May 14, 2001
P.O. Box 6
Bayside, California 95524

To California Regional Water Quality Control Board
in regards to 303 (d) Listing for Jacoby Creek

Dear Board Members and Staff,

I have lived in the Jacoby Creek watershed for 16 years, not long by old-timers' standards, but long enough to love this place and to become familiar with its stories. I have seen degradation of Jacoby Creek in these years myself, and past accounts of the watershed illustrate how impaired this creek has become over the decades.

I have seen an increase in both private/residential and logging roads, an increase in logging intensity and new homes, and decreased vegetative cover in many areas, all adding up to more pressures on the watershed and on water quality.

Jacoby Creek watershed is part of the Eureka Plain Hydrologic Unit. Under the Basin Plan, the beneficial uses of water and water quality objectives are not being met. Historical and current land management practices are adversely impacting uses/values such as agricultural irrigation, domestic water supplies, salmonid fisheries habitat, rare and endangered species habitat and viability, shellfish production, and estuary habitat quality, due to sedimentation and increased flooding. Biological and property values are being significantly diminished in the watershed as a result of increased sediment loading and resulting sedimentation.

Jacoby Creek is an integral part of the Humboldt Bay ecosystem. The wetland at the mouth of the creek represents one of the few remnants of salt marsh habitat remaining in the bay, and is one of five units in the Humboldt Bay National Wildlife Refuge. Humboldt Bay at Jacoby Creek has suffered a loss of wetlands and estuaries from sedimentation, and reduced fisheries (Tuttle, 1985). The two other large tributaries to Humboldt Bay, Freshwater Creek and Elk River, are listed as 303(d) impaired; we urge you to include Jacoby Creek as well.

Many studies and research have been done in the watershed, most of which are either included herein or referenced. Much of the included literature provides an excellent overview of the watershed and of impacts, e.g. Wunner 1980, 1988, 1998; Tuttle, 1985; Francis, 1999. Also included in this petition are residents' view of the watershed and its status, either as letters or on the accompanying videotape. A comparison of 1968, 1994 and 2000 aerial photos (available on request) also reflect some of the changes and increased activity in the watershed.

It used to be that a storm of 1 inch of rain in the Jacoby Creek valley (perhaps 2 inches at the ridges) was not a big event for the creek. Such a small amount of rainfall now frequently causes the creek to flood, such as at the bridge at Old Arcata Road (documented in the video and residents' accounts). Jacoby Creek and its tributaries frequently run thick and brown with sediment. The accompanying photos, videotape and and residents' accounts attest to increased flooding and sedimentation in the watershed.

Although many in lower Jacoby Creek obtain their water from the Mad River via the City of Arcata, both agricultural and domestic water are still drawn out of the creek. Robert Wunner's 1996 "Long Term Improvement of the Jacoby Creek Watershed" identifies 26 water intakes in upper Jacoby Creek; some intakes may serve mutiple households. Also, many families get their water from tributaries. Sedimentation and increased flooding diminishes these beneficial uses. A farmer below the Old Arcata Road bridge pointed out 9 inches of sediment surrounding his well, and five feet of sediment in his well; Rex Dixon's letter documents problems with his family's well at high water.

Jacoby Creek Road runs close to the creek--sometimes within twenty feet--for about three miles beyond the South Quarry Road fork until it terminates at Barnum Timber's quarry. Culvert failures, which often deliver sediment to the creek, are common along the road. Humboldt County recently replaced a failed culvert near Jacoby Creek Road mile 1.6. On Jacoby Creek Road, where a culvert was replaced several years ago, one can still see loads of sediment in the area that are poised to enter the creek. Erich Schimps' letter, attached, attests to his efforts to stabilize some of this sediment.

Roads are widely recognized as potential contributors of sediment to a watershed due to road failures and erosion. Calculations by Doug Smith (included electronically) from California Department of Forestry, Coast Cascade, GIS, identify a total of sixty-two miles of roads in the Jacoby Creek watershed, many of those close to streams; this does not include all seasonal roads.

Jacoby Creek has been blessed with coastal cutthroat and steelhead trout, chinook and coho salmon; numerous papers with fisheries information are included for your review. People tell stories of fish so thick that you could "walk across the creek on their backs". The Arcata Union (12 January 1889) reported "Salmon in great numbers have been finding their way from the bay into Jacoby Creek for a week or more past. The fish are in search of their spawning grounds, and are being captured by the boatload near the mouth of the creek". Yet Terry Roelofs, Humboldt State University fisheries professor, hiked several miles of Jacoby Creek in January 1987 and saw not one coho (personal communication).

Higgins, et al, Humboldt Chapter of the American Fisheries Society, 1992, identifies Humboldt Bay tributaries' fall race of chinook salmon as at high risk of extinction, and coho as a stock of concern. As you are well aware, coho are listed under the Endangered Species Act. It is our belief that sediment impacts are reducing habