the data produced by the Department's various monitoring projects use consistent methods, produce scientifically valid data, and are cost-effective, the Department produced the *Guidance Manual: Stormwater Monitoring Protocols* (Caltrans, 2000; CTSW-RT-00-005). The monitoring data presented in this report were produced according to the methods specified in this manuals.

Automated Composite Sampling

Because flow and pollutant concentrations vary throughout runoff events, the Department uses automated monitoring equipment to collect flow-proportioned composite samples. The key elements of the Department's standard automated set-up include an automated composite sampler, flow meter, rain gauge, and programmable data logger/controller. The runoff volume increment is set in advance based on the quantity of precipitation forecast, so that an adequate number of aliquots will be collected to provide sufficient composite sample volume for all planned analyses. The composite sample then represents the full event hydrograph – and accounts for variation in flow and/or runoff quality throughout event. See Figure 2-1 for a schematic representation of the typical monitoring set-up.

Clean Sampling Techniques

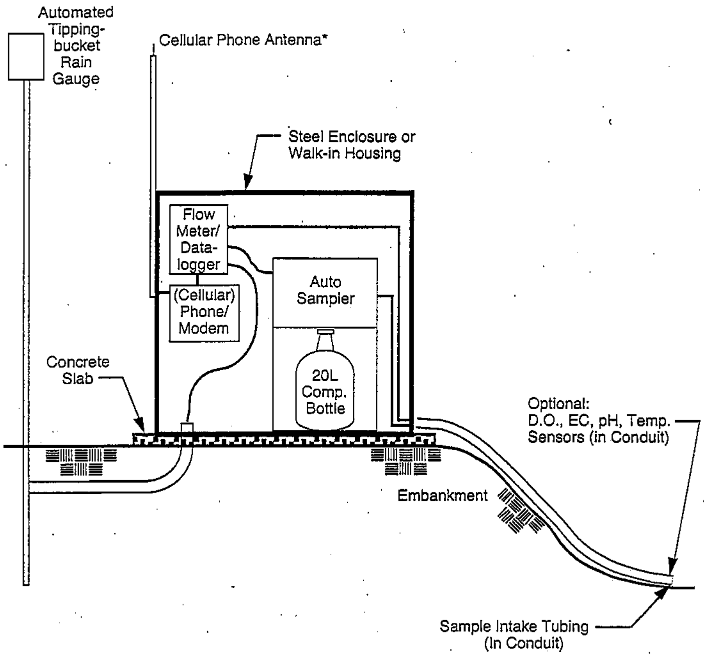
To provide superior quantification for analytical data, the Department's monitoring programs require low-level analytical reporting limits (see Table 2-1) in accordance with the Monitoring Protocols Guidance Manual. In turn, clean sample handling techniques are required to reduce the possibilities of sample contamination. The *Guidance Manual: Stormwater Monitoring Protocols* (Caltrans, 2000; CTSW-RT-00-005) contains specific sampling instructions for clean sample handling methods to minimize sample contamination.

Constituents Monitored

Monitoring for the aforementioned studies was conducted in accordance with the *Guidance Manual: Stormwater Monitoring Protocols* (Caltrans, 2000; CTSW-RT-00-005). Table 2-1 presents the minimum list of constituents used for the Department's stormwater monitoring projects by pollutant category.

Quality Assurance/Quality Control

The Department's monitoring projects include a comprehensive QA/QC program to ensure that sample contamination is minimized, and to provide data with recordable accuracy and precision. Within each Sampling and Analysis Plan, there is a schedule for the monitoring year listing the events and locations for collection of field blanks, field duplicates, laboratory duplicates, and matrix spike samples.



*Cellular phone module and antenna not needed if land line is available.

Note: 12 volt deep cycle marine batteries (with optional solar charging system) are required if AC power is not available.

Figure 2-1 Schematic representation of the typical monitoring set-up

Table 2-1 Water Quality Parameters Monitored in Stormwater Runoff, 1997 – 2003: Minimum Constituent List for Characterization [(1)]

Constituent	Units	Reporting Limit
Conventional Pollutants		
Conductivity	mmhos/cm	1 [(2)]
Hardness as $CaCO_3$	mg/L	2
pH	pH Units	± 0.1[(2)]
Temperature	°C +/-	± 0.1[(2)]
Total Dissolved Solids	mg/L	1
Total Suspended Solids	mg/L	1
Dissolved Organic Carbon (DOC)	mg/L	1
Total Organic Carbon	mg/L	1
Nutrients		
Nitrate as Nitrogen (NO_3-N)	mg/L	0.1
Total Kjeldahl Nitrogen (TKN)	mg/L	0.1
Total Phosphorous	mg/L	0.03
Dissolved Ortho-Phosphate	mg/L	0.03
Metals (total recoverable and dissolved)		
Arsenic	µg/L	1
Cadmium	µg/L	0.2
Chromium	µg/L	1
Copper	µg/L	1
Lead	µg/L	1
Nickel	µg/L	2
Zinc	µg/L	5
Herbicides [(3)]		
Diuron	µg/L	1
Glyphosate	µg/L	5
Oryzalin	µg/L	1
Oxadiazon	µg/L	0.05
Triclopyr	µg/L	0.1

(1) For analytical methods and other specifications, see Reference appropriate Caltrans document(s).

(2) Report to +/- 0.1 of the nearest standard measurement unit

(3)Analysis for the listed herbicides performed for Caltrans statewide characterization monitoring only.

Composite Sample Representativeness

Two measures are used in the Department's Stormwater Monitoring and Research Program to determine whether a composite sample is adequately representative of the runoff event from which it was collected. Each composite sample consists of a number of individual sample aliquots collected on a flow-proportioned basis throughout the runoff event; the aliquots are then mixed to form a composite sample that can be analyzed by the laboratory. The Department specifies a minimum number of sample aliquots that must be collected for the event, based on the overall rainfall amount. The Department also specifies a minimum "percent capture" for each event, which is essentially defined as the percentage of total event runoff flow during which composite sample collection occurred. These measures are evaluated upon completion of the monitoring event, and a decision on the acceptability of the composite sample representativeness is made prior to laboratory analysis of the samples. The Caltrans Hydrologic Utility (Caltrans, 2003b, CT-OT-02-002; also see description in Ruby and Kayhanian, 2003) is a software tool used by monitoring personnel to assess composite sample representativeness according to the prescribed criteria. This software utility is used to convert flow and sample aliquot data into usable information, and allow assessment of sampling representativeness on site.

Data Management and Validation

The Department's monitoring programs include a comprehensive data management and validation process (including QA/QC evaluation) that is an essential element in providing accurate, reliable, and representative data.

In addition to the Monitoring Protocols Guidance Manual, The Department has established a specific set of Data Reporting Protocols. These data reporting protocols provide detailed specifications for data fields and instructions for content. The protocols help ensure that data from all projects will be reported in consistent format – and that the data records will include sufficient information to permit their full use within the Department's Stormwater Database.

A thorough data quality evaluation is performed following receipt of the laboratory data, in which the results of QA/QC sample analyses are compared to the project's data quality objectives, and suspect data are qualified (flagged) as necessary, following guidelines established by the United States Environmental Protection Agency (EPA) for evaluation of inorganic and organic analyses.

The Department's Automated Data Validation (ADV) software (Amano *et al.*, 2001) is used to enhance the evaluation of the data. This automated program permits quick and efficient evaluation of lab data against data quality objectives and standard measures of data quality, and provides extensive error checking for a standard set of possible analytical or data transcription errors. The resulting electronic data deliverable (EDD) is then ready for final checking prior to entry into the Department's stormwater quality database.

The Hydrologic Utility also serves to standardize calculation of important storm and sampling parameters, such as total flow volume, total event rain, estimated percent capture, and others. In addition, the utility generates a hydrograph and a hyetograph in a standardized format from measured hydrologic data.

The final data validation step involves checking that the electronic data deliverable (EDD) conforms to the Department's Data Reporting Protocols for the specific data type; corrections are made as necessary to provide information for any missing or improperly populated data fields.

Characteristics of the Data Set

Table 2-2 provides an overview of the site characteristics of the data set, including the number of sites and monitoring events by facility type, as well as the range of AADT and catchment area sizes represented.

For the Statewide Runoff Characterization Study, representative sites were selected for each facility type and geographic area, according to pre-specified criteria. Refer to the *Caltrans Statewide Stormwater Runoff Characterization Study* report (Caltrans, 2003; CTSW-RT-03-052) for site selection methods.

An effort was made also to provide representative monitoring during the full range of hydrologic and antecedent conditions typically experienced within the various Caltrans Districts. Table 2-3 provides a summary of the monitoring event characteristics from 1997-2003.

Table 2-2 Summary of Site Characteristics and Events Monitored, 1997 – 2003 Monitoring Programs

CalTrans Facility Type	Number of sites	Events Monitored	Annual Average Daily Traffic		Catchment Area, hectares	
			Min	Max	Min	Max
Construction	21	118	NA	NA	0.04	8.5
Caltrans Vehicle Inspection Facility (CVIF)	2	32	2775	3503	0.97	1.68
Erosion	9	24	48000	13500	0.04	1.17
Highway (Statewide Characterization)	39	684	1800	259000	0.08	5.94
Highway (all other projects)	76	1157	3000	328000	0.03	17.32
Maintenance	17	NA	NA	251000	0.1	5.46
Parking	13	NA	NA	107000	0.06	1.13
Rest Area	3	NA	NA	41500	0.21	3.44
Toll Plaza	2	26	70000	100000	0.28	0.28
Summary for all facilities	*182*	*2626*				

"*NA*" indicates that AADT is *Not Applicable* to Facility type

Table 2-3 Summary of Event Characteristics, 1997 – 2003 Monitoring Events

Event Characteristics	Units	Monitoring Year	Number of Events	Min	Max	Median	Mean	Std. Dev.
Antecedent Dry Period	*days*	1998	253	0.6	290	5	15	36
	days	1999	329	0.7	100	4	10	16
	days	2000	646	0.3	121	8	13	17
	days	2001	565	0.2	202	10	13	17
	days	2002	488	0.4	234	11	17	21
	days	*Total*	*2281*	*0.2*	*290*	*7*	*14*	*21*
Cumulative Seasonal Precipitation	*mm*	1998	249	0	928	166	219	206
	mm	1999	312	0	2323	140	213	247
	mm	2000	579	0	1526	123	169	175
	mm	2001	519	0	1488	122	169	182
	mm	2002	436	0	915	121	166	158
	mm	*Total*	*2095*	*0*	*2323*	*127*	*181*	*191*
Event Rainfall	*mm*	1998	252	2.03	76	11	14	10
	mm	1999	329	0.25	104	16	22	19
	mm	2000	622	0.51	110	16	23	21
	mm	2001	550	0.51	97	11	16	14
	mm	2002	489	2	325	23	36	38
	mm	*Total*	*2242*	*0.25*	*325*	*15*	*23*	*25*
Maximum Intensity	*mm/hour*	1998	178	2.03	107	6	10	14
	mm/hour	1999	297	0.25	122	9	16	19
	mm/hour	2000	618	0.25	113	12	17	14
	mm/hour	2001	549	0.51	79	10	14	13
	mm/hour	2002	488	3	107	16	21	16
	mm/hour	*Total*	*2130*	*0.25*	*122*	*12*	*16*	*15*

STATISTICAL METHODS

Overview of Statistical Approach

The principal statistical methods used to address the objectives of this report consisted of Multiple Linear Regression (MLR), Analysis of Variance (ANOVA), and Analysis of Covariance (ANCOVA). Unless specified, thresholds for statistical significance were set at a confidence level of 95% ($p < 0.05$) for all analyses. MLR methods were used to evaluate the effects of precipitation factors, antecedent conditions, annual average daily traffic (AADT), and contributing drainage area on runoff quality. The MLR results were used in the ANCOVA analyses to evaluate the effects of facility type, land use, and geographic region on runoff quality. ANOVA methods were used to assess the contribution of annual variation to the overall variability of runoff quality. Relationships between pollutants in runoff were evaluated using non-parametric correlation methods. In addition to these analyses, summary statistics were calculated for runoff quality data, and distributions of these data were evaluated for normality prior to additional analyses.

MLR, ANCOVA, and ANOVA analyses were performed using only data from the Department's Statewide discharge characterization studies. This data set was used because the monitoring was more consistent in monitoring approach and methods (than earlier Department monitoring), and was specifically designed to be representative of the Department's facilities throughout the state. This consistent approach and design serves to optimize the consistency and representativeness of the results of the analyses.

The methods used to address specific objectives are summarized in Table 2-4. A summary of the analytical approach is also illustrated in Figure 2-2. Details of the statistical methods used are provided in following text.

Table 2-4 Project Objectives and Statistical Methods Used

Project Objectives	Statistical Methods
Describe distributional and statistical characteristics of runoff	Summary Statistics and frequency distribution plots
Update Multiple Linear Regression models with Statewide characterization studies data	Multiple Linear Regression
Identify relationships between runoff quality and site and environmental characteristics.	Multiple Linear Regression
Evaluate seasonal patterns in runoff quality	Multiple Linear Regression
Evaluate within-storm patterns in runoff quality (i.e., intra-event "first flush" effect)	Multiple Linear Regression
Evaluate differences in runoff quality from facility types and surrounding land uses.	ANCOVA
Evaluate differences in runoff quality from different geographic regions.	ANCOVA
Evaluate annual variation and trends in runoff quality	Non-parametric ANOVA
Evaluate relationships (correlations) between runoff quality parameters	Spearman's Rank Correlation Analysis
Compare runoff quality to water quality objectives and prioritize parameters for BMPs	Estimate percent exceedance from distribution characteristics

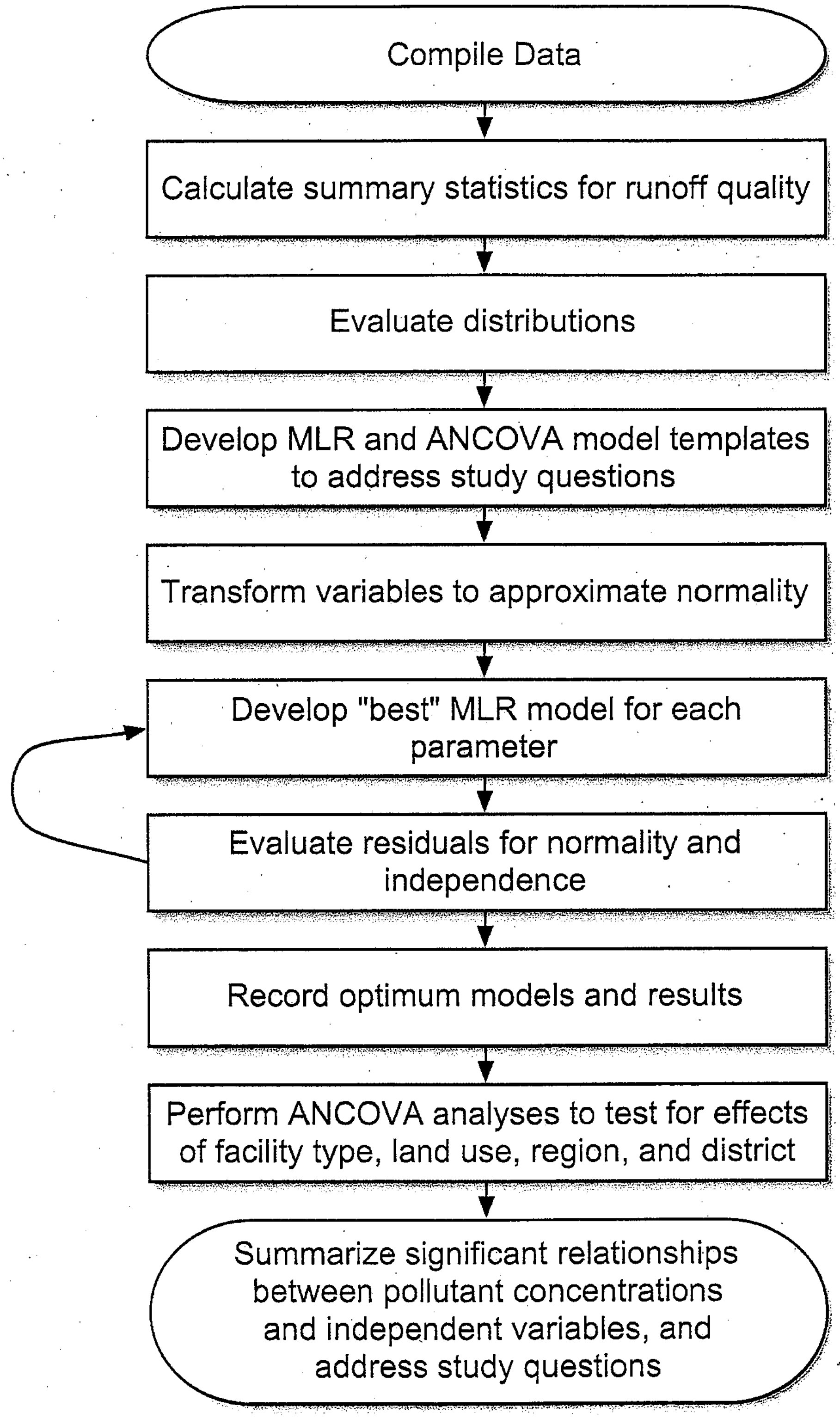


Figure 2-2 Data Evaluation Process

Summary Statistics

Summary statistics and frequency distributions were calculated to address the objectives of describing the distributional and statistical characteristics of stormwater runoff quality from the Department's facilities. Summary statistics were calculated for each constituent for the different facility types contributing the runoff to the sample. Facility types include highways, maintenance stations, Caltrans vehicle inspection facilities (CVIF), parking facilities, rest areas, toll plazas, construction zones, and erosion control sites.

The total number of data, the number and percent of detected data, minimum and maximum detected values, and minimum and maximum detection limits were generated for all data sets and categories. Distribution parameters (arithmetic mean and standard deviation, and 95% confidence limits for the arithmetic mean) were calculated for all categories with a minimum of 30% detected data.

For constituents with data below detection, summary statistics were calculated using the probability regression method described in Helsel and Cohn (1988) and Shumway *et al.* (2002). Use of these methods is important to accurately characterize stormwater runoff data (Kayhanian *et al.*, 2002), and this approach is consistent with the methods used previously to analyze the Department's runoff quality (Kayhanian *et al.*, 2003).

Summary statistics were also used to estimate the percentage of metals bound to particles in runoff. The percentage particulate fraction was calculated as:
100% x (*average of total metal minus average of dissolved metal) ÷ average of total metal.*

The distributions of runoff quality data for each constituent were evaluated for approximate normality prior to performing additional analyses. Distributions were evaluated using linear and exponential regressions of normal cumulative probability plots of untransformed data. These evaluations were performed using only detected data with probabilities adjusted for data below detection using the method of Helsel and Cohn (1988) and Shumway *et al.* (2002). The regression providing the best fit (as determined by the coefficient of determination or R^2 statistic) was selected as the appropriate starting point for additional analyses, with linear regressions indicating an approximately normal distribution and exponential regressions indicating an approximately log-normal distribution. The distributions of other continuous predictor variables (precipitation factors, antecedent conditions, AADT, and contributing drainage area) were also evaluated by inspection of cumulative probability plots, and were transformed to approximate normality, as follows: natural logarithms (event rainfall, maximum intensity, antecedent dry period, and drainage area), cube-roots (cumulative precipitation), or arcsin-square roots (impervious fraction). Note that these transformations required to satisfy the fundamental statistical assumptions of the analyses and are not necessarily indicative of any underlying physical properties of the predictor variables.

Multiple Linear Regression

Multiple Linear Regression (MLR) analyses were used to address several related objectives of this report:

- Update previously generated MLR models, using only the more consistently-collected Statewide characterization studies data

- Identify relationships between runoff quality and environmental and site characteristics
- Evaluate seasonal patterns in runoff quality
- Evaluate intra-event patterns in runoff quality (i.e., "first flush" effect)

Multiple Linear Regression models were generated using detected data for each constituent. The criteria for selection of constituents for MLR modeling was a minimum of 60% detected data overall, and at least 50 total detected data. Although using only detected data has the potential to bias MLR results by decreasing the magnitude of the model coefficients for the predictor variables, most parameters analyzed had at least 90% detected data and this effect was considered to be negligible for these parameters. There is a greater potential for bias for parameters with between 60% and 90% detected data (total arsenic, total cadmium, dissolved chromium, dissolved nickel, and dissolved orthophosphate), and MLR models for these parameters will provide less accurate predictions of runoff quality, particularly for conditions tending to result in lower pollutant concentrations in runoff. Note that the potential bias in magnitude of MLR coefficients does not effect the sign of the coefficient or invalidate the overall conclusions about the predominant effects of the predictor variables (*e.g.*, whether longer antecedent dry periods or smaller storm events tend to result in higher pollutant concentrations). Potential bias in concentration estimates could be moderated by performing logistic regression analyses in addition to the MLR analyses. Logistic regression models would provide estimates of the expected percent detection of each parameter under specific conditions. Because the conditions of greatest interest to the Department are those that result in the highest pollutant concentrations, the refinement of concentration estimates for conditions expected to result in a high proportion of concentrations below detection was considered not to be warranted for this study.

Methods used for MLR analyses followed standard statistical practice (Zar 1984, Sokal and Rohlf 1981, SPSS 2001). The primary assumptions of MLR analysis (equal variance, normality) were assessed by inspection of residual plots. Problems due to unequal variance and non-normality of residuals were largely avoided by transforming dependent and independent variables to approximate normality prior to analysis. Predictor variables were added to the models using a forward selection procedure that adds predictor variables to the model in the order of highest partial correlation with the dependent variable and retains only statistically significant ($p < 0.05$) variables. Generally, all significant predictor variables were included in the MLR model unless they exhibited symptoms of excessive collinearity or co-dependence in the set of predictors. Independence of predictor variables (the absence of collinearity) was assessed by evaluating several collinearity diagnostic values, including the Tolerance and Variance Inflation Factors (VIF) of each covariate in the model and the Condition Index for the overall model. The Tolerance statistic is interpreted as the proportion of a covariates variance not accounted for by other independent variables in the model. Variables with a low Tolerance statistic (less than 0.7) contribute little additional information to the model. The VIF statistic is the reciprocal of Tolerance and increasing VIF factors indicate increasing collinearity and an unstable estimate of the regression coefficient for that factor. When VIF values were greater than 1.4, at least one predictor variable was excluded from the MLR model to prevent collinearity. The model Condition Index was also used to screen for collinearity problems in the MLR models. Condition indices greater than 15 indicate possible collinearity problems and values greater than 30 indicate serious problems. The MLR models were optimized so that condition indices did not exceed a value of 20.

The validity of the MLR models was assessed in two ways. First, optimized MLR models were compared to models generated previously with the Department's runoff quality data (Kayhanian *et al.*, 2003). These qualitative comparisons consisted of assessment of the consistency of the conclusions derived from the two sets of MLR models. Additionally, selected MLR models were evaluated by comparing MLR-predicted values for events and highways sites not used to develop the models (i.e. a new validation dataset) to the concentrations actually measured in runoff. Standard regression methods were used for this validation.

Temporal Trends Analysis

The objective of evaluating temporal trends was addressed using MLR methods (described previously) and non-parametric ANOVA methods. Temporal trends and patterns were assessed at three levels: annual (year-to-year), seasonal, and intra-event. The specific methods used to evaluate each level of temporal variation are as follows:

> The objective of evaluating the annual variability of runoff quality was addressed using non-parametric ANOVA analyses. These were standard ANOVA analyses performed using rank-transformed data for each parameter, with data below detection substituted with a value of zero before being converted to ranks. These analyses were performed separately for each facility type in the data set. The results of these analysis are expressed as the proportion of total variability in runoff quality attributable to annual variation. The statistical threshold for significance was set at the 95% confidence level.
>
> The effect of the seasonal variation on runoff quality was assessed by evaluating the effect of cumulative seasonal precipitation on runoff quality in the Multiple Linear Regression (MLR) models. Significant negative coefficients for cumulative seasonal precipitation are interpreted to indicate a significant "seasonal first flush" with a tendency for decreasing pollutant concentrations as the wet season progresses.
>
> The significance of an intra-event first flush was assessed using the MLR results for *Event Rainfall*. A statistically significant negative coefficient for *Event Rainfall* indicates that concentrations tend to decrease as total event rainfall increases. A significant negative coefficient is consistent with the interpretation that concentrations tend to be highest in the initial portion of the runoff and are diluted as the storm event continues (i.e., it is consistent with a storm event first flush effect).

Effects of Facilities, Geographic Region, and Surrounding Land Use

ANCOVA methods were used to address three objectives of this report:

- Evaluate differences in runoff quality from different Department facilities
- Evaluate differences in runoff quality from different geographic regions
- Evaluate differences in runoff quality from different surrounding land uses.

The final "optimized" MLR model was used to generate a new fitted variable calculated as the cumulative effects of the significant predictor variables in each model. This fitted variable was then included as the single covariate in the ANCOVA models used to evaluate the effects of categorical variables (facility, geographic region, and predominant surrounding land use). Interaction effects were evaluated for the cumulative covariate effects (expressed as the MLR-fitted variable) and each categorical variable using standard ANCOVA methods. Interaction effects were retained in the ANCOVA models if they were significant.

This method of ANCOVA analysis does have some drawbacks. Ideally, all of the covariate factors and explanatory factors would be included individually in the ANCOVA models. This method would allow simultaneous evaluation of a broader range of effects and interactions, and theoretically should result in the "best" predictive model. However, an adaptation of standard ANCOVA techniques was required to accommodate the unbalanced dataset, which was not designed to allow a complete and balanced ANCOVA analyses of potential explanatory factors such as geographic region or predominant surrounding land use. There are two specific areas that are compromised by this combined covariate ANCOVA method. The first is a slight inflation of the degrees of freedom used to calculate significance. However, because the degrees of freedom for the models was typically 500 or more, the loss of the few degrees of freedom that would result from including individual covariates has little effect on the overall model significance. More important is the inability to include and evaluate the full range of potential interactions between explanatory variables and individual covariates. Although this may have been partially accomplished by limiting the analyses to only a few specific facilities, georegions, and land uses, such a strategy would have unnecessarily excluded much data of interest to the Department and still resulted in incomplete evaluation of the effects of these factors. The adaptation of ANCOVA methods used for these analyses exchanged some statistical sophistication to allow more complete use of the data to address the Department's primary questions.

When the effects of facility, geographic region, or land use were significant, differences between facilities, regions, and land uses were assessed by comparing the residuals of the MLR models using the method of Least Significant Difference (i.e. without adjustment for multiple comparisons). Differences were generally summarized as significantly greater or less than the overall average for the parameter. The effects of geographic region and surrounding land use were evaluated using only the Statewide characterization studies data for highway runoff because the broad distribution of highway sites provided the most complete assessment of these categorical factors.

Comparisons to Water Quality Objectives

Summary statistics for 1998 – 2002 data were compared to relevant water quality objectives to determine which parameters should be considered highest priority for future BMP implementation or study. Summary statistics for each parameter were compared with California Toxics Rule objectives and relevant limits from several other sources. The sources of other water quality objectives considered were *National Primary Drinking Water Maximum Contaminant Levels* (USEPA, 2002), U.S. EPA *Action Plan for Beaches and Recreational Waters* (USEPA, 1999a), U.S. EPA Aquatic Life Criteria (USEPA, 1999b), California Department of Health Services Drinking Water MCLs (CDHS, 2002), and California Department of Fish and Game Recommended Criteria for Diazinon and Chlorpyrifos (Siepman and Finlayson, 2000). In the case of CTR metals objectives that are adjusted for hardness, the objective was based on the lowest observed hardness for the data set in order to provide the most stringent assessment.

These water quality objectives were considered relevant for comparison to stormwater quality because they apply to surface waters which may receive stormwater discharges from highways and other Department facilities. Constituents were prioritized according to their estimated percent exceedance of the most stringent water quality objective. Estimated percent exceedance was calculated based on the distributional statistics calculated for each constituent, using the statistical methods described previously for characterization of runoff quality. The results of these comparisons were then used to rank parameters for monitoring priority, with higher estimated and observed exceedences receiving higher priorities for monitoring. Note that for constituents monitored by the Department, only trace metals and organics have CTR criteria.

Correlations Among Runoff Quality Parameters

Correlations between runoff quality parameters were first evaluated using Spearman's non-parametric rank correlation method, with data below detection set to a value of zero. This evaluation was performed to identify parameter pairs or groups with high correlations and therefore potentially high levels of redundancy for monitoring. The threshold used to identify potentially useful relationships was a Spearman's *rho* value greater than 0.8 and statistically significant at the 95% confidence level. (Spearman's *rho* is the non-parametric equivalent of the parametric Pearson's Product-Moment correlation coefficient, *R*.) After screening with Spearman's non-parametric method, the standard Pearson's Product-Moment correlation coefficient was calculated using only detected data to verify the linearity of the relationship. Statistically significant correlations greater than 0.8 were considered adequately strong for parameters to effectively serve as surrogates for each other. This information was used to prioritize pollutants for continued monitoring.

FACTORS LIMITING ANALYSIS

A number of factors may affect the ability to successfully analyze and interpret stormwater runoff quality data. These include data variability, "representativeness" of sampling methods and data collection, sampling design and pseudoreplication, lack of normality in dependent and predictor variables, collinearity of the predictor variables, and the overall size and quality of the data set.

Data Variability

The high degree of variability in runoff quality data increases the difficulty of demonstrating that significant differences in runoff quality are attributable to facility types, contributing land use, management efforts, or monitoring strategies. By modeling the relationships between runoff quality and precipitation factors through multiple regression analysis, some of the variability inherent in runoff quality data can be explained, thereby increasing the ability to detect effects from other site-specific characteristics. Some of the factors considered to contribute significantly to the variability of stormwater quality data are summarized in Table 2-1.

Sampling Design, Representativeness and Pseudoreplication

Sampling design and data collection methods are critical to the ability to analyze and interpret stormwater quality data correctly. Appropriate design and sampling methods will produce data that are representative of the range of hydrological conditions and runoff characteristics of interest. A good sampling design will also be based on the statistical methods needed to appropriately analyze the data. A poorly designed or biased monitoring program may produce runoff quality data that are not representative of the conditions of interest, or that represent only a limited range of the variability of the data. Even the most rigorous statistical methods can result in incorrect conclusions if based on biased or non-representative data. One of the more common symptoms of an inadequate sampling design is the phenomenon of pseudoreplication, which occurs when a particular treatment or category is represented by only a few sites (or only one site in the extreme case) that are sampled many times. The primary effect of pseudoreplication on statistical analyses is that it results in overestimation of the degrees of freedom used to calculate the error term for the statistical comparison being made (*e.g.* between facility types or land uses), and consequently leads to inflation of the estimated significance of statistical comparisons (Hurlbert, 1984). Data in the Department's Stormwater Quality Database are expected to be representative for the particular monitoring site because the Department's monitoring programs use consistent and well-documented sampling methods that are designed specifically for collection of representative stormwater samples. However, because the Department's monitoring programs were not designed specifically for this type of statistical comparison, pseudoreplication does occur to some degree in the data set used in these analyses. The effects of pseudoreplication manifests primarily in comparisons and conclusions of the effects of categorical variables (*e.g.* facility types) on runoff quality, particularly when one level of a category (*e.g.* rest areas) is represented by only a few sites, and indicates the need for caution in interpreting these comparisons. Problems with pseudoreplication for these analyses were partly controlled by using data from the Statewide characterization studies, which was designed to provide representative data for Department facilities and geographic regions throughout the state. However, although Statewide characterization studies monitoring sites were selected to be representative of "typical" Caltrans facilities, extrapolating results for a facility type with only a few representative sites (or a region with only a few representative highway sites) in the analysis to all such facilities should be done with caution. Note that pseudoreplication has little or no effect on the basic MLR analysis because each combination of event and sampling location is essentially treated as a unique independent observation.

Data Distributions

Normality and equal variance (homoscedasticity) of residuals are two central assumptions of the linear regression analysis and ANCOVA. Although these statistical methods are robust to minor violations, major deviations of these assumptions can reduce the power of these tests to detect significant effects or may lead to inaccurate characterization of effects. These potential limitations were controlled by evaluating data distributions for normality, transforming dependent and independent variables *a priori* to approximate normality if necessary, and finally by inspecting the residuals of the analyses for normality, equal variance, and nonlinearity.

Table 2-5 Factors Contributing to Stormwater Monitoring Data Variability

Category	Specific Factors
Site Specific Factors & Drainage Area Characteristics	• % imperviousness • gradients • vegetation types and coverage • runoff conveyance systems • structural controls • contributing land uses • climate
Meteorological and Storm Event Characteristics	• inter-storm precipitation factors • storm to storm variation • seasonal variation • annual variation
Pollutant Sources	• atmospheric • automotive • construction • building materials • household • commercial/industrial
Human Activities	• population density • traffic patterns • land use • public awareness
Monitoring Factors	• field sampling methods • laboratory and analytical methods

Collinearity

While not a strict requirement, independence of predictor variables (the absence of collinearity) provides an ideal condition for multiple linear regression analysis. Although collinearity does not seriously compromise the predictive value of a multiple regression model, highly correlated predictor variables can make it difficult to interpret the effect of a specific variable (*e.g.* whether it causes an increase or decrease in the dependent variable). As discussed previously, collinearity was assessed using diagnostic statistics for correlations and partial correlations among the predictor variables, and controlled by excluding highly correlated variables from the analysis. In cases where variables were highly correlated, the variable with the largest effect in the models was preferentially retained.

Data Set Quality and Size

Incomplete and censored data sets may also limit the effectiveness of statistical analyses. Incomplete data for storm event or site characteristics can eliminate an event or site from analysis. If these data are randomly missing, then this simply decreases the effective size of the data set and the power of statistical analyses. If the data are systematically missing (*e.g.*, only for storms with more than one inch of rainfall or for a particular type of facility), the data and conclusions based on the data will be biased. This particular type of non-random censoring bias was effectively controlled by the Statewide discharge characterization study's monitoring design, which ensured that runoff quality data were collected for a wide range of environmental and site-specific conditions.

Runoff quality data that are below analytical detection limits are another example of non-randomly censored data. If these data are excluded from the analysis or handled incorrectly, the data set will be biased and may violate the core distributional assumptions of the analyses. Potential biases were limited by restricting the analyses to parameters with low levels of censoring (described previously in this document) to minimize distortion of the underlying distribution characteristics of the data for each runoff quality parameter. While this method still allows for some potential bias of the results, it is preferable to simple substitution methods for censored data which introduce different and less easily predictable biases.

Another factor that can limit the effectiveness of any statistical analyses is a small data set. However, this is not a significant limitation of the Department's Stormwater Quality database. Over 60,000 total runoff quality data records were included in these analyses. In the Statewide characterization studies dataset used for MLR and ANCOVA analyses, total numbers of data points ("*n*") for individual parameters approached 1,000, and for individual parameters at specific facilities *n* ranged from 24 (*Toll Plazas*) to 635 (*Highways*). The large size of the available data set overcomes many of the other limitations by increasing statistical power and overall robustness of the analyses.

SUMMARY STATISTICS FOR WATER QUALITY DATA

The quality of stormwater runoff was characterized primarily through calculation of summary statistics and distributional parameters for runoff from the different facilities. Statistics were calculated using methods appropriate for estimating these distributional parameters for data that include values below detection ("non-detect data"). Summary statistics for Statewide characterization studies data (monitoring years 2000/01-2002/03) are provided in the Tables 3-1 through 3-6. The statistics presented include the number of samples, minimum and maximum detected values, median, mean, and standard deviation. Statistics are presented for conventional parameters, total petroleum hydrocarbons, trace metals, nutrients, pesticides and herbicides, and semi-volatile organic compounds for the following Department facilities:

Facility	Table number	Page reference
Caltrans Vehicle Inspection Facilities	Table 3-1	Page 26
Highways	Table 3-2	Page 27
Maintenance Facilities	Table 3-3	Page 28
Park-And-Ride Facilities	Table 3-4	Page 29
Rest Areas	Table 3-5	Page 30
Toll Plazas	Table 3-6	Page 31

Percentages of total metals present as particulates are summarized in Table 3-7 for all facility types.

Statistics are also provided for the complete data set (monitoring years 1998/99-2002/03) in Appendix A. Note that all runoff quality parameters (i.e., the dependent variables) were approximately lognormally distributed, with the exceptions of pH and temperature, which were approximately normal.

For constituents with at least 30% detected data, plots of annual average water quality with 95% confidence limits are presented in Appendix A for the Department's facilities that were monitored for the Statewide characterization studies, 2000/01-2002/03.

Table 3-1 Summary Statistics for CALTRANS VEHICLE INSPECTION FACILITIES: Statewide Characterization Studies Data, Monitoring Years 2000/01-2002/03

Pollutant Category	Parameter	Units	n	number of sites	% Detected	Min Detected	Max Detected	Median	Mean	SD
Conventional	DOC	mg/L	31	2	100%	2.5	67.1	13.3	18.5	15.9
	EC	µS/cm	31	2	100%	10.9	690	82.1	113.3	137.3
	Hardness as CaCO3	mg/L	31	2	100%	5	120	28.6	33.5	22.1
	pH	pH	31	2	100%	6.2	8.15	7.1	7.1	0.4
	TDS	mg/L	31	2	97%	19	470	65.1	84.8	92.1
	Temperature	°C	16	2	100%	7.7	19.3	12.1	12.5	3.3
	TOC	mg/L	31	2	100%	2.6	68	14.3	20.0	16.9
	TSS	mg/L	31	2	97%	20	200	67.3	83.4	53.0
	Turbidity	NTU	—	—	—	—	—	—	—	—
Hydro-carbons	Oil & Grease	mg/L	—	—	—	—	—	—	—	—
	TPH (Diesel)	mg/L	—	—	—	—	—	—	—	—
	TPH (Gasoline)	mg/L	—	—	—	—	—	—	—	—
	TPH (Heavy Oil)	mg/L	—	—	—	—	—	—	—	—
Metals	As, dissolved	µg/L	31	2	42%	1	2.1	1.0	1.0	0.4
	As, total	µg/L	31	2	68%	1.2	64	1.3	3.4	16.1
	Cd, dissolved	µg/L	31	2	45%	0.2	0.7	0.16	0.20	0.16
	Cd, total	µg/L	31	2	87%	0.2	1.7	0.43	0.56	0.40
	Cr, dissolved	µg/L	31	2	68%	1.1	5.5	1.4	1.8	1.2
	Cr, total	µg/L	31	2	100%	2.1	21	6.7	8.1	4.8
	Cu, dissolved	µg/L	31	2	100%	2	51	11.0	15.6	13.3
	Cu, total	µg/L	31	2	100%	6.2	96	24.8	33.6	24.1
	Hg, dissolved	ng/L	3	1	0%	ND	ND	IDD	IDD	IDD
	Hg, total	ng/L	4	1	50%	12.5	120	IDD	IDD	IDD
	Ni, dissolved	µg/L	31	2	81%	1	9.9	2.7	3.5	2.4
	Ni, total	µg/L	31	2	100%	2.9	20	7.4	8.4	4.7
	Pb, dissolved	µg/L	31	2	55%	1	14	1.1	2.7	3.9
	Pb, total	µg/L	31	2	100%	1.6	180	10.9	21.9	37.7
	Zn, dissolved	µg/L	31	2	100%	23	380	66.1	88.2	79.1
	Zn, total	µg/L	31	2	100%	66	700	206.0	244.5	151.6
Micro-biological	Fecal Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
	Total Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
Nutrients	NH3-N	mg/L	—	—	—	—	—	—	—	—
	NO3-N	mg/L	31	2	100%	0.15	3.53	0.62	0.89	0.81
	Ortho-P, dissolved	mg/L	30	2	73%	0.046	0.48	0.09	0.13	0.12
	P, total	mg/L	31	2	100%	0.046	0.67	0.23	0.28	0.16
	TKN	mg/L	30	2	87%	0.15	12.3	1.15	2.16	2.72
Pesticide & Herbicides	Chlorpyrifos	µg/L	—	—	—	—	—	—	—	—
	Diazinon	µg/L	6	1	17%	0.1	0.1	IDD	IDD	IDD
	Diuron	µg/L	—	—	—	—	—	—	—	—
	Glyphosate	µg/L	—	—	—	—	—	—	—	—
	Oryzalin	µg/L	—	—	—	—	—	—	—	—
	Oxadiazon	µg/L	—	—	—	—	—	—	—	—
	Triclopyr	µg/L	—	—	—	—	—	—	—	—
Semi-volitile Organics	Acenaphthene	µg/L	—	—	—	—	—	—	—	—
	Acenaphthylene	µg/L	—	—	—	—	—	—	—	—
	Anthracene	µg/L	—	—	—	—	—	—	—	—
	Benzo(a)Anthracene	µg/L	—	—	—	—	—	—	—	—
	Benzo(a)Pyrene	µg/L	—	—	—	—	—	—	—	—
	Benzo(b)Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Benzo(ghi)Perylene	µg/L	—	—	—	—	—	—	—	—
	Benzo(k)Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Chrysene	µg/L	—	—	—	—	—	—	—	—
	Dibenzo(a,h)Anthracene	µg/L	—	—	—	—	—	—	—	—
	Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Fluorene	µg/L	—	—	—	—	—	—	—	—
	Indeno(1,2,3-c,d)Pyrene	µg/L	—	—	—	—	—	—	—	—
	Naphthalene	µg/L	—	—	—	—	—	—	—	—
	Phenanthrene	µg/L	—	—	—	—	—	—	—	—
	Pyrene	µg/L	—	—	—	—	—	—	—	—

Notes: "—" indicates parameter was not monitored for this facility category. "ND" indicates parameter was not detected. "IDD" indicates there were insufficient detected data to calculate statistic.

Table 3-2 Summary Statistics for HIGHWAY FACILITIES: Statewide Characterization Studies Data, Monitoring Years 2000/01-2002/03

Pollutant Category	Parameter	Units	n	number of sites	% Detected	Min Detected	Max Detected	Median	Mean	SD
Conventional	DOC	mg/L	635	46	100%	1.2	483	13.1	18.7	26.2
	EC	µS/cm	634	46	100%	5	743	72.7	96.1	73.4
	Hardness as CaCO3	mg/L	635	46	99%	2	400	26.9	36.5	34.2
	pH	pH	633	46	100%	4.47	10.1	7.0	7.1	0.7
	TDS	mg/L	635	46	97%	3.7	1800	60.3	87.3	103.7
	Temperature	°C	183	30	100%	4.7	25.4	12.0	12.5	3.4
	TOC	mg/L	635	46	100%	1.6	530	15.3	21.8	29.2
	TSS	mg/L	634	46	99%	1	2988	59.1	112.7	188.8
	Turbidity	NTU	—	—	—	—	—	—	—	—
Hydro-carbons	Oil & Grease	mg/L	49	10	29%	5	61	1.44	4.95	11.41
	TPH (Diesel)	mg/L	32	4	97%	0.22	13	2.52	3.72	3.31
	TPH (Gasoline)	mg/L	32	4	0%	ND	ND	ND	IDD	IDD
	TPH (Heavy Oil)	mg/L	20	4	95%	0.12	13	1.40	2.71	3.40
Metals	As, dissolved	µg/L	635	46	40%	0.5	20	0.7	1.0	1.4
	As, total	µg/L	635	46	62%	0.5	70	1.1	2.7	7.9
	Cd, dissolved	µg/L	635	46	42%	0.2	8.4	0.13	0.24	0.54
	Cd, total	µg/L	635	46	76%	0.2	30	0.44	0.73	1.61
	Cr, dissolved	µg/L	635	46	80%	1	23	2.2	3.3	3.3
	Cr, total	µg/L	635	46	97%	1	94	5.8	8.6	9.0
	Cu, dissolved	µg/L	635	46	100%	1.1	130	10.2	14.9	14.4
	Cu, total	µg/L	635	46	100%	1.2	270	21.1	33.5	31.6
	Hg, dissolved	ng/L	19	4	16%	2.5	110	IDD	IDD	IDD
	Hg, total	ng/L	23	4	39%	7.8	160	26.0	36.7	37.9
	Ni, dissolved	µg/L	635	46	79%	1.1	40	3.4	4.9	5.0
	Ni, total	µg/L	635	46	95%	1.1	130	7.7	11.2	13.2
	Pb, dissolved	µg/L	635	46	60%	1	480	1.2	7.6	34.3
	Pb, total	µg/L	635	46	94%	1	2600	12.7	47.8	151.3
	Zn, dissolved	µg/L	635	46	99%	3	1017	40.4	68.8	96.6
	Zn, total	µg/L	635	46	100%	5.5	1680	111.2	187.1	199.8
Micro-biological	Fecal Coliform	MPN/100 mL	32	5	97%	23	6000	362	1132	1621
	Total Coliform	MPN/100 mL	32	5	100%	34	160000	3966	13438	34299
Nutrients	NH3-N	mg/L	8	1	100%	0.33	3.9	0.77	1.08	1.46
	NO3-N	mg/L	634	46	90%	0.011	48	0.60	1.07	2.44
	Ortho-P, dissolved	mg/L	630	46	64%	0.014	2.4	0.06	0.11	0.18
	P, total	mg/L	631	46	89%	0.03	4.69	0.18	0.29	0.39
	TKN	mg/L	626	46	94%	0.1	17.7	1.40	2.06	1.90
Pesticide & Herbicides	Chlorpyrifos	µg/L	—	—	—	—	—	—	—	—
	Diazinon	µg/L	34	5	21%	0.1	1.33	0.04	0.13	0.29
	Diuron	µg/L	367	30	44%	0.5	220	0.37	4.60	18.24
	Glyphosate	µg/L	541	30	56%	5.1	164	8.88	19.61	26.97
	Oryzalin	µg/L	361	30	16%	0.5	77.8	IDD	IDD	IDD
	Oxadiazon	µg/L	365	30	5%	0.05	0.8	IDD	IDD	IDD
	Triclopyr	µg/L	367	30	2%	0.3	830	IDD	IDD	IDD
Semi-volitile Organics	Acenaphthene	µg/L	32	6	3%	0.25	0.25	IDD	IDD	IDD
	Acenaphthylene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Anthracene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Benzo(a)Anthracene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Benzo(a)Pyrene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Benzo(b)Fluoranthene	µg/L	32	6	3%	0.05	0.05	IDD	IDD	IDD
	Benzo(ghi)Perylene	µg/L	32	6	19%	0.05	0.17	IDD	IDD	IDD
	Benzo(k)Fluoranthene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Chrysene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Dibenzo(a,h)Anthracene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Fluoranthene	µg/L	32	6	19%	0.05	0.1	IDD	IDD	IDD
	Fluorene	µg/L	32	6	3%	0.06	0.06	IDD	IDD	IDD
	Indeno(1,2,3-c,d)Pyrene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Naphthalene	µg/L	32	6	0%	ND	ND	ND	IDD	IDD
	Phenanthrene	µg/L	32	6	9%	0.05	0.14	IDD	IDD	IDD
	Pyrene	µg/L	32	6	25%	0.06	0.13	0.05	0.05	0.03

Notes: "—" indicates parameter was not monitored for this facility category. "ND" indicates parameter was not detected. "IDD" indicates there were insufficient detected data to calculate statistic.

Table 3-3 Summary Statistics for MAINTENANCE FACILITIES: Statewide Characterization Studies Data, Monitoring Years 2000/01-2002/03

Pollutant Category	Parameter	Units	n	number of sites	% Detected	Min Detected	Max Detected	Median	Mean	SD
Conventional	DOC	mg/L	75	7	100%	1.3	82	11.7	18.2	18.2
	EC	µS/cm	56	7	100%	12	660	49.4	80.9	110.6
	Hardness as CaCO3	mg/L	106	7	96%	2	208	17.4	26.7	28.7
	pH	pH	107	7	100%	3.5	8.5	6.8	6.8	0.6
	TDS	mg/L	106	7	97%	4	536	44.6	68.9	78.1
	Temperature	°C	17	2	100%	8.5	16.5	12.2	12.5	2.8
	TOC	mg/L	107	7	100%	1.7	128	12.7	20.6	23.0
	TSS	mg/L	106	7	100%	6	420	62.4	96.4	95.0
	Turbidity	NTU	29	3	100%	36	430	122.95	144.83	92.23
Hydro-carbons	Oil & Grease	mg/L	—	—	—	—	—	—	—	—
	TPH (Diesel)	mg/L	—	—	—	—	—	—	—	—
	TPH (Gasoline)	mg/L	—	—	—	—	—	—	—	—
	TPH (Heavy Oil)	mg/L	—	—	—	—	—	—	—	—
Metals	As, dissolved	µg/L	106	7	82%	0.53	81	2.2	9.5	17.3
	As, total	µg/L	107	7	93%	0.585	91	3.4	12.8	23.1
	Cd, dissolved	µg/L	106	7	49%	0.2	1.2	0.19	0.27	0.22
	Cd, total	µg/L	107	7	84%	0.2	2.7	0.46	0.69	0.63
	Cr, dissolved	µg/L	106	7	53%	1	5.9	1.1	1.4	1.0
	Cr, total	µg/L	107	7	99%	1.01	28	3.9	5.1	4.3
	Cu, dissolved	µg/L	106	7	99%	2.4	100	8.8	14.3	17.6
	Cu, total	µg/L	107	7	100%	3	210	17.3	29.5	37.6
	Hg, dissolved	ng/L	7	1	43%	7.85	77	14.4	27.7	51.4
	Hg, total	ng/L	8	1	75%	14.4	230	41.0	65.4	83.7
	Ni, dissolved	µg/L	106	7	57%	1.6	22	2.37	3.72	4.01
	Ni, total	µg/L	107	7	90%	2.08	51	5.48	7.86	7.68
	Pb, dissolved	µg/L	106	7	44%	1	23	0.74	1.64	2.99
	Pb, total	µg/L	107	7	98%	1	130	11.7	21.3	26.5
	Zn, dissolved	µg/L	107	7	98%	1	130	11.7	21.3	26.5
	Zn, total	µg/L	107	7	100%	26	1500	164.6	245.6	259.3
Micro-biological	Fecal Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
	Total Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
Nutrients	NH3-N	mg/L	—	—	—	—	—	—	—	—
	NO3-N	mg/L	107	7	92%	0.12	8	0.41	0.74	1.13
	Ortho-P, dissolved	mg/L	105	7	55%	0.016	3.12	0.04	0.09	0.40
	P, total	mg/L	106	7	95%	0.031	1	0.16	0.23	0.20
	TKN	mg/L	105	7	92%	0.11	11.5	1.24	1.79	1.72
Pesticide & Herbicides	Chlorpyrifos	µg/L	23	3	0%	ND	ND	IDD	IDD	IDD
	Diazinon	µg/L	33	3	39%	0.016	1.4	0.02	0.12	0.30
	Diuron	µg/L	—		—	—	—	—	—	—
	Glyphosate	µg/L	—		—	—	—	—	—	—
	Oryzalin	µg/L	—		—	—	—	—	—	—
	Oxadiazon	µg/L	—		—	—	—	—	—	—
	Triclopyr	µg/L	—		—	—	—	—	—	—
Semi-volitile Organics	Acenaphthene	µg/L	—		—	—	—	—	—	—
	Acenaphthylene	µg/L	—		—	—	—	—	—	—
	Anthracene	µg/L	—		—	—	—	—	—	—
	Benzo(a)Anthracene	µg/L	—		—	—	—	—	—	—
	Benzo(a)Pyrene	µg/L	—		—	—	—	—	—	—
	Benzo(b)Fluoranthene	µg/L	—		—	—	—	—	—	—
	Benzo(ghi)Perylene	µg/L	—		—	—	—	—	—	—
	Benzo(k)Fluoranthene	µg/L	—		—	—	—	—	—	—
	Chrysene	µg/L	—		—	—	—	—	—	—
	Dibenzo(a,h)Anthracene	µg/L	—		—	—	—	—	—	—
	Fluoranthene	µg/L	—		—	—	—	—	—	—
	Fluorene	µg/L	—		—	—	—	—	—	—
	Indeno(1,2,3-c,d)Pyrene	µg/L	—		—	—	—	—	—	—
	Naphthalene	µg/L	—		—	—	—	—	—	—
	Phenanthrene	µg/L	—		—	—	—	—	—	—
	Pyrene	µg/L	—		—	—	—	—	—	—

Notes: "—" indicates parameter was not monitored for this facility category. "ND" indicates parameter was not detected. "IDD" indicates there were insufficient detected data to calculate statistic.

Table 3-4 Summary Statistics for PARK-AND-RIDE FACILITIES: Statewide Characterization Studies Data, Monitoring Years 2000/01-2002/03

Pollutant Category	Parameter	Units	n	number of sites	% Detected	Min Detected	Max Detected	Median	Mean	SD
Conventional	DOC	mg/L	179	10	99%	1.03	278	10.8	18.0	28.6
	EC	µS/cm	179	10	100%	6	420	43.6	63.5	65.8
	Hardness as CaCO3	mg/L	179	10	97%	2	420	16.3	26.6	45.9
	pH	pH	179	10	100%	3.9	9.68	6.7	6.8	0.7
	TDS	mg/L	179	10	96%	6	720	38.1	61.7	78.3
	Temperature	°C	50	7	100%	7.7	21.8	12.2	12.6	3.4
	TOC	mg/L	179	10	100%	1.3	150	12.2	18.6	20.6
	TSS	mg/L	179	10	99%	2	340	48.3	68.5	59.3
	Turbidity	NTU	2	2	100%	29	36	IDD	IDD	IDD
Hydro-carbons	Oil & Grease	mg/L	—	—	—	—	—	—	—	—
	TPH (Diesel)	mg/L	—	—	—	—	—	—	—	—
	TPH (Gasoline)	mg/L	—	—	—	—	—	—	—	—
	TPH (Heavy Oil)	mg/L	—	—	—	—	—	—	—	—
Metals	As, dissolved	µg/L	179	10	26%	0.53	3	0.5	0.7	0.6
	As, total	µg/L	179	10	47%	0.52	60	0.8	1.4	5.9
	Cd, dissolved	µg/L	179	10	21%	0.2	0.9	0.08	0.12	0.12
	Cd, total	µg/L	179	10	59%	0.2	2.3	0.21	0.30	0.30
	Cr, dissolved	µg/L	179	10	35%	1	5.1	0.7	1.0	0.9
	Cr, total	µg/L	179	10	90%	1	24	2.7	4.0	4.2
	Cu, dissolved	µg/L	179	10	99%	1.1	70	6.2	8.7	8.8
	Cu, total	µg/L	179	10	100%	1.3	120	12.9	17.1	15.2
	Hg, dissolved	ng/L	10	2	0%	ND	ND	IDD	IDD	IDD
	Hg, total	ng/L	11	2	45%	38.6	230	42.7	57.3	73.6
	Ni, dissolved	µg/L	179	10	57%	1	26	2.0	3.3	3.9
	Ni, total	µg/L	179	10	88%	1.9	28	4.8	6.2	4.8
	Pb, dissolved	µg/L	179	10	34%	1	25	0.5	1.3	2.7
	Pb, total	µg/L	179	10	96%	1	78	5.8	10.3	11.5
	Zn, dissolved	µg/L	179	10	96%	1	78	5.8	10.3	11.5
	Zn, total	µg/L	179	10	100%	8.2	960	103.3	154.3	157.1
Micro-biological	Fecal Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
	Total Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
Nutrients	NH3-N	mg/L	—	—	—	—	—	—	—	—
	NO3-N	mg/L	179	10	93%	0.1	5.49	0.32	0.57	0.83
	Ortho-P, dissolved	mg/L	178	10	69%	0.03	1.01	0.07	0.15	0.19
	P, total	mg/L	179	10	98%	0.03	3.27	0.20	0.33	0.42
	TKN	mg/L	176	10	94%	0.13	13.6	1.52	2.28	2.20
Pesticide & Herbicides	Chlorpyrifos	µg/L	—	—	—	—	—	—	—	—
	Diazinon	µg/L	20	2	15%	0.6	1.7	IDD	IDD	IDD
	Diuron	µg/L	—	—	—	—	—	—	—	—
	Glyphosate	µg/L	—	—	—	—	—	—	—	—
	Oryzalin	µg/L	—	—	—	—	—	—	—	—
	Oxadiazon	µg/L	—	—	—	—	—	—	—	—
	Triclopyr	µg/L	—	—	—	—	—	—	—	—
Semi-volitile Organics	Acenaphthene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Acenaphthylene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Anthracene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Benzo(a)Anthracene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Benzo(a)Pyrene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Benzo(b)Fluoranthene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Benzo(ghi)Perylene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Benzo(k)Fluoranthene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Chrysene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Dibenzo(a,h)Anthracene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Fluoranthene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Fluorene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Indeno(1,2,3-c,d)Pyrene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Naphthalene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Phenanthrene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD
	Pyrene	µg/L	1	1	0%	ND	ND	IDD	IDD	IDD

Notes: "—" indicates parameter was not monitored for this facility category. "ND" indicates parameter was not detected. "IDD" indicates there were insufficient detected data to calculate statistic.

Table 3-5 Summary Statistics for REST AREAS: Statewide Characterization Studies Data, Monitoring Years 2000/01-2002/03

Pollutant Category	Parameter	Units	n	number of sites	% Detected	Min Detected	Max Detected	Median	Mean	SD
Conventional	DOC	mg/L	53	3	100%	2.1	239	13.0	19.9	39.6
	EC	µS/cm	53	3	100%	9	809	51.7	78.2	132.0
	Hardness as CaCO3	mg/L	53	3	98%	3	484	18.0	33.0	81.2
	pH	pH	53	3	100%	5.7	7.9	6.8	6.9	0.4
	TDS	mg/L	53	3	100%	4	778	38.0	61.2	130.0
	Temperature	°C	12	3	100%	5.3	16.3	11.0	11.4	3.2
	TOC	mg/L	53	3	100%	2.5	247	15.0	22.2	40.5
	TSS	mg/L	53	3	98%	7	247	44.2	63.3	54.4
	Turbidity	NTU	—	—	—	—	—	—	—	—
Hydro-carbons	Oil & Grease	mg/L	—	—	—	—	—	—	—	—
	TPH (Diesel)	mg/L	—	—	—	—	—	—	—	—
	TPH (Gasoline)	mg/L	—	—	—	—	—	—	—	—
	TPH (Heavy Oil)	mg/L	—	—	—	—	—	—	—	—
Metals	As, dissolved	µg/L	53	3	47%	1	20	0.6	1.4	3.3
	As, total	µg/L	53	3	57%	1	58	0.9	3.6	11.4
	Cd, dissolved	µg/L	53	3	17%	0.2	1.4	IDD	IDD	IDD
	Cd, total	µg/L	53	3	58%	0.2	2.8	0.17	0.32	0.53
	Cr, dissolved	µg/L	53	3	62%	1	13	1.2	1.9	2.5
	Cr, total	µg/L	53	3	100%	1	18	3.8	4.8	3.8
	Cu, dissolved	µg/L	53	3	100%	2.7	76	7.6	9.6	12.0
	Cu, total	µg/L	53	3	100%	4.6	89	13.1	16.0	14.2
	Hg, dissolved	ng/L	—	—	—	—	—	—	—	—
	Hg, total	ng/L	—	—	—	—	—	—	—	—
	Ni, dissolved	µg/L	53	3	55%	1.3	35	1.9	3.2	5.8
	Ni, total	µg/L	53	3	92%	1.7	42	4.8	7.3	8.3
	Pb, dissolved	µg/L	53	3	45%	1	8.3	0.7	1.2	1.7
	Pb, total	µg/L	53	3	98%	1.1	32	5.1	7.7	8.0
	Zn, dissolved	µg/L	53	3	100%	12	1500	46.2	82.5	263.7
	Zn, total	µg/L	53	3	100%	21	1800	91.1	142.4	298.9
Micro-biological	Fecal Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
	Total Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
Nutrients	NH3-N	mg/L	—		—	—	—	—	—	—
	NO3-N	mg/L	53	3	94%	0.2	3.83	0.69	0.96	0.88
	Ortho-P, dissolved	mg/L	52	3	83%	0.056	9.3	0.18	0.44	1.67
	P, total	mg/L	53	3	96%	0.08	2.36	0.32	0.47	0.53
	TKN	mg/L	53	3	98%	0.2	81.2	2.10	4.37	14.04
Pesticide & Herbicides	Chlorpyrifos	µg/L	—	—	—	—	—	—	—	—
	Diazinon	µg/L	—	—	—	—	—	—	—	—
	Diuron	µg/L	3	1	33%	2.2	2.2	IDD	IDD	IDD
	Glyphosate	µg/L	3	1	33%	7.7	7.7	IDD	IDD	IDD
	Oryzalin	µg/L	3	1	33%	1.7	1.7	IDD	IDD	IDD
	Oxadiazon	µg/L	3	1	0%	ND	ND	IDD	IDD	IDD
	Triclopyr	µg/L	3	1	0%	ND	ND	IDD	IDD	IDD
Semi-volitile Organics	Acenaphthene	µg/L	—	—	—	—	—	—	—	—
	Acenaphthylene	µg/L	—	—	—	—	—	—	—	—
	Anthracene	µg/L	—	—	—	—	—	—	—	—
	Benzo(a)Anthracene	µg/L	—	—	—	—	—	—	—	—
	Benzo(a)Pyrene	µg/L	—	—	—	—	—	—	—	—
	Benzo(b)Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Benzo(ghi)Perylene	µg/L	—	—	—	—	—	—	—	—
	Benzo(k)Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Chrysene	µg/L	—	—	—	—	—	—	—	—
	Dibenzo(a,h)Anthracene	µg/L	—	—	—	—	—	—	—	—
	Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Fluorene	µg/L	—	—	—	—	—	—	—	—
	Indeno(1,2,3-c,d)Pyrene	µg/L	—	—	—	—	—	—	—	—
	Naphthalene	µg/L	—	—	—	—	—	—	—	—
	Phenanthrene	µg/L	—	—	—	—	—	—	—	—
	Pyrene	µg/L	—	—	—	—	—	—	—	—

Notes: "—" indicates parameter was not monitored for this facility category. "ND" indicates parameter was not detected. "IDD" indicates there were insufficient detected data to calculate statistic.

Table 3-6 Summary Statistics for TOLL PLAZAS: Statewide Characterization Studies Data, Monitoring Years 2000/01-2002/03

Pollutant Category	Parameter	Units	n	number of sites	% Detected	Min Detected	Max Detected	Median	Mean	SD
Conventional	DOC	mg/L	24	2	100%	3.8	73	18.9	25.6	19.8
	EC	µS/cm	24	2	100%	9	370	85.8	118.9	100.2
	Hardness as CaCO3	mg/L	24	2	100%	8	120	29.6	37.1	27.7
	pH	pH	24	2	100%	6.3	7.6	6.9	6.9	0.4
	TDS	mg/L	24	2	96%	6	280	51.9	81.5	74.2
	Temperature	°C	18	2	100%	7.8	16.2	12.0	12.3	3.0
	TOC	mg/L	24	2	100%	4.4	76.7	24.7	31.0	20.3
	TSS	mg/L	24	2	100%	20	313	101.4	123.3	77.4
	Turbidity	NTU	—	—	—	—	—	—	—	—
Hydro-carbons	Oil & Grease	mg/L	—	—	—	—	—	—	—	—
	TPH (Diesel)	mg/L	—	—	—	—	—	—	—	—
	TPH (Gasoline)	mg/L	—	—	—	—	—	—	—	—
	TPH (Heavy Oil)	mg/L	—	—	—	—	—	—	—	—
Metals	As, dissolved	µg/L	24	2	25%	1	1.8	0.7	0.8	0.4
	As, total	µg/L	24	2	79%	1	4.2	1.3	1.5	0.8
	Cd, dissolved	µg/L	24	2	100%	0.2	1.2	0.37	0.43	0.29
	Cd, total	µg/L	24	2	100%	0.5	2.5	1.04	1.15	0.56
	Cr, dissolved	µg/L	24	2	100%	1.2	11	4.4	5.1	2.5
	Cr, total	µg/L	24	2	100%	2.2	31	10.3	12.5	7.7
	Cu, dissolved	µg/L	24	2	100%	6.7	75	21.8	27.3	20.6
	Cu, total	µg/L	24	2	100%	26	110	55.5	59.6	23.0
	Hg, dissolved	ng/L	4	—	25%	63	63	IDD	IDD	IDD
	Hg, total	ng/L	4	—	25%	200	200	IDD	IDD	IDD
	Ni, dissolved	µg/L	24	2	100%	1	16	4.8	6.0	4.5
	Ni, total	µg/L	24	2	100%	4.8	31	12.3	13.7	6.8
	Pb, dissolved	µg/L	24	2	71%	1.4	19	3.1	5.2	5.2
	Pb, total	µg/L	24	2	100%	11	120	27.1	31.6	24.3
	Zn, dissolved	µg/L	24	2	100%	25	340	98.5	123.7	89.4
	Zn, total	µg/L	24	2	100%	140	650	268.3	292.9	131.9
Micro-biological	Fecal Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
	Total Coliform	MPN/100 mL	—	—	—	—	—	—	—	—
Nutrients	NH3-N	mg/L	—	—	—	—	—	—	—	—
	NO3-N	mg/L	24	2	96%	0.16	2.78	0.55	0.84	0.81
	Ortho-P, dissolved	mg/L	23	2	39%	0.03	0.18	0.03	0.05	0.05
	P, total	mg/L	24	2	92%	0.077	0.52	0.23	0.25	0.11
	TKN	mg/L	24	2	100%	0.56	5.52	1.91	2.38	1.59
Pesticide & Herbicides	Chlorpyrifos	µg/L	—	—	—	—	—	—	—	—
	Diazinon	µg/L	7	1	14%	0.1	0.1	IDD	IDD	IDD
	Diuron	µg/L	—	—	—	—	—	—	—	—
	Glyphosate	µg/L	—	—	—	—	—	—	—	—
	Oryzalin	µg/L	—	—	—	—	—	—	—	—
	Oxadiazon	µg/L	—	—	—	—	—	—	—	—
	Triclopyr	µg/L	—	—	—	—	—	—	—	—
Semi-volitile Organics	Acenaphthene	µg/L	—	—	—	—	—	—	—	—
	Acenaphthylene	µg/L	—	—	—	—	—	—	—	—
	Anthracene	µg/L	—	—	—	—	—	—	—	—
	Benzo(a)Anthracene	µg/L	—	—	—	—	—	—	—	—
	Benzo(a)Pyrene	µg/L	—	—	—	—	—	—	—	—
	Benzo(b)Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Benzo(ghi)Perylene	µg/L	—	—	—	—	—	—	—	—
	Benzo(k)Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Chrysene	µg/L	—	—	—	—	—	—	—	—
	Dibenzo(a,h)Anthracene	µg/L	—	—	—	—	—	—	—	—
	Fluoranthene	µg/L	—	—	—	—	—	—	—	—
	Fluorene	µg/L	—	—	—	—	—	—	—	—
	Indeno(1,2,3-c,d)Pyrene	µg/L	—	—	—	—	—	—	—	—
	Naphthalene	µg/L	—	—	—	—	—	—	—	—
	Phenanthrene	µg/L	—	—	—	—	—	—	—	—
	Pyrene	µg/L	—	—	—	—	—	—	—	—

Notes: "—" indicates parameter was not monitored for this facility category. "ND" indicates parameter was not detected. "IDD" indicates there were insufficient detected data to calculate statistic.

Table 3-7 Percentage of Total Metals Present in the Particulate Fraction

Metal	CVIF	Highway	Maintenance	Park-and-Ride	Rest Areas	Toll Plazas	Facility Average
Arsenic	69%	62%	25%	52%	59%	47%	53%
Cadmium	63%	67%	62%	60%	IDD	63%	63%
Chromium	78%	62%	74%	74%	61%	59%	68%
Copper	54%	55%	52%	49%	40%	54%	51%
Nickel	59%	56%	53%	46%	56%	56%	54%
Lead	88%	84%	92%	87%	84%	84%	86%
Zinc	64%	63%	91%	93%	42%	58%	69%

"IDD" indicates there were insufficient detected data to calculate percent particulate fraction.

EFFECTS OF VARIOUS FACTORS ON RUNOFF QUALITY

Effects of Rainfall Parameters, Antecedent Conditions, AADT and Other Site Characteristics

Multiple Linear Regression Results

The relationships between runoff quality and various environmental and site-specific factors were investigated using Multiple Linear Regression (MLR) analysis of the Statewide characterization studies data set. This analysis included the effects of precipitation factors (event rainfall and maximum rainfall intensity), antecedent conditions (cumulative seasonal precipitation and antecedent dry period), annual average daily traffic (AADT), contributing drainage area and percent impervious area on constituent concentrations in storm runoff from the Department's facilities.

The results of the MLR analyses are presented in Table 3-8 (all monitored facilities) and Table 3-9 (highways only), including relevant model statistics and the specific effects of precipitation factors, antecedent conditions, AADT, and drainage area on the Department's facility runoff quality. A summary of patterns in significant covariate effects is provided in Table 3-10 (all facilities) and Table 3-11 (highways).

Two sets of models were developed for 24 constituents: one set for all facilities combined and excluding AADT, and a second set for highway sites only. Statistically significant coefficients of determination (R^2-values with $p<0.05$) ranged from 0.076–0.524 for highways, and from 0.019–0.415 for all facilities combined. The results of these analyses indicate that all of these factors have statistically significant effects on pollutant concentrations in runoff, and that these effects are generally consistent for most pollutants. The interpretation of dominant (most frequently observed) statistically significant effects of precipitation factors, antecedent conditions, contributing drainage area, and annual average daily traffic (AADT) on runoff quality is summarized below as follows:

- A statistically significant negative coefficient for *Event Rainfall* was observed for nearly all pollutants modeled, indicating that concentrations tend to decrease as total rainfall increases for a specific event. This significant negative coefficient indicates that average pollutant concentrations tend to be higher for smaller rainfall events and lower for larger events; this implies that pollutants tend to become diluted in larger storms. This can only be true if, on average, concentrations tend to be higher in the earlier portion of runoff and lower in the latter portion of runoff. By inference, this result is consistent with the existence of an event first flush effect; i.e., the interpretation that concentrations tend to be highest in the initial portion of runoff events, and are diluted as the storm event continues (i.e., it is consistent with a storm event first flush effect).

- A statistically significant positive coefficient for *Maximum Rainfall Intensity* would indicate that higher rainfall intensities tend to result in greater pollutant concentrations in runoff. A significant negative slope would suggests that higher rainfall intensities tend to have a diluting effect. *Maximum Rainfall Intensity* tended to be highly correlated (R^2-value of approximately 0.3) with *Event Rainfall*, had a consistently smaller effect and was less often significant than *Event Rainfall*, and was therefore eliminated from MLR models to prevent collinearity problems.

- *Antecedent Dry Period* had a statistically significant effect in the MLR models for most constituents, and significant coefficients for this factor were all positive, with the exception of pH. The significant positive slope indicates that longer antecedent dry periods tend to result in higher pollutant concentrations in storm runoff, and is consistent with the "buildup" of pollutants during dry periods.

- The effect of the seasonal first flush (*e.g.* the first significant storm event(s) of a season) was assessed by evaluating the effect of *Cumulative Seasonal Precipitation* on runoff quality. The statistically significant negative slope of the coefficient for *Cumulative Seasonal Precipitation* indicates that pollutant concentrations in runoff are highest in the early wet season and tend to decrease thereafter. *Cumulative Seasonal Precipitation* had a statistically significant effect in the MLR models for every Statewide characterization studies constituent, and significant coefficients for this factor were negative in every case.

- A significant positive slope for *Drainage Area* indicates that sites with larger contributing drainage areas tend to have higher pollutant concentrations in runoff. A significant positive slope indicates that sites with larger contributing drainage areas tend to have lower pollutant concentrations in runoff. *Drainage Area* had a statistically significant effect in four of 24 MLR models for highway sites, and eleven of 24 models for all facilities combined. Significant coefficients for *Drainage Area* were negative for all of the highway models, but for only four of eleven combined facility models. There was no clear pattern for this factor and the most common result for this factor was *not significant*.

- A statistically significant positive slope for *Impervious Fraction* indicates that sites with a higher proportion of impervious area tend to have higher pollutant concentrations in runoff. *Impervious Fraction* had a statistically significant effect in four of 24 MLR models for highway sites, and nine of 24 models for all facilities combined. Significant coefficients were evenly divided between positive and negative for highway models, and were negative for six of nine combined facility models. The most common result for this factor was *not significant*.

- A statistically significant positive slope for *AADT* indicates that higher average annual daily traffic tends to result in higher pollutant concentrations in runoff. *AADT* had a statistically significant effect in the MLR models for nearly every constituent, and significant coefficients for *AADT* were predominantly positive. A significant negative slope was observed for only one constituent (dissolved orthophosphate), suggesting that higher *AADT* tends to result in lower concentrations of this constituent in runoff. This counter-intuitive result may indicate that vehicle traffic is not a significant source of this pollutant and that lower *AADT* may be associated with other sources or conditions responsible for orthophosphate in runoff (*e.g.* agricultural land uses or higher percentages of landscaped areas).

The effects of AADT, event rainfall, cumulative precipitation and antecedent dry period are also illustrated using total recoverable copper reported and MLR-predicted values in Figure 3-1 through Figure 3-4, and the cumulative model is illustrated in Figure 3-5. Total copper was selected for this example because it is one of the best (most accurate) MLR models and best illustrates these effects.

Table 3-8 Effects of Precipitation, Antecedent Conditions, and Drainage Area on Runoff Quality from all Department Facilities: Multiple Linear Regression (MLR) Model Statistics and Coefficients for Whole Storm (EMC) data.

			Model Statistics			*Model Coefficients (1) (intercept and independent variables)*							*Standardized Model Coefficients (2)*					
Pollutant Category	Dependent Variable, X (Runoff Quality Parameter)	Form of X in Model	df	Adjusted Model R-Squared	S.E of Model Estimate	constant (y-Int.)	Ln[Event Rainfall, mm]	Ln[Max Intensity, mm/hr]	Ln[Antecedent Dry Period, days]	CubeRoot (Cumulative Precipitation, mm)	Ln[Drainage Area, hectares]	ArcSin [Impervious Fraction^0.5]	Ln[Event Rainfall, mm]	Ln[Max Intensity, mm/hr]	Ln[Antecedent Dry Period, days]	CubeRoot (Cumulative Precipitation, mm)	Ln[Drainage Area, hectares]	ArcSin [Impervious Fraction^0.5]
Conventional	DOC	Ln(X)	944	0.415	0.654	4.377	(-0.452)	—	0.154	(-0.131)	—	(-0.0033)	(-0.459)	—	0.189	(-0.318)	—	(-0.0590)
	EC	Ln(X)	945	0.263	0.729	5.338	(-0.393)	—	0.137	(-0.077)	—	—	(-0.401)	—	0.169	(-0.188)	—	—
	Hardness as CaCO3	Ln(X)	987	0.158	0.779	4.490	(-0.267)	—	—	(-0.113)	—	—	(-0.274)	—	—	(-0.273)	—	—
	pH	X	1001	0.063	0.656	7.118	(-0.061)	—	—	(-0.056)	0.086	0.0052	(-0.079)	—	—	(-0.170)	0.128	0.1200
	TDS	Ln(X)	924	0.221	0.785	5.141	(-0.358)	—	0.146	(-0.073)	0.078	—	(-0.348)	—	0.172	(-0.170)	0.089	—
	Temperature	X	283	0.114	3.033	13.115	—	—	0.485	(-0.387)	—	—	—	—	0.133	(-0.275)	—	—
	TOC	Ln(X)	990	0.119	1.012	5.405	(-0.177)	—	—	(-0.163)	—	—	(-0.142)	—	—	(-0.308)	—	—
	TSS	Ln(X)	934	0.123	1.007	4.972	(-0.146)	—	0.118	(-0.142)	—	—	(-0.118)	—	0.115	(-0.272)	—	—
Trace Metals	As, total	Ln(X)	629	0.019	0.939	1.193	—	—	—	(-0.073)	—	—	—	—	—	(-0.143)	—	—
	Cd, total	Ln(X)	744	0.123	0.690	0.471	(-0.172)	—	—	(-0.100)	0.073	—	(-0.200)	—	—	(-0.262)	0.102	—
	Cr, dissolved	Ln(X)	695	0.068	0.660	1.513	(-0.119)	—	—	(-0.056)	(-0.100)	—	(-0.150)	—	—	(-0.166)	(-0.150)	—
	Cr, total	Ln(X)	911	0.088	0.818	1.742	(-0.125)	—	0.100	(-0.071)	—	0.0054	(-0.127)	—	0.123	(-0.171)	—	0.0980
	Cu, dissolved	Ln(X)	943	0.364	0.708	3.632	(-0.390)	—	0.193	(-0.129)	0.080	—	(-0.380)	—	0.227	(-0.301)	0.092	—
	Cu, total	Ln(X)	1003	0.217	0.892	4.732	(-0.326)	—	—	(-0.174)	—	—	(-0.281)	—	—	(-0.353)	—	—
	Ni, dissolved	Ln(X)	699	0.263	0.571	2.681	(-0.280)	—	0.069	(-0.100)	(-0.078)	(-0.0030)	(-0.359)	—	0.107	(-0.309)	(-0.117)	(-0.0730)
	Ni, total	Ln(X)	892	0.177	0.679	2.703	(-0.226)	—	0.122	(-0.078)	(-0.051)	—	(-0.260)	—	0.170	(-0.212)	(-0.069)	—
	Pb, dissolved	Ln(X)	535	0.057	1.076	1.790	(-0.204)	—	—	(-0.087)	—	0.0053	(-0.164)	—	—	(-0.157)	—	0.0780
	Pb, total	Ln(X)	904	0.141	1.289	3.940	(-0.189)	—	0.097	(-0.158)	0.310	—	(-0.118)	—	0.073	(-0.230)	0.230	—
	Zn, dissolved	Ln(X)	938	0.276	0.819	5.545	(-0.369)	—	0.162	(-0.135)	—	(-0.0047)	(-0.333)	—	0.176	(-0.289)	—	(-0.0750)
	Zn, total	Ln(X)	943	0.269	0.870	6.108	(-0.298)	—	0.181	(-0.139)	0.192	—	(-0.254)	—	0.187	(-0.281)	0.194	—
Nutrient	NO3-N	Ln(X)	870	0.289	0.791	1.409	(-0.424)	—	0.140	(-0.106)	0.146	(-0.0053)	(-0.393)	—	0.155	(-0.220)	0.161	(-0.0860)
	Ortho-P, dissolved	Ln(X)	619	0.165	0.732	(-1.466)	(-0.218)	—	0.091	(-0.089)	(-0.131)	—	(-0.237)	—	0.118	(-0.215)	(-0.175)	—
	P, total	Ln(X)	867	0.137	0.770	(-0.619)	(-0.188)	—	0.147	(-0.084)	—	(-0.0036)	(-0.195)	—	0.183	(-0.199)	—	(-0.0670)
	TKN	Ln(X)	871	0.366	0.676	2.330	(-0.397)	—	0.124	(-0.146)	—	(-0.0042)	(-0.408)	—	0.153	(-0.351)	—	(-0.0750)

Notes: "—" indicates variable is not significant or was excluded from model for collinearity problems. An example model equation is provided for dissolved copper:

$$Ln[Cu,dissolved,\mu g/L] = 3.632 - 0.390(LnEventRainfall) + 0.193(LnAntecedentDryPeriod) - 0.129\left(\sqrt[3]{CumulativePrecip}\right) + 0.060(LnDrainageArea)$$

(1) Unstandardized model coefficients: Positive coefficients indicate a tendency to cause an increase in the pollutant concentration or parameter in runoff. Negative coefficients indicate a tendency to cause decrease in the parameter concentration.

(2) Standardized coefficients allow comparison of the magnitude of the effects among independent variables with different measurement units

Table 3-9 Effects of Precipitation, Antecedent Conditions, Drainage Area, and AADT on Runoff Quality from Highways: Multiple Linear Regression (MLR) Model Statistics and Coefficients for Whole Storm (EMC) data.

		Model Statistics				Model Coefficients [1] (intercept and independent variables)								Standardized Model Coefficients [2]						
Pollutant Category	Dependent Variable, X (Runoff Quality Parameter)	Form of X in Model	df	Adjusted Model R-Squared	S.E of Model Estimate	constant (y-Int.)	Ln[Event Rainfall, mm]	Ln[Max Intensity, mm/hr]	Ln[Antecedent Dry Period, days]	CubeRoot (Cumulative Precipitation, mm)	Ln[Drainage Area, hectares]	ArcSin [Impervious Fraction^0.5]	AADT*10-6 (vehicles/day)	Ln[Event Rainfall, mm]	Ln[Max Intensity, mm/hr]	Ln[Antecedent Dry Period, days]	CubeRoot (Cumulative Precipitation, mm)	Ln[Drainage Area, hectares]	ArcSin [Impervious Fraction^0.5]	AADT*10-6 (vehicles/day)
Conventional	DOC	Ln(X)	590	0.410	0.614	4.113	(-0.404)	—	0.123	(-0.129)	—	—	—	(-0.435)	—	0.163	(-0.351)	—	—	—
	EC	Ln(X)	581	0.480	0.573	4.680	(-0.316)	—	0.110	(-0.032)	—	—	4.222	(-0.343)	—	0.145	(-0.088)	—	—	0.453
	Hardness as CaCO3	Ln(X)	579	0.339	0.656	3.841	(-0.220)	—	0.046	(-0.074)	—	—	3.502	(-0.235)	—	0.060	(-0.199)	—	—	0.370
	pH	X	582	0.313	0.587	6.585	—	—	(-0.091)	(-0.032)	—	0.0055	4.406	—	—	(-0.135)	(-0.098)	—	0.1330	0.531
	TDS	Ln(X)	572	0.292	0.725	4.731	(-0.309)	—	0.126	(-0.050)	—	—	2.582	(-0.310)	—	0.154	(-0.127)	—	—	0.255
	Temperature	X	174	0.096	3.174	14.569	—	—	—	(-0.431)	—	—	—	—	—	—	(-0.318)	—	—	—
	TOC	Ln(X)	583	0.144	1.086	5.233	(-0.209)	—	0.129	(-0.154)	—	—	—	(-0.153)	—	0.116	(-0.282)	—	—	—
	TSS	Ln(X)	575	0.254	1.015	4.275	(-0.124)	—	0.102	(-0.099)	—	—	4.934	(-0.091)	—	0.091	(-0.182)	—	—	0.358
Trace Metals	As, total	Ln(X)	389	0.041	0.777	1.210	—	—	—	(-0.087)	—	—	—	—	—	—	(-0.207)	—	—	—
	Cd, total	Ln(X)	472	0.205	0.647	0.084	(-0.149)	—	—	(-0.084)	—	—	2.458	(-0.172)	—	—	(-0.228)	—	—	0.268
	Cr, dissolved	Ln(X)	505	0.253	0.601	1.098	(-0.109)	—	—	(-0.046)	(-0.246)	—	3.070	(-0.135)	—	—	(-0.136)	(-0.362)	—	0.373
	Cr, total	Ln(X)	565	0.240	0.737	1.618	(-0.099)	—	0.106	(-0.055)	(-0.234)	—	3.508	(-0.101)	—	0.131	(-0.139)	(-0.282)	—	0.353
	Cu, dissolved	Ln(X)	581	0.508	0.615	2.919	(-0.290)	—	0.185	(-0.102)	—	—	3.679	(-0.286)	—	0.222	(-0.254)	—	—	0.357
	Cu, total	Ln(X)	582	0.524	0.722	2.900	(-0.161)	—	0.163	(-0.079)	—	—	6.823	(-0.133)	—	0.164	(-0.165)	—	—	0.555
	Ni, dissolved	Ln(X)	474	0.270	0.569	2.731	(-0.270)	—	0.068	(-0.107)	(-0.094)	(-0.0029)	—	(-0.342)	—	0.105	(-0.337)	(-0.142)	(-0.0790)	—
	Ni, total	Ln(X)	557	0.224	0.673	2.511	(-0.196)	—	0.141	(-0.075)	(-0.155)	—	1.013	(-0.219)	—	0.193	(-0.208)	(-0.207)	—	0.113
	Pb, dissolved	Ln(X)	376	0.076	1.148	2.042	(-0.248)	—	—	(-0.101)	—	0.0065	—	(-0.187)	—	—	(-0.173)	—	0.0950	—
	Pb, total	Ln(X)	586	0.364	1.183	2.272	—	—	—	(-0.102)	—	—	9.650	—	—	—	(-0.144)	—	—	0.545
	Zn, dissolved	Ln(X)	577	0.316	0.794	4.740	(-0.343)	—	0.164	(-0.112)	—	—	1.676	(-0.308)	—	0.180	(-0.253)	—	—	0.149
	Zn, total	Ln(X)	579	0.509	0.757	4.827	(-0.227)	—	0.143	(-0.084)	—	—	6.747	(-0.181)	—	0.139	(-0.169)	—	—	0.532
Nutrient	NO3-N	Ln(X)	529	0.371	0.735	1.299	(-0.417)	—	0.092	(-0.090)	—	(-0.0072)	2.870	(-0.387)	—	0.103	(-0.197)	—	(-0.1340)	0.260
	Ortho-P, dissolved	Ln(X)	382	0.149	0.694	(-1.160)	(-0.240)	—	0.084	(-0.077)	—	—	(-1.927)	(-0.269)	—	0.117	(-0.209)	—	—	(-0.214)
	P, total	Ln(X)	520	0.102	0.776	(-1.212)	(-0.143)	—	0.128	(-0.051)	—	—	0.900	(-0.148)	—	0.163	(-0.128)	—	—	0.094
	TKN	Ln(X)	537	0.385	0.656	1.689	(-0.343)	—	0.102	(-0.128)	—	—	1.535	(-0.355)	—	0.128	(-0.331)	—	—	0.155

Notes: "—" indicates variable is not significant or was excluded from model for collinearity problems. An example model equation is provided for dissolved copper:

$$Ln[Cu,dissolved,\mu g/L] = 2.919 - 0.290(LnEventRainfall) + 0.185(LnAntecedentDryPeriod) - 0.102\left(\sqrt[3]{CumulativePrecip}\right) + 3.679\left(AADT \quad 10^{-6}\right)$$

(1) Unstandardized model coefficients: Positive coefficients indicate a tendency to cause an increase in the pollutant concentration or parameter in runoff. Negative coefficients indicate a tendency to cause decrease in the parameter concentration.

(2) Standardized coefficients allow comparison of the magnitude of the effects among independent variables with different measurement units

Table 3-10 Summary of Significant Covariate Effects for Multiple Linear Regression Models of Runoff Quality from all Department Facilities.

Covariate Factor (predictor variable form)	Dominant effect on pollutant concentrations[1]	Ratio of models exhibiting significant dominant effect[2]	Exceptions[3]	Comments
Event Rainfall (LnX)	Concentrations decrease with higher total event rainfall.	22 of 22 models had a significant negative coefficient	*Positive* : none; *Not significant* : As-tot, temperature	Very consistent predictor. Same pattern for all models.
Maximum Rainfall Intensity (LnX)	Not included in any models	Not included in any models	None (excluded for collinearity problems)	*Not significant* is the most common result. Although significant for some parameters, maximum intensity is highly correlated with event rainfall (R = 0.54). Generally appears not to be a good predictor variable due to collinearity problems.
Antecedent Dry Period (LnX)	Concentrations increase with longer antecedent dry period	16 of 16 models had a significant positive coefficient	*Negative* : none *Not significant* : hardness, pH, TOC, As-tot, Cd-tot, Cr-dis, Cu-tot, Pb-dis	Very consistent predictor. Same pattern for all models.
Seasonal Cumulative Precipitation (Cube Root of X)	Concentrations decrease as cumulative rainfall increases	24 of 24 models had a significant negative coefficient	*Positive* : none *Not significant* : none	Most consistent predictor. Significant for all paramters and same pattern for all models.
Drainage Area (LnX)	No consistent dominant effect	7 of 11 models had a significant negative coefficient	*Negative:* Cr-dis, Ni, dis, Ni-tot, Orthophosphate	Negative for Cr-dis, Cr-tot, Ni-dis, and Ni-tot, but *not significant* is the most common result. Appears to be a poor predictor overall.
Impervious Fraction (ArcSin-SquareRoot of X)	Concentrations decrease as imperviousness increases	6 of 9 models had a significant negative coefficient	*Positive:* pH, Cr-tot, Pb-dis	*Not significant* is the most common result. Effect is small compared to other factors. Appears to be a poor predictor.

(1) Summarized for MLR models including only Statewide characterization studies whole storm data. "Dominant Effect" is the most frequently observed sign of significant coefficients for the factor in MLR models. Concentrations are said to increase if most coefficients are positive, and to decrease if most coefficients are negative. In all cases, the relationship between covariate and dependent variables (after transforming to approximate normality) is approximately linear.

(2) Threshold of statistical significance is $p<0.05$.

(3) Constituents for which the predictor had a significant effect opposite to the dominant effect for the predictor.

Table 3-11 Summary of Significant Covariate Effects for Multiple Linear Regression Models of Highway Runoff Quality.

Covariate Factor (predictor variable form)	Dominant effect on pollutant concentrations(1)	Ratio of models exhibiting significant dominant effect(2)	Exceptions(3)	Comments
Event Rainfall (LnX)	Concentrations decrease with higher total event rainfall.	22 of 22 models had a significant negative coefficient	*Positive* : none; *Not significant* : pH, temperature, As-tot, Pb-tot	Very consistent predictor. Same pattern for all models.
Maximum Rainfall Intensity (LnX)	Not included in any models	Not included in any models	None (excluded for collinearity problems)	*Not significant* is the most common result. Although significant for some parameters, maximum intensity is highly correlated with event rainfall (R = 0.54). Generally appears not to be a good predictor variable due to collinearity problems.
Antecedent Dry Period (LnX)	Concentrations increase with longer antecedent dry period	17 of 18 models had a significant positive coefficient	*Negative* : pH *Not significant* : temperature, As-tot, Cd-tot, Cr-dis, Pb-dis, Pb-tot	Very consistent predictor. Same pattern for nearly all models.
Seasonal Cumulative Precipitation (cube root of X)	Concentrations decrease as cumulative rainfall increases	24 of 24 models had a significant negative coefficient	*Positive* : none *Not significant* : none	Most consistent predictor. Same pattern for all models.
Drainage Area (LnX)	Concentrations are lower for larger drainage areas	4 of 4 models had a significant negative coefficient	*Positive* : none	Negative for Cr-dis, Cr-tot, Ni-dis, and Ni-tot, but *not significant* is the most common result. Appears to be a poor predictor overall.
Impervious Fraction (ArcSin-SquareRoot of X)	No consistent dominant effect	2 of 4 models had a significant positive coefficient	No dominant pattern.	*Not significant* is the most common result. Effect is small compared to other factors. Appears to be a poor predictor.
AADT ($AADTx10^{-6}$)	Concentrations are higher for sites with higher traffic	17 of 18 models had a significant positive coefficient	*Negative* : Orthophosphate *Not significant* : DOC, TOC, temperature, As-tot, Ni-dis, Pb-dis.	Very consistent predictor. Same pattern for nearly all models.

(1) Summarized for MLR models including only Statewide characterization studies whole storm data for highways. "Dominant Effect" is the most frequently observed sign of significant coefficients for the factor in MLR models. Concentrations are said to increase if most coefficients are positive, and to decrease if most coefficients are negative. In all cases, the relationship between covariate and dependent variables (after transforming to approximate normality) is approximately linear.

(2) Threshold of statistical significance is $p<0.05$.

(3) Constituents for which the predictor had a significant effect opposite to the dominant effect for the predictor.

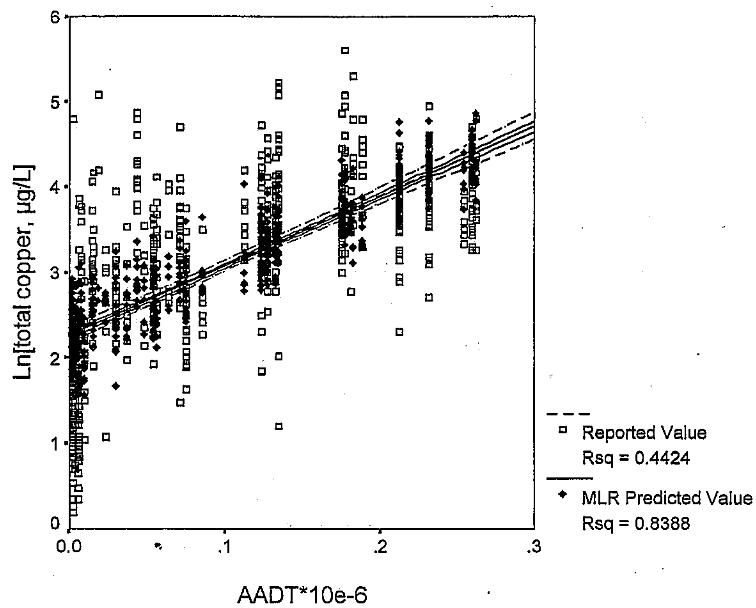


Figure 3-1 Effect of AADT on total copper concentrations.
Regression fit lines illustrate mean and 95% confidence interval for mean reported and MLR-predicted Ln(total copper) at specified AADT.

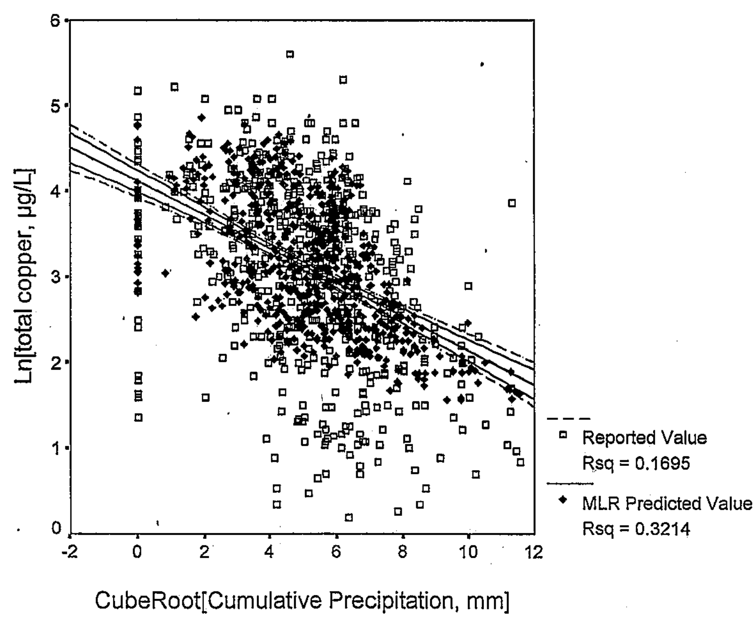


Figure 3-2 Effect of cumulative precipitation on total copper concentrations.
Regression fit lines illustrate mean and 95% confidence interval for mean reported and MLR-predicted Ln(total copper) at specified cumulative seasonal precipitation.

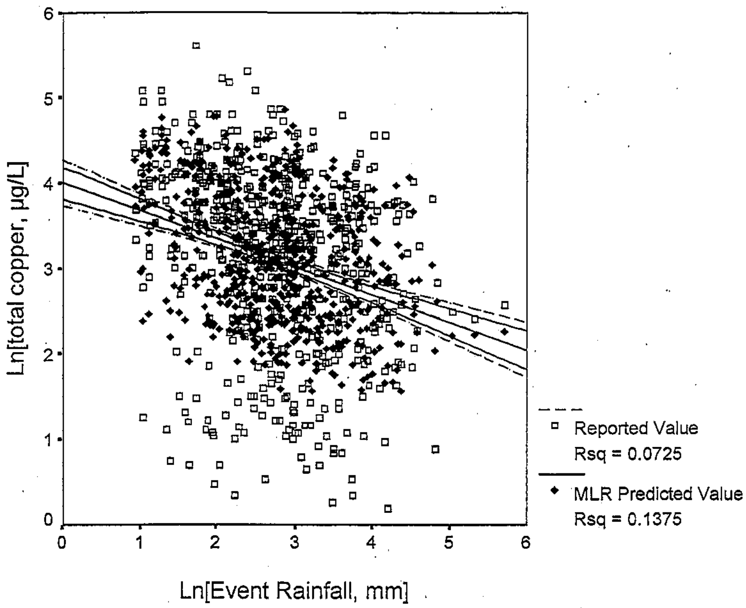


Figure 3-3 Effect of event rainfall on total copper concentrations.

Regression fit lines illustrate mean and 95% confidence interval for mean reported and MLR-predicted Ln(total copper) at specified event rainfall.

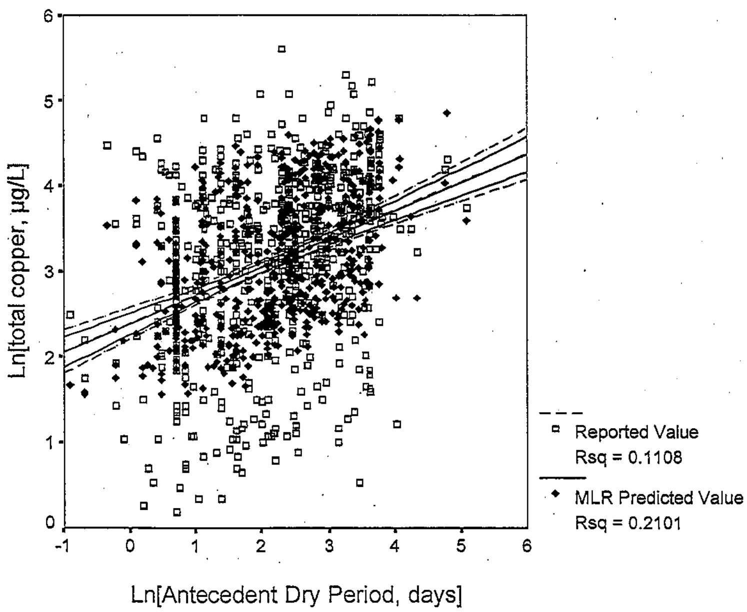


Figure 3-4 Effect of antecedent dry period on total copper concentrations.

Regression fit lines illustrate mean and 95% confidence interval for mean reported and MLR-predicted Ln(total copper) at specified antecedent dry period.

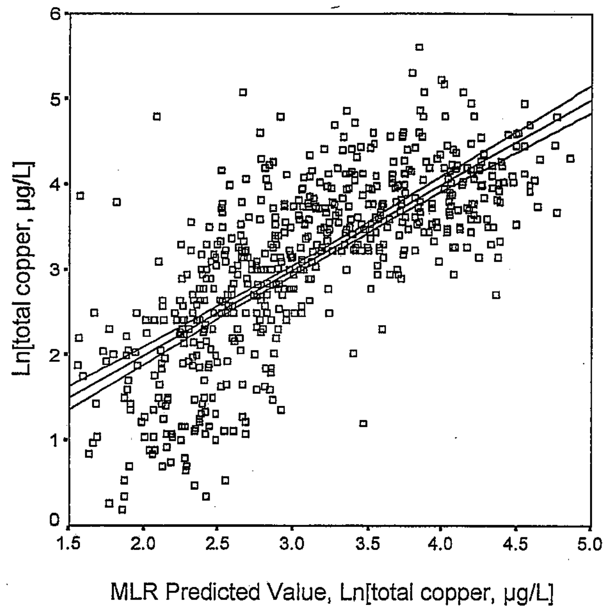


Figure 3-5 MLR model for total copper.
Regression fit lines illustrate mean and 95% confidence interval for mean reported Ln(total copper).

Model Validation

Although not a specific objective of this study, several of the best MLR models were validated using data not included in the dataset used to develop the MLR models. The MLR models for DOC, total copper, total zinc, and nitrate were used to predict concentrations of these pollutants for highway sites and storm events that were not part of the Statewide characterization studies dataset. These parameters were selected as representative models in each pollutant category. These predicted concentrations were compared to actual reported concentrations using standard linear regression analysis. The results of these comparisons are summarized in Table 3-12, and illustrated in Figure 3-6 through Figure 3-9.

The purpose of this validation exercise was to assess how well some of the best models were able to predict pollutant concentrations for new highway sites and storm events. Based on inspection of the regression plots, there was no apparent systematic bias in the predicted values and the range and distribution of the predicted values agreed well with the validation data. Note that the range of predicted values is expected to be smaller than that of the validation data set, because they are model predictions without the inherent variability of actual environmental data. The Coefficients of determination (R^2 values) for the MLR models developed with Statewide characterization studies data were compared with R^2 values for the regressions of validation data on MLR-predicted values for each parameter. The R^2 values for the regression of new data on MLR-predicted concentrations are similar to the R^2 values for the original MLR models, indicating that the overall fit of the validation data was similar to the original data used to develop the models. The slopes of the regressions were also evaluated for potential bias in MLR-predicted values. The slopes of the DOC and total zinc validation regressions were significantly different from one, indicating that models that included the validation data would differ slightly from the MLR models developed for this study. The slopes for the total copper and nitrate regressions were not significantly different from one at the 95% confidence level, indicating that models that included the validation data would not be significantly different from the current MLR models for these parameters. If the regressions of validation and predicted values were forced through zero (i.e., if the intercept was assumed to be zero), the slopes for all four validation regressions were not significantly different from one. Overall, these results indicate that the MLR-models for these parameters provide reasonable and realistic estimates of pollutant concentrations in runoff, and validates the process used to develop these models.

Table 3-12 Results of comparisons of MLR-predicted values to validation data

Model	Coefficients			95% Confidence Interval		Validation R^2	Original MLR R^2
	B	Std. Error	p-value	Lower Bound	Upper Bound		
Ln[DOC]							
Intercept	-.550	.148	.0002	-.840	-.260		
MLR predicted Ln[DOC]	1.215	.059	<.0001	1.100	1.331	.504	.410
Ln[Total Copper]							
Intercept	.107	.127	.3995	-.142	.356		
MLR predicted Ln[total copper]	.944	.037	<.0001	.871	1.017	.480	.524
Ln[Total Zinc]							
Intercept	.722	.192	.0002	.344	1.099		
MLR predicted Ln[total zinc]	.829	.038	<.0001	.755	.904	.405	.509
Ln[NO_3-N]							
Intercept	.005	.029	.0789	-.006	.109		
MLR predicted Ln[total zinc]	.939	.046	<.0001	.849	1.029	.394	.371

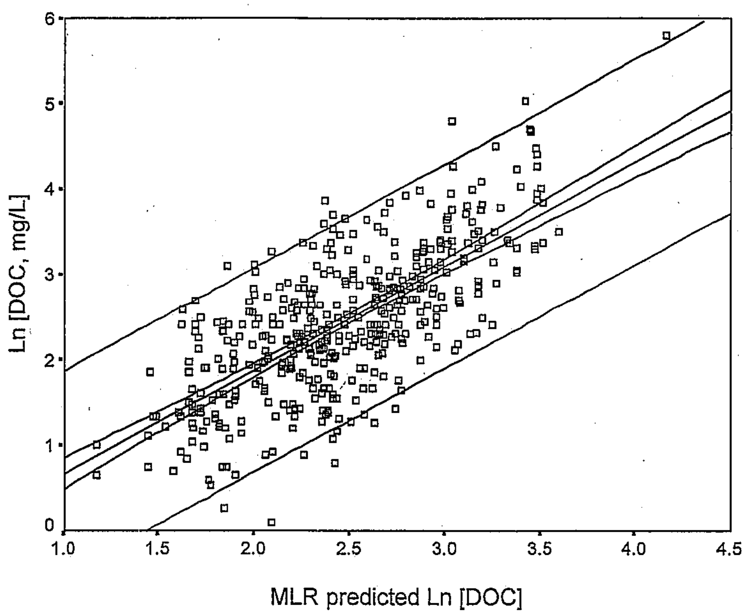


Figure 3-6 Validation data set for DOC vs. MLR-predicted values

Regression of reported values not used to develop MLR equation vs MLR predicted values. Regression fit lines indicate 95% confidence interval for mean Ln(DOC) and individual predicted Ln(DOC).

Ln(Y) = 4.113 - .404 *Ln(*EventRain*) + .123*Ln(*AntDry*) - .129*CubeRoot(*CumPrecip*)
$R^2 = .504$

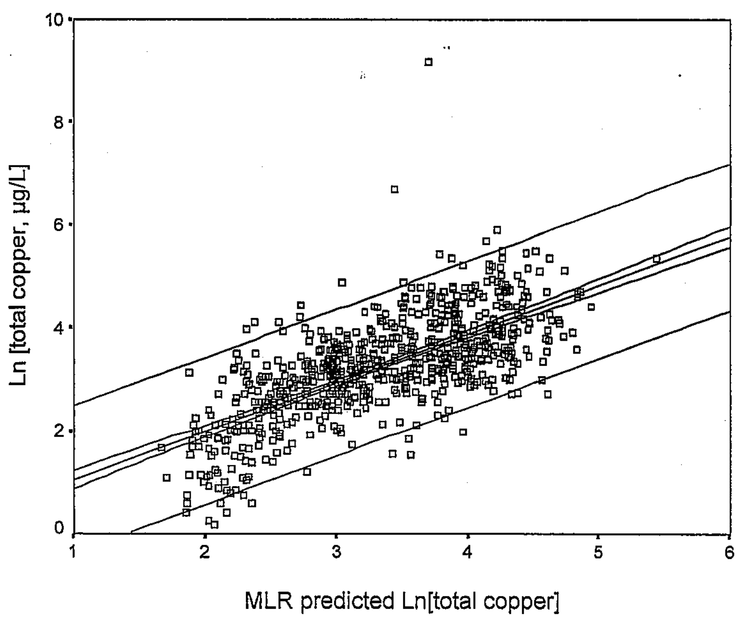


Figure 3-7 Validation data set for total copper vs. MLR-predicted values

Regression of reported values not used to develop MLR equation vs MLR predicted values. Regression fit lines indicate 95% confidence interval for mean Ln(total copper) and individual predicted Ln(total copper).

Ln(y) = 2.9 - .161 *Ln(EventRain) + .163*Ln(AntDry) - .079*CubeRoot(CumPrecip) + 6.823*AADT*10-6
$R^2 = .480$

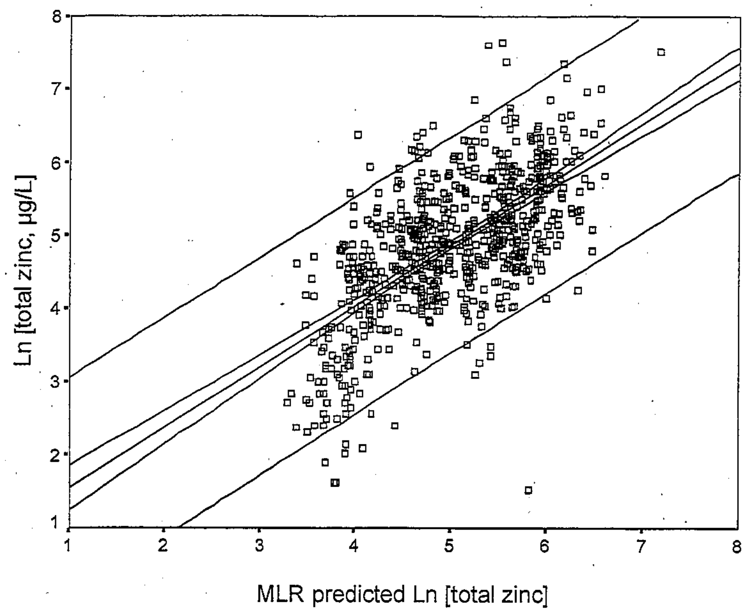


Figure 3-8 Validation data set for total zinc vs. MLR-predicted values

Regression of reported values not used to develop MLR equation vs MLR predicted values. Regression fit lines indicate 95% confidence interval for mean Ln(total zinc) and individual predicted Ln(total zinc).

Ln(y) = 4.827 - .227 *Ln(EventRain) + .143*Ln(AntDry) - .084*CubeRoot(CumPrecip) + 6.747*AADT*10-6
R^2 = .405

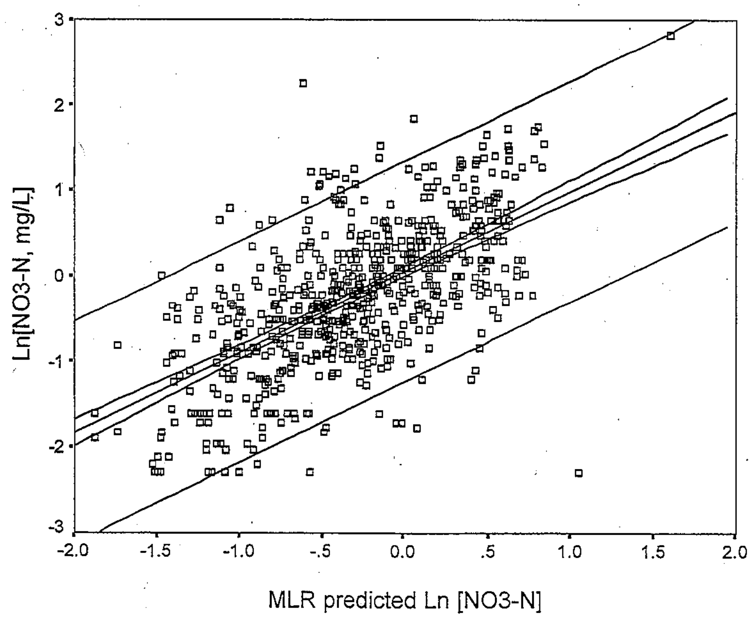


Figure 3-9 Validation data set for nitrate vs. MLR-predicted values

Regression of reported values not used to develop MLR equation vs MLR predicted values. Regression fit lines indicate 95% confidence interval for mean Ln(NO_3-N) and individual predicted Ln(NO_3-N).

Ln(y) = 1.299 - .417 *Ln(EventRain) + .092*Ln(AntDry) - .090*CubeRoot(CumPrecip) - .0072*Ln(DrainageArea) + 2.870*AADT*10-6
R^2 = .405

Annual, Seasonal, and Intra-Event Variation

Annual Variation and Trends

Annual variability in runoff quality was assessed using ANOVA methods. Results of ANOVA analyses of the effects of annual variation on runoff quality are summarized in Table 3-13 for Department facilities monitored as part of the Statewide characterization studies. Annual variability in runoff quality was significant for a variety of constituents, but was generally small in most cases. Note that because the data cover only three monitoring years, these conclusions should not be extrapolated to longer-term patterns of annual variation. Patterns in annual variation for the three year period monitored are summarized below:

> Conventional parameters (organic carbon, EC, hardness, pH, TDS, temperature, and TSS) generally exhibited the highest annual variability, and annual variation was significant in 29 of 48 comparisons for conventional parameters. Annual variability tended to be higher for vehicle inspection facilities, park-and-ride facilities, rest areas, and toll plazas, with significant variation ranging from 5% - 42% in median runoff quality (depending on parameter and facility). Annual variation was typically lower for highway sites and maintenance stations, with significant variations in median runoff quality less than 10% for all conventional parameters.
>
> Trace metals generally exhibited low or insignificant annual variability. Annual variation was significant in 31 of 84 cases for trace metals (with each case consisting of the data for one parameter and one facility type). Annual variability in trace metals was generally not significant at Caltrans vehicle inspection facilities and toll plaza sites. Variation tended to be higher for rest areas and maintenance facilities, with significant variation ranging from 7% - 55% in median runoff quality (depending on parameter and facility). Annual variation was typically lowest for highway sites and maintenance stations, with significant variation in median runoff quality of less than 5% for all metals.
>
> Nutrients (nitrate, orthophosphate, total phosphorus, and TKN) generally exhibited the most frequently significant annual variation, with significant variation in 16 of 24 comparisons. However, the contribution of annual variability was typically low (not significant or less than or equal to 10%) for most parameters and facilities. Annual variation in median runoff quality for nutrients was highest for rest areas, with significant annual variation in median orthophosphate concentrations (30%), total phosphorus (17%), and TKN (19%) for this category of facility.

Seasonal Variation

The effect of the seasonal variation on runoff quality was assessed by evaluating the effect of cumulative seasonal precipitation on runoff quality in the MLR models. Cumulative seasonal precipitation exhibited a significant negative effect in every MLR model indicating that pollutant concentrations in runoff are highest in the early wet season and tend to decrease thereafter. Cumulative seasonal precipitation had a statistically significant effect in the MLR models for every Statewide characterization studies constituent evaluated, and significant coefficients for this factor were negative in every case. Preliminary results from the Department's First Flush

Characterization study (summarized in Appendix _) also reported a significant seasonal first flush effect for many pollutants in runoff.

Intra-Event Variation ("First Flush")

The effect of an intra-event first flush was evaluated using the MLR results for Event Rainfall (the total amount of rainfall recorded for a specific storm event). The results of these analyses indicated that increasing amounts of rainfall tended to result in a decrease in pollutant concentrations in runoff. This was interpreted to mean that the highest concentrations of pollutants occurred in runoff from the early part of the storm event, with concentrations becoming more dilute with increasing rainfall amounts. This indirect evidence of significant intra-event first flush effect was observed for nearly every conventional, trace metal, and nutrient parameter, and has been corroborated by the preliminary results from the Department's First Flush Characterization study, which was designed specifically to address this question.

Table 3-13 Annual Variation in Runoff Quality, Statewide Characterization Studies Data for Caltrans Facilities, 2000/01-2002/03

Pollutant Category	Parameter	Fraction	Proportion (%) of variation in runoff quality due to annual variation					
			CVIF	Highway	Maintenance	Parking	Rest Area	Toll Plaza
Conventional	DOC		26	6	ns	15	42	27
	EC		NS	4	ns	10	27	ns
	Hardness as $CaCO_3$		NS	6	9	14	ns	ns
	pH		NS	11	7	5	ns	ns
	TDS		NS	3	ns	9	24	ns
	Temperature		—	4	ns	ns	ns	—
	TOC		29	7	6	18	28	24
	TSS		11	2	8	4	ns	30
Trace Metals	As	Dissolved	NS	2	15	5	ns	ns
	As	Total	NS	1	18	4	ns	ns
	Cd	Dissolved	NS	2	ns	4	ns	ns
	Cd	Total	NS	2	8	ns	ns	ns
	Cr	Dissolved	NS	ns	ns	5	ns	ns
	Cr	Total	NS	ns	ns	12	28	ns
	Cu	Dissolved	NS	ns	13	4	40	ns
	Cu	Total	NS	ns	8	ns	55	ns
	Ni	Dissolved	NS	2	ns	ns	ns	ns
	Ni	Total	NS	2	ns	ns	18	ns
	Pb	Dissolved	NS	ns	ns	ns	ns	ns
	Pb	Total	NS	3	ns	4	31	28
	Zn	Dissolved	18	1	18	ns	26	ns
	Zn	Total	NS	3	15	ns	38	ns
Nutrient	NO_3-N		NS	2	7	10	ns	ns
	Ortho-P	Dissolved	NS	2	13	4	30	ns
	P	Total	NS	3	8	ns	17	ns
	TKN		21	5	10	10	19	18

Note:" — " indicates paramter wasnot monitored at this location.
"ns" indicates annual variation was not statistically significant at the 95% confidence level.

Runoff Quality from Different Facilities

Differences in runoff quality from different Caltrans facilities were evaluated using Multiple Linear Regression and Analysis of Covariance (ANCOVA) methods. Results of ANCOVA analyses of differences in runoff quality for different Caltrans facilities are presented in Table 3-14. Summary statistics for the Statewide characterization studies data are also provided in Table 3-15. Caltrans facilities exhibited significant differences in runoff quality for all constituents except TKN. A significant result for the ANCOVA analysis indicates that at least one of the six facilities was significantly different from the overall average at the 95% confidence level. It does not indicate that every facility type is significantly different from every other facility type.

The results of these comparisons were as follows:

- **Conventional parameters:** Highway sites exhibited higher conventional pollutant concentrations in runoff than other facilities for DOC, EC, hardness, and TDS. Maintenance facilities, park-and-ride sites, and rest areas generally exhibited lower conventional pollutant concentrations in runoff. Toll plazas had higher than average concentrations of TOC and TSS in runoff, and lower pH. CVIF sites were generally not significantly different from overall average concentrations.
- **Trace metals:** Highway and toll plaza sites generally exhibited higher than average trace metal concentrations in runoff. Park-and-ride sites, and rest areas generally exhibited lower metals concentrations in runoff, and CVIF sites were typically not significantly different from average runoff quality. The exceptions to this pattern included arsenic and zinc, which were higher in maintenance facilities and CVIF runoff.
- **Nutrients:** Nutrient concentrations in highway runoff were not significantly different from the overall average, with the exception of NO_3-N. Maintenance facilities had consistently lower than average nutrient concentrations. There were no consistent patterns in nutrient concentrations for runoff from other facilities.

In general, these results indicate that higher pollutant concentrations in runoff are seen for facilities with generally higher vehicle traffic rates, as expected for highway and toll plaza sites. This pattern also corroborates the results of the MLR analyses, which established that higher AADT is associated with higher concentrations of most pollutant concentrations. Figure 3-10 and Figure 3-11 are provided to illustrate the interpretation of the pattern of differences in runoff quality from different facilities for TOC (Figure 3-10) and Nitrate (Figure 3-11).

Table 3-14 Significant Differences in Runoff Quality from Caltrans Facilities.

Pollutant Category	Parameter	Fraction	Significant Variation due to Facility Type?	Facilities with Significant Differences from Overall Facility Average Runoff Quality	
				Facilities Above Overall Average	Facilities Below Overall Average
Conventional	DOC		YES	HWY	PRK
	EC		YES	HWY	MAINT, PRK, REST
	Hardness as CaCO3		YES	HWY	MAINT, PRK, REST
	pH		YES	HWY	MAINT, PRK, REST, TOLL
	TDS		YES	HWY	MAINT, PRK, REST
	Temperature		NO	ns	ns
	TOC		YES	TOLL	PRK, REST
	TSS		YES	TOLL	PRK, REST
Trace Metals	As	Total	YES	MAINT	PRK, TOLL
	Cd	Total	YES	HWY, TOLL	PRK, REST
	Cr	Dissolved	YES	HWY, TOLL	CVIF, MAINT, PRK, REST
	Cr	Total	YES	HWY, TOLL	MAINT, PRK, REST
	Cu	Dissolved	YES	HWY, TOLL	PRK, REST
	Cu	Total	YES	HWY, TOLL	PRK, REST
	Ni	Dissolved	YES	HWY	PRK
	Ni	Total	YES	HWY, TOLL	PRK, REST
	Pb	Dissolved	YES	HWY	MAINT, PRK, REST
	Pb	Total	YES	HWY, TOLL	CVIF, PRK, REST
	Zn	Dissolved	YES	CVIF, MAINT, TOLL	HWY, PRK
	Zn	Total	YES	MAINT, TOLL	REST
Nutrient	NO3-N		YES	HWY	MAINT, PRK
	Ortho-P	Dissolved	YES	CVIF, REST	TOLL
	P	Total	YES	REST	MAINT
	TKN		NO	ns	ns

Notes: Threshold for statistical significance is $p < 0.05$ for all comparisons and effects. "ns" indicates not significant at the 95% confidence level. Facility Type Designations: CVIF=Caltrans Vehicle Inspection Facility, HWY = Highway, MAINT = Maintenance, PRK = Park-and-Ride, REST = Rest Area, TOLL = Toll Plaza.

Table 3-15 Summary statistics for parameters monitored by the CALTRANS Statewide Characterization Study: Mean and Standard Deviation for Facilities.

Pollutant Category	Parameter	Units	Facility: CVIF Mean	CVIF SD	Hwy Mean	Hwy SD	Maintenance Mean	Maintenance SD	Parking Mean	Parking SD	Rest Area Mean	Rest Area SD	Toll Plaza Mean	Toll Plaza SD
Conventional	DOC	mg/L	18.5	15.9	18.7	26.2	18.2	18.2	18.0	28.6	19.9	39.6	25.6	19.8
	EC	µS/cm	113.3	137.3	96.1	73.4	80.9	110.6	63.5	65.8	78.2	132.0	118.9	100.2
	Hardness as CaCO3	mg/L	33.5	22.1	36.5	34.2	26.7	28.7	26.6	45.9	33.0	81.2	37.1	27.7
	Chloride	mg/L	—	—	265.9	388.0	—	—	—	—	—	—	—	—
	pH	pH	7.1	0.4	7.1	0.7	6.8	0.6	6.8	0.7	6.9	0.4	6.9	0.4
	TDS	mg/L	84.8	92.1	87.3	103.7	68.9	78.1	61.7	78.3	61.2	130.0	81.5	74.2
	Temperature		12.5	3.3	12.5	3.4	12.5	2.8	12.6	3.4	11.4	3.2	12.3	3.0
	TOC	mg/L	20.0	16.9	21.8	29.2	20.6	23.0	18.6	20.6	22.2	40.5	31.0	20.3
	TSS	mg/L	83.4	53.0	112.7	188.8	96.4	95.0	68.5	59.3	63.3	54.4	123.3	77.4
	Turbidity	NTU	—	—	—	—	144.83	92.23	—	—	—	—	—	—
Hydro-carbons	Oil & Grease	mg/L	—	—	4.95	11.41	—	—	—	—	—	—	—	—
	TPH (Diesel)	mg/L	—	—	3.72	3.31	—	—	—	—	—	—	—	—
	TPH (Gasoline)	mg/L	—	—	IDD	IDD	—	—	—	—	—	—	—	—
	TPH (Heavy Oil)	mg/L	—	—	2.71	3.40	—	—	—	—	—	—	—	—
Metals	As, dissolved	µg/L	1.0	0.4	1.0	1.4	9.5	17.3	0.7	0.6	1.4	3.3	0.8	0.4
	As, total	µg/L	3.4	16.1	2.7	7.9	12.8	23.1	1.4	5.9	3.6	11.4	1.5	0.8
	Cd, dissolved	µg/L	0.20	0.16	0.24	0.54	0.27	0.22	0.12	0.12	IDD	IDD	0.43	0.29
	Cd, total	µg/L	0.56	0.40	0.73	1.61	0.69	0.63	0.30	0.30	0.32	0.53	1.15	0.56
	Cr, dissolved	µg/L	1.8	1.2	3.3	3.3	1.4	1.0	1.0	0.9	1.9	2.5	5.1	2.5
	Cr, total	µg/L	8.1	4.8	8.6	9.0	5.1	4.3	4.0	4.2	4.8	3.8	12.5	7.7
	Cu, dissolved	µg/L	15.6	13.3	14.9	14.4	14.3	17.6	8.7	8.8	9.6	12.0	27.3	20.6
	Cu, total	µg/L	33.6	24.1	33.5	31.6	29.5	37.6	17.1	15.2	16.0	14.2	59.6	23.0
	Hg, dissolved	ng/L	IDD	IDD	—	—	27.7	51.4	IDD	IDD	—	—	IDD	IDD
	Hg, total	ng/L	IDD	IDD	36.7	37.9	65.4	83.7	57.3	73.6	—	—	IDD	IDD
	Ni, dissolved	µg/L	3.5	2.4	4.9	5.0	3.7	4.0	3.3	3.9	3.2	5.8	6.0	4.5
	Ni, total	µg/L	8.4	4.7	11.2	13.2	7.9	7.7	6.2	4.8	7.3	8.3	13.7	6.8
	Pb, dissolved	µg/L	2.7	3.9	7.6	34.3	1.6	3.0	1.3	2.7	1.2	1.7	5.2	5.2
	Pb, total	µg/L	21.9	37.7	47.8	151.3	21.3	26.5	10.3	11.5	7.7	8.0	31.6	24.3
	Zn, dissolved	µg/L	88.2	79.1	68.8	96.6	21.3	26.5	10.3	11.5	82.5	263.7	123.7	89.4
	Zn, total	µg/L	244.5	151.6	187.1	199.8	245.6	259.3	154.3	157.1	142.4	298.9	292.9	131.9
Micro-biological	Fecal Coliform	MPN/100 mL	—	—	1132	1621	—	—	—	IDD	—	—	—	—
	Total Coliform	MPN/100 mL	—	—	13438	34299	—	—	—	IDD	—	—	—	—
Nutrients	NH3-N	mg/L	—	—	1.08	1.46	—	—	—	IDD	—	—	—	—
	NO3-N	mg/L	0.89	0.81	1.07	2.44	0.74	1.13	0.57	IDD	0.96	0.88	0.84	0.81
	Ortho-P, dissolved	mg/L	0.13	0.12	0.11	0.18	0.09	0.40	0.15	IDD	0.44	1.67	0.05	0.05
	P, total	mg/L	0.28	0.16	0.29	0.39	0.23	0.20	0.33	0.42	0.47	0.53	0.25	0.11
	TKN	mg/L	2.16	2.72	2.06	1.90	1.79	1.72	2.28	2.20	4.37	14.04	2.38	1.59
Pesticide	Chlorpyrifos	µg/L	—	—	—	—	IDD	IDD	—	—	—	—	—	—
	Diazinon	µg/L	IDD	IDD	0.13	0.29	0.12	0.30	IDD	IDD	—	—	IDD	IDD
	Diuron	µg/L	—	—	4.60	18.24	—	—	—	—	IDD	IDD	—	—
	Glyphosate	µg/L	—	—	19.61	26.97	—	—	—	—	IDD	IDD	—	—
	Oryzalin	µg/L	—	—	—	—	—	—	—	—	IDD	IDD	—	—
	Oxadiazon	µg/L	—	—	—	—	—	—	—	—	IDD	IDD	—	—
	Triclopyr	µg/L	—	—	—	—	—	—	—	—	IDD	IDD	—	—
Semi-volitile Organics	Acenaphthene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Acenaphthylene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Anthracene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Benzo(a)Anthracene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Benzo(a)Pyrene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Benzo(b)Fluoranthene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Benzo(ghi)Perylene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Benzo(k)Fluoranthene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Chrysene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Dibenzo(a,h)Anthracene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Fluoranthene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Fluorene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Indeno(1,2,3-c,d)Pyrene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Naphthalene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Phenanthrene	µg/L	—	—	IDD	IDD	—	—	IDD	IDD	—	—	—	—
	Pyrene	µg/L	—	—	0.05	0.03	—	—	IDD	IDD	—	—	—	—

Notes: "IDD" indicates that there were insufficient detected data to calculate statistic.
"— " indicates parameter was not monitored Statewide characterization studies for this facility.

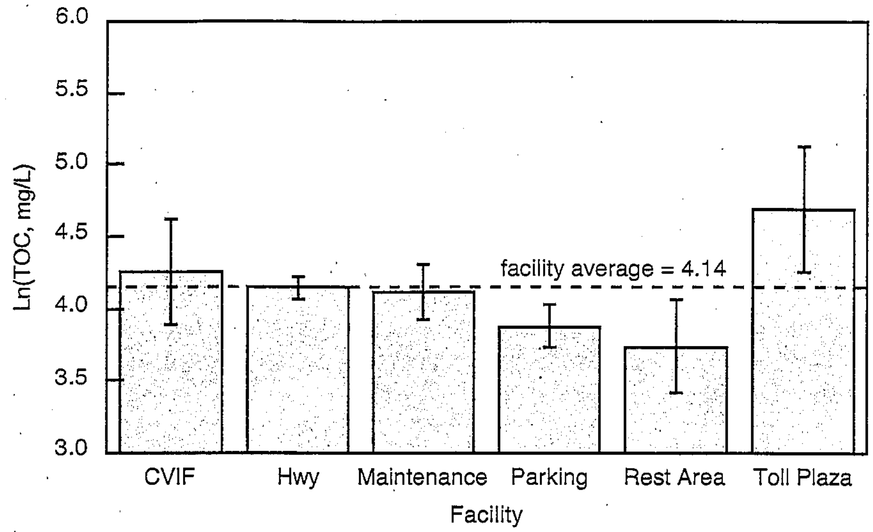


Figure 3-10 Estimated Marginal Means and 95% confidence limits for TOC

Bars represent the model-predicted concentration under the average conditions for precipitation and antecedent conditions.

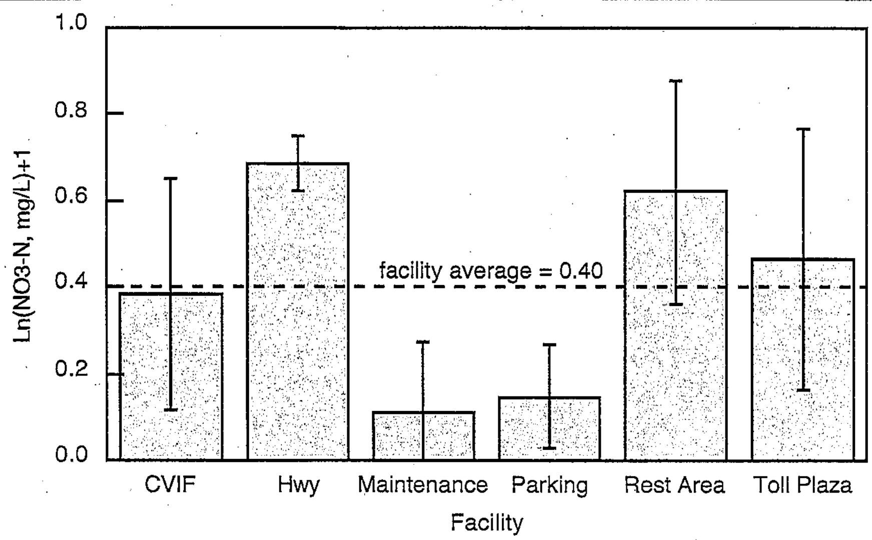


Figure 3-11 Estimated Marginal Means and 95% confidence limits for Nitrate

Bars represent the model-predicted concentration under the average conditions for precipitation and antecedent conditions.

Geographic Variation Analysis Results

The effects of geographic region on stormwater runoff quality from highways were evaluated using Multiple Linear Regression and Analysis of Covariance (ANCOVA) methods. Results of these analyses are summarized in Table 3-16. Geographic region exhibited significant effects on runoff quality for most constituents (exceptions were pH, temperature, and dissolved zinc). A few broadly defined patterns emerged for this factor:

- ***Conventional parameters:*** Highway sites in the Central and Southern Coast Ranges, the Klamath Mountains, and the Central Coast region generally exhibited higher conventional pollutant concentrations in runoff than other regions. Highway sites in the Sierra Nevada Foothills and the Temperate Desert region generally exhibited lower conventional pollutant concentrations in runoff.
- ***Trace metals:*** Highway sites in the Klamath Mountains, the Central Valley, and the Central Coast region generally exhibited higher trace metals concentrations in runoff than other regions. Highway sites in the Sierra Nevada Foothills and the Temperate Desert region generally exhibited lower metals concentrations in runoff.
- ***Nutrients:*** Highway sites in the Central Valley, the North Coast Interior Range, and the Central and Southern Coast Ranges generally exhibited higher nutrient concentrations in runoff than other regions. Highway sites in the Sierra Nevada Foothills and the Central Coast region generally exhibited lower nutrient concentrations in runoff.

Note that the numbers of sites monitored were limited for some regions (North Coast Range and Interior Range, Klamath Mountains, Temperate Desert), as these areas are characterized by relatively fewer highway miles; results of the geographical variation analysis for these regions therefore should be interpreted with a degree of caution. Figure 3-12 illustrates Caltrans monitoring locations and geographic regions. Figure 3-13 and Figure 3-14 are provided to illustrate the interpretation of the pattern of differences in runoff quality from different geographic regions for Total copper (Figure 3-13) and EC (Figure 3-14).

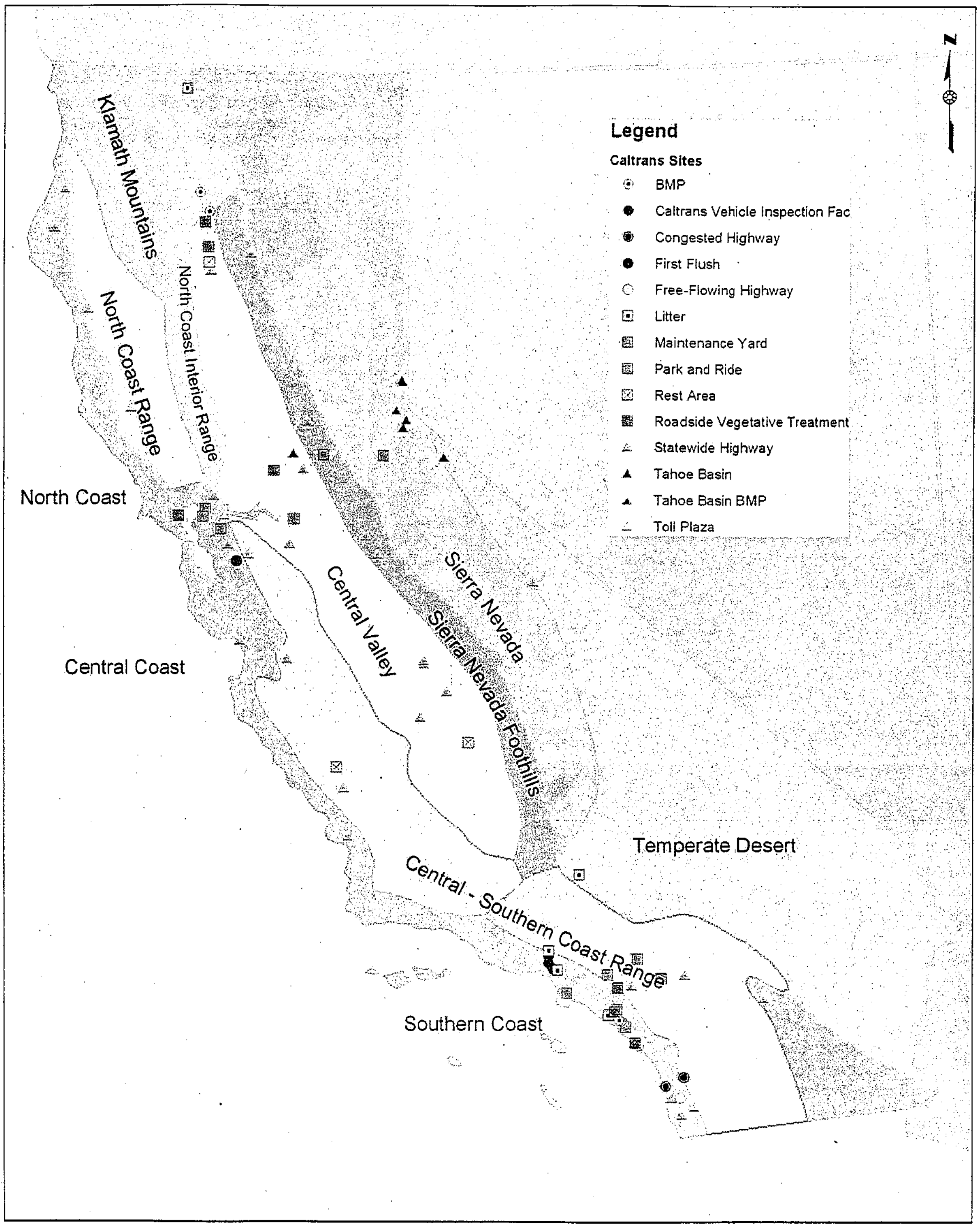


Figure 3-12 Geographic Regions and Caltrans Monitoring Sites

Table 3-16 Effect of Geographic Region on Highway Runoff Quality.

Pollutant Category	Parameter	Fraction	Significant Variation due to Geographic Region?	Regions with Significant Differences from Overall Average Runoff Quality for Geographic Regions: Regions Above Overall Average	Regions Below Overall Average
Conventional	DOC		YES	C/SCR	SNF
	EC		YES	CC, CV, C/SCR, NC, SC	SNF, TD
	Hardness as $CaCO_3$		YES	C/SCR	SNF, TD
	pH		NS	ns	ns
	TDS		YES	C/SCR	SNF
	Temperature		NS	ns	ns
	TOC		YES	CC, C/SCR, SC	SNF
	TSS		YES	CC, CV, C/SCR, KLM	ns
Trace Metals	As	Total	YES	ns	SNF
	Cd	Total	YES	CV, C/SCR	ns
	Cr	Dissolved	YES	CC, KLM, SC	C/SCR, SNF
	Cr	Total	YES	CC, CV, KLM	SNF
	Cu	Dissolved	YES	CC, CV	C/SCR, SNF
	Cu	Total	YES	CC, CV, SC	SNF
	Ni	Dissolved	YES	ns	SNF
	Ni	Total	YES	CC, KLM	SNF
	Pb	Dissolved	YES	ns	SNF
	Pb	Total	YES	CC, KLM	SNF
	Zn	Dissolved	NO	ns	ns
	Zn	Total	YES	CC, CV	NC, SNF
Nutrients	NO_3-N		YES	C/SCR, KLM	CC, SNF
	Ortho-P	Dissolved	YES	NCI	CC, SNF, SC
	P, total	Total	YES	CV, C/SCR, NCI	SNF
	TKN		YES	CV, C/SCR	SNF

Notes: Threshold for statistical significance is $p < 0.05$ for all comparisons and effects. "ns" indicates not significant at the 95% confidence level. Abbreviations for Geographic Regions: CC=Central Coast, C/SCR=Central and Southern Coast Range, CV=Central Valley, NC=North Coast, NCR = North Coast Range, NCI = North Coast Interior Range, SC=Southern Coast, SNF= Sierra Nevada Foothills, TD =Temperate Desert, KLM=Klamath Mountains.

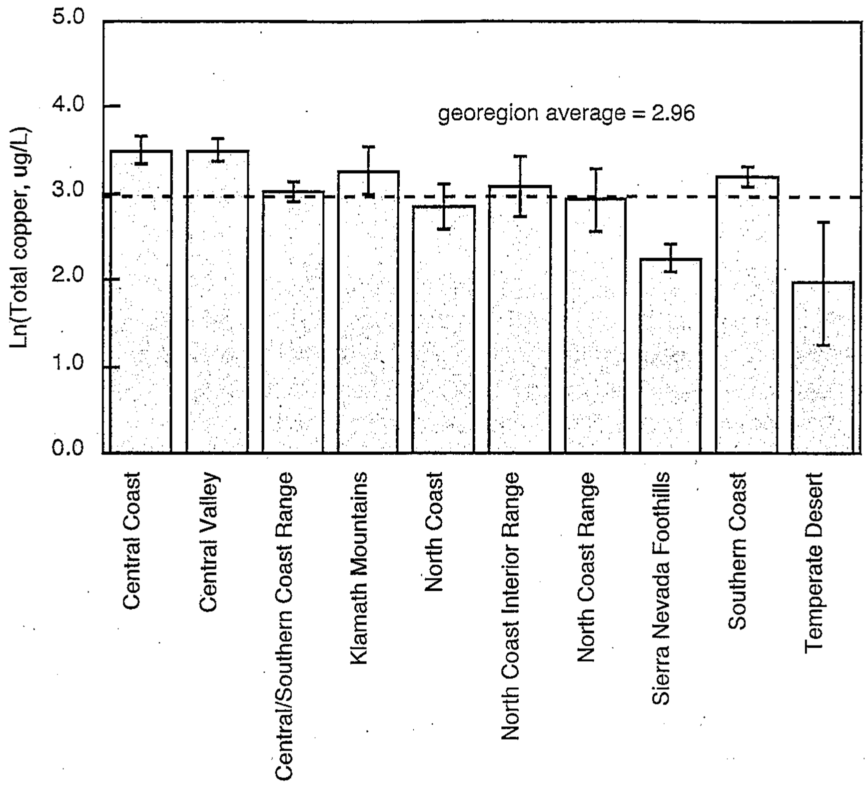


Figure 3-13 Estimated Marginal Means and 95% confidence limits for Total Copper

Bars represent the model-predicted concentration under the average conditions for precipitation and antecedent conditions. Dashed line indicates average of georegions.

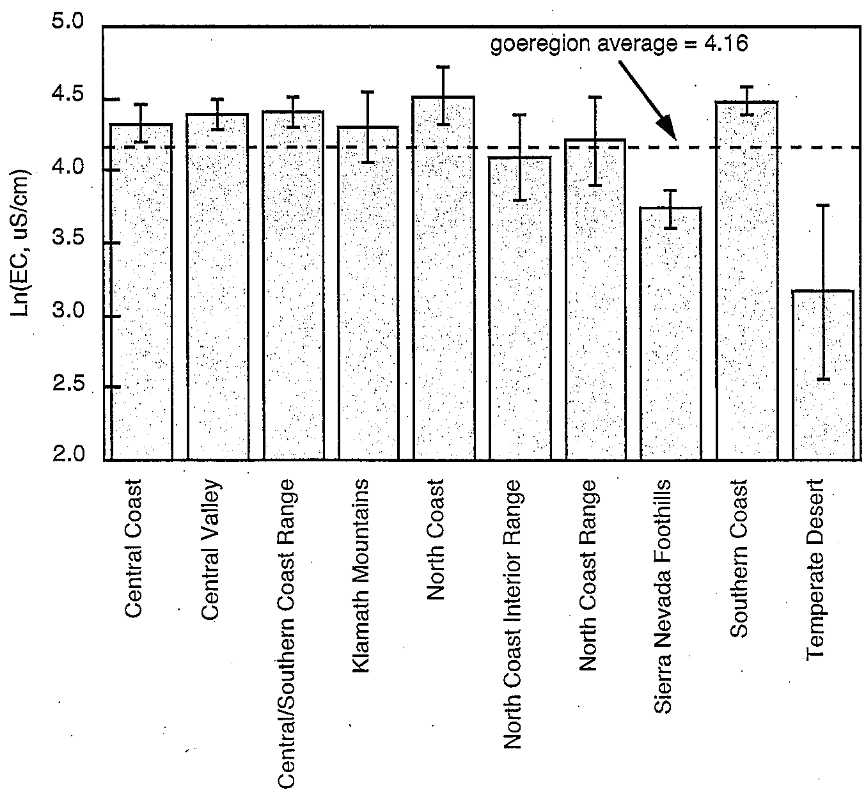


Figure 3-14 Estimated Marginal Means and 95% confidence limits for EC

Bars represent the model-predicted concentration under the average conditions for precipitation and antecedent conditions. Dashed line indicates average of georegions.

Effect of Predominant Surrounding Land Use

The effects of predominant surrounding land use on stormwater runoff quality from highways were evaluated using Multiple Linear Regression and Analysis of Covariance (ANCOVA) methods. Results of these analyses are presented in Table 3-17. Surrounding land use contributed to significant differences in runoff quality from highway sites for all constituents except total chromium, dissolved lead, and NO_3-N. Patterns of significant differences in runoff quality from different predominating land uses are summarized as follows:

- **Conventional parameters**: Runoff from highway sites in agricultural and commercial areas exhibited higher concentrations of most conventional pollutants (EC, DOC, TDS, TOC, TSS) than the overall average and all other land uses. Highway sites in predominantly residential, transportation, and open land use areas generally exhibited lower than average conventional pollutant concentrations in runoff.
- **Trace metals:** Runoff from highway sites in agricultural and commercial areas also exhibited consistently higher concentrations of most trace metals than for other land uses. Predominantly residential, transportation, and open land use areas generally exhibited average or lower than average metals pollutant concentrations in runoff. Exceptions to this pattern were total and dissolved copper and total and dissolved zinc, which were significantly higher than average in transportation areas.
- **Nutrients:** Nutrient concentrations in highway runoff followed the same general pattern. Total phosphorus, and TKN were significantly higher in agricultural and commercial areas, and orthophosphate was also higher in agricultural area. Other land uses generally nutrient concentrations that were not significantly different from the overall average.

Figure 3-15 and Figure 3-16 are provided to illustrate the interpretation of the pattern of differences in runoff quality for different surrounding land uses for EC (Figure 3-15) and total copper (Figure 3-16).

Table 3-17 Significant Variation Due to Surrounding Land Use

Pollutant Category	Parameter	Fraction	Significant Variation due to Surrounding Land Use?	Land Uses with Significant Differences from Overall Average Runoff Quality for Land Uses	
				Land Uses Above Overall Average	**Land Uses Below Overall Average**
Conventional	DOC		YES	AG	TRANS
	EC		YES	AG, COMM	RES, TRANS
	Hardness as CaCO3		YES	AG, TRANS	RES
	pH		YES	COMM, OPEN	TRANS
	TDS		YES	AG, COMM	ns
	Temperature		YES	RES	OPEN
	TOC		YES	AG, COMM, MXD	OPEN, RES
	TSS		YES	AG, COMM	ns
Trace Metals	As	Total	YES	COMM	MXD
	Cd	Total	YES	COMM	ns
	Cr	Dissolved	YES	OPEN	TRANS
	Cr	Total	NO	ns	ns
	Cu	Dissolved	YES	AG, TRANS	OPEN, RES
	Cu	Total	YES	AG, COMM	OPEN, RES
	Ni	Dissolved	YES	AG	TRANS
	Ni	Total	YES	AG, COMM	TRANS
	Pb	Dissolved	NO	ns	ns
	Pb	Total	YES	AG, COMM	TRANS
	Zn	Dissolved	YES	TRANS	OPEN
	Zn	Total	YES	AG, COMM, TRANS	MXD, OPEN, RES
Nutrient	NO3-N		NO	ns	ns
	Ortho-P	Dissolved	YES	AG	TRANS
	P	Total	YES	AG, COMM	ns
	TKN		YES	AG, COMM, TRANS	OPEN

Notes: Threshold for statistical significance is $p < 0.05$ for all comparisons and effects. "ns" indicates not significant at the 95% confidence level. <u>Land Use designations</u>: AG = Agriculture, COMM = Commercial, MXD = Mixed, no dominant land use determined, OPEN = Open, RES = Residential, TRANS=Transportation

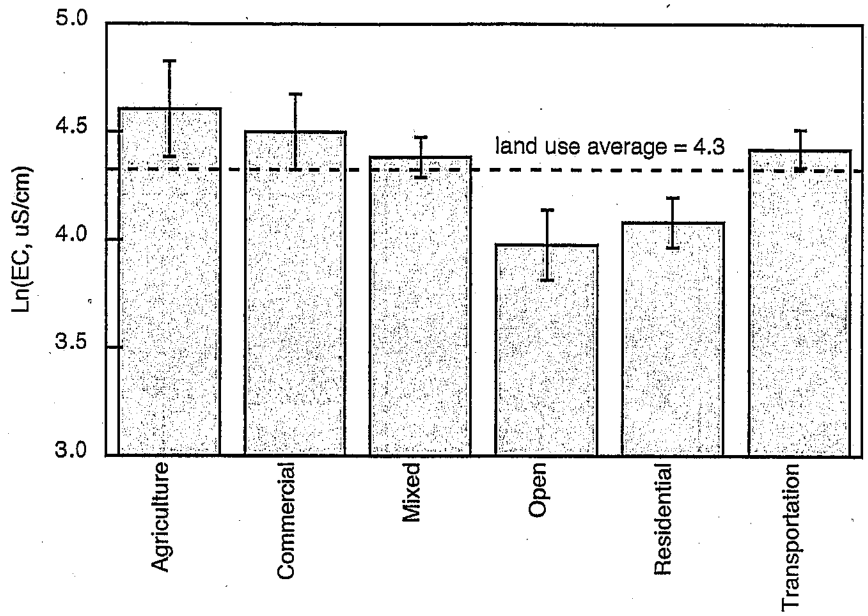


Figure 3-15 Estimated Marginal Means and 95% confidence limits for EC

Bars represent the model-predicted concentration under the average conditions for precipitation and antecedent conditions. Dashed line indicates average for land uses.

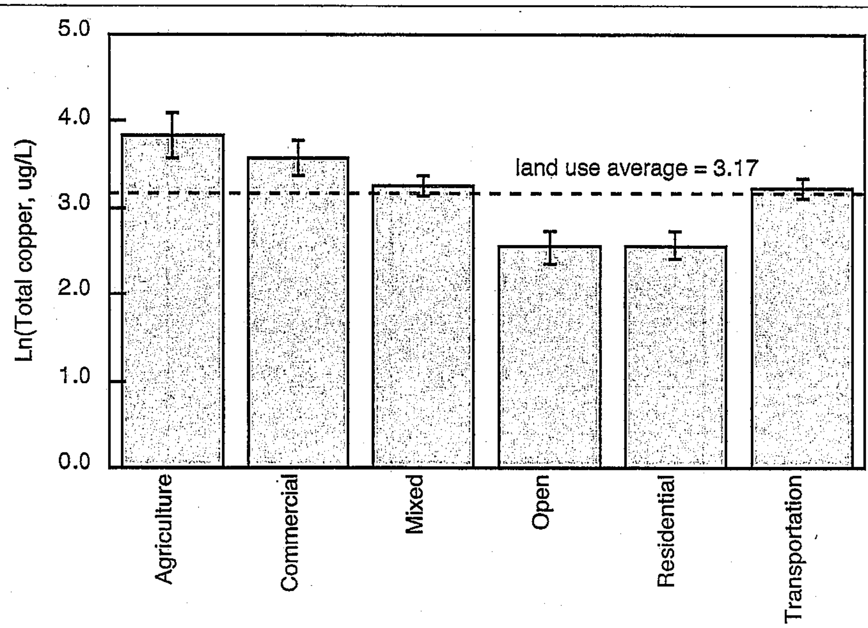


Figure 3-16 Estimated Marginal Means and 95% confidence limits for Total Copper

Bars represent the model-predicted concentration under the average conditions for precipitation and antecedent conditions. Dashed line indicates average for land uses.

Comparisons with Water Quality Objectives

For the purpose of prioritizing constituents for future BMP implementation and study, runoff quality data were compared to California Toxics Rule (CTR) objectives (USEPA 2000) and to several other surface water quality objectives considered potentially relevant to stormwater runoff quality. The sources of other water quality objectives considered were National Primary Drinking Water Maximum Contaminant Levels (USEPA 2002), U.S. EPA Action Plan for Beaches and Recreational Waters (USEPA 1999a), U.S. EPA Aquatic Life Criteria (USEPA 1999b), California Department of Health Services Drinking Water MCLs (CDHS 2002), and California Department of Fish and Game Recommended Criteria for Diazinon and Chlorpyrifos (Siepman and Finlayson 2000). In the case of CTR metals objectives that are adjusted for hardness, the objective was based on the lowest observed hardness for the data set for the most stringent assessment of percent exceedance.

These surface water quality objectives were considered relevant for comparison to stormwater quality because they apply to surface waters which may receive stormwater discharges from highways and other Caltrans facilities. Because these water quality objectives apply to receiving waters, and not directly to runoff, the comparisons are useful only as general guidelines for identifying pollutants with a higher priority for management, and do not reflect regulatory compliance status. Constituents were prioritized according to their estimated percent exceedance of the most stringent water quality objective, i.e. parameters with a higher percent exceedance received a higher monitoring priority, with greater 50% exceedance receiving *high* priority, 5–50% receiving a *medium* priority, and less than 5% receiving a *low* priority. Estimated percent exceedance was calculated based on the distributional parameters calculated for each constituent, using the statistical methods described previously for characterization of runoff quality (Section 2, page 17). Specifically, percent exceedance was estimated as the cumulative probability of exceeding the specific water quality objective, based on the normal or lognormal distribution statistics, as appropriate for the constituent of interest.

Runoff concentrations of most pollutants were observed to exceed the most stringent receiving water quality objectives, and a few parameters exceeded the objectives in a majority of runoff samples. It should be noted that the water quality objectives cited are not intended to apply specifically to stormwater discharges, and are used here only in the context of establishing priorities for continued monitoring. It should also be noted that many constituents monitored do not have relevant water quality objectives. The results of comparisons with the most stringent CTR and other relevant water quality objectives are provided in Table 3-18, and summarized below. Constituents that were monitored by Caltrans in stormwater runoff, but without relevant surface water quality objectives, are listed in Table 3-19.

- Copper, lead, and zinc were estimated to exceed their CTR surface water quality objectives for dissolved and total fractions in greater than 50% of samples.
- Dissolved fractions of cadmium and nickel were estimated to exceed CTR surface water quality objectives in less than 3% of runoff samples, while total fractions of cadmium and nickel were estimated to exceed CTR objectives in 22% and 15% of runoff samples,

respectively. Dissolved arsenic and chromium were estimated to exceed CTR objectives in fewer than 0.01% of runoff samples, while total fractions of arsenic and chromium were estimated to exceed objectives in approximately 5% and 2% of runoff samples, respectively.

- In all cases, trace metals exceeded objectives based on total fractions much more frequently than objectives for dissolved fractions.
- Of the trace organics (semi-volatile organic compounds), only benzo(b)fluoranthene was observed to exceed its CTR objective. Other trace organic compounds were not detected or not expected to exceed CTR objectives more frequently than in 0.01% of runoff samples. Note that because SVOCs were only monitored for highway facilities for a total of 32 samples, these results can not be generalized to other facilities.
- In comparisons with relevant non-CTR criteria, TDS, nitrate, and nitrite were estimated to exceed the drinking water MCLs for these parameters in less than 4% of samples.
- Total aluminum and iron were estimated to exceed their chronic U.S. EPA Aquatic Life Criteria in nearly 100% and 70% of runoff samples, respectively. It should be noted that these metals were monitored for a relatively few events and sites, and these results should not be generalized to all facility types. Chloride was estimated to exceed the chronic U.S. EPA Aquatic Life Criterion in 32% of samples.
- Diazinon was estimated to exceed the California Department of Fish and Game (CDFG) recommended chronic criterion in 79% of stormwater runoff samples, and chlorpyrifos was estimated to exceed the CDFG recommended chronic criterion in 73% of samples.
- Total and fecal coliforms were estimated to exceed the California Department of Health Services Action Level (for recreational beach use) in 21% and 43% of samples, respectively. These parameters were monitored only at selected highway and construction sites for a limited number of events.

Although geographic region and contributing land use were determined to have some statistically-significant effects on runoff quality, these effects use are less consistent than AADT and the precipitation factors. Consequently, geographic region and land use characteristics are less valuable in predicting runoff quality and should be considered less important in planning and prioritizing stormwater monitoring and management activities. The results of this analysis may be applied to other transportation facility types within California.

Other factors that have not received such intensive attention may influence runoff quality from transportation facilities. Predominant among these are the effects of runoff from additional surfaces beyond the paved surfaces, within the transportation corridor right-of-way.

CONCLUSIONS

The following are the principal conclusions derived from this study:

- Transportation facilities with higher traffic levels (i.e., higher AADT), particularly highways and toll plazas, produce higher pollutant concentrations in runoff than lower AADT sites and other types of facilities.
- Concentrations of most pollutants are higher early in the wet season and after extended dry periods. These results support the idea that there is a build-up of pollutants during dry periods, with progressive wash-off during the rainy season, leading to what is commonly known as the seasonal "first flush effect."
- Runoff pollutant concentrations decrease as storm size increases; smaller storms produce higher pollutant concentrations in runoff than those with larger rainfall amounts.
- The majority of the metals present in runoff are found in the particulate form.

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Table 3-18 Comparisons of Caltrans runoff quality data with CTR and other relevant water quality objectives

Parameter	Units	Mean	Standard Deviation	Max Detected Value	CTR Objective	Other Objective	Source of non-CTR objective[1]	Estimated % exceedance	Rank[4]
Parameters with CTR Objectives									
Pb, total	µg/L	49	142	2600	0.66	15	—	97.2%	HIGH
Cu, total	µg/L	39	262	9500	3.2	1000	—	97.1%	HIGH
Cu, dissolved	µg/L	14	15	195	3.1	—	—	88.0%	HIGH
Zn, total	µg/L	207	286	4800	41	—	—	86.8%	HIGH
Pb, dissolved	µg/L	4.5	21.3	480	0.64	—	—	61.1%	HIGH
Zn, dissolved	µg/L	75	128	3320	40	—	—	51.7%	HIGH
Cd, total	µg/L	0.76	1.26	30	0.97	5	MCL	22.4%	MED
Ni, total	µg/L	13	67	2420	18	100	MCL	15.3%	MED
As, total	µg/L	3.3	8.9	91	150	10	MCL	4.7%	LOW
Cd, dissolved	µg/L	0.23	0.39	8.4	0.93	—	—	2.6%	LOW
Ni, dissolved	µg/L	4.2	5.3	98	18	—	—	1.9%	LOW
Cr, total	µg/L	10	21	620	76	50	CA DHS	1.8%	LOW
Benzo(b)fluoranthene (2)	µg/L	IDD	IDD	0.05	0.0044	—	—	(3)	LOW
Cr, dissolved	µg/L	2.9	4.9	141	65	—	—	0.01%	LOW
As, dissolved	µg/L	1.7	5.1	81	150	—	—	0.001%	LOW
Acenaphthene (2)	µg/L	IDD	IDD	0.25	1200	—	—	<0.01%	LOW
Fluoranthene (2)	µg/L	IDD	IDD	0.1	300	—	—	<0.01%	LOW
Fluorene (2)	µg/L	IDD	IDD	0.06	1300	—	—	<0.01%	LOW
Pyrene (2)	µg/L	0.05	0.03	0.13	960	—	—	<0.01%	LOW
Anthracene (2)	µg/L	IDD	IDD	ND	9.6	—	—	ND	LOW
Benzo(a)anthracene (2)	µg/L	IDD	IDD	ND	0.0044	—	—	ND	LOW
Benzo(a)pyrene (2)	µg/L	IDD	IDD	ND	0.0044	—	—	ND	LOW
Chrysene (2)	µg/L	IDD	IDD	ND	0.0044	—	—	ND	LOW
Dibenzo(a,h)anthracene (2)	µg/L	IDD	IDD	ND	0.0044	—	—	ND	LOW
Indeno(1,2,3-c,d)pyrene (2)	µg/L	IDD	IDD	ND	0.0044	—	—	ND	LOW
Parameters with Other Relevant Objectives									
Al, total (2)	µg/L	8863	9746	31430	none	87	EPA AL	99.9%	HIGH
Diazinon (2)	µg/L	0.17	0.20	1.0914	none	0.05	CA DFG	78.8%	HIGH
Chlorpyrifos (2)	µg/L	0.044	0.08	0.97	none	0.014	CA DFG	72.6%	HIGH
Fe, total (2)	µg/L	6794	6794	43500	none	1000	EPA AL	69.2%	HIGH
Fecal Coliform Bacteria (2)	MPN/100 ml	1415	3029	16000	none	400	EPA AP	42.6%	MED
Chloride (2)	mg/L	280	407	1800	none	230	EPA AL	32.4%	MED
Total Coliform Bacteria (2)	MPN/100 ml	9169	25975	160000	none	10000	EPA AP	21.2%	MED
TDS	mg/L	139	466	11700	none	500	MCL	3.5%	LOW
NO_2-N (2)	mg/L	0.14	0.30	2.8	none	1	MCL	1.5%	LOW
NH_3-N (2)	mg/L	0.71	1.48	24.66	none	5.91	EPA AL	0.6%	LOW
NO_3-N	mg/L	0.93	1.50	48	none	10	MCL	0.3%	LOW

Table Notes: IDD indicates insufficient detected data to estimate statistic. ND indicates constituent was not detected.

(1) MCL = U.S. EPA Drinking Water Maximum Contaminant Level, DHS = California Department of Health Services, EPA AL = U.S. EPA Aquatic Life Criterion, CA DFG = California Department of Fish and Game Recommended Criteria for Diazinon and Chlorpyrifos. (2) Parameter is not included on Caltrans Minimum Constituent List for Runoff Characterization. (3) Maximum observed value exceeded CTR objective, but there were insufficient detected data to estimate percent exceedance. (4) Rank is the assigned monitoring priority based on percent exceedance: HIGH—greater than 50% exceedance, MED–from 5-50% exceedance, LOW—less than 5% exceedance or infrequently detected in runoff.

Table 3-19 Statewide characterization studies constituents without CTR or other relevant water quality objectives

Conventional parameters	***Hydrocarbons***	***Metals***	***Pesticides***
BOD[1]	Oil and Grease[1]	Aluminum, dissolved[1]	Diuron
COD[1]	TPH (Diesel)[1]	Iron, dissolved[1]	Glyphosate
EC	TPH (Heavy Oil)[1]	Mercury, total and dissolved[1]	Oryzalin
Hardness	TPH (Gasoline)[1]		Oxadiazon
pH			Triclopyr
Temperature			
Organic carbon, total and dissolved	***SVOCs***	***Nutrients***	
TSS	Acenaphthylene	Orthophosphate, dissolved	
Turbidity[1]	Benzo(g,h,I,)perylene	Phosphorus, dissolved[1]	
	Benzo(k)fluoranthene	Phosphorus, total	
	Napthalene	TKN	
	Phenanthrene		

(1) Parameter is not included on Caltrans Minimum Constituent List for Runoff Characterization

Correlations Between Runoff Quality Parameters

Correlations between runoff quality parameters were screened using Spearman's non-parametric rank correlation procedure, and verified for significant linear relationship using Pearson's standard parametric procedure. Because of the large amount of data there were many correlations significant at the 95% confidence level. However, correlations with a Spearman's *rho*[1] value less than 0.8 were considered to be too weak for one parameter to serve as practical monitoring surrogate for the other parameter, even if correlations were significant. Significant correlations greater than 0.8 are summarized in Table 3-20, along with their corresponding Pearson's Product-Moment correlation coefficient, *R*. The complete Spearman's correlation matrix is presented in Appendix E.

Correlations were generally strongest within pollutant categories, with few correlations greater than 0.8 between constituents in different categories. Exceptions to this pattern included TSS with total aluminum and iron, and dissolved aluminum with ammonia nitrogen. Within the conventional parameters, the strongest correlations were observed among parameters associated with dissolved minerals (EC, TDS, and chloride), organic carbon (TOC and DOC), and suspended particulate materials (TSS and turbidity). Within the metals category, total concentrations of most metals were highly correlated, but correlations between total and dissolved concentrations were all less than 0.8, even between total and dissolved concentrations of the same metals. Total petroleum hydrocarbons were generally poorly correlated with all other parameters, but did exhibit a strong correlation between the diesel and heavy oil fractions of this category. Nutrients were generally not strongly correlated within the nutrient category or with other categories (with the odd exception of ammonia and dissolved aluminum). Total and fecal coliform bacteria exhibited no significant correlations greater than 0.8 within or outside the microbiological category.

These results suggest that for the purpose of assessing trends, the effectiveness of BMPs, and other pollutant management alternatives, some reductions in the parameters monitored would be practical:

- Organic carbon could be adequately monitored as either the total or dissolved fraction.
- Dissolved minerals could be adequately monitored as EC with estimates of TDS and chloride based on the relationship between these parameters.
- Suspended particulate matter could be adequately assessed by measurements of TSS, eliminating turbidity.
- TPH could be adequately monitored as either the diesel or the heavy oil fraction.
- Total aluminum and iron could be adequately monitored as TSS based on the relationship between these parameters.
- Correlations among total concentrations of the total fractions of several metals (cadmium, chromium, copper, lead, nickel, and zinc, as well as aluminum and iron) were consistently strong enough to monitor a select subset of these parameters to assess effectiveness of BMPs.

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[1] Spearman's *rho* is a non-parametric measure of association calculated from ranks. Spearmans's *rho* is analogous to the Pearson's Product-Moment correlation coefficient, *R*. In all cases, these values were nearly identical.

Table 3-20 Summary of correlations between runoff quality parameters. Spearman's *rho* > 0.8 and significant at the 95% confidence level.

Constituent Categories	Parameter Pairs	Spearman's *rho*	*n*	Pearson's R	*n*
Conventionals with Conventionals	TOC and DOC	0.962	1687	0.960	1677
	TSS and Turbidity	0.844	395	0.784	394
	EC and Chloride	0.976	27	0.970	27
	EC and TDS	0.794	1857	0.805	1799
	TDS and Chloride	0.891	27	0.876	27
Conventionals with Hydrocarbons	*None > 0.8*	—	—	—	—
Conventionals with Metals	TSS and Al, total	0.861	26	0.878	26
	TSS and Fe, total	0.891	59	0.898	59
Conventionals with Microbiologicals	*None > 0.8*	—	—	—	—
Conventionals with Nutrients	*None > 0.8*	—	—	—	—
Hydrocarbons with Hydrocarbons	TPH, Diesel and Heavy Oil	0.877	20	0.858	19
Hydrocarbons with other categories	*None > 0.8*	—	—	—	—
Metals with Metals	Al, total and Cd, total	0.814	28	0.823	25
	Al, total and Cr, total	0.893	28	0.951	28
	Al, total and Ni, total	0.822	28	0.879	26
	Cr, total and Fe, total	0.919	59	0.880	53
	Cu, total and Fe, total	0.863	59	0.872	59
	Cu, total and Pb, total	0.809	2231	0.792	2133
	Cu, total and Zn, total	0.857	2231	0.850	2224
	Fe, total and Ni, total	0.866	59	0.803	51
	Fe, total and Pb total	0.919	59	0.900	48
	Fe, total and Zn, total	0.822	59	0.842	59
Metals with Nutrients	Al, dissolved and NH_3-N	-0.901	14	-0.766	9
Metals with Microbiologicals	*None > 0.8*	—	—	—	—
Microbiologicals and other categories	*None > 0.8*	—	—	—	—
Nutrients and other categories	*None > 0.8*	—	—	—	—

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SECTION 4 DISCUSSION

The results of the runoff characterization monitoring performed by the Department, together with the analyses of the monitoring data presented in Section 3 of this report, provide adequate information to address the primary objectives of this report (listed in Section 1). Discussions of the results and interpretations of the analytical evaluations of stormwater runoff quality are presented below.

Effects of AADT and Other Factors on Runoff Quality, and Implications for Stormwater Management

Multiple Linear Regression (MLR) analyses of the Department's runoff quality data demonstrate a set of generally consistent relationships between runoff quality and precipitation factors, antecedent conditions, AADT, and drainage area. The results are generally consistent with—and provide qualitative validation of—models generated from previous analyses of the Department's stormwater runoff quality data (Kayhanian *et al.*, 2003). However, the use of the more representative Statewide Characterization Study data for MLR analyses results in a more consistent picture of the effects of these factors than derived from the previous analysis.

The current results provide confirming evidence that traffic volumes and rainfall conditions – including antecedent conditions – are the most significant factors influencing runoff quality from the Department's facilities. Runoff quality is significantly correlated with traffic level; pollutant concentrations are higher for sites with higher AADT. Pollutant concentrations are also higher during events that occur at lower cumulative (seasonal) rainfall levels (i.e., those occurring earlier in the rainy season), and during storm events preceded by longer antecedent dry periods. Pollutant concentrations tend to decrease for storm events with higher event rainfall totals.

Larger drainage areas were also generally associated with lower pollutant concentrations for some parameters, but this effect was less consistent than the effects of AADT, event rainfall, cumulative precipitation, and antecedent dry period on runoff quality. Maximum rainfall intensity was not a statistically significant or consistent predictor of runoff quality for most constituents, due in part to correlation with event rainfall totals.

Seasonal and Event First Flush Effects

The MLR analyses indicate that pollutant concentrations decrease with increasing cumulative seasonal rainfall, and increase with antecedent dry period. California's climate is characterized by an extended summer dry season. The "first flush" rainfall event in the fall, with the longest annual antecedent dry period and the lowest cumulative seasonal rainfall total, is therefore expected to produce the highest runoff pollutant concentrations. The results of the current study are consistent with a significant seasonal "first flush effect," resulting in higher pollutant concentrations early in the wet season, with concentrations tending to decrease through the remainder of the wet season. The mechanism underlying these effects is generally understood to be the build-up of pollutants on exposed surfaces during dry weather, and wash-off during rainfall events.

A significant storm event first flush effect was also suggested for most pollutants by the statistically significant effect of storm event rainfall totals on pollutant concentrations. Although demonstration of a storm event first flush effect was not a specific goal of discharge characterization monitoring, this result suggests that concentrations of most pollutants monitored by the Department are significantly higher in the initial runoff of a storm event and tend to be diluted by additional rainfall and runoff. The Department is currently conducting studies designed specifically to address this question.

The findings of significant seasonal and storm event first flush effects confirm conclusions reached in other studies of these phenomena. The first year of results from a study conducted by UCLA and supported by the Department (Stenstrom *et al.* 2001) demonstrated a statistically significant storm event first flush effect for a number of pollutants. Analysis of stormwater runoff quality data from the City of Sacramento's Storm Water Monitoring Program have also demonstrated significant event and seasonal first flush effects for a variety of pollutants, as well as significant effects of precipitation factors and antecedent conditions (LWA 1996). The weight of evidence from these and other studies appear to provide compelling evidence of the relationships of these factors with stormwater runoff quality.

Effects of Categorical Factors on Runoff Quality

Several consistent differences were also found in the results of analyses of the effects of categorical factors (facility type, land use, and geographical region) on runoff quality. However, conclusions drawn from these results should be interpreted with caution. Although significant differences were found for most constituents for every category evaluated, the analyses and interpretation of the results are limited by some largely unavoidable imbalances in the sampling design. Specifically, most of the data for each categorical comparison was dominated by one district, geographical region, facility type, or land use, with few sites representing other levels of each category. Several land uses and geographic regions were represented by two sites with many sample events, resulting in pseudoreplication and artificial inflation of the significance of the effect of that categorical factor. This imbalance in design results in some uncertainty in interpreting the effects of specific land uses and geographic regions that must be acknowledged. Given this warning, the following patterns were noted in the Statewide characterizations studies data:

- The analysis of runoff quality from different facilities indicated that facilities expected to have the highest vehicle traffic, *e.g.* highways and toll plazas, exhibited elevated concentrations of most pollutants in runoff, compared to other facilities. Pollutant concentrations in runoff from lower traffic facilities (maintenance facilities, park-and-ride lots, Caltrans vehicle inspection facilities, and rest areas) were generally similar to each other and lower than highways and toll plazas. This pattern was consistent for the categories of conventional constituents and trace metals with few exceptions, and somewhat less consistent for nutrients. These results for facility types tend to confirm the importance of AADT as a predictor of pollutant concentrations in runoff and as an important factor in prioritizing the implementation of management alternatives.

- There were also significant differences in highway runoff quality for different geographic regions. However, the apparent effects of region may be due more to the actual effects of typical AADT and land use within those regions. Regions with pollutant concentrations that were significantly higher than average (Klamath Mountains, Central Coast, Central Valley, and North Coast and Interior Ranges) were represented by only a few sites with high AADT, or were in primarily urban areas (the Central Coast region is predominantly comprised of San Francisco Bay area sites). Lower than average regions (Sierra Nevada Foothills and Temperate Desert) were represented by only a few sites with low AADT and little urban influence. These results appear to be more supportive of the effects of AADT and urban influence on runoff quality than for consistent region-wide effects of other undefined factors.

- The results of analysis of surrounding land use effects indicated that most conventional pollutants, trace metals, and nutrients were higher in agricultural and commercial areas. Runoff quality from residential areas, transportation corridors, and open land use areas were generally similar to each other and lower than agricultural and commercial areas.

Relevance to Management of Runoff from Department Facilities

It should be noted that the large number of data in the Department's Stormwater Quality Database provides statistical power sufficient to detect relatively small effects on runoff quality (as small as 5% of total variation, as evidenced by the low R^2-values for significant MLR models for some constituents). Taking that into consideration, three results of these analyses have particular relevance to management or treatment of runoff from the Department's facilities:

- *AADT* - Pollutant concentrations increase in proportion to the annual average daily traffic for the contributing facility.

- *Seasonal First Flush Effect and Antecedent Dry Period* - Concentrations of most pollutants are higher when cumulative seasonal precipitation is lower — i.e., early in the wet season — and pollutant concentrations also tend to increase with longer antecedent dry periods.

- *Storm Event First Flush Effect* - This and other studies provide evidence that concentrations of most pollutants are significantly higher in the initial runoff from a storm event.

Value of MLR Models for Prediction and Runoff Management

MLR analysis of the Department's runoff quality data has been able to successfully identify environmental and site-specific factors that significantly effect runoff quality. Knowledge of these factors and their effects on runoff quality should be useful to the Department in evaluating future management alternatives, planning future monitoring efforts, and designing studies of management effectiveness. However, although MLR analyses have been valuable in identifying factors that have the greatest known influence on runoff quality, the MLR models developed for this study are still able to account for much less than 50% of the variability of most constituents in runoff. For this reason, there are significant limitations to the use of the models resulting from these analyses. Although the models developed herein may not be adequately accurate for prediction of concentrations or loads for specific sites and storm events, they can be used to provide improved estimates of long-term average concentrations or loads from Department facilities as a whole.

In a review of the statistical procedures used for this study, staff of the University of California, Davis Statistics Laboratory concluded that some marginal improvements in predictive value of the models would likely be gained and some potential biases moderated by expanding the statistical techniques used, particularly by introducing additional covariate terms. The additional methods recommended for consideration in this review included expanded exploration of transformations of predictor variables, multivariate ANCOVA, and principal components analysis. However, the review also concluded that improvements in the models would be incremental and would not change the overall conclusions drawn based on this study of the data.

Discharge Load Modeling and TMDLs

Developing MLR models for runoff quality has a number of practical applications. Modeling of runoff quality allows more accurate comparisons with relevant water quality regulatory limits than the simple statistical estimates of percent exceedance generated for this study. These models also provide tools relevant to BMP development and assessment and runoff management. Additionally, by combining runoff quality models of EMCs with runoff quantity models, pollutant loads can be better estimated. The relatively low coefficients of determination (R^2-values) for most of the significant MLR model parameters may limit appropriate uses of the MLR models to "big picture" management decisions. However, the current MLR models will still provide estimates of overall runoff quality and loads that are unbiased and with narrower confidence limits than simply using average annual estimates of mean runoff quality and rainfall or runoff.

The ability to estimate pollutant loads from the Department's highway facilities as accurately as possible may be important in developing TMDLs for specific pollutants (depending on the form of the TMDLs) and subsequently in assessing the ability of the Department to comply with TMDL requirements included in their NPDES permit. If estimating pollutant loads is the ultimate use of MLR models, it may be possible to develop more accurate models of loads (i.e., models with higher R^2-values and lower residual mean squared values) directly from pollutant load data and additional site-specific or environmental independent factors. However, variability of pollutant loads (as measured by coefficient of variation) is typically much higher than for EMCs because storm event runoff volumes and loads typically vary by a couple of orders of magnitude for a specific drainage. The inherently higher variability of loads means models based directly on load data may be no more accurate or predictive than the current models.

Percentage of Metals in the Particulate Fraction

A large proportion of the concentrations of most metals are bound to particulate matter in runoff. Because most management practices and processes for treating stormwater target the particulate portion of runoff, metals with a higher percentages in the particulate fraction are presumed to be more efficiently removed or controlled. Based on data from Statewide discharge characterization studies for the metals with data available for both dissolved and total analyses, lead has the highest proportion present as particulates (86%). Cadmium, chromium, and zinc are between 60-70% in the particulate fraction, and arsenic, copper and nickel are between 50-55% in the particulate fraction. This indicates that at least 50% of these metals may be effectively managed or removed from runoff by targeting the particulate fraction, with the most effective removals expected for lead, cadmium, chromium, and zinc. Table 4-1 summarizes the particulate percentages for the several metals for which both dissolved and total concentration data were available.

Table 4-1 Particulate fraction of metals.

Metal	Percent Present as Particulates (Average for all facilities)
Arsenic	53%
Cadmium	63%
Chromium	68%
Copper	51%
Nickel	54%
Lead	86%
Zinc	69%

Use of Statewide Discharge Characterization Data

Summary statistics for highway runoff data from the three-year Statewide Discharge Characterization Study and from the overall Caltrans monitoring dataset were evaluated for patterns of differences between the two datasets. For these comparisons, the "overall" data set contains data from projects conducted generally before the Statewide Discharge Characterization Study, plus the data from the Statewide Characterization Study, while the "statewide characterization" data set contains only data from the Statewide Characterization Study. Ratios of the means, standard deviations, and coefficients of variation (COV) for highway runoff data were calculated as *Overall statistic ÷ Statewide characterization study statistic*, for core Department monitoring parameters. This analysis was performed to evaluate whether use of the representative Statewide Characterization Study monitoring design was able to moderate a bias of earlier monitoring efforts towards highly urbanized sites. The results of the evaluation are summarized in Table 4-2.

Averaged across monitoring parameters, the means, standard deviations, and COVs were all higher for the overall dataset. Means decreased by about 8% on average for the statewide characterization dataset when compared to the overall data set, with decreases of more than 10% for 27% of parameters, and decreases of 20% or more for 19% of parameters. This pattern indicates that earlier concerns about potential biases due to site selection in the pre-Statewide Characterization Study data set were warranted, and that the more rigorous process of selection of monitoring locations for the Statewide Characterization Study was important in providing a more representative estimate of runoff quality.

The difference in variation for the datasets (as measured by standard deviation and COV) was even more dramatic, with variability of the statewide characterization dataset lower than the overall data set by 10% for approximately 50% of the parameters, and lower than the overall data set by 20% for about 20% of the parameters. This suggests that implementation of more consistent sampling procedures as part of the Statewide Characterization Study was successful in decreasing data variability, even with an increase in the variety and range of sites and geographic regions monitored. The overall pattern of these results highlights the importance of using the Statewide Characterization Study data to characterize the Department's runoff quality and to evaluate the factors affecting stormwater runoff.

Table 4-2 Comparison of highway summary statistics from the Statewide Characterization Study (2000/01-2002/03) and overall dataset (1998/99-2002/03)

Ratios of Summary Statistics for SWCS Data to Overall Dataset

Parameter	Mean	SD	COV
DOC	0.96	0.83	0.86
EC	0.49	0.11	0.22
Hardness as CaCO3	0.81	0.53	0.65
pH	0.99	1.03	1.04
TDS	0.57	0.22	0.39
Temperature	0.99	1.02	1.03
TOC	1.03	0.91	0.89
TSS	0.79	0.65	0.83
As, dissolved	0.91	0.86	0.95
As, total	1.01	1.17	1.16
Cd, dissolved	0.99	1.21	1.22
Cd, total	0.92	1.28	1.40
Cr, dissolved	1.07	0.90	0.84
Cr, total	0.96	0.90	0.94
Cu, dissolved	0.99	0.92	0.92
Cu, total	0.76	0.09	0.12
Ni, dissolved	1.09	0.96	0.88
Ni, total	1.02	0.84	0.82
Pb, dissolved	1.31	1.31	1.01
Pb, total	0.82	0.94	1.16
Zn, dissolved	0.96	0.89	0.92
Zn, total	0.94	0.95	1.01
NO3-N	1.05	1.39	1.33
Ortho-P, dissolved	1.03	1.23	1.19
P, total	0.64	0.29	0.45
TKN	0.93	0.82	0.89
mean ratio	0.92	0.86	0.89
% decreases in statistic	69%	69%	62%
% of decreases > 10%	27%	46%	46%
% of decreases > 20%	19%	23%	19%

Annual Variability in Stormwater Runoff Quality

For highways, annual variation in statewide runoff quality was very low. Other types of facilities saw relatively higher degrees of annual variation.

Overall, annual variation was less than 10% or not significant for 75% of the facilities and parameters (116 of 154 separate comparisons). Notably, the overall trend observed in the results is that facility types with higher numbers of sites and broader geographic representation exhibited lower annual variability. Highways, which are represented by the most sites (46) and have the broadest geographic representation in the data set, exhibit annual variation that is less than 5% of the total variation for most parameters. Maintenance and park-and-ride facilities (with seven and ten sites, respectively) exhibit an intermediate level of annual variation (less than 15% for most parameters). Caltrans vehicle inspection facilities (two sites), rest areas (three sites), and toll plazas (two sites) exhibited the highest annual variation, with statistically significant annual variation in the range of 20-40% for many parameters, and greater than 40% annual variation for DOC and total copper from rest areas.

The most likely reason for this pattern in significant annual variation is that many of the factors expected to cause significant annual variation in runoff quality (e.g., changes in patterns of use, annual variations in weather and deposition patterns, or implementation of management practices) are site-specific or regional factors and would not affect all sites equally. Consequently, runoff quality for facility types represented by few sites is more likely to exhibit significant annual variation. However, based on the results for highways, annual variation for any facility type with broad geographic representation and sufficient numbers of sites is likely to be fairly low on a statewide basis—less than 5% of total variation for most parameters. Conversely, annual variability is expected to be much higher on a site-specific and regional level.

Based on the results for highways, it can be concluded that annual variation will have little impact on the characterization of the Department's average runoff quality *on a statewide basis*. However, annual variation becomes more important for characterization of runoff quality at smaller regional or site-specific scales. The conclusions drawn from these analyses also depend on the assumption that the period monitored is adequately representative of longer-term annual variability —an assumption that is probably not valid for the state as whole.

Comparisons with Water Quality Objectives

The Department's stormwater runoff quality data were compared to statewide water quality objectives found in the California Toxics Rule (CTR) and other surface water quality regulations as a means of identifying constituents with higher priority for future monitoring, or potentially greater need for BMP study and implementation (either structural or source controls). Because these water quality objectives apply to receiving waters, and not directly to runoff, the comparisons are useful as general guidelines for prioritizing pollutants, and do not reflect regulatory compliance status. After comparisons to CTR and other water quality objectives relevant to the discharge of stormwater, constituents were ranked according to their expected frequency of exceedance of the most stringent objective. Priority rankings of *high*, *medium*, and *low* were assigned based on exceedance rates of greater than 50%, 5%-50%, and less than 5%, respectively.

As result of these comparisons, it was determined that copper, lead, and zinc exceeded relevant objectives most frequently and therefore receive a *high* priority for future monitoring, and BMP study or implementation. The comparisons between CTR and other relevant surface water quality objectives and the Department's stormwater runoff quality data are discussed below:

- Based on comparisons with CTR and other relevant water quality objectives, copper, lead, and zinc are assigned high priorities, due to frequent exceedances of surface water quality objectives for both total and dissolved fractions of these metals. Expected frequencies of exceedance for these metals in stormwater runoff is greater than 85% for total fractions and greater than 50% for dissolved fractions of these metals.

- Based on comparisons with CTR and other relevant surface water quality objectives, arsenic, cadmium, chromium, and nickel receive lower priorities. As a group, the total fractions of these metals exceeded objectives in fewer than 25% of stormwater runoff samples, and the dissolved fractions are expected to exceed objectives in fewer than 5% of runoff samples. (Note: It is expected that these parameters would all benefit from the same BMPs as copper, lead, and zinc.)

- Based on comparisons with CTR and other relevant surface water quality objectives, semi-volatile organic compounds merit low priority rankings. In this category, only benzo(b)fluoranthene was observed to exceed any objective, and most constituents were not detected or were well below any relevant objectives.

- Based on comparisons with U.S. EPA drinking water MCLs for TDS, nitrate, and nitrite (the most stringent objectives), these parameters receive low priority rankings. These parameters were estimated to exceed their MCLs in less than 4% of samples. However, nitrate, TKN, total phosphorus, and dissolved orthophosphate are elevated to a higher priority in anticipation of the development of statewide nutrient objectives in the future.

Certain other constituents, such as chlorpyrifos and diazinon, were found at elevated concentrations, but were monitored for few events and at few sites. While these constituents were frequently observed at concentrations above California Department of Fish and Game recommended criteria for diazinon and chlorpyrifos, these criteria have not been officially adopted and do not currently have official regulatory status in California. Furthermore, these pesticides are not routinely used by the Department within highway right-of-ways. For these reasons, these constituents are not designated as high priority parameters for monitoring or management.

Many other parameters monitored by the Department do not have relevant statewide water quality objectives and were therefore not ranked based on comparisons to objectives.

Correlations Between Stormwater Runoff Quality Parameters

The purpose of evaluating correlations between stormwater runoff quality parameters was to determine whether monitoring of some specific parameters could be discontinued or reduced, based on strong correlations with other parameters. Based on the results of these analyses, there were a few cases for which relationships were strong enough to allow reduced monitoring for specific constituents of interest. The majority of these cases were conventional constituents: organic carbon, parameters related to dissolved minerals or dissolved solids (EC, TDS, and chloride), and suspended solids (TSS and turbidity). Additionally, total petroleum hydrocarbons could be adequately monitored by a single fraction in this category (diesel or heavy oil), because other fractions were below detection in the majority of samples. For the purpose of assessing BMP and management effectiveness, it would also be adequate to monitor only a few of the highly correlated metals in the total metals category.

The following priorities are identified for future monitoring and BMP studies based on strong correlations between runoff quality parameters:

- Continue monitoring TOC and discontinue DOC (based on a significant Pearson's correlation of 0.960).
- Continue monitoring TSS and discontinue turbidity (based on a significant Pearson's *R* of 0.784).
- Continue monitoring EC and discontinue chloride and TDS (based on significant Pearson's correlations of 0.970 and 0.805).
- Continue monitoring TPH (Heavy Oil) or TPH (Diesel), but not both (based on a significant Pearson's correlation of 0.858 between these parameters).
- For the purpose of assessing the effectiveness of management alternatives and BMPs in reducing total metals in runoff, only copper, lead, and zinc are high priorities for future monitoring. This is based on a high degree of intercorrelation among total concentrations of these metals with aluminum, cadmium, chromium, iron and nickel, as well as the fact that copper, lead, and zinc warrant a higher priority than other trace metals, based on comparisons with water quality objectives discussed previously.

Prioritization of parameters for future monitoring and BMP studies is summarized in Table 4-3.

Based on comparisons to objectives and evaluation of correlations between parameters, the constituents with high priority for future monitoring and BMP studies are as follows:

▪ pH	▪ Aluminum (total and dissolved)
▪ Temperature	▪ Iron (total and dissolved)
▪ Conductivity (EC)	▪ Copper (total and dissolved)
▪ Total Suspended Solids (TSS)	▪ Lead (total and dissolved)
▪ Total Organic Carbon (TOC)	▪ Zinc (total and dissolved)

Table 4-3 Summary of priority rankings for future monitoring and BMP studies, based on comparisons with water quality objectives and correlation analyses.

Parameter	Priority (Based on Comparison to Water Quality Objectives)	Comment
Conventional		
Conductivity (EC)	No relevant objective	Surrogate for TDS and chloride
Chloride	MEDIUM	Replace with EC
Hardness as CaCO3	No relevant objective	
pH	No relevant objective	
Temperature	No relevant objective	
Total Dissolved Solids (TDS)	LOW	Replace with EC
Total Suspended Solids (TSS)	No relevant objective	Replace with Turbidity
Turbidity	No relevant objective	Surrogate for TSS
Organic Carbon, Total (TOC)	No relevant objective	Surrogate for DOC
Organic Carbon, Dissolved (DOC)	No relevant objective	Replace with TOC
Metals		
Aluminum	HIGH	
Arsenic	LOW	
Cadmium	MEDIUM	
Chromium	LOW	Assess effectiveness of BMPs for metals based only on highest priority metals: copper, lead and zinc
Copper	HIGH	
Iron	HIGH	
Lead	HIGH	
Nickel	MEDIUM	
Zinc	HIGH	
Nutrients		
Ammonia	LOW	
Nitrate	LOW	
Nitrite	LOW	Infrequently detected (~25%)
Total Kjeldahl Nitrogen	No relevant objective	
Tota Phosphorus	No relevant objective	
Dissolved Orthophosphate	No relevant objective	
Herbicides		
Diuron	No relevant objective	
Glyphosate	No relevant objective	
Oryzalin	No relevant objective	
Oxadiazon	No relevant objective	
Triclopyr	No relevant objective	
Total Petroleum Hydrocarbons		
Oil and Grease	No relevant objective	
TPH (Gasoline)	No relevant objective	Rarely detected
TPH (Heavy Oil)	No relevant objective	Surrogate for TPH (Diesel)
TPH (Diesel)	No relevant objective	Replace with TPH (Heavy Oil)
Semi-Volatile Organic Compounds		
Acenaphthene	LOW	Rarely detected
Acenaphthylene	LOW	Rarely detected
Anthracene	LOW	Rarely detected
Benzo(a)Anthracene	LOW	Rarely detected
Benzo(a)Pyrene	LOW	Rarely detected
Benzo(b)Fluoranthene	LOW	Rarely detected
Benzo(ghi)Perylene	LOW	Rarely detected
Benzo(k)Fluoranthene	LOW	Rarely detected
Chrysene	LOW	Rarely detected
Dibenzo(a,h)Anthracene	LOW	Rarely detected
Fluoranthene	LOW	Rarely detected
Fluorene	LOW	Rarely detected
Indeno(1,2,3-c,d)Pyrene	LOW	Rarely detected
Naphthalene	LOW	Rarely detected
Phenanthrene	LOW	Rarely detected
Pyrene	LOW	Rarely detected

SECTION 5 SUMMARY AND CONCLUSIONS

SUMMARY

The Department conducted comprehensive monitoring of runoff from transportation facilities throughout the State of California during the period 1997-2003. The centerpiece of this effort was the three-year Statewide Characterization Study, conducted from 2000-2003. The Statewide Characterization Study was designed to provide data representative of runoff from the full range of transportation facility types, geographic locations, traffic levels, and land use characteristics for facilities under the Department's purview.

The monitoring was conducted using consistent protocols designed to ensure the scientific validity of the data. Several significant innovations were developed to assist the Department's staff and contractors in assuring quality control and consistency in monitoring and data management.

The Department's extensive monitoring has provided sufficient data with which to characterize the quality of runoff from the "edge of pavement" from the Department's highway facilities. This goal also has been achieved, though less intensively, for other types of transportation facilities that have been monitored by the Department. Based on these results, continued extensive monitoring of the type and scale performed under the Statewide Characterization Study is not necessary, as this study has provided sufficient information about the characteristics of edge-of-pavement runoff quality and its variability.

Factors Affecting Runoff Quality

Environmental factors affecting the quality of edge-of-pavement runoff have been identified and quantified in this report, and the major patterns of temporal variability (annual, seasonal, and intra-storm) have been evaluated. Analysis of the Statewide Characterization Study monitoring data has confirmed that AADT and storm event characteristics have statistically-significant effects on runoff quality from transportation facilities. Consideration of these factors can be included in planning and prioritizing efforts for future monitoring and for management of runoff quality from such facilities.

AADT is the most important site characteristic affecting runoff quality of those identified to date for highways. Precipitation characteristics, particularly antecedent dry period, cumulative seasonal rainfall, and event rainfall amount, are also statistically-significant factors affecting the quality of runoff from highways.

However, because the correlation coefficients were generally low ($R^2 < 0.5$), it is also clear that there are other unaccounted-for factors contributing to variability in runoff. These factors may include aerial deposition under both wet and dry conditions.

TOXICITY OF STORM WATER FROM CALTRANS FACILITIES

A REPORT PREPARED FOR THE
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Executive Summary

This study was undertaken to determine the toxicity associated with various constituents in storm water runoff from Caltrans roadways and facilities. A submitochondrial particle (SMP) test (Mitoscan©) was evaluated as a potential screening tool to determine if the assay was acceptable to screen for toxicity at Caltrans facilities. Receiver Operating Characteristic analysis was used to compare the SMP test to established 3-species EPA toxicity test protocols. SMP are fragmented particles of mitochondria manipulated so that the inner membrane of the organelle faces outward, allowing toxicants access to the enzymatic reactions. Toxicity is registered if the enzymatic reactions are disrupted, which is indicated by a change in a photometric signal. Discharges from several transportation related sites were evaluated, including highways, California Department of Transportation maintenance facilities, Park and Ride commuter parking areas, and highway rest areas. Thirty-eight sites were sampled over three years of testing. The results indicated that Mitoscan tests at the 10% inhibition level can be used as a reliable screening tool for storm water toxicity in the general sense, i.e., they reliably indicate that toxicity will be present in at least one of the standard 3-species EPA toxicity test protocols. They are reasonably reliable as indicators of toxicity in at least two of the tests, but become less reliable as an indicator of toxicity in more than two standard tests. They are generally unreliable as indicators of toxicity in any specific test, i.e., it is generally not possible to determine which standard toxicity test will be positive by examining the results of the SMP tests.

The objectives of the toxicity testing project were to enable Caltrans to assess the toxicity associated with its storm water discharges, and provide some understanding of the basis

of the toxicity. The first objective was achieved by performing three-species toxicity bioassays with storm water discharges from highways, maintenance facilities, park and ride facilities, and rest areas. Testing was conducted from years 2000 to 2003 at 38 sites from across the entire state. Sites were selected from sites monitored as part of Caltrans' Statewide Monitoring and Characterization project. Each year, water from several storms was tested for toxicity. Storm water from the first rain event of the year was collected, and then from several additional storms during the remainder of the winter. Water was collected and transported to the UCD Aquatic Toxicology Laboratory for testing. Complete sets of toxicity tests consisted of a *Selanastrum* growth test, *Ceriodaphnia dubia* mortality and reproduction, and *Pimephales promelas* biomass and mortality tests. If acute toxicity was present, additional Toxicity Identification Evaluations (TIE) were conducted to determine the cause of the toxicity. Complete sets of tests were performed on 223 site-event samples during the three years of the project. There were 68 samples classified as first event, 76 that were classified as second event, and 63 that were classified as third event. An additional 13 samples were collected as fourth events and 3 samples were collected as fifth events. All samples were collected immediately after entering the storm drain; no samples were collected after discharge to vegetated ditches or treatment systems. Essentially every site produced toxicity at some time during the course of the first two years of the study (Table 2). Most sites produced storm water that was toxic to more than one test organism (161 events – 72%) during more than one storm. Sites for the third year of the study were selected because they exhibited acute toxicity during the first two years. However, two sites did not exhibit any toxicity during one event in the third year. Generally, it appears that long antecedent dry periods result in lower reproduction and higher toxicity in the *C. dubia* and *P. promelas* tests. A higher percent impervious fraction in the catchment also results in higher toxicity, as does a higher traffic volume. The greater the cumulative precipitation, the lower the *P. promelas* mortality, but the correlation was not quite significant at $p = 0.05$, and no other toxicity assay exhibited a nearly significant relationship (although all had signs for the correlations indicating that higher precipitation resulted in lower toxicity).

Chapter I. Use of Submitochondrial Particle Tests as a Screening Tool for Detecting the Toxicity in Storm Water Runoff

Introduction

Toxicity in aquatic systems has traditionally been monitored using whole-organism bioassays, including the standard three species bioassays for freshwater species: *Pimephales promelas* (fathead minnow), *Ceriodaphnia dubia*, and *Selenastrum capricornutum* (green algae). These three species can be used to assess chronic or acute toxicity by comparing the biomass (*P. promelas*), mortality (*P. promelas*, *C. dubia*), reproduction (*C. dubia*), or growth (*S. capricornutum*) of ambient waters or effluent with control water. Toxicity is determined by the presence of a statistically significant difference in any of these parameters in the control and ambient waters.

While such tests are effective in determining the presence of toxicity, there are drawbacks associated with them. These tests are time-consuming, expensive, and subject to technician error. Toxicity screening tests utilizing these bioassays can take 4 to 10 days to complete and require an extensive amount of time each day to maintain. Since these tests require live cultured whole-organisms and a large amount of technician maintenance and possible error, their costs can be rather high, decreasing the amount of testing possible with limited funding. However, these and other standard tests (e.g., *Hyalella azteca* for sediment toxicity) are currently considered to be the gold standards in assessments of toxicity of whole effluent, including storm water discharges.

More recently submitochondrial particle-based bioassays have been developed that offer the potential to monitor toxicity within a short period of time after sample collection with a minimum of technician input and a minimum of expense. Numerous studies have been published comparing the results of submitochondrial particle (SMP) toxicity assays with test results from "toxicity test standards" such as fish (e.g., Blondin et al. 1989, Gustavson et al. 2000, Knobeloch et al. 1990a, 1990b, 1990c) or invertebrates (e.g., Argese et al. 1994, Betterman et al. 1996). Generally, comparisons are made between the outcomes of the various tests using known chemicals with established LC50s and the outcome of a SMP assay. An evaluation of the "sensitivity" of the SMP test is made using the r^2 value of a regression of the LC50 of the SMP test on the LC50 of a standard toxicity bioassay (for example see Blondin et al. 1990 p 557 or Read et al. 1998 p 48). Unfortunately, the r^2 value is the coefficient of determination, which is defined as the amount of variation in the dependent variable that is explained by the variation in the independent variable. R^2 is not related to a measure of sensitivity in the formal sense, which is defined as the probability of obtaining a positive response in a test when the true condition is positive. In many of the earlier tests and comparisons, sensitivity in the formal sense is not a significant issue (although the term sensitivity as a descriptor should not be used) as the goal was to understand the relative variation of different toxicity tests in establishing LC50 values for various chemicals. However, if the desire is to establish the presence or absence of toxicity in surface waters or effluent discharges, using a high r^2 from comparisons of LC50 values of SMP tests with standard toxicity assays for specific chemicals or using the r^2 value from a logistic regression comparing SMP tests to standard toxicity bioassays is not sufficient to establish the sensitivity of the SMP test. Consequently, it is still an open question as to whether SMP tests are a sensitive indicator of toxicity when compared to the outcomes of standard toxicity tests. We report here on the results of a study comparing the outcomes of SMP assays with the outcomes of 5 standard toxicity assays; *P. promelas* biomass, *P. promelas* mortality, *C. dubia* reproduction, *C. dubia* mortality, and *S. capricornutum* growth. Using Receiver Operating Characteristic analysis (see below), we evaluate SMP tests with respect to their sensitivity, specificity, and their utility as indicators of toxicity relative to the "gold standards". The toxicity tests were performed on storm water effluent collected during three storm seasons from 38 California Department of Transportation storm drains located on highways, maintenance yards, Park & Rides, and rest areas. Additional toxicity testing with the Microtox© system was not completed due to the manufacturer's inability to provide high quality reagents.

SMP tests

Mitochondria supply energy to the cell through several enzymatic reactions (Lehninger 1964). Because mitochondria are an essential part of cellular metabolism, the effect of toxic substances on them represents similar effects on higher organisms. In mitochondria, substrates must pass through two membranes to effect energy production. The outer membrane is permeable while the inner membrane is not; it maintains an ion gradient, requiring a carrier to transport substrates across. In the mitochondrial-based assays, sub-mitochondrial particles (SMP) are used as the testing organism. SMP are fragmented particles of mitochondria manipulated so that the inner membrane faces outward, allowing toxicants easy access to the enzymatic reactions (Read et al. 1998). Blondin et al. (1987, 1989) described ways to test for aquatic toxicity using SMP and spectrophotometry via electron transport (ETr) and reverse electron transport (RET). Other studies (Knobeloch et al. 1990, Read et al. 1998, and Gustavson et al. 2000) have also been done on the comparison of the SMP assays to other proven methods of aquatic toxicity testing with generally supportive results.

In both assays, toxicity is measured via spectrophotometric readings of NADH absorption at 340nm. In the ETr assay, NADH is oxidized to NAD^+, giving off electrons to pass through the transport chain (Knobeloch, 1990). With no toxicity present, NADH would steadily decrease as the electrons moved through the chain. With a toxic substance present, this decrease of NADH would be diminished as the toxicant inhibits the forward action of the electron transport chain. Toxic substances would produce an increase in the absorption reading compared to the control. In the RET assay, NAD^+ is reduced to NADH (Knobeloch, 1990) as the electrons go through the chain in reverse. In the presence of a non-toxic substance the concentration of NADH would increase as the reaction proceeded, showing an increase in the absorption reading. A toxicant would inhibit the reduction of NAD^+, resulting in a lower concentration of NADH and a lower absorption reading compared to the control.

The SMP are extracted from bovine heart, prepared, frozen for long-term storage, and then thawed and reconstituted as needed, eliminating the necessity for live, cultured organisms. This significantly reduces the cost of running each test. Each test also can be completed within 30 minutes, producing much quicker results and significantly reducing the cost. Since each test takes less than thirty minutes and can be performed with relative ease, the potential for technician error is also significantly reduced.

Study Design

This project was undertaken to assess the causes of toxicity found in storm water discharges from transportation related sites. If patterns of toxicity were found over time and in relation to location, then specific treatments related to the origins of the toxicity could be undertaken.

This study was three years in duration, with each year beginning in the fall—after the dry summer season—and ending in the spring of the following year. Thirty-eight sites were sampled across California. The sites were sampled three times during each year for toxicity assessment—once during the first rainfall event of the year, and then two more times during randomly selected storm events. During the first year of the study, the majority of the sites were only sampled during the last event. Starting with the second event in the second year, all samples were run twice to account for any contamination within microplates. The exception to this involved 10 samples received on Jan. 26, 2002. Due to an unexpected high amount of rainfall over a majority of the state, a significantly large number of samples were received. Because of the unforeseen nature of this event, there were not enough reagents on stock to run all the samples twice. For the third year, the number of sites collected was reduced to 17, concentrating on sites that displayed high amounts of toxicity in the previous years; only the first flush and a second storm event were sampled. All samples collected during the third year were run only once due to a limited amount of available SMP.

Site Descriptions

This study was part of a larger assessment of the toxicity associated with runoff from Caltrans facilities and the primary sampling was associated with toxicity testing of storm water using standard toxicity test procedures. The submitochondrial particle study was performed on a subset of the samples collected. Of the 38 sites sampled across California for toxicity testing, 23 of the sites were highways, 8 were parking lots, 4 were California Department of Transportation maintenance facilities, and 3 were rest areas. Highways consisted of either highways or freeways; parking lots were defined as any public parking area such as Park & Ride facilities. High concentrations of sampling sites were located in certain areas of the state due to the large populations in those areas, e.g., Southern California.

During the first year of the study (2000-2001), one site was sampled during the first rain event, three sites were sampled during a second storm event, 13 sites were sampled during a third storm event, and two sites were sampled during a fourth storm event. During the second year (2001-2002), all 38 sites were sampled during the first event, 35 sites were sampled during a second storm event, 24 sites were sampled during a third storm event, and two sites were sampled during a fourth storm event. For the third year of the study (2002-2003), 15 sites were sampled during the first event and 16 sites were sampled during a second storm event.

ROC Analysis

Receiver Operating Characteristic, or ROC analysis, is relatively common in the medical field and is becoming more common in other fields such as ecology and toxicology. A recent article by Shine et al. (2003) provides a good introduction to the technique and our discussion will be brief.

Any outcome of any indicator when compared to the "true" condition results in 4 possible outcomes, true positive (TP), true negative (TN), false positive (FP), and false negative

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(FN). In our case, we wish to determine how well the SMP test performs relative to a standard toxicity test, for example the *P. promelas* biomass (Ppb) assay. A TP results when the SMP test indicates the sample is toxic when the Ppb test also indicates the sample is toxic, a FP results when the SMP test indicates that the sample is toxic when the Ppb test indicates that it is not, a TN results when both tests indicate that the sample is not toxic, and a FN results when the Ppb test indicates that the sample is negative and the SMP test indicates that the sample is positive. Given these four outcomes, sensitivity is defined as TP/(TP + FN), and specificity is defined as TN/(TN + FP). It is clear from these expressions that reducing the number of FNs and FPs, can increase specificity and sensitivity respectively. It is also clear that sensitivity and specificity can't be maximized simultaneously. For example, increasing the sensitivity of the test can be accomplished simply by selecting an outcome that always gives a positive toxicity response regardless of the true state of the sample. With no negative response possible, there can be no FN response and whenever the Ppb test provides a positive outcome, so does the SMP test. However, whenever the Ppb test provides a negative response, the SMP provides a FP and the specificity is increased. A similar argument can be made for maximizing specificity at the expense of sensitivity. These tradeoffs are further complicated by the fact that determining a positive or negative response in the SMP test depends on an arbitrary cutoff point. In the case of the SMP dilution series, toxicity is established by a level of inhibition in the ambient water sample relative to the control. The level of inhibition that is used to determine if the sample is toxic is the cutoff point, and it is the cutoff point that determines the number of TP, FP, TN, and FN outcomes. For example, using a cutoff point of 1% inhibition as the designation of a toxic sample would be very conservative and identify most samples as toxic resulting in a high sensitivity, but for the reasons explained above, a low specificity.

ROC curves are developed by first calculating the specificity and sensitivity of the test for every cutoff point that is possible to use. The curve is constructed by plotting the sensitivity and (1 – specificity) for all cutoff values. The area under the curve determines the utility of the test as an indicator of the true condition. The SMP test is considered to be an effective indicator of toxicity if the plot of sensitivity and (1 – specificity) results in a large area under the curve (AUC), and the SMP test would be considered ineffective if the AUC is near 0.5. The AUC can be used to compare the utility of two tests, the test with the larger AUC being generally considered the better test, all other considerations (such as cost) being equal.

Methods

After transport to the ATL, water samples were stored at –4°C until testing. In some instances, 250ml samples of the runoff water were not taken prior to delivery to the laboratory; in this case, 250ml aliquots were taken from the samples supplied for the standard 3-species bioassays. The aliquots were stored in opaque plastic containers, labeled with site number and sample date, and then also placed in a –4°C chamber.

Prior to testing, 5ml, filtered aliquots of each sample were taken using Monoject® 6cc syringes and Millex® 0.45μm filters and placed into 30ml glass beakers. Next a dilution series for each sample was prepared in a 12-dilution series well. Control water (glass distilled) was placed in the first and last wells; one hundred percent sample was placed in the second well. The concentration gradient in the remaining cells was 50%, 25%, 12.5%, 6.25%, 3.125%, 1.563%, 0.781%, 0.391%, and 0.195%.

Three replicates for each assay were run on 96-well microplates with only one sample run on each plate. Both the ETr assay and the RET assay were performed on the same plate. Each sample dilution series and all reagents were added to the plates using a Finnpipette® BioControl Multichannel pipette with a 300μl 12-channel module. All samples were run according to protocols supplied by Harvard Bioscience (Electron Transport and Reverse Electron Transport Protocols, 2001, updated 2002) in a Revelation MRX Microplate Reader from Dynex Technologies.

Statistical Determination of Toxicity

Standard 3-species toxicity tests were performed on all samples and toxicity was established using a statistically significant difference between the control and the ambient water sample. Statistical significance of the sample (= indicating toxicity in sample) was determined using the standard EPA statistical protocols for toxicity testing. Every sample was identified as either nontoxic or toxic for a specific toxicity bioassay. The combination of endpoints resulted in the potential for the sample to be toxic in any of five ways, *P. promelas* survival, *P. promelas* biomass, *C. dubia* biomass, *C. dubia* survival, and *S. capricornutum* growth. Some samples were toxic for only one of the five endpoints, while others were toxic for a combination of the endpoints.

For the SMP tests, the average of the three replicates was calculated for each sample. For the control, the average was derived from six replicates. The results are reported as change in absorbance over time (slope). From these data, a percent inhibition was calculated for each dilution in every sample, using the equation:

% Inhibition = (1-(sample slope/control slope))*100.

To compare the bioassay results with the SMP results, ROC analysis was used. The results of the SMP tests had to be compared against a "gold standard", i.e., the definitive test(s) that established whether the sample was toxic. To establish the gold standard, we used the results of each bioassay individually as the definitive standard, and we used combinations of bioassays including all bioassays considered jointly. For example, we used the results of the *P. promelas* survival bioassay as the single measure of toxicity to compare against the results of the Mitoscan test. We then used the combination of the fathead minnow survival and fathead minnow biomass bioassays such that if either test indicated toxicity, the sample was considered toxic.

To establish a sample as toxic in the SMP test, a cutoff value for the level of inhibition was established. This inhibition cutoff for toxicity was an arbitrarily chosen value because statistical tests for toxicity could not be performed due to the type of testing that was performed. For the purposes of this study, it was decided to report the result with two different toxicity cutoff values—10% inhibition and 25% inhibition.

Results

During the first year of testing, Mitoscan tests were performed on 19 samples. At least one assay for each sample was significantly different from the control at all but one site.

Of the two types of SMP tests, the ETr test resulted in the greater amount of positive test results with both a 10% inhibition toxicity cutoff and a 25% inhibition toxicity cutoff. Using a 10% inhibition cutoff, 19 samples showed ETr toxicity, 17 samples showed RET toxicity, and 17 samples showed toxicity in both assays. With a 25% inhibition cutoff, 17 samples resulted in ETr toxicity, 8 samples resulted in RET toxicity, and 7 samples resulted in toxicity in both assays. For these samples, seventeen demonstrated toxicity with the *P. promelas* bioassays, 14 showed toxicity with the *C. dubia* tests, and 1 had toxicity in the *S. capricornutum* test.

During the second year, tests were performed on 102 samples. At least one assay for each sample was significantly different from the control at all but one site during the year. Of the two types of assays, the ETr test resulted in the greater amount of positive test results with both a 10% inhibition toxicity cutoff and a 25% inhibition toxicity cutoff. Using a 10% inhibition cutoff, 99 samples showed ETr toxicity, 85 samples showed RET toxicity, and 85 samples showed toxicity in both assays. With a 25% inhibition cutoff, 82 samples resulted in ETr toxicity, 56 samples resulted in RET toxicity, and 52 samples resulted in toxicity in both assays. For these samples, 83 showed toxicity with the *P. promelas* bioassays, 73 demonstrated toxicity with the *C. dubia* tests, and 49 showed toxicity with the *S. capricornutum* test.

In the last year of sampling, testing was performed on 32 samples total. All of the samples tested showed toxicity in at least one of the two assays. Of the two types of assays, the ETr test resulted in the greater amount of positive test results with both a 10%

inhibition toxicity cutoff and a 25% inhibition toxicity cutoff. With a 10% inhibition cutoff, 32 samples showed ETr toxicity, 29 samples showed RET toxicity, and 29 samples showed toxicity in both assays. With a 25%inhibition cutoff, 28 samples resulted in ETr toxicity, 25 samples resulted in RET toxicity, and 24 samples resulted in toxicity in both assays. For these samples, the *P. promelas* bioassays showed toxicity in 30 of the samples, the *C. dubia* tests showed toxicity in 16 out of the 21 samples tested, and the *S. capricornutum* tests demonstrated toxicity in 20 out of 24 samples tested.

Quality control was also performed during this study. Eleven blanks were run during the entire three years. For the bioassays, none of the *P. promelas* tests were toxic to the blanks, one *C. dubia* test demonstrated toxicity, and one *S. capricornutum* test demonstrated toxicity. For the SMP, three of the ETr tests were toxic with a 10% inhibition cutoff and one was toxic with a 25% inhibition cutoff. None of the RET blank tests were toxic. Duplicate samples were also run to determine repeatability. For the bioassays, seven duplicates were run total in the whole project. There were no differences between the duplicate and the original sample in any of the bioassays. For the Mitoscan, 86 duplicates were run throughout the project. The ETr had four duplicate sample outcomes that differed from the original sample outcome (i.e., non-toxic v. toxic) with a 10% inhibition cutoff and 23 differences with a 25% inhibition cutoff. The RET had 12 duplicate sample outcomes that differed from the original sample outcomes with a 10% inhibition cutoff and 11 differences with a 25% inhibition cutoff.

ROC Analysis

To provide a benchmark, the results of the SMP tests were compared to the results of each definitive toxicity response (one of the 3-species tests). Additionally, the results of the remaining standard toxicity tests were compared to the results of the definitive test. Generally, the 3-species tests are sensitive to different toxicants, and there is no expectation that if one of the 3-species tests results in a positive response, the other tests will be positive. However, the tests do provide a basis for comparison that can be readily understood.

Using the *P. promelas* biomass as the definitive toxicity response (or gold standard), both the ETr inhibition and the RET inhibition had larger AUCs (area under the curve)—0.749 and 0.762, respectively—than all the bioassays except the *P. promelas* mortality, which had an AUC of 0.866. Similarly, with the *P. promelas* mortality as the definitive toxicity response, the ETr and RET inhibitions had greater or equivalent AUCs—0.788 and 0.823, respectively—than all the other standard bioassays except the *P. promelas* biomass, which had an AUC of 0.930. Using the *C. dubia* reproduction as the gold standard, the AUCs of the ETr and RET, 0.749 and 0.764, were equivalent or larger than all of the bioassay AUCs. With the *C. dubia* mortality as the definitive response, the ETr AUC (0.699) was greater than that of both the *P. promelas* biomass (0.596) and the *S. capricornutum* growth (0.657) and was only slightly lower than the *P. promelas* mortality AUC (0.725); the AUC for the RET inhibition (0.757) was larger than all the AUCs for the bioassays except the *C. dubia* reproduction, which had a value of 0.960. With the *S. capicornutm* as the definitive toxicity response, the AUCs of both the ETr and the RET inhibitions—0.770 and 0.782, respectively—were greater than the AUCs for all of the bioassays except that for the *P. promelas* mortality, which had a nearly equivalent AUC of 0.786.

If the gold standard was defined as at least one of the bioassays resulting in toxicity, then the AUCs for the ETr and RET were 0.866 and 0.850, respectively. When the definitive toxicity response was two or more of the bioassays resulting in toxicity, the AUCs for the ETr and RET were 0.785 and 0.807. If three or more toxic responses in the bioassays was used as the definitive toxicity response, the AUCs for the ETr and RET were 0.781 and 0.816. When the combination of four or more of the bioassays resulting in toxicity was the gold standard, the AUCs for the ETr and RET were 0.657 and 0.564.

The SMP results also were compared to different combinations of the three bioassays considered to be general screens of toxicity—*S. capricornutum* growth, *P. promelas* mortality, and *C. dubia* mortality. When looking at all three bioassays, if the definitive toxicity response was at least one of the bioassays having a toxic response, the ETr AUC was 0.817 and the RET AUC was 0.805. If two or more toxic responses were used as the definitive response, the AUCs for the ETr and RET were 0.827 and 0.872, respectively. When the definitive response was defined as all three bioassays resulting in toxicity, the AUCs for the ETr and RET decreased to 0.733 and 0.796. When comparing only the *P. promelas* and *C. dubia* mortality, if a toxic response in at least one of the bioassays was used as the definitive response, the AUCs for the ETr and RET were the same, 0.831. If the definitive response was that both of the bioassays had to be toxic, the AUCs decreased to 0.700 for the ETr and 0.791 for the RET. When comparing the

S. capricornutum growth and the *P. promelas* mortality, if the definitive response was toxicity in at least one of the two bioassays, the AUCs for the ETr and RET were 0.763 and 0.799. If toxicity in both of the bioassays was used as the definitive response, the AUCs increased to 0.830 and 0.847, respectively. When analyzing the *S. capricornutum* growth and the *C. dubia* mortality, if the gold standard was a toxic response in at least one of the two bioassays, the ETr and RET AUCs were very similar, 0.785 and 0.788, respectively. If the gold standard was increase to toxicity in both bioassays the AUCs changed to 0.740 and 0.800, respectively.

The SMP results were compared to different combinations of another set of three bioassays, *S. capricornutum* growth, *P. promelas* biomass, and *C. dubia* reproduction—which are considered to be the more sensitive bioassays. When analyzing all three of the sensitive bioassays, if the gold standard was a toxic response in at lease one, the AUCs of the ETr and RET were similar, 0.703 and 0.695, respectively. When the gold standard was increased to two or more toxic responses, the AUCs decrease to 0.655 and 0.620, respectively. If a toxic response in all of the three bioassays was the gold standard, the AUCs decreased further to 0.612 and 0.499. When evaluating only the *P. promelas* biomass and the *C. dubia* reproduction, if toxicity in at least one of the two bioassays was used as the definitive toxicity response, the AUCs for the ETr and RET were again similar—0.763 and 0.768, respectively. If the definitive response was toxicity in both bioassays, the AUCs decreased to similar values of 0.514 for the ETr and 0.528 for the RET. When comparing the SMP to only the *S. capricornutum* growth and the *P. promelas* biomass, if the definitive response is toxicity in at least one of the two tests, the

AUCs for the ETr and RET were similar again—0.697 and 0.699, respectively. When the definitive response was changed to toxicity in both bioassays, the AUCs decrease to 0.645 and 0.583. When looking at the *S. capricornutum* growth and *C. dubia* reproduction, if at least one toxic response from the two bioassays was used as the gold standard, the AUC for the ETr was 0.717 and the AUC for the RET was 0.736. When the gold standard was changed to toxicity in both bioassays, the AUC for the ETr increased to 0.773, while the AUC for the RET was 0.719, relatively the same as for a single positive test.

Discussion

The goal of this analysis was to determine if the SMP test could be used as a screening tool in toxicity testing of storm water by comparing it to currently accepted, but more costly and time consuming tests. The ROC analysis was used to evaluate the SMP test relative to the results of single or combinations of standard toxicity bioassays. In general, an AUC value of 0.9 or larger suggests that the proposed test is a good indicator of the gold standard and could be used with little or no concern that the test results would include substantial numbers of false positives or false negatives. In other words, there is in a sense an optimal tradeoff between sensitivity and specificity of the test. AUC values between 0.8 and 0.9 indicate that the test is a reasonably reliable indicator of toxicity, and values below 0.8 reflect a relatively poor indicator.

The results presented above are dependent on the choice of the inhibition cutoff value. For this analysis, we selected two cutoff values as an indication of toxicity in the test; 10% and 25%. The 10% cutoff value is the more conservative indicator of toxicity, i.e., toxicity was established at a low level of inhibition. However, based on the relative number of toxic samples at each cutoff, the 25% inhibition cutoff value was almost as conservative as the 10% value. For the ETr test, at the 10% inhibition rate 150 samples were considered toxic and 127 of those were also toxic at the 25% inhibition rate (85%). The RET test was less conservative (fewer samples considered toxic) than the ETr test at both cutoff values, and there was a greater difference in the results at the two inhibition rates. For the RET test, 131 samples were toxic at the 10% cutoff value and 89 were considered toxic at the 25% cutoff value (68%). These results suggest that the ETr test at the 10% cutoff value would provide the best indication of the results of a toxicity test.

The results also indicate that using the SMP test would not be a good indication of the results of any specific toxicity test (e.g., ETr as a predictor of *C. dubia* mortality). Interestingly, if all of the standard bioassays are used as indicators of each other, the SMP tests generally perform better. If using the ETr or RET tests as an indicator of toxicity in any of the standard bioassays, the AUCs suggest that the SMP tests perform well with AUC values at 0.866 and 0.850. In other words, if the desire is only to screen for toxicity as indicated by any of the standard bioassays, the SMP tests perform well enough to be used as a screening tool. Using only the three bioassays considered to be general indicators of toxicity (*S. capricornutum* growth, *P. promelas* mortality, and *C. dubia* mortality), both SMP tests performed well and would be reliable screening tools.

Conclusions

The SMP tests can be used as a reliable screening tool for storm water toxicity in the general sense, i.e., they reliably indicate that toxicity will be present in at least one of the standard toxicity bioassays. They are reasonably reliable as indicators of toxicity in at least two of the tests, but become less reliable as an indicator of toxicity in more than two standard tests. They are generally unreliable as indicators of toxicity in any specific test. These results are remarkable since the SMP submitochondrial tests are really designed to test for toxicity in a relatively narrow range of mechanisms of toxicity. However, they may provide a relatively inexpensive alternative to toxicity testing. Tests can be performed by a laboratory technician with relatively little training, and the tests can be completed in a short period of time. The test results can be obtained within the holding time for standard laboratory toxicity tests (assuming delivery within 24 hours) and any positive samples can undergo full toxicity testing. The only potential drawback to using the SMP tests is being able to obtain sufficient quantities of substrate to perform the tests.

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Chapter II. Toxicity of Storm Water Discharge from Caltrans Facilities

Introduction

The objectives of the project are to 1) to assess the toxicity associated with its storm drain system discharges, and 2) provide some understanding of the basis of the toxicity. This chapter is an overview of data collected to assess the toxicity of storm water discharge associated with transportation sites in 2000-1, 2001-2, and 2002-3. In this chapter, we focus on methodology and analytical results and discuss suspected toxicants in relation to facility type as well as inter-annual variation in causes of toxicity.

Methods

Sampling Sites

Monitoring sites (Tables 1, 2) were selected from a larger set of sites being sampled as part of the Caltrans Statewide Characterization and Monitoring Project. Sites for the toxicity study were selected to represent a range of transportation facility types, urban and rural areas, different climate types and ecological and hydrogeological areas. For years 2000-1 and 2001-2, 40 sites were selected including 3 rest areas, 4 maintenance yards, 25 highway storm drains, and 8 park-and-rides. In 2002-3, only 17 sites that previously demonstrated repeated toxicity were tested: 3 maintenance yards, 10 highway storm drains and 4 park-and-rides. Because of variability in rainfall, not all sites were sampled during each storm event, and sites in the southern part of the state did not experience sufficient rainfall to be sampled across the entire rainy season.

Table 1. Site number, site description, and sample frequency. An X indicates that a sample was collected during that storm event. Storm events are sequentially numbered based on the number of collections for this project. Storm event #1 was the first event of each year, however, several additional storm events may have occurred between storms #1 and #2 and #3. Some sites were sampled as many as 5 times. If so, events 4 and 5 are included in the year 3 sample box.

				Year/Event							
				2000-01			2001-02			2002-03	
				1	2	3	1	2	3	1	2
Site Number	Surface Type	Land Use*	Site Type								
10-02	Asphalt	R	Highway	X		X	X		X	X	X
10-03	Asphalt	M	Highway		X	X**	X	X	X	X	X
10-04	Pavement	R	Highway						X		
10-05	Pavement	C	Park and Ride		X	X*	X	X	X		
11-100	Asphalt/Concrete	M	Highway		X		X	X	X	X	X
11-101	Asphalt/Concrete	M	Highway		X	X	X	X		X	X
11-97	Asphalt/Concrete	M	Highway	X		X	X	X		X	X
11-98	Asphalt/Concrete	C	Highway	X	X		X	X	X*	X	X
12-10	Asphalt	T	Maintenance		X	X	X	X	X	X	X
12-11	Right-of-Way	T	Park and Ride		X	X	X	X	X	X	X
1-34	Pavement	R	Highway	X	X	X	X	X	X		
1-36	Pavement	R	Highway	X	X	X	X	X	X		
1-37	Pavement	R	Maintenance		X	X*	X	X	X		
1-38	Pavement	T	Highway	X							
2-01	Pavement	T	Highway	X			X	X	X		
2-02	Right-of-Way	O	Highway		X		X	X	X		
2-03	Pavement	O	Rest Area		X		X	X			
3-04	Asphalt	O	Park and Ride	X	X	X	X	X	X	X	X
3-05	Right-of-Way	T	Highway	X	X	X	X				
3-06	Right-of-Way	T	Highway	X	X	X	X	X	X		
3-08	Asphalt	T	Maintenance	X	X	X	X	X	X	X	X
3-224	Right-of-Way	T	Highway					X	X		
4-34	Right-of-Way	T	Park and Ride	X	X	X	X	X	X	X	

4-36	Asphalt	T	Park and Ride	X	X	X	X	X	X	X	X
4-37	Asphalt	T	Maintenance	X	X	X	X	X	X	X	X
4-38	Asphalt/Concrete	M	Highway		X	X	X	X	X	X	X
4-39	Pavement	M	Highway	X	X	X	X	X	X*		
5-04	Right-of-Way	R	Highway		X	X*	X	X	X		
5-06	Asphalt	R	Highway		X	X*	X		X	X	X
5-07	Pavement	R	Rest Area		X		X		X		
6-05	Pavement	A	Highway		X	X	X		X		
6-06	Asphalt	A	Highway		X	X*	X	X	X	X	X
6-07	Pavement	A	Rest Area		X	X*	X		X		
7-186	Right-of-Way	T	Park and Ride		X	X	X	X	X		
7-187	Right-of-Way	T	Park and Ride		X	X	X	X	X		
8-07	Pavement	R	Highway			X*					
8-08	Asphalt	R	Highway			X*	X		X	X	X
8-09	Pavement	R	Park and Ride		X	X*	X	X			
8-10	Pavement	M	Highway		X	X	X	X	X		
9-01	Pavement	R	Highway			X*	X				

*R= Residential,

C= Commercial .

I= Industrial

A= Agricultural

F= Forest

O= Open

T= Transportation

M= Mixed

Sample Collection and Storage

Samples were collected directly from storm drains. No attempt was made to sample from locations where the drain system discharged to vegetated ditches. Additionally, no storm water was collected as it drained from the edge of the pavement through Caltrans' right-of ways. Samples were collected opportunistically during storm events. Although some attempt was made to collect from the rising limb of the hydrograph, the water was collected whenever personnel reached the site for duties associated with the Caltrans Statewide Characterization and Monitoring project. Samples were collected as sub-surface grabs in pre-cleaned, one-gallon, amber glass bottles. Each bottle was rinsed three times with site water prior to final filling. In 2000-1 and 2001-2, three rain events were sampled representing the first rainfall event, mid-season and end-of-season storm events. In 2002-3 only two events were sampled due to reduced funding. First events were defined as the first rainfall event of the water year. However, not all sites were sampled during the first rainfall event of the year. Consequently, the first storm sampled during a year may have been a mid-winter storm, in which case it was classified as a second event for the year. Similarly, the late winter storm events were classified as third or fourth events even though they may have been only the second or third sample from that site. Sites with only two sample collections could have had those samples classified as second and third events if no water was collected during the first rainfall of the year. Field measurements of water quality (pH, electrical conductivity (EC), and temperature) were recorded for each site.

To assess laboratory variability, duplicate samples and blank samples were collected from randomly selected sites and dates. Samples were collected and put on wet ice during transport to Regional Board facilities, and then transferred to coolers filled with wet ice for transport to the UCD ATL. Once received by the UCD ATL, samples were kept in dark chambers kept at 4°C ± 2°C. All samples were employed in toxicity tests within 36 hours of sample collection. Field measurements were compared to laboratory measurements to ensure consistency of water quality parameters after sample storage.

Toxicity Testing

All toxicity testing procedures followed those outlined in Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms (US EPA, 1993) with some exceptions. All samples were tested using *C. dubia* (a cladoceran, zooplankton species), larval *P. promelas* (a cyprinid minnow), and *S. capricornutum* (a freshwater algae). Prior to exposing test organisms, assay water was shaken in the original container to homogenize the sample. All waters for *C. dubia* and *P. promelas* assays were poured through a 60 μm screen, warmed to 25°C and aerated at a rate of 100 bubbles/minute. Before *S. capricornutum* cells were introduced to the sample, water was filtered through a type A/E glass fiber filter (nominal pore size 1.0 μm) and allowed to warm to 25°C.

While US EPA methods do not specifically recommend aeration of the renewal water, the UCD ATL protocols included aeration. This deviation was employed because the ambient samples tested at the UCD ATL frequently require aeration to prevent oxygen super-saturation. Aeration time was limited to when the sample reached 102% saturation to minimize the loss of potential toxicity due to volatile toxicants. Each day, renewal water samples were placed in a 25°C water bath and slowly aerated to bring the samples from 4°C up to 25 ± 1°C. The DO was measured prior to test initiation and daily renewal to ensure that the test solutions were near saturation.

Initial Screenings
Ceriodaphnia
The *C. dubia* assay consisted of ten replicate glass vials. The US EPA recommends using plastic cups for the *C. dubia* toxicity test, but plastic adsorbs organic compounds so plastic cups are not appropriate for determining the role of organic compounds in *C. dubia* toxicity. Each vial contained 15 ml of sample and one *C. dubia*. Less than 24-hour-old *C. dubia,* all born within a 16-hour period, were employed at test initiation. *C. dubia* were obtained from in-house cultures. *S. capricornutum* and YCT (a mixture of yeast, CEROPHYLL®, and trout chow) were used in daily renewal waters as nourishment for *C. dubia*. *C. dubia* were transferred into a vial containing 15 ml of fresh sample water each day. The test was incubated in a temperature-controlled room kept at 25 ± 1°C with a 16:8 hour light:dark photoperiod for six to eight days. Mortality and reproduction were measured daily and upon test termination.

C. dubia Toxicity Identification Evaluations (TIEs) consisted of acute style tests in which four replicate vials contained 18 ml of sample and five *C. dubia* each. *C. dubia* were fed a mixture of *S. capricornutum* and YCT four hours prior to test renewal. No food was added to the daily renewal sample waters to minimize chemical sorption to food particles. *C. dubia* were transferred into a vial of fresh test solution daily. Mortality was measured daily and at test termination.

Selenastrum

The *S. capricornutum* assay consisted of four replicate flasks, each containing 100 ml of sample. Samples were filtered using a type A/E glass fiber filter to remove any algae that may have already been present in the test sample. Each treatment was inoculated with the standard US EPA amounts of algal nutrients (without EDTA) and 10,000 cells/ml of *S. capricornutum*. The *S. capricornutum* were obtained from the University of Texas Starr collection (#1648) and placed in US EPA algae nutrient media (with EDTA) for four to seven days prior to test initiation to ensure the cells were in exponential growth. The flasks were then randomly placed on shaker tables and constantly shaken at 100 rpm. The samples were incubated at 25 ± 1°C under a continuous light source at an intensity of 400 ± 40 ft-candles for 96 hours. The flasks were randomized twice daily. Upon test termination, cell number was measured using a Coulter Counter® model ZM.

Pimephales

The *P. promelas* assay consisted of four replicate 500-ml beakers, each containing 250ml of sample and 10 individuals. Less than 48-hour-old *P. promelas* were employed upon test initiation. The *P. promelas* were obtained from Aquatox, Hot Springs, Arkansas. *P. promelas* were fed three times daily with the brine shrimp *Artemia* nauplii. Approximately 80 % of the test solution was renewed daily. Dead fish, *Artemia*, and debris were removed from the test beakers daily. The test solution was incubated in a water bath at 25 ± 1°C under ambient laboratory light with a 16:8 hour light:dark photoperiod for seven days. Mortality was measured daily upon test solution renewal. At test termination the surviving minnows were dosed with MS-222, dried to constant weight at 103-105 °C (approximately 16 hours), and weighed with a Mettler H54 AR balance. Mortality and growth endpoints were measured upon test termination.

Quality Assurance

Each toxicity test survey included a laboratory control. The laboratory control waters varied for each species. For the *C. dubia* assay, the laboratory control was commercial bottled water amended to a hardness of 80 to 100 mg/L as $CaCO_3$. Glass distilled water was used in the *S. capricornutum* assay and de-ionized water amended to a hardness of 80 to 100 mg/L as $CaCO_3$ was used in the *P. promelas* assay. Each screening included a secondary control consisting of control water amended with filtered salt water. This was added to determine the effects, if any, of high electrical conductivity (EC) in a controlled environment. The EC of this secondary control was similar to the sample with the highest EC during each event.

Positive control reference-toxicant tests for each species using NaCl and/or $ZnCl_2$ were conducted monthly during the study period. These tests included the laboratory control and a dilution series of NaCl and/or $ZnCl_2$ in laboratory control water. The purpose of these tests was to assess changes in organism sensitivity to a known toxicant. The LC/EC_{50} for each test was plotted to determine if it fell within an acceptable range relative to previous results. If a test did not fall within acceptable ranges, the toxicity tests were repeated.

Test Acceptability Criteria

Test acceptability for all *C. dubia* and larval *P. promelas* 7-day tests requires 80% or greater survival in the controls. In addition, 60% of the surviving *C. dubia* adult females in the control must have their third brood in 7 ± 1 days, and the average number of surviving young must be 15 or greater/surviving female. For *S. capricornutum* 96-hour tests, the cell number of the control must equal or exceed 200,000 cell/ml, and the replicates in the control must not vary more than 20%. When the control performance did not meet test acceptability criteria, all data from the test were rejected.

The method the UCD ATL uses to calculate the acceptable range of variation differs from that recommended by the US EPA. The US EPA recommends that acceptable data should fall within two standard deviations of the mean for the total data set. The UCD ATL accepts data that falls within two standard deviations from the running mean. These standard deviations, at any one point on the control chart, represent the standard deviation for that particular data point and all points previous to it. This difference resulted in a more conservative approach for this study.

The UCD ATL uses reference toxicant data to track changes in animal sensitivity over time. These changes may indicate problems with organism health, technician-handling techniques, and/or organism genetic variations. The US EPA (1994) suggests that one outlying value may be expected to occur by chance when 20 or more data points are plotted. The UCD ATL evaluates patterns of outlying values. When more than one outlying value occurs, corrective actions were taken. For example, when two consecutive data points plot above the two standard deviation lines on an LC_{50} control chart, this may indicate that the test organisms are becoming less sensitive to the toxicants. The appropriate corrective measure would be to introduce a new genetic line of organisms to increase sensitivity. Corrective actions are only effective when the two-standard deviation range is calculated monthly, rather than waiting until the end of the survey period (as is the case with the EPA method).

Water Quality

Water quality parameters of temperature, pH, dissolved oxygen (DO), and electrical conductivity (EC) were measured on all test samples upon initiation of the test and on the 24-hour-old sample upon test sample renewal. The 24-hour-old sample is the water that the test organisms had been living in since test initiation. Temperature, pH, dissolved oxygen, and EC meters were calibrated daily according to the manufacturer's instructions. Hardness and alkalinity were measured on all samples utilizing titrimetric methods. Ammonia was measured on all samples using an ammonium test kit. Dissolved oxygen and temperature also were measured daily in both the *C. dubia* and *P. promelas* assays. Upon test termination, pH and temperature were recorded for the *S. capricornutum*.

Dilution Series

When toxicity was detected in the initial screening tests, TIEs were conducted to help determine the cause. When 100% mortality occurred within 24 hours in a sample, a series of dilutions of the sample were tested to determine the toxicant's potency. The results of dilution series tests were used to estimate the number of toxic units present in a sample. This estimation was done using linear interpolation. Dilutions were made with the appropriate control water, and tested at 100, 50, 25, 12.5, and 0 percent dilutions.

Chemical Analysis

Once a sample exhibited toxicity, a 500ml sub-sample was preserved in one-liter polyethylene containers with 1.23ml of 15.8N nitric acid and sent to APPL, Inc. (Fresno, CA) for pesticide and herbicide analysis using Gas Chromatography methods.

Phase I TIEs

TIEs consisted of a set of manipulations that were designed to identify a specific chemical or class of chemicals responsible for any observed toxicity. Due to funding constraints, modified Phase I TIEs were designed to identify the general class of chemical causing the toxicity in the test sample.

Six ml C8 Solid Phase Extraction columns were used to remove non-polar organic chemicals from the ambient water samples. All waters were pumped through the column at a rate of 5 to 10 ml/min. Control blank waters were first pumped through the columns prior to the ambient water samples. Settled ambient samples (1000-1800 ml) were then passed through the column. The first 200 ml of the C8 solid phase extracted water for both the control blank and the ambient water was discarded to minimize potential artifactual column toxicity. HPLC grade or OPTIMA grade methanol (MeOH) was used for column activation and extraction. Eluates (methanol extractions) were obtained by running 3.0 ml of MeOH through the loaded column at a rate of one ml/min. The concentration at which the eluate was added back in the Phase I TIEs ranges from 2-3 times the ambient concentration.

When pesticides were suspected, piperonyl butoxide (PBO) was added to samples at 100 to 200 µg/L to help identify the class of pesticide present in the sample. PBO was used to determine whether the toxicant was a metabolically activated organophosphorous (OP) pesticide. OP pesticides, such as diazinon, chlorpyrifos, or malathion, are metabolically activated by the cytochrome P450 detoxification system by conversion of the parent compound to the more toxic –oxon form. PBO, by blocking the cytochrome P450 system prevents oxon formation and toxicity. PBO has been shown to block the toxicity of up to four toxic units of metabolically activated OP pesticides (Bailey *et al.*, 1996).

EDTA and sodium thiosulfate, in concentrations ranging from 1.25 to 50 mg/L and from 7.5 to 60 mg/L, respectively, were added to ambient water in cases where preliminary screening results suggest that toxicity was due to chemicals other than non-polar organic compounds.

Phase II TIEs

Phase II procedures utilize 6 ml C8 solid phase extraction (SPE) columns to remove non-polar organic chemicals from the ambient water. The chemicals were subsequently eluted with increasing concentrations of methanol. The eight methanol: water fractions were 50:50, 70:30, 75:25, 80:20, 85:15, 90:10, and 100:0. Bioassays were performed on each fraction and on a methanol laboratory control blank to determine whether any fraction retained toxicity. Bailey *et al.* (1996) and Crepeau (1997) determined the fraction in which several of the more common insecticides used in the Central Valley elute. HPLC grade or OPTIMA grade methanol (MeOH) was used for column activation and extraction. Eluates (methanol extractions) were obtained by running 3 ml of MeOH through the loaded column at a rate of one ml/min. The concentration at which the eluate was added back in the Phase II TIEs is 2.5-3 times the sample concentration.

Statistical Analysis

Toxicity was defined as a statistically significant difference ($p<0.05$) between a sample and the laboratory control water. Acute toxicity in the *C. dubia* and *P. promelas* assays was defined as a statistically significant increase in mortality in a test sample when compared to the laboratory control within 96-hours. Chronic toxicity was defined as a significant increase in mortality compared to the laboratory control in greater than 96-hours or a significant decrease in growth or reproduction compared to the laboratory control.

The UCD ATL used twice the number of control replicates in the *C. dubia* and *S. capricornutum* assays to increase the power of the statistical analysis. It is recommended that the optimal size of the control group (when a single control is to be compared to multiple treatments) should be approximately the square root of k-1 (where k = the total number of treatments in the experiment) times the size of each other group.

All *C. dubia* reproduction, *P. promelas* biomass and mortality, and *S. capricornutum* growth data were analyzed with Bartlett's Test for homogeneity of variance. When variances were homogeneous, data were analyzed using an Analysis of Variance and Dunnett's mean separation tests. When variances were heterogeneous, data were transformed to relative ranks and analyzed using an Analysis of Variance and Dunnett's mean separation test. *C. dubia* mortality was analyzed with Fisher's Exact Test. No statistical analysis was performed on TIE results.

These statistical analyses differ from those outlined in US EPA (1993). US EPA (1993) protocols were designed for whole effluent toxicity testing in which all samples are tested in a dilution series, and the statistical analyses recommended by US EPA (1993) were designed to analyze data from a dilution series.

Results and Discussion

Initial Toxicity Screening

Complete sets of toxicity tests consisted of a *S. capricornutum* growth test, *C. dubia* mortality and reproduction, and *P. promelas* biomass and mortality tests. Complete sets of tests were performed on 223 site-event samples during the three years of the project. There were 68 samples classified as first event, 76 that were classified as second event, and 63 that were classified as third event. An additional 13 samples were collected as fourth events and 3 samples were collected as fifth events. Essentially every site produced

Table 2. Summary of toxicity test results for all three years of the study. Results are provided by site. An X in a box indicates that the sample exhibited significant differences from the control, i.e., the sample was toxic for that test. A blank indicates no significant difference from the control.

Site Number	Site Type	Year Sampled	Event Number	Date Sampled	Initial Screening Toxicity- significantly different from control				
					Ceriodaphnia dubia		*Pimephales promelas*		Selenastrum capricornutum
					Reproduction	Mortality	Biomass	Mortality	Growth
10-02	Highway	2000-1	1	10/25/2000			x		
10-02	Highway	2000-1	3	03/04/2001			x		
10-02	Highway	2001-2	1	10/30/2001	x		x	x	
10-02	Highway	2001-2	3	02/17/2002	x	x	x	x	x
10-02	Highway	2002-3	1	11/07/2002	x	x	x	x	x
10-02	Highway	2002-3	2	02/12/2003	x	x	x	x	x
10-03	Highway	2000-1	2	01/10/2001			x		
10-03	Highway	2000-1	3	03/04/2001			x		
10-03	Highway	2000-1	3	04/06/2001	x	x	x		
10-03	Highway	2000-1	3	04/20/2001	x	x	x	x	
10-03	Highway	2001-2	1	10/30/2001	x	x	x	x	x

10-03	Highway	2001-2	2	02/17/2002	x	x	x	x	
10-03	Highway	2001-2	3	03/17/2002	x	x			x
10-03	Highway	2002-3	1	11/07/2002	x	x	x	x	x
10-03	Highway	2002-3	2	02/12/2003	x	x	x	x	x
10-04	Highway	2001-2	3	02/17/2002					x
10-05	Park and Ride	2000-1	2	01/10/2001	x	x	x	x	
10-05	Park and Ride	2000-1	3	03/03/2001			x	x	
10-05	Park and Ride	2000-1	4	04/06/2001	x	x	x	x	
10-05	Park and Ride	2001-2	1	10/30/2001	x	x		x	x
10-05	Park and Ride	2001-2	2	02/17/2002	x		x	x	
10-05	Park and Ride	2001-2	3	03/17/2002	x	x			x
11-100	Highway	2000-1	2	01/08/2001			x	x	x
11-100	Highway	2001-2	1	11/12/2001	x		x	x	x
11-100	Highway	2001-2	2	01/28/2002	x	x		x	x
11-100	Highway	2001-2	3	03/17/2002	x	x	x	x	x
11-100	Highway	2002-3	1	11/08/2002	x	x	x	x	x
11-100	Highway	2002-3	2	02/11/2003	x	x	x	x	x
11-101	Highway	2000-1	2	01/11/2001	x		x	x	
11-101	Highway	2000-1	3	02/25/2001			x		x
11-101	Highway	2001-2	1	11/24/2001	x	x		x	x
11-101	Highway	2001-2	2	01/28/2002	x	x		x	
11-101	Highway	2002-3	1	11/08/2002	x	x	x	x	x

11-101	Highway	2002-3	2	02/11/2003	x	x	x	x	x
11-97	Highway	2000-1	1	10/27/2000	x	x	x		
11-97	Highway	2000-1	3	02/25/2001	x		x		
11-97	Highway	2001-2	1	11/24/2001	x		x		x
11-97	Highway	2001-2	2	01/28/2002	x		x	x	
11-97	Highway	2002-3	1	11/08/2002	x	x	x	x	x
11-97	Highway	2002-3	2	02/11/2003			x	x	x
11-98	Highway	2000-1	1	10/27/2000	x	x	x	x	
11-98	Highway	2000-1	2	01/11/2001					
11-98	Highway	2001-2	1	11/12/2001	x		x	x	x
11-98	Highway	2001-2	2	01/28/2002	x	x	x	x	
11-98	Highway	2001-2	3	03/07/2002	x			x	x
11-98	Highway	2001-2	3	03/17/2002					x
11-98	Highway	2002-3	1	11/08/2002	x	x	x	x	x
11-98	Highway	2002-3	2	02/11/2003			x	x	x
12-10	Maintenance	2000-1	2	01/08/2001			x	x	x
12-10	Maintenance	2000-1	3	02/12/2001			x		
12-10	Maintenance	2001-2	1	11/12/2001	x		x	x	x
12-10	Maintenance	2001-2	2	02/17/2002	x		x	x	
12-10	Maintenance	2001-2	3	03/17/2002	x			x	x
12-10	Maintenance	2002-3	1	11/08/2002	x	x	x	x	x
12-10	Maintenance	2002-3	2	02/11/2003			x	x	

12-11	Park and Ride	2000-1	2	01/08/2001				x	x
12-11	Park and Ride	2000-1	3	03/06/2001			x	x	
12-11	Park and Ride	2001-2	1	11/24/2001	x	x		x	x
12-11	Park and Ride	2001-2	3	02/17/2002			x		
12-11	Park and Ride	2001-2	3	03/17/2002	x	x	x	x	x
12-11	Park and Ride	2002-3	1	11/08/2002	x	x	x	x	x
12-11	Park and Ride	2002-3	2	02/11/2003			x		x
1-34	Highway	2000-1	1	10/28/2000	x	x	x	x	
1-34	Highway	2000-1	2	02/09/2001			x		
1-34	Highway	2000-1	3	04/06/2001			x		
1-34	Highway	2001-2	1	10/29/2001			x	x	
1-34	Highway	2001-2	2	01/21/2002	x		x		
1-34	Highway	2001-2	3	02/19/2002			x		
1-36	Highway	2000-1	1	10/28/2000	x	x	x	x	x
1-36	Highway	2000-1	2	02/09/2001			x		
1-36	Highway	2000-1	3	04/20/2001			x		
1-36	Highway	2001-2	1	10/30/2001	x	x		x	x
1-36	Highway	2001-2	2	01/21/2002			x		
1-36	Highway	2001-2	3	02/19/2002			x		
1-37	Maintenance	2000-1	2	02/09/2001			x		
1-37	Maintenance	2000-1	3	04/06/2001			x		
1-37	Maintenance	2000-1	3	04/20/2001			x	x	

1-37	Maintenance	2001-2	1	10/29/2001	x		x	x	
1-37	Maintenance	2001-2	2	01/21/2002			x	x	
1-37	Maintenance	2001-2	3	02/19/2002					
1-38	Highway	2000-1	1	10/28/2000					
2-01	Highway	2000-1	1	11/29/2000					
2-01	Highway	2001-2	1	10/30/2001			x		
2-01	Highway	2001-2	2	01/26/2002	x				
2-01	Highway	2001-2	3	02/19/2002					
2-02	Highway	2000-1	2	01/08/2001			x	x	x
2-02	Highway	2001-2	1	10/30/2001			x		
2-02	Highway	2001-2	2	02/07/2002	x	x			
2-02	Highway	2001-2	3	03/07/2002					x
2-03	Rest Area	2000-1	2	01/08/2001			x	x	
2-03	Rest Area	2001-2	1	10/29/2001	x			x	x
2-03	Rest Area	2001-2	2	02/07/2002	x	x	x		
3-04	Park and Ride	2000-1	1	10/10/2000			x		
3-04	Park and Ride	2000-1	2	01/23/2001	x	x	x		
3-04	Park and Ride	2000-1	3	04/06/2001			x		
3-04	Park and Ride	2001-2	1	10/30/2001	x		x		
3-04	Park and Ride	2001-2	2	01/26/2002	x		x	x	
3-04	Park and Ride	2001-2	3	03/06/2002			x	x	
3-04	Park and Ride	2002-3	1	11/07/2002	x		x	x	x

3-04	Park and Ride	2002-3	2	03/14/2003			x	x	
3-05	Highway	2000-1	1	10/10/2000	x	x	x	x	x
3-05	Highway	2000-1	2	01/23/2001	x	x	x	x	
3-05	Highway	2000-1	3	04/06/2001	x	x	x	x	
3-05	Highway	2001-2	1	10/30/2001	x		x		x
3-06	Highway	2000-1	1	10/11/2000			x		
3-06	Highway	2000-1	2	01/25/2001					
3-06	Highway	2000-1	3	04/06/2001			x	x	
3-06	Highway	2001-2	1	10/30/2001	x		x	x	
3-06	Highway	2001-2	2	01/26/2002	x				
3-06	Highway	2001-2	3	03/06/2002			x	x	
3-08	Maintenance	2000-1	1	10/10/2000			x	x	x
3-08	Maintenance	2000-1	2	01/23/2001	x	x	x	x	
3-08	Maintenance	2000-1	3	04/06/2001	x		x	x	
3-08	Maintenance	2001-2	1	10/30/2001	x		x	x	x
3-08	Maintenance	2001-2	2	01/26/2002	x	x	x	x	x
3-08	Maintenance	2001-2	3	03/06/2002	x	x	x	x	x
3-08	Maintenance	2002-3	1	11/07/2002	x			x	x
3-08	Maintenance	2002-3	2	03/14/2003			x	x	
3-224	Highway	2001-2	2	01/26/2002	x				
3-224	Highway	2001-2	3	03/06/2002			x		
4-34	Park and Ride	2000-1	1	10/28/2000					

4-34	Park and Ride	2000-1	2	01/10/2001					
4-34	Park and Ride	2000-1	3	04/20/2001			x	x	
4-34	Park and Ride	2001-2	1	10/30/2001					
4-34	Park and Ride	2001-2	2	01/26/2002					
4-34	Park and Ride	2001-2	3	02/19/2002					x
4-34	Park and Ride	2002-3	1	11/07/2002			x	x	
4-36	Park and Ride	2000-1	1	10/28/2000					
4-36	Park and Ride	2000-1	2	01/10/2001					
4-36	Park and Ride	2000-1	3	04/20/2001			x	x	
4-36	Park and Ride	2001-2	1	10/30/2001			x	x	x
4-36	Park and Ride	2001-2	2	01/26/2002	x		x		x
4-36	Park and Ride	2001-2	3	02/16/2002					
4-36	Park and Ride	2002-3	1	11/07/2002	x	x	x	x	x
4-36	Park and Ride	2002-3	2	02/12/2003			x	x	
4-37	Maintenance	2000-1	1	10/28/2000			x	x	
4-37	Maintenance	2000-1	2	01/10/2001			x	x	
4-37	Maintenance	2000-1	3	04/06/2001	x		x	x	
4-37	Maintenance	2001-2	1	10/30/2001	x		x	x	x
4-37	Maintenance	2001-2	2	01/26/2002	x		x	x	
4-37	Maintenance	2001-2	3	02/16/2002	x			x	
4-37	Maintenance	2002-3	1	11/07/2002	x		x	x	x
4-37	Maintenance	2002-3	2	02/12/2003			x	x	

4-38	Highway	2000-1	2	01/10/2001				x	
4-38	Highway	2000-1	3	04/06/2001	x		x	x	
4-38	Highway	2001-2	2	01/26/2001	x	x	x		
4-38	Highway	2001-2	1	11/10/2001			x	x	
4-38	Highway	2001-2	3	02/16/2002	x				
4-38	Highway	2002-3	1	12/10/2002			x		
4-38	Highway	2002-3	2	02/12/2003	x	x	x		
4-39	Highway	2000-1	1	10/28/2000	x	x			
4-39	Highway	2000-1	2	01/10/2001	x	x	x	x	
4-39	Highway	2000-1	3	04/06/2001	x	x	x	x	
4-39	Highway	2001-2	1	10/30/2001	x	x	x	x	
4-39	Highway	2001-2	1	11/12/2001	x	x	x	x	x
4-39	Highway	2001-2	2	01/26/2002	x	x	x	x	x
4-39	Highway	2001-2	3	02/17/2002	x		x	x	
5-04	Highway	2000-1	2	01/10/2001			x		
5-04	Highway	2000-1	3	04/07/2001	x	x	x	x	
5-04	Highway	2000-1	3	04/20/2001	x	x	x	x	
5-04	Highway	2001-2	1	10/30/2001	x	x		x	x
5-04	Highway	2001-2	2	02/17/2002	x			x	x
5-04	Highway	2001-2	3	03/17/2002	x	x		x	x
5-06	Highway	2000-1	2	01/10/2001					x
5-06	Highway	2000-1	3	04/07/2001			x		

5-06	Highway	2001-2	1	10/30/2001	x	x	x	x	x
5-06	Highway	2001-2	2						
5-06	Highway	2001-2	3	02/16/2002			x	x	
5-06	Highway	2002-3	1	11/07/2002					
5-06	Highway	2002-3	2	03/14/2003	x	x	x		
5-07	Rest Area	2000-1	2	01/10/2001			x		
5-07	Rest Area	2001-2	3	02/16/2001	x			x	x
5-07	Rest Area	2001-2	1	10/30/2001	x	x		x	x
6-05	Highway	2000-1	2	01/10/2001			x		
6-05	Highway	2000-1	3	03/03/2001	x	x	x	x	
6-05	Highway	2001-2	1	11/12/2001	x	x		x	
6-05	Highway	2001-2	3	03/06/2002	x	x	x	x	x
6-06	Highway	2000-1	2	02/09/2001	x	x	x	x	
6-06	Highway	2000-1	3	02/24/2001	x	x	x	x	
6-06	Highway	2000-1	4	03/04/2001	x	x	x		
6-06	Highway	2000-1	5	04/07/2001	x	x			
6-06	Highway	2001-2	1	11/12/2001	x	x			
6-06	Highway	2001-2	2	02/17/2002	x	x		x	x
6-06	Highway	2001-2	3	03/17/2002	x	x		x	x
6-06	Highway	2002-3	1	11/07/2002	x	x	x		x
6-06	Highway	2002-3	2	03/14/2003	x	x	x	x	x
6-07	Rest Area	2000-1	2	01/10/2001			x		

6-07	Rest Area	2000-1	3	02/24/2001	x		x	x	
6-07	Rest Area	2000-1	4	03/04/2001			x		
6-07	Rest Area	2001-2	1	11/12/2001			x	x	x
6-07	Rest Area	2001-2	3	03/06/2002	x	x	x	x	x
7-186	Park and Ride	2000-1	2	01/10/2001			x		
7-186	Park and Ride	2000-1	3	03/05/2001			x		
7-186	Park and Ride	2001-2	1	11/12/2001					
7-186	Park and Ride	2001-2	2	02/17/2002	x		x	x	
7-186	Park and Ride	2001-2	3	03/17/2002	x			x	x
7-187	Park and Ride	2000-1	2	01/26/2001					
7-187	Park and Ride	2000-1	3	04/07/2001	x		x		
7-187	Park and Ride	2001-2	1	10/30/2001	x	x		x	x
7-187	Park and Ride	2001-2	2	02/17/2002	x		x	x	
7-187	Park and Ride	2001-2	3	03/17/2002			x	x	x
8-07	Highway	2000-1	3	02/25/2001	x	x	x	x	
8-07	Highway	2000-1	4	03/06/2001	x	x	x	x	
8-08	Highway	2000-1	3	03/07/2001			x		
8-08	Highway	2000-1	4	04/07/2001	x	x			
8-08	Highway	2000-1	5	04/09/2001	x	x	x		
8-08	Highway	2001-2	1	11/12/2001	x		x	x	x
8-08	Highway	2001-2	3	03/06/2002	x	x	x	x	
8-08	Highway	2002-3	1	12/16/2002	x	x			

8-08	Highway	2002-3	2	02/25/2003					
8-09	Park and Ride	2000-1	2	01/10/2001			x	x	
8-09	Park and Ride	2000-1	3	02/10/2001			x		
8-09	Park and Ride	2000-1	3	04/07/2001	x	x	x		
8-09	Park and Ride	2001-2	1	11/24/2001			x	x	
8-09	Park and Ride	2001-2	2	02/17/2002	x		x	x	
8-10	Highway	2000-1	2	01/08/2001		x	x	x	
8-10	Highway	2000-1	3	02/13/2001			x		
8-10	Highway	2001-2	1	11/12/2001	x			x	x
8-10	Highway	2001-2	2	02/17/2002	x	x		x	
8-10	Highway	2001-2	3	03/17/2002	x	x		x	x
9-01	Highway	2000-1	3	03/06/2001			x	x	
9-01	Highway	2000-1	4	05/12/2001	x		x	x	x
9-01	Highway	2001-2	1	11/24/2001	x			x	

toxicity at some time during the course of the first two years of the study (Table 2). Most sites produced storm water that was toxic to more than one test organism (161 events – 72%) during more than one storm. Sites for the third year of the study were selected because they exhibited acute toxicity during the first two years. However, two sites did not exhibit any toxicity during one event in the third year.

The most sensitive tests with respect to demonstrating toxicity were the *P. promelas* biomass assay (161 positive tests – 79%) followed by the *P. promelas* mortality assay (135 positive tests – 61%). The *C. dubia* reproduction test was the next most sensitive (129 positive tests – 58%) followed by the *C. dubia* mortality assay (83 positive tests – 37%) and the *S. capricornutum* assay (79 positive tests – 35%). It was generally true that if toxicity was exhibited in only a single test, it was in the *P. promelas* biomass assay.

Toxicity Identification Evaluation (TIE) - Phase I Evaluation: Non-polar organic compounds, heavy metals and surfactants – singly or in combination - were the major contaminant groups causing toxicity (Table 3a). Of 35 storm water runoff samples subject to TIE in 2000/01, 51% identified non-polar organic chemicals as the primary toxicant category, 14% identified heavy metals, 17% organophosphorous (OP) pesticides and 9% dissolved oxygen or low pH. In 2001/02, the primary toxicant groups were non-polar organics in 62% of samples, heavy metals in 43%, surfactants in 26%, OP pesticides in 12%, and DO/pH in 2% of samples tested. Samples tested in 2002/03 identified non-polar organics in 58%, heavy metals in 28%, and surfactants in 47% of samples.

When interpreting the data, it is important to consider the different sensitivities of the test organisms for certain groups of contaminants. For example, *C. dubia* is highly sensitive to OP pesticides, while *P. promelas* and *S. capricornutum* are relatively tolerant to these chemicals. *S. capricornutum* are more sensitive to heavy metals than both *P. promelas* and *C. dubia*. This is illustrated in Table 3b, where TIE results are listed by test species. Of 53 water samples that underwent TIE testing with fish, 70% identified non-polar organics, 40% surfactants and 25% metals as the primary toxicant groups. Physiological stress caused by low DO or the pH of the water was responsible for toxicity seen in 8% of the samples. Of 40 samples tested with *C. dubia*, 63% identified non-polar organics, 28% OP pesticides, 15% surfactants and 8% metals as the cause of toxicity. Lastly, of 20 samples tested with *S. capricornutum*, 85% indicated that heavy metals were the cause of toxicity. Only 25% of *S. capricornutum* tests identified non-polar organic chemicals as a toxicant.

Toxicity Identification Evaluation (TIE) - Phase II Evaluation:

Available LC50s for metals and organic contaminants are listed in Table 4. These values and available chemical concentrations for individual compounds in water samples were used for calculating toxic units (TU), where 1 TU = concentration/LC50. Due to a lack of available LC50 data for a large proportion of the compounds, this approach is clearly limited and results can indicate trends at best. Heavy metals that were present at >0.5 TU are shown in Table 5. In general, lead, copper and zinc were the metals with the highest TU values. Zinc, in particular, was present at concentrations toxic to *P. promelas* and *S.*

capricornutum in most samples with the highest TU values being 13.1 (*P. promelas*) and 16.4 (*S. capricornutum*) at site 7-187 (sampled on 10-30-2001). The sum of TUs was calculated for each water sample and results indicated that metals contributed significantly to toxicity at most sampling sites.

Organic chemicals: Phase II TIEs performed in 2002/03 of this study resulted in a qualitative identification of the primary organic toxicants present in water samples (Table 6). The vast majority of these compounds, present at concentrations that caused toxicity to either *P. promelas* or both *P. promelas* and *C. dubia,* were pesticides. Anthracene-dione (sites 4-36, 4-37 Contra Costa Co.) is a bird repellant. Thiabendazole (6-06, Hwy, agricultural land) is a systemic benzimidazole fungicide used to control fruit and vegetable diseases such as mold, rot, blight, and stain. Propyzamide (pronamide) is used as an herbicide on lettuce and alfalfa (10-02 Hwy, Tuolumne Co., 11-97 -I15, San Diego Co, 6-06 ag land). Trifluralin (10-03, San Joaquin Co.) is another herbicide. Samples that were toxic to both species often contained organophosphate or pyrethroid insecticides (diazinon, malathion, permethrin) at toxic concentrations. Malathion (sites 10-03, San Joaquin Co., industrial, 11-100 San Diego Co, Hw I8) and diazinon (11-100, 10-03) are organophosphate insecticides applied in agricultural as well as in urban areas. Permethrin (11-98, Hwy I805, San Diego Co) is a pyrethroid insecticide, and Piperonyl butoxide (PBO) (11-98) is a synergist, applied with some pyrethroids to enhance toxicity. In addition, two phthalates were responsible for, or contributed to, *P. promelas* and *C. dubia* toxicity at sites 4-37 (Maintenance Station, Contra Costa Co.), 11-97 (I-15, San Diego Co.), and 12-10 (Maintenance station, Orange Co.). DEHP is a plasticizer and is used in a wide variety of products. Animal studies indicate very low toxicity and DEHP is used to contain blood products for transfusion.

Because Caltrans does not apply the majority of the organic compounds detected in the samples, the question arises as to how these compounds reached transportation right-of-ways. It is unlikely that spills during transport were responsible. The remaining three potential mechanisms are 1) drift from applications immediately adjacent to the sites, 2) dry deposition, or 3) wet deposition. Although drift from adjacent applications cannot be ruled out, given the range of sites at which the organics are found, dry and wet deposition may be significant contributors to the loads. Ongoing studies by USGS in the Mustang Creek watershed in Merced County indicate that wet and dry deposition can account for a significant portion of the organics observed at a large range of sites in an agricultural watershed (C. Kratzer, presentation at UC Davis March 3, 2005). The current study raises the question of whether dry and wet deposition could be occurring in a wide range of sites across urban and rural areas.

The primary causes of toxicity were categorized by surface type to determine if landscapes, agricultural, or residential areas (most probable sites of origin for metabolically activated pesticides) were disproportionately responsible for the TIE results (Table 7).

Table 3 a. TIE results by sampling year: Chemical groups identified as primary toxicants (PT).

Sampling Season	Number of TIE samples	Metals	Non-polar organics	OP Pesticides	Surfactants	Other
2000/2001	35	5 (14%)	18 (51%)	6 (17%)	0	DO/pH: 3 (9%)
2001/2002	42	18 (43%)	26 (62%)	5 (12%)	11 (26%)	DO/pH: 1 (2%)
2002/2003	36	10 (28%)	21 (58%)	0	17 (47%)	0
Total	113	33 (29%)	65 (58%)	11 (10%)	28 (25%)	0

Table 3 b. TIE results and primary toxicant groups by test species

Test Species	Number of TIE samples	Metals	Other Non-polar organics	OP Pesticides	Surfactants	Other/TL
P. promelas	53	13 (25%)	37 (70%)	0	21 (40%)	DO/pH: 4 (8%)
C. dubia	40	3 (8%)	25 (63%)	11 (28%)	6 (15%)	0
S. capricornutum	20	17 (85%)	5 (25%)	0	0	0

Table 4. Available LC50s for heavy metals and organic chemicals by test species.

Chemical Compound	48 h-LC50 (µg/L) *C. dubia*	96 h-LC50 (µg/L) *P. promelas* µg/L	72 h-EC50 (µg/L) *S. capricornutum* µg/L
Ag	10.233	9.500	
As	13350	12600	
Cd	27.300	3215	137
Cr	47650	52000	
Cu	96	66	396.500
Pb	248	2100	
Se		3840	
Zn	14433.330	282	225
Diazinon	0.470	0.178	
Diuron	[A]17.900 mg/L	14.200 mg/L	
Endosulfan		1.320	
Malathion	1.600	8600*	
Naled	[A] 0.200-0.800	3300	
Prowl	[C]280*	138*	588.800
PBO	1000 µg/L		
Simazine		100*	[B]1240
Trifluran	[C]500-600*	20-3400*	[B] 673

[A] *Daphnia pulex* LC50
[B] 96 h- EC50
[C] *Daphnia magna* LC50
* from Extoxnet

3-04	3/14/2003	0.028	0.039	0.055	10.950	0.180	2.520	0.020
3-05	10/30/2001	0.495	1.279	1.701	360.000	5.900	40.000	0.800
3-08	1/23/2001	0.040	0.185	0.240	52.200	0.240	3.130	0.080
3-08	1/26/2002	0.072	0.284	0.371	80.000	0.420	6.200	0.000
3-08	11/7/2002	0.082	0.389	0.504	109.700	0.260	6.670	0.100
3-08	3/14/2003	0.045	0.103	0.137	29.030	0.690	3.190	0.160
4-36	11/7/2002	0.755	1.894	2.519	532.200	13.410	60.990	0.780
4-36	2/12/2003	0.482	0.619	0.872	173.300	8.320	40.370	0.400
4-37	10/30/2001	0.155	0.356	0.475	100.000	2.100	12.000	0.400
4-37	11/7/2002	0.475	1.797	2.341	505.900	4.530	36.890	1.020
4-37	2/12/2003	0.275	0.534	0.726	150.400	2.010	22.770	0.490
4-38	12/10/2002	0.705	0.415	0.640	113.300	26.300	53.970	0.770
4-38	2/12/2003	0.497	0.227	0.397	63.680	1.280	45.380	0.410
5-06	11/7/2002	0.327	0.622	0.844	174.800	5.180	26.720	0.420
5-06	3/14/2003	0.196	0.123	0.191	33.990	5.310	15.730	0.190
5-07	10/30/2001	0.674	7.094	9.005	2000.000	3.000	46.000	1.200
6-05	11/12/2001	0.144	0.178	0.252	50.000	2.100	12.000	0.200
6-06	2/9/2001	0.448	0.417	0.622	117.000	2.390	40.500	0.220
6-06	11/12/2001	0.576	2.479	3.125	690.000	68.000	23.000	0.400
6-06	11/7/2002	0.981	0.664	0.892	172.800	107.500	49.280	0.590
7-187	10/30/2001	2.253	13.123	16.873	3700.000	4.200	170.000	5.700
8-08	12/16/2002	0.226	0.136	0.197	36.140	15.840	14.350	0.200
8-08	2/25/2003	0.286	0.189	0.268	50.520	21.050	17.090	0.470
8-10	1/8/2001	0.313	0.498	0.693	140.000	3.000	28.000	0.000

Table 5. Toxic units (TU) of heavy metals present in storm water samples, and concentrations of dominant metals.

		Total Metal TU			Metal Concentration (μg/L)			
Site Number	Sampling Date	C. dubia	P. promelas	Algae	Zn	Pb	Cu	Cd
10-02	11/7/2002	0.515	1.538	2.031	433.200	4.210	41.940	0.850
10-02	2/12/2003	0.325	0.259	0.398	72.940	1.410	29.130	0.280
10-03	11/7/2002	1.001	4.163	5.412	1173.000	6.170	78.720	2.030
10-03	2/12/2003	0.968	1.348	1.900	379.500	4.780	84.470	1.150
10-05	10/30/2001	0.225	0.462	0.626	130.000	2.700	19.000	0.200
11-100	1/10/2001	0.184	0.887	1.151	250.000	0.000	16.000	0.000
11-100	11/8/2002	0.962	2.575	3.435	725.600	3.540	83.300	0.800
11-100	2/11/2003	0.418	0.660	0.913	185.500	4.600	35.290	0.490
11-101	11/8/2002	0.365	0.287	0.435	80.120	4.780	31.480	0.330
11-101	2/11/2003	0.601	0.273	0.434	72.810	29.870	43.820	0.430
11-97	11/8/2002	0.873	0.560	0.890	156.700	8.600	76.860	0.730
11-97	2/11/2003	0.747	0.463	0.737	129.200	9.700	64.580	0.640
11-98	11/12/2001	1.293	0.821	1.080	210.000	160.000	58.000	0.800
11-98	11/8/2002	0.709	1.556	2.097	437.600	8.520	60.200	0.460
11-98	2/11/2003	0.748	0.271	0.387	65.340	81.510	38.340	0.370
12-10	1/8/2001	0.535	0.709	1.015	200.000	0.000	50.000	0.000
12-10	11/12/2001	0.357	0.852	1.140	240.000	2.100	29.000	0.800
12-10	11/8/2002	0.053	0.659	0.823	185.100	4.430	30.470	0.610
12-10	2/11/2003	0.086	0.074	0.108	20.420	1.930	6.690	0.150
12-11	11/8/2002	0.030	0.585	0.733	164.900	1.150	13.330	0.370
12-11	2/11/2003	0.113	0.176	0.245	49.550	0.640	10.010	0.060
1-36	10/28/2000	0.032	1.631	2.044	460.000	0.000	0.000	0.000
1-36	10/30/2001	0.075	1.064	1.346	300.000	0.000	5.200	0.000
1-37	4/20/2001	0.041	0.001	0.009	0.000	1.200	3.500	0.000
2-02	1/8/2001	0.208	0.496	0.670	140.000	0.000	19.000	0.000
2-03	10/29/2001	0.279	0.320	0.463	90.000	1.200	25.000	0.200
3-04	11/7/2002	0.351	2.005	2.582	565.100	1.950	27.800	0.390

Table 6. Results from chemical analysis of toxic organic chemicals identified in Phase II TIEs in samples collected during the winter of 2002/2003. These samples were toxic to both *C. dubia* and *P. promelas*.

Sampling Date	Site Number	Toxicant	Concentration (ppb)
11/7/2002	4-36	anthracene-dione	7.2
"	4-37	anthracene-dione (also two phthalates)	4.9
"	10-03*	malathion	4.7
11/8/2002	11-97	two phthalates	contaminated
"	11-98*	permethrin** , piperonyl butoxide	7.7, 0.37
"	11-100*	diazinon, malathion	4.6, 1.8
"	11-101	DEHP	contaminated
"	12-10	two phthalates	contaminated
2/11/2003	11-100	malathion	0.6
"	11-97	propyzamide	0.125
2/12/2003	10-02	propyzamide	0.41
"	10-03*	diazinon, trifluralin	3.8, 1.35
3/14/2003	6-06*	propyzamide and thiabendazole	0.68, 2.8

*done single as well as stacked (for which analytes generally agreed with the same fraction or an adjacent one)

**permethrin concentration is the sum of cis- and trans- isomers

Table 7. Distribution of TIE results organized by land use class for the major sources of contaminant. Only results that indicated one cause of toxicity are included.

Contaminant	Year	R	C	I	A	F	O	T	M
		Land Use Type							
Metals	2000	2	1					1	
	2001	4	1				1	2	1
	2002							1	1
Surfactants	2000								
	2001	1			1				3
	2002							2	
Metabolically activated pesticide	2000	1							2
	2001				1		2		1
	2002								
Non-polar organic	2000				1			2	
	2001								
	2002								
Totals		8	2	0	3	0	3	8	8

R = residential
C = commercial
I = industrial
A = agricultural
F = forest
O = open
T = transportation
M = mixed (combination of any of the above)

Table 8. Distribution of TIE results organized by surface type. Only results that indicated one cause of toxicity are included.

Contaminant	Year	Surface Type Landscape	Pavement	Right-of-Way
Metals	2000		4	
	2001		7	2
	2002		2	
Surfactants	2000			
	2001		5	
	2002		2	
Metabolically activated pesticide	2000		2	2
	2001		3	
	2002			
Non-polar organic	2000		3	
	2001			
	2002			
Totals		0	28	4

Over the course of the study, 204 of 223 samples had at least one test give a positive result, i.e., the sample could be considered toxic by at least one toxicity test. There were no significant differences between site categories (highway, maintenance yard, park & ride, rest area) with respect to the proportion of positive toxicity tests for *C. dubia* reproduction, *P. promelas* biomass or reproduction, or *S. capricornutum* growth (Table 7). *C. dubia* mortality test results did show a significant difference among site categories with highways having a significantly higher proportion of positive tests than the other three categories. Also, metabolically activated pesticides were found in sites associated with pavement and right-of-ways, but not open landscapes (Table 8).

There were significant differences between the proportion of positive *C. dubia* mortality and *S. capricornutum* toxicity tests among storm events with Events 4/5 having a higher proportion of positive *C. dubia* tests and Event 1 having a higher proportion of *S. capricornutum* tests (Table 9). Within each site category, there were no differences between storm events in the proportion of positive toxicity tests, i.e., the same proportion of assays exhibited toxicity in first storm events, mid-winter storms, and late-winter storms with the exception of *S. capricornutum* tests from maintenance facilities.

Spearman rank correlations were calculated between several site-specific variables and the results of the toxicity assays for the 2002-03 sampling season (Table 10). The results of all five toxicity tests (using actual numerical values for all test outcomes, e.g., reproduction is provided in number of neonates counted during the test) were correlated with event rainfall (amount), maximum intensity of rainfall, antecedent dry period, antecedent event rainfall, total flow volume during the event, peak flow during the event, cumulative precipitation to the event, catchment area, impervious fraction in catchment area, and AADT. There were no correlations between any of the toxicity test results and the measures of maximum intensity, antecedent event rainfall, total flow volume, peak flow volume, or catchment area. Nor was there any correlation between *S. capricornutum* toxicity and any of the environmental variables.

Generally, it appears that long antecedent dry periods result in lower reproduction and higher toxicity in the *C. dubia* and *P. promelas* tests. A higher percent impervious fraction in the catchment also results in higher toxicity, as does a higher traffic volume. The greater the cumulative precipitation, the lower the *P. promelas* mortality, but the correlation was not quite significant at $p = 0.05$, and no other toxicity assay exhibited a nearly significant relationship (although all had negative signs for the correlations indicating that higher precipitation resulted in lower toxicity). The only somewhat counterintuitive result was that the greater the event rainfall, the higher the *P. promelas* mortality, although again, the relationship was not significant at the $p = 0.05$ level.

Table 9. Comparisons of toxicity results by Caltrans site category and across storm events. Numbers in each cell are the chi square value in a two-tailed chi-square test of homogeneity. Among site categories refers to all years and all events included in the four site categories. Across storm events refers to all first storms for all site categories combined, compared to second, third and fourth/fifth storms. Across storm events within site categories refers to first event highways compared to second event highways and third event highways and fourth/fifth event highways.

Test	Chi-square Values				
	C. dubia reproduction	C. dubia mortality	P. promelas biomass	P. promelas mortality	S. capricornutum growth
Among site categories	8.83	33.98***	6.10	9.48	1.42
Across storm events	8.73	9.55*	4.49	3.19	18.12***
Across storm events within site categories					
Highways	4.95	1.34	2.88	0.74	5.60
Maintenance	1.42	0.63	7.15	5.26	8.32*
Park & Ride	1.41	3.27	1.93	0.20	3.83

* $p < 0.05$
** $p < 0.01$
*** $p < 0.005$
Small sample sizes precluded statistical analyses on Rest Area sites. Unless otherwise noted with an asterisk, χ^2 values are not significant at $p = 0.05$. Degrees of freedom for all tests are 2. No adjustment of the Type I error rate was made for multiple tests.

Table 10. Spearman rank correlation coefficients for all correlations with $p < 0.10$. Numbers in parentheses are significance value and the degrees of freedom for that correlation. A blank cell indicates a correlation was present with a $p > 0.10$.

	C. dubia reproduction	*C. dubia* mortality	*P. promelas* biomass	*P. promelas* mortality
Event rainfall				0.303 (0.086, 33)
Antecedent dry period	-0.395 (0.076, 21)	0.436 (0.048, 21)	-0.395 (0.076, 21)	0.322 (0.072, 32)
Cumulative precipitation				-0.318 (0.076, 32)
Impervious fraction	-0.444 (0.039, 22)	0.410 (0.059, 22)	-0.444 (0.039, 22)	0.362 (0.038, 33)
AADT	-0.509 (0.037, 17)	0.441 (0.077, 17)	-0.509 (0.037, 17)	0.496 (0.014, 24)

Summary

- Storm water was collected directly from storm drains and not from discharge points to vegetated ditches. No storm water was collected as it drained from the edge of the pavement through the Caltrans right-of-way.
- Toxicity in at least one assay occurred at every site during the three years of the study.
- Over the three years, 92% of the samples exhibited toxicity in at least one of the five bioassays. 58% of the *C. dubia* reproduction tests, 37% of the *C. dubia* mortality tests, 72% of the *P. promelas* biomass tests, 61% of the *P. promelas* mortality tests, and 35% of the *S. capricornutum* tests gave a positive test result indicating toxicity.
- Highways exhibited significantly higher toxicity using the *C. dubia* mortality assay; otherwise there were no differences in any toxicity assay among sites or across storm events.
- Results of the TIEs indicate a range of potential causes of toxicity including several sources such as metabolically activated pesticides that are not the result of transportation related activities.
- There is a significant difference between storm events in the proportion of tests that indicate toxicity, most probably due to the high proportion of toxic events from first storm events on highways.
- Analyses indicate that large amounts of impervious surface, longer dry periods with high traffic volume result in higher levels of toxicity across all assays.

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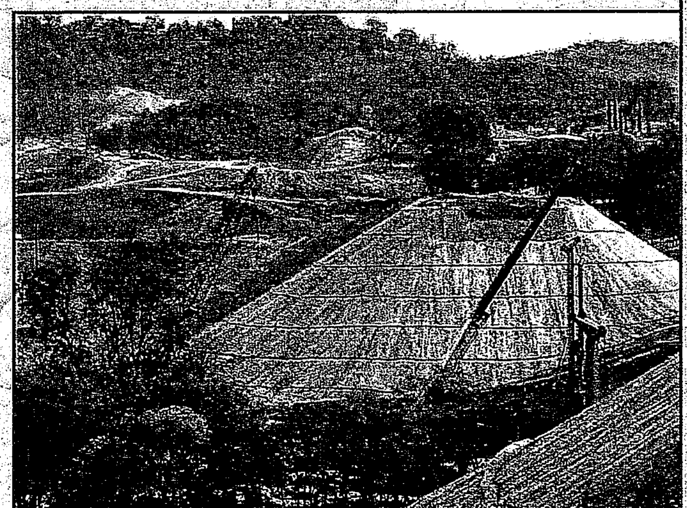
Storm Water Quality Handbooks

Project Planning and Design Guide

Storm Water Pollution Prevention Plan (SWPPP)
and Water Pollution Control Program (WPCP) Preparation Manual

Construction Site
Best Management Practices (BMPs) Manual



Caltrans

State of California
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1.1 Introduction

On July 15, 1999, the State Water Resources Control Board (SWRCB) issued the "*National Pollutant Discharge Elimination System (NPDES) Permit, Statewide Storm Water Permit and Waste Discharge Requirements (WDRs) for the State of California, Department of Transportation (Caltrans)*" (Order No. 99-06-DWQ, NPDES No. CAS000003) hereby called "Permit". The Permit regulates storm water discharges from Caltrans properties, facilities and activities, and requires that Caltrans' construction program comply with the requirements of the "*NPDES General Permit, Waste Discharge Requirements (WDRs) for Discharges of Storm Water Runoff Associated with Construction Activity*" (Order No. 99-08-DWQ, NPDES No. CAS000002) (General Permit) issued by the SWRCB, to regulate discharges from construction sites that disturb 5 acres or more. Beginning March 10, 2003, U.S. Environmental Protection Agency (EPA) and SWRCB regulations will regulate discharges from projects with soil disturbance of 1 acre or more by amending the General Permit and thus including coverage of projects with soil disturbance of 1 acre or more. SWRCB Resolution No. 2001-46 modified provisions of the General Permit that require permittees to implement specific water quality sampling and analytical procedures implemented on a construction site.

1.2 Storm Water Pollution Prevention Plan (SWPPP) and Water Pollution Control Program (WPCP)

Caltrans requires contractors to prepare and implement a program to control water pollution effectively during the construction of all projects (see Standard Specification Section 7-1.01G Water Pollution). Projects resulting in 0.4 hectares (ha) [1 ac] or more of soil disturbance are subject to the General Permit. Caltrans Special Provisions require that for larger projects, defined as those resulting in 0.4 ha (1 ac) or more of soil disturbance, Contractors prepare and submit a Storm Water Pollution Prevention Plan (SWPPP). When a SWPPP is required for a project, it will satisfy the requirements of Standard Specification Section 7-1.01G, in addition to meeting other permit requirements.

Caltrans requires that a Water Pollution Control Program (WPCP) addressing control measures be prepared and implemented by the construction contractor for projects resulting in soil disturbance of less than 0.4 ha (1ac). For detailed step-by-step procedures, instructions and templates to prepare a SWPPP or a WPCP, refer to the Caltrans *Storm Water Quality Handbooks, Storm Water Pollution Prevention Plan (SWPPP) and Water Pollution Control Program (WPCP) Preparation Manual.*

If two (2) or more small projects [less than 0.4 ha (1 ac) of soil disturbance] in the same corridor are part of a larger common plan of development [0.4 ha (1 ac) or more], then these small projects are also subject to the requirements of the General Permit to develop and implement a SWPPP.

1.3 Organization of this Manual

This *Storm Water Quality Handbooks, Construction Site Best Management Practices Manual* (manual) is intended to provide Contractors and Caltrans staff with detailed information of construction site BMPs. This Manual is organized as follows:

- Section 1 provides an introduction to the Construction Site Best Management Practices (BMPs) Manual.
- Section 2 provides instructions for the selection and implementation of construction site BMPs.
- Section 3 provides listing and working details for Caltrans construction site BMPs for Temporary Soil Stabilization.
- Section 4 provides listing and working details for Caltrans construction site BMPs for Temporary Sediment Control.
- Section 5 provides listing and working details for Caltrans construction site BMPs for Wind Erosion Control.
- Section 6 provides listing and working details for Caltrans construction site BMPs for Tracking Control.
- Section 7 provides listing and working details for Caltrans construction site BMPs for Non-Storm Water Management.
- Section 8 provides listing and working details for Caltrans construction site BMPs for Waste Management and Materials Pollution Control.
- Appendix A provides a listing of frequently used abbreviations, acronyms, and definitions of terms used throughout this Manual.
- Appendix B provides guidance on the selection of temporary soil stabilization controls.

1.4 Caltrans Construction Site BMPs

This section lists those BMPs considered during the construction of Caltrans projects. Construction site BMPs (also called temporary control practices) are best conventional technology/best available technology (BCT/BAT)-based BMPs that are consistent with the BMPs and control practices required under the General Permit. Caltrans construction site BMPs are divided into six categories (see Table 1-1):

1.4.1 Approved Construction Site BMPs for Statewide Use

Approved construction site BMPs are BMPs that have been approved by Caltrans Deputy Directors or Program Managers for statewide implementation. Implementation is dependent on conditions/applicability of deployment described as part of the BMP. These BMPs are typically implemented in all Caltrans construction projects; they include practices for soil stabilization, sediment control, wind erosion control, tracking control, non-storm water management and waste management. Some of the approved construction site BMPs have been designated as "minimum requirements"; these BMPs will be implemented in all highway construction projects statewide when they are applicable to a project.

1.4.2 Approved Construction Site BMPs for Use on a Project-by-Project Basis

These are other construction site BMPs have not been approved for statewide use by the Statewide Storm Water Management Plan (SWMP), but may be implemented, on a project-by-project basis, in addition to required approved BMPs and when determined necessary and feasible by the Resident Engineer (RE). Caltrans may, on a project-by-project basis, specify or require Contractors to implement some of these construction site BMPs. Additionally, Caltrans will consider a Contractor's recommendation to implement some of these construction site BMPs on a project, subject to headquarters approval.

Construction site BMPs within each of these categories are described in Sections 3 through 8 of this Manual. Table 1-1 lists the construction site BMPs. It is important to note that some BMPs were grouped to show that a combination of those BMPs will enhance protection over the use of only one BMP.

TABLE 1-1

CONSTRUCTION SITE BMPs				
ID	BMP NAME	APPROVED FOR STATEWIDE USE ON ALL PROJECTS [1]	APPROVED FOR USE ON A PROJECT-BY-PROJECT BASIS	MINIMUM REQUIREMENT
TEMPORARY SOIL STABILIZATION				
SS-1	Scheduling	X		✓
SS-2	Preservation of Existing Vegetation	X		✓
SS-3	Hydraulic Mulch	X		✓[2]
SS-4	Hydroseeding	X		✓[2]
SS-5	Soil Binders	X		✓[2]
SS-6	Straw Mulch	X		✓[2]
SS-7	Geotextiles, Plastic Covers, & Erosion Control Blankets/Mats	X		✓[2]
SS-8	Wood Mulching	X		
SS-9	Earth Dikes/Drainage Swales & Lined Ditches		X	
SS-10	Outlet Protection/Velocity Dissipation Devices		X	
SS-11	Slope Drains		X	
SS-12	Streambank Stabilization	X		
TEMPORARY SEDIMENT CONTROL				
SC-1	Silt Fence	X		✓[3]
SC-2	Sediment/Desilting Basin		X	
SC-3	Sediment Trap		X	
SC-4	Check Dam		X	
SC-5	Fiber Rolls		X	✓[3]
SC-6	Gravel Bag Berm		X	
SC-7	Street Sweeping and Vacuuming	X		✓
SC-8	Sandbag Barrier		X	
SC-9	Straw Bale Barrier		X	
SC-10	Storm Drain Inlet Protection		X	✓
WIND EROSION CONTROL				
WE-1	Wind Erosion Control	X		✓
TRACKING CONTROL				
TC-1	Stabilized Construction Entrance/Exit		X	
TC-2	Stabilized Construction Roadway		X	
TC-3	Entrance/Outlet Tire Wash		X	

(1) Implementation depends on applicability to a project

(2) The Contractor shall select one of the five measures listed or a combination thereof to achieve and maintain the contract's rainy season disturbed soil area (DSA) requirements

(3) The Contractor shall select one of the two measures listed or a combination thereof to achieve and maintain the contract's rainy season disturbed soil area (DSA) requirements"

TABLE 1-1

CONSTRUCTION SITE BMPs				
ID	BMP NAME	APPROVED FOR STATEWIDE USE ON ALL PROJECTS [1]	APPROVED FOR USE ON A PROJECT-BY-PROJECT BASIS	MINIMUM REQUIREMENT
NON-STORM WATER MANAGEMENT				
NS-1	Water Conservation Practices	X		
NS-2	Dewatering Operations	X		
NS-3	Paving and Grinding Operations	X		
NS-4	Temporary Stream Crossing	X		
NS-5	Clear Water Diversion	X		
NS-6	Illicit Connection/Illegal Discharge Detection and Reporting	X		✓
NS-7	Potable Water/Irrigation	X		
NS-8	Vehicle and Equipment Cleaning	X		✓
NS-9	Vehicle and Equipment Fueling	X		✓
NS-10	Vehicle and Equipment Maintenance	X		✓
NS-11	Pile Driving Operations	X		
NS-12	Concrete Curing	X		
NS-13	Material and Equipment Use Over Water	X		
NS-14	Concrete Finishing	X		
NS-15	Structure Demolition/Removal Over or Adjacent to Water	X		
WASTE MANAGEMENT AND MATERIALS POLLUTION CONTROL				
WM-1	Material Delivery and Storage	X		✓
WM-2	Material Use	X		✓
WM-3	Stockpile Management	X		✓
WM-4	Spill Prevention and Control	X		✓
WM-5	Solid Waste Management	X		✓
WM-6	Hazardous Waste Management	X		
WM-7	Contaminated Soil Management	X		
WM-8	Concrete Waste Management	X		
WM-9	Sanitary/Septic Waste Management	X		✓
WM-10	Liquid Waste Management	X		

(1) Implementation depends on applicability to a project

(2) The Contractor shall select one of the five measures listed or a combination thereof to achieve and maintain the contract's rainy season disturbed soil area (DSA) requirements

(3) The Contractor shall select one of the two measures listed or a combination thereof to achieve and maintain the contract's rainy season disturbed soil area (DSA) requirements"

Section 2
Selecting and Implementing Construction Site Best Management Practices

This section provides instructions for the selection and implementation of construction site best management practices (BMPs). It is important to note that the requirements of this Section are Caltrans minimum requirements, and that Caltrans Districts may impose more stringent requirements on a project-by-project basis, and that the Contractor implements additional construction site BMPs if deemed necessary. Changes in field implementation of construction site BMPs require written approval of the Resident Engineer (RE). Any additional requirements will be included in the project's Standard Special Provisions (SSPs). Working details of construction site BMPs are presented in Sections 3 through 8 of this Manual.

2.1 Definitions

2.1.1 Disturbed Soil Area (DSA)

Disturbed soil areas (DSAs) are areas of exposed, erodible soil that are within the construction limits and that result from construction activities. The following are not considered DSAs:

- Areas where soil stabilization, erosion control, highway planting, or slope protection are applied and associated drainage facilities are in place and functional.
- Roadways, construction roads, access roads or contractor's yards that have been stabilized by the placement of compacted subbase or base material or paved surfacing.
- Areas where construction has been completed in conformance with the contract plans and permanent erosion control is in place and functional.

Erosion control is considered functional when a uniform vegetative cover equivalent to 70 percent of the native background vegetation coverage has been established or equivalent stabilization measures have been employed.

2.1.2 Active Areas and Non-Active Areas

Active Areas are construction areas where soil-disturbing activities have already occurred and continue to occur or will occur during the ensuing 21 days.

Non-Active Areas are construction areas (formerly active areas) that will be idle for at least 21 days.

The RE will conduct a review of the existing active areas on a regular basis to determine if a non-active status should be applied to some DSAs.

2.1.3 Slope Length and Benches

Slope length is measured or calculated along the continuous inclined surface. Each discrete slope is between one of the following: top to toe, top to bench, bench to bench, and bench to toe.

Benches are drainage facilities that intercept surface flow and convey the resulting concentrated flow away from a slope. For the purpose of determining slope lengths, fiber rolls or other appropriate BMPs (used for temporary sediment control) can be considered equivalent to a bench.

2.1.4 Rainy Season

The average rainfall in California varies greatly from region to region. To account for the various rainfall patterns (time frame, intensities, and amounts) the state is separated into several rainy seasons. Shown in Figure 2-1 is a map identifying the rainy seasons throughout the state. These rainy seasons are used to identify the appropriate level of soil stabilization and sediment control protection.

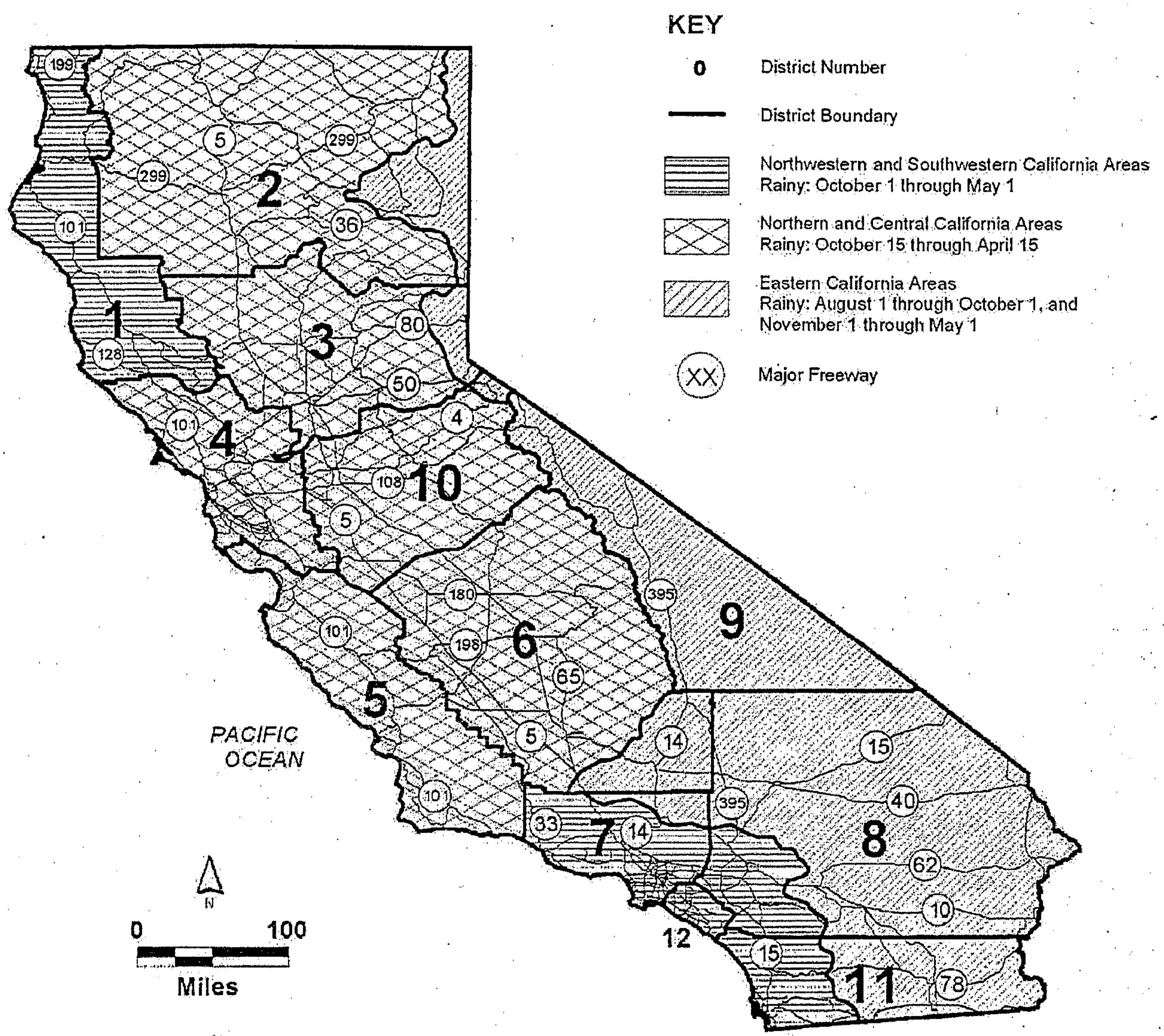


Figure 2-1
DESIGNATION OF RAINY SEASONS

2.2 Temporary Soil Stabilization and Sediment Control Implementation Guidance

Storm water pollution control requirements are intended to be implemented on a year-round basis at an appropriate level. The requirements must be implemented in a proactive manner during all seasons while construction is ongoing. California has varied rainfall patterns throughout the state; therefore, the appropriate level of BMP implementation will also vary throughout the state. The temporary sediment controls and soil stabilization specified in this section are based on rainfall patterns (time frames, intensities, and amounts), general soil types, the seasons, slope inclinations and slope lengths. Appropriate water pollution control includes the implementation of an effective combination of both soil stabilization and sediment controls.

This section describes both general principles and specific guidance for selecting and implementing temporary soil stabilization and sediment control BMPs. Sections 2.2.1, 2.2.2, and 2.2.3 provide key principles for preventing erosion on construction sites. Sections 2.2.4 and 2.2.5 provide the specific guidance for selecting and implementing temporary soil stabilization and sediment control BMPs to manage disturbed soil areas. It is important to note that the Districts may require implementation of additional construction site BMPs if deemed necessary.

2.2.1 Scheduling

Construction scheduling shall consider the amount and duration of soil exposed to erosion by wind, rainfall, runoff, and vehicle tracking and seek to minimize disturbed soil area during the rainy season. A schedule shall be prepared that shows the sequencing of construction activities with the installation and maintenance of soil stabilization and sediment control BMPs. See BMP SS-1, Scheduling, in this Manual for BMP details.

2.2.2 Preservation of Existing Vegetation

Preserving existing vegetation to the maximum extent possible and for as long as possible on a construction site reduces or eliminates erosion in those areas. To facilitate this practice, on a year-round basis temporary fencing shall be provided prior to commencement of clearing and grubbing operations or other soil-disturbing activities in areas where no construction activity is planned or construction will occur at a later date. See BMP SS-2, Preservation of Existing Vegetation, for BMP details.

2.2.3 Storm Water Run-on and Concentrated Flows

The diversion of storm water run-on and conveyance of concentrated flows must be considered in determining the appropriateness of the BMPs chosen. BMPs to divert or manage concentrated flows in a non-erodible fashion may be required on a project-by-project basis to divert off-site drainage through or around the construction site or to properly manage construction site storm water runoff. See BMPs SS-9, Earth Dikes, Drainage Swales and Lined Ditches; SS-10, Outlet Protection/ Velocity Dissipation Devices; and SS-11, Slope Drains, for BMP details.

2.2.4 Disturbed Soil Area Management

The DSA management guidelines are based on rainfall patterns (time frames, intensities, and amounts), general soil types, the seasons, slope inclinations, and slope lengths. All of these factors are considered in developing the appropriate levels of soil stabilization and sediment control, and will be considered by the RE when directing specific site-by-site actions.

2.2.4.1 Disturbed Soil Area Size Limitations

Limiting the amount of disturbed soil is a critical component in conducting an effective storm water management program; contract special provisions may specify limits of disturbed soil area. Standard Specifications Section 7-1.01G, Water Pollution states *"Unless otherwise approved by the Engineer in writing, the Contractor shall not expose a total area of erodible earth, which may cause water pollution, exceeding 70,000 m^2 for each separate location, operation or spread of equipment before either temporary or permanent erosion control measures are accomplished"*. The RE has the option of increasing the size of disturbed soil areas beyond 70,000 square meters (17 acres) if appropriate control practices and an implementation plan are included in an approved SWPPP.

Furthermore, District design teams may elect to further restrict the size of the project's total disturbed soil area to 2 hectares (5 acres) during the rainy season.. The RE has the option of increasing the limit of the total disturbed soil area during the rainy season beyond 5 acres if appropriate control practices and an implementation plan are included in an approved SWPPP.

2.2.5 DSA Protection by Temporary Soil Stabilization and Temporary Sediment Controls

To account for rainfall patterns (time frames, intensities, and amounts) and to a lesser extent general soil type differences, the state has been divided into seven areas requiring common protection requirements. These rainfall areas are described in Table 2-1. The specific temporary soil stabilization and sediment control practices for DSA protection in each area are determined from Tables 2-2 and 2-3 (for non-active disturbed soil areas and active disturbed soil areas, respectively). Based on consultation with experts, the slope length and slope inclination are seen as the most important criteria for soil stabilization and sediment control requirements, as these factors have the largest potential impact on the erosion rate. As indicated on these tables, the temporary soil stabilization and sediment controls at a construction site will increase with increasing slope length and slope inclination combination.

DSAs shall be protected as follows:

- Temporary control practices (as required in Table 2-2) shall be performed on non-active DSAs within 14 days from the cessation of soil-disturbing activities or one day prior to the onset of precipitation, whichever occurs first.
- Temporary control practices for active DSAs (as required in Table 2-3) shall be performed prior to the onset of precipitation and throughout each day for which precipitation is forecasted.

- For non-active DSAs, limit the erosive effects of storm water flow on slopes by implementing BMPs such as fiber rolls to break up the slope lengths as follows:
  - Slope inclination 1:4 (V:H) and flatter: BMPs shall be placed on slopes at intervals no greater than 6 m.
  - Slope inclination between 1:4 (V:H) and 1:2 (V:H): BMPs shall be placed on slopes at intervals no greater than 4.5 m.
  - Slope inclination 1:2 (V:H) or greater: BMPs shall be placed on slopes at intervals no greater than 3 m.
- For non-active DSAs, permanent erosion control shall be applied to areas deemed complete during the project's defined seeding window.
- Provide construction site BMPs in addition to those specified in Tables 2-2 and 2-3 to convey concentrated flows in a non-erodible fashion.

2.2.6 Procedures for Rainfall Area 7

For construction sites within Rainfall Area 7 (District 8 within the Colorado River Basin RWQCB jurisdictions, District 9 and District 11 within the Colorado River Basin RWQCB jurisdiction), the soil stabilization and control practices required for the construction site will be determined by the applicable RWQCB on a site-by-site basis. The following procedure shall be used to notify the applicable RWQCB for construction sites in Rainfall Area 7:

- Caltrans will notify the applicable RWQCB staff of construction sites in these areas at least 30 days prior to the start of construction.
- During the 30-day notification period, the RWQCB staff may request to review the SWPPP or meet with Caltrans to discuss the construction project.
- Within the 30-day notification period, the RWQCB may respond with specific soil stabilization and sediment control practices required for the site. If the RWQCB does not respond within the 30-day review period, then Caltrans can proceed with its construction activities as scheduled.
- Regardless of the RWQCB action, the RWQCB may inspect the site and take enforcement actions, if necessary, pending inspection findings.

For construction sites within Rainfall Area 7 (District 6, 7, and 8 within the Lahontan RWQCB jurisdiction) and within one mile of the Mojave or Amargosa River and their tributaries that are within one mile of these waterways, soil stabilization and sediment control measures must be implemented as specified for Area 4. All equipment must also be removed from waterways prior to any flash floods. All other projects located in the Lahontan RWQCB are not required to implement soil stabilization and sediment control measures.

Table 2-1

AREA DEFINITIONS		
AREA	**Applicability**	**Elevation**
1	**District 1** in the following areas: all of Del Norte and Humboldt Counties within 20 miles of the coast in Mendocino County	≤1200m
2	**District 1** (except within Area 1) **District 2** within the North Coast, Lahontan, and Central Valley RWQCB jurisdictions **Districts 3, 4** and **5** **District 10** within the Lahontan RWQCB jurisdiction	<250m
3	**District 1** (except within Area 1) **District 2** within the North Coast, Lahontan, and Central Valley RWQCB jurisdictions **Districts 3, 4** and **5** **District 10** within the Lahontan RWQCB jurisdiction	250m – 1200m
4	**District 6** within the Central Valley RWQCB jurisdiction **District 7** within the Central Coast, Los Angeles, and Central Valley RWQCB jurisdictions **District 8** within the Santa Ana and San Diego RWQCB jurisdictions **District 10** (except for the Lahontan RWCB jurisdiction) **District 11** within the San Diego RWQCB jurisdiction **District 12**	<500m
5	**District 6** within the Central Valley RWQCB jurisdiction **District 7** within the Central Coast, Los Angeles, and Central Valley RWQCB jurisdictions **District 8** within the Santa Ana and San Diego RWQCB jurisdictions **District 10** (except for the Lahontan RWCB jurisdiction) **District 11** within the San Diego RWQCB jurisdiction **District 12**	500m – 1200m
6	**Statewide**	>1200m
7	**District 6** within the Lahontan RWQCB jurisdiction **District 7** within the Lahontan RWQCB jurisdiction **District 8** within the Lahontan and Colorado River Basin RWQCB jurisdictions **District 9** **District 11** within the Colorado River Basin RWQCB jurisdiction	≤1200m

Table 2-2

REQUIRED COMBINATION OF TEMPORARY SOIL STABILIZATION AND TEMPORARY SEDIMENT CONTROLS AND BARRIERS [6] [7]

NON-ACTIVE DISTURBED SOIL AREAS

SEASON	AREA(S)	TEMPORARY BMP	SLOPE (V:H) [1]			
			≤ 1:20	> 1:20 ≤ 1:4	> 1:4 ≤ 1:2	> 1:2
RAINY[2]	1 & 6	SOIL STABILIZATION [5]	X	X	X	X
		SEDIMENT BARRIER [5]	X	X	X	X
		DESILTING BASIN [3]		X	X	X
	2, 3, 4 & 5	SOIL STABILIZATION [5]	X	X	X	X
		SEDIMENT BARRIER		X	X	X
		DESILTING BASIN				
	7	SOIL STABILIZATION AND SEDIMENT CONTROL PRACTICES TO BE DETERMINED BY APPLICABLE RWQCB[8]				
NON-RAINY	1	SOIL STABILIZATION [5]	X[4]	X[4]	X	X
		SEDIMENT BARRIER		X[4]	X	X
		DESILTING BASIN				
	2 & 4	SOIL STABILIZATION				
		SEDIMENT BARRIER				
		DESILTING BASIN				
	3 & 5	SOIL STABILIZATION				
		SEDIMENT BARRIER				X[4]
		DESILTING BASIN				
	6	SOIL STABILIZATION [5]	X[4]	X[4]	X	X
		SEDIMENT BARRIER		X[4]	X	X
		DESILTING BASIN [3]				X
	7	SOIL STABILIZATION AND SEDIMENT CONTROL PRACTICES TO BE DETERMINED BY APPLICABLE RWQCB[8]				

(1) Unless otherwise noted, the temporary BMP is required for the slope inclinations indicated on slope lengths greater than 3 meters.

(2) The maximum slope length is 30 meters for slope inclinations between 1:20 (V:H) and 1:2 (V:H) and 15 meters for steeper slopes.

(3) Required in addition to the temporary sediment barrier, where feasible. Feasibility will depend on site-specific factors such as available right-of-way within the project limits, topography, soil type, disturbed soil area within watershed, and climate conditions.

(4) Implementation of controls not required except at least 24 hours prior to all predicted rain events.

(5) The indicated temporary BMP is required on all slope lengths.

(6) Sediment controls and barriers include all temporary sediment control construction BMPs identified in the Statewide Storm Water Quality Practice Guidelines associated with the SWMP and Section 4 of these guidelines. Linear barrier systems are equivalent to what are referred to in the General Construction Permit as perimeter controls. The intent is prevent the transport of sediment at the downslope edge of disturbed soil areas.

(7) Permanent erosion control seeding shall be applied to all non-active areas deemed substantially complete during the project's defined seeding window.

(8) Refer to Section 2.2.6 for procedure.

Table 2-3

REQUIRED COMBINATION OF TEMPORARY SOIL STABILIZATION AND TEMPORARY SEDIMENT CONTROLS AND BARRIERS (6) **ACTIVE** DISTURBED SOIL AREAS (3)					
SEASON	**AREA(S)**	**TEMPORARY BMP**	**SLOPE (V:H) (1)**		
			≤ 1:20	**> 1:20 ≤ 1:2**	**> 1:2**
RAINY	1 & 6	SOIL STABILIZATION		X	X
		SEDIMENT BARRIER (4)	X	X	X
		DESILTING BASIN (2)		X	X
	2, 4 & 5	SOIL STABILIZATION			
		SEDIMENT BARRIER		X	X
		DESILTING BASIN (2)			X
	3	SOIL STABILIZATION			X(5)
		SEDIMENT BARRIER		X	X
		DESILTING BASIN (2)			X
	7	SOIL STABILIZATION AND SEDIMENT CONTROL PRACTICES TO BE DETERMINED BY APPLICABLE RWQCB(7)			
NON-RAINY	1	SOIL STABILIZATION			
		SEDIMENT BARRIER		X	X
		DESILTING BASIN(2)			X
	2, 3, 4 & 5	SOIL STABILIZATION			
		SEDIMENT BARRIER			
		DESILTING BASIN			
	6	SOIL STABILIZATION			
		SEDIMENT BARRIER		X	X
		DESILTING BASIN (2)			X
	7	SOIL STABILIZATION AND SEDIMENT CONTROL PRACTICES TO BE DETERMINED BY APPLICABLE RWQCB(7)			

(1) Unless otherwise noted, the BMP is required for the slope inclinations indicated on slope lengths greater than 3 meters.

(2) Required in addition to the temporary sediment barrier, where feasible. Feasibility will depend on site-specific factors such available right-of-way within the project limits, topography, soil type, disturbed soil area within watershed, and climate conditions.

(3) Implementation of soil stabilization controls are not required except prior to predicted rain.

(4) The indicated temporary BMP required on all slope lengths.

(5) The indicated temporary BMP required on slope lengths greater than 15 meters.

(6) Sediment controls and barriers include all temporary sediment control construction BMPs identified in the Statewide Storm Water Quality Practice Guidelines associated with the SWMP and Section 4 of these Guidelines. Linear barrier systems are equivalent to what are referred to in the General Construction Permit as perimeter controls. The intent is to provide a barrier to prevent the transport of sediment at the downslope edge of disturbed soil areas.

(7) Refer to Section 2.2.6 for procedures.

2.2.7 Basins

The practices described herein are typical of those that will be implemented on a project-by-project basis. However, it is important to note that there will be instances where project and site conditions require deviation from the BMPs and the descriptions provided in this manual. For instance, the proposed implementation of sediment/desilting basins (see BMP SC-2, "Sediment/Desilting Basin") is a new commitment that has not been incorporated into existing designs. In addition, the nature of linear projects and constrained rights-of-way inherent to Caltrans work may prohibit the use of sediment/desilting basins at some locations on certain projects and on some projects altogether. Implementation of sediment/desilting basins will be considered on a project-by-project basis. Caltrans is committed to refining the sediment/desilting basin implementation criteria during the term of the Permit while implementing the sediment/desilting basins on projects as practicable.

2.2.8 Stockpile Management

Soil stabilization and sediment control requirements as they apply to stockpiles of various materials are presented in BMP WM-3, Stockpile Management, in Section 8 of this Manual.

2.3 Guidance for Implementation of Other BMPs

2.3.1 Mobile Operations

Mobile operations common to the construction of a project include asphalt recycling, concrete mixing, crushing and the storage of materials. BMPs shall be implemented year-round, as appropriate, to control the individual situations these mobile operations can create.

2.3.2 Wind Erosion Controls

Wind erosion controls shall be considered year-round for all disturbed soils on the project site that are subject to wind erosion and when significant wind and dry conditions are anticipated during construction of the project. See BMP WE-1, Wind Erosion, for BMP details.

2.3.3 Tracking Controls

Tracking controls shall be implemented year-round, as needed, to reduce the tracking of sediment and debris from the construction site. At a minimum, entrances and exits shall be inspected daily, and controls implemented as needed. See Section 6 of this Manual for BMP details.

2.3.4 Non-Storm Water and Waste Management and Materials Pollution Controls

The objective of the non-storm water and waste management and materials pollution controls is to reduce the discharge of materials other than storm water to the storm water drainage system or to receiving waters. These controls shall be implemented year-round for all applicable activities, material usage, and site conditions. Sections 7 and 8 of this Manual provide guidance on implementation of BMPs related to the specific activity being conducted.

2.4 BMP Inspections

The BMPs deployed on construction sites will be inspected on a frequency as described below. Improperly installed or damaged practices shall be corrected immediately, or by a later date and time if requested by the Contractor and approved by the Resident Engineer (RE) in writing, but not later than the onset of forecasted rain events. Inspections of construction site BMPs are conducted as follows:

- Prior to a forecast storm.
- After a rain event that causes runoff from the construction site.
- At 24-hour intervals during extended rain events.
- As specified in the project Special Provisions and/or SWPPP.
- Every two weeks during the non-rainy season.
- Weekly during the rainy season.
- Or as directed by BMP Inspection Requirements or the Resident Engineer (RE).

Section 3
Temporary Soil Stabilization Best Management Practices

3.1 Temporary Soil Stabilization

Temporary soil stabilization consists of preparing the soil surface and applying one of the best management practices (BMPs) shown in Table 3-1, or combination thereof, to disturbed soil areas. Temporary soil stabilization shall be applied to disturbed soil areas of construction projects in conformance with the criteria presented in Section 2, Selecting and Implementing Construction Site BMPs, of this Manual. Refer to Appendix B for additional guidance on the selection of temporary soil stabilization controls.

3.1.1 Temporary Concentrated Flow Conveyance Controls

Temporary concentrated flow conveyance controls consist of a system of measures or BMPs that are used alone or in combination to intercept, divert, convey and discharge concentrated flows with a minimum of soil erosion, both on-site and downstream (off-site). Temporary concentrated flow conveyance controls may be required to direct run-on around or through the project in a non-erodible fashion. Temporary concentrated flow conveyance controls include the following BMPs:

- Earth Dikes/Drainage Swales & Lined Ditches
- Outlet Protection/Velocity Dissipation Devices
- Slope Drains

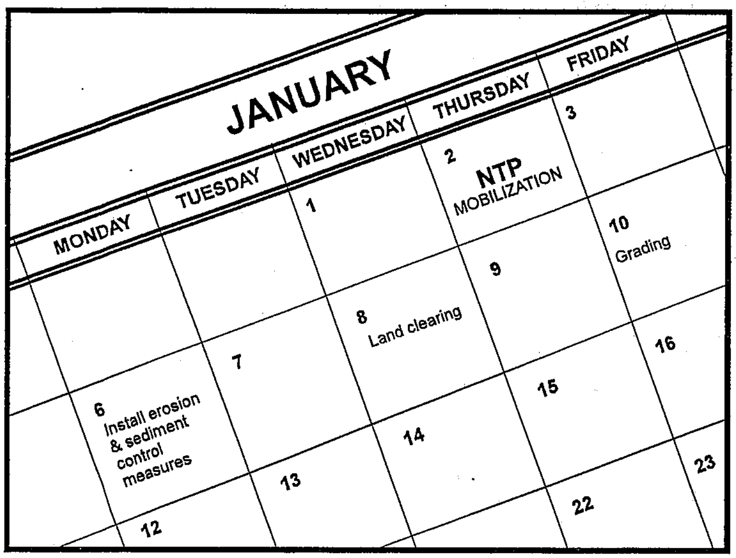
Table 3-1

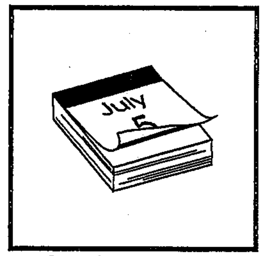
TEMPORARY SOIL STABILIZATION BMPs	
ID	**BMP NAME**
SS-1	Scheduling
SS-2	Preservation of Existing Vegetation
SS-3	Hydraulic Mulch
SS-4	Hydroseeding
SS-5	Soil Binders
SS-6	Straw Mulch
SS-7	Geotextiles, Plastic Covers, & Erosion Control Blankets/Mats
SS-8	Wood Mulching
Temporary Concentrated Flow Conveyance Controls	
SS-9	Earth Dikes/Drainage Swales & Lined Ditches
SS-10	Outlet Protection/Velocity Dissipation Devices
SS-11	Slope Drains
SS-12	Streambank Stabilization

The remainder of this Section shows the working details for each of the temporary soil stabilization BMPs.

Scheduling

SS-1





Standard Symbol

BMP Objectives

- Soil Stabilization
- Sediment Control
- Tracking Control
- Wind Erosion Control
- Non-Storm Water Management
- Materials and Waste Management

Definition and Purpose

This best management practice (BMP) involves developing, for every project, a schedule that includes sequencing of construction activities with the implementation of construction site BMPs such as temporary soil stabilization (erosion control) and temporary sediment controls measures. The purpose is to reduce the amount and duration of soil exposed to erosion by wind, rain, runoff and vehicle tracking, and to perform the construction activities and control practices in accordance with the planned schedule.

Appropriate Applications

Construction sequencing shall be scheduled to minimize land disturbance for all projects during the rainy and non-rainy season. Appropriate BMPs shall be implemented during both rainy and non-rainy seasons.

Limitations

None identified.

Standards and Specifications

- Developing a schedule and planning the project are the very first steps in an effective storm water program. The schedule shall clearly show how the rainy season relates to soil-disturbing and re-stabilization activities. The construction schedule shall be incorporated into the SWPPP or WPCP.
- The schedule shall include detail on the rainy season implementation and deployment of:
  - Temporary soil stabilization BMPs.
  - Temporary sediment control BMPs.
  - Tracking control BMPs.
  - Wind erosion control BMPs.

- Non-storm water BMPs.
- Waste management and materials pollution control BMPs.

■ Schedule shall also include dates for significant long-term operations or activities that may have planned non-storm water discharges such as dewatering, sawcutting, grinding, drilling, boring, crushing, blasting, painting, hydro-demolition, mortar mixing, bridge cleaning, etc.

■ Schedule work to minimize soil disturbing activities during the rainy season.

■ Develop the sequencing and timetable for the start and completion of each item such as site clearing and grubbing, grading, excavation, paving, pouring foundations, installing utilities, etc., to minimize the active construction area during the rainy season.

■ Schedule major grading operations for the non-rainy season when practical.

■ Stabilize non-active areas within 14 days from the cessation of soil-disturbing activities or one day prior to the onset of precipitation, whichever occurs first.

■ Monitor the weather forecast for rainfall.

■ When rainfall is predicted, adjust the construction schedule to allow the implementation of soil stabilization and sediment controls and sediment treatment controls on all disturbed areas prior to the onset of rain.

■ Be prepared year-round to deploy soil stabilization and sediment control practices as required by Section 2 of this Manual. Erosion may be caused during dry seasons by unseasonal rainfall, wind, and vehicle tracking. Keep the site stabilized year-round, and retain and maintain rainy season sediment trapping devices in operational condition.

■ Sequence trenching activities so that most open portions are closed before new trenching begins.

■ Incorporate staged seeding and re-vegetation of graded slopes as work progresses.

■ Consider scheduling when establishing permanent vegetation (appropriate planting time for specified vegetation).

■ Apply permanent erosion control to areas deemed substantially complete during the project's defined seeding window.

Maintenance and Inspection

- Verify that work is progressing in accordance with the schedule. If progress deviates, take corrective actions.
- Amend the schedule when changes are warranted or when directed by the Resident Engineer (RE).
- The Special Provisions require annual submittal of a rainy season implementation schedule. Amend the schedule prior to the rainy season to show updated information on the deployment and implementation of construction site BMPs.

- Fence posts shall be either wood or metal, at the Contractor's discretion, as appropriate for the intended purpose. The post spacing and depth shall be adequate to completely support the fence in an upright position.

- Minimize the disturbed areas by locating temporary roadways to avoid stands of trees and shrubs and to follow existing contours to reduce cutting and filling.

- Consider the impact of grade changes to existing vegetation and the root zone.

Installation

- Construction materials, equipment storage, and parking areas shall be located where they will not cause root compaction.

- Keep equipment away from trees to prevent trunk and root damage.

- Maintain existing irrigation systems.

- Employees and subcontractors shall be instructed to honor protective devices. No heavy equipment, vehicular traffic, or storage piles of any construction materials shall be permitted within the drip line of any tree to be retained. Removed trees shall not be felled, pushed, or pulled into any retained trees. Fires shall not be permitted within 30 m (100 ft) of the drip line of any retained trees. Any fires shall be of limited size, and shall be kept under continual surveillance. No toxic or construction materials (including paint, acid, nails, gypsum board, chemicals, fuels, and lubricants) shall be stored within 15 m (50 ft) of the drip line of any retained trees, nor disposed of in any way which would injure vegetation.

Trenching and Tunneling

- Trenching shall be as far away from tree trunks as possible, usually outside of the tree drip line or canopy. Curve trenches around trees to avoid large roots or root concentrations. If roots are encountered, consider tunneling under them. When trenching and/or tunneling near or under trees to be retained, tunnels shall be at least 450 mm (18 in) below the ground surface, and not below the tree center to minimize impact on the roots.

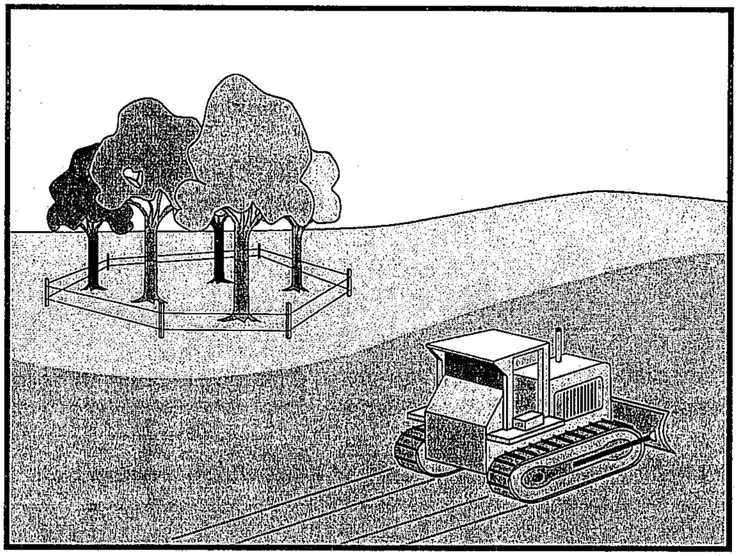
- Tree roots shall not be left exposed to air; they shall be covered with soil as soon as possible, protected, and kept moistened with wet burlap or peat moss until the tunnel and/or trench can be completed.

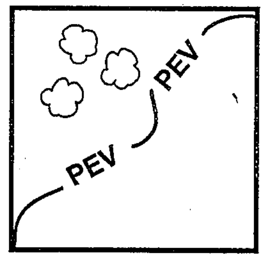
- The ends of damaged or cut roots shall be cut off smoothly.

- Trenches and tunnels shall be filled as soon as possible. Careful filling and tamping will eliminate air spaces in the soil which can damage roots.

- Remove any trees intended for retention if those trees are damaged seriously enough to affect their survival. If replacement is desired or required, the new tree shall be of similar species, and at least 50 mm (2 in) caliper, unless

Preservation of Existing Vegetation **SS-2**





Standard Symbol

BMP Objectives

- Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose Preservation of existing vegetation is the identification and protection of desirable vegetation that provides erosion and sediment control benefits.

Appropriate Applications

- Preserve existing vegetation at areas on a site where no construction activity is planned or will occur at a later date. Specifications for preservation of existing vegetation can be found in Standard Specifications, Section 7-1.11.
- On a year-round basis, temporary fencing shall be provided prior to the commencement of clearing and grubbing operations or other soil-disturbing activities in areas.
- Clearing and grubbing operations should be staged to preserve existing vegetation.

Limitations Protection of existing vegetation requires planning, and may limit the area available for construction activities.

Standards and Specifications

Timing

- Preservation of existing vegetation shall be provided prior to the commencement of clearing and grubbing operations or other soil-disturbing activities in areas identified on the plans to be preserved, especially on areas designated as Environmentally Sensitive Areas (ESAs).
- Preservation of existing vegetation shall conform to scheduling requirements set forth in the special provisions.

Design and Layout

- Mark areas to be preserved with temporary fencing made of orange polypropylene that is stabilized against ultraviolet light. The temporary fencing shall be at least 1 meter (3.2. ft) tall and shall have openings not larger than 50 mm by 50 mm (2 in by 2 in).

otherwise required by the contract documents.

- After all other work is complete, fences and barriers shall be removed last. This is because protected trees may be destroyed by carelessness during the final cleanup and landscaping.

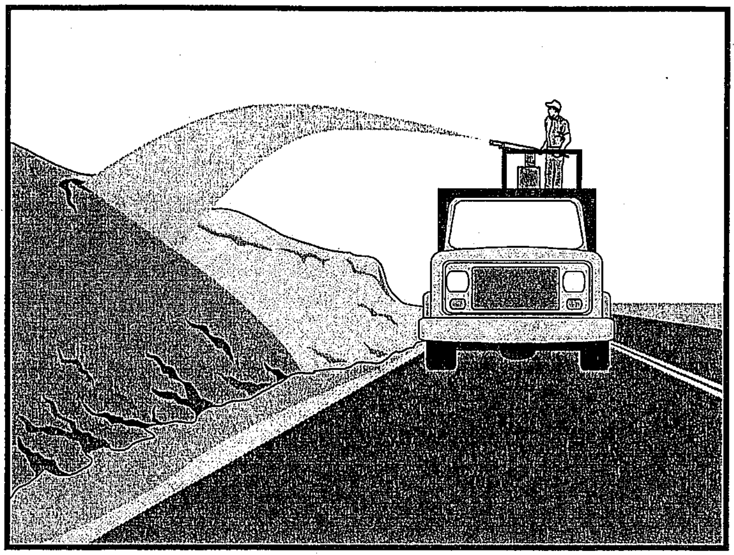
Maintenance and Inspection

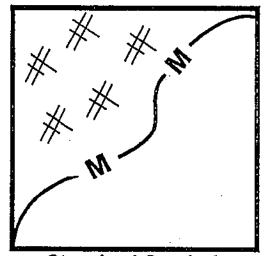
During construction, the limits of disturbance shall remain clearly marked at all times. Irrigation or maintenance of existing vegetation shall conform to the requirements in the landscaping plan. If damage to protected trees still occurs, maintenance guidelines described below shall be followed:

- Serious tree injuries shall be attended to by an arborist.
- During construction, District Environmental shall be contacted to ensure that ESAs are protected.

Hydraulic Mulch

SS-3





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ● Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Hydraulic mulch consists of applying a mixture of shredded wood fiber or a hydraulic matrix and a stabilizing emulsion or tackifier with hydroseeding equipment, which temporarily protects exposed soil from erosion by raindrop impact or wind. This is one of five temporary soil stabilization alternatives to consider.

Appropriate Applications

- Hydraulic mulch is applied to disturbed areas requiring temporary protection until permanent vegetation is established or disturbed areas that must re-disturbed following an extended period of inactivity.

Limitations

- Wood fiber hydraulic mulches are generally short-lived (only last a part of a growing season) and need 24 hours to dry before rainfall occurs to be effective.
- Paper mulches are not permitted.
- Avoid use in areas where the mulch would be incompatible with immediate future earthwork activities and would have to be removed.

Standards and Specifications

- Prior to application, roughen embankment and fill areas by rolling with a crimping or punching type roller or by track walking. Track walking shall only be used where other methods are impractical.
- Hydraulic matrices require 24 hours to dry before rainfall occurs to be effective unless approved by the Resident Engineer.
- Avoid mulch over-spray onto the traveled way, sidewalks, lined drainage channels, and existing vegetation.
- Selection of hydraulic mulches by the Contractor must be approved by the Resident Engineer (RE) or Construction Storm Water Coordinator.

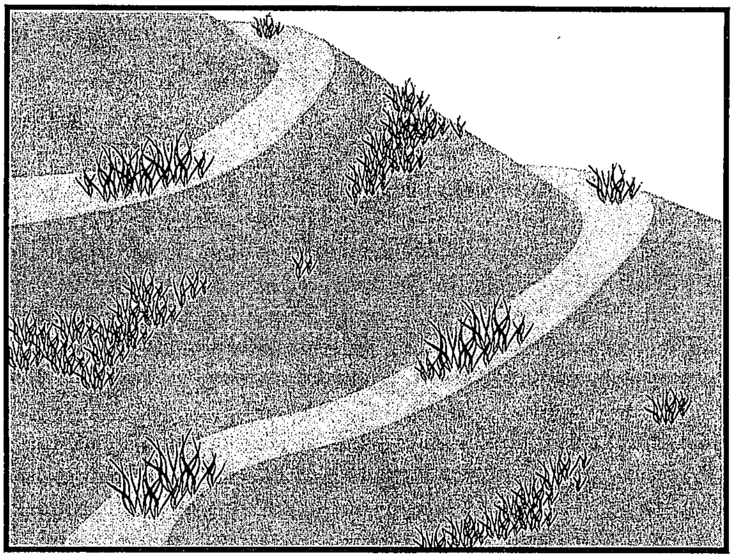
- Materials for wood fiber based hydraulic mulches and hydraulic matrices shall conform to Standard Specifications Section 20-2.07.
- Hydraulic Mulch
- Wood fiber mulch is a component of hydraulic applications. It is typically applied at the rate of 2,250 to 4,500 kilograms per hectare (kg/ha) (2,000 to 4,000 lb/ac) with 0-5% by weight of a stabilizing emulsion or tackifier (e.g., guar, psyllium, acrylic copolymer) and applied as a slurry. This type of mulch is manufactured from wood or wood waste from lumber mills or from urban sources. Specifications for wood fiber mulch can be found in Standard Specifications Sections 20-2.07 and 20-2.08.
- Hydraulic matrix is a combination of wood fiber mulch and a tackifier applied as a slurry. It is typically applied at the rate of 2,250 to 4,500 kilograms per hectare (kg/Ha) with 5-10% by weight of a stabilizing emulsion or tackifier (e.g., guar, psyllium, acrylic copolymer).
- Hydraulic Matrix
- Hydraulic matrix is a combination of wood fiber mulch and tackifier applied as a slurry. It is typically applied at the rate of 2,250 to 4,500 kg/ha with 5-10% by weight of a stabilizing emulsion or tackifier (e.g., guar, psyllium, acrylic copolymer).
- Bonded Fiber Matrix
- Bonded fiber matrix (BFM) is a hydraulically-applied system of fibers and adhesives that upon drying forms an erosion-resistant blanket that promotes vegetation, and prevents soil erosion. BFMs are typically applied at rates from 3,400 kg/ha to 4,500 kg/ha based on the manufacturer's recommendation. The biodegradable BFM is composed of materials that are 100% biodegradable. The binder in the BFM should also be biodegradable and should not dissolve or disperse upon re-wetting. Typically, biodegradable BFMs should not be applied immediately before, during or immediately after rainfall if the soil is saturated. Depending on the product, BFMs require 12 to 24 hours to dry to become effective.

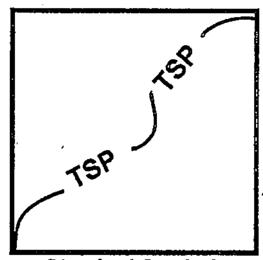
Maintenance and Inspections

- Maintain an unbroken, temporary mulched ground cover throughout the period of construction when the soils are not being reworked. Inspect before expected rain storms and repair any damaged ground cover and re-mulch exposed areas of bare soil.
- After any rainfall event, the Contractor is responsible for maintaining all slopes to prevent erosion.

Hydroseeding

SS-4





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ● Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Hydroseeding typically consists of applying a mixture of wood fiber, seed, fertilizer, and stabilizing emulsion with hydro-mulch equipment, which temporarily protects exposed soils from erosion by water and wind. This is one of five temporary soil stabilization alternatives to consider.

Appropriate Applications

- Hydroseeding is applied on disturbed soil areas requiring temporary protection until permanent vegetation is established or disturbed soil areas that must be re-disturbed following an extended period of inactivity.

Limitations

- Hydroseeding may be used alone only when there is sufficient time in the season to ensure adequate vegetation establishment and erosion control. Otherwise, hydroseeding must be used in conjunction with a soil binder or mulching (i.e., straw mulch), refer to BMP SS-5, Table 1 for options.
- Steep slopes are difficult to protect with temporary seeding.
- Temporary seeding may not be appropriate in dry periods without supplemental irrigation.
- Temporary vegetation may have to be removed before permanent vegetation is applied.
- Temporary vegetation is not appropriate for short-term inactivity.

Standards and Specifications

To select appropriate hydroseeding mixtures, an evaluation of site conditions shall be performed with respect to:

- Soil conditions
- Site topography
- Season and climate
- Vegetation types
- Maintenance requirements
- Sensitive adjacent areas
- Water availability
- Plans for permanent vegetation

- Selection of hydroseeding mixtures shall be approved by the District Landscape Architect and the Construction Storm Water Coordinator.

The following steps shall be followed for implementation:

- Seed mix shall comply with the Standard Specifications Section 20-2.10, and the project's special provisions.
- Hydroseeding can be accomplished using a multiple-step or one-step process; refer to the special provisions for specified process. The multiple-step process ensures maximum direct contact of the seeds to soil. When the one-step process is used to apply the mixture of fiber, seed, etc., the seed rate shall be increased to compensate for all seeds not having direct contact with the soil.
- Prior to application, roughen the slope, fill area, or area to be seeded with the furrows trending along the contours. Rolling with a crimping or punching type roller or track walking is required on all slopes prior to hydroseeding. Track walking shall only be used where other methods are impractical.
- Apply a straw mulch to keep seeds in place and to moderate soil moisture and temperature until the seeds germinate and grow, refer to Standard Specifications Sections 20-2.06 and 20-3.03.
- All seeds shall be in conformance with the California State Seed Law of the Department of Agriculture. Each seed bag shall be delivered to the site sealed and clearly marked as to species, purity, percent germination, dealer's guarantee, and dates of test; provide the Resident Engineer (RE) with such documentation. The container shall be labeled to clearly reflect the amount of Pure Live Seed (PLS) contained. All legume seed shall be pellet-inoculated. Inoculant sources shall be species-specific and shall be applied at a rate of 2 kg of inoculant per 100 kg of seed (2-lb inoculant per 100-lb seed), refer to Standard Specifications Section 20-2.10.
- Commercial fertilizer shall conform to the requirements of the California Food and Agricultural Code. Fertilizer shall be pelleted or granular form.

- Follow-up applications shall be made as needed to cover weak spots, and to maintain adequate soil protection.

- Avoid over-spray onto the traveled way, sidewalks, lined drainage channels, and existing vegetation.

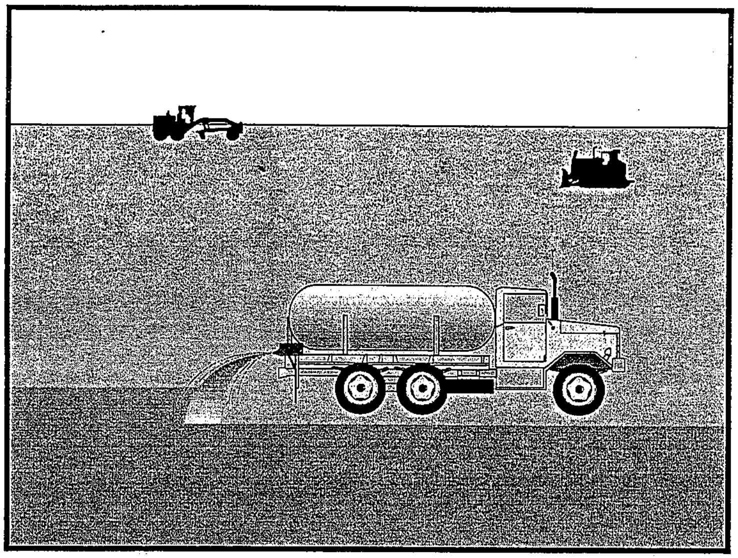
Maintenance and Inspection

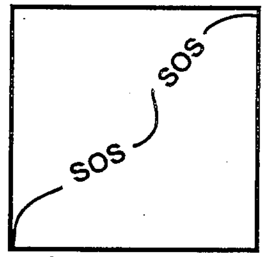
- All seeded areas shall be inspected for failures and re-seeded, fertilized, and mulched within the planting season, using not less than half the original application rates. Any temporary revegetation efforts that do not provide adequate cover must be reapplied at a scheduled recommended by the Caltrans Landscape Architect or RE.

- After any rainfall event, the Contractor is responsible for maintaining all slopes to prevent erosion.

Soil Binders

SS-5





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ● Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Soil binders consist of applying and maintaining a soil stabilizer to exposed soil surfaces. Soil binders are materials applied to the soil surface to temporarily prevent water-induced erosion of exposed soils on construction sites. Soil binders also provide temporary dust, wind, and soil stabilization (erosion control) benefits. This is one of five temporary soil stabilization alternatives to consider.

Appropriate Applications

Soil binders are typically applied to disturbed areas requiring short-term temporary protection. Because soil binders can often be incorporated into the work, they may be a good choice for areas where grading activities will soon resume. Application on stockpiles to prevent water and wind erosion.

Limitations

- Soil binders are temporary in nature and may need reapplication.
- Soil binders require a minimum curing time until fully effective, as prescribed by the manufacturer, which may be 24 hours or longer. Soil binders may need reapplication after a storm event.
- Soil binders will generally experience spot failures during heavy rainfall events. If runoff penetrates the soil at the top of a slope treated with a soil binder, it is likely that the runoff will undercut the stabilized soil layer and discharge at a point further down slope.
- Soil binders do not hold up to pedestrian or vehicular traffic across treated areas.
- Soil binders may not penetrate soil surfaces made up primarily of silt and clay, particularly when compacted.
- Storm water quality runoff sampling is required for many soil binders. Soil binders that do not require sampling are identified in the Caltrans SWPPP/WPCP Preparation Manual, Pollutant Table, Attachment S.

- Some soil binders may not perform well with low relative humidity. Under rainy conditions, some agents may become slippery or leach out of the soil.
- May not cure if low temperatures occur within 24 hours of application.

Standards and Specifications

General Considerations

- Site-specific soil types will dictate appropriate soil binders to be used.
- A soil binder must be environmentally benign (non-toxic to plant and animal life), easy to apply, easy to maintain, economical, and shall not stain paved or painted surfaces, refer to Standard Specifications Section 20-2.11.
- Some soil binders are compatible with existing vegetation.
- Performance of soil binders depends on temperature, humidity, and traffic across treated areas.
- Avoid over-spray onto the traveled way, sidewalks, lined drainage channels, and existing vegetation.

Soil Binders Applications

After selecting an appropriate soil binder, the untreated soil surface must be prepared before applying the soil binder. The untreated soil surface must contain sufficient moisture to assist the agent in achieving uniform distribution. In general, the following steps shall be followed:

- Follow manufacturer's recommendations for application rates, pre-wetting of application area, and cleaning of equipment after use.
- Prior to application, roughen embankment and fill areas by rolling with a crimping or punching type roller or by track walking. Track walking shall only be used where rolling is impractical.
- Consider the drying time for the selected soil binder and apply with sufficient time before anticipated rainfall. Soil binders shall not be applied during or immediately before rainfall.
- Avoid over-spray onto the traveled way, sidewalks, lined drainage channels, sound walls, and existing vegetation.
- Soil binders shall not be applied to frozen soil, areas with standing water, under freezing or rainy conditions, or when the air temperature is below 4oC (40oF) during the curing period.
- More than one treatment is often necessary, although the second treatment may be diluted or have a lower application rate.
- Generally, soil binders require a minimum curing time of 24 hours before they are fully effective. Refer to manufacturer's instructions for specific cure times.

- For liquid agents:
  - Crown or slope ground to avoid ponding.
  - Uniformly pre-wet ground at 0.14 to 1.4 L/m^2 (0.03 to 0.3 gal/yd^2) or according to manufacturer's recommendations.
  - Apply solution under pressure. Overlap solution 150 to 300 mm (6 to 12 in).
  - Allow treated area to cure for the time recommended by the manufacturer; typically, at least 24 hours.
  - In low humidities, reactivate chemicals by re-wetting with water at 0.5 to 0.9 L/m^2 (0.1 to 0.2 gal/yd^2).

Selecting a Soil Binder

Properties of common soil binders used for erosion control are provided in Table 1 and Appendix B. Use Table 1 to select an appropriate soil binder.

Factors to consider when selecting a soil binder include the following:

- Suitability to situation - Consider where the soil binder will be applied; determine if it needs a high resistance to leaching or abrasion, and whether it needs to be compatible with any existing vegetation. Determine the length of time soil stabilization will be needed, and if the soil binder will be placed in an area where it will degrade rapidly. In general, slope steepness is not a discriminating factor for the listed soil binders.
- Soil types and surface materials - Fines and moisture content are key properties of surface materials. Consider a soil binder's ability to penetrate, likelihood of leaching, and ability to form a surface crust on the surface materials.
- Frequency of application - The frequency of application can be affected by subgrade conditions, surface type, climate, and maintenance schedule. Frequent applications could lead to high costs. Application frequency may be minimized if the soil binder has good penetration, low evaporation, and good longevity. Consider also that frequent application will require frequent equipment clean-up.

After considering the above factors, the soil binders in Table 1 will be generally appropriate as follows:

Plant-Material Based (Short Lived)

-Guar: Guar is a non-toxic, biodegradable, natural galactomannan-based hydrocolloid treated with dispersent agents for easy field mixing. It shall be diluted at the rate of 1.2 to 1.8 kg per 1,000 liters (1 to 5 lb per 100 gallons) of water, depending on application machine capacity. Recommended minimum application rates are as follows:

Application Rates for Guar Soil Stabilizer

Slope (V:H):	Flat	1:4	1:3	1:2	1:1
Kg/Ha:	45	50	56	67	78
lb/ac	40	45	50	60	70

-Psyllium: Psyllium is composed of the finely ground muciloid coating of plantago seeds that is applied as a dry powder or in a wet slurry to the surface of the soil. It dries to form a firm but rewettable membrane that binds soil particles together but permits germination and growth of seed. Psyllium requires 12 to 18 hours drying time. Psyllium shall be applied at a rate of 90 to 225 kg/ha (80 to 200 lb/ac), with enough water in solution to allow for a uniform slurry flow.

-Starch: Starch is non-ionic, cold-water soluble (pre-gelatinized) granular cornstarch. The material is mixed with water and applied at the rate of 170 kg/ha (150 lb/ac). Approximate drying time is 9 to 12 hours.

Plant-Material Based (Long Lived)

-Pitch and Rosin Emulsion: Generally, a non-ionic pitch and rosin emulsion has a minimum solids content of 48%. The rosin shall be a minimum of 26% of the total solids content. The soil stabilizer shall be non-corrosive, water-dilutable emulsion that upon application cures to a water insoluble binding and cementing agent. For soil erosion control applications, the emulsion is diluted and shall be applied as follows:

For clayey soil: 5 parts water to 1 part emulsion

For sandy soil: 10 parts water to 1 part emulsion

Application can be by water truck or hydraulic seeder with the emulsion/product mixture applied at the rate specified by the manufacturer. Approximate drying time is 19 to 24 hours.

Polymeric Emulsion Blends

-Acrylic Copolymers and Polymers: Polymeric soil stabilizers shall consist of a liquid or solid polymer or copolymer with an acrylic base that contains a minimum of 55% solids. The polymeric compound shall be handled and mixed in a manner that will not cause foaming or shall contain an anti-foaming agent. The polymeric emulsion shall not exceed its shelf life or expiration date; manufacturers shall provide the expiration date. Polymeric soil stabilizer shall be readily miscible in water, non-injurious to seed or animal life, non-flammable, shall provide surface soil stabilization for various soil types without totally inhibiting water infiltration, and shall not re-emulsify when cured. The applied compound shall air cure within a maximum of 36 to 48 hours. Liquid copolymer shall be diluted at a rate of 10 parts water to 1 part polymer and applied to soil at a rate of 11,000 liters/hectare (1,175 gal/ac).

-Liquid Polymers of Methacrylates and Acrylates: This material consists of a tackifier/sealer that is a liquid polymer of methacrylates and acrylates. It is an aqueous 100% acrylic emulsion blend of 40% solids by volume that is free from styrene, acetate, vinyl, ethoxylated surfactants or silicates. For soil stabilization applications, it is diluted with water in accordance with manufacturer's recommendations, and applied with a hydraulic seeder at the rate of 190 L/ha (20 gal/ac). Drying time is 12 to 18 hours after application.

-Copolymers of Sodium Acrylates and Acrylamides: These materials are non-toxic, dry powders that are copolymers of sodium acrylate and acrylamide. They are mixed with water and applied to the soil surface for erosion control at rates that are determined by slope gradient:

Slope Gradient (V:H)	kg/ha (lb/ac)
Flat to 1:5	3.4 – 5.6 (3-5)
1:5 to 1:3	5.6 – 11.2 (5-10)
1:2 to 1:1	11.2 – 22.4 (10-20)

-Poly-Acrylamide and Copolymer of Acrylamide: Linear copolymer polyacrylamide is packaged as a dry-flowable solid. When used as a stand-alone stabilizer, it is diluted at a rate of 1.5 kg/1,000 liters (1 lb/100 gal) of water and applied at the rate of 5.6 kg/ha (5 lb/ac).

-Hydro-Colloid Polymers: Hydro-Colloid Polymers are various combinations of dry-flowable poly-acrylamides, copolymers and hydro-colloid polymers that are mixed with water and applied to the soil surface at rates of 60 to 70 kg/ha (53 to 62 lb/ac). Drying times are 0 to 4 hours.

Cementitious-Based Binders

-*Gypsum:* This is a formulated gypsum-based product that readily mixes with water and mulch to form a thin protective crust on the soil surface. It is composed of high purity gypsum that is ground, calcined and processed into calcium sulfate hemihydrate with a minimum purity of 86%. It is mixed in a hydraulic seeder and applied at rates 4,500 to 13,500 kg/ha (4,000 to 12,000 lb/ac). Drying time is 4 to 8 hours.

Maintenance and Inspection

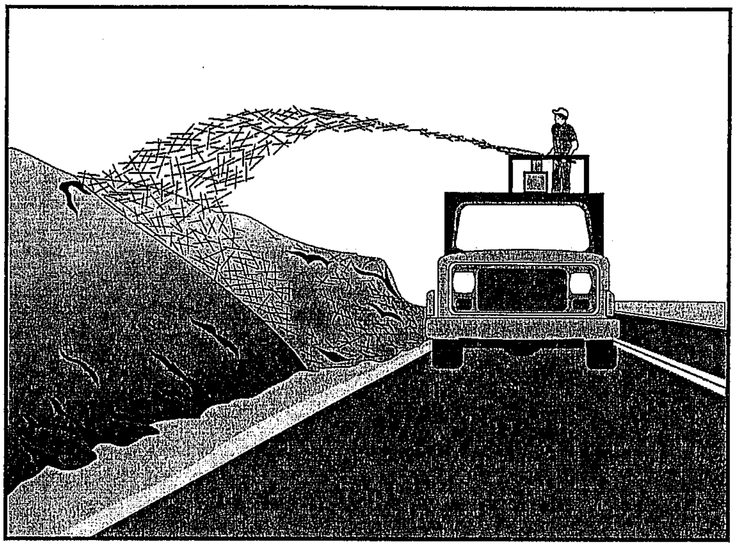
- Reapplying the selected soil binder may be needed for proper maintenance. High traffic areas shall be inspected daily, and lower traffic areas shall be inspected weekly.
- After any rainfall event, the Contractor is responsible for maintaining all slopes to prevent erosion.
- Maintain an unbroken, temporary stabilized area while DSAs are nonactive. Repair any damaged stabilized area and re-apply soil binder to exposed areas.

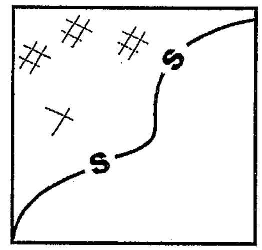
Table 1 Properties of Soil Binders for Erosion Control				
Chemicals	**Plant Material Based (Short Lived)**	**Plant Material Based (Long Lived)**	**Polymeric Emulsion Blends**	**Cementitious-Based Binders**
Relative Cost	Low	Low	Low	Low
Resistance to Leaching	High	High	Low to Moderate	Moderate
Resistance to Abrasion	Moderate	Low	Moderate to High	Moderate to High
Longevity	Short to Medium	Medium	Medium to Long	Medium
Minimum Curing Time before Rain	9 to 18 hours	19 to 24 hours	0 to 24 hours	4 to 8 hours
Compatibility with Existing Vegetation	Good	Poor	Poor	Poor
Mode of Degradation	Biodegradable	Biodegradable	Photodegradable/ Chemically Degradable	Photodegradable/ Chemically Degradable
Labor Intensive	No	No	No	No
Specialized Application Equipment	Water Truck or Hydraulic Mulcher	Water Truck or Hydraulic Mulcher	Water Truck or Hydraulic Mulcher	Water Truck or Hydraulic Mulcher
Liquid/Powder	Powder	Liquid	Liquid/Powder	Powder
Surface Crusting	Yes, but dissolves on rewetting	Yes	Yes, but dissolves on rewetting	Yes
Clean-Up	Water	Water	Water	Water
Erosion Control Application Rate	Varies (1)	Varies (1)	Varies (1)	4,500 to 13,500 kg/ha

(1) Dependant on product, soil type, and slope inclination

Straw Mulch

SS-6





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ● Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Straw mulch consists of placing a uniform layer of straw and incorporating it into the soil with a studded roller or anchoring it with a stabilizing emulsion. This is one of five temporary soil stabilization alternatives to consider.

Appropriate Applications

- Straw mulch is typically used for soil stabilization as a temporary surface cover on disturbed areas until soils can be prepared for revegetation and permanent vegetation is established.
- Also typically used in combination with temporary and/or permanent seeding strategies to enhance plant establishment.

Limitations

- Availability of erosion control contractors and straw may be limited prior to the rainy season due to high demand.
- There is a potential for introduction of weed-seed and unwanted plant material.
- When straw blowers are used to apply straw mulch, the treatment areas must be within 45 m (150 ft) of a road or surface capable of supporting trucks.
- Straw mulch applied by hand is more time intensive and potentially costly.
- May have to be removed prior to permanent seeding or soil stabilization.
- "Punching" of straw does not work in sandy soils.

Standards and Specifications

- Straw shall be derived from wheat, rice, or barley.
- All materials shall conform to Standard Specifications Sections 20-2.06, 20-2.07 and 20-2.11.
- A tackifier is the preferred method for anchoring straw mulch to the soil on slopes.
- Crimping, punch roller-type rollers, or track-walking may also be used to incorporate straw mulch into the soil on slopes. Track walking shall only be used where other methods are impractical.
- Avoid placing straw onto the traveled way, sidewalks, lined drainage channels, sound walls, and existing vegetation.
- Straw mulch with tackifier shall not be applied during or immediately before rainfall.

Application Procedures

- Apply loose straw at a minimum rate of 3,570 kg/ha (4,000 lb/ac), or as indicated in the project's special provisions, either by machine or by hand distribution.
- If stabilizing emulsion will be used to anchor the straw mulch in lieu of incorporation, roughen embankment or fill areas by rolling with a crimping or punching-type roller or by track walking before placing the straw mulch. Track walking should only be used where rolling is impractical.
- The straw mulch must be evenly distributed on the soil surface.
- Anchor the mulch in place by using a tackifier or by "punching" it into the soil mechanically (incorporating).
- A tackifier acts to glue the straw fibers together and to the soil surface. The tackifier shall be selected based on longevity and ability to hold the fibers in place.
- A tackifier is typically applied at a rate of 140 kg/ha (125 lb/ac). In windy conditions, the rates are typically 200 kg/ha (178 lb/ac).
- Methods for holding the straw mulch in place depend upon the slope steepness, accessibility, soil conditions and longevity. If the selected method is incorporation of straw mulch into the soil, then do as follows:
  - Applying and incorporating straw shall follow the requirements in Standard Specifications Section 20-3.03.
  - On small areas, a spade or shovel can be used.

- On slopes with soils, which are stable enough and of sufficient gradient to safely support construction equipment without contributing to compaction and instability problems, straw can be "punched" into the ground using a knife-blade roller or a straight bladed coulter, known commercially as a "crimper."

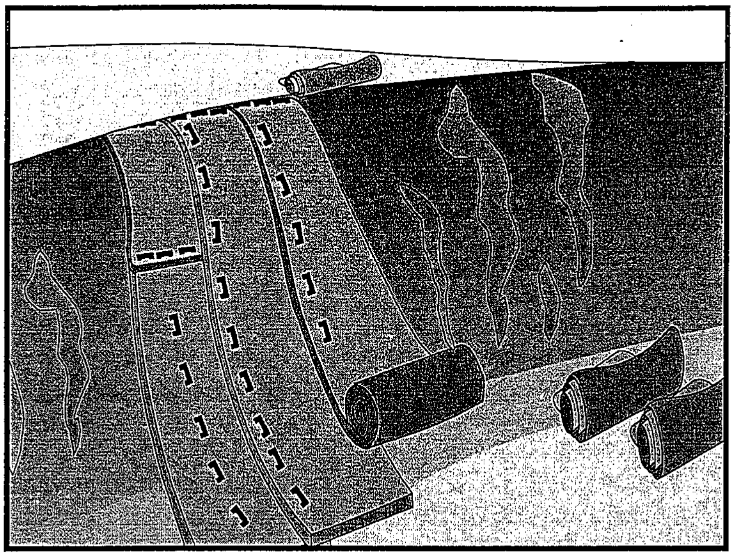
- On small areas and/or steep slopes, straw can also be held in place using plastic netting or jute. The netting shall be held in place using 11 gauge wire staples, geotextile pins or wooden stakes. Refer to BMP SS-7, "Geotextiles, Plastic Covers and Erosion Control Blankets/Mats."

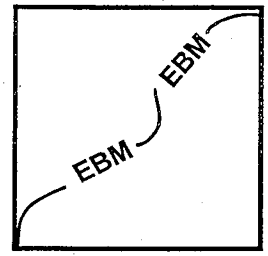
Maintenance and Inspections

- The key consideration in Maintenance and Inspection is that the straw needs to last long enough to achieve erosion control objectives.
- Maintain an unbroken, temporary mulched ground cover while DSAs are non-active. Repair any damaged ground cover and re-mulch exposed areas.
- Reapplication of straw mulch and tackifier may be required by the Resident Engineer (RE) to maintain effective soil stabilization over disturbed areas and slopes.
- After any rainfall event, the Contractor is responsible for maintaining all slopes to prevent erosion.

Geotextiles, Mats, Plastic Covers and Erosion Control Blankets

SS-7





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ● Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

This Best Management Practice (BMP) involves the placement of geotextiles, mats, plastic covers, or erosion control blankets to stabilize disturbed soil areas and protect soils from erosion by wind or water. This is one of five temporary soil stabilization alternatives to consider.

Appropriate Applications

These measures are used when disturbed soils may be particularly difficult to stabilize, including the following situations:

- Steep slopes, generally steeper than 1:3 (V:H).
- Slopes where the erosion potential is high.
- Slopes and disturbed soils where mulch must be anchored.
- Disturbed areas where plants are slow to develop.
- Channels with flows exceeding 1.0 m/s (3.3 ft/s).
- Channels to be vegetated.
- Stockpiles.
- Slopes adjacent to water bodies of Environmentally Sensitive Areas (ESAs).

Limitations

- Blankets and mats are more expensive than other erosion control measures, due to labor and material costs. This usually limits their application to areas inaccessible to hydraulic equipment, or where other measures are not applicable, such as channels.
- Blankets and mats are generally not suitable for excessively rocky sites, or areas where the final vegetation will be mowed (since staples and netting can catch in mowers).
- Blankets and mats must be removed and disposed of prior to application of permanent soil stabilization measures.
- Plastic sheeting is easily vandalized, easily torn, photodegradable, and must be disposed of at a landfill.
- Plastic results in 100% runoff, which may cause serious erosion problems in the areas receiving the increased flow.
- The use of plastic shall be limited to covering stockpiles, or very small graded areas for short periods of time (such as through one imminent storm event), until alternative measures, such as seeding and mulching, may be installed.
- Geotextiles, mats, plastic covers, and erosion control covers have maximum flow rate limitations; consult the manufacturer for proper selection.

Standards and Specifications

Material Selection

There are many types of erosion control blankets and mats, and selection of the appropriate type shall be based on the specific type of application and site conditions. Selection(s) made by the Contractor must be approved by the Resident Engineer (RE); certification of compliance shall be in accordance with Standard Specifications Section 6-1.07.

Geotextiles

- Material shall be a woven polypropylene fabric with minimum thickness of 1.5 mm (0.06 inch), minimum width of 3.7 m (12 ft) and shall have minimum tensile strength of 0.67 kN (warp) 0.36 kN (fill) in conformance with the requirements in ASTM Designation: D 4632. The permittivity of the fabric shall be approximately 0.07 sec –1 in conformance with the requirements in ASTM Designation: D4491. The fabric shall have an ultraviolet (UV) stability of 70 percent in conformance with the requirements in ASTM designation: D4355. Geotextile blankets shall be secured in place with wire staples or sandbags and by keying into tops of slopes and edges to prevent infiltration of surface waters under Geotextile. Staples shall be made of 3.05-mm (0.12-inch) steel wire and shall be U-shaped with 200-mm (8-inch) legs and 50-mm (2-inch) crown.
- Geotextiles may be reused if, in the opinion of the RE, they are suitable for the use intended.

Plastic Covers

- Plastic sheeting shall have a minimum thickness of 6 mil, and shall be keyed in at the top of slope and firmly held in place with sandbags or other weights placed no more than 3 m (10 ft) apart. Seams are typically taped or weighted down their entire length, and there shall be at least a 300 mm to 600 mm (12 to 24 inches) overlap of all seams. Edges shall be embedded a minimum of 150 mm (6 inches) in soil.

- All sheeting shall be inspected periodically after installation and after significant rainstorms to check for erosion, undermining, and anchorage failure. Any failures shall be repaired immediately. If washout or breakages occurs, the material shall be re-installed after repairing the damage to the slope.

Erosion Control Blankets/Mats

- Biodegradable rolled erosion control products (RECPs) are typically composed of jute fibers, curled wood fibers, straw, coconut fiber, or a combination of these materials. For an RECP to be considered 100% biodegradable, the netting, sewing or adhesive system that holds the biodegradable mulch fibers together must also be biodegradable.

  - **Jute** is a natural fiber that is made into a yarn, which is loosely woven into a biodegradable mesh. It is designed to be used in conjunction with vegetation and has longevity of approximately one year. The material is supplied in rolled strips, which shall be secured to the soil with U-shaped staples or stakes in accordance with manufacturers' recommendations.

  - **Excelsior (curled wood fiber)** blanket material shall consist of machine produced mats of curled wood excelsior with 80 percent of the fiber 150 mm (6 inches) or longer. The excelsior blanket shall be of consistent thickness. The wood fiber shall be evenly distributed over the entire area of the blanket. The top surface of the blanket shall be covered with a photodegradable extruded plastic mesh. The blanket shall be smolder resistant without the use of chemical additives and shall be non-toxic and non-injurious to plant and animal life. Excelsior blanket shall be furnished in rolled strips, a minimum of 1220 mm (48 inches) wide, and shall have an average weight of 0.5 kg/m^2 (12 lb/ft^2), ±10 percent, at the time of manufacture. Excelsior blankets shall be secured in place with wire staples. Staples shall be made of 3.05-mm (0.12 inch) steel wire and shall be U-shaped with 200-mm (8-inch) legs and 50-mm (2-inch) crown.

- **Straw blanket** shall be machine-produced mats of straw with a lightweight biodegradable netting top layer. The straw shall be attached to the netting with biodegradable thread or glue strips. The straw blanket shall be of consistent thickness. The straw shall be evenly distributed over the entire area of the blanket. Straw blanket shall be furnished in rolled strips a minimum of 2 m (6.5 ft) wide, a minimum of 25 m (80 ft) long and a minimum of 0.27 kg/m2 (6.4 lb/ft2). Straw blankets shall be secured in place with wire staples. Staples shall be made of 3.05-mm (0.12 inch) steel wire and shall be U-shaped with 200-mm (8-inch) legs and 50-mm (2-inch) crown.

- **Wood fiber blanket** is composed of biodegradable fiber mulch with extruded plastic netting held together with adhesives. The material is designed to enhance revegetation. The material is furnished in rolled strips, which shall be secured to the ground with U-shaped staples or stakes in accordance with manufacturers' recommendations.

- **Coconut fiber blanket** shall be machine-produced mats of 100% coconut fiber with biodegradable netting on the top and bottom. The coconut fiber shall be attached to the netting with biodegradable thread or glue strips. The coconut fiber blanket shall be of consistent thickness. The coconut fiber shall be evenly distributed over the entire area of the blanket. Coconut fiber blanket shall be furnished in rolled strips with a minimum of 2 m (6.5 ft) wide, a minimum of 25 m (80 ft) long and a minimum of 0.27-kg/m2 (6.4 lb/ft2). Coconut fiber blankets shall be secured in place with wire staples. Staples shall be made of 3.05-mm (0.12 inch) steel wire and shall be U-shaped with 200-mm (8-inch) legs and 50-mm (2-inch) crown.

- **Coconut fiber mesh** is a thin permeable membrane made from coconut or corn fiber that is spun into a yarn and woven into a biodegradable mat. It is designed to be used in conjunction with vegetation and typically has longevity of several years. The material is supplied in rolled strips, which shall be secured to the soil with U-shaped staples or stakes in accordance with manufacturers' recommendations.

- **Straw coconut fiber blanket** shall be machine-produced mats of 70% straw and 30% coconut fiber with a biodegradable netting top layer and a biodegradable bottom net. The straw and coconut fiber shall be attached to the netting with biodegradable thread or glue strips. The straw coconut fiber blanket shall be of consistent thickness. The straw and coconut fiber shall be evenly distributed over the entire area of the blanket. Straw coconut fiber blanket shall be furnished in rolled strips a minimum of 2 m (6.5 ft) wide, a minimum of 25 m (80 ft) long and a minimum of 0.27 kg/m2 (6.4 lb/ft2). Straw coconut fiber blankets shall be secured in place with wire staples. Staples shall be made of 3.05-mm (0.12-inch) steel wire and shall be U-shaped with 200-mm (8-inch) legs and 50-mm (2-inch) crown.

- Non-biodegradable RECPs are typically composed of polypropylene, polyethylene, nylon or other synthetic fibers. In some cases, a combination of biodegradable and synthetic fibers is used to construct the RECP. Netting used to hold these fibers together is typically non-biodegradable as well.

  - **Plastic netting** is a lightweight biaxially-oriented netting designed for securing loose mulches like straw to soil surfaces to establish vegetation. The netting is photodegradable. The netting is supplied in rolled strips, which shall be secured with U-shaped staples or stakes in accordance with manufacturers' recommendations.

  - **Plastic mesh** is an open-weave geotextile that is composed of an extruded synthetic fiber woven into a mesh with an opening size of less than 0.5 cm (0.2 inch). It is used with revegetation or may be used to secure loose fiber such as straw to the ground. The material is supplied in rolled strips, which shall be secured to the soil with U-shaped staples or stakes in accordance with manufacturers' recommendations.

  - **Synthetic fiber with netting** is a mat that is composed of durable synthetic fibers treated to resist chemicals and ultraviolet light. The mat is a dense, three-dimensional mesh of synthetic (typically polyolefin) fibers stitched between two polypropylene nets. The mats are designed to be revegetated and provide a permanent composite system of soil, roots, and geomatrix. The material is furnished in rolled strips, which shall be secured with U-shaped staples or stakes in accordance with manufacturers' recommendations.

  - **Bonded synthetic fibers** consist of a three-dimensional geomatrix nylon (or other synthetic) matting. Typically it has more than 90% open area, which facilitates root growth. Its tough root-reinforcing system anchors vegetation and protects against hydraulic lift and shear forces created by high volume discharges. It can be installed over prepared soil, followed by seeding into the mat. Once vegetated, it becomes an invisible composite system of soil, roots, and geomatrix. The material is furnished in rolled strips that shall be secured with U-shaped staples or stakes in accordance with manufacturers' recommendations.

  - **Combination synthetic and biodegradable RECPs** consist of biodegradable fibers, such as wood fiber or coconut fiber, with a heavy polypropylene net stitched to the top and a high-strength continuous-filament geomatrix or net stitched to the bottom. The material is designed to enhance revegetation. The material is furnished in rolled strips, which shall be secured with U-shaped staples or stakes in accordance with manufacturers' recommendations.

Site Preparation

- Proper site preparation is essential to ensure complete contact of the blanket or matting with the soil.
- Grade and shape the area of installation.
- Remove all rocks, clods, vegetation or other obstructions so that the installed blankets or mats will have complete, direct contact with the soil.
- Prepare seedbed by loosening 50 mm (2 in) to 75 mm (3 in) of topsoil.

Seeding

Seed the area before blanket installation for erosion control and revegetation. Seeding after mat installation is often specified for turf reinforcement application. When seeding prior to blanket installation, all check slots and other areas disturbed during installation must be re-seeded. Where soil filling is specified, seed the matting and the entire disturbed area after installation and prior to filling the mat with soil.

Anchoring

- U-shaped wire staples, metal geotextile stake pins or triangular wooden stakes can be used to anchor mats and blankets to the ground surface.
- Staples shall be made of 3.05 mm (0.12 inch) steel wire and shall be U-shaped with 200-mm (8-inch) legs and 50-mm (2-inch) crown.
- Metal stake pins shall be 5 mm (0.188 in) diameter steel with a 40 mm (1.5 in) steel washer at the head of the pin.
- Wire staples and metal stakes shall be driven flush to the soil surface.
- All anchors shall be 150 mm (6 in) to 450 mm (18 in) long and have sufficient ground penetration to resist pullout. Longer anchors may be required for loose soils.

Installation on Slopes

Installation shall be in accordance with the manufacturer's recommendations. In general, these will be as follows:

- Begin at the top of the slope and anchor the blanket in a 150 mm (6 in) deep by 150 mm (6 in) wide trench. Backfill trench and tamp earth firmly.
- Unroll blanket downslope in the direction of water flow.

- Overlap the edges of adjacent parallel rolls 50 mm (2 in) to 75 mm (3 in) and staple every 1 m (3 ft).
- When blankets must be spliced, place blankets end over end (shingle style) with 150 mm (6 in) overlap. Staple through overlapped area, approximately 300 mm (12 in) apart.
- Lay blankets loosely and maintain direct contact with the soil. Do not stretch.
- Staple blankets sufficiently to anchor blanket and maintain contact with the soil. Staples shall be placed down the center and staggered with the staples placed along the edges. Steep slopes, 1:1 (V:H) to 1:2 (V:H), require a minimum of 2 staples/m2 (2 staples/yd2). Moderate slopes, 1:2 (V:H) to 1:3 (V:H), require a minimum of 1½ staples/m2 (1 ½ staples/yd2), placing 1 staple/m (1 staple/yd) on centers. Gentle slopes require a minimum of 1 staple/m2 (1 staple/yd2).

Installation in Channels

Installation shall be in accordance with the manufacturer's recommendations. In general, these will be as follows:

- Dig initial anchor trench 300 mm (12 in) deep and 150 mm (6 in) wide across the channel at the lower end of the project area.
- Excavate intermittent check slots, 150 mm (6 in) deep and 150 mm (6 in) wide across the channel at 8 m to 10 m (25 ft to 30 ft) intervals along the channels.
- Cut longitudinal channel anchor slots 100 mm (4 in) deep and 100 mm (4 in) wide along each side of the installation to bury edges of matting, whenever possible extend matting 50 mm (2 in) to 75 mm (3 in) above the crest of the channel side slopes.
- Beginning at the downstream end and in the center of the channel, place the initial end of the first roll in the anchor trench and secure with fastening devices at 300 mm (12 in) intervals. Note: matting will initially be upside down in anchor trench.
- In the same manner, position adjacent rolls in anchor trench, overlapping the preceding roll a minimum of 75 mm (3 in).
- Secure these initial ends of mats with anchors at 300 mm (12 in) intervals, backfill and compact soil.
- Unroll center strip of matting upstream. Stop at next check slot or terminal anchor trench. Unroll adjacent mats upstream in similar fashion, maintaining a 75 mm (3 in) overlap.

- Fold and secure all rolls of matting snugly into all transverse check slots. Lay mat in the bottom of the slot then fold back against itself. Anchor through both layers of mat at 300 mm (12 in) intervals, then backfill and compact soil. Continue rolling all mat widths upstream to the next check slot or terminal anchor trench.

- Alternate method for non-critical installations: Place two rows of anchors on 150 mm (6 in) centers at 8 m (25 ft) to 10 m (30 ft) intervals in lieu of excavated check slots.

- Shingle-lap spliced ends by a minimum of 300 mm (12 in) apart on 300 mm (12 in) intervals.

- Place edges of outside mats in previously excavated longitudinal slots, anchor using prescribed staple pattern, backfill and compact soil.

- Anchor, fill and compact upstream end of mat in a 300 mm (12 in) by 150 mm (6 in) terminal trench.

- Secure mat to ground surface using U-shaped wire staples, geotextile pins, or wooden stakes.

- Seed and fill turf reinforcement matting with soil, if specified.

Soil Filling (if specified for turf reinforcement)

- Always consult the manufacturer's recommendations for installation.

- Do not drive tracked or heavy equipment over mat.

- Avoid any traffic over matting if loose or wet soil conditions exist.

- Use shovels, rakes or brooms for fine grading and touch up.

- Smooth out soil filling, just exposing top netting of mat.

Temporary Soil Stabilization Removal

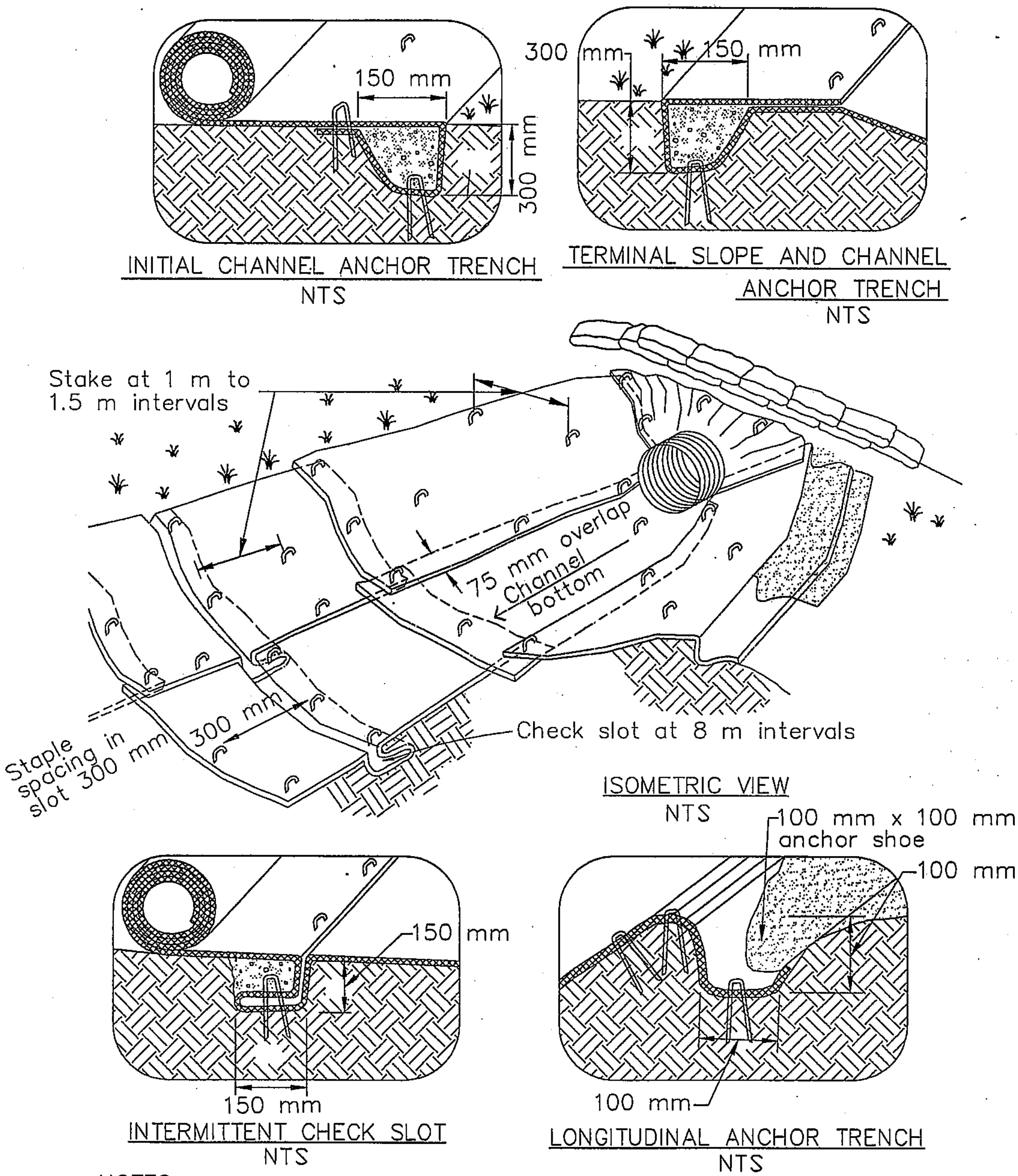
- When no longer required for the work, temporary soil stabilization shall become the property of the Contractor. Temporary soil stabilization removed from the site of the work shall be disposed of outside the highway right-of-way in conformance with the provisions in Standard Specifications Section 7-1.13. If approved by the RE, the contractor may leave the temporary soil stabilizer in place.

Maintenance and Inspection

Areas treated with temporary soil stabilization shall be inspected as specified in the special provisions. Areas treated with temporary soil stabilization shall be maintained to provide adequate erosion control. Temporary soil stabilization shall be reapplied or replaced on exposed soils when area becomes exposed or exhibits visible erosion.

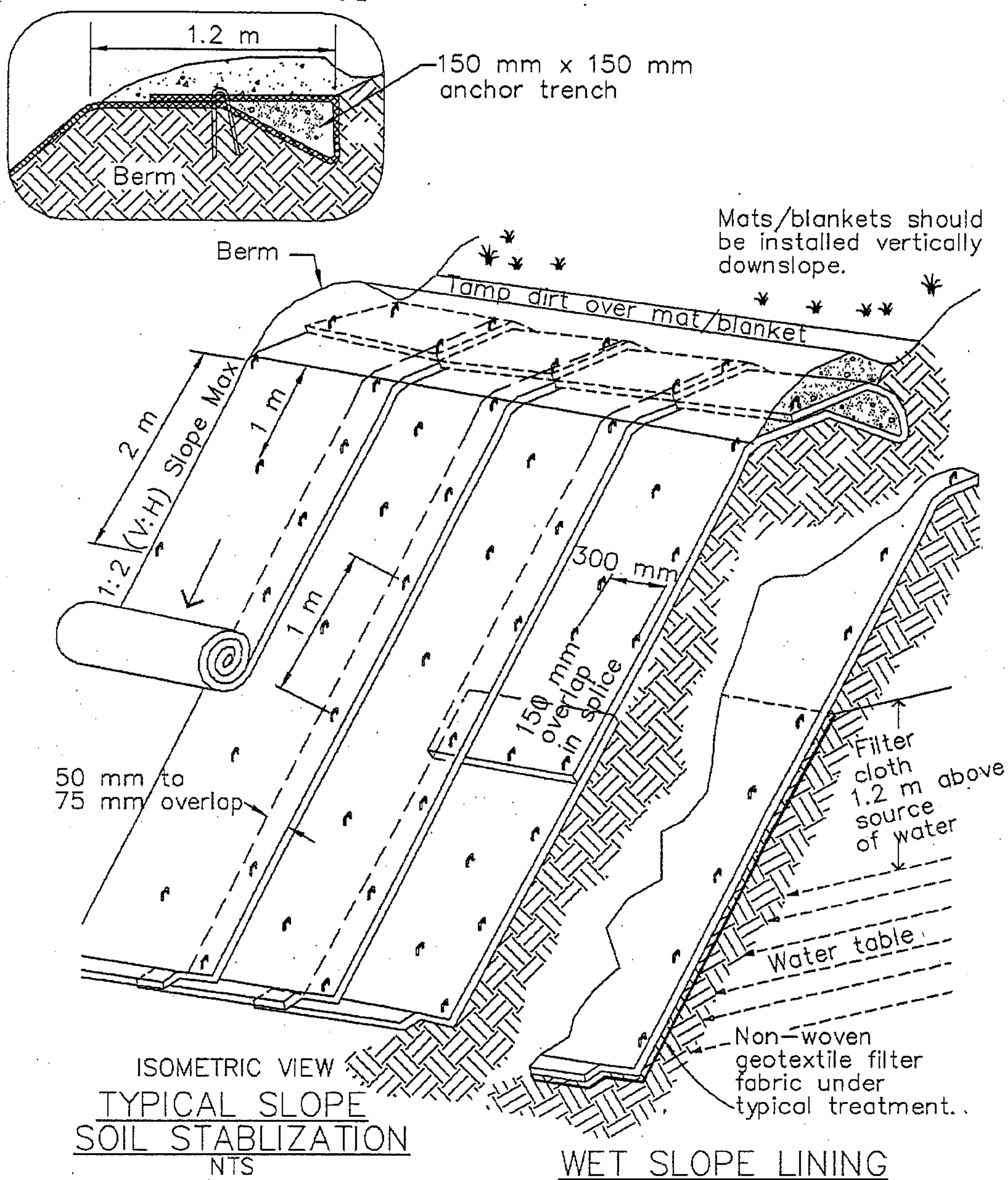
- All blankets and mats shall be inspected periodically after installation.
- Installation shall be inspected after significant rain storms to check for erosion and undermining. Any failures shall be repaired immediately.
- If washout or breakage occurs, re-install the material after repairing the damage to the slope or channel.

Typical Installation Detail



NOTES:
1. Check slots to be constructed per manufacturers specifications.
2. Staking or stapling layout per manufacturers specifications.
3. Install per manufacturer's recommendations

Typical Installation Detail

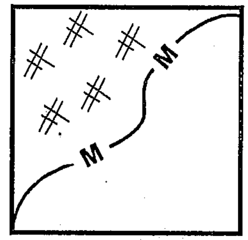


NOTES:

1. Slope surface shall be free of rocks, clods, sticks and grass. Mats/blankets shall have good soil contact.
2. Lay blankets loosely and stake or staple to maintain direct contact with the soil. Do not stretch.
3. Install per manufacturer's recommendations

Wood Mulching

SS-8



Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ● Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Wood mulching consist of applying a mixture of shredded wood mulch, bark or compost. Wood mulch is mostly applicable to landscape projects.

The primary function of wood mulching is to reduce erosion by protecting bare soil from rainfall impact, increasing infiltration, and reducing runoff.

Appropriate Applications

Wood mulching is considered a temporary soil stabilization (erosion control) alternative in the following situations:

- As a stand-alone temporary surface cover on disturbed areas until soils can be prepared for revegetation and permanent vegetative cover can be established.
- As short term, non-vegetative ground cover on slopes to reduce rainfall impact, decrease the velocity of sheet flow, settle out sediment and reduce wind erosion.

Limitations

- Wood mulch may introduce unwanted species.
- Shredded wood does not withstand concentrated flows and is prone to sheet erosion.
- Green material has the potential for the presence of unwanted weeds and other plant materials. Delivery system is primarily by manual labor, although pneumatic application equipment is available.

Standards and Specifications

Mulch Selection

There are many types of mulches, and selection of the appropriate type shall be based on the type of application and site conditions. Prior to use of wood mulches, there shall be concurrence with the District Landscape Architect since some mulch use on construction projects may not be compatible with planned or future projects. Selection of wood mulches by the Contractor shall comply with Standard Specifications Section 20-2.08, and must be approved by the Resident Engineer (RE).

Application Procedures

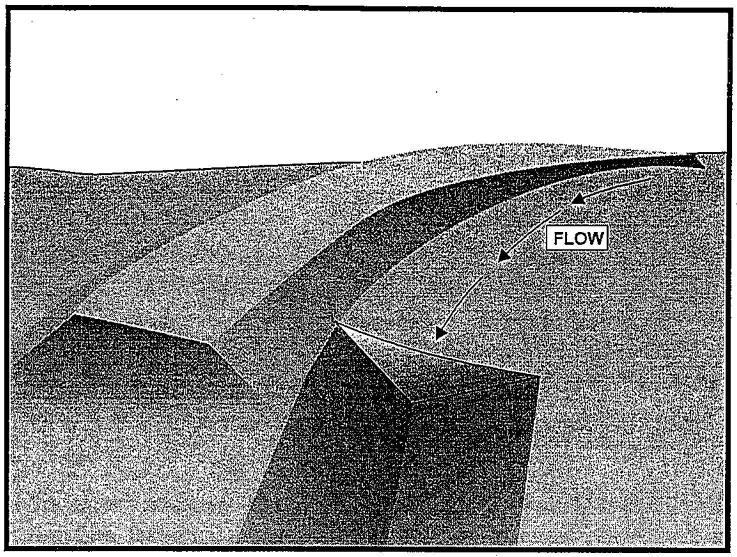
Prior to application, after existing vegetation has been removed, roughen embankment and fill areas by rolling with a punching-type roller or by track walking. The construction-application procedures for mulches vary significantly depending upon the type of mulching method specified. Two (2) methods are highlighted here:

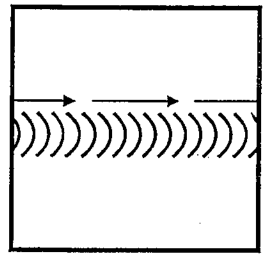
- Green Material: This type of mulch is produced by recycling vegetation trimmings such as grass, shredded shrubs and trees. Methods of application are generally by hand, although pneumatic methods are available. Mulch shall be composted to kill weed seeds.
  - It can be used as a temporary ground cover with or without seeding.
  - The green material shall be evenly distributed on site to a depth of not more than 50 mm (2 in).
- Shredded Wood: Suitable for ground cover in ornamental or revegetated plantings.
  - Shredded wood/bark is conditionally suitable; see note under limitations.
  - Shall be distributed by hand (although pneumatic methods may be available).
  - The mulch shall be evenly distributed across the soil surface to a depth of 50 mm (2 in) to 75 mm (3 in).
- Avoid mulch placement onto the traveled way, sidewalks, lined drainage channels, sound walls, and existing vegetation.
- All material must be removed before re-starting work on the slopes.

Maintenance and Inspection	■ Regardless of the mulching technique selected, the key consideration in Maintenance and Inspection is that the mulch needs to last long enough to achieve erosion-control objectives. If the mulch is applied as a stand-alone erosion control method over disturbed areas (without seed), it shall last the length of time the site will remain barren or until final re-grading and revegetation. ■ Where vegetation is not the ultimate cover, such as ornamental and landscape applications of bark or wood chips, inspection and maintenance shall focus on longevity and integrity of the mulch.

Earth Dikes/Drainage Swales and Lined Ditches

SS-9





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

These are structures that intercept, divert and convey surface run-on, generally sheet flow, to prevent erosion.

Appropriate Applications

- Earth dikes/drainage swales and lined ditches may be used to:
  - Convey surface runoff down sloping land.
  - Intercept and divert runoff to avoid sheet flow over sloped surfaces.
  - Divert and direct runoff towards a stabilized watercourse, drainage pipe or channel.
  - Intercept runoff from paved surfaces.
- Earth dikes/drainage swales and lined ditches also may be used:
  - Below steep grades where runoff begins to concentrate.
  - Along roadways and facility improvements subject to flood drainage.
  - At the top of slopes to divert run-on from adjacent or undisturbed slopes.
  - At bottom and mid-slope locations to intercept sheet flow and convey concentrated flows.
- This BMP may be implemented on a project-by-project basis with other BMPs when determined necessary and feasible by the Resident Engineer (RE).

Earth Dikes/Drainage Swales and Lined Ditches

SS-9

Limitations

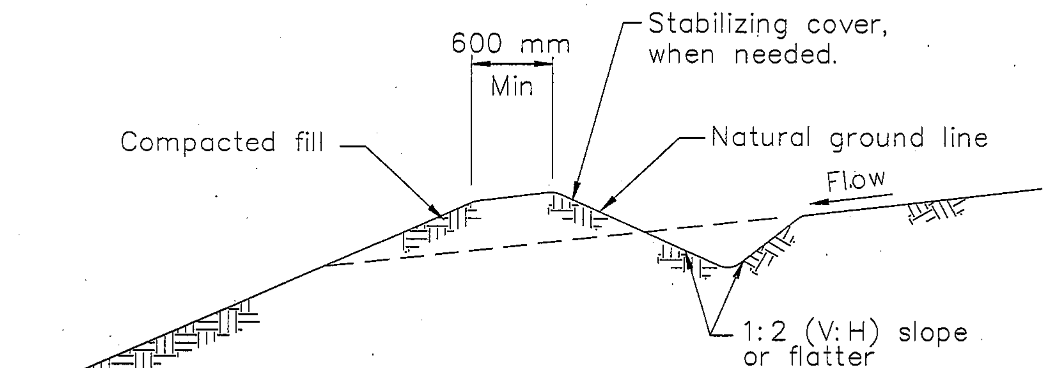
- Earth dikes/drainage swales and lined ditches are not suitable as sediment trapping devices.
- May be necessary to use other soil stabilization and sediment controls, such as check dams, plastics, and blankets, to prevent scour and erosion in newly graded dikes, swales and ditches.

Standards and Specifications

- Care must be applied to correctly size and locate earth dikes, drainage swales and lined ditches. Excessively steep, unlined dikes and swales are subject to erosion and gully formation.
- Conveyances shall be stabilized.
- Use a lined ditch for high flow velocities.
- Select flow velocity based on careful evaluation of the risks due to erosion of the measure, soil types, over topping, flow backups, washout, and drainage flow patterns for each project site.
- Compact any fills to prevent unequal settlement.
- Do not divert runoff from the highway right-of-way onto other property.
- When possible, install and utilize permanent dikes, swales and ditches early in the construction process.
- Provide stabilized outlets. Refer to SS-10, "Outlet Protection/Velocity/ Dissipation Devices."

Maintenance and Inspections

- Inspect temporary measures prior to the rainy season, after rainfall events, and regularly (approximately once per week) during the rainy season.
- Inspect ditches and berms for washouts. Replace lost riprap, damaged linings or soil stabilizers as needed.
- Inspect channel linings, embankments, and beds of ditches and berms for erosion and accumulation of debris and sediment. Remove debris and sediment, and repair linings and embankments as needed or as directed by the RE.
- Temporary conveyances shall be completely removed as soon as the surrounding drainage area has been stabilized, or at the completion of construction.

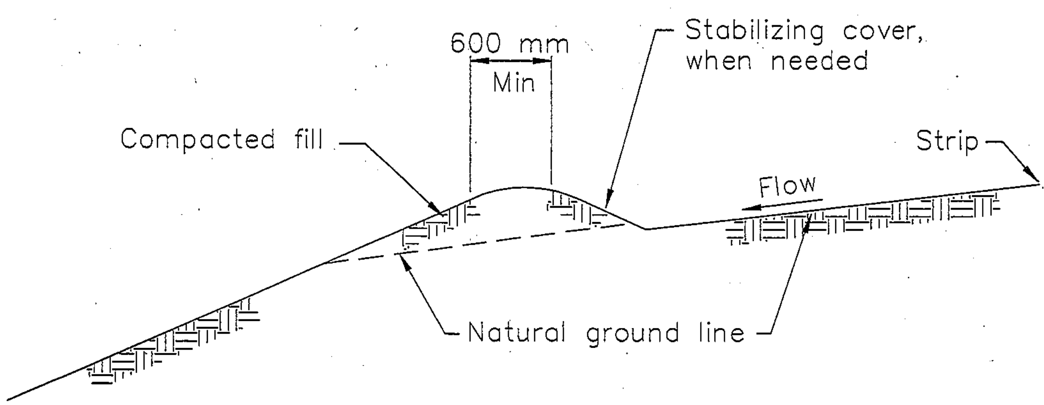


TYPICAL DRAINAGE SWALE

NOT TO SCALE

NOTES:

1. Stabilize inlet, outlets and slopes.
2. Properly compact the subgrade, in conformance with Section 19–5 of the Caltrans Standard Specifications.

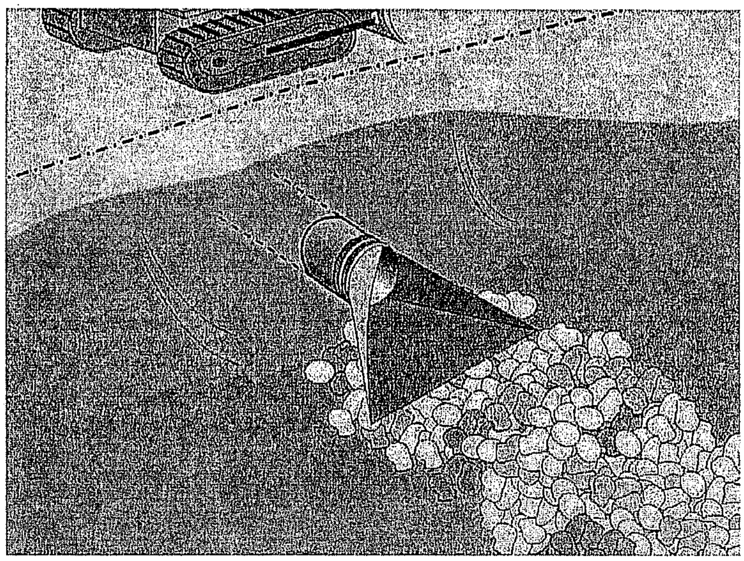


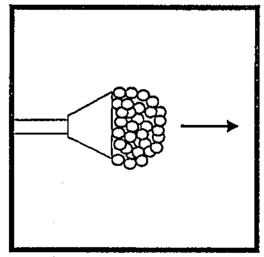
TYPICAL EARTH DIKE

NOT TO SCALE

Outlet Protection/Velocity Dissipation Devices

SS-10





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

These devices are placed at pipe outlets to prevent scour and reduce the velocity and/or energy of storm water flows.

Appropriate Applications

- These devices may be used at the following locations:
  - Outlets of pipes, drains, culverts, slope drains, diversion ditches, swales, conduits or channels.
  - Outlets located at the bottom of mild to steep slopes.
  - Discharge outlets that carry continuous flows of water.
  - Outlets subject to short, intense flows of water, such as flash floods.
  - Points where lined conveyances discharge to unlined conveyances.
- This BMP may be implemented on a project-by-project basis with other BMPs when determined necessary and feasible by the Resident Engineer (RE).

Limitations

- Loose rock may have stones washed away during high flows.
- Grouted riprap may break up in areas of freeze and thaw.
- If there is not adequate drainage, and water builds up behind grouted riprap, it may cause the grouted riprap to break up due to the resulting hydrostatic pressure.

Standards and Specifications

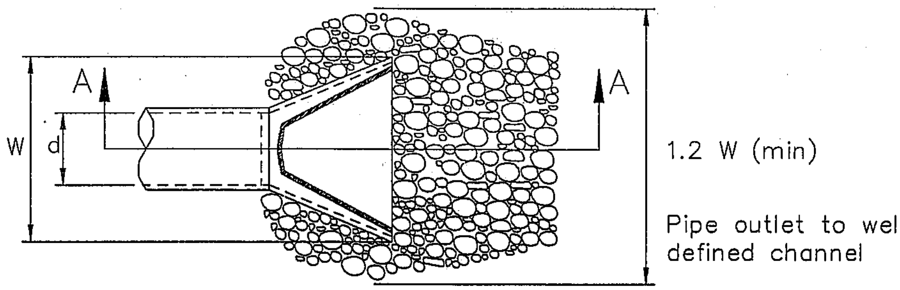
- There are many types of energy dissipaters, with rock being the one that is represented in the figure on Page 3. Please note that this is only one example and the RE may approve other types of devices proposed by the contractor.
- Install riprap, grouted riprap, or concrete apron at selected outlet. Riprap aprons are best suited for temporary use during construction.
- Carefully place riprap to avoid damaging the filter fabric.
- For proper operation of apron:
  - Align apron with receiving stream and keep straight throughout its length. If a curve is needed to fit site conditions, place it in upper section of apron.
  - If size of apron riprap is large, protect underlying filter fabric with a gravel blanket.
- Outlets on slopes steeper than 10% shall have additional protection.

Maintenance and Inspection

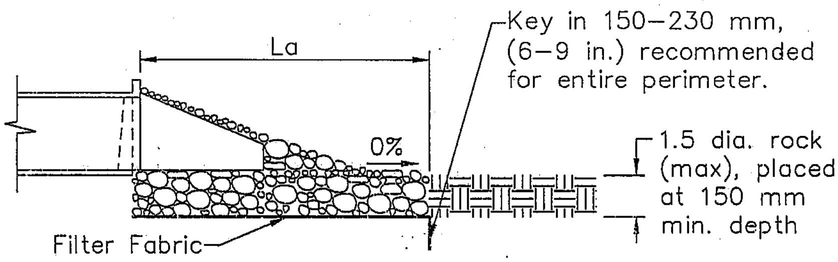
- Inspect temporary measures prior to the rainy season, after rainfall events, and regularly (approximately once per week) during the rainy season.
- Inspect apron for displacement of the riprap and/or damage to the underlying fabric. Repair fabric and replace riprap that has washed away.
- Inspect for scour beneath the riprap and around the outlet. Repair damage to slopes or underlying filter fabric immediately.
- Temporary devices shall be completely removed as soon as the surrounding drainage area has been stabilized, or at the completion of construction.

Outlet Protection/Velocity Dissipation Devices

SS-10



PLAN VIEW
NTS



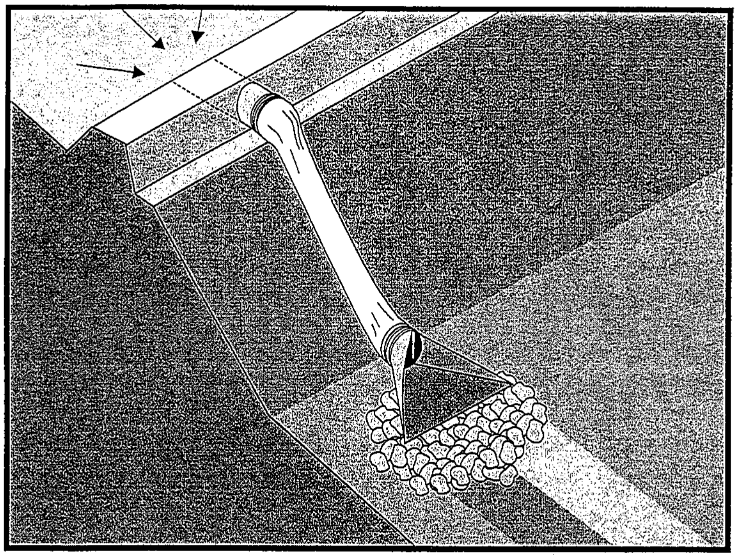
SECTION A–A
NTS

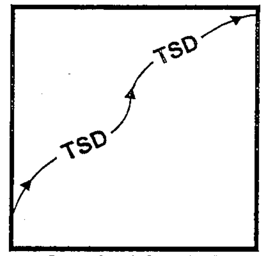
Pipe Diameter mm	Discharge m^3/s	Apron Length, La m	Rip Rap D_{50} Diameter Min mm
300	0.14	3	100
	0.28	4	150
450	0.28	3	150
	0.57	5	200
	0.85	7	300
	1.13	8	400
600	0.85	5	200
	1.13	8	200
	1.42	8	300
	1.70	9	400
For larger or higher flows, consult a Registered Civil Engineer			

Source: USDA – SCS

Slope Drains

SS-11





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A slope drain is a pipe used to intercept and direct surface runoff or groundwater into a stabilized watercourse, trapping device or stabilized area. Slope drains are used with lined ditches to intercept and direct surface flow away from slope areas to protect cut or fill slopes.

Appropriate Applications

- Slope drains may be used on construction sites where slopes may be eroded by surface runoff.
- This BMP may be implemented on a project-by-project basis with other BMPs when determined necessary and feasible by the Resident Engineer (RE).

Limitations

- Severe erosion may result when slope drains fail by overtopping, piping, or pipe separation.

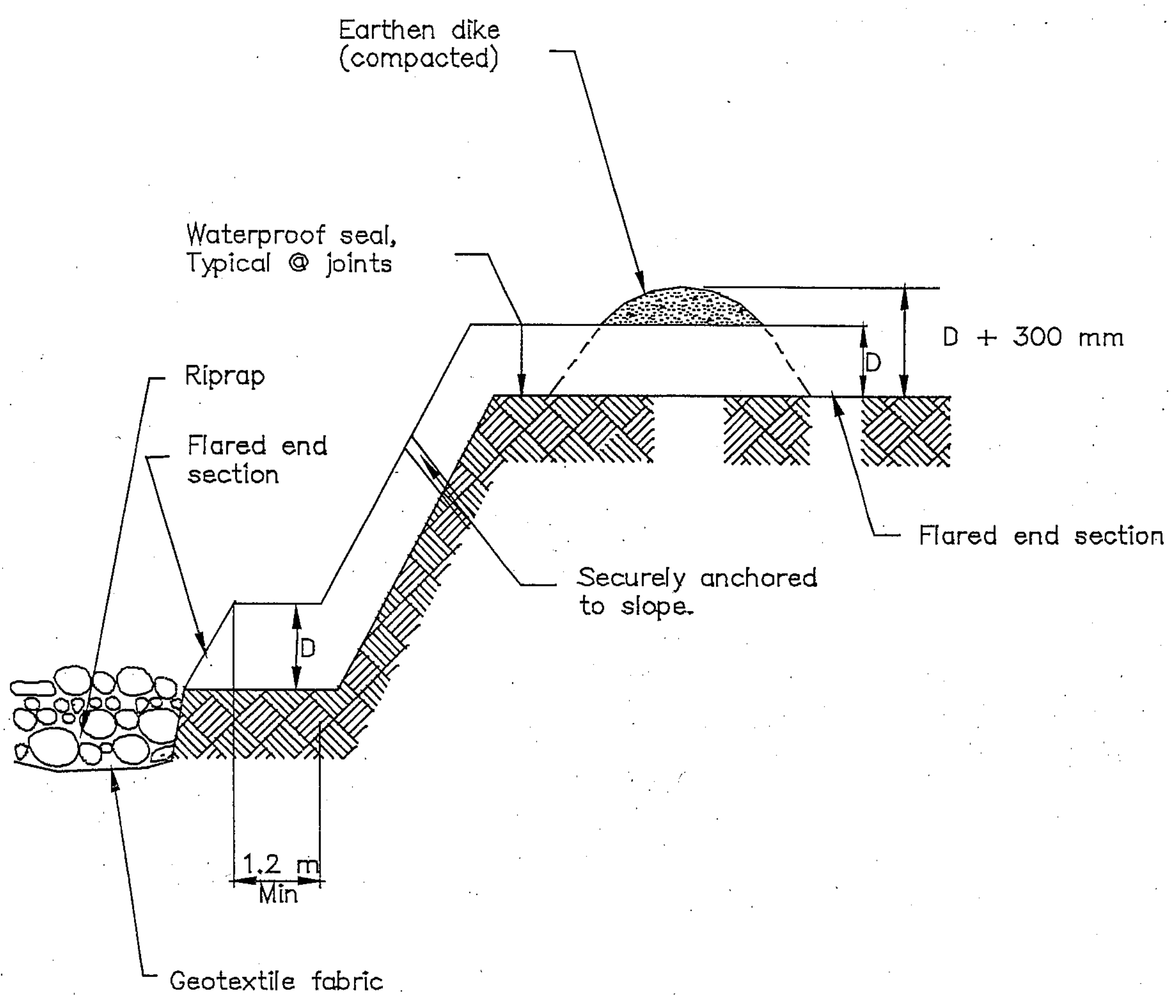
Standards and Specifications

- When using slope drains, limit drainage area to 4 ha (10 ac) per pipe. For larger areas, use a rock-lined channel or a series of pipes.
- Maximum slope generally limited to 1:2 (V:H), as energy dissipation below steeper slopes is difficult.
- Direct surface runoff to slope drains with interceptor dikes. See BMP SS-8, "Earth Dikes/Drainage Swales, and Lined Ditches."
- Slope drains can be placed on or buried underneath the slope surface.
- Recommended materials are PVC, ABS, or comparable pipe.
- When installing slope drains:
  - Install slope drains perpendicular to slope contours.

- Compact soil around and under entrance, outlet, and along length of pipe.
- Securely anchor and stabilize pipe and appurtenances into soil.
- Check to ensure that pipe connections are water tight.
- Protect area around inlet with filter cloth. Protect outlet with riprap or other energy dissipation device. For high energy discharges, reinforce riprap with concrete or use reinforced concrete device.
- Protect inlet and outlet of slope drains; use standard flared end section at entrance and exit for pipe slope drains 300 mm (12in) and larger.

Maintenance and Inspection

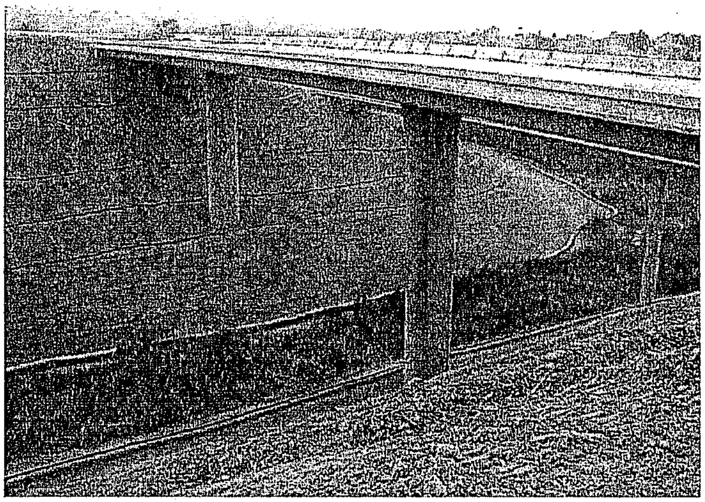
- Inspect before and after each rain storm, and twice monthly until the tributary drainage area has been stabilized. Follow routine inspection procedures for inlets thereafter.
- Inspect outlet for erosion and downstream scour. If eroded, repair damage and install additional energy dissipation measures. If downstream scour is occurring, it may be necessary to reduce flows being discharged into the channel unless other preventative measures are implemented.
- Inspect slope drainage for accumulations of debris and sediment.
- Remove built-up sediment from entrances, outlets, and within drains as required.
- Make sure water is not ponding onto inappropriate areas (e.g., active traffic lanes, material storage areas, etc.).

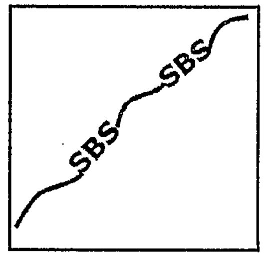


TYPICAL SLOPE DRAIN
NOT TO SCALE

Streambank Stabilization

SS-12





Standard Symbol

BMP Objectives
- ● Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

Drainage systems including the stream channel, streambank, and associated riparian areas, are dynamic and sensitive ecosystems that respond to changes in land use activity. Streambank and channel disturbance resulting from construction activities can increase the stream's sediment load, which can cause channel erosion or sedimentation and have adverse affects on the biotic system. Best Management Practices can reduce the discharge of sediment and other pollutants and minimize the impact of construction activities on watercourses. Streams included on the 303(d) list by the State Water Resources Control Board (SWRCB) may require careful evaluation to prevent any increases in sedimentation, siltation and/or turbidity to the stream.

Appropriate Applications

These procedures typically apply to all construction projects that disturb or occur within stream channels and their associated riparian areas.

Limitations

Specific permit requirements or mitigation measures such as Regional Water Quality Control Board (RWQCB) 401 Certification, U.S. Army Corps of Engineers 404 permit and approval by California Department of Fish and Game may be included in contract documents. If numerical-based water quality standards are mentioned in any of these and other related permits, testing and sampling may be required. Streams included on the 303(d) list by the State Water Resources Control Board because of being impaired by sediment, silt, or turbidity are required to conduct sampling to verify that there is no net increase in sediment load due to construction activities.

Standards and Specifications

PLANNING

- Proper planning, design, and construction techniques can minimize impacts normally associated with in-stream construction activities. Poor planning can adversely affect soil, fish, and wildlife resources, land uses, or land users. Planning should take into account: scheduling, avoidance of in-stream construction; minimizing disturbance area and construction time period; using pre-disturbed areas; selecting crossing location; and selecting equipment.

Scheduling (SS-1)

- Construction activities should be scheduled according to the relative sensitivity of the environmental concerns and in accordance with SS-1, "Scheduling." Scheduling considerations will be different when working near perennial streams vs. ephemeral streams and are as follows:

  – Construction work in perennial streams should optimally be performed during the rainy season. This is because in the summer, any sediment-containing water that is discharged into the watercourse will cause a large change in both water clarity and water chemistry. During the rainy season, there is typically more and faster flowing water in the stream so discharges are diluted faster. However, should in-stream work be scheduled for summer, establishing an isolation area, or diverting the stream will significantly decrease the amount of sediment stirred up by construction work. Construction work near perennial streams should optimally be performed during the dry season (see below).

  – When working in or near ephemeral streams, or near perennial streams, work should be performed during the dry season. By their very nature, ephemeral streams are usually dry in the summer, and therefore, in-stream construction activities will not cause significant water quality problems. However, when closing the site at the end of the project, wash any fines (see Washing Fines) that accumulated in the channel back into the bed material, to decrease pollution from the first rainstorm ("first flush") of the season. When working near ephemeral or perennial streams, erosion and sediment controls (see silt fences, straw bale barriers, etc.) should be implemented to keep sediment out of stream channel.

Minimize Disturbance

- Minimize disturbance through: selection of the narrowest crossing location; limiting the number of equipment trips across a stream during construction; and, minimizing the number and size of work areas (equipment staging areas and spoil storage areas). Place work areas at least 15 m (50 ft) from the stream channel. Provide stabilized access to the stream when in-stream work is required. Field reconnaissance should be conducted during the planning stage to identify work areas.

Use of Pre-Disturbed Areas

- Locate project sites and work areas in pre-disturbed areas when possible.

Selection of Project Site

- Avoid steep and unstable banks, highly erodible or saturated soils, or highly fractured rock.

- Select project site that minimizes disturbance to aquatic species or habitat.

Equipment Selection

- Select equipment that reduces the amount of pressure exerted on the ground surface, and therefore, reduces erosion potential and/or use overhead or aerial access for transporting equipment across drainage channels. Use equipment that exerts ground pressures of less than 5 or 6 pounds per square inch (PSI), where possible. Low ground pressure equipment includes: wide or high flotation tires (860 to 1850 mm [34 to 72 in] wide); dual tires; bogie axle systems; tracked machines; lightweight equipment; and, central tire inflation systems.

STREAMBANK STABILIZATION

Preservation of Existing Vegetation (SS-2)

- Preserve existing vegetation in accordance with SS-2, "Preservation of Existing Vegetation." In a streambank environment preservation of existing vegetation provides the following benefits:

  Water Quality Protection:

  Vegetated buffers on slopes trap sediment and promote groundwater recharge. The buffer width needed to maintain water quality ranges from 5 to 30 m (16 to 98 ft). On gradual slopes, most of the filtering occurs within the first 10 m (33 ft). Steeper slopes require a greater width of vegetative buffer to provide water quality benefits.

  Streambank Stabilization:

  The root system of riparian vegetation stabilizes streambanks by increasing tensile strength in the soil. The presence of vegetation modifies the moisture condition of slopes (infiltration, evapotranspiraton, interception) and increases bank stability.

  Riparian Habitat

  Buffers of diverse riparian vegetation provide food and shelter for riparian and aquatic organisms. Minimizing impacts to fisheries habitat is a major concern when working near streams and rivers. Riparian vegetation provides shade, shelter, organic matter (leaf detritus and large woody debris), and other nutrients that are necessary for fish and other aquatic organisms. Buffer widths for habitat concerns are typically wider than those recommended for water quality concerns (30 to 500 m [98 to 1,640 ft]).

  When working near watercourses, it is important to understand the work site's placement in the watershed. Riparian vegetation in the headwater streams has a greater impact on overall water quality than vegetation in downstream reaches. Preserving existing vegetation upstream is necessary to maintain water quality, minimize bank failure, and maximize riparian habitat downstream of the work site.

Limitations:

- Local county and municipal ordinances regarding width, extent and type of vegetative buffer required may exceed the specifications provided here; these ordinances should be investigated prior to construction.

Streambank Stabilization Specific Installation:

- As a general rule, the width of a buffer strip between a road and the stream is recommended to be 15 m (48 ft) plus four times the percent slope of the land, measured between the road and the top of stream bank.

Hydraulic Mulch (SS-3)

- Apply hydraulic mulch on disturbed streambanks above the mean high water level in accordance with SS-3, "Hydraulic Mulch" to provide temporary soil stabilization.

Limitations

- Do not place hydraulic mulch or tackifiers below the mean high water level, as these materials could wash into the channel and impact water quality or possibly cause eutrophication.

Hydroseeding (SS-4)

- Hydroseed disturbed streambanks in accordance with SS-4, "Hydroseeding."

Limitations

- Do not place tackifiers or fertilizers below the mean high water level, as these materials could wash into the channel and impact water quality or possibly cause eutrophication.

Soil Binders (SS-5)

- Apply soil binders to disturbed streambanks in accordance with SS-5, "Soil Binders."

Limitations

- Do not place soil binders below the mean high water level. Soil binder must be environmentally benign and non-toxic to aquatic organisms.

Straw Mulch (SS-6)

- Apply straw mulch to disturbed streambanks in accordance with SS-6, "Straw Mulch."

Limitations

- Do not place straw mulch below the mean high water level, as this material could wash into the channel and impact water quality or possibly cause eutrophication.

Geotextiles, Plastic Covers, & Erosion Control Blankets/Mats (SS-7)

- Install geotextiles, erosion control blankets and plastic as described in SS-7, "Geotextiles, Plastic Covers, & Erosion Control Blankets/Mats" to stabilize disturbed channels and streambanks. Not all applications should be in the channel, for example, certain geotextile netting may snag fish gills and are not appropriate in fish-bearing streams. Geotextile fabrics that are not biodegradable are not appropriate for in-stream use. Additionally, geotextile fabric or blankets placed in channels must be adequate to sustain anticipated hydraulic forces.

Earth Dikes/Drainage Swales, and Lined Ditches (SS-9)

- Convey, intercept, or divert runoff from disturbed streambanks using SS-9, "Earth Dikes/Drainage Swales, and Lined Ditches."

Limitations

- Do not place earth dikes in watercourses, as these structures are only suited for intercepting sheet flow, and should not be used to intercept concentrated flow.
- Place appropriately sized outlet protection and energy dissipation in accordance with SS-10, "Outlet Protection/Velocity dissipation Devices."

Outlet Protection/Velocity Dissipation Devices (SS-10)

- Place outlet protection or velocity dissipation devices at outlets of pipes, drains, culverts, slope drains, diversion ditches, swales, conduits or channels in accordance with SS-10.

Slope Drains (SS-11)

- Use slope drains to intercept and direct surface runoff or groundwater into a stabilized watercourse, trapping device or stabilized area in accordance with SS-11, "Slope Drains."

Limitations

- Appropriately sized outlet protection/velocity dissipation devices must be placed at outlets to minimize erosion and scour.

STREAMBANK SEDIMENT CONTROL

Silt Fences (SC-1)

- Install silt fences in accordance with SC-1, "Silt Fence" to control sediment. Silt fences should only be installed where sediment-laden water can pond, thus allowing the sediment to settle out.

Fiber Rolls (SC-5)

- Install fiber rolls in accordance with SC-5, "Fiber Rolls" along slope contour above the high water level to intercept runoff, reduce flow velocity, release the runoff as sheet flow and provide removal of sediment from the runoff. In a stream environment, fiber rolls should be used in conjunction with other sediment control methods such as SC-1, "Silt Fence" or SC-9, "Straw Bale Barrier." Install silt fence, straw bale barrier, or other erosion control methods along the toe of slope above the high water level.

Gravel Bag Berm (SC-6)

- A gravel bag berm or barrier can be utilized to intercept and slow the flow of sediment-laden sheet flow runoff in accordance with SC-6, "Gravel Bag Berm." In a stream environment gravel bag barriers can allow sediment to settle from runoff before water leaves the construction site and can be used to isolate the work area from the stream.

Limitations:

- Gravel bag barriers are not recommended as a perimeter sediment control practice around streams.

Straw Bale Barrier (SC-9)

- Install straw bale barriers in accordance with SC-9, "Straw Bale Barrier" to control sediment. Straw bale barriers should only be installed where sediment-laden water can pond, thus allowing the sediment to settle out. Install a silt fence in accordance with SC-1, "Silt Fence" on the down-slope side of the straw bale barrier closest to stream channel to provide added sediment control.

Rock Filter

Description and Purpose:

- Rock filters are temporary erosion-control barriers composed of rock that is anchored in place. Rock filters detain the sediment-laden runoff, retain the sediment, and release the water as sheet flow at a reduced velocity. Typical rock filter installations are illustrated at the end of this Section.

Applications:

- Near the toe of slopes that may be subject to flow and rill erosion.

Limitations:

- Inappropriate for drainage areas greater than 2 ha (5 ac).
- Requires sufficient space for ponded water.
- Ineffective for diverting runoff because filters allow water to slowly seep through.

- Rock filter berms are difficult to remove when construction is complete.
- Unsuitable in developed areas or locations where esthetics is a concern.

Specifications:

- Rock: open-graded rock, 19 to 125 mm (0.75 to 5 inches) for concentrated flow applications.
- Woven wire sheathing: 25 mm (1 inch) diameter, hexagonal mesh, galvanized 20-gauge (used with rock filters in areas of concentrated flow).
- In construction traffic areas, maximum rock berm heights should be 300 mm (12 in). Berms should be constructed every 90 m (300 ft) on slopes less than 5:100 (V:H) (5%), every 60 m (200 ft) on slopes between 5:100 (V:H) (5%) and 10:100 (V:H) (10%), and every 30 m (100 ft) on slopes greater than 10:100 (V:H) (10%).

Maintenance and Inspection:

- Inspect berms before and after each significant rainfall event and weekly throughout the rainy season.
- Reshape berms as needed and replace lost or dislodged rock, and/or filter fabric.
- Inspect for sediment accumulation, remove sediment when depth reaches one-third of the berm height or 300 mm (12 in), whichever occurs first.

K-rail

Description and Purpose:

- This is temporary sediment control that uses K-rails to form the sediment deposition area, or to isolate the near-bank construction area. Install K-rails at toe of slope in accordance with procedures described in NS-5, "Clear Water Diversion."
- Barriers are placed end-to-end in a pre-designed configuration and gravel-filled bags are used at the toe of the barrier and also at their abutting ends to seal and prevent movement of sediment beneath or through the barrier walls.

Appropriate Applications:

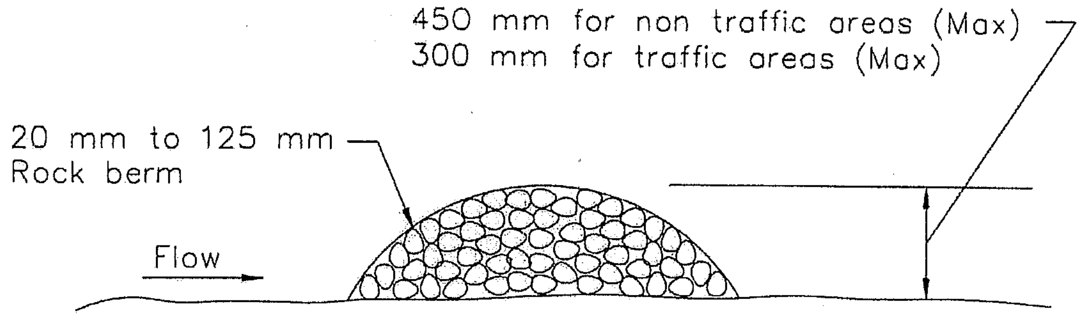
- This technique is useful at the toe of embankments, cut or fill slopes.

Limitations:

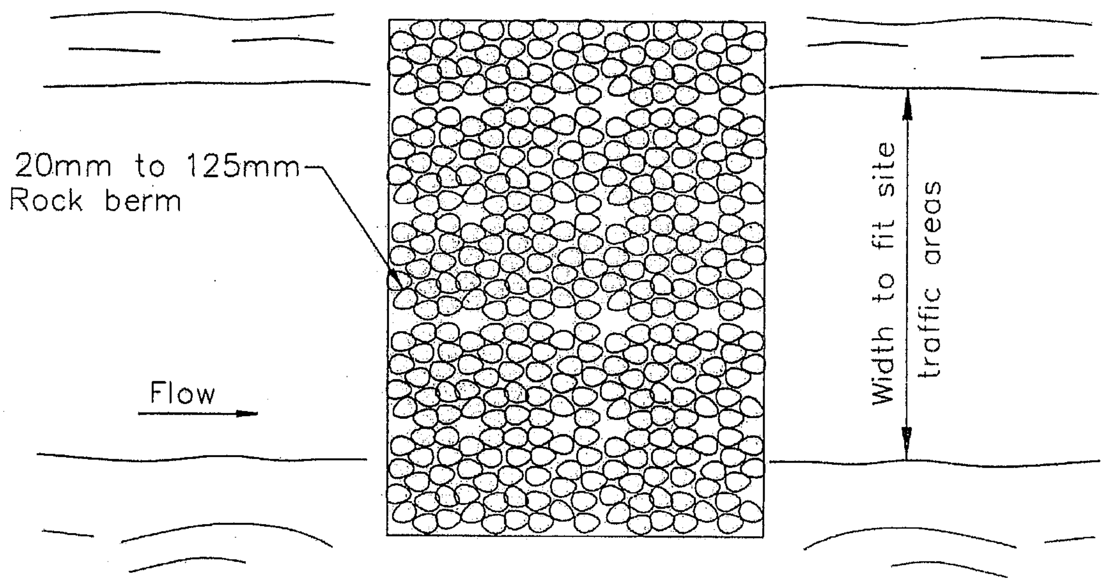
- The K-rail method is not watertight and its proper use should be considered accordingly.

Inspection and Maintenance

- Inspect BMPs daily during construction.
- Maintain and repair BMPs.
- Remove accumulated sediment as necessary.



SECTION



PLAN

TYPICAL ROCK FILTER

NOT TO SCALE

Section 4
Temporary Sediment Control Best Management Practices

4.1 Temporary Sediment Controls

Temporary sediment control practices include those practices that intercept and slow or detain the flow of storm water to allow sediment to settle and be trapped. These practices can consist of installing temporary linear sediment barriers (such as silt fences, sandbag barriers, and straw bale barriers); providing fiber rolls, gravel bag berms, or check dams to break up slope length or flow; or constructing a temporary sediment/desilting basin on sediment trap. Linear sediment barriers are typically placed below the toe of exposed and erodible slopes, downslope of exposed soil areas, around temporary stockpiles, and at other appropriate locations along the site perimeter.

Temporary sediment control practices shall be implemented in conformance with the criteria presented in Section 2, Selecting and Implementing Construction Site Best Management Practices, of this Manual. Temporary sediment control practices include the BMPs listed in Table 4-1.

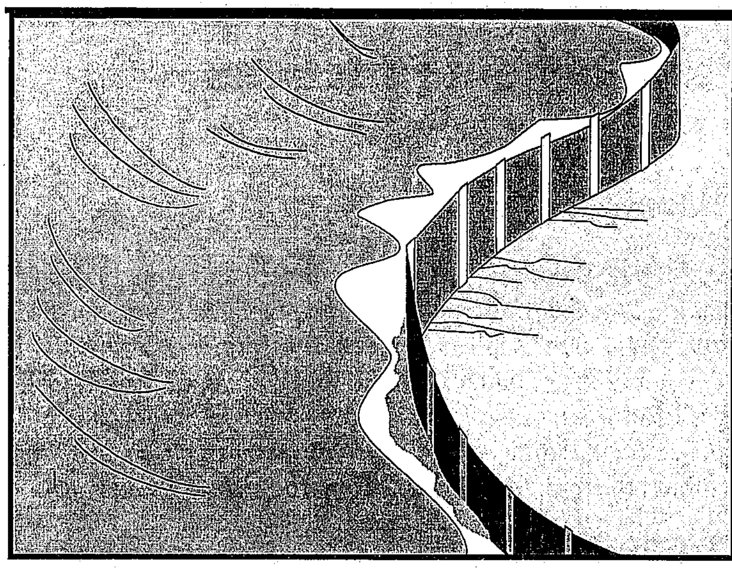
Table 4-1

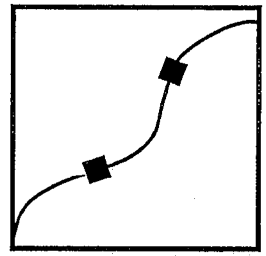
TEMPORARY SEDIMENT CONTROL BMPs	
ID	**BMP NAME**
SC-1	Silt Fence
SC-2	Sediment/Desilting Basin
SC-3	Sediment Trap
SC-4	Check Dam
SC-5	Fiber Rolls
SC-6	Gravel Bag Berm
SC-7	Street Sweeping and Vacuuming
SC-8	Sandbag Barrier
SC-9	Straw Bale Barrier
SC-10	Storm Drain Inlet Protection

The remainder of this Section shows the working details for each of the temporary sediment control BMPs.

Silt Fence

SC-1





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A silt fence is a temporary linear sediment barrier of permeable fabric designed to intercept and slow the flow of sediment-laden sheet flow runoff. Silt fences allow sediment to settle from runoff before water leaves the construction site.

Appropriate Applications

Silt fences are placed:

- Below the toe of exposed and erodible slopes.
- Down-slope of exposed soil areas.
- Around temporary stockpiles.
- Along streams and channels.
- Along the perimeter of a project.

Limitations

- Not effective unless trenched and keyed in.
- Not intended for use as mid-slope protection on slopes greater than 1:4 (V:H).
- Must be maintained.
- Must be removed and disposed of.
- Don't use below slopes subject to creep, slumping, or landslides.
- Don't use in streams, channels, drain inlets, or anywhere flow is concentrated.
- Don't use silt fences to divert flow.

Standards and Specifications

Design and Layout

- The maximum length of slope draining to any point along the silt fence shall be 61 m (200 ft) or less.
- Slope of area draining to silt fence shall be less than 1:1 (V:H).
- Limit to locations suitable for temporary ponding or deposition of sediment.
- Fabric life span generally limited to between five and eight months. Longer periods may require fabric replacement.
- Silt fences shall not be used in concentrated flow areas.
- Lay out in accordance with Pages 5 and 6 of this BMP.
- For slopes steeper than 1:2 (V:H) and that contain a high number of rocks or large dirt clods that tend to dislodge, it may be necessary to install additional protection immediately adjacent to the bottom of the slope, prior to installing silt fence. Additional protection may be a chain link fence or a cable fence.
- For slopes adjacent to water bodies or Environmentally Sensitive Areas (ESAs), additional temporary soil stabilization BMPs shall be used.

Materials

- Silt fence fabric shall be woven polypropylene with a minimum width of 900 mm (36 inches) and a minimum tensile strength of 0.45-kN. The fabric shall conform to the requirements in ASTM designation D4632 and shall have an integral reinforcement layer. The reinforcement layer shall be a polypropylene, or equivalent, net provided by the manufacturer. The permittivity of the fabric shall be between 0.1 sec^{-1} and 0.15 sec^{-1} in conformance with the requirements in ASTM designation D4491. Contractor must submit certificate of compliance in accordance with Standard Specifications Section 6-1.07.
- Wood stakes shall be commercial quality lumber of the size and shape shown on the plans. Each stake shall be free from decay, splits or cracks longer than the thickness of the stake or other defects that would weaken the stakes and cause the stakes to be structurally unsuitable.
- Bar reinforcement may be used, and its size shall be equal to a number four (4) or greater. End protection shall be provided for any exposed bar reinforcement.
- Staples used to fasten the fence fabric to the stakes shall be not less than 45 mm (1.75 inches) long and shall be fabricated from 1.57 mm (0.06 inch) or heavier wire. The wire used to fasten the tops of the stakes together when

joining two sections of fence shall be 3.05 mm (0.12 inch) or heavier wire. Galvanizing of the fastening wire is not required.

Installation

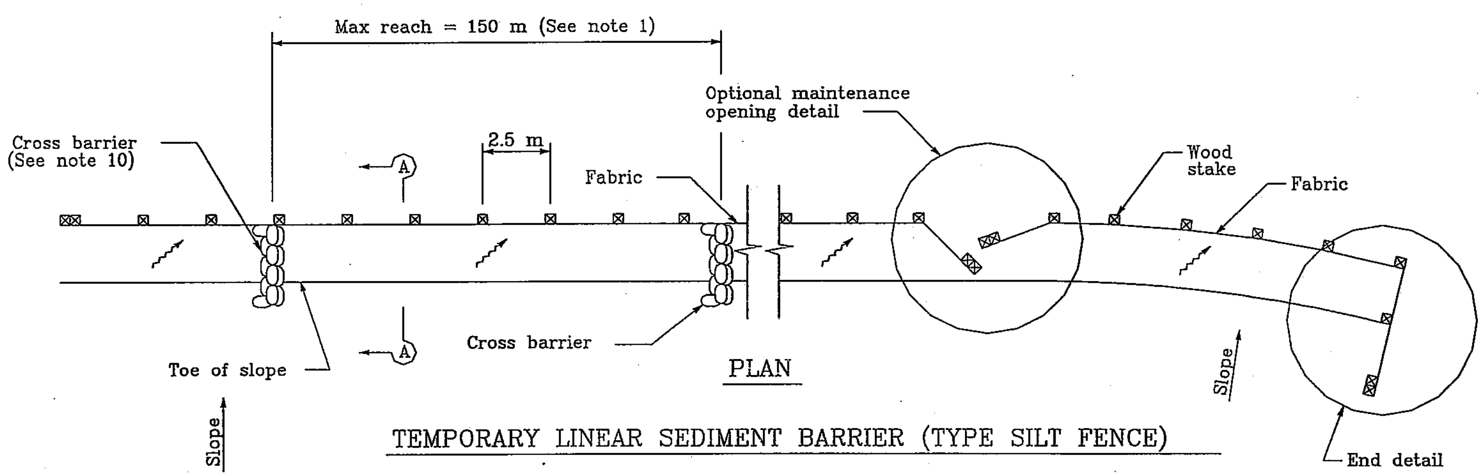
- Generally, silt fences shall be used in conjunction with soil stabilization source controls up slope to provide effective erosion and sediment control.
- Bottom of the silt fence shall be keyed-in a minimum of 150 mm (12 inches).
- Trenches shall not be excavated wider and deeper than necessary for proper installation of the temporary linear sediment barriers.
- Excavation of the trenches shall be performed immediately before installation of the temporary linear sediment barriers.
- Construct silt fences with a set-back of at least 1m (3 ft) from the toe of a slope. Where a silt fence is determined to be not practical due to specific site conditions, the silt fence may be constructed at the toe of the slope, but shall be constructed as far from the toe of the slope as practical.
- Construct the length of each reach so that the change in base elevation along the reach does not exceed 1/3 the height of the barrier; in no case shall the reach exceed 150 meters (490 ft)..
- Cross barriers shall be a minimum of 1/3 and a maximum of 1/2 the height of the linear barrier.
- Install in accordance with Pages 5 and 6 of this BMP.

Maintenance and Inspection

- Repair undercut silt fences.
- Repair or replace split, torn, slumping, or weathered fabric.
- Inspect silt fence when rain is forecast. Perform necessary maintenance, or maintenance required by the Resident Engineer (RE).
- Inspect silt fence following rainfall events. Perform maintenance as necessary, or as required by the RE.
- Maintain silt fences to provide an adequate sediment holding capacity. Sediment shall be removed when the sediment accumulation reaches one-third (1/3) of the barrier height. Removed sediment shall be incorporated in the project at locations designated by the RE or disposed of outside the right-of-way in conformance with the Standard Specifications.
- Silt fences that are damaged and become unsuitable for the intended purpose, as determined by the RE, shall be removed from the site of work, disposed of outside the highway right-of-way in conformance with the Standard Specifications, and replaced with new silt fence barriers.

- Holes, depressions or other ground disturbance caused by the removal of the temporary silt fences shall be backfilled and repaired in conformance with the Standard Specifications.

- Remove silt fence when no longer needed or as required by the RE. Fill and compact post holes and anchorage trench, remove sediment accumulation, and grade fence alignment to blend with adjacent ground.



PLAN

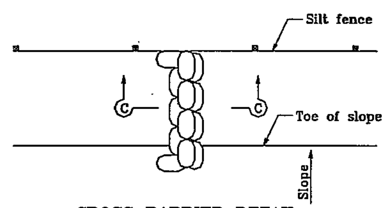
TEMPORARY LINEAR SEDIMENT BARRIER (TYPE SILT FENCE)

NOTES

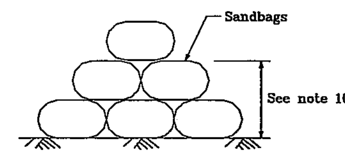
1. Construct the length of each reach so that the change in base elevation along the reach does not exceed 1/3 the height of the linear barrier, in no case shall the reach length exceed 150m.
2. The last 2.5 m of fence shall be turned up slope.
3. Stake dimensions are nominal.
4. Dimension may vary to fit field condition.
5. Stakes shall be spaced at 2.5 m maximum and shall be positioned on downstream side of fence.
6. Stakes to overlap and fence fabric to fold around each stake one full turn. Secure fabric to stake with 4 staples.
7. Stakes shall be driven tightly together to prevent potential flow-through of sediment at joint. The tops of the stakes shall be secured with wire.
8. For end stake, fence fabric shall be folded around two stakes one full turn and secured with 4 staples.
9. Minimum 4 staples per stake. Dimensions shown are typical.
10. Cross barriers shall be a minimum of 1/3 and a maximum of 1/2 the height of the linear barrier.
11. Maintenance openings shall be constructed in a manner to ensure sediment remains behind silt fence.
12. Joining sections shall not be placed at sump locations.
13. Sandbag rows and layers shall be offset to eliminate gaps.

LEGEND

Tamped backfill
Slope direction
Direction of flow



CROSS BARRIER DETAIL



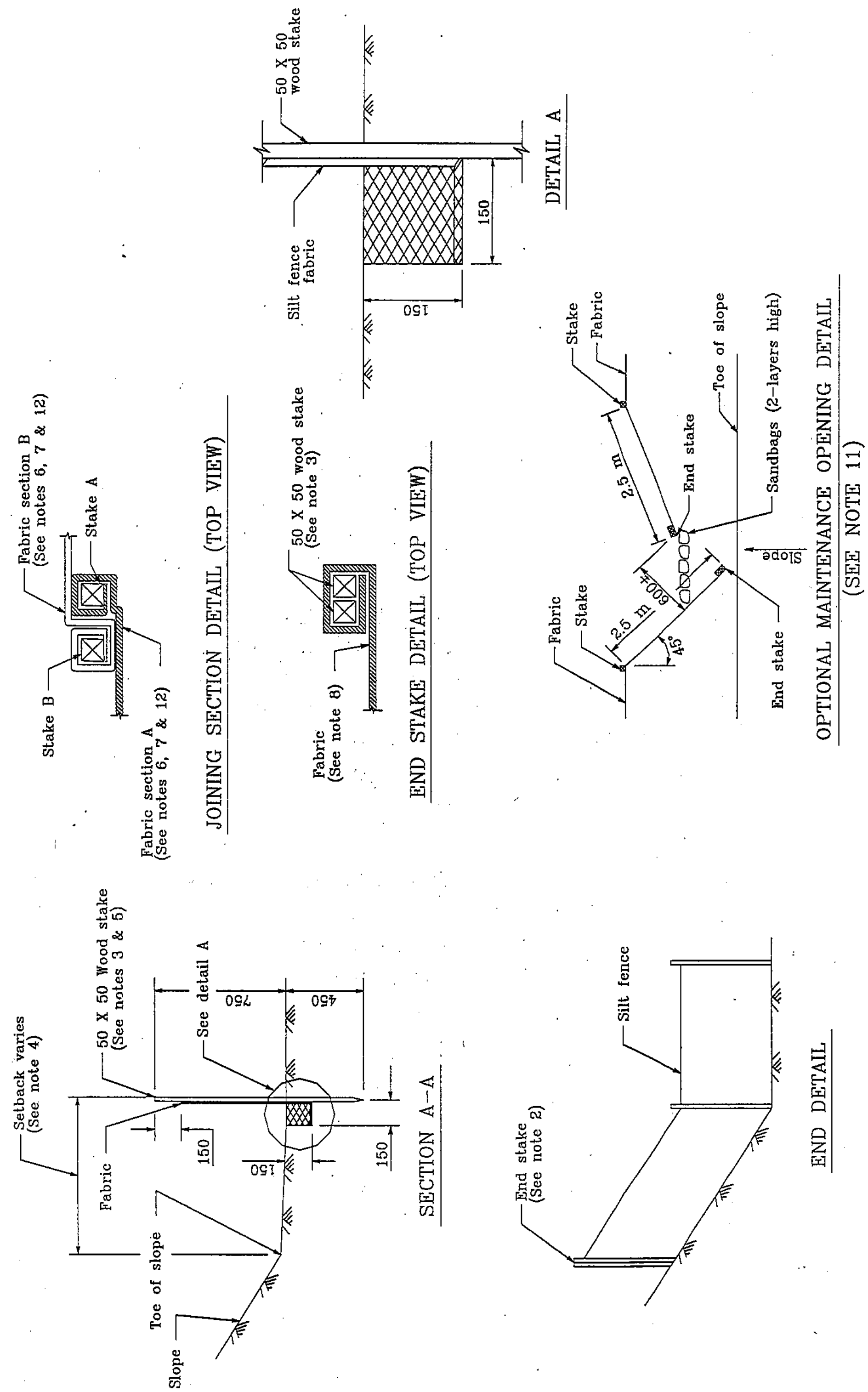
SECTION C–C

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION

TEMPORARY LINEAR SEDIMENT BARRIER
(TYPE SILT FENCE)

NO SCALE

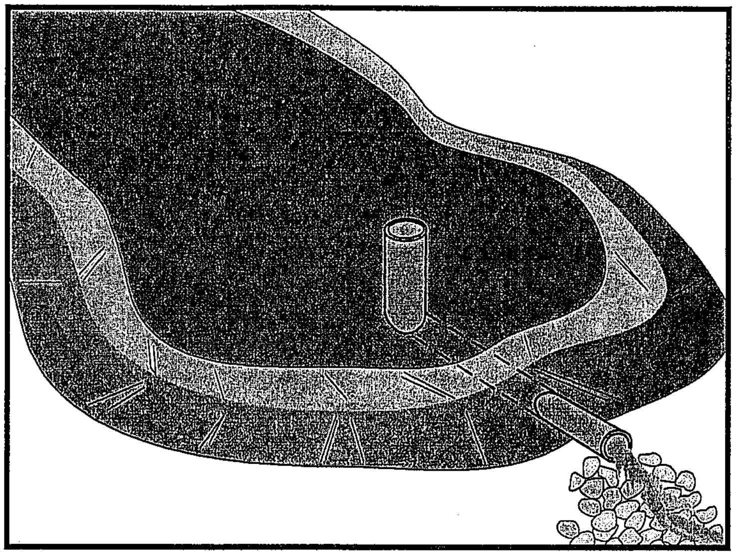
ALL DIMENSIONS ARE IN
MILLIMETERS UNLESS OTHERWISE SHOWN

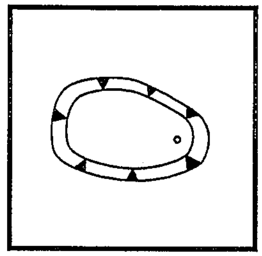

50 X 50
wood stake
Silt fence
fabric
150
150
DETAIL A
Fabric section B
(See notes 6, 7 & 12)
Stake A
Stake B
Fabric section A
(See notes 6, 7 & 12)
JOINING SECTION DETAIL (TOP VIEW)
50 X 50 wood stake
(See note 3)
Fabric
(See note 8)
END STAKE DETAIL (TOP VIEW)
Stake
Fabric
Toe of slope
Sandbags (2-layers high)
End stake
2.5 m
600+
Slope
Fabric
Stake
2.5 m
45°
End stake
OPTIONAL MAINTENANCE OPENING DETAIL
(SEE NOTE 11)
Setback varies
(See note 4)
50 X 50 Wood stake
(See notes 3 & 5)
See detail A
750
450
Fabric
150
150
150
Toe of slope
Slope
SECTION A-A
Silt fence
End stake
(See note 2)
END DETAIL

A001499

Sediment/Desilting Basin

SC-2





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A sediment/desilting basin is a temporary basin formed by excavating and/or constructing an embankment so that sediment-laden runoff is temporarily detained under quiescent conditions, allowing sediment to settle out before the runoff is discharged (refer to Figures 1 and 2).

Appropriate Applications

Sediment basins shall be designed in accordance with Section A of the State of California NPDES General Permit for Storm Water Discharges Associated with Construction Activities (General Permit). If there is insufficient area to construct a sediment basin in accordance with the General Permit requirements, then the alternate desilting design standards specified herein may be used. This BMP may be implemented on a project-by-project basis with other BMPs when determined necessary and feasible by the RE.

Sediment/Desilting Basins shall be considered for use:

- On construction projects with disturbed areas during the rainy season.
- Where sediment-laden water may enter the drainage system or watercourses.
- At outlets of disturbed soil areas with areas between 2 ha and 4 ha (5 ac and 10 ac).

Limitations

- Alternative BMPs must be thoroughly investigated for erosion control before selecting temporary desilting basins.
- Requires large surface areas to permit settling of sediment.
- Not appropriate for drainage areas greater than 30 ha (75 ac).
- Not to be located in live streams

- For safety reasons, basins shall have protective fencing.
- Size may be limited by availability of right-of-way.

Standards and Specifications

- Limit the contributing area to the sediment/desilting basin to only the runoff from the disturbed soil areas. Use temporary concentrated flow conveyance controls to divert runoff from undisturbed areas away from the sediment/desilting basin.

Sediment Basin

- Sediment basins shall, at a minimum, be designed as follows:
  - Option 1: Pursuant to local ordinance for sediment basin design and maintenance, provided that the design efficiency is as protective or more protective of water quality than Option 3.

OR

  - Option 2: Sediment basin(s), as measured from the bottom of the basin to the principal outlet, shall have at least a capacity equivalent to 102 cubic meters (3,600 cubic feet) of storage per 0.4 hectare (1 acre) draining into the sediment basin. The length of the basin shall be more than twice the width of the basin. The length is determined by measuring the distance between the inlet and the outlet; and the depth must not be less than 0.9 m (3 ft) nor greater than 1.5 m (5 ft) for safety reasons and for maximum efficiency.

OR

  - Option 3: Sediment basin(s) shall be designed using the standard equation:

$$As=1.2Q/Vs \qquad \text{(Eq. 1)}$$

Where:

As = Minimum surface area for trapping soil particles of a certain size

Vs = Settling velocity of the design particle size chosen

$Q = C\,I\,A$

Where:

Q = Discharge rate measured in cubic feet per second

C = Runoff coefficient

I = Precipitation intensity for the 10-year, 6-hour rain event

A = Area draining into the sediment basin in acres

The design particle size shall be the smallest soil grain size determined by wet sieve analysis, or the fine silt sized (0.01mm) particle, and the *Vs* used shall be 100 percent of the calculated settling velocity.

The length is determined by measuring the distance between the inlet and the outlet; the length shall be more than twice the dimension as the width; the depth shall not be less than 0.9 m (3 ft) nor greater than 1.5 m (5 ft) for safety reasons and for maximum efficiency [0.6 m (2 ft) of sediment storage, 0.6 m (2 ft) of capacity). The basin(s) shall be located on the site where it can be maintained on a year-round basis and shall be maintained on a schedule to retain the 0.6 m (2 ft) of capacity.

OR

- Option 4: The use of an equivalent surface area design or equation, provided that the design efficiency is as protective or more protective of water quality than Option 3.

Desilting Basin

- Desilting basins shall be designed to have a capacity equivalent to 100 cubic meters of storage (as measured from the top of the basin to the principal outlet) per hectare of contributory area. This design is less than the required to capture the 0.01 mm particle size but larger than that required to capture particles 0.02 mm or larger.
- The length of the basin shall be more than twice the width of the basin; the length shall be determined by measuring the distance between the inlet and the outlet.
- The depth must be no less than one (1) meter nor greater than 1.5 m.
- Basins with an impounding levee greater than 1.5 m (5 ft) tall, measured from the lowest point to the impounding area to the highest point of the levee, and basins capable of impounding more than 1000 cubic meters (35,300 cubic feet), shall be designed by a professional Civil Engineer registered with the state of California. The design must be submitted to the Resident Engineer (RE) for approval at least 7 days prior to the basin construction. The design shall include maintenance requirements, including sediment and vegetation removal, to ensure continuous function of the basin outlet and bypass structures.

General Requirements

- Design and locate sediment/desilting basins so that they can be maintained. Construct desilting basins prior to the rainy season and construction activities.
- Sediment/desilting basins, regardless of size and storage volume, shall include features to accommodate overflow or bypass flows that exceed the design storm event. The calculated basin volume and proposed location shall be submitted to

the RE for approval at least 3 days prior to the basin construction.

- Construct an emergency spillway to accommodate flows not carried by the principal spillway. Spillway shall consist of an open channel (earthen or vegetated) over undisturbed material (not fill) or constructed of a non-erodible riprap.

- Spillway control section, which is a level portion of the spillway channel at the highest elevation in the channel, shall be a minimum of 6 m (20 ft) in length.

- A forebay, constructed upstream of the basin may be provided to remove debris and larger particles.

- Basin inlets shall be located to maximize travel distance to the basin outlet.

- Rock or vegetation shall be used to protect the basin inlet and slopes against erosion.

- The outflow from the basins shall be provided with outlet protection to prevent erosion and scouring of the embankment and channel. See BMP SS-10, "Outlet Protection/Velocity Dissipation Devices."

- Basin shall be located: (1) by excavating a suitable area or where a low embankment can be constructed across a swale, (2) where post-construction (permanent) detention basins will be constructed, (3) where failure would not cause loss of life or property damage, (4) where the basins can be maintained on a year-round basins to provide access for maintenance, including sediment removal and sediment stockpiling in a protected area, and to maintain the basin to provide the required capacity.

- Areas under embankments, structural works, and sediment/desilting basin must be cleared, stripped of vegetation in accordance with Standard Specifications Section 16 – "Clearing and Grubbing."

- Earthwork shall be in accordance with Standard Specifications Section 19 – "Earthwork". Contractor is specifically directed to Standard Specifications Sections 19-5, "Compaction," and 19-6, "Embankment Construction."

- Structure shall be placed on a firm, smooth foundation with the base securely anchored with concrete or other means to prevent floatation.

- Discharge from the basin shall be accomplished through a water quality outlet. An example is shown in Figure 3. The Principal outlet shall consist of a corrugated metal, high density polyethylene (HDPE), or reinforced concrete riser pipe with dewatering holes and an anti-vortex device and trash rack attached to the top of the riser, to prevent floating debris from flowing out of the basin or obstructing the system. This principal structure shall be designed to accommodate the inflow design storm.

- A rock pile or rock-filled gabions can serve as alternatives to the debris screen, although the designer should be aware of the potential for extra maintenance involved should the pore spaces in the rock pile clog.

- Proper hydraulic design of the outlet is critical to achieving the desired performance of the basin. The water quality outlet should be designed to drain the basin within 24 to 72 hours (also referred to as "drawdown time"). (The 24-hour limit is specified to provide adequate settling time; the 72-hour limit is specified to mitigate vector control concerns.)

- The two most common outlet problems that occur are: (1) the capacity of the outlet is too great resulting in only partial filling of the basin and drawdown time less than designed for; and (2) the outlet clogs because it is not adequately protected against trash and debris. To avoid these problems, the following outlet types are recommended for use: (1) a single orifice outlet with or without the protection of a riser pipe, and (2) perforated riser. Design guidance for single orifice and perforated riser outlets are as follows:

Flow Control Using a Single Orifice At The Bottom Of The Basin (Figure 1): The outlet control orifice should be sized using the following equation:

$$a = \frac{2A(H - Ho)^{0.5}}{3600CT(2g)^{0.5}} = \frac{(7x10^{-5})A(H - Ho)^{0.5}}{CT} \qquad \text{(Eq. 2)}$$

where:

a	=	area of orifice (ft^2) (1 ft^2 =0.0929m^2)
A	=	surface area of the basin at mid elevation (ft^2)
C	=	orifice coefficient
T	=	drawdown time of full basin (hrs)
G	=	gravity (32.2 ft/s^2)
H	=	elevation when the basin is full (ft)
Ho	=	final elevation when basin is empty (ft)

With a drawdown time of 40 hours, the equation becomes:

$$a = \frac{(1.75x10^{-6})A(H - Ho)^{0.5}}{C} \qquad \text{(Eq. 3)}$$

Flow Control Using Multiple Orifices (see Figure2):

$$a_t = \frac{2A(h_{max})}{CT(2g[h_{max} - h_{centroid\ of\ orifices}])^{0.5}} \qquad \text{(Eq. 4)}$$

With terms as described above except:

a_t = total area of orifices

h_{max} = maximum height from lowest orifice to the maximum water surface (ft)

$h_{centroid\ of\ orifices}$ = height from the lowest orifice to the centroid of the orifice configuration (ft)

Allocate the orifices evenly on two rows; separate the holes by 3x hole diameter vertically, and by 120 degrees horizontally (refer to Figure 3).

Because basins are not maintained for infiltration, water loss by infiltration should be disregarded when designing the hydraulic capacity of the outlet structure.

Care must be taken in the selection of "C"; 0.60 is most often recommended and used. However, based on actual tests, GKY (1989), "Outlet Hydraulics of Extended Detention Facilities for Northern Virginia Planning District Commission", recommends the following:

C = 0.66 for thin materials; where the thickness is equal to or less than the orifice diameter, or

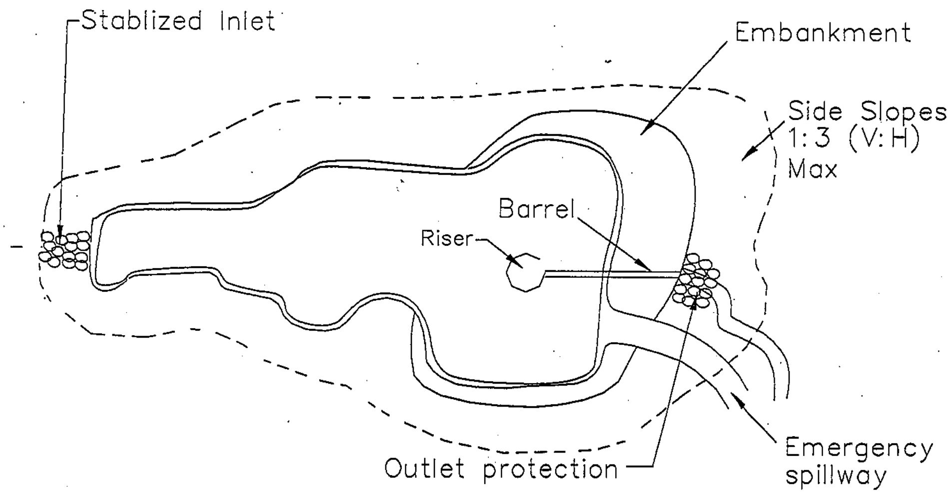
C = 0.80 when the material is thicker than the orifice diameter

- The Contractor shall verify that the outlet is properly designed to handle the design and peak flows.
- Attach riser pipe (watertight connection) to a horizontal pipe (barrel), which extends through the embankment to toe of fill. Provide anti-seep collars on the barrel.
- Cleanout level shall be clearly marked on the riser pipe
- Avoid dewatering of groundwater to the sediment/desilting basin during the rainy season. Insignificant quantities of accumulated precipitation may be dewatered to the sediment/desilting basin unless precipitation is forecasted within 24 hours. Refer to NS-2 "Dewatering Operations."
- Chain link fencing shall be provided around each sediment/desilting basin to prevent unauthorized entry to the basin or if safety is a concern. Fencing shall be in accordance with Standard Specifications Section 80 – "Fencing."

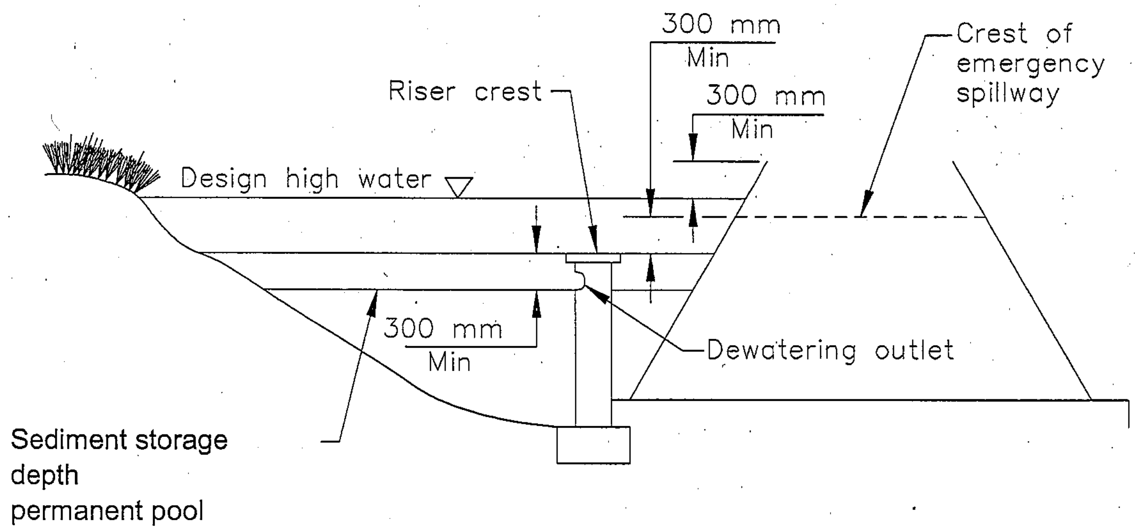
Maintenance and Inspection

- Inspect sediment/desilting basins before and after rainfall events and weekly during the rest of the rainy season. During extended rainfall events, inspect at least every 24 hours.

- Examine basin banks for seepage and structural soundness.
- Check inlet and outlet structures and spillway for any damage or obstructions. Repair damage and remove obstructions as needed, or as directed by the RE.
- Remove standing water from the basin within 72 hours after accumulation.
- Check inlet and outlet area for erosion and stabilize if required, or if directed by the RE.
- Remove accumulated sediment when its volume reaches one-third the volume of the sediment storage. Properly dispose of sediment and debris removed from the basin.
- Check fencing for damage and repair as needed or as directed by the RE.

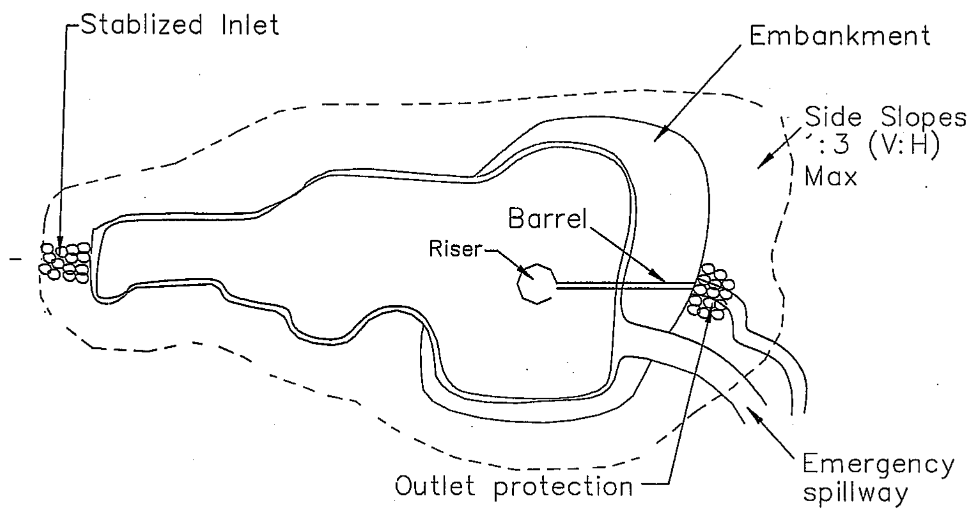


TOP VIEW



This outlet provides no drainage
for permanent pool.

FIGURE 1: SINGLE ORIFICE DESIGN
NOT TO SCALE



TOP VIEW

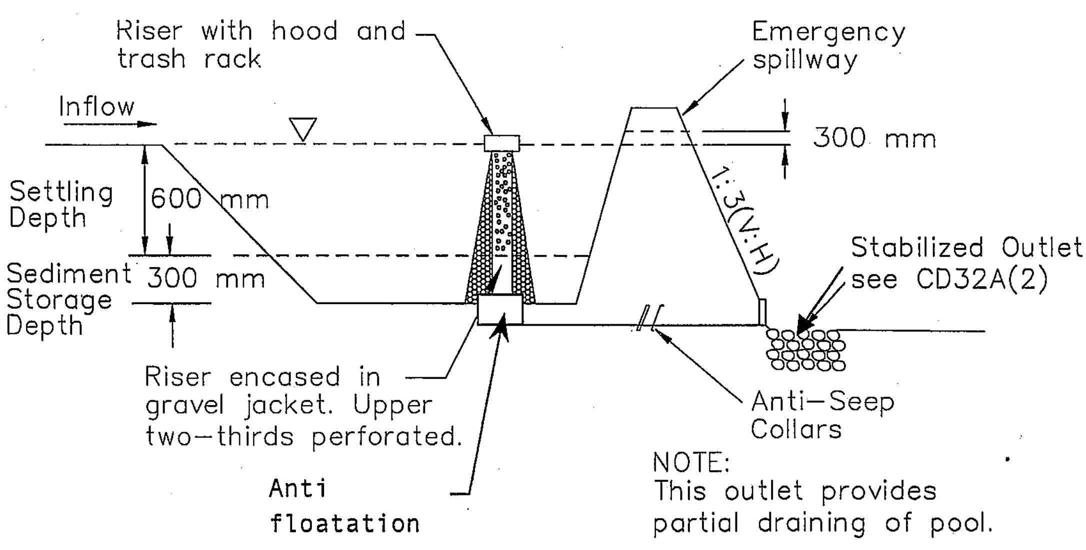


FIGURE 2: MULTIPLE ORIFICE DESIGN
NOT TO SCALE

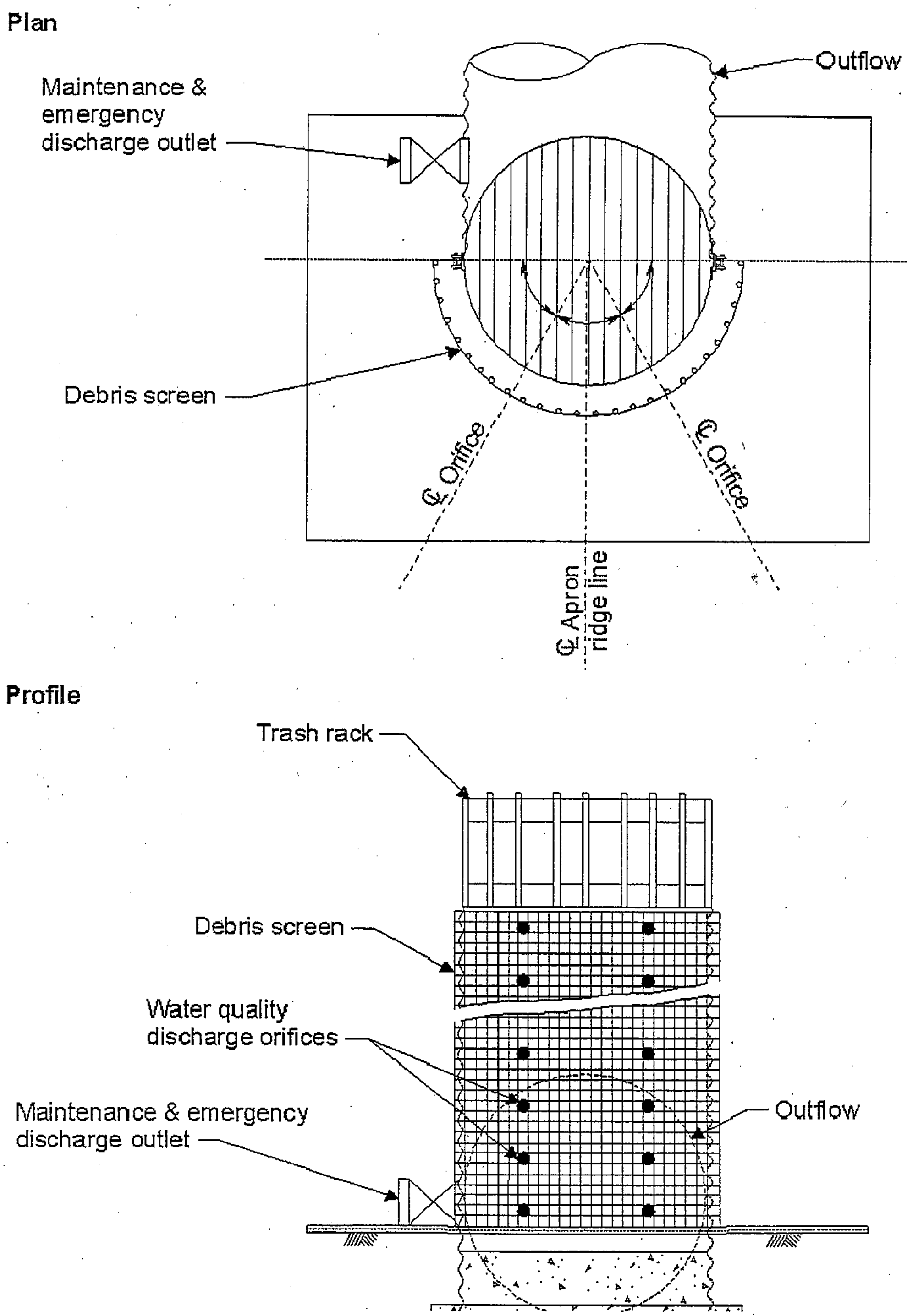
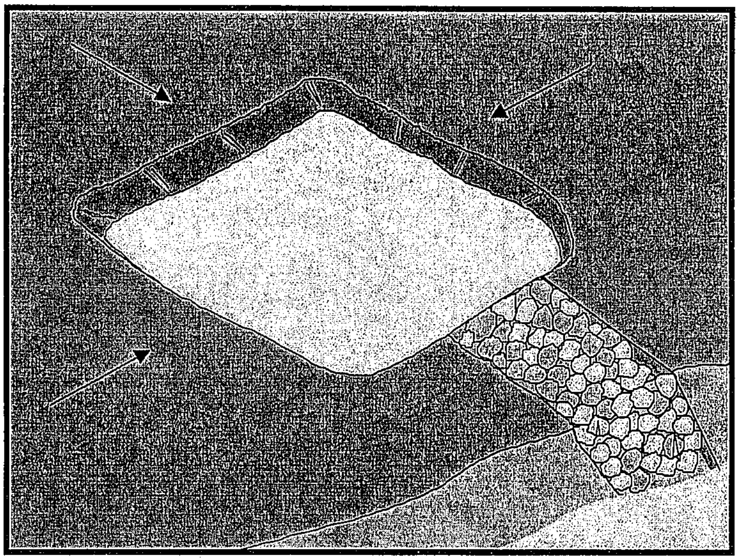
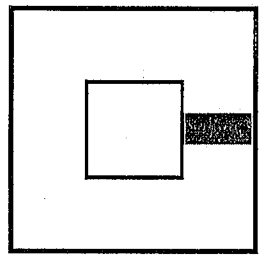


FIGURE 3: MULTIPLE ORIFICE OUTLET RISER
NOT TO SCALE

Sediment Trap

SC-3





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A sediment trap is a temporary containment area that allows sediment in collected storm water to settle out during infiltration or before the runoff is discharged through a stabilized spillway. Sediment traps are formed by excavating or constructing an earthen embankment across a waterway or low drainage area.

Appropriate Applications

- Sediment traps may be used on construction projects where the drainage area is less than 2 ha (5 ac). Traps should be placed where sediment-laden storm water enters a storm drain or watercourse.
- This BMP may be implemented on a project-by-project basis with other BMPs when determined necessary and feasible by the Resident Engineer (RE).
- As a supplemental control, sediment traps provide additional protection for a water body or for reducing sediment before it enters a drainage system.

Limitations

- Requires large surface areas to permit infiltration and settling of sediment.
- Not appropriate for drainage areas greater than 2 ha (5 ac).
- Only removes large and medium sized particles and requires upstream erosion control.
- Attractive and dangerous to children, requiring protective fencing.
- Not to be located in live streams.
- Size may be limited by availability of right-of-way.

Standards and Specifications

- Construct sediment traps prior to rainy season and construction activities.
- Trap shall be situated according to the following criteria: (1) by excavating a suitable area or where a low embankment can be constructed across a swale, (2) where failure would not cause loss of life or property damage, and (3) to provide access for maintenance, including sediment removal and sediment stockpiling in a protected area.
- Trap shall be sized to accommodate a settling zone and sediment storage zone with recommended minimum volumes of 130 m3/ha (67 yd3/ac) and 65 m3/ha (33 yd3/ac) of contributing drainage area, respectively, based on 12.7 mm (0.5 in) of runoff volume over a 24-hr period. Multiple traps and/or additional volume may be required to accommodate site specific rainfall and soil conditions.
- Traps with an impounding levee greater than 1.5 m (5 ft) tall, measured from the lowest point to the impounding area to the highest point of the levee, and traps capable of impounding more than 1000 cubic meters (35,300 cubic feet), shall be designed by a professional Civil Engineer registered with the state of California. The design must be submitted to the Resident Engineer (RE) for approval at least 7 days prior to the basin construction. The design shall include maintenance requirements, including sediment and vegetation removal, to ensure continuous function of the trap outlet and bypass structures.
- Earthwork shall be in accordance with Standard Specifications Section 19 – "Earthwork". Contractor is specifically directed to Standard Specifications Sections 19-5 and 19-6 entitled, "Compaction" and "Embankment Construction," respectively.
- Areas under embankments, structural works, and sediment traps shall be cleared and stripped of vegetation in accordance with Standard Specifications Section 16 – "Clearing and Grubbing."
- Use rock or vegetation to protect the trap outlets against erosion.
- Fencing, in accordance with Standard Specifications Section 80 – "Fencing," shall be provided to prevent unauthorized entry.

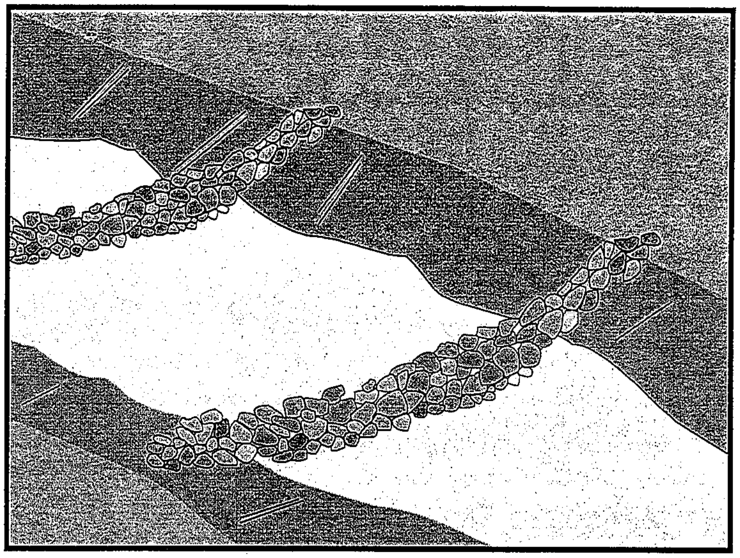
Maintenance and Inspection

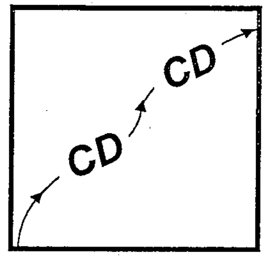
- Inspect sediment traps before and after rainfall events and weekly during the rest of the rainy season. During extended rainfall events, inspect sediment traps at least every 24 hours.
- If captured runoff has not completely infiltrated within 72 hours then the sediment trap must be dewatered.
- Inspect trap banks for embankment seepage and structural soundness.

- Inspect outlet structure and rock spillway for any damage or obstructions. Repair damage and remove obstructions as needed or as directed by the RE.
- Inspect outlet area for erosion and stabilize if required, or as directed by the RE.
- Remove accumulated sediment when the volume has reached one-third the original trap volume.
- Properly disposed of sediment and debris removed from the trap.
- Inspect fencing for damage and repair as needed or as directed by the RE.

Check Dams

SC-4





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Check dams reduce scour and channel erosion by reducing flow velocity and encouraging sediment settlement. A check dam is a small device constructed of rock, gravel bags, sandbags, fiber rolls, or other proprietary product placed across a natural or man-made channel or drainage ditch.

Appropriate Applications

- Check dams may be installed:
  - In small open channels that drain 4 ha (10 ac) or less.
  - In steep channels where storm water runoff velocities exceed 1.5 m/s (4.9 ft/sec).
  - During the establishment of grass linings in drainage ditches or channels.
  - In temporary ditches where the short length of service does not warrant establishment of erosion-resistant linings.
- This BMP may be implemented on a project-by-project basis with other BMPs when determined necessary and feasible by the Resident Engineer (RE).

Limitations

- Not to be used in live streams.
- Not appropriate in channels that drain areas greater than 4 ha (10 ac).
- Not to be placed in channels that are already grass lined unless erosion is expected, as installation may damage vegetation.
- Require extensive maintenance following high velocity flows.
- Promotes sediment trapping, which can be re-suspended during subsequent storms or removal of the check dam.

- Not to be constructed from straw bales or silt fence.

Standards and Specifications

- Check dams shall be placed at a distance and height to allow small pools to form behind them. Install the first check dam approximately 5 meters (16 ft) from the outfall device and at regular intervals based on slope gradient and soil type.
- For multiple check dam installation, backwater from downstream check dam shall reach the toe of the upstream dam.
- High flows (typically a 2-year storm or larger) shall safely flow over the check dam without an increase in upstream flooding or damage to the check dam.
- Where grass is used to line ditches, check dams shall be removed when grass has matured sufficiently to protect the ditch or swale.
- Rock shall be placed individually by hand or by mechanical methods (no dumping of rock) to achieve complete ditch or swale coverage.
- Fiber rolls may be used as check dams if approved by the RE or the Construction NPDES Coordinator. Refer to SC-5 "Fiber Rolls."
- Gravel bags may be used as check dams with the following specifications:

Materials

- ***Bag Material:*** Bags shall be either polypropylene, polyethylene or polyamide woven fabric, minimum unit weight 135 g/m2 (four ounces per square yard), mullen burst strength exceeding 2,070 kPa (300 psi) in conformance with the requirements in ASTM designation D3786, and ultraviolet stability exceeding 70% in conformance with the requirements in ASTM designation D4355.
- ***Bag Size:*** Each gravel-filled bag shall have a length of 450 mm (18 in), width of 300 mm (12 in), thickness of 75 mm (3 in), and mass of approximately 15 kg (33 lb). Bag dimensions are nominal, and may vary based on locally available materials. Alternative bag sizes shall be submitted to the RE for approval prior to deployment.
- ***Fill Material:*** Fill material shall be between 10 mm and 20 mm (0.4 and 0.8 inch) in diameter, and shall be clean and free from clay balls, organic matter, and other deleterious materials. The opening of gravel-filled bags shall be secured such that gravel does not escape. Gravel-filled bags shall be between 13 kg and 22 kg (28 and 48 lb) in mass. Fill material is subject to approval by the RE.

Installation

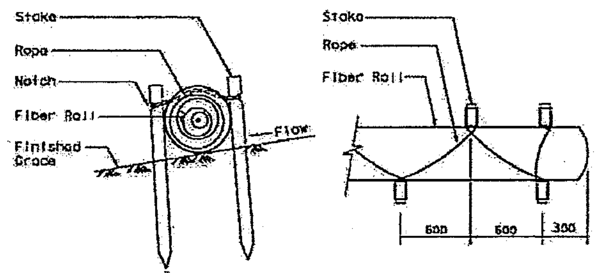
- Install along a level contour.
- Tightly abut bags and stack gravel bags using a pyramid approach.

Gravel bags shall not be stacked any higher than 1 meter (3.2 ft).

– Upper rows of gravel bags shall overlap joints in lower rows.

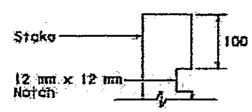
Maintenance and Inspection

- Inspect check dams after each significant rainfall event. Repair damage as needed or as required by the RE.
- Remove sediment when depth reaches one-third of the check dam height.
- Remove accumulated sediment prior to permanent seeding or soil stabilization.
- Remove check dam and accumulated sediment when check dams are no longer needed or when required by the RE.
- Removed sediment shall be incorporated in the project at locations designated by the RE or disposed of outside the highway right-of-way in conformance with the Standard Specifications.



SECTION

PLAN



ELEVATION

NOTCH DETAIL

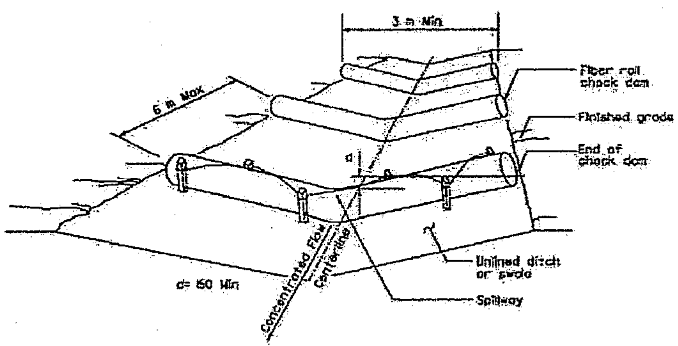
STAKING AND LASHING DETAIL

SECTION

TEMPORARY CHECK DAM (TYPE 2)

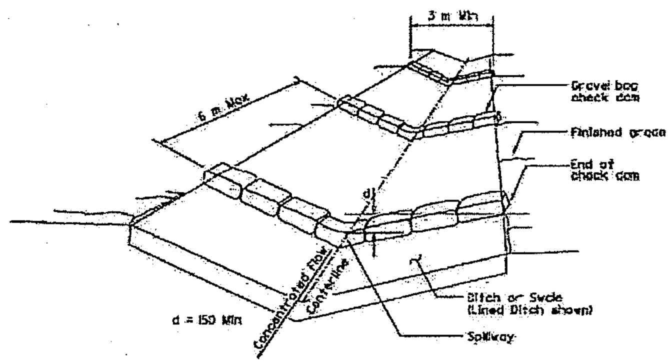
NOTE

1. Spillway depth "d" shall be maintained to prevent flanking of concentrated flow around the ends of check dam.



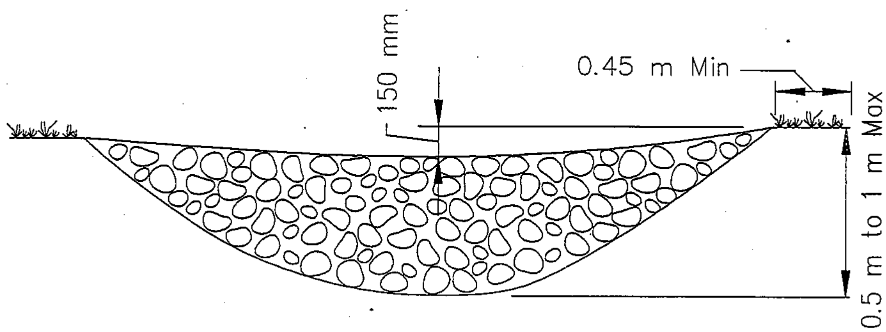
PERSPECTIVE

TEMPORARY CHECK DAM (TYPE 1)

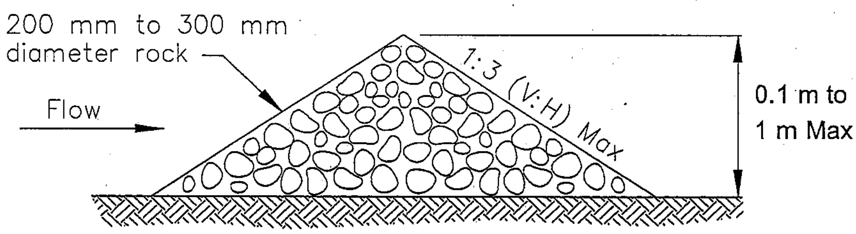


PERSPECTIVE

TEMPORARY CHECK DAM (TYPE 2)

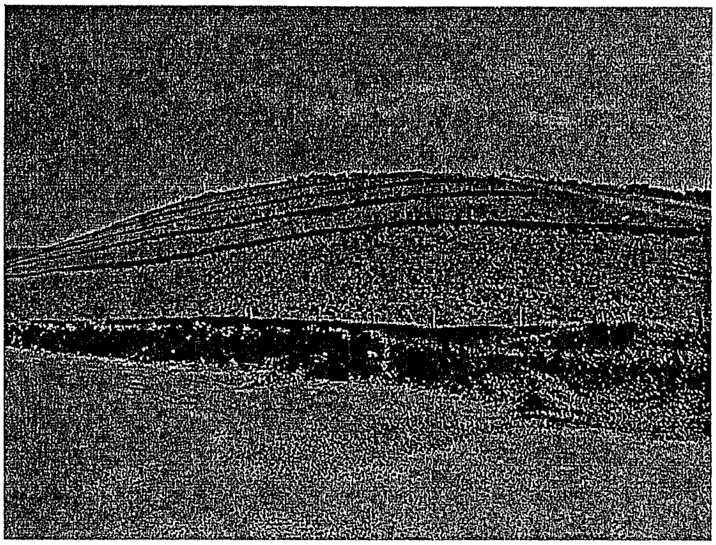


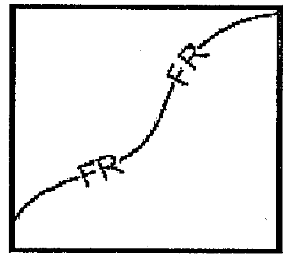
ELEVATION



TYPICAL ROCK CHECK DAM SECTION

ROCK CHECK DAM
NOT TO SCALE





Standard Symbol

BMP Objectives
- ● Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A fiber roll consists of wood excelsior, rice or wheat straw, or coconut fibers that is rolled or bound into a tight tubular roll and placed on the toe and face of slopes to intercept runoff, reduce its flow velocity, release the runoff as sheet flow and provide removal of sediment from the runoff. Fiber rolls may also be used for inlet protection and as check dams under certain situations.

Appropriate Applications

- This BMP may be implemented on a project-by-project basis with other BMPs when determined necessary and feasible by the RE.
- Along the toe, top, face, and at grade breaks of exposed and erodible slopes to shorten slope length and spread runoff as sheet flow.
- Below the toe of exposed and erodible slopes.
- Fiber rolls may be used as check dams in unlined ditches if approved by the Resident Engineer (RE) or the District Construction Storm Water Coordinator (refer to SC-4 "Check Dams").
- Fiber rolls may be used for drain inlet protection if approved by the RE or the District Construction Storm Water Coordinator (refer to SC-10 "Storm Drain Inlet Protection").
- Down-slope of exposed soil areas.
- Around temporary stockpiles.
- Along the perimeter of a project.

Limitations

- Runoff and erosion may occur if fiber roll is not adequately trenched in.
- Fiber rolls at the toe of slopes greater than 1:5 may require the use of 500 mm (20" diameter) or installations achieving the same protection (i.e., stacked smaller diameter fiber rolls, etc.).
- Fiber rolls may be used for drainage inlet protection if they can be properly anchored.
- Difficult to move once saturated.
- Fiber rolls could be transported by high flows if not properly staked and trenched in.
- Fiber rolls have limited sediment capture zone.
- Do not use fiber rolls on slopes subject to creep, slumping, or landslide.

Standards and Specifications

Fiber Roll Materials

- Fiber rolls shall be either:

  (1) Prefabricated rolls.

  (2) Rolled tubes of erosion control blanket.

Assembly of Field Rolled Fiber Roll

- Roll length of erosion control blanket into a tube of minimum 200 mm (8 in) diameter.
- Bind roll at each end and every 1.2 m (4 ft) along length of roll with jute-type twine.

Installation

- Slope inclination of 1:4 or flatter: fiber rolls shall be placed on slopes 6.0 m apart.
- Slope inclination of 1:4 to 1:2: fiber rolls shall be placed on slopes 4.5 m apart.
- Slope inclination 1:2 or greater: fiber rolls shall be placed on slopes 3.0 m apart.
- Stake fiber rolls into a 50 to 100 mm (2 to 4 in) trench.

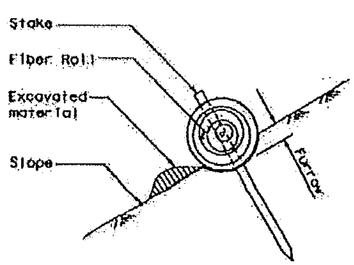
- Drive stakes at the end of each fiber roll and spaced 600 mm (2 ft) apart if Type 2 installation is used (refer to Page 4). Otherwise, space stakes 1.2 m (4 ft) maximum on center if installed as shown on Pages 5 and 6.
- Use wood stakes with a nominal classification of 19 by 19 mm (3/4 by 3/4 in), and minimum length of 600 mm (24 in).
- If more than one fiber roll is placed in a row, the rolls shall be overlapped; not abutted.

Removal

- Fiber rolls are typically left in place.
- If fiber rolls are removed, collect and dispose of sediment accumulation, and fill and compact holes, trenches, depressions or any other ground disturbance to blend with adjacent ground.

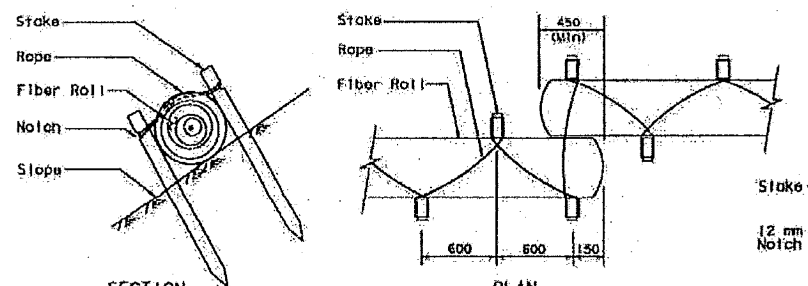
Maintenance and Inspection

- Repair or replace split, torn, unraveling, or slumping fiber rolls.
- Inspect fiber rolls when rain is forecast. Perform maintenance as needed or as required by the RE.
- Inspect fiber rolls following rainfall events and a least daily during prolonged rainfall. Perform maintenance as needed or as required by the RE.
- Maintain fiber rolls to provide an adequate sediment holding capacity. Sediment shall be removed when the sediment accumulation reaches three quarters (3/4) of the barrier height. Removed sediment shall be incorporated in the project at locations designated by the RE or disposed of outside the highway right-of-way in conformance with the Standard Specifications.



SECTION

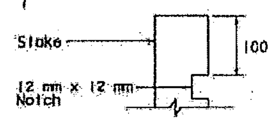
TEMPORARY FIBER ROLL (TYPE 1)



SECTION

PLAN

TEMPORARY FIBER ROLL (TYPE 2)

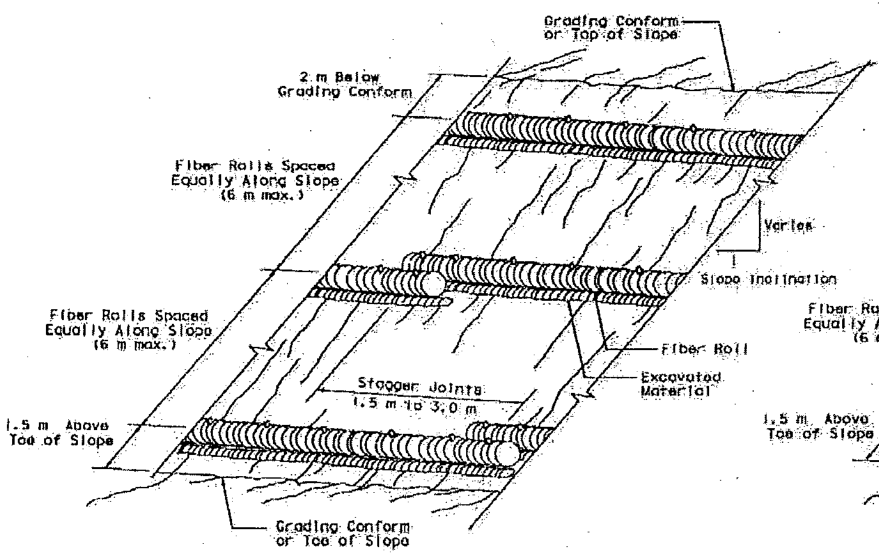


ELEVATION

NOTCH DETAIL

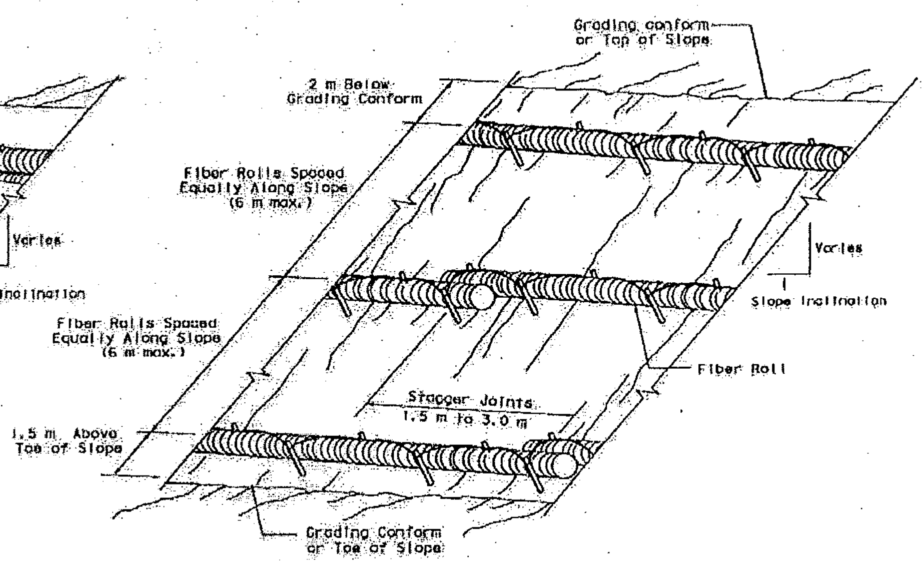
NOTE

1. Temporary fiber roll spacing varies depending upon slope inclination.



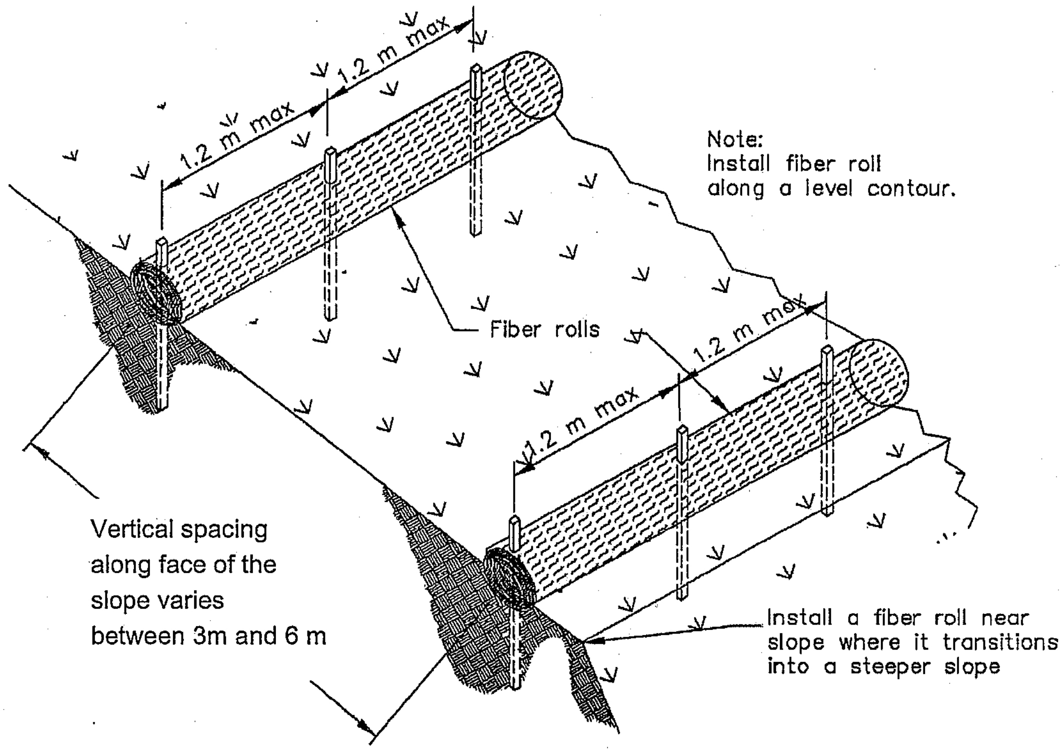
PERSPECTIVE

TEMPORARY FIBER ROLL (TYPE 1)



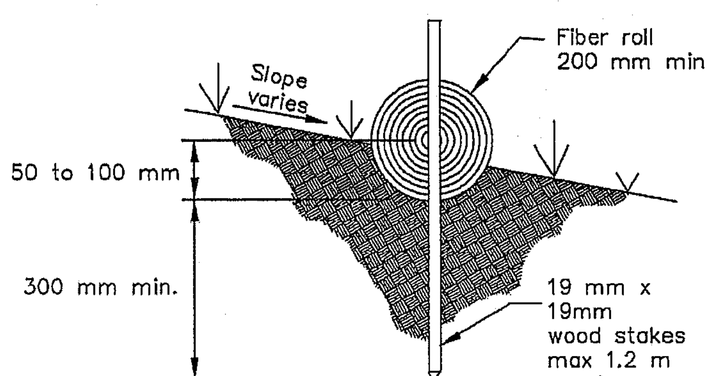
PERSPECTIVE

TEMPORARY FIBER ROLL (TYPE 2)



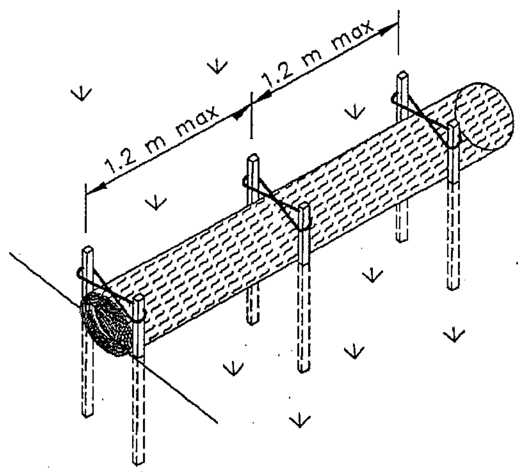
TYPICAL FIBER ROLL INSTALLATION

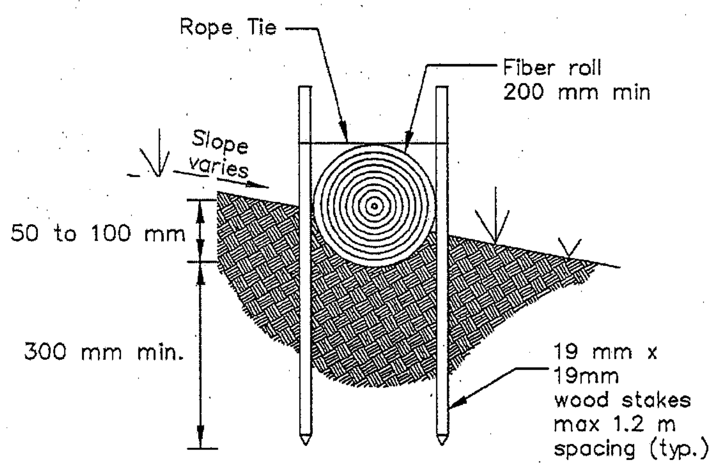
N.T.S.



ENTRENCHMENT DETAIL

N.T.S.



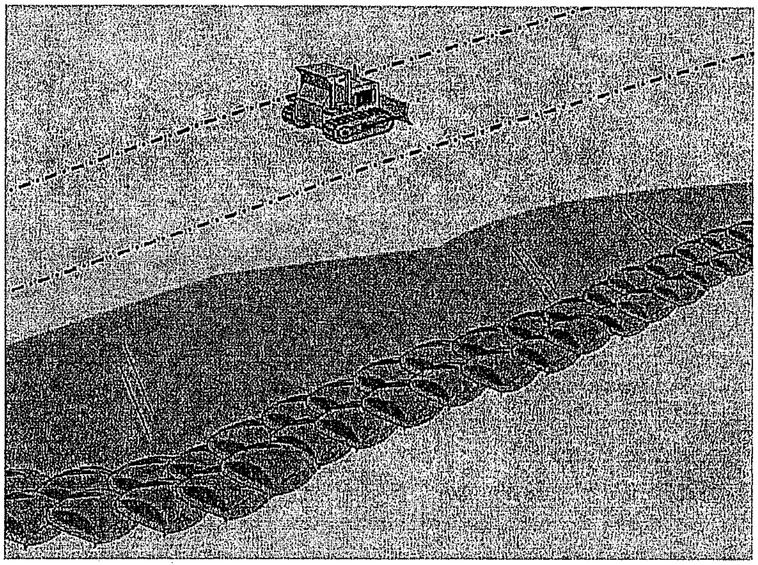


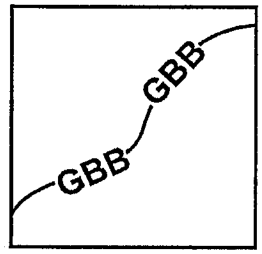
OPTIONAL ENTRENCHMENT DETAIL

N.T.S.

Gravel Bag Berm

SC-6





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A gravel bag berm consists of a single row of gravel bags that are installed end to end to form a barrier across a slope to intercept runoff, reduce its flow velocity, release the runoff as sheet flow and provide some sediment removal. Gravel bags can be used where flows are moderately concentrated, such as ditches, swales, and storm drain inlets (see BMP SC-10, Storm Drain Inlet Protection) to divert and/or detain flows.

Appropriate Applications

- BMP may be implemented on a project-by-project basis with other BMPs when determined necessary and feasible by the RE.
- Along streams and channels.
- Below the toe of exposed and erodible slopes.
- Down slope of exposed soil areas.
- Around stockpiles.
- Across channels to serve as a barrier for utility trenches or provide a temporary channel crossing for construction equipment, to reduce stream impacts.
- Parallel to a roadway to keep sediment off paved areas.
- At the top of slopes to divert roadway runoff away from disturbed slopes.
- Along the perimeter of a site.
- To divert or direct flow or create a temporary sediment basin.
- During construction activities in stream beds when the contributing drainage

area is less than 2 ha (5 ac).

- When extended construction period limits the use of either silt fences or straw bale barriers.

- When site conditions or construction sequencing require adjustments or relocation of the barrier to meet changing field conditions and needs during construction.

- At grade breaks of exposed and erodible slopes to shorten slope length and spread runoff as sheet flow.

Limitations

- Degraded gravel bags may rupture when removed, spilling contents.

- Installation can be labor intensive.

- Limited durability for long term projects.

- When used to detain concentrated flows, maintenance requirements increase.

Standards and Specifications

Materials

- Bag Material: Bags shall be woven polypropylene, polyethylene or polyamide fabric, minimum unit weight 135 g/m2 (four ounces per square yard), mullen burst strength exceeding 2,070 kPa (300 psi) in conformance with the requirements in ASTM designation D3786, and ultraviolet stability exceeding 70% in conformance with the requirements in ASTM designation D4355.

- Bag Size: Each gravel-filled bag shall have a length of 450 mm (18 in), width of 300 mm (12 in), thickness of 75 mm (3 in), and mass of approximately 15 kg (33 lb). Bag dimensions are nominal, and may vary based on locally available materials. Alternative bag sizes shall be submitted to the RE for approval prior to deployment.

- Fill Material: Gravel shall be between 10 mm and 20 mm (0.4 and 0.8 inch) in diameter, and shall be clean and free from clay balls, organic matter, and other deleterious materials. The opening of gravel-filled bags shall be between 13 kg and 22 kg (28 and 48 lb) in mass. Fill material is subject to approval by the RE.

Installation

- When used as a linear control for sediment removal:
  - Install along a level contour.
  - Turn ends of gravel bag row up slope to prevent flow around the ends.
  - Generally, gravel bag barriers shall be used in conjunction with temporary soil stabilization controls up slope to provide effective erosion and sediment

control.

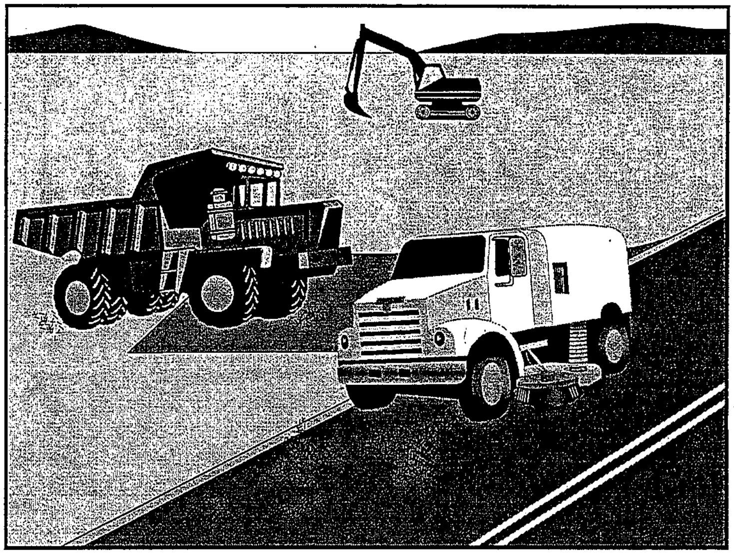
- When used for concentrated flows:
  - Stack gravel bags to required height using a pyramid approach.
  - Upper rows of gravel bags shall overlap joints in lower rows.
- Construct gravel bag barriers with a set-back of at least 1m from the toe of a slope. Where it is determined to be not practicable due to specific site conditions, the gravel bag barrier may be constructed at the toe of the slope, but shall be constructed as far from the toe of the slope as practicable.
- Requires Certificate of Compliance per Standard Specifications 6-1.07.

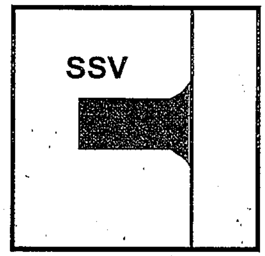
Maintenance and Inspection

- Inspect gravel bag berms before and after each rainfall event, and weekly throughout the rainy season.
- Reshape or replace gravel bags as needed, or as directed by the RE.
- Repair washouts or other damages as needed, or as directed by the RE.
- Inspect gravel bag berms for sediment accumulations and remove sediments when accumulation reaches one-third of the berm height. Removed sediment shall be incorporated in the project at locations designated by the RE or disposed of outside the highway right-of-way in conformance with the Standard Specifications.
- Remove gravel bag berms when no longer needed. Remove sediment accumulations and clean, re-grade, and stabilize the area.

Street Sweeping and Vacuuming

SC-7





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ● Sediment Control
- ● Tracking Control
- o Wind Erosion Control
- o Non-Storm Water Management
- o Materials and Waste Management

Definition and Purpose
Practices to remove tracked sediment to prevent the sediment from entering a storm drain or watercourse.

Appropriate Applications
These practices are implemented anywhere sediment is tracked from the project site onto public or private paved roads, typically at points of ingress/egress.

Limitations
Sweeping and vacuuming may not be effective when soil is wet or muddy.

Standards and Specifications

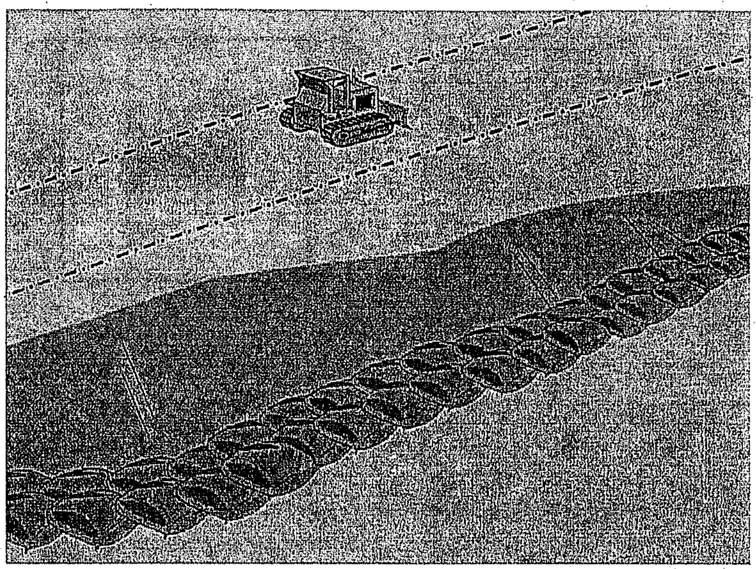
- Kick brooms or sweeper attachments shall not be used.
- Inspect potential sediment tracking locations daily.
- Visible sediment tracking shall be swept and/or vacuumed daily.
- If not mixed with debris or trash, consider incorporating the removed sediment back into the project.

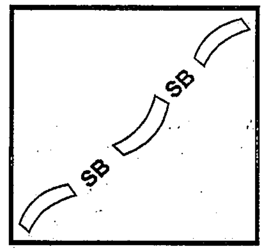
Maintenance and Inspection

- Inspect ingress/egress access points daily and sweep tracked sediment as needed, or as required by the Resident Engineer (RE).
- Be careful not to sweep up any unknown substance or any object that may be potentially hazardous.
- Adjust brooms frequently; maximize efficiency of sweeping operations.
- After sweeping is finished, properly dispose of sweeper wastes at an approved dumpsite in conformance with the provisions in Standard Specifications Section 7-1.13 .

Sandbag Barrier

SC-8





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A sandbag barrier is a temporary linear sediment barrier consisting of stacked sandbags, designed to intercept and slow the flow of sediment-laden sheet flow runoff. Sandbag barriers allow sediment to settle from runoff before water leaves the construction site.

Appropriate Applications

- This BMP may be implemented on a project-by-project basis in addition to other BMPs when determined necessary and feasible by the Resident Engineer (RE).
- Along the perimeter of a site.
- Along streams and channels.
- Below the toe of exposed and erodible slopes.
- Down slope of exposed soil areas.
- Around stockpiles.
- Across channels to serve as a barrier for utility trenches or provide a temporary channel crossing for construction equipment, to reduce stream impacts.
- Parallel to a roadway to keep sediment off paved areas.
- At the top of slopes to divert roadway runoff away from disturbed slopes.
- To divert or direct flow or create a temporary sediment/desilting basin.
- During construction activities in stream beds when the contributing drainage area is less than 2 ha (5 ac).

- When extended construction period limits the use of either silt fences or straw bale barriers.
- Along the perimeter of vehicle and equipment fueling and maintenance areas or chemical storage areas.
- To capture and detain non-storm water flows until proper cleaning operations occur.
- When site conditions or construction sequencing require adjustments or relocation of the barrier to meet changing field conditions and needs during construction.
- To temporarily close or continue broken, damaged or incomplete curbs.

Limitations

- Limit the drainage area upstream of the barrier to 2 ha (5 ac).
- Degraded sandbags may rupture when removed, spilling sand.
- Installation can be labor intensive.
- Limited durability for long-term projects.
- When used to detain concentrated flows, maintenance requirements increase.

Standards and Specifications

Materials

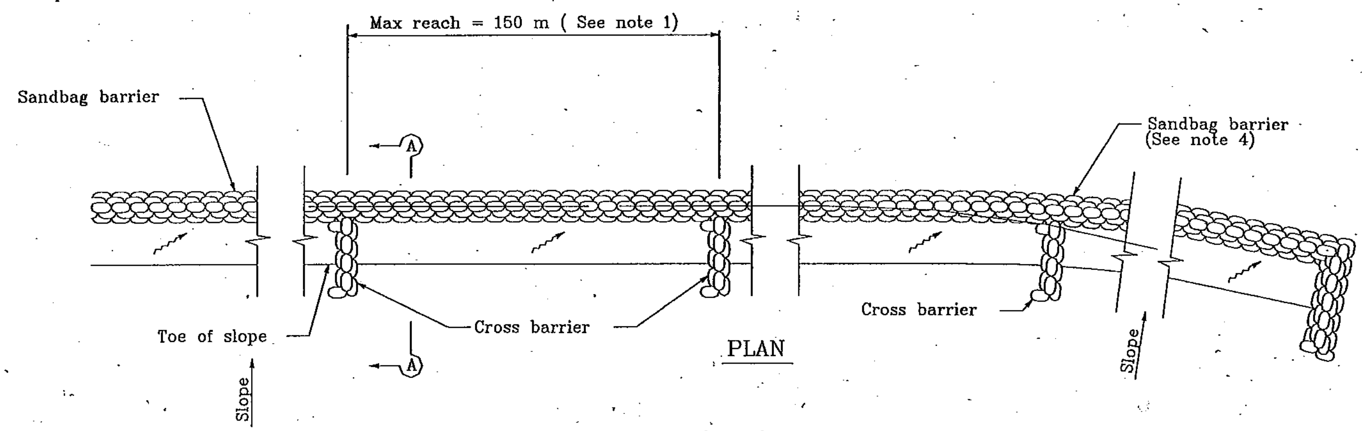
- Sandbag Material: Sandbag shall be woven polypropylene, polyethylene or polyamide fabric, minimum unit weight 135 g/m2 (four ounces per square yard), mullen burst strength exceeding 2,070 kPa (300 psi) in conformance with the requirements in ASTM designation D3786, and ultraviolet stability exceeding 70% in conformance with the requirements in ASTM designation D4355. Use of burlap is not acceptable.
- Sandbag Size: Each sand-filled bag shall have a length of 450 mm (18 in), width of 300 mm (12 in), thickness of 75 mm (3 in), and mass of approximately 15 kg (33 lb.). Bag dimensions are nominal, and may vary based on locally available materials. Alternative bag sizes shall be submitted to the RE for approval prior to deployment.
- Fill Material: All sandbag fill material shall be non-cohesive, Class 1 or Class 2 permeable material free from clay and deleterious material, conforming to the provisions in Standard Specifications Section 68-1.025 "Permeable Material". The requirements for the Durability Index and Sand Equivalent do not apply. Fill material is subject to approval by the RE.

Installation

- When used as a linear sediment control:
  - Install along a level contour.
  - Turn ends of sandbag row up slope to prevent flow around the ends.
  - Generally, sandbag barriers shall be used in conjunction with temporary soil stabilization controls up slope to provide effective erosion and sediment control.
  - Install as shown in Pages 4 and 5 of this BMP.
- Construct sandbag barriers with a set-back of at least 1m (3 ft) from the toe of a slope. Where it is determined to be not practical due to specific site conditions, the sandbag barrier may be constructed at the toe of the slope, but shall be constructed as far from the toe of the slope as practicable.

Maintenance and Inspection

- Inspect sandbag barriers before and after each rainfall event, and weekly throughout the rainy season.
- Reshape or replace sandbags as needed, or as directed by the RE.
- Repair washouts or other damages as needed, or as directed by the RE.
- Inspect sandbag barriers for sediment accumulations and remove sediments when accumulation reaches one-third the barrier height. Removed sediment shall be incorporated in the project at locations designated by the RE or disposed of outside the highway right-of-way in conformance with the Standard Specifications.
- Remove sandbags when no longer needed. Remove sediment accumulation, and clean, re-grade, and stabilized the area.



TEMPORARY-LINEAR SEDIMENT BARRIER (TYPE SANDBAG)

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION

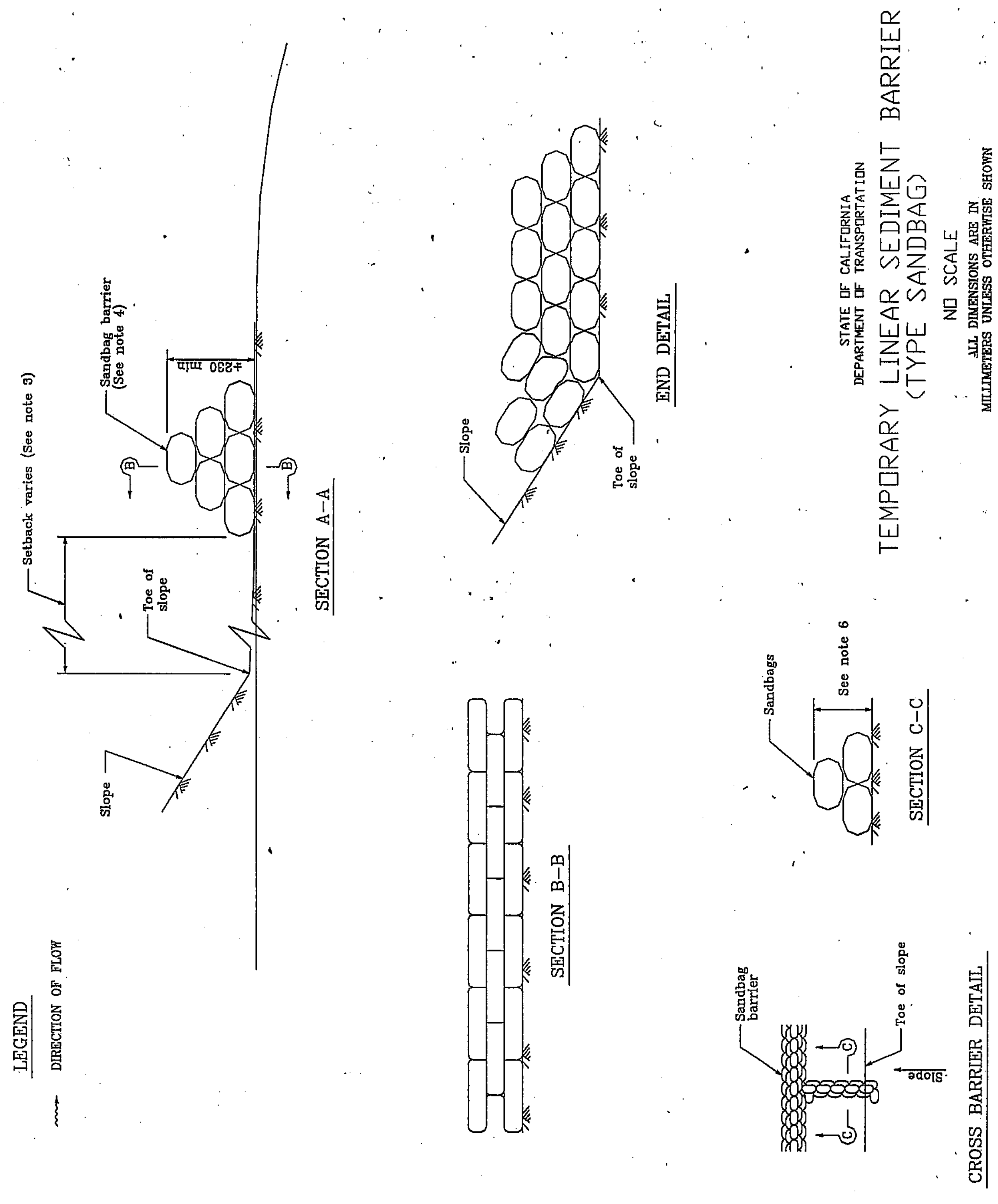
TEMPORARY LINEAR SEDIMENT BARRIER (TYPE SANDBAG)

NO SCALE

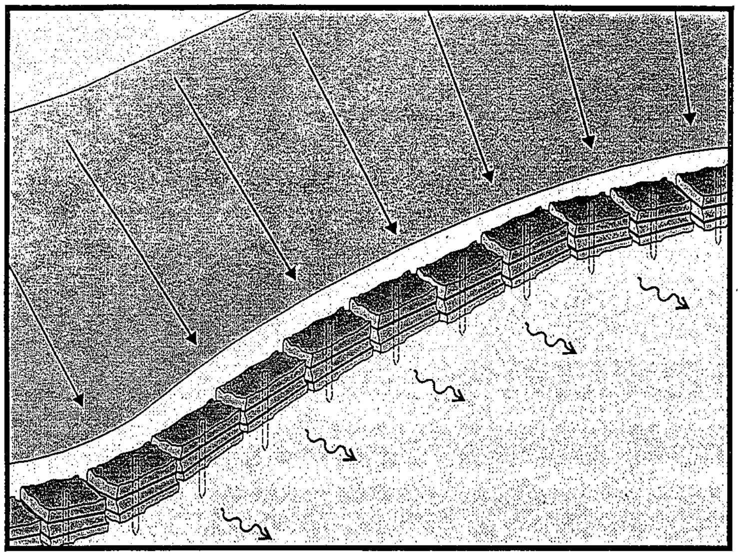
ALL DIMENSIONS ARE IN MILLIMETERS UNLESS OTHERWISE SHOWN

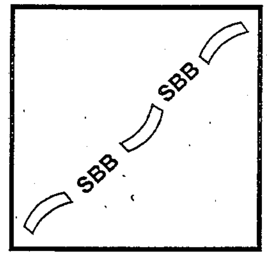
NOTES

1. Construct the length of each reach so that the change in base elevation along the reach does not exceed 1/2 the height of the linear barrier. In no case shall the reach length exceed 150 m.
2. Place sandbags tightly.
3. Dimension may vary to fit field condition.
4. Sandbag barrier shall be a minimum of 3 bags high.
5. The end of the barrier shall be turned up slope.
6. Cross barriers shall be a min of 1/2 and a max of 2/3 the height of the linear barrier.
7. Sandbag rows and layers shall be staggered to eliminate gaps.


LEGEND
DIRECTION OF FLOW
Slope
Setback varies (See note 3)
Toe of slope
Sandbag barrier (See note 4)
+230 min
B
B
SECTION A-A
SECTION B-B
Slope
Toe of slope
END DETAIL
Sandbags
See note 6
SECTION C-C
Sandbag barrier
Toe of slope
Slope
C
C
CROSS BARRIER DETAIL
STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
TEMPORARY LINEAR SEDIMENT BARRIER
(TYPE SANDBAG)
NO SCALE
ALL DIMENSIONS ARE IN MILLIMETERS UNLESS OTHERWISE SHOWN

Straw Bale Barrier





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A straw bale barrier is a temporary linear sediment barrier consisting of straw bales, designed to intercept and slow sediment-laden sheet flow runoff. Straw bale barriers allow sediment to settle from runoff before water leaves the construction site.

Appropriate Applications

- This BMP may be implemented on a project-by-project basis in addition to other BMPs when determined necessary and feasible by the Resident Engineer (RE).
- Along the perimeter of a site.
- Along streams and channels.
- Below the toe of exposed and erodible slopes.
- Down slope of exposed soil areas.
- Around stockpiles.
- Across minor swales or ditches with small catchments.
- Around above grade type temporary concrete washouts (See BMP WM-8, "Concrete Waste Management").
- Parallel to a roadway to keep sediment off paved areas.

Limitations

- Installation can be labor intensive.
- Straw bale barriers are maintenance intensive.
- Degraded straw bales may fall apart when removed or left in place for extended periods.
- Can't be used on paved surfaces.
- Not to be used for drain inlet protection.
- Shall not be used in areas of concentrated flow.
- Can be an attractive food source for some animals.
- May introduce undesirable non-native plants to the area.

Standards and Specifications

Materials

- ***Straw Bale Material:*** Straw bale materials shall conform to the provisions in Standard Specifications Section 20-2.06, "Straw."
- Straw Bale Size: Each straw bale shall be a minimum of 360 mm (14 in) wide, 450 mm (18 in) in height, 900 mm (36 in) in length and shall have a minimum mass of 23 kg (51 lb.) The straw bale shall be composed entirely of vegetative matter, except for the binding material.
- Bale Bindings: Bales shall be bound by either steel wire, nylon or polypropylene string placed horizontally. Jute and cotton binding shall not be used. Baling wire shall be a minimum diameter of 1.57 mm (0.06 inch). Nylon or polypropylene string shall be approximately 2 mm (0.08 inch) in diameter with a breaking strength of 360 N.
- Stakes: Wood stakes shall be commercial quality lumber of the size and shape shown on the plans. Each stake shall be free from decay, splits or cracks longer than the thickness of the stake, or other defects that would weaken the stakes and cause the stakes to be structurally unsuitable. Steel bar reinforcement shall be equal to a number four designation or greater. End protection shall be provided for any exposed bar reinforcement.

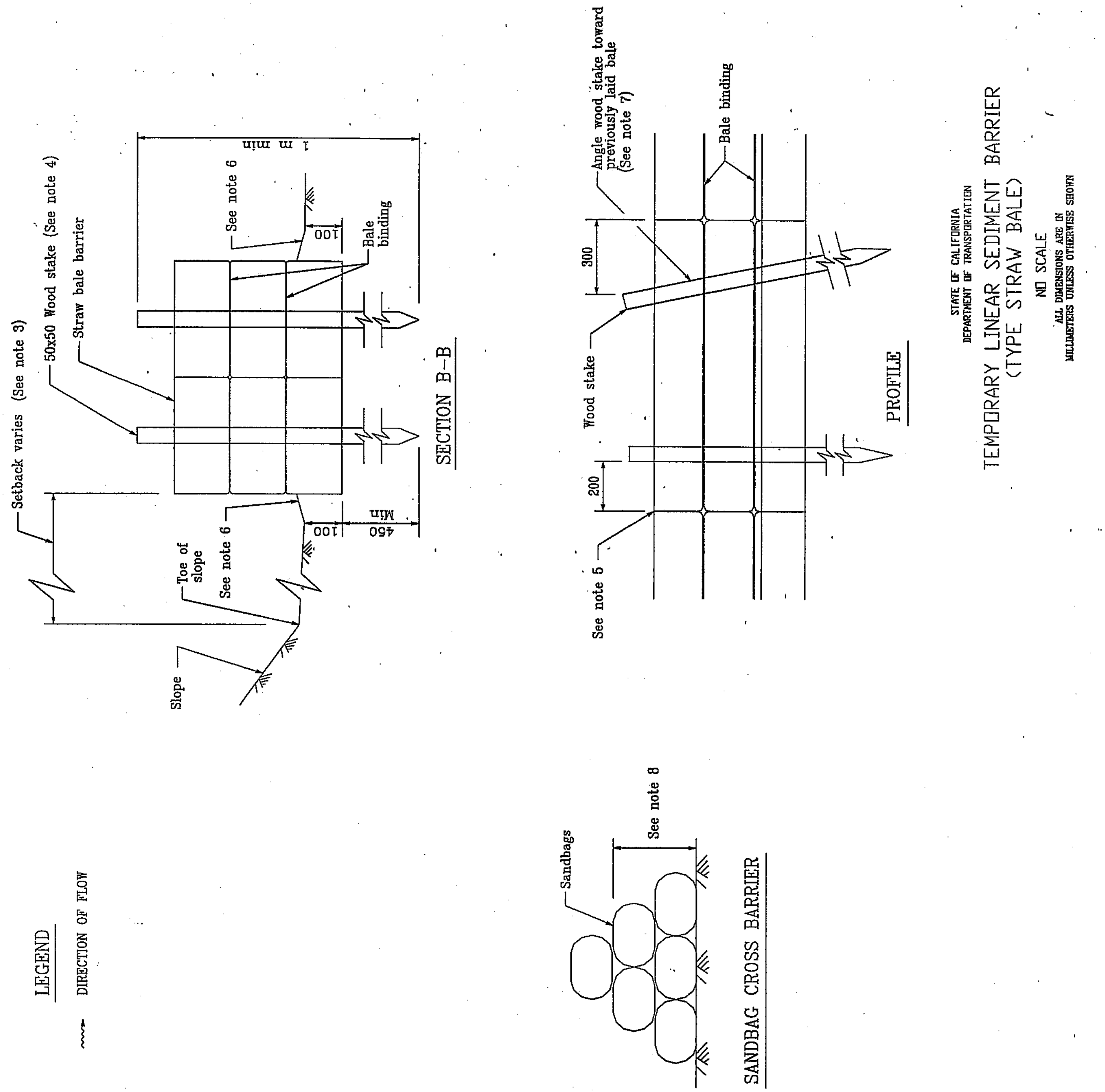
Installation

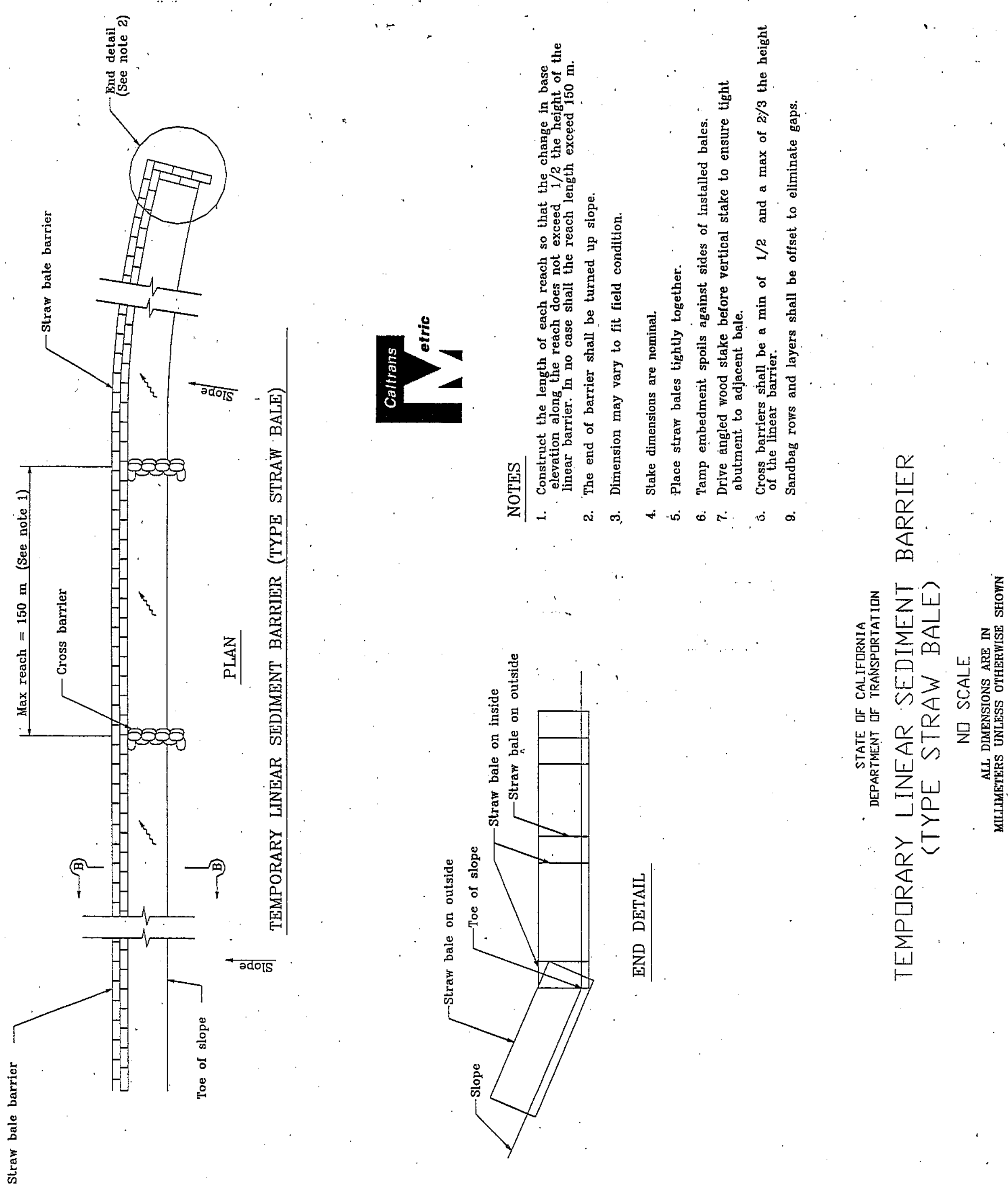
- Limit the drainage area upstream of the barrier to 0.3 ha/100 m (0.25 ac/100ft) or barrier.
- Limit the slope length draining to the straw bale barrier to 30 m (100 ft.)

- Slopes of 2:100 (V:H) (2%) or flatter are preferred. If the slope exceeds 1:10 (V:H) (10%), the length of slope upstream of the barrier must be less than 15 m (50 ft).
- Install straw bale barriers along a level contour, with the last straw bale turned up slope.
- Straw bales must be installed in a trench and tightly abut adjacent bales.
- Construct straw bale barriers with a set-back of at least 1 m (3 ft) from the toe of a slope. Where it is determined to be not practical due to specific site conditions, the straw bale barrier may be constructed at the toe of the slope, but shall be constructed as far from the toe of the slope as practical.
- See pages 4 and 5 of this BMP for installation detail.

Maintenance and Inspection

- Inspect straw bale barriers before and after each rainfall event, and weekly throughout the rainy season.
- Inspect straw bale barriers for sediment accumulations and remove sediment when depth reaches one-third the barrier height. Removed sediment shall be incorporated in the project at locations designated by the RE or disposed of outside the highway right-of-way in conformance with the Standard Specifications.
- Replace or repair damage bales as needed or as directed by the RE.
- Repair washouts or other damages as needed or as directed by the RE.
- Remove straw bales when no longer needed. Remove sediment accumulation, and clean, re-grade, and stabilized the area.

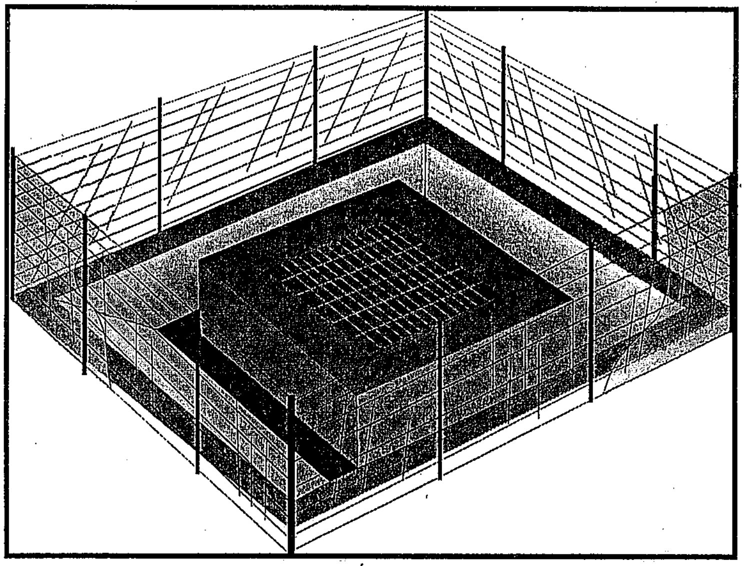

Setback varies (See note 3)
50x50 Wood stake (See note 4)
Straw bale barrier
See note 6
Bale binding
1 m min
100
450 Min
Toe of slope
Slope
SECTION B-B
Angle wood stake toward previously laid bale (See note 7)
Bale binding
300
200
Wood stake
See note 5
PROFILE
STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
TEMPORARY LINEAR SEDIMENT BARRIER
(TYPE STRAW BALE)
NO SCALE
ALL DIMENSIONS ARE IN MILLIMETERS UNLESS OTHERWISE SHOWN
LEGEND
DIRECTION OF FLOW
Sandbags
See note 8
SANDBAG CROSS BARRIER

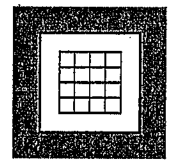


End detail (See note 2)
Straw bale barrier
Slope
Max reach = 150 m (See note 1)
Cross barrier
B
B
Slope
Straw bale barrier
Toe of slope
PLAN
TEMPORARY LINEAR SEDIMENT BARRIER (TYPE STRAW BALE)
Caltrans Metric
Straw bale on outside
Toe of slope
Straw bale on inside
Straw bale on outside
Straw bale on outside
Slope
END DETAIL
NOTES
1. Construct the length of each reach so that the change in base elevation along the reach does not exceed 1/2 the height of the linear barrier. In no case shall the reach length exceed 150 m.
2. The end of barrier shall be turned up slope.
3. Dimension may vary to fit field condition.
4. Stake dimensions are nominal.
5. Place straw bales tightly together.
6. Tamp embedment spoils against sides of installed bales.
7. Drive angled wood stake before vertical stake to ensure tight abutment to adjacent bale.
8. Cross barriers shall be a min of 1/2 and a max of 2/3 the height of the linear barrier.
9. Sandbag rows and layers shall be offset to eliminate gaps.
STATE OF CALIFORNIA DEPARTMENT OF TRANSPORTATION
TEMPORARY LINEAR SEDIMENT BARRIER (TYPE STRAW BALE)
NO SCALE
ALL DIMENSIONS ARE IN MILLIMETERS UNLESS OTHERWISE SHOWN

Storm Drain Inlet Protection

SC-10





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Devices used at storm drain inlets that are subject to runoff from construction activities to detain and/or to filter sediment-laden runoff to allow sediment to settle and/or to filter sediment prior to discharge into storm drainage systems or watercourses.

Appropriate Applications

- Where ponding will not encroach into highway traffic.
- Where sediment laden surface runoff may enter an inlet.
- Where disturbed drainage areas have not yet been permanently stabilized.
- Where the drainage area is 0.4 ha (1 ac) or less.
- Appropriate during wet and snow-melt seasons.

Limitations

- Requires an adequate area for water to pond without encroaching upon traveled way and should not present itself to be an obstacle to oncoming traffic.
- May require other methods of temporary protection to prevent sediment-laden storm water and non-storm water discharges from entering the storm drain system.
- Sediment removal may be difficult in high flow conditions or if runoff is heavily sediment laden. If high flow conditions are expected, use other on-site sediment trapping techniques (e.g. check dams) in conjunction with inlet protection.
- Frequent maintenance is required.
- For drainage areas larger than 0.4 ha (1 ac), runoff shall be routed to a sediment trapping device designed for larger flows. See BMPs SC-2, "Sediment/Desilting Basin," and SC-3 "Sediment Trap."

- Filter fabric fence inlet protection is appropriate in open areas that are subject to sheet flow and for flows not exceeding 0.014 m3/s (0.5 cfs).
- Gravel bag barriers for inlet protection are applicable when sheet flows or concentrated flows exceed 0.014 m3/s (0.5 cfs), and it is necessary to allow for overtopping to prevent flooding.
- Fiber rolls and foam barriers are not appropriate for locations where they cannot be properly anchored to the surface.
- Excavated drop inlet sediment traps are appropriate where relatively heavy flows are expected and overflow capability is needed.

Standards and Specifications

Identify existing and/or planned storm drain inlets that have the potential to receive sediment-laden surface runoff. Determine if storm drain inlet protection is needed, and which method to use.

Methods and Installation

- ***DI Protection Type 1 - Filter Fabric Fence -*** The filter fabric fence (Type 1) protection is illustrated on Page 5. Similar to constructing a silt fence. See BMP SC-1, "Silt Fence." Do not place filter fabric underneath the inlet grate since the collected sediment may fall into the drain inlet when the fabric is removed or replaced.
- ***DI Protection Type 2 - Excavated Drop Inlet Sediment Trap -*** The excavated drop inlet sediment trap (Type 2) is illustrated in Page 6. Similar to constructing a temporary silt fence, See BMP SC-1, "Silt Fence." Size excavated trap to provide a minimum storage capacity calculated at the rate of 130 m3/ha (67 yd3/ac) of drainage area.
- ***DI Protection Type 3 – Gravel bag -*** The gravel bag barrier (Type 3) is illustrated in Page 7. Flow from a severe storm shall not overtop the curb. In areas of high clay and silts, use filter fabric and gravel as additional filter media. Construct gravel bags in accordance with BMP SC-6, "Gravel Bag Berm." Gravel bags shall be used due to their high permeability.
- ***DI Protection Type 4 – Foam Barriers and Fiber Rolls –*** Foam barrier or fiber roll (Type 4) is placed around the inlet and keyed and anchored to the surface. Foam barriers and fiber rolls are intended for use as inlet protection where the area around the inlet is unpaved and the foam barrier or fiber roll can be secured to the surface. RE or Construction Storm Water Coordinator approval is required.

Maintenance and Inspection

General

- Inspect all inlet protection devices before and after every rainfall event, and weekly during the rest of the rainy season. During extended rainfall events, inspect inlet protection devices at least once every 24 hours.

- Inspect the storm drain inlet after severe storms in the rainy season to check for bypassed material.
- Remove all inlet protection devices within thirty days after the site is stabilized, or when the inlet protection is no longer needed.
  - Bring the disturbed area to final grade and smooth and compact it. Appropriately stabilize all bare areas around the inlet.
  - Clean and re-grade area around the inlet and clean the inside of the storm drain inlet as it must be free of sediment and debris at the time of final inspection.

Requirements by Method

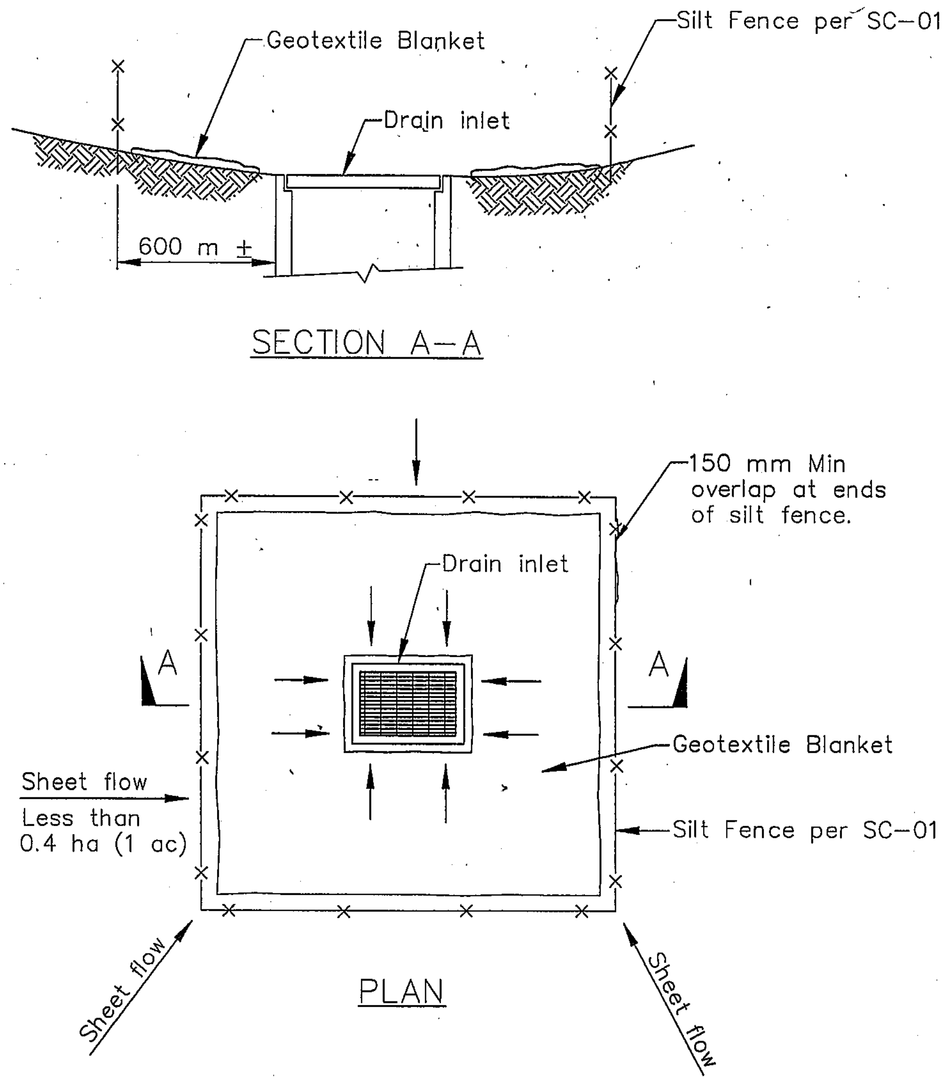
- ***Type 1 - Filter Fabric Fence***
  - This method shall be used for drain inlets requiring protection in areas where finished grade is established and erosion control seeding has been applied or is pending.
  - Make sure the stakes are securely driven in the ground and are structurally sound (i.e., not bent, cracked, or splintered, and are reasonably perpendicular to the ground). Replace damaged stakes.
  - Replace or clean the fabric when the fabric becomes clogged with sediment. Make sure the fabric does not have any holes or tears. Repair or replace fabric as needed or as directed by the RE.
  - At a minimum, remove the sediment behind the fabric fence when accumulation reaches one-third the height of the fence or barrier height. Removed sediment shall be incorporated in the project at locations designated by the RE or disposed of outside the highway right-of-way in conformance with the Standard Specifications Section 7-1.13.
- ***Type 2 – Excavated Drop Inlet Sediment Trap***
  - This method may be used for drain inlets requiring protection in areas that have been cleared and grubbed, and where exposed soil areas are subject to grading.
  - Remove sediment from basin when the volume of the basin has been reduced by one-half.
- ***Type 3 - Gravel Bag Barrier***
  - This method may be used for drain inlets surrounded by AC or paved surfaces.
  - Inspect bags for holes, gashes, and snags.

- Check gravel bags for proper arrangement and displacement. Remove the sediment behind the barrier when it reaches one-third the height of the barrier. Removed sediment shall be incorporated in the project at locations designated by the RE or disposed of outside the highway right-of-way in conformance with the Standard Specifications Section 7-1.13.

- *Type 4 Foam Barriers and Fiber Rolls*

  - This method may be used for drain inlets requiring protection in areas that have been cleared and grubbed, and where exposed soil areas subject to grading. RE or Construction Storm Coordinator approval is required.

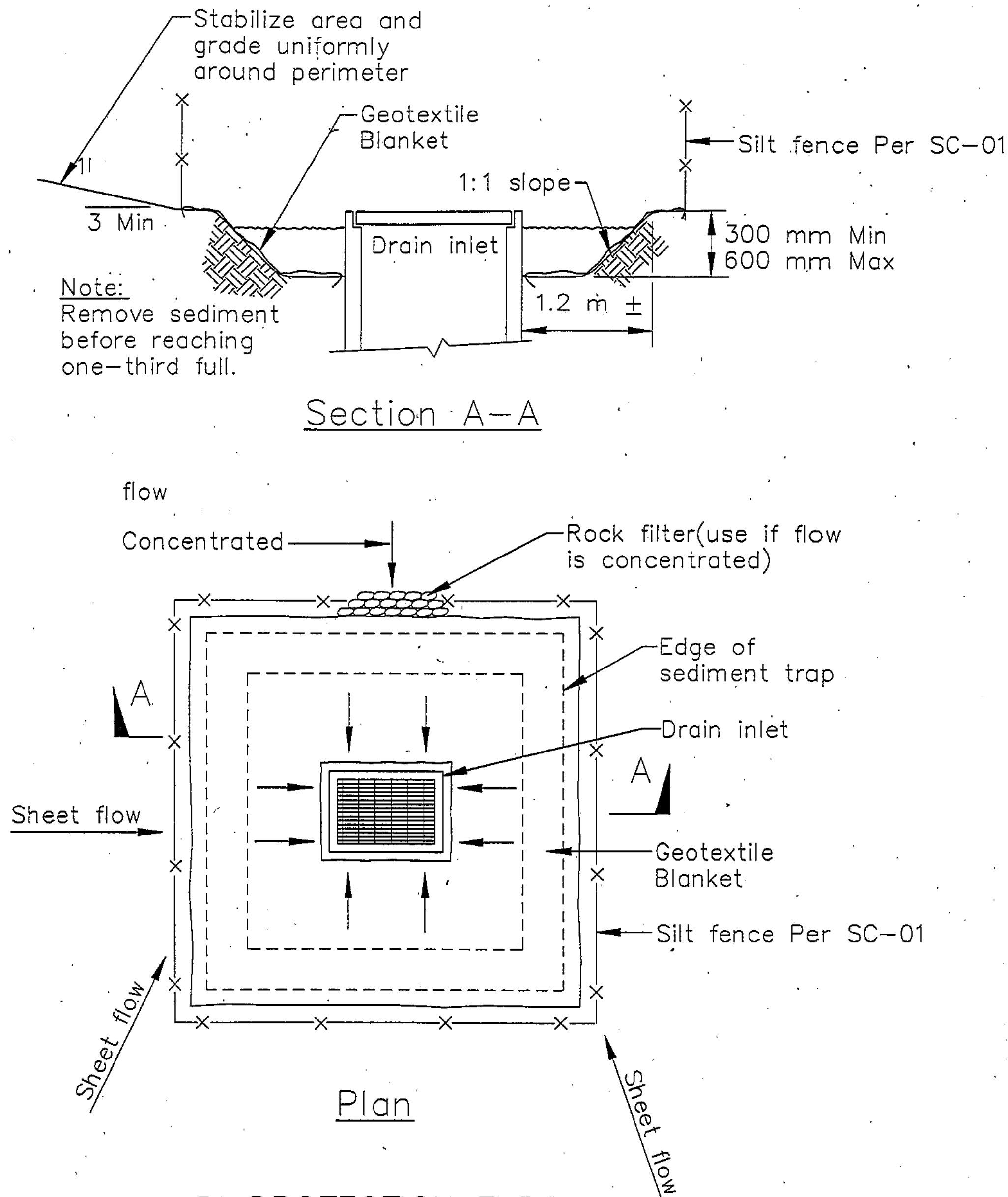
  - Check foam barrier or fiber roll for proper arrangement and displacement. Remove the sediment behind the barrier when it reaches one-third the height of the barrier. Removed sediment shall be incorporated in the project at locations designated by the RE or disposed of outside the highway right-of-way in conformance with the Standard Specifications.



DI PROTECTION TYPE 1
NOT TO SCALE

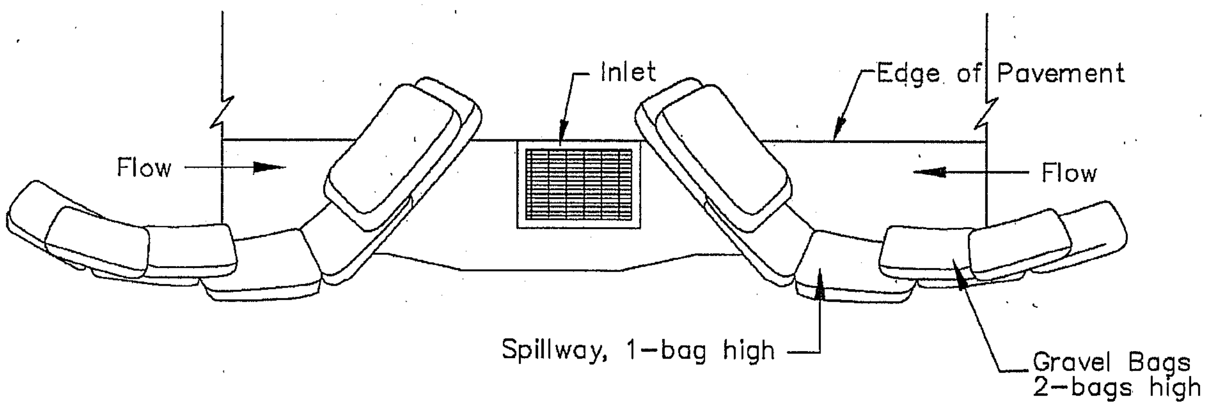
NOTES:

1. For use in areas where grading has been completed and final soil stabilization and seeding are pending.
2. Not applicable in paved areas.
3. Not applicable with concentrated flows.

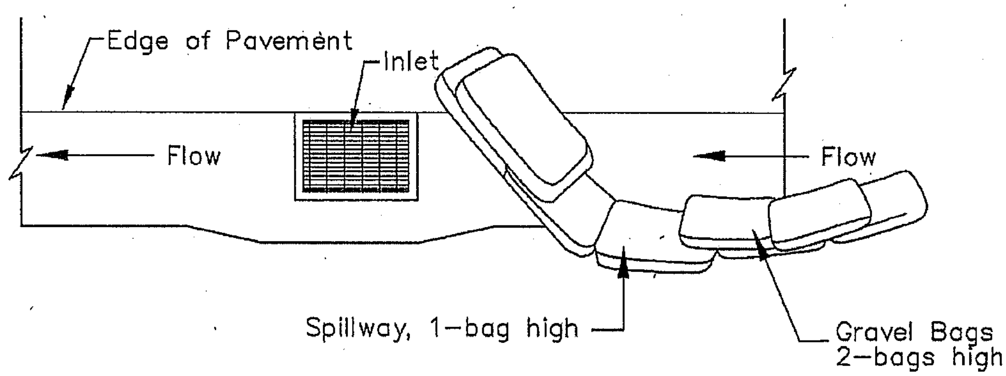


DI PROTECTION TYPE 2
NOT TO SCALE

Notes
1. For use in cleared and grubbed and in graded areas.
2. Shape basin so that longest inflow area faces longest length of trap.
3. For concentrated flows, shape basin in 2:1 ratio with length oriented towards direction of flow.



TYPICAL PROTECTION FOR INLET WITH OPPOSING FLOW DIRECTIONS



TYPICAL PROTECTION FOR INLET WITH SINGLE FLOW DIRECTION

NOTES:

1. Intended for short-term use.
2. Use to inhibit non-storm water flow.
3. Allow for proper maintenance and cleanup.
4. Bags must be removed after adjacent operation is completed
5. Not applicable in areas with high silts and clays without filter fabric.

Section 5
Wind Erosion Control
Best Management Practices

5.1 Wind Erosion Control

Wind erosion control consists of applying water or other dust palliatives as necessary to prevent or alleviate dust nuisance. Wind erosion control best management practices (BMPs) are shown in Table 5-1.

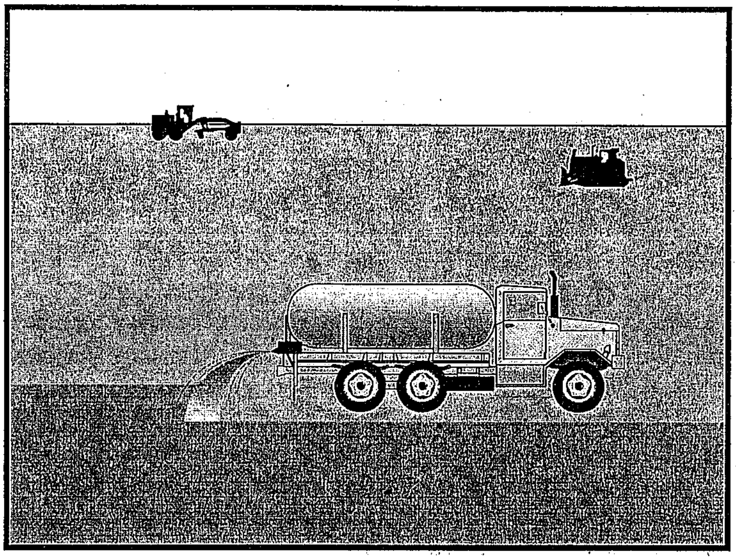
Table 5-1

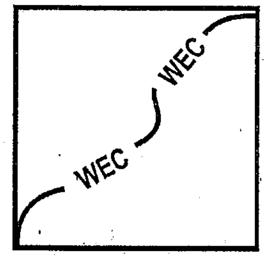
WIND EROSION CONTROL BMPs	
ID	**BMP NAME**
WE-1	Wind Erosion Control

Other BMPs that are sometimes applied to disturbed soil areas to control wind erosion are BMPs SS-3 through SS-7, shown in Section 3 of this Manual; BMP TC-2, shown in Section 6; and BMP NS-7, shown in Section 7. The remainder of this Section shows the working details for the Wind Erosion Control BMP.

Wind Erosion Control

WE-1





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ● Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Wind erosion control consists of applying water and/or other dust palliatives as necessary to prevent or alleviate erosion by the forces of wind. Dust control shall be applied in accordance with Caltrans standard practices. Covering of small stockpiles or areas is an alternative to applying water or other dust palliatives.

Appropriate Applications

- This practice is implemented on all exposed soils subject to wind erosion.

Limitations

- Effectiveness depends on soil, temperature, humidity and wind velocity.

Standards and Specifications

- Water shall be applied by means of pressure-type distributors or pipelines equipped with a spray system or hoses and nozzles that will ensure even distribution.
- All distribution equipment shall be equipped with a positive means of shutoff.
- Unless water is applied by means of pipelines, at least one mobile unit shall be available at all times to apply water or dust palliative to the project.
- If reclaimed water is used, the sources and discharge must meet California Department of Health Services water reclamation criteria and the Regional Water Quality Control Board requirements. Non-potable water shall not be conveyed in tanks or drain pipes that will be used to convey potable water and there shall be no connection between potable and non-potable supplies. Non-potable tanks, pipes and other conveyances shall be marked "NON-POTABLE WATER - DO NOT DRINK."
- Materials applied as temporary soil stabilizers and soil binders will also provide wind erosion control benefits.

Maintenance and Inspection

- Check areas that have been protected to ensure coverage.

A001546

Section 6
Tracking Control
Best Management Practices

6.1 Tracking Control

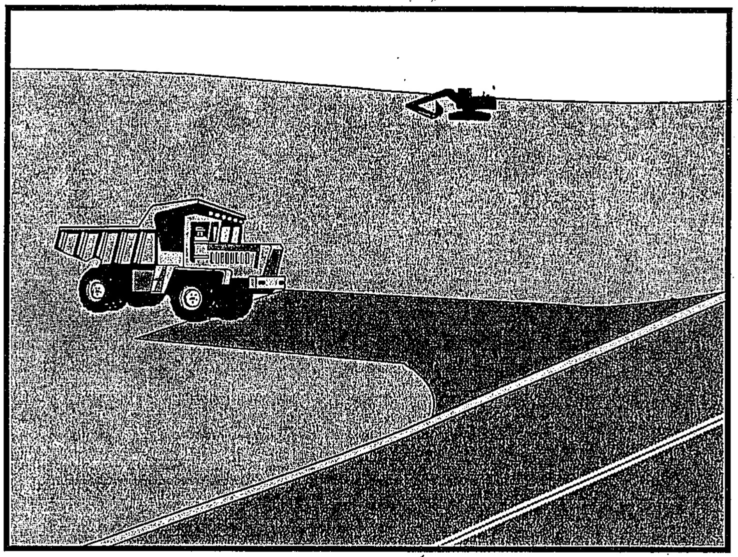
Tracking control consists of preventing or reducing vehicle tracking from entering a storm drain or watercourse. Tracking control best management practices (BMPs) are shown in Table 6-1.

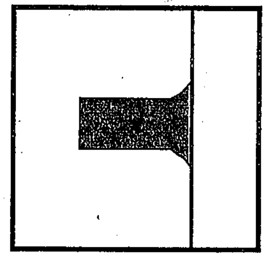
Table 6-1

TRACKING CONTROL BMPs	
ID	**BMP NAME**
TC-1	Stabilized Construction Entrance/Exit
TC-2	Stabilized Construction Roadway
TC-3	Entrance/Outlet Tire Wash

The remainder of this Section shows the working details for the tracking control BMPs.

Stabilized Construction Entrance/Exit TC-1





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ● Tracking Control
- ● Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A stabilized construction access is defined by a point of entrance/exit to a construction site that is stabilized to reduce the tracking of mud and dirt onto public roads by construction vehicles.

Appropriate Applications

- Use at construction sites:
  - Where dirt or mud can be tracked onto public roads.
  - Adjacent to water bodies.
  - Where poor soils are encountered.
  - Where dust is a problem during dry weather conditions.
- This BMP may be implemented on a project-by-project basis in addition to other BMPs when determined necessary and feasible by the Resident Engineer (RE).

Limitations

- Site conditions will dictate design and need.

Standards and Specifications

- Limit the points of entrance/exit to the construction site.
- Limit speed of vehicles to control dust.
- Properly grade each construction entrance/exit to prevent runoff from leaving the construction site.
- Route runoff from stabilized entrances/exits through a sediment-trapping device before discharge.
- Design stabilized entrance/exit to support the heaviest vehicles and equipment that will use it.

- Select construction access stabilization (aggregate, asphaltic concrete, concrete) based on longevity, required performance, and site conditions. The use of asphalt concrete (AC) grindings for stabilized construction access/roadway is not allowed.

- Use of constructed/manufactured steel plates with ribs for entrance/exit access is allowed with written approval from the RE.

- If aggregate is selected, place crushed aggregate over geotextile fabric to at least 300 mm (12 in) depth, or place aggregate to a depth recommended by the RE. Crushed aggregate greater than 75 mm (3 inches) and smaller than 150 mm (6 inches) shall be used.

- Designate combination or single purpose entrances and exits to the construction site.

- Implement BMP SC-7, "Street Sweeping and Vacuuming" as needed and as required.

- Require all employees, subcontractors, and suppliers to utilize the stabilized construction access.

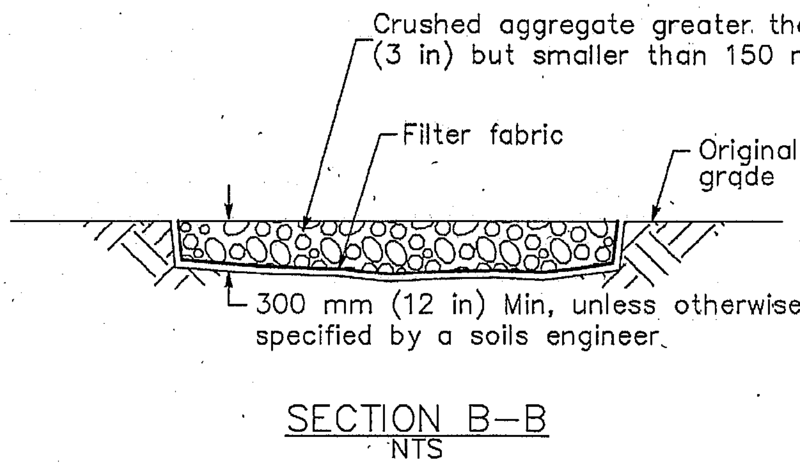
- All exit locations intended to be used continuously and for a period of time shall have stabilized construction entrance/exit BMPs (TC-1 "Stabilized Construction Entrance/Exit" or TC-3 "Entrance/Outlet Tire Wash").

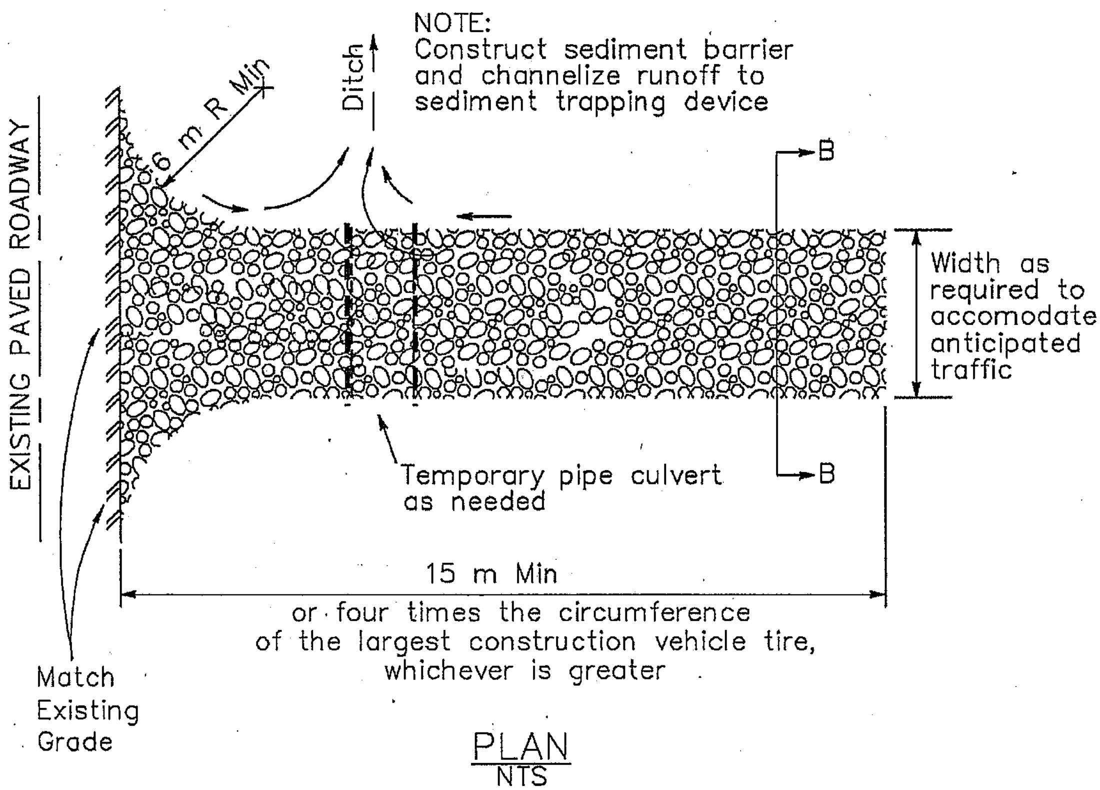
Maintenance and Inspection

- Inspect routinely for damage and assess effectiveness of the BMP. Remove aggregate, separate and dispose of sediment if construction entrance/exit is clogged with sediment or as directed by the RE.

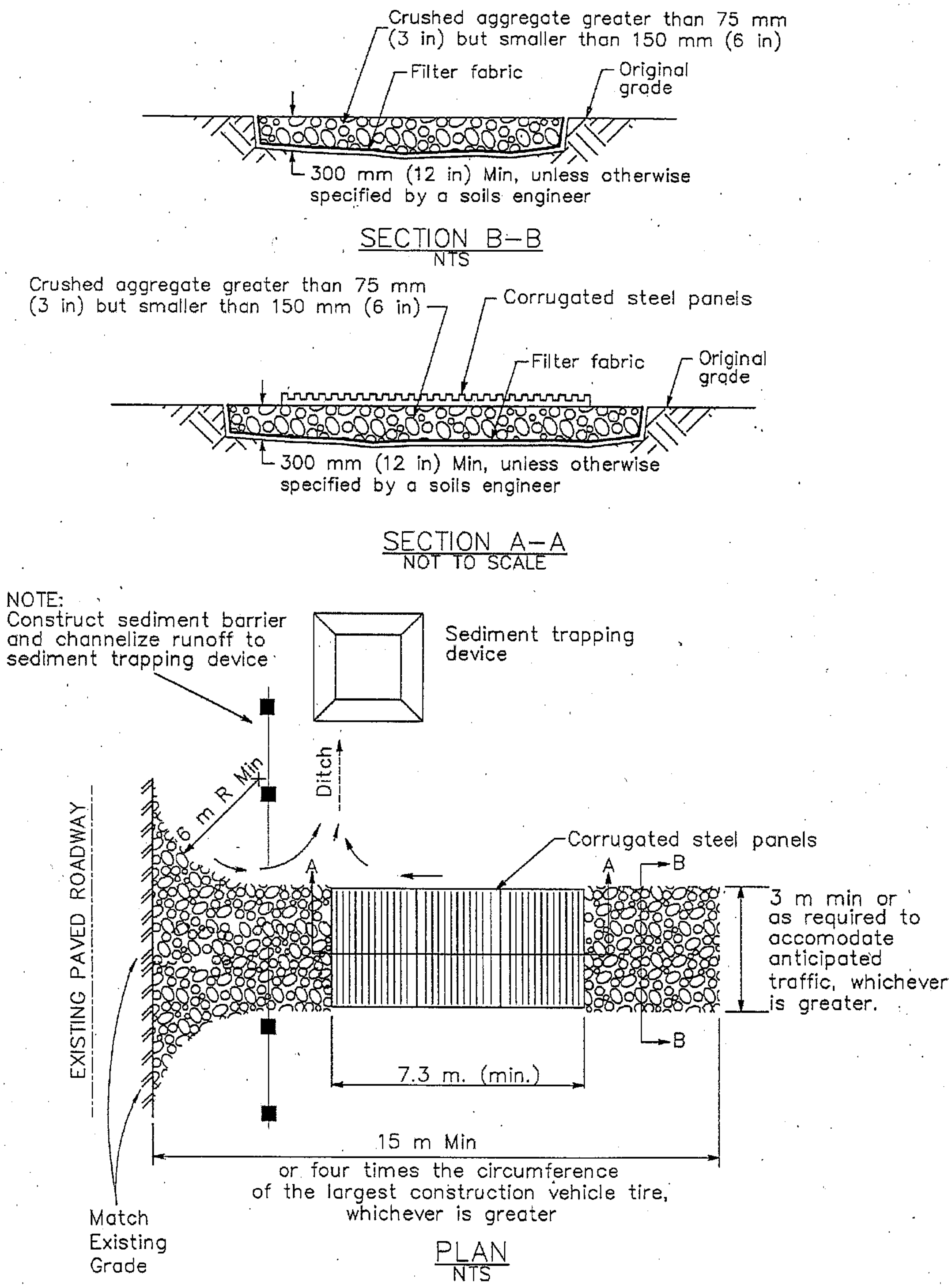
- Keep all temporary roadway ditches clear.

- Inspect for damage and repair as needed.



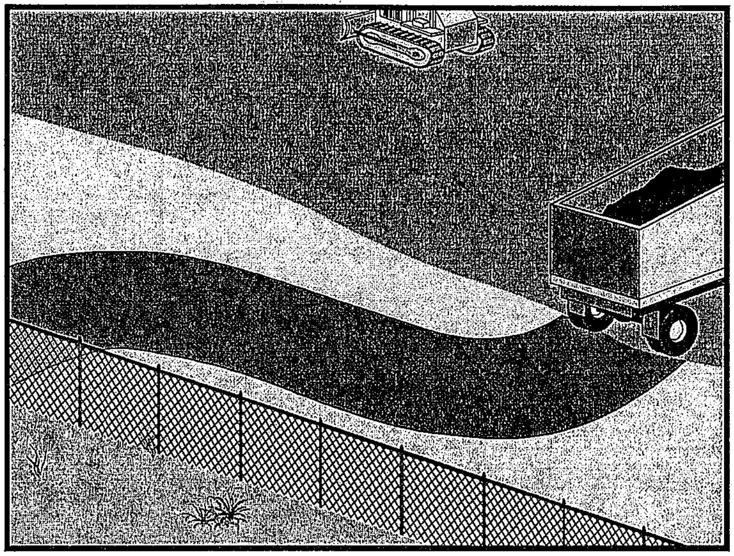


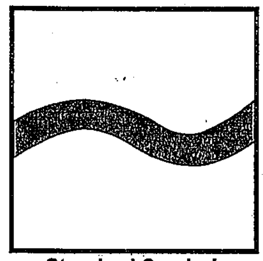
Stabilized Contraction Entrance/Exit (Type 1)



Stabilized Construction Entrance/Exit (Type 2)

Stabilized Construction Roadway **TC-2**





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ● Tracking Control
- ● Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A stabilized construction roadway is a temporary access road. It is designed for the control of dust and erosion created by vehicular tracking.

Appropriate Applications

- Construction roadways and short-term detour roads:
  - Where mud tracking is a problem during wet weather.
  - Where dust is a problem during dry weather.
  - Adjacent to water bodies.
  - Where poor soils are encountered.
  - Where there are steep grades and additional traction is needed.
- This BMP may be implemented on a project-by-project basis with other BMPs when determined necessary and feasible by the Resident Engineer (RE).

Limitations

- Materials will likely need to be removed prior to final project grading and stabilization.
- Site conditions will dictate design and need.
- May not be applicable to very short duration projects.
- Limit speed of vehicles to control dust.

Standards and Specifications

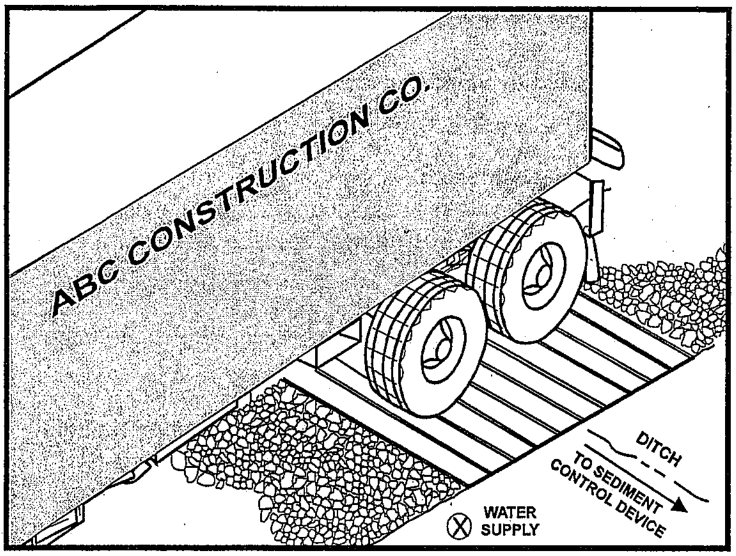
- Properly grade roadway to prevent runoff from leaving the construction site.
- Design stabilized access to support the heaviest vehicles and equipment that will use it.
- Stabilize roadway using aggregate, asphalt concrete, or concrete based on longevity, required performance, and site conditions. The use of cold mix asphalt or asphalt concrete (AC) grindings for stabilized construction roadway is not allowed.
- Coordinate materials with those used for stabilized construction entrance/exit points.
- If aggregate is selected, place crushed aggregate over geotextile fabric to at least 300 mm (12 in) depth, or place aggregate to a depth recommended by the RE or Construction Storm Water Coordinator. Crushed aggregate greater than 75 mm (3 inches) and smaller than 150 mm (6 inches) shall be used.

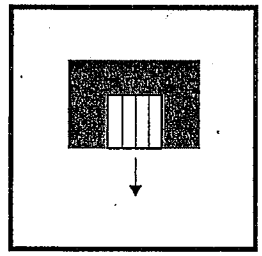
Maintenance and Inspection

- Inspect routinely for damage and repair as needed, or as directed by the RE.
- Keep all temporary roadway ditches clear.
- When no longer required, remove stabilized construction roadway and re-grade and repair slopes.

Entrance/Outlet Tire Wash

TC-3





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ● Sediment Control
- ● Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A tire wash is an area located at stabilized construction access points to remove sediment from tires and undercarriages, and to prevent sediment from being transported onto public roadways.

Appropriate Applications

- Tire washes may be used on construction sites where dirt and mud tracking onto public roads by construction vehicles may occur.
- This BMP may be implemented on a project-by-project basis with other BMPs when determined necessary and feasible by the Resident Engineer (RE).

Limitations

- Requires a supply of wash water.
- Requires a turnout or doublewide exit to avoid having entering vehicles drive through the wash area.

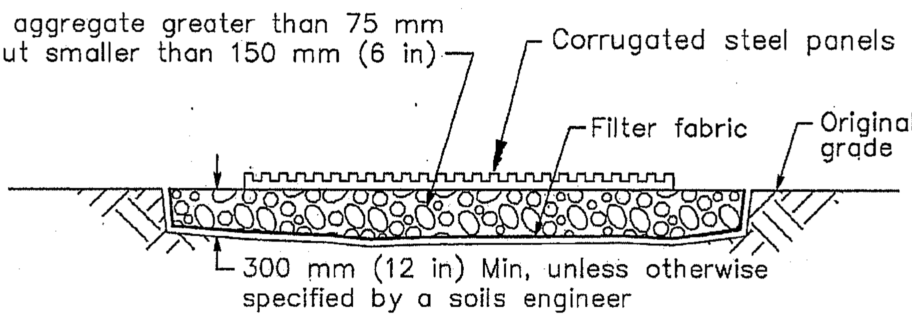
Standards and Specifications

- Incorporate with a stabilized construction entrance/exit. See BMP TC-1, "Stabilized Construction Entrance/Exit."
- Construct on level ground when possible, on a pad of coarse aggregate, greater than 75 mm (3 inches) and smaller than 150 mm (6 inches). A geotextile fabric shall be placed below the aggregate.
- Wash rack shall be designed and constructed/manufactured for anticipated traffic loads.
- Provide a drainage ditch that will convey the runoff from the wash area to a sediment trapping device. The drainage ditch shall be of sufficient grade, width, and depth to carry the wash runoff.

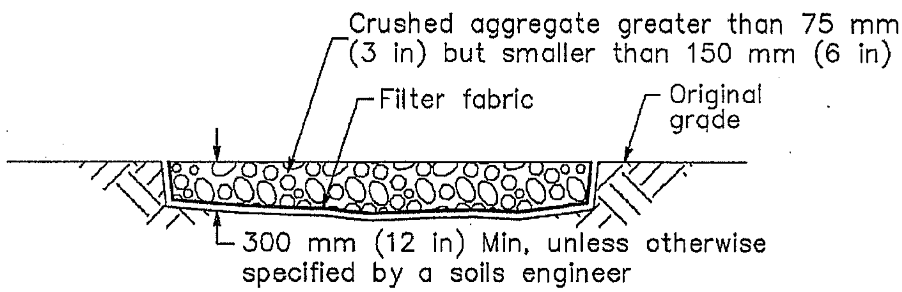
- Require all employees, subcontractors, and others that leave the site with mud-caked tires and/or undercarriages to use the wash facility.
- Implement BMP SC-7, "Street Sweeping and Vacuuming" as needed.
- Use of constructed or prefabricated steel plate with ribs for entrance/exit access is allowed with written approval of RE.

Maintenance and Inspection

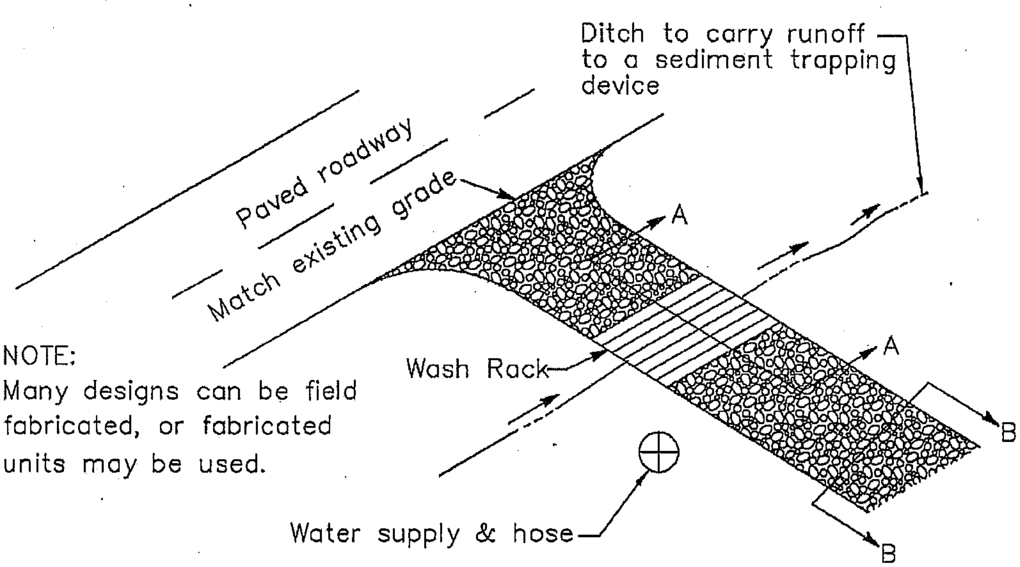
- Remove accumulated sediment in wash rack and/or sediment trap to maintain system performance.
- Inspect routinely for damage and repair as needed.



SECTION A–A
NOT TO SCALE



SECTION B–B
NTS



NOTE:
Many designs can be field fabricated, or fabricated units may be used.

TYPICAL TIRE WASH
NOT TO SCALE

Section 7
Non-Storm Water Management Best Management Practices

7.1 Non-Storm Water Management

Non-storm water management best management practices (BMPs) are source control BMPs that prevent pollution by limiting or reducing potential pollutants at their source before they come in contact with storm water. These practices involve day-to-day operations of the construction site and are usually under the control of the Contractor. These BMPs are also referred to as "good housekeeping practices", which involve keeping a clean, orderly construction site.

Table 7-1 lists the non-storm water management BMPs. It is important to note that all these BMPs have been approved by Caltrans for statewide use and they shall be implemented depending on the conditions/applicability of deployment described as part of the BMP.

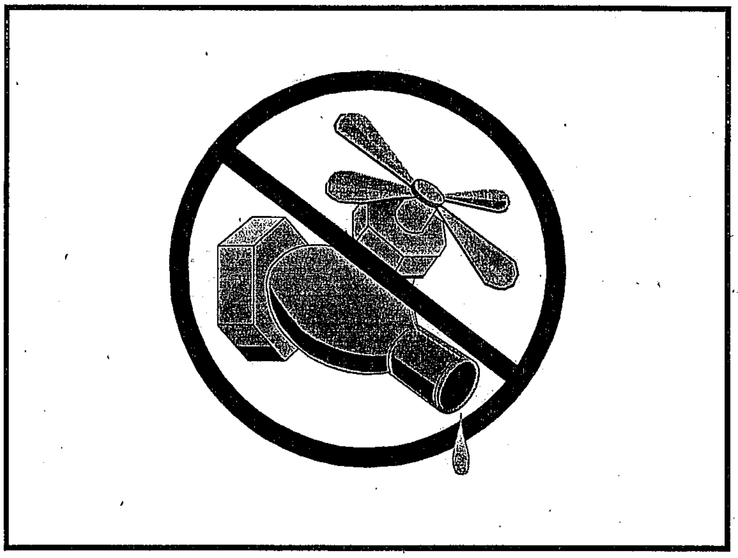
Table 7-1

NON-STORM WATER MANAGEMENT BMPs	
ID	**BMP NAME**
NS-1	Water Conservation Practices
NS-2	Dewatering Operations
NS-3	Paving and Grinding Operations
NS-4	Temporary Stream Crossing
NS-5	Clear Water Diversion
NS-6	Illicit Connection/Illegal Discharge Detection and Reporting
NS-7	Potable Water/Irrigation
NS-8	Vehicle and Equipment Cleaning
NS-9	Vehicle and Equipment Fueling
NS-10	Vehicle and Equipment Maintenance
NS-11	Pile Driving Operations
NS-12	Concrete Curing
NS-13	Material and Equipment Use Over Water
NS-14	Concrete Finishing
NS-15	Structure Demolition/Removal Over or Adjacent to Waters

The remainder of this Section shows the working details for each of the non-storm water management BMPs.

Water Conservation Practices

NS-1



Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Water conservation practices are activities that use water during the construction of a project in a manner that avoids causing erosion and/or the transport of pollutants off site.

Appropriate Applications

- Water conservation practices are implemented on all construction sites and wherever water is used.
- Applies to all construction projects.

Limitations

- None identified.

Standards and Specifications

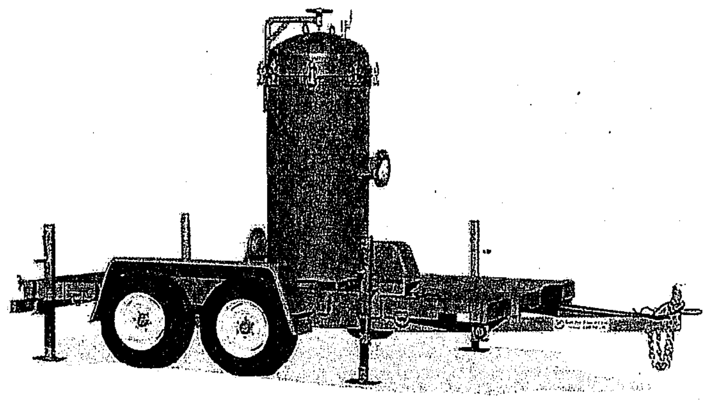
- Keep water equipment in good working condition.
- Stabilize water truck filling area.
- Repair water leaks promptly.
- Vehicles and equipment washing on the construction site is discouraged.
- Avoid using water to clean construction areas. Do not use water to clean pavement. Paved areas shall be swept and vacuumed.
- Direct construction water runoff to areas where it can infiltrate into the ground.
- Apply water for dust control in accordance with the Standard Specifications Section 10, and WE-1, "Wind Erosion Control."
- Report discharges to RE immediately.

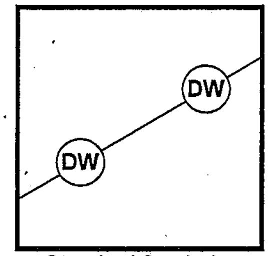
Maintenance and Inspection

- Inspect water equipment at least weekly.
- Repair water equipment as needed.

Dewatering Operations

NS-2





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Dewatering Operations are practices that manage the discharge of pollutants when non-storm water and accumulated precipitation (storm water) must be removed from a work location so that construction work may be accomplished.

Appropriate Applications

- These practices are implemented for discharges of non-storm water and storm water (accumulated rain water) from construction sites. Non-storm water includes, but is not limited to, groundwater, dewatering of piles, water from cofferdams, water diversions, and water used during construction activities that must be removed from a work area.
- Practices identified in this section are also appropriate for implementation when managing the removal of accumulated precipitation (storm water) from depressed areas at a construction site.
- Storm water mixed with non-storm water should be managed as non-storm water.

Limitations

- Dewatering operations for non-storm water will require, and must comply with, applicable local permits, project-specific permits, and regulations.
- Site conditions will dictate design and use of dewatering operations.
- A dewatering plan shall be submitted as part of the SWPPP/WPCP detailing the location of dewatering activities, equipment, and discharge point.
- The controls discussed in this best management practice (BMP) address sediment only. If the presence of polluted water with hazardous substances is identified in the contract, the contractor shall implement dewatering pollution controls as required by the contract documents. If the quality of water to be removed by dewatering is not identified as polluted in the contract documents, but is later determined by observation or testing to be polluted, the contractor shall notify the Resident Engineer (RE) and comply with Standard Specifications Section 5-1.116, "Differing Site Conditions."

- Avoid dewatering discharges where possible by using the water for dust control, by infiltration, etc.

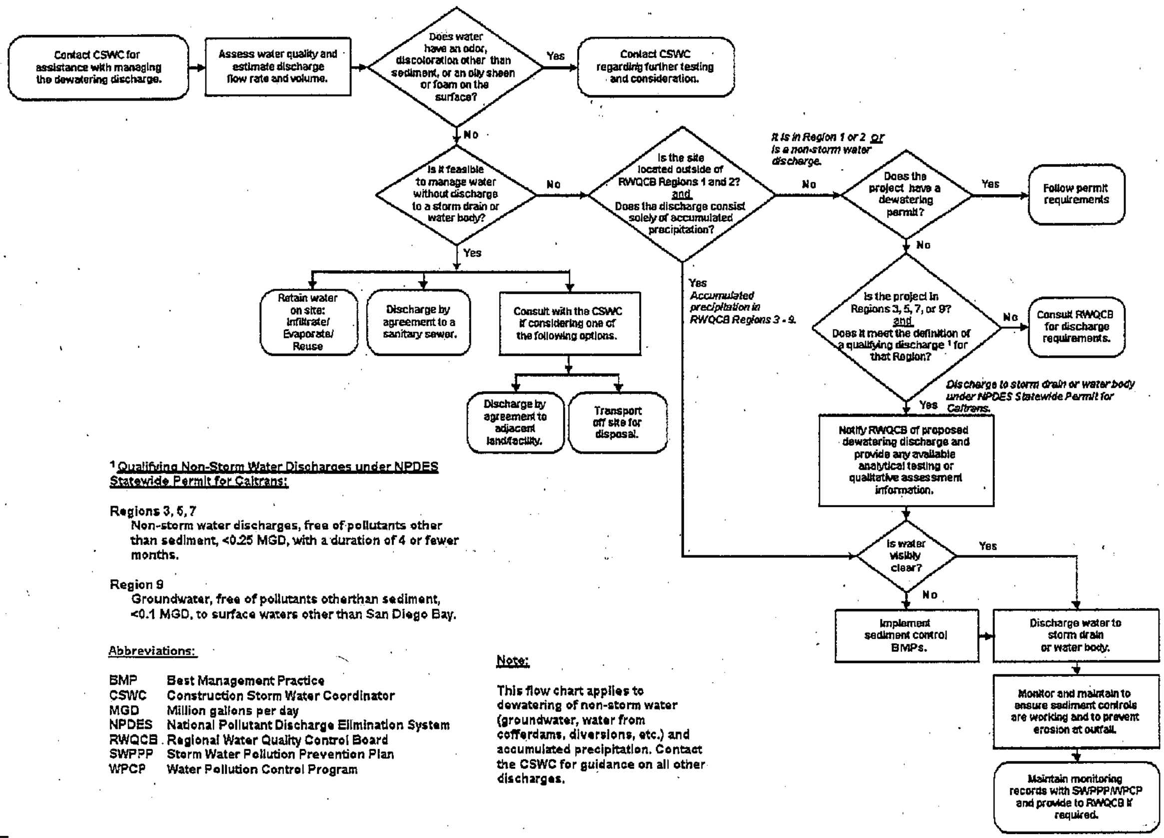
Standards and Specifications

- Dewatering shall be conducted in accordance with the Field Guide to Construction Site Dewatering, October 2001, CTSW-RT-01-010.
- Dewatering for accumulated precipitation (storm water) shall follow this BMP and use treatment measures specified herein.
- The RWQCB may require a separate NPDES permit prior to the dewatering discharge of non-storm water. These permits will have specific testing, monitoring, and discharge requirements and can take significant time to obtain.
- Except in RWQCB Regions 1 and 2, the discharge of accumulated precipitation (storm water) to a water body or storm drain is subject to the requirements of Caltrans NPDES permit. Sediment control and other appropriate BMPs (e.g., outlet protection/energy dissipation) must be employed when this water is discharged.
- RWQCB Regions 1 and 2 require notification and approval prior to any discharge of water from construction sites.
- In RWQCB Regions 3, 5, 7, and 9 non-storm water dewatering for discharges meeting certain conditions are allowed under an RWQCB general dewatering NPDES Permit. Notification and approval from the RWQCB is required prior to conducting these operations. This includes storm water that is mixed with groundwater or other non-storm water sources. Once the discharge is allowed, appropriate BMPs must be implemented to ensure that the discharge complies with all permit requirements. Conditions for potential discharge under an RWQCB general dewatering NPDES Permit include:
  - Regions 3, 5, 7: Non-storm water discharges, free of pollutants other than sediment, <0.25 MGD, with a duration of 4 or fewer months.
  - Region 9: Groundwater, free of pollutants other than sediment, <0.10 MGD, to surface waters other than San Diego Bay.
- The flow chart shown on Page 4 shall be utilized to guide dewatering operations.
- The RE will coordinate monitoring and permit compliance.
- Discharges must comply with regional and watershed-specific discharge requirements.
- Additional permits or permissions from other agencies may be required for dewatering cofferdams or diversions.
- Dewatering discharges must not cause erosion at the discharge point.

- Dewatering records shall be maintained for a period of 3 years.

Maintenance and Inspection

- Inspect all BMPs implemented to comply with permit requirements frequently and repair or replace to ensure the BMPs function as designed.
- Conduct water quality monitoring pursuant to the "Storm Water Dewatering Operations BMP Discharge Monitoring Forms".
- Accumulated sediment removed during the maintenance of a dewatering device may be incorporated in the project at locations designated by the RE or disposed of outside the right-of-way in conformance with the Standard Specifications.
- Accumulated sediment that is commingled with other pollutants must be disposed of in accordance with all applicable laws and regulations and as approved by the RE.



[1] <u>Qualifying Non-Storm Water Discharges under NPDES Statewide Permit for Caltrans:</u>

Regions 3, 5, 7
Non-storm water discharges, free of pollutants other than sediment, <0.25 MGD, with a duration of 4 or fewer months.

Region 9
Groundwater, free of pollutants otherthan sediment, <0.1 MGD, to surface waters other than San Diego Bay.

<u>Abbreviations:</u>

BMP	Best Management Practice
CSWC	Construction Storm Water Coordinator
MGD	Million gallons per day
NPDES	National Pollutant Discharge Elimination System
RWQCB	Regional Water Quality Control Board
SWPPP	Storm Water Pollution Prevention Plan
WPCP	Water Pollution Control Program

<u>Note:</u>

This flow chart applies to dewatering of non-storm water (groundwater, water from cofferdams, diversions, etc.) and accumulated precipitation. Contact the CSWC for guidance on all other discharges.

Sediment Treatment

A variety of methods can be used to treat water during dewatering operations from the construction site. Several devices are presented in this section that provide options to achieve sediment removal. The size of particles present in the sediment and Permit or receiving water limitations on sediment are key considerations for selecting sediment treatment option(s); in some cases, the use of multiple devices may be appropriate.

Category 1: Constructed Settling Technologies

The devices discussed in this category are to be used exclusively for dewatering operations only.

Sediment/Desilting Basin (SC-2)

Description:

A desilting basin is a temporary basin with a controlled release structure that is formed by excavation and/or construction of an embankment to detain sediment-laden runoff and allow sediment to settle out before discharging.

Appropriate Applications:

- Effective for the removal of trash, gravel, sand, and silt and some metals that settle out with the sediment.

Implementation:

- Excavation and construction of related facilities is required.
- Temporary desilting basins must be fenced if safety is a concern.
- Outlet protection is required to prevent erosion at the outfall location.

Maintenance:

- Maintenance is required for safety fencing, vegetation, embankment, inlet and outfall structures, as well as other features.
- Removal of sediment is required when the storage volume is reduced by one-third.

Sediment Trap (SC-3)

Description:

A sediment trap is a temporary basin formed by excavation and/or construction of an earthen embankment across a waterway or low drainage area to detain sediment-laden runoff and allow sediment to settle out before discharging.

Appropriate Applications:

- Effective for the removal of large and medium sized particles (sand and gravel) and some metals that settle out with the sediment.

Implementation:

- Excavation and construction of related facilities is required.
- Trap inlets shall be located to maximize the travel distance to the trap outlet.
- Use rock or vegetation to protect the trap outlets against erosion.

Maintenance:

- Maintenance is required for vegetation, embankment, inlet and outfall structures, as well as other features.
- Removal of sediment is required when the storage volume is reduced by one-third.

Category 2: Mobile Settling Technologies

The devices discussed in this category are typical of tanks that can be used for sediment treatment of dewatering operations. A variety of vendors are available who supply these tanks.

<u>Weir Tank</u>

Description:

A weir tank separates water and waste by using weirs. The configuration of the weirs (over and under weirs) maximizes the residence time in the tank and determines the waste to be removed from the water, such as oil, grease, and sediments.

Appropriate Applications:

- The tank removes trash, some settleable solids (gravel, sand, and silt), some visible oil and grease, and some metals (removed with sediment). To achieve high levels of flow, multiple tanks can be used in parallel. If additional treatment is desired, the tanks can be placed in series or as pre-treatment for other methods.

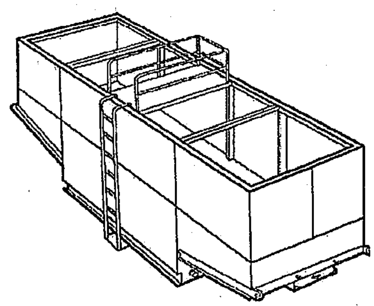
Implementation:

- Tanks are delivered to the site by the vendor, who can provide assistance with set-up and operation.
- Tank size will depend on flow volume, constituents of concern, and residency period required. Vendors shall be consulted to appropriately size tank.

Maintenance:

- Periodic cleaning is required based on visual inspection or reduced flow.
- Oil and grease disposal must be by licensed waste disposal company.

Schematic Diagrams:



Weir Tanks

Dewatering Tank

Description:

A dewatering tank removes debris and sediment. Flow enters the tank through the top, passes through a fabric filter, and is discharged through the bottom of the tank. The filter separates the solids from the liquids.

Appropriate Applications:

- The tank removes trash, gravel, sand, and silt, some visible oil and grease, and some metals (removed with sediment). To achieve high levels of flow, multiple tanks can be used in parallel. If additional treatment is desired, the tanks can be placed in series or as pre-treatment for other methods.

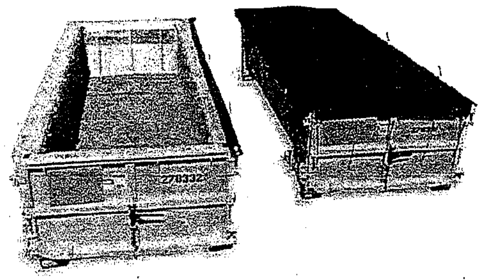
Implementation:

- Tanks are delivered to the site by the vendor, who can provide assistance with set-up and operation.
- Tank size will depend on flow volume, constituents of concern, and residency period required. Vendors shall be consulted to appropriately size tank.

Maintenance:

- Periodic cleaning is required based on visual inspection or reduced flow.
- Oil and grease disposal must be by licensed waste disposal company.

Schematic Diagrams:



Dewatering Tanks

Category 3: Basic Filtration Technologies

Gravity Bag Filter

Description:

A gravity bag filter, also referred to as a dewatering bag, is a square or rectangular bag made of non-woven geotextile fabric that collects sand, silt, and fines.

Appropriate Applications:

- Effective for the removal of sediments (gravel, sand, and silt). Some metals are removed with the sediment.

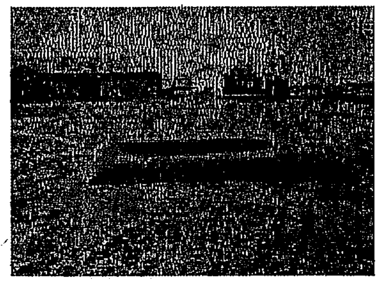
Implementation:

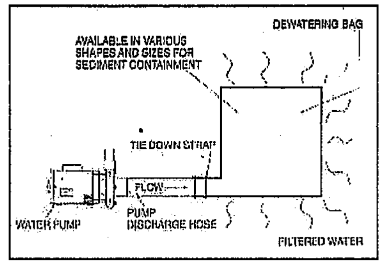
- Water is pumped into one side of the bag and seeps through the bottom and sides of the bag.
- A secondary barrier, such as a rock filter bed or straw/hay bale barrier, is placed beneath and beyond the edges of the bag to capture sediments that escape the bag.

Maintenance:

- Inspection of the flow conditions, bag condition, bag capacity, and the secondary barrier is required.
- Replace the bag when it no longer filters sediment or passes water at a reasonable rate.
- The bag is disposed off-site, or on-site as directed by the RE.

Schematic Diagrams:





Gravity Bag Filter

Category 4: Advanced Filtration Technologies

Sand Media Particulate Filter

Description:

Water is treated by passing it through canisters filled with sand media. Generally, sand filters provide a final level of treatment. They are often used as a secondary or higher level of treatment after a significant amount of sediment and other pollutants have been removed.

Appropriate Applications:

- Effective for the removal of trash, gravel, sand, and silt and some metals, as well as the reduction of biochemical oxygen demand (BOD) and turbidity.
- Sand filters can be used for standalone treatment or in conjunction with bag and cartridge filtration if further treatment is required.
- Sand filters can also be used to provide additional treatment to water treated via settling or basic filtration.

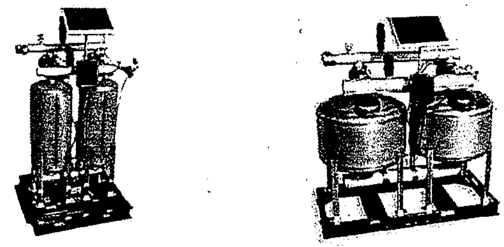
Implementation:

- The filters require delivery to the site and initial set up. The vendor can provide assistance with installation and operation.

Maintenance:

- The filters require monthly service to monitor and maintain the sand media.

Schematic Diagrams:



Sand Media Particulate Filters

Pressurized Bag Filter

Description:

A pressurized bag filter is a unit composed of single filter bags made from polyester felt material. The water filters through the unit and is discharged through a header, allowing for the discharge of flow in series to an additional treatment unit. Vendors provide pressurized bag filters in a variety of configurations. Some units include a combination of bag filters and cartridge filters for enhanced contaminant removal.

Appropriate Applications:

- Effective for the removal of sediment (sand and silt) and some metals, as well as the reduction of BOD, turbidity, and hydrocarbons. Oil absorbent bags are available for hydrocarbon removal.
- Filters can be used to provide secondary treatment to water treated via settling or basic filtration.

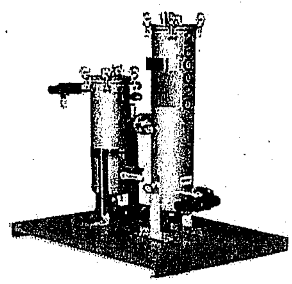
Implementation:

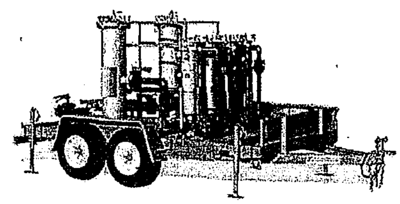
- The filters require delivery to the site and initial set up. The vendor can provide assistance with installation and operation.

Maintenance:

- The filter bags require replacement when the pressure differential exceeds the manufacturer's recommendation.

Schematic Diagrams:





Pressurized Bag Filter

Cartridge Filter

Description:

Cartridge filters provide a high degree of pollutant removal by utilizing a number of individual cartridges as part of a larger filtering unit. They are often used as a secondary or higher (polishing) level of treatment after a significant amount of sediment and other pollutants are removed. Units come with various cartridge configurations (for use in series with pressurized bag filters) or with a larger single cartridge filtration unit (with multiple filters within).

Appropriate Applications:

- Effective for the removal of sediment (sand, silt, and some clays) and metals, as well as the reduction of BOD, turbidity, and hydrocarbons. Hydrocarbons can effectively be removed with special resin cartridges.
- Filters can be used to provide secondary treatment to water treated via settling or basic filtration.

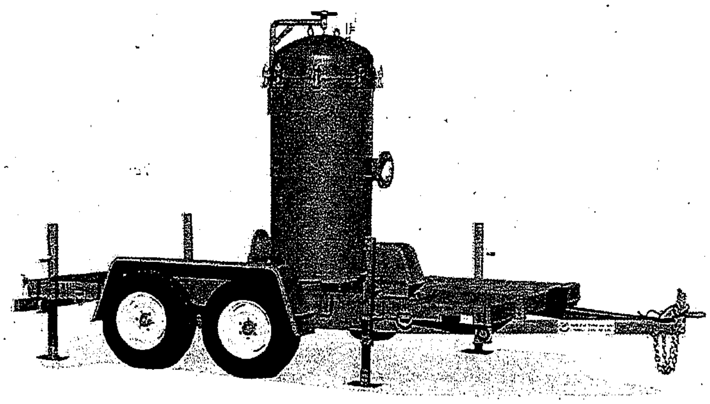
Implementation:

- The filters require delivery to the site and initial set up. The vendor can provide assistance.

Maintenance:

- The cartridges require replacement when the pressure differential exceeds the manufacturer's recommendation.

Schematic Designs:



Cartridge Filter

STORM WATER DEWATERING OPERATIONS BMP DISCHARGE MONITORING FORM [a]

Central Coast Region (RWQCB 3)
For Inland Surface Waters [b]

GENERAL INFORMATION	
Project Name	
Contract No	
Contractor	
Sampler's Name	
Sampler's Signature	
Date Discharge Began	
Date of Sampling	

WATER SAMPLE LOG [c, d, e]				
		Results		
		Effluent	Receiving Water [f]	
Constituents	Units		Upstream (R-1)	Downstream (R-2)
Dissolved Oxygen	mg/L			
pH	unitless			
Turbidity	JTUs			

DISCHARGE LIMITATIONS [g, h, i]			
		EFFLUENT	RECEIVING WATER
Constituent	Units	Daily Maximum	Daily Maximum
Dissolved Oxygen	mg/L	--	5.0 [i]
pH	unitless	--	Between 7.0 - 8.5 [j]
Turbidity	JTUs	--	20% (Where Ambient is 0 - 50 JTUs) 10 (Where Ambient is 50 - 100 JTUs) 10% (Where Ambient is > 100 JTUs)

NOTES:

Ambient - Upstream sample result (i.e.. R-1)
BMP - Best Management Practice
JTUs - Jackson turbidity units
mg/L - Milligrams per liter

RWQCB - Regional Water Quality Control Board
SAR - Sodium absorption ratio
-- - Not required
> - Greater Than

a This form shall be used only for dewatering of storm water/accumulated precipitation. Dewatering non-storm water shall monitor constituents required in the applicable NPDE permit or Waste Discharge Requirements.

b All inland surface waters, enclosed bays, and estuaries. Based on the 1994 RWQCB 3 Basin Plan. [http://www.swrcb.ca.gov/rwqcb3/BasinPlan/Index.htm]

c Collect monthly samples. The first sample shall be collected at the start of the discharge and the last sample shall be collected at the completion of the discharge. Use the same sample collection criteria for discharges less than one month in duration for a total of two samples per discharge event.

d Each constituent will be analyzed in the effluent and the two receiving water samples.

e Dissolved oxygen, pH, and turbidity are required to be analyzed throughout the basin.
The following constituents shall be sampled if suspected to present in the discharge: ammonia for toxicity, MBAS, PCBs, phenols, and phthalate esters are required to be analyzed throughout the basin, however, bacteria, boron, chemical color, temperature, and total dissolved solids shall be analyzed if the project lies in an area designated for a specific beneficial use, as noted in the Basin Plan.

f R-1 shall be collected 100 feet upstream from the closest point of discharge. R-2 shall be collected 100 feet downstream from the closest point of discharge.

g If the results from receiving water sample exceed any of the discharge limits then discontinue dewatering activities to surface waters.

h All discharge limitations are listed in the Water Quality Objectives Section of the Basin Plan.

i Water shall not contain concentrations that cause nuisance or adversely affect beneficial uses of the following: Biostimulatory substances, floating material, oil and grease, pesticides, sediment, settleable materials, suspended materials, and tastes and odors.

j In addition, dissolved oxygen and pH have specific beneficial uses discharge limitations. See basin plan for specific limitations.

STORM WATER DEWATERING OPERATIONS BMP DISCHARGE MONITORING FORM[a]

Los Angeles Region (RWQCB 4)
Los Angeles and Ventura Counties
For Inland Surface Waters[b]

GENERAL INFORMATION	
Project Name	
Contract No	
Contractor	
Sampler's Name	
Sampler's Signature	
Date Discharge Began	
Date of Sampling	

WATER SAMPLE LOG[c, d, e]

Constituents	Units	Results		
		Effluent	Receiving Water[f]	
			Upstream (R-1)	Downstream (R-2)
pH	unitless			
Turbidity	NTUs			
TDS[i]	mg/L			

DISCHARGE LIMITATIONS[g, h, k, l]

Constituent	Units	EFFLUENT Daily Maximum	RECEIVING WATER Daily Maximum
pH	unitless	--	Between 6.5 - 8.5[j]
Turbidity	NTUs	--	20% (Where Ambient is 0 - 50 NTUs)
			10% (Where Ambient is > 50 NTUs)
TDS	mg/L	--	See Table 3-8 in Basin Plan

NOTES:
Ambient - Upstream sample result (ie. R-1)
BMP - Best Management Practice
mg/L - Milligrams per liter
NTUs - Nephelometric turbidity units
RWQCB - Regional Water Quality Control Board
-- - Not required
> - Greater Than

a This form shall be used only for dewatering of storm water/accumulated precipitation. Dewatering non-storm water shall monitor constituents required in the applicable NPDES permit or Waste Discharge Requirements.

b All inland surface waters, enclosed bays, and estuaries, including wetlands. Based on the 1995 RWQCB 4 Basin Plan. [http://www.swrcb.ca.gov/rwqcb4/html/meetings/tmdl/Basin_plan/basin_plan_doc.html]

c Collect monthly samples. The first sample shall be collected at the start of the discharge and the last sample shall be collected at the completion of the discharge. Use the same sample collection criteria for discharges less than one month in duration for a total of two samples per discharge event.

d Each constituent will be analyzed in the effluent and the two receiving water samples.

e pH, and turbidity are required to be analyzed throughout the basin, however, ammonia, bacteria/coliform, boron, chemical constituents, chloride, dissolved oxygen, methylene blue activated substances, nitrogen, pesticides, polychlorinated biphenyls, radioactive substances, sodium absorption ratio, sulfate, temperature, and total dissolved solids shall be analyzed if the project lies in an area designated for a specific beneficial use, as noted in the Basin Plan.

f R-1 shall be collected 100 feet upstream from the closest point of discharge. R-2 shall be collected 100 feet downstream from the closest point of discharge.

g If the results from receiving water sample exceed any of the discharge limits then discontinue dewatering activities to surface waters

h All discharge limitations are listed in the Water Quality Objectives Section of the Basin Plan.

i Water shall not contain concentrations that cause nuisance or adversely affect beneficial uses of the following: Bioaccumulation, biochemical oxygen demand, biostimulatory substances, color, exotic vegetation, floating material, oil and grease, solid/suspended/settleable materials, tastes and odors, and toxicity.

j In addition, ambient pH levels shall not be changed more than 0.2 units for inland surface waters, and 0.5 for bays or estuaries from natural conditions.

k See Table 3-8 in Basin Plan for applicable watershed

STORM WATER DEWATERING OPERATIONS BMP DISCHARGE MONITORING FORM [a]

Central Valley Region (RWQCB 5)
Sacramento River Basin and The San Joaquin River Basin
For Inland Surface Waters [b]

GENERAL INFORMATION	
Project Name	
Contract No.	
Contractor	
Sampler's Name	
Sampler's Signature	
Date Discharge Began	
Date of Sampling	

WATER SAMPLE LOG [c, d, e]

Constituents	Units	Results		
		Effluent	Receiving Water [f]	
			Upstream (R-1)	Downstream (R-2)
pH	unitless			
Turbidity	NTUs			

DISCHARGE LIMITATIONS [g, h, i]

Constituent	Units	EFFLUENT Daily Maximum	RECEIVING WATER Daily Maximum
pH	unitless	--	Between 6.5 - 8.5
Turbidity	NTUs	--	1 NTU increase (Where Ambient is 0 - 5 NTUs)
			20% increase (Where Ambient is 5 - 50 NTUs)
			10 NTU increase (Where Ambient is 50 - 100 NTUs)
			10% increase (Where Ambient is > 100 NTUs)

NOTES:

Ambient - Upstream sample result (i.e., R-1)
BMP - Best Management Practice
NTUs - Nephelometric turbidity units
RWQCB - Regional Water Quality Control Board
-- - Not required
> - Greater Than

a This form shall be used only for dewatering of storm water/accumulated precipitation. Dewatering non-storm water shall monitor constituents required in the applicable NPDES permit or Waste Discharge Requirements.

b All surface waters in the Sacramento and San Joaquin River Basins, including the Delta. Based on the 1998 RWQCB 5a/5b Basin Plan. [http://www.swrcb.ca.gov/rwqcb5/available_documents/index.html#anchor616381]

c Collect monthly samples. The first sample shall be collected at the start of the discharge and the last sample shall be collected at the completion of the discharge. Use the same sample collection criteria for discharges less than one month in duration for a total of two samples per discharge event.

d Each constituent will be analyzed in the effluent and the two receiving water samples.

e Turbidity and pH are required to be analyzed throughout the basin, however, bacteria, chemical constituents, dissolved oxygen, pesticides, radioactivity, salinity, and temperature shall be analyzed if the project lies in an area designated for a specific beneficial use or along a specific waterbody, as noted in the Basin Plan.

f R-1 shall be collected 100 feet upstream from the closest point of discharge. R-2 shall be collected 100 feet downstream from the closest point of discharge.

g If the results from receiving water sample exceed any of the discharge limits then discontinue dewatering activities to surface water

h All discharge limitations are listed in the Water Quality Objectives Section of the Basin Plar

i Water shall not contain concentrations that cause nuisance or adversely affect beneficial uses of the following: Biostimulatory substances, color, floating material, oil and grease, sediment, settleable material, suspended material, tastes and odors, and toxicity.

STORM WATER DEWATERING OPERATIONS BMP DISCHARGE MONITORING FORM[a]

Central Valley Region (RWQCB 5)
Tulare Lake Basin
For Inland Surface Waters[b]

GENERAL INFORMATION	
Project Name	
Contract No	
Contractor	
Sampler's Name	
Sampler's Signature	
Date Discharge Began	
Date of Sampling	

WATER SAMPLE LOG[c, d, e]

		Results		
		Effluent	Receiving Water[f]	
Constituents	Units		Upstream (R-1)	Downstream (R-2)
pH	unitless			
Turbidity	NTUs			
Dissolved Oxygen	mg/L			
Electrical Conductivity	umho/cm			

DISCHARGE LIMITATIONS[g, h, i]

		EFFLUENT	RECEIVING WATER
Constituent	Units	Daily Maximum	Daily Maximum
pH	unitless	--	Between 6.5 - 8.3 0.3 unit change for background
Turbidity	NTUs	--	1 (Where Ambient is 0 - 5 NTUs) 20% (Where Ambient is 5 - 50 NTUs) 10 (Where Ambient is 50 - 100 NTUs) 10% (Where Ambient is > 100 NTUs)
Dissolved Oxygen	mg/L		See Table III-1 in Basin Plan
Electrical Conductivity	umho/cm		See Table III-2 in Basin Plan

NOTES:

Ambient - Upstream sample result (i.e.. R-1)
BMP - Best Management Practice
cm - Centimeter
mg/L - Milligrams per liter
NTUs - Nephelometric turbidity units
RWQCB - Regional Water Quality Control Board
-- - Not required
> - Greater Than

a This form shall be used only for dewatering of storm water/accumulated precipitation. Dewatering non-storm water shall monitor constituents required in the applicable NPDES permit or Waste Discharge Requirements.

b Based on the 1995 RWQCB 5c Basin Plan. [http://www.swrcb.ca.gov/rwqcb5/available_documents/index.html#anchor616381]

c Collect monthly samples. The first sample shall be collected at the start of the discharge and the last sample shall be collected at the completion of the discharge. Use the same sample collection criteria for discharges less than one month in duration for a total of two samples per discharge event.

d Each constituent will be analyzed in the effluent and the two receiving water samples.

e Bacteria, chemical constituents, pesticides, radioactivity, salinity, and temperature shall be analyzed for a specific beneficial use as noted in the Basin Plan. Ammonia is suspected at elevated levels.

f R-1 shall be collected 100 feet upstream from the closest point of discharge. R-2 shall be collected 100 feet downstream from the closest point of discharge.

g If the results from receiving water sample exceed any of the discharge limits then discontinue dewatering activities to surface water

h All discharge limitations are listed in the Water Quality Objectives Section of the Basin Plan

i Water shall not contain concentrations that cause nuisance or adversely affect beneficial uses of the following: Biostimulatory substances, color, floating material, oil and grease, sediment, settleable material, suspended material, tastes and odors, and toxicity.

STORM WATER DEWATERING OPERATIONS BMP DISCHARGE MONITORING FORM[a]

Lahontan Region (RWQCB 6)
For Surface Waters[b]

GENERAL INFORMATION	
Project Name	
Contract No	
Contractor	
Sampler's Name	
Sampler's Signature	
Date Discharge Began	
Date of Sampling	

WATER SAMPLE LOG[c, d, e]

Constituents	Units	Results		
		Effluent	Receiving Water[f]	
			Upstream (R-1)	Downstream (R-2)
pH	unitless			
Turbidity	NTUs			

DISCHARGE LIMITATIONS[g, h, i]

Constituent	Units	EFFLUENT Daily Maximum	RECEIVING WATER Daily Maximum
pH	unitless	--	Between 6.5 - 8.5[j]
Turbidity	NTUs	--	10% of Ambient[j]

NOTES:

Ambient - Upstream sample result (i.e.. R-1)
BMP - Best Management Practice
NTUs - Nephelometric turbidity units
mg/L - Milligrams per liter

RWQCB - Regional Water Quality Control Board
-- - Not required
> - Greater Than

a This form shall be used only for dewatering of storm water/accumulated precipitation. Dewatering non-storm water shall monitor constituents required in the applicable NPDES permit or Waste Discharge Requirements.

b All surface waters including wetlands. Based on the 1994 RWQCB 6 Basin Plan. [http://www.swrcb.ca.gov/rwqcb6/BPlan/BPlan_Index.htm]

c Collect monthly samples. The first sample shall be collected at the start of the discharge and the last sample shall be collected at the completion of the discharge. Use the same sample collection criteria for discharges less than one month in duration for a total of two samples per discharge event.

d Each constituent will be analyzed in the effluent and the two receiving water samples.

e pH and turbidity are required to be analyzed throughout the basin, however, adjusted sodium adsorption ration, algal growth potential, biological indicators, biostimulatory substances, boron, chemical constituents, chlorophyll-a, clarity, color, dissolved inorganic nitrogen, dissolved orthophosphate, dissolved oxygen, electrical conductivity, fluoride, iron, nitrogen as nitrate, pesticides, plankton counts, radioactivity, sodium adsorption ratio, soluble reactive iron, soluble reactive phosphorous, species composition, sulfate, suspended sediment, tastes & odors, temperatures, total dissolved solids, total alkalinity as carbonate, total kjeldahl nitrogen, total nitrogen, total phosphorous, total reactive iron, toxicity, transparency, un-ionized ammonia shall be analyzed if the project lies in an area designated for a specific beneficial use, as noted in the Basin Plan. Bacteria/Coliform if high levels are suspected. Residual chlorine if suspected to be present.

f R-1 shall be collected 100 feet upstream from the closest point of discharge. R-2 shall be collected 100 feet downstream from the closest point of discharge.

g If the results from receiving water sample exceed any of the discharge limits then discontinue dewatering activities to surface waters

h All discharge limitations are listed in the Water Quality Objectives Section of the Basin Plan.

i Water shall not contain concentrations that cause nuisance or adversely affect beneficial uses of the following: Floating material, nondegradation of aquatic communities and populations, oil and grease, sediment, settleable materials, and suspended materials.

j In addition, bacteria/coliform, pH, total residual chlorine, and turbidity have specific beneficial uses and/or location specific discharge limitations. See basin plan for specific limitations.

STORM WATER DEWATERING OPERATIONS BMP DISCHARGE MONITORING FORM[a]

Colorado River Basin Region (RWQCB 7)
For Surface Waters[b]

GENERAL INFORMATION	
Project Name	
Contract No.	
Contractor	
Sampler's Name	
Sampler's Signature	
Date Discharge Began	
Date of Sampling	

WATER SAMPLE LOG[c, d, e]				
		Results		
		Effluent	Receiving Water[f]	
Constituents	Units		Upstream (R-1)	Downstream (R-2)
pH	unitless			
TDS[f]	mg/L			

DISCHARGE LIMITATIONS[g, h, i]			
		EFFLUENT	RECEIVING WATER
Constituent	Units	Daily Maximum	Daily Maximum
pH	unitless	--	Between 6.0 - 9.0
TDS[g]	mg/L	--	See Basin Plan

NOTES:
BMP - Best Management Practice
RWQCB - Regional Water Quality Control Board
-- - Not required
> - Greater Than

a This form shall be used only for dewatering of storm water/accumulated precipitation. Dewatering non-storm water shall monitor constituents required in the applicable NPDES permit or Waste Discharge Requirements.

b Based on the 2002 RWQCB 7 Water Quality Plan. [http://www.swrcb.ca.gov/rwqcb7/documents/RB7Plan.pdf]

c Collect monthly samples. The first sample shall be collected at the start of the discharge and the last sample shall be collected at the completion of the discharge. Use the same sample collection criteria for discharges less than one month in duration for a total of two samples per discharge event.

d Each constituent will be analyzed in the effluent and the two receiving water samples.

e Bacteria, biochemical oxygen demand, chemical constituents, chemical oxygen demand, dissolved oxygen, radioactivity, and selenium shall be analyzed for specific beneficial uses as noted in the Basin Plan.

f R-1 shall be collected 100 feet upstream from the closest point of discharge. R-2 shall be collected 100 feet downstream from the closest point of discharge.

g Total Dissolved Solids (TDS) has specific location discharge limitations. See basin plan for specific limitations.

h If the results from receiving water sample exceed any of the discharge limits then discontinue dewatering activities to surface water.

i All discharge limitations are listed in the Water Quality Objectives Section of the Basin Plan.

j Water shall not contain concentrations that cause nuisance or adversely affect beneficial uses of the following: Biostimulatory substances, color, floating material, herbicides, oil and grease, pesticides, sediment, settleable and suspended solids, tainting substances, tastes and odors, temperature, toxicity, and turbidity.

STORM WATER DEWATERING OPERATIONS BMP DISCHARGE MONITORING FORM[a]

Santa Ana Region (RWQCB 8)
For Inland Surface Waters [b]

GENERAL INFORMATION	
Project Name	
Contract No	
Contractor	
Sampler's Name	
Sampler's Signature	
Date Discharge Began	
Date of Sampling	

WATER SAMPLE LOG [c, d, e]

Constituents	Units	Results		
		Effluent	Receiving Water [f]	
			Upstream (R-1)	Downstream (R-2)
pH	unitless			
Turbidity	NTUs			
TDS	mg/L			

DISCHARGE LIMITATIONS [g, h, i, j]

Constituent	Units	EFFLUENT Daily Maximum	RECEIVING WATER Daily Maximum
pH	unitless	–	Between 7.0 - 8.6 (bays and estuaries)
		–	Between 6.5 - 8.5 (inland surface waters)
Turbidity	NTUs	–	20% (Where Ambient is 0 - 50 NTUs)
			10 NTUs (Where Ambient is 50 - 100 NTUs)
			10% (Where Ambient is > 100 NTUs)
TDS	mg/L	–	See Table 4-1 in Basin Plan

NOTES:
Ambient - Upstream sample result (i.e.. R-1)
BMP - Best Management Practice
NTUs - Nephelometric turbidity units
mg/L - Milligrams per liter
RWQCB - Regional Water Quality Control Board
-- - Not required
> - Greater Than

a This form shall be used only for dewatering of storm water/accumulated precipitation. Dewatering non-storm water shall monitor constituents required in the applicable NPDE permit or Waste Discharge Requirements.

b All inland surface waters including streams, rivers, lakes, and wetlands. Based on the 1995 RWQCB 8 Basin Plan. [http://www.swrcb.ca.gov/rwqcb8/pdf/R8BPlan.pdf]

c Collect monthly samples. The first sample shall be collected at the start of the discharge and the last sample shall be collected at the completion of the discharge. Use the same sample collection criteria for discharges less than one month in duration for a total of two samples per discharge event.

d Each constituent will be analyzed in the effluent and the two receiving water samples.

e Bacteria/coliform, dissolved oxygen, fluoride, methylene blue-activated substances (MBAS), metals, nitrate, radioactivity, temperature, and un-ionized ammonia shall be analyzed for a specific beneficial use, as noted in the Basin Plan. Boron, Residual Chlorine, Hardness, sodium, chloride, total inorganic nitrogen, sulfate, and chemical oxygen demand if present at elevated levels.

f R-1 shall be collected 100 feet upstream from the closest point of discharge. R-2 shall be collected 100 feet downstream from the closest point of discharge.

g If the results from receiving water sample exceed any of the discharge limits then discontinue dewatering activities to surface waters.

h All discharge limitations are listed in the Water Quality Objectives Section of the Basin Plan.

i Water shall not contain concentrations that cause nuisance or adversely affect beneficial uses of the following: Algae, color, floatables, oil and grease, suspended & settleable solids, sulfides, sulfides, surfactants, tastes and odors, and toxic substances.

j Total dissolved solids (TDS), hardness, sodium (Na), chloride (Cl), total inorganic nitrogen (TIN), sulfate (SO_4) and chemical oxygen demand (COD) shall be analyzed for specific waterbodies as identified in the Basin Plan.

STORM WATER DEWATERING OPERATIONS BMP DISCHARGE MONITORING FORM [a] San Diego Region (RWQCB 9) For Inland Surface Waters [b]	
GENERAL INFORMATION	
Project Name	
Contract No	
Contractor	
Sampler's Name	
Sampler's Signature	
Date Discharge Began	
Date of Sampling	

WATER SAMPLE LOG [c,d,e]

Constituents	Units	Results: Effluent	Results: Receiving Water [f] Upstream (R-1)	Results: Receiving Water [f] Downstream (R-2)
pH	unitless			
Turbidity	NTUs			
TDS	mg/L			
Dissolved Oxygen	mg/L			
Color				

DISCHARGE LIMITATIONS [g,h,i]

Constituent	Units	EFFLUENT Daily Maximum	RECEIVING WATER Daily Maximum
pH	unitless	--	Between 6.5 - 8.5
Turbidity	NTUs	--	20% (Where Ambient is 0 - 50 NTUs) 10 NTUs (Where Ambient is 50 - 100 NTUs) 10% (Where Ambient is > 100 NTUs) 0.2 NTUs (ocean waters)
TDS	mg/L		See Table 3-2 in Basin Plan
Dissolved Oxygen	mg/L		5.0 mg/l in inland surface waters 6.0 mg/l in waters with designated COLD beneficial uses
Color		--	See Table 3-2 in Basin Plan

NOTES:

Ambient - Upstream sample result (i.e., R-1)
BMP - Best Management Practice
NTUs - Nephelometric turbidity units
mg/L - Milligrams per liter
RWQCB - Regional Water Quality Control Board
-- - Not required
> - Greater Than

a This form shall be used only for dewatering of storm water/accumulated precipitation. Dewatering non-storm water shall monitor constituents required in the applicable NPDES permit or Waste Discharge Requirements.

b All inland surface waters, enclosed bays, and estuaries and coastal lagoons. Based on the 1994 RWQCB 9 Basin Plan. [http://www.swrcb.ca.gov/rwqcb9/programs/basinplan.html]

c Collect monthly samples. The first sample shall be collected at the start of the discharge and the last sample shall be collected at the completion of the discharge. Use the same sample collection criteria for discharges less than one month in duration for a total of two samples per discharge event.

d Each constituent will be analyzed in the effluent and the two receiving water samples.

e Bacteria, E. Coli & enterococci, biostimulatory substances, dissolved oxygen, inorganic chemicals, organic chemicals, pesticides, phenolic compounds, radioactivity, tastes & odors, temperatures, and trihalomethanes shall be analyzed for specific beneficial use, as noted in the Basin Plan. Un-ionized Ammonia, chloride, sulfate, sodium, iron, manganese, MBAS, boron, and fluoride if suspected at elevated levels.

f R-1 shall be collected 100 feet upstream from the closest point of discharge. R-2 shall be collected 100 feet downstream from the closest point of discharge.

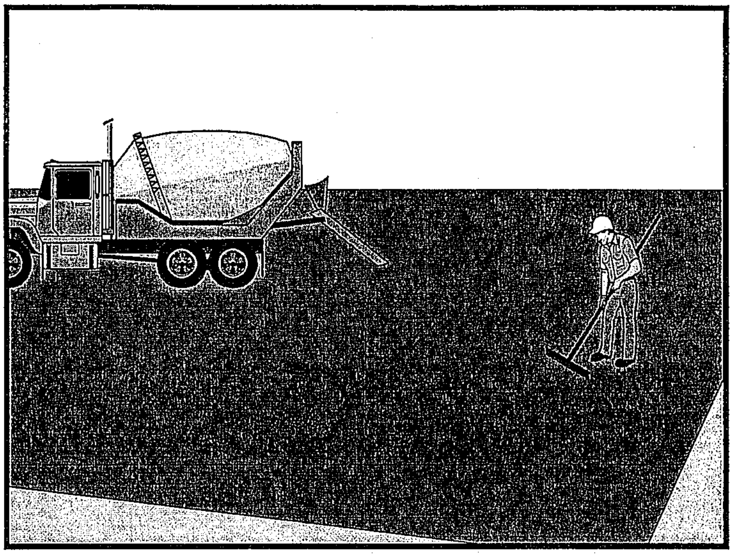
g If the results from receiving water sample exceed any of the discharge limits then discontinue dewatering activities to surface waters.

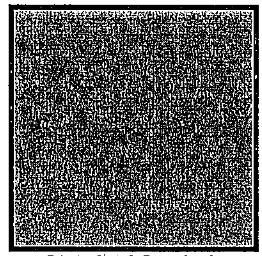
h All discharge limitations are listed in the Water Quality Objectives Section of the Basin Plan.

i Water shall not contain concentrations that cause nuisance or adversely affect beneficial uses as required in the Basin Plan.

Paving and Grinding Operations

NS-3





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Procedures and practices for conducting paving, saw cutting, and grinding operations to minimize the transport of pollutants to the storm drain system or receiving water body.

Appropriate Applications

These procedures are implemented where paving, surfacing, resurfacing, grinding or sawcutting, may pollute storm water runoff or discharge to the storm drain system or watercourses.

Limitations

- Finer solids are not effectively removed by filtration systems.
- Paving opportunities may be limited during wet weather.

Standards and Specifications

- Substances used to coat asphalt transport trucks, asphalt trucks, and asphalt spreading equipment shall not contain soap and shall be non-foaming and non-toxic.
- Place plastic materials under asphaltic concrete (AC) paving equipment while not in use, to catch and/or contain drips and leaks. See also BMP WM-4, "Spill Prevention and Control."
- When paving involves AC, the following steps shall be implemented to prevent the discharge of uncompacted or loose AC, tack coats, equipment cleaners, or other paving materials:
  - Minimize sand and gravel from new asphalt from getting into storm drains, streets, and creeks by sweeping.
  - Old or spilled asphalt must be recycled or disposed as approved by the Resident Engineer (RE).

- AC grindings, pieces, or chunks used in embankments or shoulder backing must not be allowed to enter any storm drain or watercourses. Install silt fence until structure is stabilized or permanent controls are in place.
- Collect and remove all broken asphalt and recycle when practical; otherwise, dispose in accordance with Standard Specification 7-1.13.
- Any AC chunks and pieces used in embankments must be placed above the water table and covered by at least 0.3 m (1 ft) of material.
- During chip seal application and sweeping operations, petroleum or petroleum covered aggregate must not be allowed to enter any storm drain or water courses. Use silt fence until installation is complete.
- Use only non-toxic substances to coat asphalt transport trucks and asphalt spreading equipment.

■ Drainage inlet structures and manholes shall be covered with filter fabric during application of seal coat, tack coat, slurry seal, and/or fog seal.

■ Seal coat, tack coat, slurry seal, or fog seal shall not be applied if rainfall is predicted to occur during the application or curing period.

■ Paving equipment parked onsite shall be parked over plastic to prevent soil contamination.

■ Clean asphalt-coated equipment off-site whenever possible. When cleaning dry, hardened asphalt from equipment, manage hardened asphalt debris as described in BMP WM-5, "Solid Waste Management." Any cleaning onsite shall follow BMP NS-8, "Vehicle and Equipment Cleaning."

■ Do not wash sweepings from exposed aggregate concrete into a storm drain system. Collect and return to aggregate base stockpile, or dispose of properly.

■ Allow aggregate rinse to settle. Then, either allow rinse water to dry in a temporary pit as described in BMP WM-8, "Concrete Waste Management," or dispose in accordance with Standard Specifications Section 7-1.13.

■ Do not allow saw-cut Portland Concrete Cement (PCC) slurry to enter storm drains or watercourses.

Pavement Grinding or Removal

■ Residue from PCC grinding operations shall be picked up by means of a vacuum attachment to the grinding machine, shall not be allowed to flow across the pavement, and shall not be left on the surface of the pavement. See also BMP WM-8, "Concrete Waste Management;" and BMP WM-10, "Liquid Waste Management," and Standard Specifications Section 42-2

"Grindings."

- Collect pavement digout material by mechanical or manual methods. This material may be recycled if approved by the RE for use as shoulder backing or base material at locations approved by the RE.
- If digout material cannot be recycled, transport the material back to a maintenance facility or approved storage site.
- Digout activities shall not be conducted in the rain.
- When approved by the RE, stockpile material removed from roadways away from drain inlets, drainage ditches, and watercourses and stored consistent with BMP WM-3, "Stockpile Management."
- Disposal or use of AC grindings shall be approved by the RE. See also BMP WM-8, "Concrete Waste Management."

Thermoplastic Striping

- All thermoplastic striper and pre-heater equipment shutoff valves shall be inspected to ensure that they are working properly to prevent leaking thermoplastic from entering drain inlets, the storm water drainage system, or watercourses.
- The pre-heater shall be filled carefully to prevent splashing or spilling of hot thermoplastic. Leave six inches of space at the top of the pre-heater container when filling thermoplastic to allow room for material to move when the vehicle is deadheaded.
- Contractor shall not pre-heat, transfer, or load thermoplastic near drain inlets or watercourses.
- Clean truck beds daily of loose debris and melted thermoplastic. When possible recycle thermoplastic material. Thermoplastic waste shall be disposed of in accordance with Standard Specification 7-1.13.

Raised/Recessed Pavement Marker Application and Removal

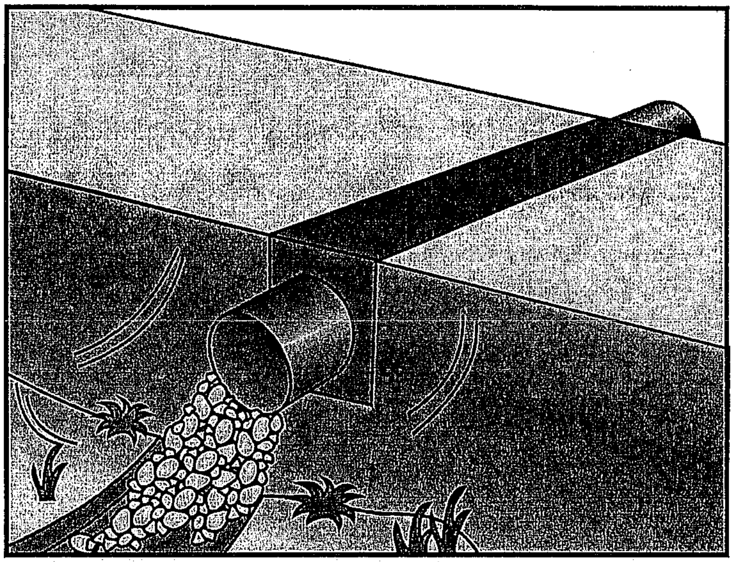
- Do not transfer or load bituminous material near drain inlets, the storm water drainage system or watercourses.
- Melting tanks shall be loaded with care and not filled to beyond six inches from the top to leave room for splashing when vehicle is deadheaded.
- When servicing or filling melting tanks, ensure all pressure is released before removing lids to avoid spills.
- On large scale projects, use mechanical or manual methods to collect excess

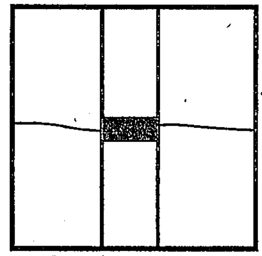
- bituminous material from the roadway after removal of markers.
- Waste shall be disposed of in accordance with Standard Specification 7-1.13.

Maintenance and Inspection

- Inspect and maintain machinery regularly to minimize leaks and drips.
- Ensure that employees and subcontractors are implementing appropriate measures during paving operations.

Temporary Stream Crossing **NS-4**





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A temporary stream crossing is a structure placed across a waterway that allows vehicles to cross the waterway during construction, minimizing, reducing, or managing erosion and downstream sedimentation caused by the vehicles.

Appropriate Applications

Temporary stream crossings are installed at sites:

- Where appropriate permits have been secured (1601 Agreements, 404 Permits, and 401 Certification).
- Where construction equipment or vehicles need to frequently cross a waterway.
- When alternate access routes impose significant constraints.
- When crossing perennial streams or waterways causes significant erosion.
- Where construction activities will not last longer than one year.

Limitations

- Will usually disturb the waterway during installation and removal.
- May require Regional Water Quality Control Board (RWQCB) 401 Certification, U.S. Army Corps of Engineers 404 permit and approval by California Department of Fish and Game. If numerical-based water quality standards are mentioned in any of these and other related permits, testing and sampling may be required. If monitoring related to these numerical-based water quality standards is not addressed in the contract documents, contact the Resident Engineer (RE).
- Installation may require dewatering or temporary diversion of the stream. See BMP NS-2, "Dewatering Operations" and NS-5, "Clear Water Diversion."
- May become a constriction in the waterway, which can obstruct flood flow and cause flow backups or washouts. If improperly designed, flow backups can increase the pollutant load through washouts and scouring.

- Use of natural or other gravel in the stream for construction of Cellular Confinement System (CCS) (refer to figure at the end of the section) ford crossing will be contingent upon approval by fisheries agencies.
- Ford crossings may degrade water quality due to contact with vehicles and equipment.
- CCS should not be used in excessively high or fast flows.
- Upon completion of construction activities, CCS blocks must be removed from stream.

Standards and Specifications

General Considerations

Location of the temporary stream crossing shall address:

- Site selection where erosion potential is low.
- Areas where the side slopes from highway runoff will not spill into the side slopes of the crossing.

The following types of temporary stream crossings shall be considered:

- Culverts - Used on perennial and intermittent streams.
- Fords - Appropriate during the dry season in arid areas. Used on dry washes and ephemeral streams, and low flow perennial streams. CCS, a type of ford crossing is also appropriate for use in streams.
- Bridges - Appropriate for streams with high flow velocities, steep gradients and/or where temporary restrictions in the channel are not allowed.

Design and installation requires knowledge of stream flows and soil strength. Designs shall be prepared under direction of, and approved by, a registered civil and/or structural engineer. Both hydraulic and construction loading requirements shall be considered with the following:

- Comply with the requirements for culvert and bridge crossings, as contained in the Caltrans Highway Design Manual, particularly if the temporary stream crossing will remain through the rainy season.
- Provide stability in the crossing and adjacent areas to withstand the design flow. The design flow and safety factor shall be selected based on careful evaluation of the risks due to over topping, flow backups, or washout.
- Avoid oil or other potentially hazardous waste materials for surface treatment.

Construction Considerations:

- Stabilize construction roadways, adjacent work area and stream bottom against erosion.

- Construct during dry periods to minimize stream disturbance and reduce costs.
- Construct at or near the natural elevation of the stream bed to prevent potential flooding upstream of the crossing.
- Install temporary sediment control BMPs in accordance with sediment control BMPs presented in Section 4 to minimize erosion of embankment into flow lines.
- Vehicles and equipment shall not be driven, operated, fueled, cleaned, maintained, or stored in the wet or dry portions of a water body where wetland vegetation, riparian vegetation, or aquatic organisms may be destroyed, except as authorized by the RE, as necessary to complete the work.
- Temporary water body crossings and encroachments shall be constructed to minimize scour. Cobbles used for temporary water body crossings or encroachments shall be clean, rounded river cobble.
- The exterior of vehicles and equipment that will encroach on the water body within the project shall be maintained free of grease, oil, fuel, and residues.
- Disturbance or removal of vegetation shall not exceed the minimum necessary to complete operations. Precautions shall be taken to avoid damage to vegetation by people or equipment. Disturbed vegetation shall be replaced with the appropriate soil stabilization measures.
- Riparian vegetation, when removed pursuant to the provisions of the work, shall be cut off no lower than ground level to promote rapid re-growth. Access roads and work areas built over riparian vegetation shall be covered by a sufficient layer of clean river run cobble to prevent damage to the underlying soil and root structure. The cobble shall be removed upon completion of project activities.
- Any temporary artificial obstruction placed within flowing water shall only be built from material, such as clean gravel, that will cause little or no siltation.
- Drip pans shall be placed under all vehicles and equipment placed on docks, barges, or other structures over water bodies when the vehicle or equipment is planned to be idle for more than one hour.
- Conceptual temporary stream crossings are shown in figures at the end of this section.

Specific Considerations:

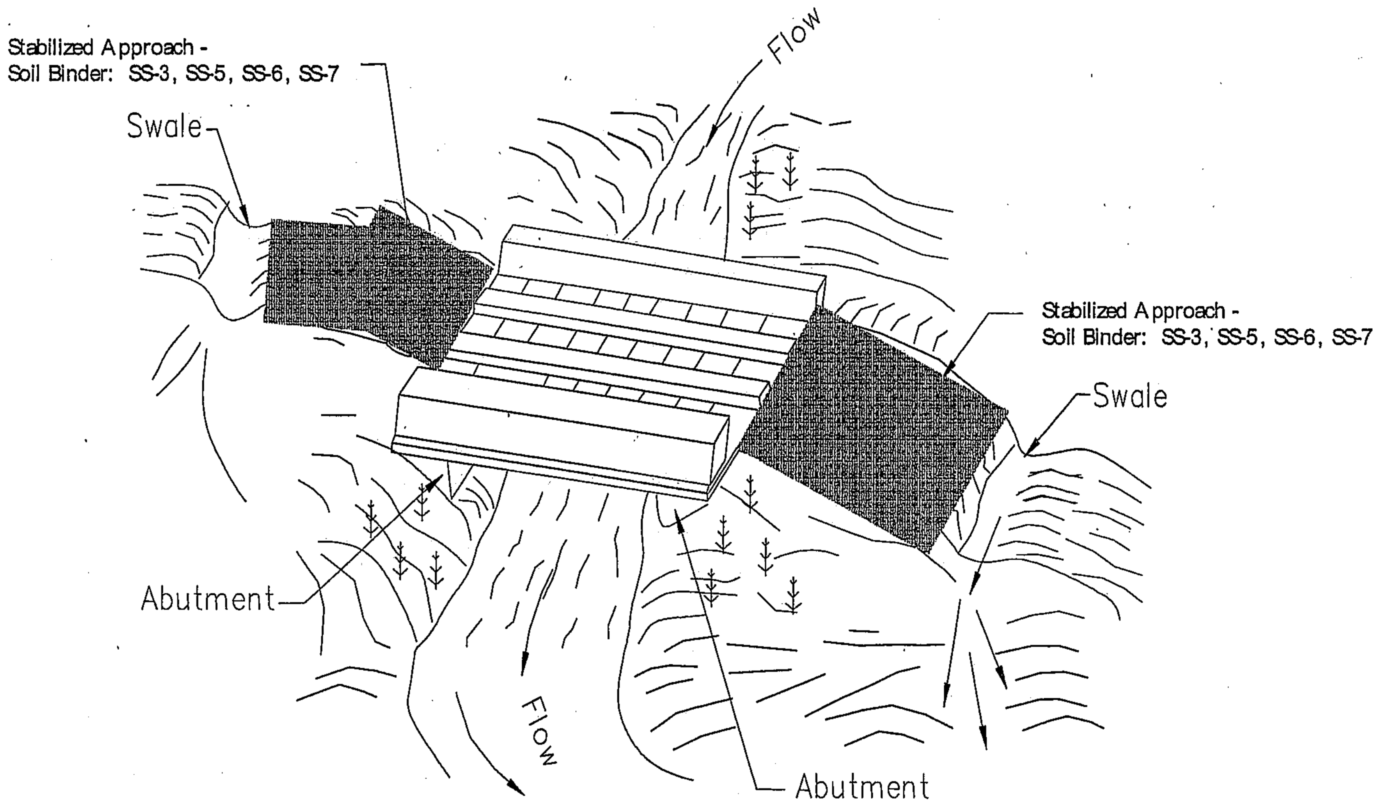
- Culverts are relatively easy to construct and able to support heavy equipment loads.
- Fords are the least expensive of the crossings, with maximum load limits.
- Temporary fords are not appropriate if construction will continue through the rainy season, if thunderstorms are likely, or if the stream is perennial.

- CCS crossing structures consist of clean, washed gravel and cellular confinement system blocks. CCS are appropriate for streams that would benefit from an influx of gravel; for example, salmonid streams, streams or rivers below reservoirs, and urban, channelized streams. Many urban stream systems are gravel-deprived due to human influences, such as dams, gravel mines, and concrete channels.
- CCS allow designers to use either angular or naturally-occurring, rounded gravel, because the cells provide the necessary structure and stability. In fact, natural gravel is optimal for this technique, because of the habitat improvement it will provide after removal of the CCS.
- A gravel depth of 152 to 305 mm (6 to 12 inches) for a CCS structure is sufficient to support most construction equipment.
- An advantage of a CCS crossing structure is that relatively little rock or gravel is needed, because the CCS provides the stability.
- Bridges are generally more expensive to design and construct, but provides the least disturbance of the stream bed and constriction of the waterway flows.

Maintenance and Inspection

Maintenance provisions shall include:

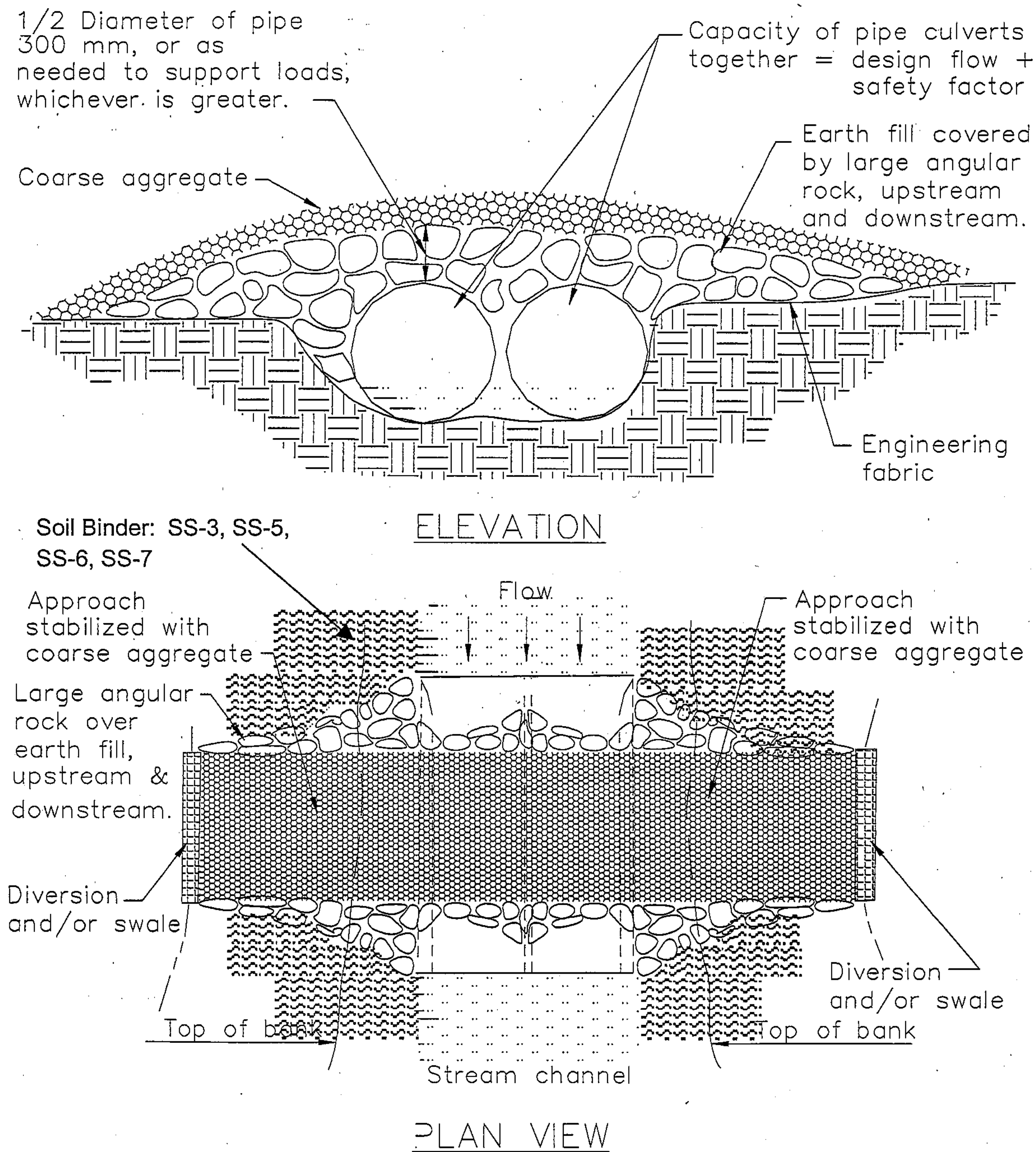
- Periodic removal of debris behind fords, in culverts, and under bridges.
- Replacement of lost protective aggregate from inlets and outlets of culverts.
- Removal of temporary crossing promptly when it is no longer needed.
- Inspection shall, at a minimum, occur weekly and after each significant rainfall, and include:
  - Checking for blockage in the channel, debris buildup in culverts or behind fords, and under bridges.
  - Checking for erosion of abutments, channel scour, riprap displacement, or piping in the soil.
  - Checking for structural weakening of the temporary crossing, such as cracks, and undermining of foundations and abutments.



NOTE:
Surface flow of road diverted by swale and/or dike.

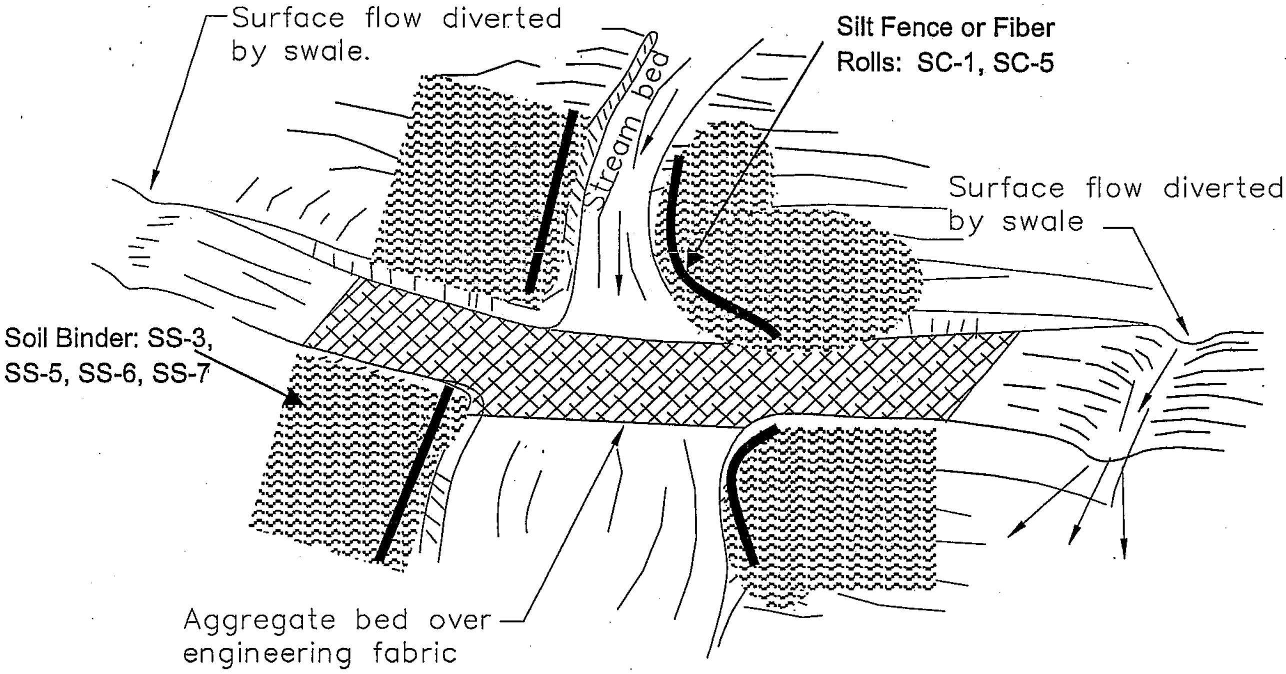
TYPICAL BRIDGE CROSSING

NOT TO SCALE

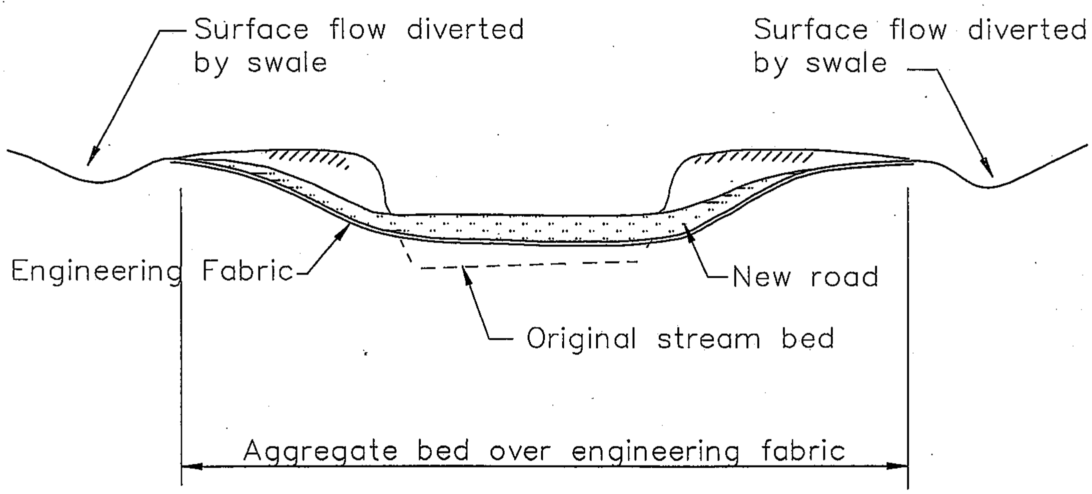


TYPICAL CULVERT CROSSING

NOT TO SCALE



Aggregate approch
1:5 (V:H) Maximum slope on road



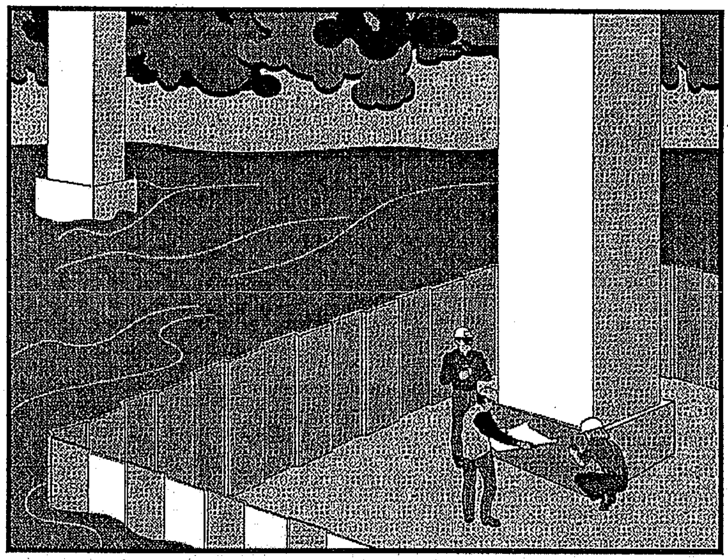
TYPICAL FORD CROSSING
NOT TO SCALE

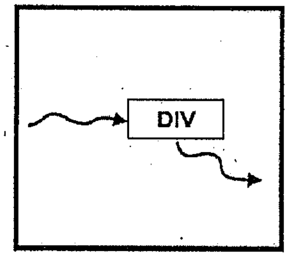
CELLULAR CONFINEMENT SYSTEM

A001591

Clear Water Diversion

NS-5





Standard Symbol

BMP Objectives
- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Clear water diversion consists of a system of structures and measures that intercept clear surface water runoff upstream of a project site, transport it around the work area, and discharge it downstream with minimal water quality degradation for either the project construction operations or the construction of the diversion. Clear water diversions are used in a waterway to enclose a construction area and reduce sediment pollution from construction work occurring in or adjacent to water. Isolation techniques are methods that isolate near shore work from a waterbody. Structures commonly used as part of this system include diversion ditches, berms, dikes, slope drains, rock, gravel bags, wood, sheet piles, aqua barriers, cofferdams, filter fabric or turbidity curtains, drainage and interceptor swales, pipes, or flumes.

Appropriate Applications

- A clear water diversion is typically implemented where appropriate permits (1601 Agreement, 404 Permits, and 401 Water Quality Certifications) have been secured and work must be performed in a live stream or water body.
- Clear water diversions are appropriate for isolating construction activities occurring within or near a water body such as streambank stabilization, or culvert, bridge, pier or abutment installation. They may also be used in combination with other methods, such as clear water bypasses and/or pumps.
- Pumped diversions are suitable for intermittent and low flow streams. Excavation of a temporary bypass channel, or passing the flow through a pipe (called a "flume") is appropriate for the diversion of streams less than 6 m (20 ft) wide, with flow rates less than 2.8 m^3/sec (99 ft^3/sec).
- Clear water diversions incorporating clean washed gravel may be appropriate for use in salmon spawning streams.

Limitations

- Diversion/encroachment activities will usually disturb the waterway during installation and removal of diversion structures.
- Specific permit requirements or mitigation measures, such as the U.S. Army Corps of Engineers, California Department of Fish and Game, Federal Emergency Management Agency (FEMA), Regional Water Quality Control Board (RWQCB), etc. may be included in contract documents because of clear water diversion/encroachment activities.
- Diversion/encroachment activities may constrict the waterway, which can obstruct flood flows and cause flooding or washouts. Diversion structures should not be installed without identifying potential impacts to the stream channel.
- Diversion or isolation activities should not completely dam stream flow.
- Dewatering and removal may require additional sediment control or water treatment (See NS-2, "Dewatering Operations").

Standards and Specifications

General

- Implement guidelines presented in NS-17, Streambank Stabilization to minimize impacts to streambanks.
- Where working areas encroach on live streams, barriers adequate to prevent the flow of muddy water into streams shall be constructed and maintained between working areas and streams. During construction of the barriers, muddying of streams shall be held to a minimum.
- Diversion structures must be adequately designed to accommodate fluctuations in water depth or flow volume due to tides, storms, flash floods, etc.
- Heavy equipment driven in wet portions of a water body to accomplish work shall be completely clean of petroleum residue, and water levels shall be below the gearboxes of the equipment in use, or lubricants and fuels are sealed such that inundation by water shall not result in leaks.
- Mechanical equipment operated in the water shall not be submerged to a point above any axle of said mechanical equipment.
- Excavation equipment buckets may reach out into the water for the purpose of removing or placing fill materials. Only the bucket of the crane/excavator/backhoe may operate in a water body. The main body of the crane/excavator/backhoe shall not enter the water body, except as necessary to cross the stream to access the work site.
- Clear water diversions that require dewatering shall be conducted in accordance with policies and guidelines presented in Field Guide to Construction Site Dewatering, October 2001, CTSW-RT-01-010.

- Stationary equipment such as motors and pumps, located within or adjacent to a water body, shall be positioned over drip pans.
- When any artificial obstruction is being constructed, maintained, or placed in operation, sufficient water shall, at all times, be allowed to pass downstream to maintain aquatic life downstream.
- The exterior of vehicles and equipment that will encroach on a water body within the project shall be maintained free of grease, oil, fuel, and residues.
- Equipment shall not be parked below the high water mark unless allowed by a permit.
- Disturbance or removal of vegetation shall not exceed the minimum necessary to complete operations. Precautions shall be taken to avoid damage to vegetation by people or equipment. Disturbed vegetation shall be replaced with the appropriate soil stabilization measures.
- Riparian vegetation, when removed pursuant to the provisions of the work, shall be cut off no lower than ground level to promote rapid re-growth. Access roads and work areas built over riparian vegetation shall be covered by a sufficient layer of clean river run rock to prevent damage to the underlying soil and root structure. The rock shall be removed upon completion of project activities.
- Drip pans shall be placed under all vehicles and equipment placed on docks, barges, or other structures over water bodies when the vehicle or equipment is planned to be idle for more than one hour.
- Where possible, avoid or minimize diversion/encroachment impacts by scheduling construction during periods of low flow or when the stream is dry. See also the project special provisions for scheduling requirements. Scheduling shall also consider seasonal releases of water from dams, fish migration and spawning seasons, and water demands due to crop irrigation.
- Construct diversion structures with materials free of potential pollutants such as soil, silt, sand, clay, grease, or oil.

Temporary Diversions/Encroachments

- Construct diversion channels in accordance with BMP SS-9, "Earth Dikes/Drainage Swales, and Ditches."
- In high flow velocity areas, stabilize slopes of embankments and diversion ditches using an appropriate liner, in accordance with BMP SS-7, "Geotextiles, Plastic Covers & Erosion Control Blankets/Mats", or use rock slope protection, as described in Standard Specifications Section 72-2, "Rock Slope Protection."

- Where appropriate, use natural streambed materials such as large cobbles and boulders for temporary embankment/slope protection, or other temporary soil stabilization methods.

- Provide for velocity dissipation at transitions in the diversion, such as the point where the stream is diverted to the channel and the point where the diverted stream is returned to its natural channel. See also BMP SS-10, "Outlet Protection/Velocity Dissipation Devices."

Temporary Dry Construction Areas

- When dewatering behind temporary structures to create a temporary dry construction area, such as coffer dams, pass pumped water through a sediment settling device, such as a portable tank or settling basin, before returning water to the water body; See also BMP NS-2, "Dewatering Operations."

- If the presence of polluted water or sediment is identified in the contract, the contractor shall implement dewatering pollution controls as required by the contract documents. If the quality of water or sediment to be removed while dewatering is not identified as polluted in the contract documents, but is later determined by observation or testing to be polluted, the contractor shall notify the Resident Engineer (RE) and comply with Standard Specifications Section 5-1.116 "Differing Site Conditions."

- Any substance used to assemble or maintain diversion structures, such as form oil, shall be non-toxic and non-hazardous.

- Any material used to minimize seepage underneath diversion structures, such as grout, shall be non-toxic, non-hazardous, and as close to a neutral pH as possible.

Isolation Techniques:

Isolation techniques are methods that isolate near shore work from a waterbody. Techniques include sheet pile enclosures, water-filled geotextile (Aqua Dam) , gravel berm with impermeable membrane, gravel bags, coffer dams, and K-rail.

Filter Fabric Isolation Technique

Definition and Purpose:

A filter fabric isolation structure (See Figure 1-C) is a temporary structure built into a waterway to enclose a construction area and reduce sediment pollution from construction work in or adjacent to water. This structure is composed of filter fabric, gravel bags, and steel t-posts.

Appropriate Applications:

- Filter fabric may be used for construction activities such as streambank stabilization, or culvert, bridge, pier or abutment installation. It may also be used in combination with other methods, such as clean water bypasses and/or pumps.

- This method involves placement of gravel bags or continuous berms to "key-in" the fabric, and subsequently staking the fabric in place.
- If spawning gravel (gravel between 25 and 100 mm [1 and 4 inches]) is used, all other components of the isolation can be removed from the stream, and the gravel can be spread out and left as salmon spawning habitat. Whether spawning gravel or other types of gravel are used, only clean washed gravel should be used as infill for the gravel bags or continuous berm.
- This is a method that should be used in relatively calm water, and can be used in smaller streams.

Limitations

- Do not use if the installation, maintenance and removal of the structures will disturb sensitive aquatic species of concern.
- Not appropriate for projects where dewatering is necessary.
- Not appropriate to completely dam streamflow.

Standards and Specifications:

- For the filter fabric isolation method, a non-woven or heavy-duty fabric (refer to Standard Specifications Section 88) is recommended over standard silt fence. Using rolled geotextiles allows non-standard widths to be used.
- Anchor filter fabric with gravel bags filled with clean, washed gravel. Do not use sand. If a bag should split open, the gravel can be left in the stream, where it can provide aquatic habitat benefits.
- Another anchor alternative is a continuous berm, made with the Continuous Berm Machine. This is a gravel-filled bag that can be made in very long segments. The length of the berms is usually limited to 6 m (20 ft) for ease of handling.

Installation

- Place the fabric on the bottom of the stream, and place either a bag of clean, washed gravel or a continuous berm over the bottom of the fabric, such that a bag-width of fabric lies on the stream bottom. The bag should be placed on what will be the outside of the isolation area.
- Pull the fabric up, and place a metal t-post immediately behind the fabric, on the inside of the isolation area; attach the fabric to the post with three diagonal nylon ties.

- Continue placing fabric as described above until the entire work area has been isolated, staking the fabric at least every 1.8 m (6 ft).

Maintenance and Inspection:

- During construction, inspect daily during the workweek.
- Schedule additional inspections during storm events.
- Immediately repair any gaps, holes or scour.
- Remove sediment buildup.
- Remove BMP upon completion of construction activity. Recycle or re-use if applicable.
- Re-vegetate areas disturbed by BMP removal if needed.

Turbidity Curtain Isolation Technique

Definition and purpose:

A turbidity curtain (refer to Figures 1A through 1D) is a fabric barrier used to isolate the near shore work area. The barriers are intended to confine the suspended sediment. The curtain is a floating barrier, and thus does not prevent water from entering the isolated area; rather, it prevents suspended sediment from getting out.

Appropriate applications:

Turbidity curtains should be used where sediment discharge to a stream is unavoidable. They are used when construction activities adjoin quiescent waters, such as lakes, ponds, lagoons, bays, and slow flowing rivers. The curtains are designed to deflect and contain sediment within a limited area and provide sufficient retention time so that the soil particles will fall out of suspension.

Limitations:

- Turbidity curtains should not be used in flowing water; they are best suited for use in ponds, lakes, lagoons, bays, and very slow-moving rivers.
- Turbidity curtains should not be placed across the width of a channel.
- Removing sediment that has been deflected and settled out by the curtain may create a discharge problem through the re-suspension of particles and by accidental dumping by the removal equipment.

Standards and Specifications:

- Turbidity curtains should be oriented parallel to the direction of flow.

- The curtain should extend the entire depth of the watercourse in calm-water situations.
- In wave conditions, the curtain should extend to within 0.3 m (1 ft) of the bottom of the watercourse, such that the curtain does not stir up sediment by hitting the bottom repeatedly. If it is desirable for the curtain to reach the bottom in an active-water situation, a pervious filter fabric may be used for the bottom 0.3 m (1 ft).
- The top of the curtain should consist of flexible flotation buoys, and the bottom shall be held down by a load line incorporated into the curtain fabric. The fabric shall be a brightly colored impervious mesh.
- The curtain shall be held in place by anchors placed at least every 30 m (100 ft).
- First place the anchors, then tow the fabric out in a furled condition, and connect to the anchors. The anchors should be connected to the flotation devices, and not to the bottom of the curtain. Once in place, cut the furling lines, and allow the bottom of the curtain to sink.
- Sediment that has been deflected and settled out by the curtain may be removed if so directed by the on-site inspector or the RE. Consideration must be given to the probable outcome of the removal procedure. It must be asked if it will create more of a sediment problem through re-suspension of the particles or by accidental dumping of material during removal. It is recommended that the soil particles trapped by the turbidity curtain only be removed if there has been a significant change in the original contours of the affected area in the watercourse.
- Particles should always be allowed to settle for a minimum of 6 to 12 hours prior to their removal or prior to removal of the turbidity curtain.

Maintenance and Inspection:

- The curtain should be inspected daily for holes or other problems, and any repairs needed should be made promptly.
- Allow sediment to settle for 6 to 12 hours prior to removal of sediment or curtain. This means that after removing sediment, wait an additional 6 to 12 hours before removing the curtain.
- To remove, install furling lines along the curtain, detach from anchors, and tow out of the water.

K-rail River Isolation

Definition and Purpose:

This is temporary sediment control, or stream isolation method that uses K-rails (refer to Figure 2) to form the sediment deposition area, or to isolate the in-stream or near-bank construction area.

Barriers are placed end-to-end in a pre-designed configuration and gravel-filled bags are used at the toe of the barrier and also at their abutting ends to seal and prevent movement of sediment beneath or through the barrier walls.

Appropriate Applications:

- The K-rail isolation can be used in streams with higher water velocities than many other isolation techniques.

Limitations:

- The K-rail method does not allow for full dewatering.

Standards and Specifications:

- To create a floor for the K-rail, move large rocks and obstructions. Place washed gravel and gravel-filled bags to create a level surface for K-rail to sit.

- Place the bottom two K-rails adjacent to each other, and parallel to the direction of flow; fill the center portion with gravel bags. Then place the third K-rail on top of the bottom two; there should be sufficient gravel bags between the bottom K-rails such that the top one is supported by the gravel. Place plastic sheeting around the K-rails, and secure at the bottom with gravel bags.

- Further support can be added by pinning and cabling the K-rails together. Also, large riprap and boulders can be used to support either side of the K-rail, especially where there is strong current.

Maintenance and Inspection:

- The barrier should be inspected at least once daily, and any damage, movement or other problems should be addressed immediately.

- Sediment should be allowed to settle for at least 6 to 12 hours prior to removal of sediment, and for 6 to 12 hours prior to removal of the barrier.

Stream Diversions

Definition and Purpose:

Stream diversions consist of a system of structures and measures that intercept an existing stream upstream of the project and, transports it around the work area, and discharges it downstream (refer to Figure 3). The selection of which stream diversion technique to use depends upon the type of work involved, physical characteristics of the site, and the volume of water flowing through the project.

Appropriate Applications:

- Pumped diversions are appropriate in areas where de-watering is necessary.
- Dam-type diversions may serve as temporary access to the site.
- Where work areas require isolation from flows.

Limitations:

- Pumped diversions have limited flow capacity.
- Pumped diversion require frequent monitoring of pumps.
- Large flows during storm events can overtop dams.
- Flow diversion and re-direction with small dams involves in-stream disturbance and mobilization of sediment.

Standards and Specifications:

- Installation guidelines will vary based on existing site conditions and type of diversion used.
- Diversions shall be sized to convey design flood flows.
- Pump capacity must be sufficient for design flow; the upper limit is approximately 0.3 m^3/sec (10 cfs) (the capacity of two 200 mm [8 inch] pumps).
- Adequate energy dissipation must be provided at the outlet to minimize erosion.
- Dam materials used to create dams upstream and downstream of diversion should be erosion resistant; materials such as steel plate, sheetpile, sandbags, continuous berms, inflatable water bladders, etc. would be acceptable.
- When constructing a diversion channel, begin excavation of the channel at the proposed downstream end, and work upstream. Once the watercourse to be diverted is reached, and the excavated channel is stable, breach the upstream end, and allow water to flow down the new channel. Once flow has been established in the diversion channel, install the diversion weir in the main channel; this will force all water to be diverted from the main channel.

Maintenance and Inspection:

- Inspect diversion/encroachment structures before and after significant storms, and at least once per week while in service. Inspect daily during the construction.
- Pumped diversions require frequent monitoring of pumps.

- Inspect embankments and diversion channels before and after significant storms, and at least once per week while in service for damage to the linings, accumulating debris, sediment buildup, and adequacy of the slope protection. Remove debris and repair linings and slope protection as required. Repair holes, gaps, or scour.

- Upon completion of work, the diversion or isolation structure should be removed and flow should be re-directed through the new culvert or back into the original stream channel. Recycle or re-use if applicable.

Instream Construction Sediment Control

There are three different options currently available for reducing turbidity while working in a stream or river. The stream can be isolated from the area in which work is occurring by means of a water barrier, the stream can be diverted around the work site through a pipe or temporary channel, or one can employ construction practices that minimize sediment suspension.

Whatever technique is implemented, an important thing to remember is that dilution can sometimes be the solution. A probable "worst time" to release high TSS into a stream system might be when the stream is very low; summer low flow, for example. During these times, the flow may be low while the biological activity in the stream is very high. Conversely, the addition of high TSS or sediment during a big storm discharge might have a relatively low impact, because the stream is already turbid, and the stream energy is capable of transporting both suspended solids, and large quantities of bedload through the system. The optimum time to remove in-stream structures may be during the rising limb of a storm hydrograph.

Techniques to minimize Total Suspended Solids (TSS)

- Padding - Padding laid in the stream below the work site may trap some solids that are deposited in the stream during construction. After work is done, the padding is removed from the stream, and placed on the bank to assist in revegetation.

- Clean, washed gravel - Using clean, washed gravel decreases solid suspension, as there are fewer small particles deposited in the stream.

- Excavation using a large bucket -Each time a bucket of soil is placed in the stream, a portion is suspended. Approximately the same amount is suspended whether a small amount of soil is placed in the stream, or a large amount. Therefore, using a large excavator bucket instead of a small one, will reduce the total amount of soil that washes downstream.

- Use of dozer for backfilling - Using a dozer for backfilling instead of a backhoe follows the same principles – the fewer times soil is deposited in the stream, the less soil will be suspended.

- Partial dewatering with a pump - Partially dewatering a stream with a pump reduces the amount of water, and thus the amount of water that can suspend sediment.

Washing Fines

Definition and Purpose:

Washing fines is an "in-channel" sediment control method, which uses water, either from a water truck or hydrant, to wash any stream fines that were brought to the surface of the channel bed during restoration, back into the interstitial spaces of the gravel and cobbles.

The purpose of this technique is to reduce or eliminate the discharge of sediment from the channel bottom during the first seasonal flows, or "first flush." Sediment should not be allowed into stream channels; however, occasionally in-channel restoration work will involve moving or otherwise disturbing fines (sand and silt-sized particles) that are already in the stream, usually below bankfull discharge elevation. Subsequent re-watering of the channel can result in a plume of turbidity and sedimentation.

This technique washes the fines back into the channel bed. Bedload materials, including gravel cobbles, boulders and those fines, are naturally mobilized during higher storm flows. This technique is intended to delay the discharge until the fines would naturally be mobilized.

Appropriate Applications:

- This technique should be used when construction work is required in channels. It is especially useful in intermittent or ephemeral streams in which work is performed "in the dry", and which subsequently become re-watered.

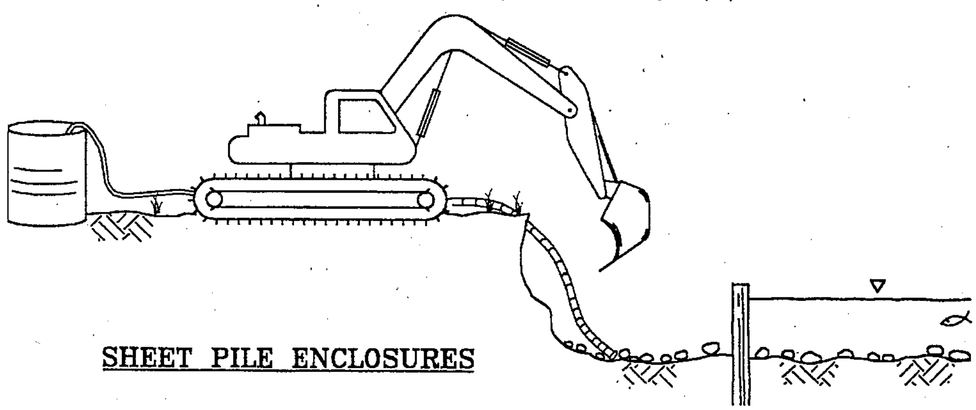
Limitations:

- The stream must have sufficient gravel and cobble substrate composition.
- The use of this technique requires consideration of time of year and timing of expected stream flows.
- The optimum time for the use of this technique is in the fall, prior to winter flows.
- Consultation with, and approval from the Department of Fish and Game and the Regional Water Quality Control Board may be required.

Standards and Specifications:

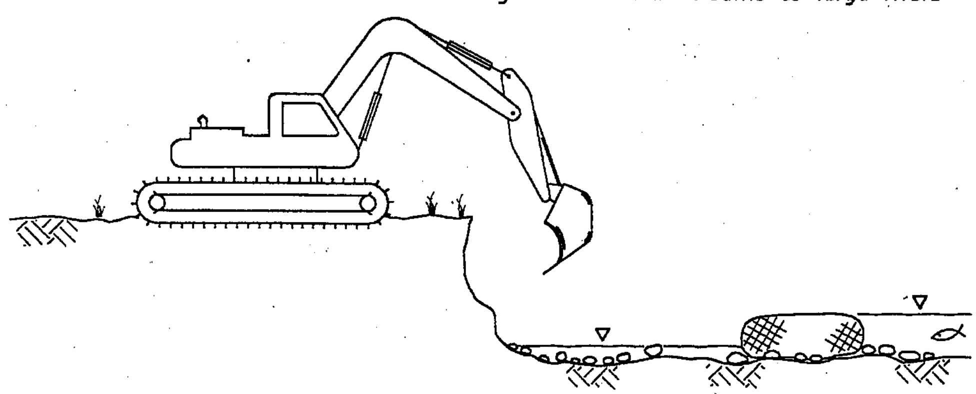
- Apply sufficient water to wash fines, but not cause further erosion or runoff.
- Apply water slowly and evenly to prevent runoff and erosion.
- Consult with Department of Fish and Game and the Regional Water Quality Control Board for specific water quality requirements of applied water (e.g. chlorine).

BENEFITS/LIMITATIONS
- *Allows full dewatering*
- *Relatively expensive*
- *Useful in large rivers, lakes, high velocity*
- *Not really appropriate for small streams*
- *Requires staging and heavy equipment access areas*



SHEET PILE ENCLOSURES

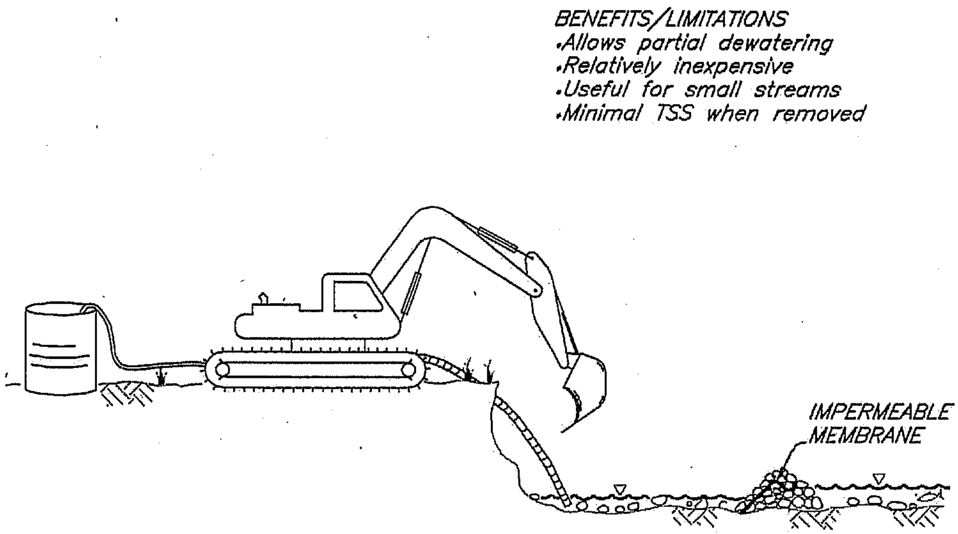
BENEFITS/LIMITATIONS
- *Allows partial dewatering*
- *Moderately expensive*
- *Ease of installation and removal unknown*
- *Can be designed for small streams to large rivers*



WATER–FILLED GEOTEXTILE (AQUA DAM)

INSTREAM EROSION AND SEDIMENT CONTROL ISOLATION TECHNIQUES

Figure 1A



NOTES:

Step 1. Install clean gravel with impermeable membrane

Step 2. Do work

Step 3. Decommission berm by removing impermeable membrane

Step 4. Pump work area. Head differential will cause water to flow into work area through gravel

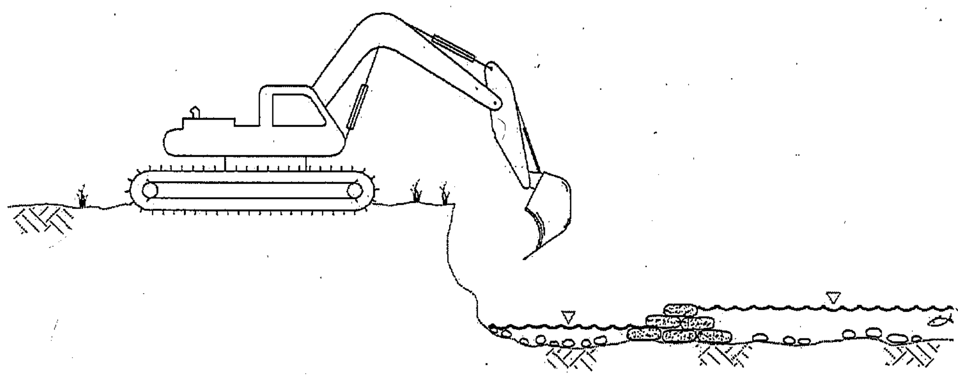
Step 5. Remove or spread gravel

GRAVEL BERM WITH IMPERMEABLE MEMBRANE

INSTREAM EROSION AND SEDIMENT CONTROL ISOLATION TECHNIQUES

Figure 1B

BENEFITS/LIMITATIONS
- Difficult to dewater
- Inexpensive
- Labor intensive to install and remove
- Use clean gravel

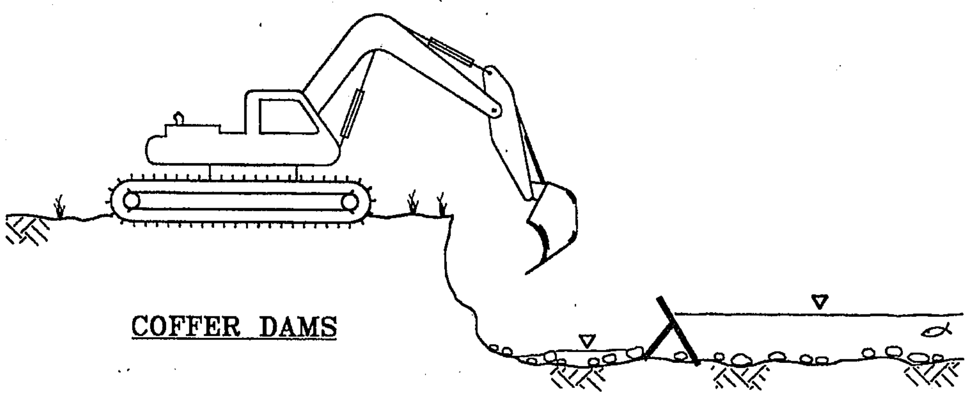


GRAVEL BAG TECHNIQUE

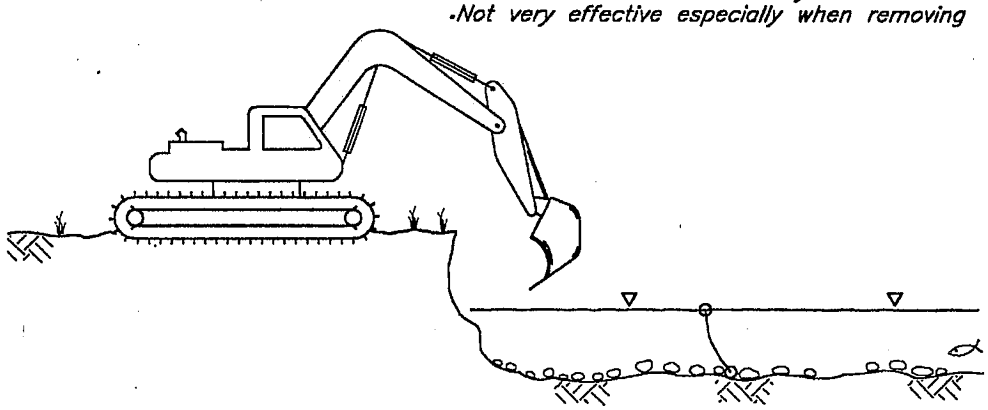
INSTREAM EROSION AND SEDIMENT CONTROL ISOLATION TECHNIQUES

Figure 1C

BENEFITS/LIMITATIONS
- *Allows partial dewatering*
- *Many different types available*
- *Relatively expensive*
- *Can be designed for large and small streams*
- *Ease of installation and removal unknown*



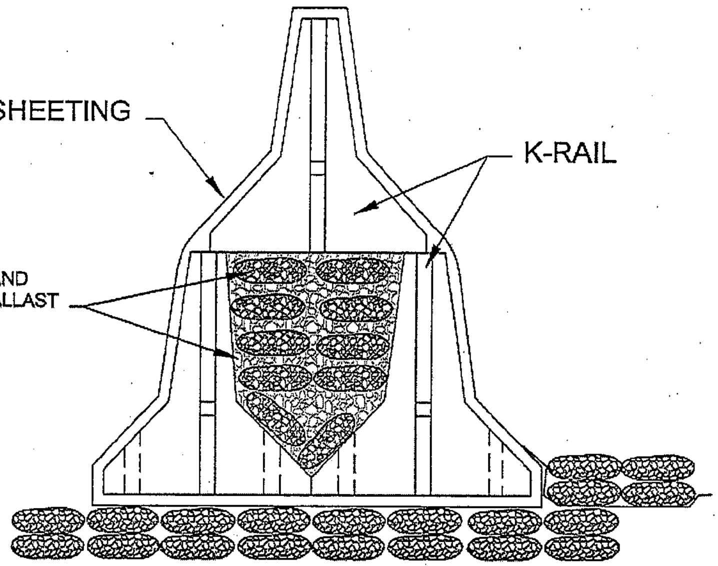
BENEFITS/LIMITATIONS
- *Does not allow dewatering*
- *Inexpensive*
- *Used in slow water lakes only*
- *Not very effective especially when removing*



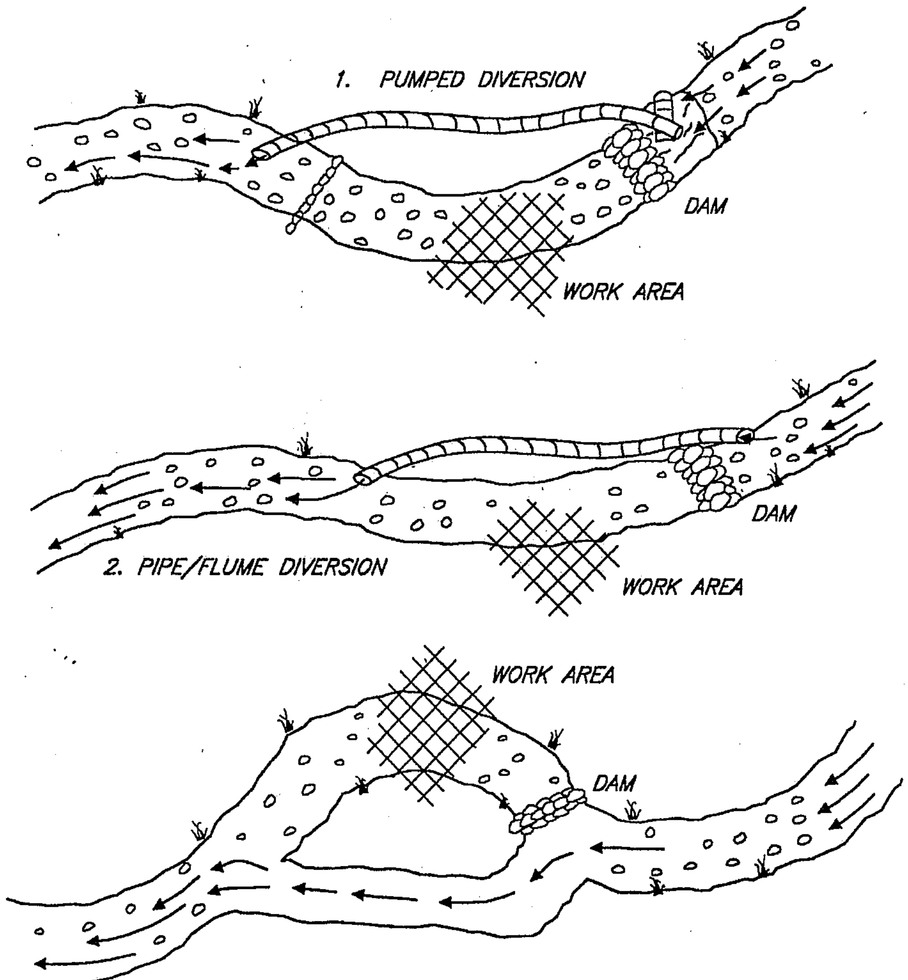
:EOTEXTILES, SILT BARRIERS, CURTAINS

INSTREAM EROSION AND SEDIMENT CONTROL ISOLATION TECHNIQUES

Figure 1D



K-Rail Isolation
Figure 2

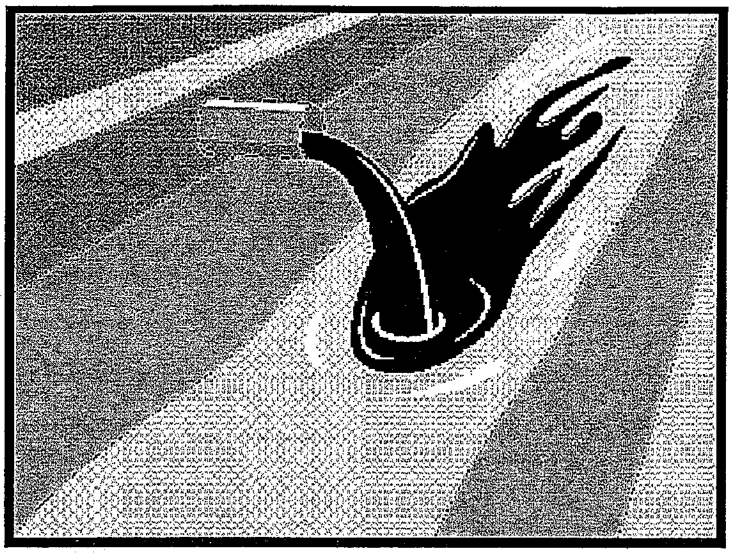


TYPICAL STREAM DIVERSION TECHNIQUES

Figure 3

Illicit Connection/Illegal Discharge Detection and Reporting

NS-6



Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Procedures and practices designed for construction contractors to recognize illicit connections or illegally dumped or discharged materials on a construction site and report incidents to the Resident Engineer (RE).

Appropriate Applications

- Illicit connection/illegal discharge detection and reporting is applicable anytime an illicit connection or discharge is discovered or illegally dumped material is found on the construction site.
- This best management practice (BMP) applies to all construction projects.

Limitations

- Unlabeled or non-identifiable material shall be assumed to be hazardous.
- Illicit connections and illegal discharges or dumping, for the purposes of this BMP, refer to discharges and dumping caused by parties other than the contractor.
- Procedures and practices presented in this BMP are general. Contractor shall use extreme caution, immediately notify the RE when illicit connections or illegal dumping or discharges are discovered, and take no further action unless directed by the RE.
- If pre-existing hazardous materials or wastes are known to exist onsite, the contractor's responsibility will be detailed in separate special provisions.

Standards and Specifications

Planning

- Inspect site before beginning the job for evidence of illicit connections or illegal dumping or discharges.
- Inspect site regularly during project execution for evidence of illicit connections or illegal dumping or discharges.
- Observe site perimeter for evidence or potential of illicitly discharged or illegally dumped material, which may enter the job site.

Identification of illicit connections and illegal dumping or discharges.

- Solids - Look for debris, or rubbish piles. Solid waste dumping often occurs on roadways with light traffic loads or in areas not easily visible from the traveled way.
- Liquids – signs of illegal liquid dumping or discharge can include:
  - Visible signs of staining or unusual colors to the pavement or surrounding adjacent soils.
  - Pungent odors coming from the drainage systems.
  - Discoloration or oily substances in the water or stains and residues detained within ditches, channels or drain boxes.
  - Abnormal water flow during the dry weather season.
- Urban Areas - Evidence of illicit connections or illegal discharges is typically detected at storm drain outfall locations or at manholes. Signs of an illicit connection or illegal discharge can include:
  - Abnormal water flow during the dry weather season.
  - Unusual flows in subdrain systems used for dewatering.
  - Pungent odors coming from the drainage systems.
  - Discoloration or oily substances in the water or stains and residues detained within ditches, channels or drain boxes.
  - Excessive sediment deposits, particularly adjacent to or near active off-site construction projects.

- Rural Areas - Illicit connections or illegal discharges involving irrigation drainage ditches are detected by visual inspections. Signs of an illicit discharge can include:
  - Abnormal water flow during the dry weather season.
  - Non-standard junction structures.
  - Broken concrete or other disturbances at or near junction structures.

Reporting

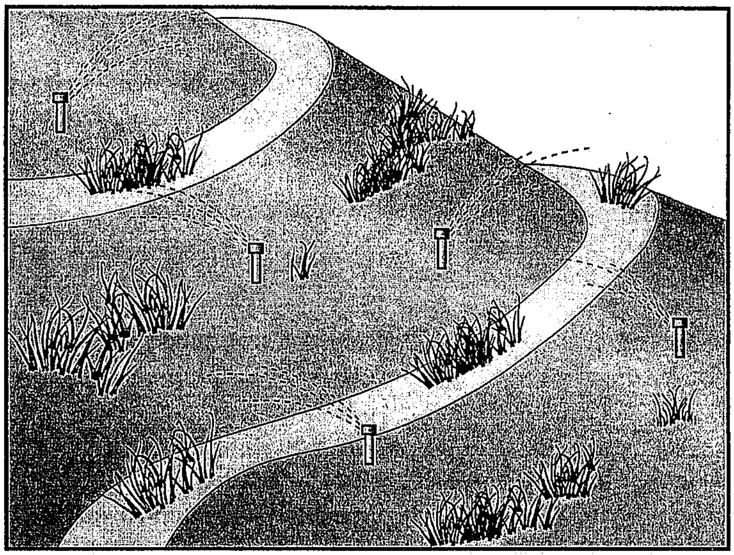
- Notify the RE of any illicit connections and illegal dumping or discharge incidents at the time of discovery. The RE will notify the District Construction Storm Water Coordinator and the Construction Hazmat Coordinator for reporting.

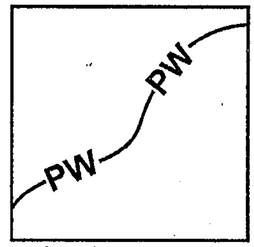
Cleanup and Removal

The contractor is not responsible for investigation and clean up of illicit or illegal dumping or discharges not generated by the contractor. Caltrans may direct contractor to clean up non-hazardous dumped or discharged material on the construction site.

Potable Water/Irrigation

NS-7





Standard Symbol

BMP Objectives

- o Soil Stabilization
- o Sediment Control
- o Tracking Control
- o Wind Erosion Control
- ● Non-Storm Water Management
- o Materials and Waste Management

Definition and Purpose

Potable Water/Irrigation management consists of practices and procedures to manage the discharge of potential pollutants generated during discharges from irrigation water lines, landscape irrigation, lawn or garden watering, planned and unplanned discharges from potable water sources, water line flushing, and hydrant flushing.

Appropriate Applications

Implement this BMP whenever the above activities or discharges occur at or enter a construction site.

Limitations

- None identified.

Standards and Specifications

- Inspect irrigated areas within the construction limits for excess watering. Adjust watering times and schedules to ensure that the appropriate amount of water is being used and to minimize runoff. Consider factors such as soil structure, grade, time of year, and type of plant material in determining the proper amounts of water for a specific area.

- RE approval is required prior to commencing any washing activities that could discharge to the storm drain or receiving waterbody.

- Where possible, direct water from off-site sources around or through a construction site in a way that minimizes contact with the construction site.

- When possible, discharges from water line flushing shall be reused for landscaping purposes.

- Shut off the water source to broken lines, sprinklers, or valves as soon as possible to prevent excess water flow.

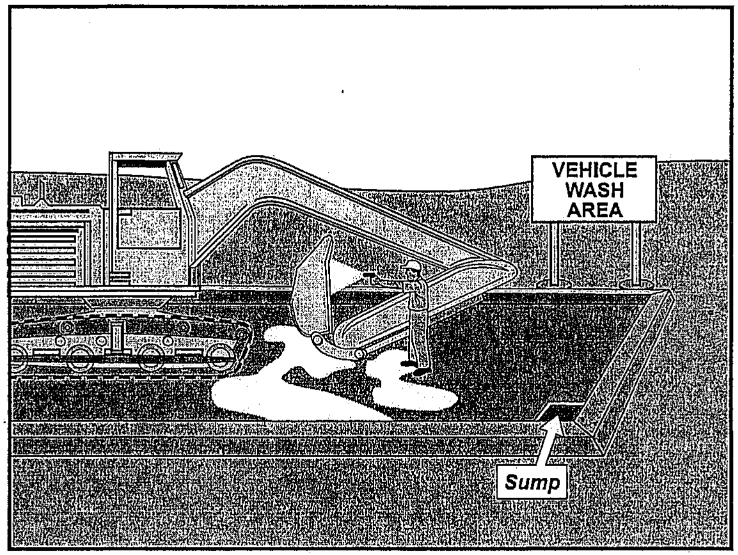
- Protect downstream storm water drainage systems and watercourses from water pumped or bailed from trenches excavated to repair water lines.

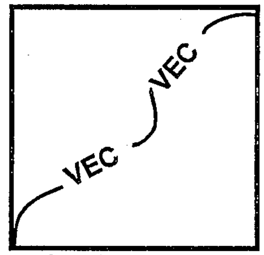
Maintenance and Inspection

- Repair broken water lines as soon as possible or as directed by the RE.
- Inspect irrigated areas regularly for signs of erosion and/or discharge.

Vehicle and Equipment Cleaning

NS-8





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Vehicle and equipment cleaning procedures and practices are used to minimize or eliminate the discharge of pollutants from vehicle and equipment cleaning operations to storm drain system or to watercourses.

Appropriate Applications

These procedures are applied on all construction sites where vehicle and equipment cleaning is performed.

Limitations

- None.

Standards and Specifications

- On-site vehicle and equipment washing is discouraged.

- Cleaning of vehicles and equipment with soap, solvents or steam shall not occur on the project site unless the Resident Engineer (RE) has been notified in advance and the resulting wastes are fully contained and disposed of outside the highway right-of-way in conformance with the provisions in the Standard Specifications Section 7-1.13. Resulting wastes and by-products shall not be discharged or buried within the highway right-of-way, and must be captured and recycled or disposed according to the requirements of WM-10, "Liquid Waste Management" or WM-6, "Hazardous Waste Management," depending on the waste characteristics. Minimize use of solvents. The use of diesel for vehicle and equipment cleaning is prohibited.

- Vehicle and equipment wash water shall be contained for percolation or evaporative drying away from storm drain inlets or watercourses and shall not be discharged within the highway right-of-way. Apply sediment control BMPs if applicable.

- All vehicles/equipment that regularly enter and leave the construction site must be cleaned off-site.

- When vehicle/equipment washing/cleaning must occur onsite, and the operation cannot be located within a structure or building equipped with appropriate disposal facilities, the outside cleaning area shall have the following characteristics, and shall be arranged with the construction storm water coordinator:

- Located away from storm drain inlets, drainage facilities, or watercourses.
- Paved with concrete or asphalt and bermed to contain wash waters and to prevent run-on and runoff.
- Configured with a sump to allow collection and disposal of wash water.
- Wash waters shall not be discharged to storm drains or watercourses.
- Used only when necessary.

■ When cleaning vehicles/equipment with water:

- Use as little water as possible. High pressure sprayers may use less water than a hose, and shall be considered.
- Use positive shutoff valve to minimize water usage.
- Facility wash racks shall discharge to a sanitary sewer, recycle system or other approved discharge system and shall not discharge to the storm drainage system or watercourses.

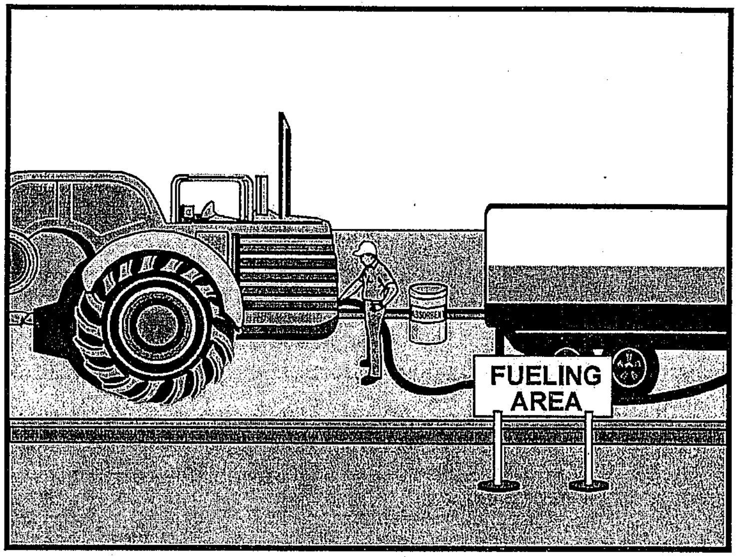
Maintenance and Inspection

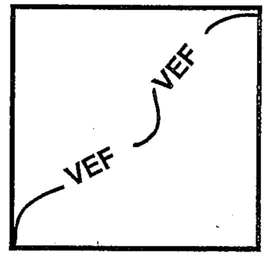
■ The control measure shall be inspected at a minimum of once a week.

■ Monitor employees and subcontractors throughout the duration of the construction project to ensure appropriate practices are being implemented.

■ Inspect sump regularly and remove liquids and sediment as needed or as directed by the RE.

Vehicle and Equipment Fueling





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Vehicle and equipment fueling procedures and practices are designed to minimize or eliminate the discharge of fuel spills and leaks into storm drain systems or to watercourses.

Appropriate Applications

These procedures are applied on all construction sites where vehicle and equipment fueling takes place.

Limitations

- Onsite vehicle and equipment fueling shall only be used where it's impractical to send vehicles and equipment off-site for fueling.

Standards and Specifications

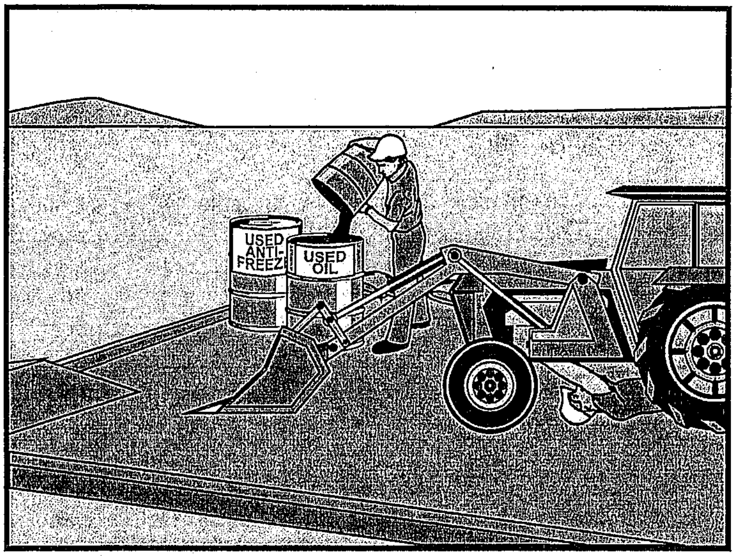
- When fueling must occur onsite, the contractor shall select and designate an area to be used, subject to approval of the Resident Engineer (RE).
- Absorbent spill clean-up materials and spill kits shall be available in fueling areas and on fueling trucks and shall be disposed of properly after use.
- Drip pans or absorbent pads shall be used during vehicle and equipment fueling, unless the fueling is performed over an impermeable surface in a dedicated fueling area.
- Dedicated fueling areas shall be protected from storm water run-on and runoff, and shall be located at least 15 m (50 ft) from downstream drainage facilities and watercourses. Fueling must be performed on level-grade areas.
- Nozzles used in vehicle and equipment fueling shall be equipped with an automatic shut-off to control drips. Fueling operations shall not be left unattended.
- Protect fueling areas with berms and/or dikes to prevent run-on, runoff, and to contain spills.

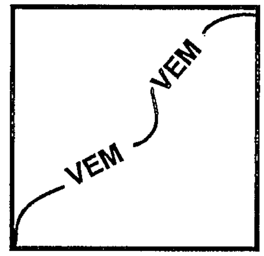
- Use vapor recovery nozzles to help control drips as well as air pollution where required by Air Quality Management Districts (AQMD). Ensure the nozzle is secured upright when not in use.
- Fuel tanks shall not be "topped-off."
- Vehicles and equipment shall be inspected on each day of use for leaks. Leaks shall be repaired immediately or problem vehicles or equipment shall be removed from the project site.
- Absorbent spill clean-up materials shall be available in fueling and maintenance areas and used on small spills instead of hosing down or burying techniques. The spent absorbent material shall be removed promptly and disposed of properly.
- Federal, state, and local requirements shall be observed for any stationary above ground storage tanks. Refer to WM-1, "Material Delivery and Storage."
- Mobile fueling of construction equipment throughout the site shall be minimized. Whenever practical, equipment shall be transported to the designated fueling area.

Maintenance and Inspection

- Fueling areas and storage tanks shall be inspected regularly.
- Keep an ample supply of spill cleanup material on the site.
- Immediately cleanup spills and properly dispose of contaminated soil and cleanup materials.

Vehicle and Equipment Maintenance NS-10





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Procedures and practices to minimize or eliminate the discharge of pollutants to the storm drain systems or to watercourses from vehicle and equipment maintenance procedures.

Appropriate Applications

These procedures are applied on all construction projects where an onsite yard area is necessary for storage and maintenance of heavy equipment and vehicles.

Limitations

- None identified.

Standards and Specifications

- Drip pans or absorbent pads shall be used during vehicle and equipment maintenance work that involves fluids, unless the maintenance work is performed over an impermeable surface in a dedicated maintenance area.
- All maintenance areas are required to have spill kits and/or use other spill protection devices.
- Dedicated maintenance areas shall be protected from storm water run-on and runoff, and shall be located at least 15 m (50 ft) from downstream drainage facilities and watercourses.
- Drip Pans or plastic sheeting shall be placed under all vehicles and equipment placed on docks, barges, or other structures over water bodies when the vehicle or equipment is planned to be idle for more than one hour.
- Absorbent spill clean-up materials shall be available in maintenance areas and shall be disposed of properly after use. Substances used to coat asphalt transport trucks and asphalt-spreading equipment shall be non-toxic.
- Use off-site maintenance facilities whenever practical.

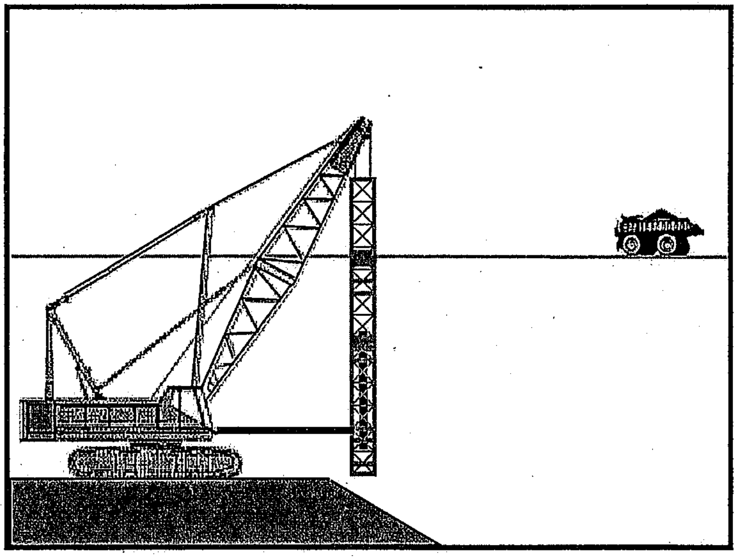
- For long-term projects, consider constructing roofs or using portable tents over maintenance areas.
- Properly dispose of used oils, fluids, lubricants, and spill cleanup materials.
- Do not dump fuels and lubricants onto the ground.
- Do not place used oil in a dumpster or pour into a storm drain or watercourse.
- Properly dispose or recycle used batteries.
- Do not bury used tires.
- Repair of fluid and oil leaks immediately.
- Provide spill containment dikes or secondary containment around stored oil and chemical drums.

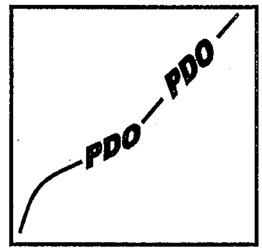
Maintenance and Inspection

- Maintain waste fluid containers in leak proof condition.
- Vehicle and equipment maintenance areas shall be inspected regularly.
- Vehicles and equipment shall be inspected on each day of use. Leaks shall be repaired immediately or the problem vehicle(s) or equipment shall be removed from the project site.
- Inspect equipment for damaged hoses and leaky gaskets routinely. Repair or replace as needed.

Pile Driving Operations

NS-11





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

The construction and retrofit of bridges and retaining walls often include driving piles for foundation support and shoring operations. Driven piles are typically constructed of concrete, steel, or timber. Driven sheet piles are used for shoring and cofferdam construction. Proper control and use of equipment, materials, and waste products from pile driving operations will reduce the discharge of potential pollutants to the storm drain system or watercourses.

Appropriate Applications

These procedures apply to construction sites near or adjacent to a watercourse or groundwater where permanent and temporary pile driving operations (impact and vibratory) take place, including operations using pile shells for construction of cast-in-steel-shell and cast-in-drilled-hole piles.

Limitations

- None identified.

Standards and Specifications

- Use drip pans or absorbent pads during vehicle and equipment maintenance, cleaning, fueling, and storage. Refer to BMPs NS-9 "Vehicle and Equipment Fueling" and NS-10 "Vehicle and Equipment Maintenance."
- Have spill kits and cleanup materials available at all locations of pile driving. Refer to BMP WM-4 "Spill Prevention and Control."
- Keep equipment that is in use in streambeds; or on docks, barges, or other structures over water bodies, leak free.
- Park equipment over plastic sheeting or equivalent where possible. Plastic sheeting is not a substitute for drip pans or absorbent pads. The storage or use of equipment in streambeds or other bodies of water shall comply with all applicable permits.
- Implement other BMPs as applicable, such as NS-2 "Dewatering Operations," WM-5 "Solid Waste Management," WM-6 "Hazardous Waste Management," and WM-10 "Liquid Waste Management."

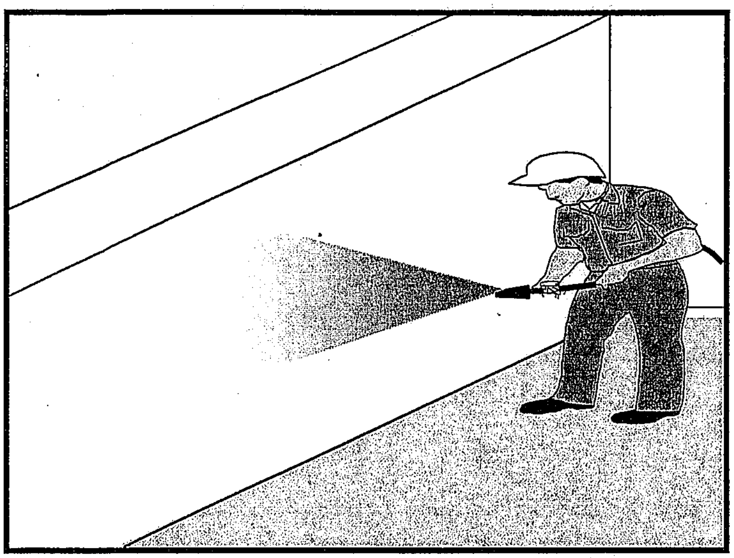
- When not in use, store pile driving equipment away from concentrated flows of storm water, drainage courses, and inlets. Protect hammers and other hydraulic attachments from run-on by placing them on plywood and covering them with plastic or a comparable material prior to the onset of rain.
- Use less hazardous products, e.g. vegetable oil instead of hydraulic fluid, when practicable.

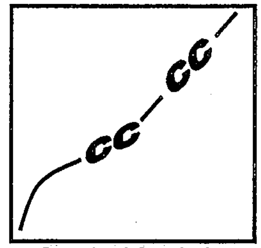
Maintenance and Inspection

- Inspect pile driving areas and equipment for leaks and spills on a daily basis.
- Inspect equipment routinely and repair equipment as needed (e.g., worn or damaged hoses, fittings, gaskets).

Concrete Curing

NS-12





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

Concrete curing is used in the construction of structures such as bridges, retaining walls, and pump houses. Concrete curing includes the use of both chemical and water methods. Proper procedures minimize pollution of runoff during concrete curing.

Appropriate Applications

All concrete elements of a structure (e.g., footings, columns, abutments, stems, soffit, deck) are subject to curing requirements.

Limitations

- None identified.

Standards and Specifications

Chemical Curing

- Avoid over-spray of curing compounds.
- Minimize the drift of chemical cure as much as possible by applying the curing compound close to the concrete surface. Apply an amount of compound that covers the surface, but does not allow any runoff of the compound.
- Use proper storage and handling techniques for concrete curing compounds. Refer to BMP WM-1, "Material Delivery and Storage."
- Protect drain inlets prior to the application of curing compounds.
- Refer to WM-4, "Spill Prevention and Control."

Water Curing for Bridge Decks, Retaining Walls, and other Structures

- Direct cure water away from inlets and watercourses to collection areas for removal as approved by the RE and in accordance with all applicable permits.

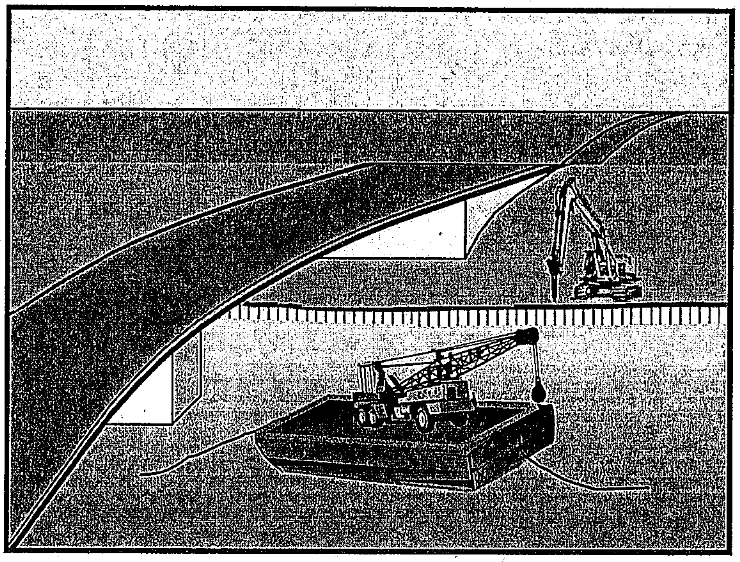
- Collect cure water and transport or dispose of water in a non-erodible manner. See BMPs SS-9, "Earth Dikes/Drainage Swales & Lined Ditches," SS-10, "Outlet Protection/Velocity Dissipation Devices," and SS-11, "Slope Drains."
- Utilize wet blankets or a similar method that maintains moisture while minimizing the use and possible discharge of water.

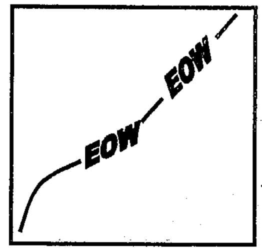
Maintenance and Inspection

- Ensure that employees and subcontractors implement appropriate measures for storage, handling, and use of curing compounds.
- Inspect any temporary diversion devices, lined channels, or swales for washouts, erosion, or debris. Replace lining and remove debris as necessary.
- Inspect cure containers and spraying equipment for leaks.

Material and Equipment Use Over Water

NS-13





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

Procedures for the proper use, storage, and disposal of materials and equipment on barges, boats, temporary construction pads, or similar locations that minimize or eliminate the discharge of potential pollutants to a watercourse.

Appropriate Applications

These procedures shall be implemented for construction materials and wastes (solid and liquid) and any other materials that may be detrimental if released. Applies where materials and equipment are used on barges, boats, docks, and other platforms over or adjacent to a watercourse.

Limitations

- None identified.

Standards and Specifications

- Refer to BMPs WM-1, "Material Delivery and Storage" and WM-4, "Spill Prevention and Control."
- Use drip pans and absorbent materials for equipment and vehicles and ensure that an adequate supply of spill cleanup materials is available.
- Drip pans shall be placed under all vehicles and equipment placed on docks, barges, or other structures over water bodies when the vehicle or equipment is expected to be idle for more than one hour.
- Maintain equipment in accordance with BMP NS-10, "Vehicle and Equipment Maintenance." If a leaking line cannot be repaired, remove equipment from over the water.
- Provide watertight curbs or toe boards to contain spills and prevent materials, tools, and debris from leaving the barge, platform, dock, etc.
- Secure all materials to prevent discharges to receiving waters via wind.

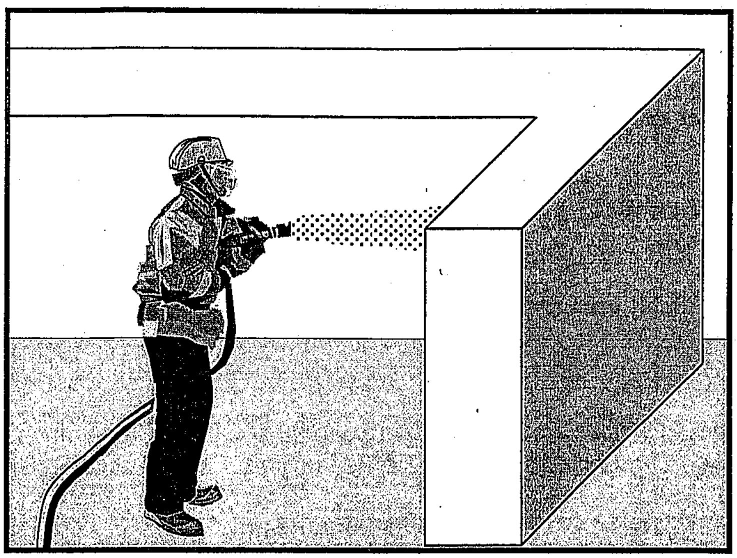
- Identify types of spill control measures to be employed, including the storage of such materials and equipment. Ensure that staff are trained regarding the deployment and access of control measures and that measures are being used.
- Ensure the timely and proper removal of accumulated wastes. Refer to BMPs WM-5, "Solid Waste Management" (non-hazardous) and WM-6, "Hazardous Waste Management."
- Comply with all necessary permits required for construction within or near the watercourse, such as RWQCB, U.S. Army Corps of Engineers, Department of Fish and Game and other local permitting agencies.
- Discharges to waterways shall be reported to the RE immediately upon discovery. A written discharge notification must follow within 7 days.
- Refer to BMP NS-15, "Structure Demolition/Removal Over or Adjacent to Water."

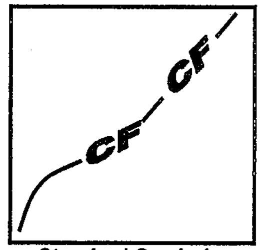
Maintenance and Inspection

- Inspect equipment for leaks and spills on a daily basis, and make necessary repairs.
- Ensure that employees and subcontractors implement appropriate measures for storage and use of materials and equipment.
- Inspect and maintain all associated BMPs and perimeter controls to ensure continuous protection of the watercourse.

Concrete Finishing

NS-14





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

Concrete finishing methods are used for bridge deck rehabilitation, paint removal, curing compound removal, and final surface finish appearances. Methods include sand blasting, shot blasting, grinding, or high pressure water blasting. Proper procedures minimize the impact that concrete finishing methods may have on runoff.

Appropriate Applications

These procedures apply to all construction locations where concrete finishing operations are performed.

Limitations

- Specific permit requirements may be included in the contract documents for certain concrete finishing operations.

Standards and Specifications

- Follow containment requirements stated in the project special provisions, if any.
- Collect and properly dispose of water and solid waste from high-pressure water blasting operations.
- Collect water from blasting operations and transport or dispose of water in a non-erodible manner. Refer to BMPs SS-9, "Earth Dikes/Drainage Swales & Lined Ditches," SS-10, "Outlet Protection/Velocity Dissipation Devices," and SS-11, "Slope Drains."
- Direct water from blasting operations away from inlets and watercourses to collection areas for removal (e.g., dewatering) as approved in advance by the RE and in accordance with applicable permits.
- Protect inlets during sandblasting operations. Refer to BMP SC-10, "Storm Drain Inlet Protection."

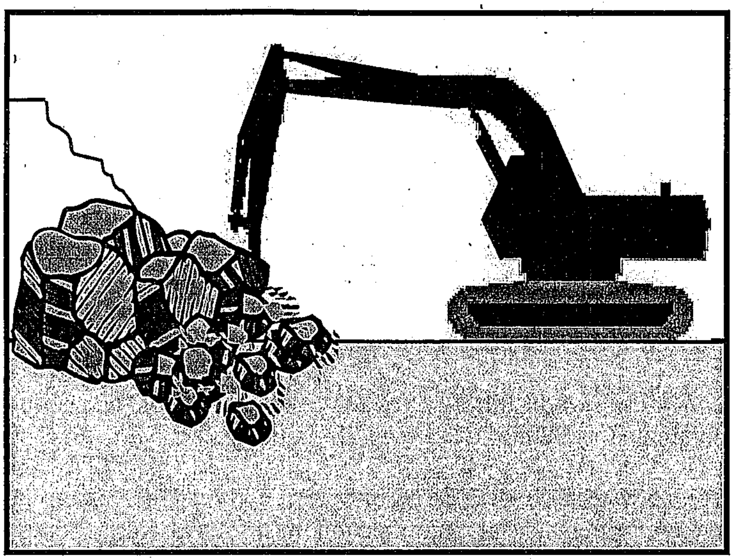
- Refer to BMP WM-8, "Concrete Waste Management."
- Minimize the drift of dust and blast material as much as possible by keeping the blasting nozzle close to the surface.
- When blast residue contains a potentially hazardous waste, refer to BMP WM-6, "Hazardous Waste Management."

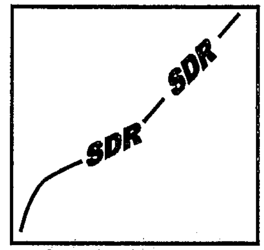
Maintenance and Inspection

- Follow inspection procedure as required in the project special provisions.
- At a minimum, inspect containment structures, if any, for damage or voids prior to use each day and prior to the onset of rain.
- At the end of each work shift, remove and contain the liquid and solid wastes from containment structures, if any, and from the general work area.
- Discharges to waterways shall be reported to RE immediately upon discovery. A written discharge notification must follow within 7 days or as required by special provisions.

Structure Demolition/Removal Over or Adjacent to Water

NS-15





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

Procedures to protect water bodies from debris and wastes associated with structure demolition or removal over or adjacent to watercourses.

Appropriate Applications

Full bridge demolition and removal, partial bridge removal (e.g., barrier rail, edge of deck) associated with bridge widening projects, concrete channel removal, or any other structure removal that could potentially affect water quality.

Limitations

- Specific permit requirements may be included in the contract documents.

Standards and Specifications

- Do not allow demolished material to enter waterway.
- Refer to BMP NS-5, "Clear Water Diversion" to direct water away from work areas.
- Use attachments on construction equipment such as backhoes to catch debris from small demolition operations.
- Use covers or platforms to collect debris.
- Platforms and covers are to be approved by the RE.
- Stockpile accumulated debris and waste generated during demolition away from watercourses and in accordance with BMP WM-3, "Stockpile Management."
- Ensure safe passage of wildlife, as necessary.
- Discharges to waterways shall be reported to the RE immediately upon discovery. A written discharge notification must follow within 7 days.

- For structures containing hazardous materials (e.g., lead paint or asbestos) refer to BMP WM-6, "Hazardous Waste Management." For demolition work involving soil excavation around lead-painted structures, refer to BMP WM-7, "Contaminated Soil Management."

Maintenance and Inspection

- Contractor must inspect demolition areas over or near adjacent watercourses on a daily basis.
- Any debris-catching devices shall be emptied regularly. Collected debris shall be removed and stored away from the watercourse and protected from run-on and runoff.

Section 8
Waste Management and Materials Pollution Control Best Management Practices

8.1 Waste Management and Materials Pollution Control

Waste management and materials pollution control best management practices (BMPs), like non-storm water management BMPs, are source control BMPs that prevent pollution by limiting or reducing potential pollutants at their source before they come in contact with storm water. These BMPs also involve day-to-day operations of the construction site and are under the control of the Contractor, and are additional "good housekeeping practices", which involve keeping a clean, orderly construction site.

8.1.1 Waste Management BMPs

Waste management consists of implementing procedural and structural BMPs for handling, storing, and disposing of wastes generated by a construction project to prevent the release of waste materials into storm water discharges. Waste management includes the following BMPs:

- Spill Prevention and Control
- Solid Waste Management
- Hazardous Waste Management
- Contaminated Soil Management
- Concrete Waste Management
- Sanitary/Septic Waste Management
- Liquid Waste Management

8.1.2 Materials Pollution Control BMPs

Materials pollution control (also called materials handling) consists of implementing procedural and structural BMPs for handling, storing, and using construction materials to prevent the release of those materials into storm water discharges. The objective is to reduce the opportunity for rainfall to come in contact with these materials. These controls shall be implemented for all applicable activities, material usage and site conditions. Materials handling practices include the following BMPs:

- Material Delivery and Storage
- Material Use
- Stockpile Management

Table 8-1 lists the waste management and materials pollution control BMPs. It is important to note that all these BMPs have been approved by Caltrans for statewide use and they shall be implemented depending on the conditions/applicability of deployment described as part of the BMP.

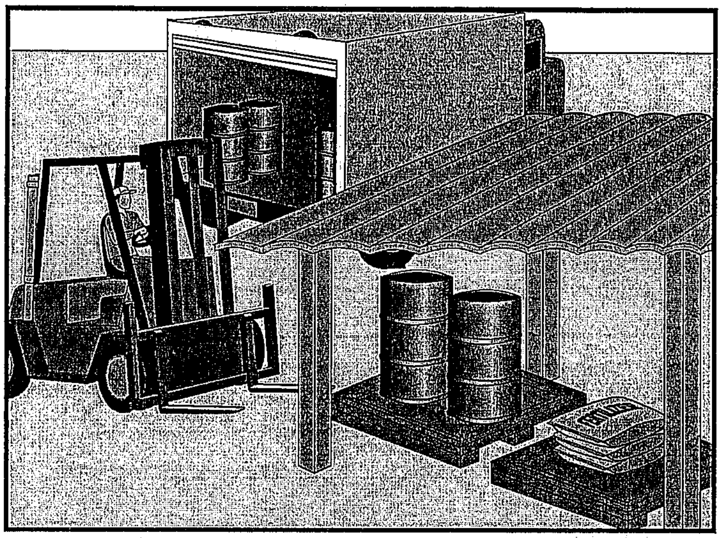
Table 8-1

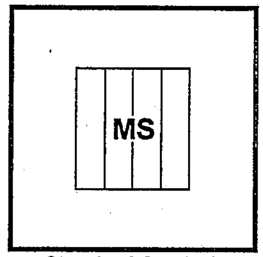
WASTE MANAGEMENT AND MATERIALS POLLUTION CONTROL BMPs	
ID	**BMP NAME**
WM-1	Material Delivery and Storage
WM-2	Material Use
WM-3	Stockpile Management
WM-4	Spill Prevention and Control
WM-5	Solid Waste Management
WM-6	Hazardous Waste Management
WM-7	Contaminated Soil Management
WM-8	Concrete Waste Management
WM-9	Sanitary/Septic Waste Management
WM-10	Liquid Waste Management

The remainder of this Section shows the working details for each of the waste management and materials pollution control BMPs.

Material Delivery and Storage

WM-1





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

Procedures and practices for the proper handling and storage of materials in a manner that minimizes or eliminates the discharge of these materials to the storm drain system or to watercourses.

Appropriate Applications

These procedures are implemented at all construction sites with delivery and storage of the following:

- Hazardous chemicals such as:
  - Acids,
  - lime,
  - glues,
  - adhesives,
  - paints,
  - solvents, and
  - curing compounds.
- Soil stabilizers and binders.
- Fertilizers.
- Detergents.
- Plaster.
- Petroleum products such as fuel, oil, and grease.
- Asphalt and concrete components.
- Pesticides and herbicides.

- Other materials that may be detrimental if released to the environment.

Limitations

- Space limitation may preclude indoor storage.
- Storage sheds must meet building & fire code requirements.

Standards and Specifications

General

- Train employees and subcontractors on the proper material delivery and storage practices.
- Temporary storage area shall be located away from vehicular traffic.
- Material Safety Data Sheets (MSDS) shall be supplied to the Resident Engineer (RE) for all materials stored.

Material Storage Areas and Practices

- Liquids, petroleum products, and substances listed in 40 CFR Parts 110, 117, or 302 shall be stored in approved containers and drums and shall be placed in temporary containment facilities for storage.
- Throughout the rainy season, each temporary containment facility shall have a permanent cover and side wind protection or be covered during non-working days and prior to and during rain events.
- A temporary containment facility shall provide for a spill containment volume able to contain precipitation from a 24-hour, 25-year storm event, plus the greater of 10% of the aggregate volume of all containers or 100% of the capacity of the largest container within its boundary, whichever is greater.
- A temporary containment facility shall be impervious to the materials stored therein for a minimum contact time of 72 hours.
- A temporary containment facility shall be maintained free of accumulated rainwater and spills. In the event of spills or leaks, accumulated rainwater and spills shall be collected and placed into drums. These liquids shall be handled as a hazardous waste unless testing determines them to be non-hazardous. All collected liquids or non-hazardous liquids shall be sent to an approved disposal site.
- Sufficient separation shall be provided between stored containers to allow for spill cleanup and emergency response access.
- Incompatible materials, such as chlorine and ammonia, shall not be stored in the same temporary containment facility.
- Materials shall be stored in their original containers and the original product labels shall be maintained in place in a legible condition. Damaged or otherwise illegible labels shall be replaced immediately.

-

- Bagged and boxed materials shall be stored on pallets and shall not be allowed to accumulate on the ground. To provide protection from wind and rain, throughout the rainy season, bagged and boxed materials shall be covered during non-working days and prior to rain events.

- Stockpiles shall be protected in accordance with BMP WM-3, "Stockpile Management."

- Minimize the material inventory stored on-site (e.g., only a few days supply).

- Have proper storage instructions posted at all times in an open and conspicuous location.

- Do not store hazardous chemicals, drums, or bagged materials directly on the ground. Place these items on a pallet and when possible, under cover in secondary containment.

- Keep hazardous chemicals well labeled and in their original containers.

- Keep ample supply of appropriate spill clean up material near storage areas.

- Also see BMP WM-6, "Hazardous Waste Management", for storing of hazardous materials.

Material Delivery Practices

- Keep an accurate, up-to-date inventory of material delivered and stored on-site.

- Employees trained in emergency spill clean-up procedures shall be present when dangerous materials or liquid chemicals are unloaded.

Spill Clean-up

- Contain and clean up any spill immediately.

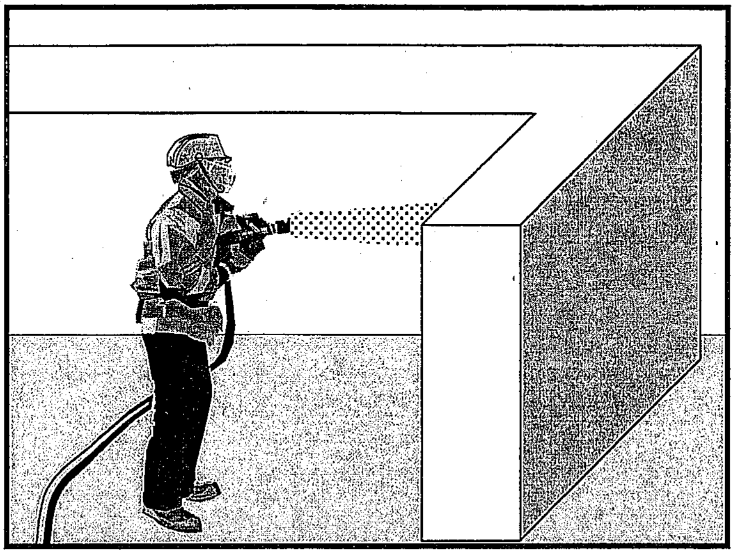
- If significant residual materials remain on the ground after construction is complete, properly remove and dispose any hazardous materials or contaminated soil.

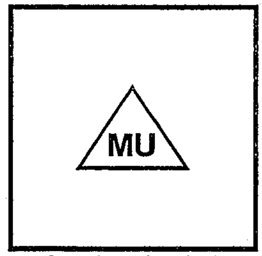
- See BMP WM-4, "Spill Prevention and Control", for spills of chemicals and/or hazardous materials.

Maintenance and Inspection

- Storage areas shall be kept clean, well organized, and equipped with ample clean-up supplies as appropriate for the materials being stored.
- Perimeter controls, containment structures, covers, and liners shall be repaired or replaced as needed to maintain proper function.
- Inspect storage areas before and after rainfall events, and at least weekly during other times. Collect and place into drums any spills or accumulated rainwater.

Material Use





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

These are procedures and practices for use of construction material in a manner that minimizes or eliminates the discharge of these materials to the storm drain system or to watercourses.

Appropriate Applications

This BMP applies to all construction projects. These procedures apply when the following materials are used or prepared on site:

- Hazardous chemicals such as:

  Acids,
  lime,
  glues,
  adhesives,
  paints,
  solvents, and
  curing compounds.

- Soil stabilizers and binders.
- Fertilizers.
- Detergents.
- Plaster.
- Petroleum products such as fuel, oil, and grease.
- Asphalt and concrete components.
- Pesticides and herbicides.
- Other materials that may be detrimental if released to the environment.

Limitations

- Safer alternative building and construction products may not be available or suitable in every instance.

Standards and Specifications

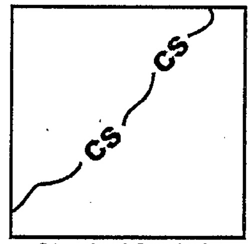
- Material Safety Data Sheets (MSDS) shall be supplied to the Resident Engineer (RE) for all materials.
- Latex paint and paint cans, used brushes, rags, absorbent materials, and drop cloths, when thoroughly dry and are no longer hazardous, may be disposed of with other construction debris.
- Do not remove the original product label, it contains important safety and disposal information. Use the entire product before disposing of the container.
- Mix paint indoors, or in a containment area. Never clean paintbrushes or rinse paint containers into a street, gutter, storm drain or watercourse. Dispose of any paint thinners, residue and sludge(s), that cannot be recycled, as hazardous waste.
- For water-based paint, clean brushes to the extent practical, and rinse to a drain leading to a sanitary sewer where permitted, or into a concrete washout pit. For oil-based paints, clean brushes to the extent practical and filter and reuse thinners and solvents.
- Use recycled and less hazardous products when practical. Recycle residual paints, solvents, non-treated lumber, and other materials.
- Use materials only where and when needed to complete the construction activity. Use safer alternative materials as much as possible. Reduce or eliminate use of hazardous materials on-site when practical.
- Do not over-apply fertilizers and pesticides. Prepare only the amount needed. Strictly follow the recommended usage instructions. Apply surface dressings in smaller applications, as opposed to large applications, to allow time for it to work in and to avoid excess materials being carried off-site by runoff.
- Application of herbicides and pesticides shall be performed by a licensed applicator.
- Contractors are required to complete the "Report of Chemical Spray Forms" when spraying herbicides and pesticides.
- Keep an ample supply of spill clean up material near use areas. Train employees in spill clean up procedures.
- Avoid exposing applied materials to rainfall and runoff unless sufficient time has been allowed for them to dry.

Maintenance and Inspections

- Spot check employees and subcontractors monthly throughout the job to ensure appropriate practices are being employed.

Stockpile Management

WM-3



Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

Stockpile management procedures and practices are designed to reduce or eliminate air and storm water pollution from stockpiles of soil, and paving materials such as portland cement concrete (PCC) rubble, asphalt concrete (AC), asphalt concrete rubble, aggregate base, aggregate subbase or pre-mixed aggregate, asphalt binder (so called "cold mix" asphalt) and pressure treated wood.

Appropriate Applications

Implemented in all projects that stockpile soil and other materials.

Limitations

- None identified

Standards and Specifications

- Protection of stockpiles is a year-round requirement.
- Locate stockpiles a minimum of 15 m (50 ft)away from concentrated flows of storm water, drainage courses, and inlets.
- Implement wind erosion control practices as appropriate on all stockpiled material. For specific information see BMP WE-1, "Wind Erosion Control."
- Stockpiles of contaminated soil shall be managed in accordance with BMP WM-7, "Contaminated Soil Management."
- Bagged materials should be placed on pallets and under cover.

Protection of Non-Active Stockpiles

Non-active stockpiles of the identified materials shall be protected further as follows:

- *Soil stockpiles:*
  - During the rainy seasons, soil stockpiles shall be covered or protected with soil stabilization measures and a temporary perimeter sediment barrier at all times.
  - During the non-rainy season, soil stockpiles shall be covered and protected with a temporary perimeter sediment barrier prior to the onset of precipitation.
- ***Stockpiles of portland cement concrete rubble, asphalt concrete, asphalt concrete rubble, aggregate base, or aggregate subbase:***
  - During the rainy season, the stockpiles shall be covered or protected with a temporary perimeter sediment barrier at all times.
  - During the non-rainy season, the stockpiles shall be covered or protected with a temporary perimeter sediment barrier prior to the onset of precipitation.
- ***Stockpiles of "cold mix":***
  - During the rainy season, cold mix stockpiles shall be placed on and covered with plastic or comparable material at all times.
  - During the non-rainy season, cold mix stockpiles shall be placed on and covered with plastic or comparable material prior to the onset of precipitation.
- ***Stockpiles/Storage of pressure treated wood with copper, chromium, and arsenic or ammonical, copper, zinc, and arsenate:***
  - During the rainy season, treated wood shall be covered with plastic or comparable material at all times.
  - During the non-rainy season, treated wood shall be covered with plastic or comparable material and shall be placed on pallets prior to the onset of precipitation.

Protection of Active Stockpiles

Active stockpiles of the identified materials shall be protected further as follows:

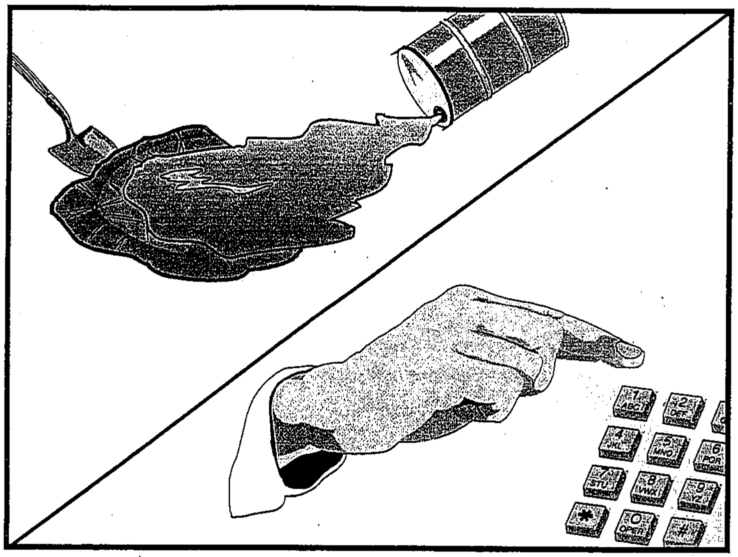
- All stockpiles shall be covered, stabilized, or protected with a temporary linear sediment barrier prior to the onset of precipitation.
- Stockpiles of "cold mix" shall be placed on and covered with plastic or comparable material prior to the onset of precipitation.

Maintenance and Inspections

- Repair and/or replace perimeter controls and covers as needed, or as directed by the RE, to keep them functioning properly. Sediment shall be removed when sediment accumulation reaches one-third (1/3) of the barrier height.

Spill Prevention and Control

WM-4



Standard Symbol

BMP Objectives
- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

These procedures and practices are implemented to prevent and control spills in a manner that minimizes or prevents the discharge of spilled material to the drainage system or watercourses.

Appropriate Application

This best management practice (BMP) applies to all construction projects. Spill control procedures are implemented anytime chemicals and/or hazardous substances are stored. Substances may include, but are not limited to:

- Soil stabilizers/binders.
- Dust Palliatives.
- Herbicides.
- Growth inhibitors.
- Fertilizers.
- Deicing/anti-icing chemicals.
- Fuels.
- Lubricants.
- Other petroleum distillates.

To the extent that the work can be accomplished safely, spills of oil, petroleum products, substances listed under 40 CFR parts 110, 117, and 302, and sanitary and septic wastes shall be contained and cleaned up immediately.

Spill Prevention and Control

Limitations

- This BMP only applies to spills caused by the contractor.
- Procedures and practices presented in this BMP are general. Contractor shall identify appropriate practices for the specific materials used or stored on-site.

Standards and Specifications

- To the extent that it doesn't compromise clean up activities, spills shall be covered and protected from storm water run-on during rainfall.
- Spills shall not be buried or washed with water.
- Used clean up materials, contaminated materials, and recovered spill material that is no longer suitable for the intended purpose shall be stored and disposed of in conformance with the special provisions.
- Water used for cleaning and decontamination shall not be allowed to enter storm drains or watercourses and shall be collected and disposed of in accordance with BMP WM-10, "Liquid Waste Management."
- Water overflow or minor water spillage shall be contained and shall not be allowed to discharge into drainage facilities or watercourses.
- Proper storage, clean-up and spill reporting instruction for hazardous materials stored or used on the project site shall be posted at all times in an open, conspicuous and accessible location.
- Waste storage areas shall be kept clean, well organized and equipped with ample clean-up supplies as appropriate for the materials being stored. Perimeter controls, containment structures, covers and liners shall be repaired or replaced as needed to maintain proper function.

Education

- Educate employees and subcontractors on what a "significant spill" is for each material they use, and what is the appropriate response for "significant" and "insignificant" spills.
- Educate employees and subcontractors on potential dangers to humans and the environment from spills and leaks.
- Hold regular meetings to discuss and reinforce appropriate disposal procedures (incorporate into regular safety meetings).
- Establish a continuing education program to indoctrinate new employees.
- The Contractor's Water Pollution Control Manager (WPCM) shall oversee and enforce proper spill prevention and control measures.

Cleanup and Storage Procedures

- Minor Spills
  - Minor spills typically involve small quantities of oil, gasoline, paint, etc., which can be controlled by the first responder at the discovery of the spill.
  - Use absorbent materials on small spills rather than hosing down or burying the spill.
  - Remove the absorbent materials promptly and dispose of properly.
  - The practice commonly followed for a minor spill is:
    - Contain the spread of the spill.
    - Recover spilled materials.
    - Clean the contaminated area and/or properly dispose of contaminated materials.
- Semi-Significant Spills
  - Semi-significant spills still can be controlled by the first responder along with the aid of other personnel such as laborers and the foreman, etc. This response may require the cessation of all other activities.
  - Clean up spills immediately:
    - Notify the project foreman immediately. The foreman shall notify the Resident Engineer (RE).
    - Contain spread of the spill.
    - If the spill occurs on paved or impermeable surfaces, clean up using "dry" methods (absorbent materials, cat litter and/or rags). Contain the spill by encircling with absorbent materials and do not let the spill spread widely.
    - If the spill occurs in dirt areas, immediately contain the spill by constructing an earthen dike. Dig up and properly dispose of contaminated soil.
    - If the spill occurs during rain, cover spill with tarps or other material to prevent contaminating runoff.

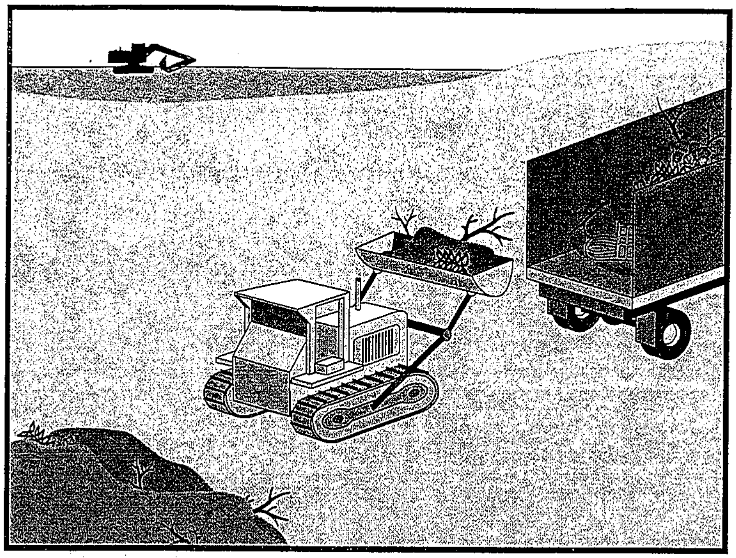
- Significant/Hazardous Spills
  - For significant or hazardous spills that cannot be controlled by personnel in the immediate vicinity, the following steps shall be taken:
    - Notify the RE immediately and follow up with a written report.
    - Notify the local emergency response by dialing 911. In addition to 911, the contractor will notify the proper county officials. It is the contractor's responsibility to have all emergency phone numbers at the construction site.
    - Notify the Governor's Office of Emergency Services Warning Center, (805) 852-7550.
    - For spills of federal reportable quantities, in conformance with the requirements in 40 CFR parts 110,119, and 302, the contractor shall notify the National Response Center at (800) 424-8802.
    - Notification shall first be made by telephone and followed up with a written report.
    - The services of a spills contractor or a Haz-Mat team shall be obtained immediately. Construction personnel shall not attempt to clean up the spill until the appropriate and qualified staff have arrived at the job site.
    - Other agencies which may need to be consulted include, but are not limited to, the Fire Department, the Public Works Department, the Coast Guard, the Highway Patrol, the City/County Police Department, Department of Toxic Substances, California Division of Oil and Gas, Cal/OSHA, RWQCB, etc.

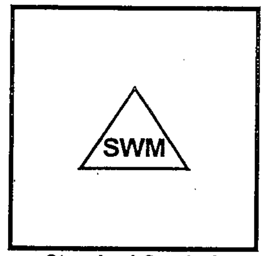
Maintenance and Inspection

- Verify weekly that spill control clean up materials are located near material storage, unloading, and use areas.
- Update spill prevention and control plans and stock appropriate clean-up materials whenever changes occur in the types of chemicals used or stored onsite.

Solid Waste Management

WM-5





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

Solid waste management procedures and practices are designed to minimize or eliminate the discharge of pollutants to the drainage system or to watercourses as a result of the creation, stockpiling, or removal of construction site wastes.

Appropriate Applications

Solid waste management procedures and practices are implemented on all construction projects that generate solid wastes.

Solid wastes include but are not limited to:

- Construction wastes including brick, mortar, timber, steel and metal scraps, sawdust, pipe and electrical cuttings, non-hazardous equipment parts, styrofoam and other materials used to transport and package construction materials.
- Highway planting wastes, including vegetative material, plant containers, and packaging materials.
- Litter, including food containers, beverage cans, coffee cups, paper bags, plastic wrappers, and smoking materials, including litter generated by the public.

Limitations

- Temporary stockpiling of certain construction wastes may not necessitate stringent drainage related controls during the non-rainy season or in desert areas with low rainfall.

Standards and Specifications

Education

- The Contractor's Water Pollution Control Manager (WPCM) shall oversee and enforce proper solid waste procedures and practices.
- Instruct employees and subcontractors on identification of solid waste and hazardous waste.
- Educate employees and subcontractors on solid waste storage and disposal procedures.
- Hold regular meetings to discuss and reinforce disposal procedures (incorporate into regular safety meetings).
- Require that employees and subcontractors follow solid waste handling and storage procedures.
- Prohibit littering by employees, subcontractors, and visitors.
- Wherever possible, minimize production of solid waste materials.

Collection, Storage, and Disposal

- Dumpsters of sufficient size and number shall be provided to contain the solid waste generated by the project and properly serviced.
- Littering on the project site shall be prohibited.
- To prevent clogging of the storm drainage system litter and debris removal from drainage grates, trash racks, and ditch lines shall be a priority.
- Trash receptacles shall be provided in the Contractor's yard, field trailer areas, and at locations where workers congregate for lunch and break periods.
- Construction debris and litter from work areas within the construction limits of the project site shall be collected and placed in watertight dumpsters at least weekly regardless of whether the litter was generated by the Contractor, the public, or others. Collected litter and debris shall not be placed in or next to drain inlets, storm water drainage systems or watercourses.
- Full dumpsters shall be removed from the project site and the contents shall be disposed of outside the highway right-of-way in conformance with the provisions in the Standard Specifications Section 7-1.13.
- Litter stored in collection areas and containers shall be handled and disposed of by trash hauling contractors.
- Construction debris and waste shall be removed from the site every two weeks or as directed by the RE.

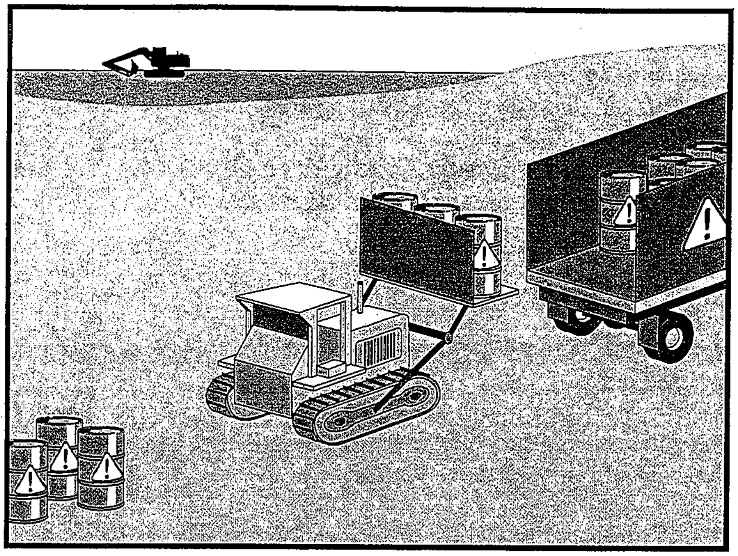
- Construction material visible to the public shall be stored or stacked in an orderly manner to the satisfaction of the RE.
- Storm water run-on shall be prevented from contacting stored solid waste through the use of berms, dikes, or other temporary diversion structures or through the use of measures to elevate waste from site surfaces.
- Solid waste storage areas shall be located at least 15 m (50 ft) from drainage facilities and watercourses and shall not be located in areas prone to flooding or ponding.
- Except during fair weather, construction and highway planting waste not stored in watertight dumpsters shall be securely covered from wind and rain by covering the waste with tarps or plastic sheeting or protected in conformance with the applicable Disturbed Soil Area protection section.
- Dumpster washout on the project site is not allowed.
- Notify trash hauling contractors that only watertight dumpsters are acceptable for use on-site.
- Plan for additional containers during the demolition phase of construction.
- Plan for more frequent pickup during the demolition phase of construction.
- Construction waste shall be stored in a designated area approved by the RE.
- Segregate potentially hazardous waste from non-hazardous construction site waste.
- Keep the site clean of litter debris.
- Make sure that toxic liquid wastes (e.g., used oils, solvents, and paints) and chemicals (e.g., acids, pesticides, additives, curing compounds) are not disposed of in dumpsters designated for construction debris.
- Dispose of non-hazardous waste in accordance with Standard Specification 7-1.13, Disposal of Material Outside the Highway Right of Way.
- For disposal of hazardous waste, see BMP WM-6, "Hazardous Waste Management." Have hazardous waste hauled to an appropriate disposal and/or recycling facility.
- Salvage or recycle useful vegetation debris, packaging and/or surplus building materials when practical. For example, trees and shrubs from land clearing can be converted into wood chips, then used as mulch on graded areas. Wood pallets, cardboard boxes, and construction scraps can also be recycled.

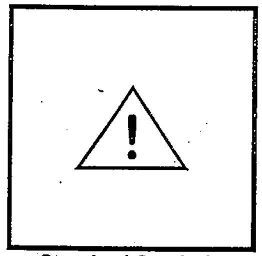
Maintenance and Inspection

- The WPCM shall monitor onsite solid waste storage and disposal procedures.
- Police site for litter and debris.

Hazardous Waste Management

WM-6





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

These are procedures and practices to minimize or eliminate the discharge of pollutants from construction site hazardous waste to the storm drain systems or to watercourses.

Appropriate Applications

- This best management practice (BMP) applies to all construction projects.
- Hazardous waste management practices are implemented on construction projects that generate waste from the use of:
  - Petroleum Products,
  - Asphalt Products,
  - Concrete Curing Compounds,
  - Pesticides,
  - Acids,
  - Paints,
  - Stains,
  - Solvents,
  - Wood Preservatives,
  - Roofing Tar, or
  - Any materials deemed a hazardous waste in California, Title 22 Division 4.5, or listed in 40 CFR Parts 110, 117, 261, or 302.

Limitations

- Nothing in this BMP relieves the Contractor from responsibility for compliance with federal, state, and local laws regarding storage, handling, transportation, and disposal of hazardous wastes.
- This BMP does not cover aerially deposited lead (ADL) soils. For ADL soils refer to BMP WM-7, "Contaminated Soil Management," and the project special provisions.

Standards and Specifications

Education

- Educate employees and subcontractors on hazardous waste storage and disposal procedures.
- Educate employees and subcontractors on potential dangers to humans and the environment from hazardous wastes.
- Instruct employees and subcontractors on safety procedures for common construction site hazardous wastes.
- Instruct employees and subcontractors in identification of hazardous and solid waste.
- Hold regular meetings to discuss and reinforce hazardous waste management procedures (incorporate into regular safety meetings).
- The Contractor's Water Pollution Control Manager (WPCM) shall oversee and enforce proper hazardous waste management procedures and practices.
- Make sure that hazardous waste is collected, removed, and disposed of only at authorized disposal areas.

Storage Procedures

- Wastes shall be stored in sealed containers constructed of a suitable material and shall be labeled as required by Title 22 CCR, Division 4.5 and 49 CFR Parts 172,173, 178, and 179.
- All hazardous waste shall be stored, transported, and disposed as required in Title 22 CCR, Division 4.5 and 49 CFR 261-263.
- Waste containers shall be stored in temporary containment facilities that shall comply with the following requirements:
  - Temporary containment facility shall provide for a spill containment volume able to contain precipitation from a 24-hour, 25 year storm event, plus the greater of 10% of the aggregate volume of all containers or 100% of the capacity of the largest tank within its boundary, whichever is greater.

- Temporary containment facility shall be impervious to the materials stored there for a minimum contact time of 72 hours.
- Temporary containment facilities shall be maintained free of accumulated rainwater and spills. In the event of spills or leaks accumulated rainwater and spills shall be placed into drums after each rainfall. These liquids shall be handled as a hazardous waste unless testing determines them to be non-hazardous. Non-hazardous liquids shall be sent to an approved disposal site.
- Sufficient separation shall be provided between stored containers to allow for spill cleanup and emergency response access.
- Incompatible materials, such as chlorine and ammonia, shall not be stored in the same temporary containment facility.
- Throughout the rainy season, temporary containment facilities shall be covered during non-working days, and prior to rain events. Covered facilities may include use of plastic tarps for small facilities or constructed roofs with overhangs. A storage facility having a solid cover and sides is preferred to a temporary tarp. Storage facilities shall be equipped with adequate ventilation.

■ Drums shall not be overfilled and wastes shall not be mixed.

■ Unless watertight, containers of dry waste shall be stored on pallets.

■ Paint brushes and equipment for water and oil based paints shall be cleaned within a contained area and shall not be allowed to contaminate site soils, watercourses or drainage systems. Waste paints, thinners, solvents, residues, and sludges that cannot be recycled or reused shall be disposed of as hazardous waste. When thoroughly dry, latex paint and paint cans, used brushes, rags, absorbent materials, and drop cloths shall be disposed of as solid waste.

■ Ensure that adequate hazardous waste storage volume is available.

■ Ensure that hazardous waste collection containers are conveniently located.

■ Designate hazardous waste storage areas on site away from storm drains or watercourses and away from moving vehicles and equipment to prevent accidental spills.

■ Minimize production or generation of hazardous materials and hazardous waste on the job site.

■ Use containment berms in fueling and maintenance areas and where the potential for spills is high.

- Segregate potentially hazardous waste from non-hazardous construction site debris.
- Keep liquid or semi-liquid hazardous waste in appropriate containers (closed drums or similar) and under cover.
- Clearly label all hazardous waste containers with the waste being stored and the date of accumulation.
- Place hazardous waste containers in secondary containment.
- Do not allow potentially hazardous waste materials to accumulate on the ground.
- Do not mix wastes.

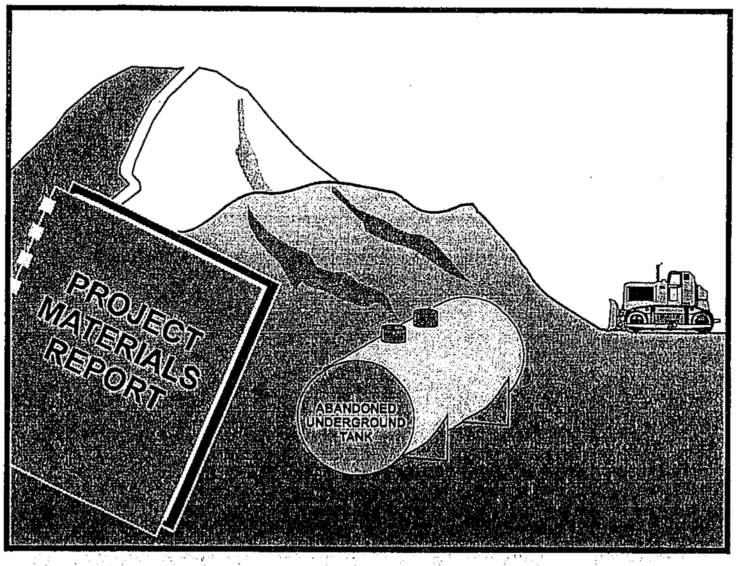
Disposal Procedures

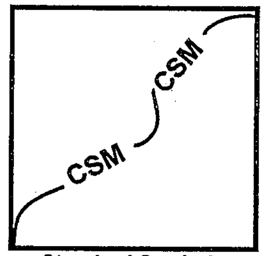
- Waste shall be disposed of outside the highway right-of-way within 90 days of being generated, or as directed by the Resident Engineer (RE). In no case shall hazardous waste storage exceed requirements in Title 22 CCR, Section 66262.34.
- Waste shall be disposed of by a licensed hazardous waste transporter at an authorized and licensed disposal facility or recycling facility utilizing properly completed Uniform Hazardous Waste Manifest forms.
- A Department of Health Services (DHS) certified laboratory shall sample waste and classify it to determine the appropriate disposal facility.
- Make sure that toxic liquid wastes (e.g., used oils, solvents, and paints) and chemicals (e.g., acids, pesticides, additives, curing compounds) are not disposed of in dumpsters designated for solid waste construction debris.
- Properly dispose of rainwater in secondary containment that may have mixed with hazardous waste.
- Recycle any useful material such as used oil or water-based paint when practical.
- Attention is directed to "Hazardous Material", "Contaminated Material", and "Aerially Deposited Lead" of the contract documents regarding the handling and disposal of hazardous materials.

Maintenance and Inspection

- A foreman and/or construction supervisor shall monitor on-site hazardous waste storage and disposal procedures.
- Waste storage areas shall be kept clean, well organized, and equipped with ample clean-up supplies as appropriate for the materials being stored.
- Storage areas shall be inspected in conformance with the provisions in the contract documents.
- Perimeter controls, containment structures, covers, and liners shall be repaired or replaced as needed to maintain proper function.
- Hazardous spills shall be cleaned up and reported in conformance with the applicable Material Safety Data Sheet (MSDS) and the instructions posted at the project site.
- The National Response Center, at (800) 424-8802, shall be notified of spills of Federal reportable quantities in conformance with the requirements in 40 CFR parts 110, 117, and 302.
- Copy of the hazardous waste manifests shall be provided to the RE.

Contaminated Soil Management **WM-7**





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

These are procedures and practices to minimize or eliminate the discharges of pollutants to the drainage system or to watercourses from contaminated soil.

Appropriate Applications

- Contaminated soil management is implemented on construction projects in highly urbanized or industrial areas where soil contamination may have occurred due to spills, illicit discharges, and leaks from underground storage tanks.
- It may also apply to highway widening projects in older areas where median and shoulder soils may have been contaminated by aerially deposited lead (ADL).

Limitations

- The procedures and practices presented in this best management practice (BMP) are general. The contractor shall identify appropriate practices and procedures for the specific contaminants known to exist or discovered on site.

Standards and Specifications

Identifying Contaminated Areas

- Contaminated soils are often identified during project planning and development with known locations identified in the plans and specifications. The contractor shall review applicable reports and investigate appropriate call-outs in the plans and specifications.
- The contractor may further identify contaminated soils by investigating:
  - Past site uses and activities.
  - Detected or undetected spills and leaks.
  - Acid or alkaline solutions from exposed soil or rock formations high in acid or alkaline forming elements.

– Look for contaminated soil as evidenced by discoloration, odors, differences in soil properties, abandoned underground tanks or pipes, or buried debris. Test suspected soils at a certified laboratory.

Education

- Prior to performing any excavation work at the locations containing material classified as hazardous, employees and subcontractors shall complete a safety training program which meets 29 CFR 1910.120 and 8 CCR 5192 covering the potential hazards as identified.
- Educate employees and subcontractors in identification of contaminated soil and on contaminated soil handling and disposal procedures.
- Hold regular meetings to discuss and reinforce disposal procedures (incorporate into regular safety meetings).

Handling Procedures for Material with Aerially Deposited Lead (ADL)

- Materials from areas designated as containing (ADL) may, if allowed by the contract special provisions, be excavated, transported, and used in the construction of embankments and/or backfill.
- Excavation, transportation, and placement operations shall result in no visible dust.
- Use caution to prevent spillage of lead containing material during transport.
- Monitor the air quality during excavation of soils contaminated with lead.

Handling Procedures for Contaminated Soils

- To minimize on-site storage, contaminated soil shall be disposed of properly in accordance with all applicable regulations. All hazardous waste storage will comply with the requirements in Title 22, CCR, Sections 6626.250 to 66265.260.
- Test suspected soils at a DHS approved certified laboratory.
- If the soil is contaminated, work with the local regulatory agencies to develop options for treatment and/or disposal.
- Avoid temporary stockpiling of contaminated soils or hazardous material.
- If temporary stockpiling is necessary:

  (1) Cover the stockpile with plastic sheeting or tarps.

  (2) Install a berm around the stockpile to prevent runoff from leaving the area.

  (3) Do not stockpile in or near storm drains or watercourses.

- Contaminated material and hazardous material on exteriors of transport vehicles shall be removed and placed either into the current transport vehicle or the excavation prior to the vehicle leaving the exclusion zone.
- Monitor the air quality continuously during excavation operations at all locations containing hazardous material.
- Procure all permits and licenses, pay all charges and fees, and give all notices necessary and incident to the due and lawful prosecution of the work, including registration for transporting vehicles carrying the contaminated material and the hazardous material.
- Collect water from decontamination procedures and treat and/or dispose of it at an appropriate disposal site.
- Collect non-reusable protective equipment, once used by any personnel, and dispose of at an appropriate disposal site.
- Install temporary security fence to surround and secure the exclusion zone. Remove fencing when no longer needed.
- Excavation, transport, and disposal of contaminated material and hazardous material shall be in accordance with the rules and regulations of the following agencies (the specifications of these agencies supersede the procedures outlined in this BMP):
  - United States Department of Transportation (USDOT).
  - United States Environmental Protection Agency (USEPA).
  - California Environmental Protection Agency (CAL-EPA).
  - California Division of Occupation Safety and Health Administration (CAL-OSHA).
  - Local regulatory agencies.

Procedures for Underground Storage Tank Removals

- Prior to commencing tank removal operations, obtain the required underground storage tank removal permits and approval from the federal, state, and local agencies, which have jurisdiction over such work.
- Arrange to have tested, as directed by the Resident Engineer (RE), any liquid or sludge found in the underground tank prior to its removal to determine if it contains hazardous substances.
- Following the tank removal, take soil samples beneath the excavated tank and perform analysis as required by the local agency representative(s).

- The underground storage tank, any liquid and/or sludge found within the tank, and all contaminated substances and hazardous substances removed during the tank removal shall be transported to disposal facilities permitted to accept such waste.

Water Control

- Take all necessary precautions and preventive measures to prevent the flow of water, including ground water, from mixing with hazardous substances or underground storage tank excavations. Such preventative measures may consist of, but are not limited to: berms, cofferdams, grout curtains, freeze walls, and seal course concrete or any combination thereof.

- If water does enter an excavation and becomes contaminated, such water, when necessary to proceed with the work, shall be dewatered consistent with BMP NS-2, "Dewatering Operations."

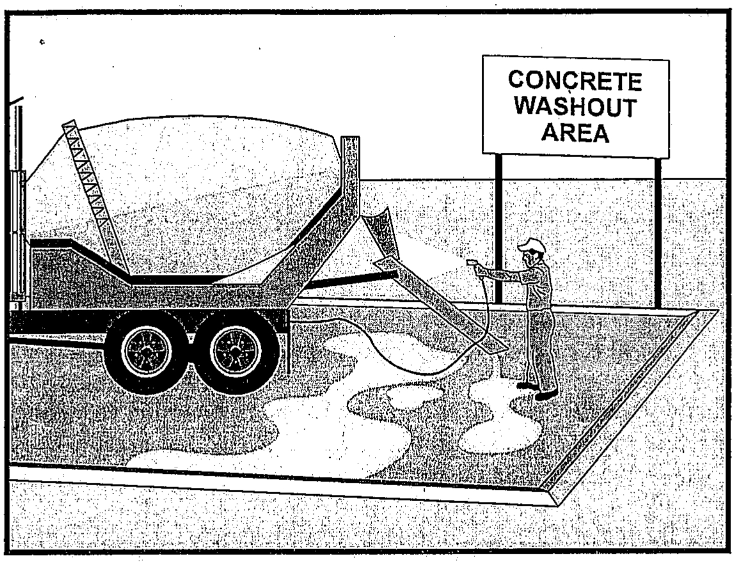
Maintenance and Inspection

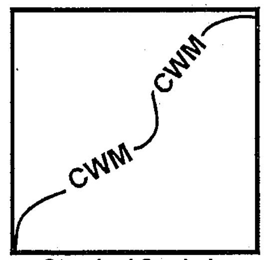
- The Contractor's Water Pollution Control Manager, foreman, and/or construction supervisor shall monitor on-site contaminated soil storage and disposal procedures.

- Monitor air quality continuously during excavation operations at all locations containing hazardous material.

- Coordinate contaminated soils and hazardous substances/waste management with the appropriate federal, state, and local agencies.

- Inspect hazardous waste receptacles and areas regularly.





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

These are procedures and practices that are designed to minimize or eliminate the discharge of concrete waste materials to the storm drain systems or watercourses.

Appropriate Applications

- Concrete waste management procedures and practices are implemented on construction projects where concrete is used as a construction material or where concrete dust and debris result from demolition activities.
- Where slurries containing portland cement concrete (PCC) or asphalt concrete (AC) are generated, such as from sawcutting, coring, grinding, grooving, and hydro-concrete demolition.
- Where concrete trucks and other concrete-coated equipment are washed on site, when approved by the Resident Engineer (RE). See also NS-8, "Vehicle and Equipment Cleaning."
- Where mortar-mixing stations exist.

Limitations

- None identified.

Standards and Specifications

Education

- Educate employees, subcontractors, and suppliers on the concrete waste management techniques described herein.
- The Contractor's Water Pollution Control Manager (WPCM) shall oversee and enforce concrete waste management procedures.

Concrete Demolition Wastes

- Stockpile concrete demolition wastes in accordance with BMP WM-3, "Stockpile Management."
- Disposal of hardened PCC and AC waste shall be in conformance with

Standard Specifications Section 7-1.13 or 15-3.02.

Concrete Slurry Waste Management and Disposal

- PCC and AC waste shall not be allowed to enter storm drainage systems or watercourses.

- A sign shall be installed adjacent to each temporary concrete washout facility to inform concrete equipment operators to utilize the proper facilities as shown on Page 7.

- A foreman and/or construction supervisor shall monitor onsite concrete working tasks, such as saw cutting, coring, grinding and grooving to ensure proper methods are implemented.

- Residue from saw cutting, coring and grinding operations shall be picked up by means of a vacuum device. Residue shall not be allowed to flow across the pavement and shall not be left on the surface of the pavement. See also BMP NS-3, "Paving and Grinding Operations."

- Vacuumed slurry residue shall be disposed in accordance with BMP WM-5, "Solid Waste Management" and Standard Specifications Section 7-1.13. Slurry residue shall be temporarily stored in a facility as described in "Onsite Temporary Concrete Washout Facility, Concrete Transit Truck Washout Procedures" below), or within an impermeable containment vessel or bin approved by the Engineer.

- Collect and dispose of all residues from grooving and grinding operations in accordance with Standard Specifications Section 7-1.13, 42-1.02 and 42-2.02.

Onsite Temporary Concrete Washout Facility, Concrete Transit Truck Washout Procedures

- Temporary concrete washout facilities shall be located a minimum of 15 m (50 ft) from storm drain inlets, open drainage facilities, and watercourses, unless determined infeasible by the RE. Each facility shall be located away from construction traffic or access areas to prevent disturbance or tracking.

- A sign shall be installed adjacent to each washout facility to inform concrete equipment operators to utilize the proper facilities. The sign shall be installed as shown on the plans and in conformance with the provisions in Standard Specifications Section 56-2, Roadside Signs.

- Temporary concrete washout facilities shall be constructed above grade or below grade at the option of the Contractor. Temporary concrete washout facilities shall be constructed and maintained in sufficient quantity and size to contain all liquid and concrete waste generated by washout operations.

- Temporary washout facilities shall have a temporary pit or bermed areas of sufficient volume to completely contain all liquid and waste concrete materials generated during washout procedures.

- Perform washout of concrete mixers, delivery trucks, and other delivery systems in designated areas only.
- Wash concrete only from mixer chutes into approved concrete washout facility. Washout may be collected in an impermeable bag or other impermeable containment devices for disposal.
- Pump excess concrete in concrete pump bin back into concrete mixer truck.
- Concrete washout from concrete pumper bins can be washed into concrete pumper trucks and discharged into designated washout area or properly disposed offsite.
- Once concrete wastes are washed into the designated area and allowed to harden, the concrete shall be broken up, removed, and disposed of in conformance with the provisions in Standard Specifications Section 7-1.13 or 15-3.02.

Temporary Concrete Washout Facility Type "Above Grade"

- Temporary concrete washout facility Type "Above Grade" shall be constructed as shown on Page 6 or 7, with a recommended minimum length and minimum width of 3 m (10 ft), but with sufficient quantity and volume to contain all liquid and concrete waste generated by washout operations. The length and width of a facility may be increased, at the Contractor's expense, upon approval from the RE.
- Straw bales, wood stakes, and sandbag materials shall conform to the provisions in BMP SC-9, "Straw Bale Barrier."
- Plastic lining material shall be a minimum of 10-mil polyethylene sheeting and shall be free of holes, tears or other defects that compromise the impermeability of the material. Liner seams shall be installed in accordance with manufacturers' recommendations.
- Portable delineators shall conform to the provisions in Standard Specifications Section 12-3.04, "Portable Delineators." The delineator bases shall be cemented to the pavement in the same manner as provided for cementing pavement markers to pavement in Standard Specifications Section 85-1.06, "Placement." Portable delineators shall be applied only to a clean, dry surface.

Temporary Concrete Washout Facility (Type Below Grade)

- Temporary concrete washout facility Type "Below Grade" shall be constructed as shown on page 6, with a recommended minimum length and minimum width of 3m (10 ft). The quantity and volume shall be sufficient to contain all liquid and concrete waste generated by washout operations. The length and width of a facility may be increased, at the Contractor's expense, upon approval of the RE. Lath and flagging shall be commercial type.

- Plastic lining material shall be a minimum of 10-mil polyethylene sheeting and shall be free of holes, tears or other defects that compromise the impermeability of the material. Liner seams shall be installed in accordance with manufacturers' recommendations.
- The soil base shall be prepared free of rocks or other debris that may cause tears or holes in the plastic lining material.

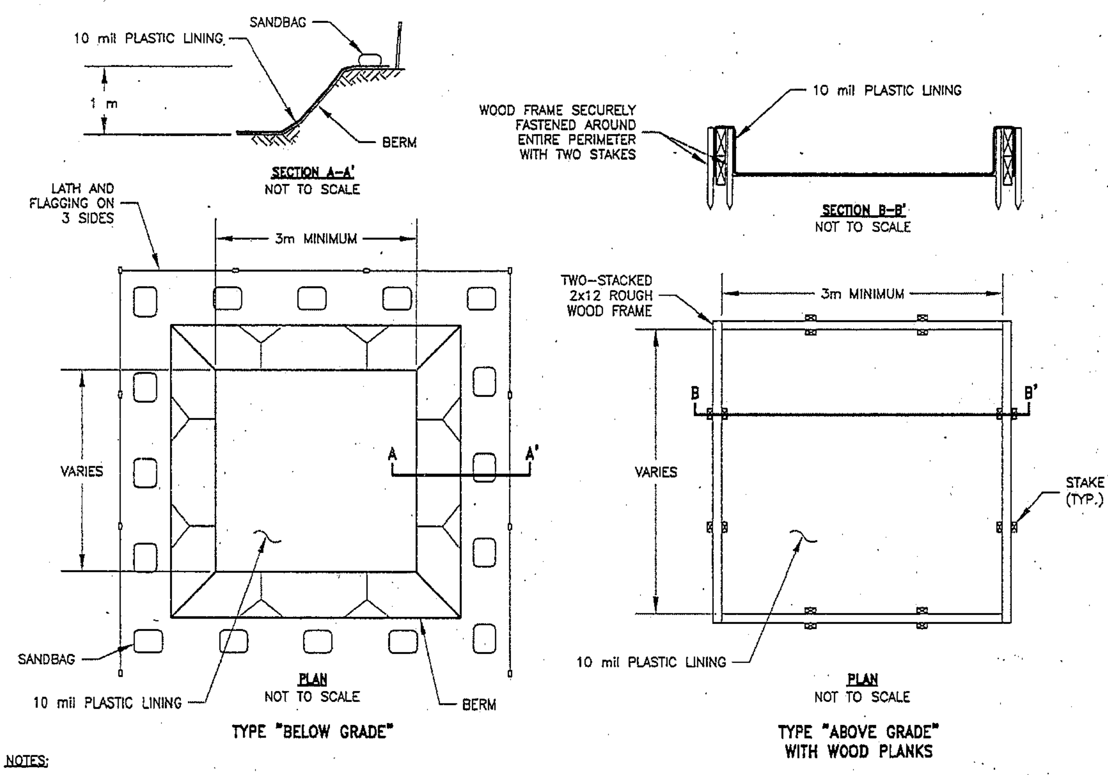
Removal of Temporary Concrete Washout Facilities

- When temporary concrete washout facilities are no longer required for the work, as determined by the RE, the hardened concrete shall be removed and disposed of in conformance with the provisions in Standard Specifications Section 7-1.13 or 15-3.02. Disposal of PCC dried residues, slurries or liquid waste shall be disposed of outside the highway right-of-way in conformance with provisions of Standard Specifications Section 7-1-13. Materials used to construct temporary concrete washout facilities shall become the property of the Contractor, shall be removed from the site of the work, and shall be disposed of outside the highway right-of-way in conformance with the provisions of the Standard Specifications, Section 7-1.13.
- Holes, depressions or other ground disturbance caused by the removal of the temporary concrete washout facilities shall be backfilled and repaired in conformance with the provisions in Standard Specifications Section 15-1.02, "Preservation of Property."

Maintenance and Inspection

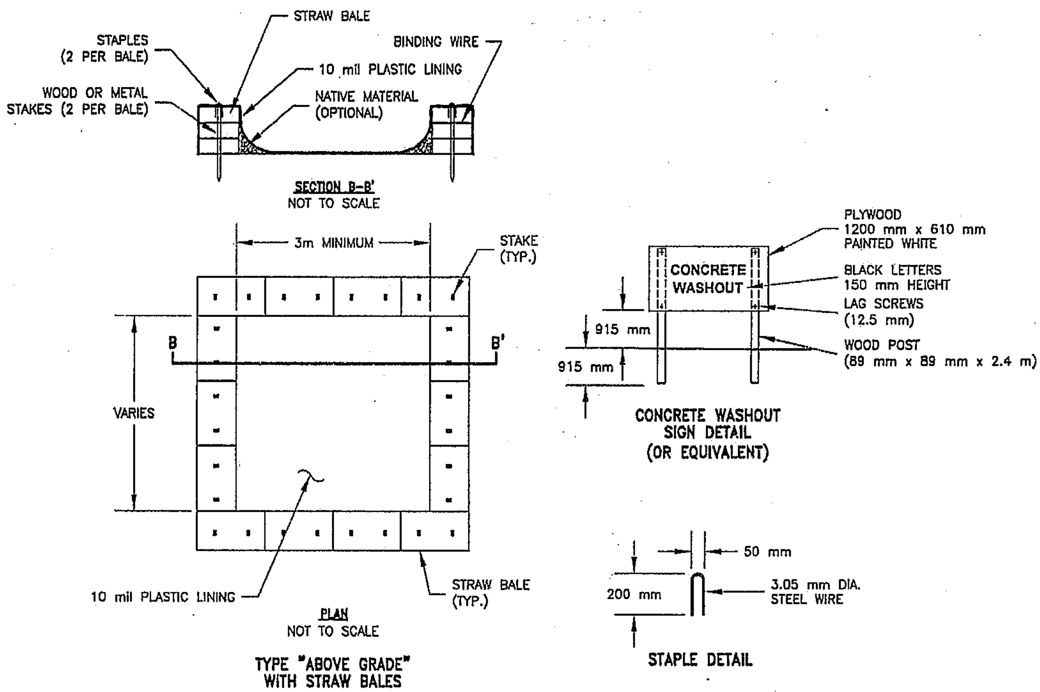
- The Contractor's Water Pollution Control Manager (WPCM) shall monitor on site concrete waste storage and disposal procedures at least weekly or as directed by the RE.
- The WPCM shall monitor concrete working tasks, such as saw cutting, coring, grinding and grooving daily to ensure proper methods are employed or as directed by the RE.
- Temporary concrete washout facilities shall be maintained to provide adequate holding capacity with a minimum freeboard of 100 mm (4 inches) for above grade facilities and 300 mm (12 inches) for below grade facilities. Maintaining temporary concrete washout facilities shall include removing and disposing of hardened concrete and returning the facilities to a functional condition. Hardened concrete materials shall be removed and disposed of in conformance with the provisions in Standard Specifications Section 7-1.13 or 15-3.02.
- Existing facilities must be cleaned, or new facilities must be constructed and ready for use once the washout is 75% full.
- Temporary concrete washout facilities shall be inspected for damage (i.e.

tears in polyethylene liner, missing sandbags, etc.). Damaged facilities shall be repaired.



NOTES:

1. ACTUAL LAYOUT DETERMINED IN THE FIELD.
2. THE CONCRETE WASHOUT SIGN (SEE PAGE 6) SHALL BE INSTALLED WITHIN 10 m OF THE TEMPORARY CONCRETE WASHOUT FACILITY.

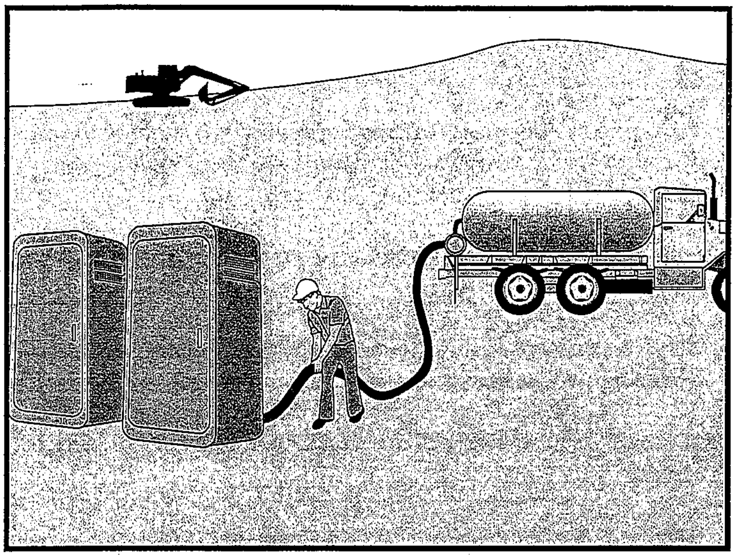


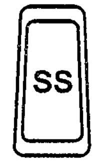
NOTES:

1. ACTUAL LAYOUT DETERMINED IN THE FIELD.
2. THE CONCRETE WASHOUT SIGN (SEE FIG. 4-15) SHALL BE INSTALLED WITHIN 10 m OF THE TEMPORARY CONCRETE WASHOUT FACILITIY.

CALTRANS/FIG4-14.DWG SAC 8-14-02

Sanitary/Septic Waste Management **WM-9**





Standard Symbol

BMP Objectives
- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose Procedures and practices to minimize or eliminate the discharge of construction site sanitary/septic waste materials to the storm drain system or to watercourses.

Appropriate Applications Sanitary/septic waste management practices are implemented on all construction sites that use temporary or portable sanitary/septic waste systems.

Limitations

- None identified.

Standards and Specifications

Education

- Educate employees, subcontractors, and suppliers on sanitary/septic waste storage and disposal procedures.
- Educate employees, subcontractors, and suppliers of potential dangers to humans and the environment from sanitary/septic wastes.
- Instruct employees, subcontractors, and suppliers in identification of sanitary/septic waste.
- Hold regular meetings to discuss and reinforce disposal procedures (incorporate into regular safety meetings).
- Establish a continuing education program to indoctrinate new employees.

Storage and Disposal Procedures

- Temporary sanitary facilities shall be located away from drainage facilities, watercourses, and from traffic circulation. When subjected to high winds or risk.

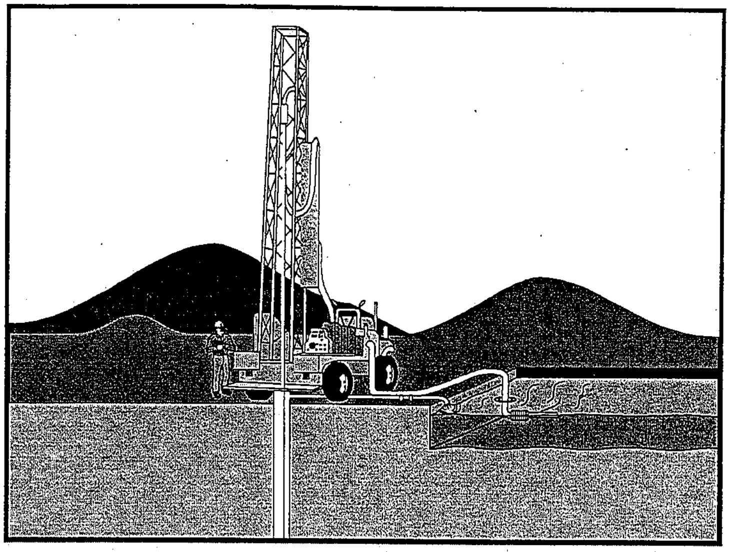
- Wastewater shall not be discharged or buried within the highway right-of-way.
- Sanitary and septic systems that discharge directly into sanitary sewer systems, where permissible, shall comply with the local health agency, city, county, and sewer district requirements.
- If using an on site disposal system, such as a septic system, comply with local health agency requirements.
- Properly connect temporary sanitary facilities that discharge to the sanitary sewer system to avoid illicit discharges.
- Ensure that sanitary/septic facilities are maintained in good working order by a licensed service.
- Use only reputable, licensed sanitary/septic waste haulers.

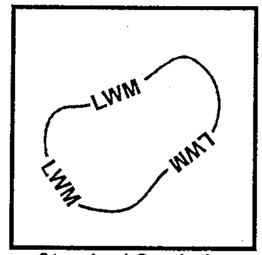
Maintenance and Inspection

- The Contractor's Water Pollution Control Manager (WPCM) shall monitor onsite sanitary/septic waste storage and disposal procedures at least weekly.

Liquid Waste Management

WM-10





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

Procedures and practices to prevent discharge of pollutants to the storm drain system or to watercourses as a result of the creation, collection, and disposal of non-hazardous liquid wastes.

Appropriate Applications

Liquid waste management is applicable to construction projects that generate any of the following non-hazardous byproducts, residuals, or wastes:

- Drilling slurries and drilling fluids.
- Grease-free and oil-free wastewater and rinse water.
- Dredgings.
- Other non-storm water liquid discharges not permitted by separate permits.

Limitations

- Disposal of some liquid wastes may be subject to specific laws and regulations, or to requirements of other permits secured for the construction project (e.g., National Pollutant Discharge Elimination System [NPDES] permits, Army Corps permits, Coastal Commission permits, etc.).
- Does not apply to dewatering operations (see BMP NS-2, "Dewatering Operations"), solid waste management (see BMP WM-5, "Solid Waste Management"), hazardous wastes (see BMP WM-6, "Hazardous Waste Management"), or concrete slurry residue (see BMP WM-8, "Concrete Waste Management").
- Does not apply to non-stormwater discharges permitted by any NPDES permit held by the pertinent Caltrans District, unless the discharge is determined by Caltrans to be a source of pollutants. Typical permitted non-stormwater discharges can include: water line flushing; landscape irrigation; diverted stream flows; rising ground waters; uncontaminated pumped ground

water; discharges from potable water sources; foundation drains; irrigation water; springs; water from crawl space pumps; footing drains; lawn watering; flows from riparian habitats and wetlands; and, discharges or flows from emergency fire fighting activities.

Standards and Specifications

General Practices

- The Contractor's Water Pollution Control Manager (WPCM) shall oversee and enforce proper liquid waste management procedures and practices.
- Instruct employees and subcontractors how to safely differentiate between non-hazardous liquid waste and potential or known hazardous liquid waste.
- Instruct employees, subcontractors, and suppliers that it is unacceptable for any liquid waste to enter any storm drainage structure, waterway, or receiving water.
- Educate employees and subcontractors on liquid waste generating activities, and liquid waste storage and disposal procedures.
- Hold regular meetings to discuss and reinforce disposal procedures (incorporate into regular safety meetings).
- Verify which non-stormwater discharges are permitted by the Caltrans Statewide NPDES permit; different regions might have different requirements not outlined in this permit. Some listed discharges may be prohibited if Caltrans determines the discharge to be a source of pollutants.
- Apply the NS-8, "Vehicle and Equipment Cleaning" BMP for managing wash water and rinse water from vehicle and equipment cleaning operations.

Containing Liquid Wastes

- Drilling residue and drilling fluids shall not be allowed to enter storm drains and watercourses and shall be disposed of outside the highway right-of-way in conformance with the provisions in Standard Specifications Section 7-1.13.
- If an appropriate location is available, as determined by the Resident Engineer (RE), drilling residue and drilling fluids that are exempt under California Code of Regulations (CCR) Title 23 §2511(g) may be dried by infiltration and evaporation in a containment facility constructed in conformance with the provisions concerning the Temporary Concrete Washout Facilities detailed in BMP WM-08, "Concrete Waste Management."
- Liquid wastes generated as part of an operational procedure, such as water-laden dredged material and drilling mud, shall be contained and not allowed to flow into drainage channels or receiving waters prior to treatment.

- Contain liquid wastes in a controlled area, such as a holding pit, sediment basin, roll-off bin, or portable tank.
- Containment devices must be structurally sound and leak free.
- Containment devices must be of sufficient quantity or volume to completely contain the liquid wastes generated.
- Take precautions to avoid spills or accidental releases of contained liquid wastes. Apply the education measures and spill response procedures outlined in BMP WM-4, "Spill Prevention and Control."
- Do not locate containment areas or devices where accidental release of the contained liquid can threaten health or safety, or discharge to water bodies, channels, or storm drains.

Capturing Liquid Wastes

- Capture all liquid wastes running off a surface, which has the potential to affect the storm drainage system, such as wash water and rinse water from cleaning walls or pavement.
- Do not allow liquid wastes to flow or discharge uncontrolled. Use temporary dikes or berms to intercept flows and direct them to a containment area or device for capture.
- If the liquid waste is sediment laden, use a sediment trap (see BMP SC-3, "Sediment Trap") for capturing and treating the liquid waste stream, or capture in a containment device and allow sediment to settle.

Disposing of Liquid Wastes

- Typical method is to dewater the contained liquid waste, using procedures such as described in BMP NS-2, "Dewatering Operations", and BMP SC-2, "Sediment/Desilting Basin"; and dispose of resulting solids per BMP WM-5, "Solid Waste Management", or per Standard Specifications Section 7-1.13, "Disposal of Material Outside the Highway Right of Way", for off-site disposal.
- Method of disposal for some liquid wastes may be prescribed in Water Quality Reports, NPDES permits, Environmental Impact Reports, 401 Water Quality Certifications or 404 permits, local agency discharge permits, etc., and may be defined elsewhere in the special provisions.
- Liquid wastes, such as from dredged material, may require testing and certification whether it is hazardous or not before a disposal method can be determined.

- For disposal of hazardous waste, see BMP WM-6, "Hazardous Waste Management."
- If necessary, further treat liquid wastes prior to disposal. Treatment may include, though is not limited to, sedimentation, filtration, and chemical neutralization.

Maintenance and Inspection

- Spot check employees and subcontractors at least monthly throughout the job to ensure appropriate practices are being employed.
- Remove deposited solids in containment areas and capturing devices as needed, and at the completion of the task. Dispose of any solids as described in BMP WM-5, "Solid Waste Management."
- Inspect containment areas and capturing devices frequently for damage, and repair as needed.

Appendix A
Abbreviations, Acronyms, and Definition of Terms

Abbreviations

ac	acre
°C	Degrees Celsius
cfs	cubic feet per second
cy	cubic yards
°F	Degrees Fahrenheit
ft	feet
g	gram
gal	gallon
gpm	gallons per minute
ha	hectares
hr	hour
in	inches
kg	kilogram
kN	Kilo-Newton
kPa	Kilo-Pascal
l	liter
lbs	pound
lf	linear feet
m	meter
m^2	square meters
m^3	cubic meters
mm	millimeter
N	Newton
psi	pounds per square inch
s	second
yd	yard
y^2	square yards
y^3	cubic yards

Acronyms

AC	Asphalt Concrete
ABS	Acrylonitrile Butadiene Styrene
ADL	Aerially Deposited Lead
AQMD	Air Quality Management District
ASTM	American Society of Testing Materials
BAT	Best Available Technology
BCT	Best Conventional Technology
BMP	Best Management Practice
CAL-EPA	California Environmental Protection Agency
CAL-OSHA	California Occupation Safety and Health Association
CMP	Corrugated Metal Pipe
CFR	Code of Federal Regulations
DSA	Disturbed Soil Area
ESA	Environmentally Sensitive Area
FEMA	Federal Emergency Management Agency
L:W	Length versus Width
MSDS	Material Safety Data Sheet
OSHA	Occupation Safety and Health Association
PCC	Portland Cement Concrete
PVC	Polyvinyl Chloride
RE	Resident Engineer

RWQCB	California Regional Water Quality Control Board	USDA	United States Department of Agriculture
SSP	Standard Special Provisions	USDOT	United States Department of Transportation
SWMP	Storm Water Management Plan		
SWRCB	California State Water Resources Control Board	US EPA	United States Environmental Protection Agency
V:H	Vertical versus Horizontal	USLE	Universal Soil Loss Equation

Definition of Terms

Active Construction Area: Construction areas where soil-disturbing activities have already occurred and continue to occur or will occur during the ensuing 21 days. This may include areas where soils have been disturbed as well as areas where soil disturbance has not yet occurred.

Antecedent Moisture: Amount of moisture present in soil prior to the application of a soil stabilization product.

Best Management Practice (BMP): Any program, technology, process, siting criteria, operating method, measure, or device that controls, prevents, removes, or reduces pollution.

Construction Activity: Includes clearing, grading, or excavation and contractor activities that result in soil disturbance.

Construction Site: The area involved in a construction project as a whole.

Contamination: An impairment of the quality of the waters of the state by waste to a degree that creates a hazard to the public health through poisoning or through the spread of disease including any equivalent effect resulting from the disposal of waste, whether or not waters of the state are affected.

Contractor: Party responsible for carrying out the contract per plans and specifications. The Standard Specifications and Special Provisions contain storm water protection requirements the contractor must address.

Degradability: Method by which the chemical components of a soil stabilization product are degraded over time.

Desert Areas: Areas within the Colorado River Basin RWQCB and the North and South Lahontan RWQCB jurisdictions (excluding the Mono and Antelope areas, East and West Walker River, East and West Carson River, and the Truckee and Little Truckee River).

Discharge: Any release, spill, leak, pump, flow, escape, dumping, or disposal of any liquid, semi-solid or solid substance.

Disturbed Soil Areas (DSAs): Areas of exposed, erodible soil, including stockpiles, that are within the construction limits and that result from construction activities

Drying Time: Time it takes for a soil stabilization product to dry or cure for it to become erosion control effective.

Environmental Protection Agency (EPA): Agency that issued the regulations to control pollutants in storm water runoff discharges (The Clean Water Act and NPDES permit requirements).

Erosion: The wearing away of land surface primarily by wind or water. Erosion occurs naturally as a result of weather or runoff but can be intensified by clearing, grading, or excavation of the land surface.

Erosion Control Effectiveness: The ability of a particular product to reduce soil erosion relative to the amount of erosion measured for bare soil. Percentage of erosion that would be reduced as compared to an untreated or control condition.

Exempt Construction Activities: Activities exempt from the General Permit, including routine maintenance to maintain original line and grade, hydraulic capacity, or original purpose of the facility; and emergency construction activities required to protect public health and safety. Local permits may not exempt these activities.

Existing vegetation: Any vegetated area that has not already been cleared and grubbed.

Fair Weather Prediction: When there is no precipitation in the forecast between the current calendar day and the next working day. The National Weather Service NOAA Weather Radio forecast shall be used. The contractor may propose an alternative forecast for use if approved by the Resident Engineer.

Feasible: Economically achievable or cost-effective measures, which reflect a reasonable degree of pollutant reduction achievable through the application of available nonpoint pollution control practices, technologies, processes, site criteria, operating methods, or other alternatives.

General Permit: The General Permit for Storm Water Discharges Associated with Construction Activity (Order No. 99-08-DWQ, NPDES Permit CAS000002) issued by the State Water Resources Control Board.

Good Housekeeping: A common practice related to the storage, use, or cleanup of materials, performed in a manner that minimizes the discharge of pollutants.

Local permit: An NPDES storm water permit issued to a District by the RWQCB having jurisdiction over the job site. Requirements of the local permit are generally similar to, but supersede the requirements of the General Permit. The District Storm Water Coordinator should be consulted to identify and to incorporate variances between the local permit and General Permit.

Longevity: The time the soil erosion product maintains its erosion control effectiveness.

Mode of Application: Type of labor or equipment that is required to install the product or technique.

National Pollutant Discharge Elimination System (NPDES) Permit: A permit issued pursuant to the Clean Water Act that requires the discharge of pollutants to waters of the United States from storm water be controlled.

Native: Living or growing naturally in a particular region. Compatibility and competitiveness of selected plant materials with the environment.

Non-active Construction Area: Any area not considered to be an active construction area. Active construction areas become non-active construction areas whenever construction activities are expected to be discontinued for a period of 21 days or longer.

Non-Storm Water Discharge: Any discharge to a storm drain system or receiving water that is not composed entirely of storm water.

Permit: The Caltrans Statewide NPDES Permit (see Statewide Permit), General Construction Permit, or local permit, whichever is applicable to the construction project.

Pollution: The man-made or man-induced alteration of the chemical, physical, biological, and radiological integrity of water. An alteration of the quality of the water of the state by waste to a degree, which unreasonably affects either the waters for beneficial uses or facilities that serve these beneficial uses.

Rainy Season: The dates of the rainy season shall be as specified: use dates in the local permit if a local permit is applicable to the project site and rainy season dates are specified therein; or, if the local permit does not specify rainy season dates and/or in areas of the state not subject to a local permit, the rainy season dates shall be determined using Figure 2-1.

Receiving Waters: All surface water bodies within the permit area.

Regional Water Quality Control Board (RWQCB): California agencies that implement and enforce Clean Water Act Section 402(p) NPDES permit requirements, and are issuers and administrators of these permits as delegated by EPA. There are nine regional boards working with the State Water Resources Control Board.

Resident Engineer (RE): The Caltrans representative charged with administration of construction contracts. The RE decides questions regarding acceptability of material furnished and work performed. The RE has "contractual authority" to direct the contractor and impose sanctions if the contractor fails to take prompt and appropriate action to correct deficiencies. The following contractual sanctions can be imposed by the RE: (a) withholding payments (or portions of payments), (b) suspending work, (c) bringing in a separate contractor to complete work items (the contractor is billed for such costs), (d) assessing liquidated damages including passing along fines for permit violations, (e) initiating cancellation of the construction contract.

Residual Impact: The impact that a particular practice might have on construction activities once they are resumed on the area that was temporarily stabilized.

Runoff Effect: The effect that a particular soil stabilization product has on the production of storm water runoff. Runoff from an area protected by a particular product may be compared to the amount of runoff measured for bare soil.

Sediment: Organic or inorganic material that is carried by or suspended in water and that settles out to form deposits in the storm drain system or receiving waters.

Statewide Permit: The National Pollutant Discharge Elimination System (NPDES) Permit, Statewide Storm Water Permit and Waster Discharge Requirements (WDRs) for the State of California Department of Transportation (Caltrans). Order No. 99-06-DWQ, NPDES No. CAS000003.

State Water Resources Control Board (SWRCB): California agency that implements and enforces Clean Water Act Section 402(p) NPDES permit requirements, is issuer and administrator of these permits as delegated by EPA. Works with the nine Regional Water Quality Control Boards.

Storm Drain System: Streets, gutters, inlets, conduits, natural or artificial drains, channels and watercourses, or other facilities that are owned, operated, maintained and used for the purpose of collecting, storing, transporting, or disposing of storm water.

Storm Water: Rainfall runoff, snow melt runoff, and surface runoff and drainage. It excludes infiltration and runoff from agricultural land.

Storm Water Inspector: Caltrans staff member who provides support to the Resident Engineer. Coordinates activities and correspondence related to WPCP and SWPPP review and implementation.

Storm Water Pollution Prevention Plan (SWPPP): A plan required by the Permit that includes site map(s), an identification of construction/contractor activities that could cause pollutants in the storm water, and a description of measures or practices to control these pollutants. It must be prepared and approved before construction begins. A SWPPP prepared in accordance with the special provisions and the Handbooks will satisfy Standard Specifications Section 7-1.01G - Water Pollution, requirement for preparation of a program to control water pollution.

Temporary Construction Site BMPs: Construction Site BMPs that are required only temporarily to address a short-term storm water contamination threat. For example, silt fences are located near the base of newly graded slopes that have a substantial area of exposed soil. Then, during rainfall, the silt fences filter and collect sediment from runoff flowing off the slope.

Waste Discharge Identification Number (WDID): The unique project number issued by the SWRCB upon receipt of the notice of intent (NOI).

Water Pollution Control Program (WPCP): A program that must be prepared and implemented by the construction contractor under Standard Specifications Section 7-1.01G - Water Pollution.

Appendix B
Selection of Temporary Soil Stabilization Controls

There are many treatments available to provide soil stabilization. A group of criteria was developed to allow for comparison and differentiation among the product types that are available. These criteria include installed cost, erosion control effectiveness, drying time, and others. For some criteria, values have been assigned by characteristics: an example would be mode of application (e.g., hydraulic seeder, water truck, and hand labor). For other criteria, actual numeric values should be considered based on available data, such as drying time in hours. Refer to Table B-1 for a summary of selection criteria information and ratings for temporary soil stabilization BMPs.

B.1 Antecedent Moisture

This criterion relates to the effect of existing soil moisture on the effectiveness of a soil stabilization method. While antecedent soil moisture conditions can have an effect on the performance of some methods, (e.g., hydraulic soil stabilizers, temporary seeding) other methods, such as erosion control blankets or impervious covers, are not affected – except perhaps in their ease of installation.

Suppliers of manufactured soil stabilization products affected by antecedent soil moisture specify the conditions under which their products are to be applied. For example, some products clearly benefit from having the soil "pre-wetted" before application of the hydraulic soil stabilizer and as a result, some manufacturers recommend application of water by itself as a first step. Conversely, the binding action of some adhesives on soil particles (and thereby their erosion control effectiveness) can be affected by excessive soil moisture. Therefore, some manufacturers recommend that their products not be applied when the soil is visibly saturated or when standing water is present.

B.2 Availability

A critical aspect of product specification and use is whether or not a soil stabilization product is readily available. While local sources may be preferable, the seasonal nature of soil stabilization work can create localized shortages of materials. In these cases, usually the material that can be delivered to the job most quickly is the material that is selected for application.

B.3 Ease of Clean-Up

This criterion applies primarily to the hydraulically-applied soil stabilization materials, but there may be clean-up issues associated with some of the other categories as well (e.g., packaging materials, disposal of excess product, etc).

All of the approved hydraulic soil stabilization products are typically applied using water as a carrier, and to varying degrees, these products can be removed from application machinery and overspray areas with the application of clean water as well. However, cleaning must occur before the material sets or dries, otherwise stronger cleaning solutions of detergent, a strong alkali solution, or a petrochemical solvent must be used. A prudent contractor will take precautions when working with hydraulic products that have some clean-up limitations, and must follow the BMPs in the SWPPP or WPCP for cleaning of equipment on site.

Regardless of which approach is used for temporary soil stabilization, site clean-up can be problematic due to the following:

- Added time to dispose of waste materials
- Added time to clean hydraulic equipment before the material sets or dries
- Additional quantities of water needed for cleaning operations
- Impact of quick-setting materials on overspray areas such as sidewalks, roads, vehicles
- Contractor resistance to products that require excessive clean-up
- Additional operation and maintenance costs included in contractor's bid.

B.4 Installed Cost

The estimated installed cost (the cost of the material itself, plus the cost associated with its installation) has a value that corresponds to cost in dollars per hectares, which are used for estimating and bidding. This approach allows for the direct comparison of approaches.

B.5 Degradability

Degradability relates to the method by which the chemical components of a soil stabilization product are degraded over time. As might be expected, the way in which a product degrades is related to longevity, which is another selection criterion. Both degradability and longevity are sometimes key issues in temporary soil stabilization and long term erosion and sediment control planning.

Soil properties, climate, existing vegetation as well as slope aspect contribute to the degradation of soil stabilization materials. Knowing something about the physical and chemical properties of a product and how these characteristics might interact with site conditions is important when selecting a particular material.

B.6 Length of Drying Time

Not all materials require drying time, and the drying criterion may be used to differentiate categorical approaches as well as a final screen for the various types of materials within a class of approaches.

Determining when a soil stabilization material is dry or completely cured is a subjective exercise that relies a great deal on manufacturer-published information. In setting standards for this criteria, where drying or curing time is necessary for a particular method to become erosion control effective, manufacturers' recommendations have been followed.

B.7 Time to Effectiveness

Not all soil stabilization products are immediately effective in controlling erosion: some take time to dry (e.g., hydraulic soil stabilizers) and others take time to grow (e.g., temporary seeding).

However, when some treatments are applied (e.g., rolled erosion control products, plastic sheeting, and straw mulch) they are immediately effective.

B.8 Erosion Control Effectiveness

This criterion measures the ability of a particular product to reduce soil erosion relative to the amount of erosion measured for bare soil. Erosion control effectiveness is described as a percentage the erosion would be reduced as compared to an untreated or control condition.

B.9 Longevity

This criterion simply considers the time that a soil stabilization product maintains its erosion control effectiveness.

B.10 Mode of Application

The mode of application criterion refers to the type of labor or equipment that is required to install the product or technique.

B.11 Residual Impact

This criterion relates to the impact that a particular practice might have on construction activities once they are resumed on the area that was temporarily stabilized. Some examples include:

- Temporary vegetation covers or standard biodegradable mulches might create problems with achieving final slope stability or compaction due to their organic content, and therefore would require removal and disposal.
- Applications of straw or hay fibers might keep soil from drying out as quickly as it might if it was bare.
- Plastic sheeting, netting or materials used in a soil stabilization product might persist longer than needed on or in the soil.

B.12 Native

This criterion relates primarily to selection of plant materials and is important from the standpoint of environmental compatibility and competitiveness.

B.13 Runoff Effect

This criterion measures the effect that a particular soil stabilization product has on the production of storm water runoff. Similar to the erosion control effectiveness criterion, runoff from an area protected by a particular product may be compared to the amount of runoff measured for bare soil and is presented in the matrix as a percentage of the runoff that would occur in an untreated, or control condition.

Table B-1
Temporary Soil Stabilization Criteria Matrix

CLASS	TYPE	Antecedent Moisture	Availability	Ease of Clean-Up	Installed Cost Per Ha	EC Effectiveness (%)	Degradability	Length of Drying Time (hrs)	Time to Effectiveness (days)	Longevity	Mode of Application	Residual Impact	Native	Runoff Effect
Straw Mulch	Wheat Straw	D	S	H	$5,200	90-95	B	0	1	M	L/M	M		+
	Rice Straw	D	S	H	$5,200	90-95	B	0	1	M	L/M	M		+
Wood Fiber Mulch	Wood Fiber	D	S	H	$2,200	50-60	B	0-4	1	M	H	L		+
Recycled Paper Mulch	Cellulose Fiber	D	S	H	$2,100	50-60	B	0-4	1	S	H	L		+
Bonded Fiber Matrix	Biodegradable	D	S	H	$13,600	90-95	B	12-18	1	M	H	M		+
Biodegradable	Jute Mesh	D	S	H	$16,000	65-70	B		1	M	L	M		+
	Curled Wood Fiber	D	S	H	$26,000	85-90	P/B		1	M	L	M		+
	Straw	D	S	H	$22,000	85-90	P/B		1	M	L	M		+
	Wood Fiber	D	S	H	$22,000	85-90	P/B		1	M	L	M		+
	Coconut Fiber	D	S	H	$32,000	90-95	P/B		1	L	L	M		+
	Coconut Fiber Mesh	D	S	H	$77,000	85-90	B		1	L	L	M		+
	Straw Coconut Fiber	D	S	H	$27,000	90-95	P/B		1	L	L	M		+
Non-Biodegradable	Plastic Netting	D	M	H	$5,000	<50	P		1	L	L	H		+
	Plastic Mesh	D	M	H	$8,000	75-80	P		1	L	L	H		+
	Synthetic Fiber with Netting	D	M	H	$86,000	90-95	P		1	L	L	H		+
	Bonded Synthetic Fibers	D	M	H	$121,000	90-95	P		1	L	L	H		+
	Combination with Biodegradable	D	M	H	$79,000	85-90	P		1	L	L	H		+
High-Density	Ornamentals		S-M	H	$1000 - $4000	50-60			28	M-L	H	L-M	N/E	+
	Turf species		S	H	$900	50-60			28	L	H	M-H	N/E	+
	Bunch grasses		S-M	H	$750 - $3200	50-60			28	L	H	L-M	N	+
Fast-Growing	Annual		S	H	$900 - $1,600	50-60			28	L	H	L-H	N/E	+
	Perennial		S	H	$800 - $2000	50-60			28	L	H	M	N/E	+
Non-Competing	Native		S-M	H	$700 - $4000	50-60			28	L	H	L-M	N	+
	Non-Native		S-M	H	$1000 - $1200	50-60			28	L	H	L-H	E	+
Sterile	Cereal Grain		S	H	$1,200	50-60			28	L	H	L	E	+
Plastic	Rolled Plastic Sheeting		S		$17,000	100	P		1	M	L	H		-
	Geotextile (Woven)		S		$14,800	90-95	P		1	M	L	H		-
(PBS) Plant Material Based- Short Lived	Guar	D	S	H	$1,000	80-85	B	12-18	Same as Length of Drying Time.	S	B	L		0/+
	Psyllium	P	S	H	$1,000	25-35	B	12-18		M	B	L		0
	Starches	D	S	H	$1,000	25-30	B	9-12		S	H	L		0
(PBL) Plant Material Based- Long Lived	Pitch/ Rosin Emulsion	D	S	M	$3,000	60-75	B	19-24		M	B	M		-
(PEB) Polymeric Emulsion Blends	Acrylic polymers and copolymers	D	S	M	$3,000	35-70	P/C	19-24		L	B	M		+/-
	Methacrylates and acrylates	D	M	M	$1,000	35-40	P/C	12-18		S	W	L		0/+
	Sodium acrylates and acrylamides	D	M	M	$1,000	20-70	P/C	12-18		S	H	L		+/-
	Polyacrylamide	D	M	M	$1,000	55-65	P/C	4-8		M	H	L		0/+
	Hydro-colloid polymers	D	M	H	$1,000	25-40	P/C	0-4		M	H	L		0/+
(PRB) Petroleum/ Resin-Based Emulsions	Emulsified Petroleum Resin	D	M	L	$3,000	10-50	P/C	0-4		M	B	M		0/-
(CBB) Cementitious Based Binders	Gypsum	D	S	M	$2,000	75-85	P/C	4-8		M	H	L		-

[shaded] = not applicable for category, class or type
UNK = unknown

Source: *Guidance Document – Soil Stabilization for Temporary Slopes*, URS Greiner Woodward Clyde, November 1999.

Table B-1 (continued)
TEMPORARY SOIL STABILIZATION CRITERIA MATRIX

Antecedent Moisture	**D** **P**	Soil should be relatively dry before application Soil should be pre-wetted before application
Availability	**S** **M**	A short turn-around time between order and delivery, usually 3-5 days A moderate turnaround time, between 1-2 weeks
Ease of Clean-Up	**L** **M** **H**	Require pressure washing, a strong alkali solution, or solvent to clean up Requires cleanup with water while wet; more difficult to clean up once dry May be easily removed from equipment and overspray areas by a strong stream of water
Installed Cost		Dollars per hectare
Erosion Control Effectiveness		Percent reduction in soil loss over bare soil condition.
Degradability	**C** **P** **B**	Chemically degradable Photodegradable Biodegradable
Length of Drying Time		Estimated hours
Time to Effectiveness		Estimated days
Longevity	**S** **M** **L**	1 - 3 months 3 – 12 months > than 12 months
Application Mode	**L** **W** **H** **B** **M**	Applied by hand labor Applied by water truck Applied by hydraulic mulcher Applied by either water truck or hydraulic mulcher Applied by a mechanical method other than those listed above (e.g., straw blower)
Residual Impact	**L** **M** **H**	Projected to have a low impact on future construction activities Projected to have a moderate impact on future construction activities Projected to have a significant impact on future construction activities
Native	**N** **E**	Plant or plant material native to the State of California Exotic plant not native to the State of California
Runoff Effect	**+** **0** **-**	Runoff is decreased over baseline (bare soil) No change in runoff from baseline Runoff is increased over baseline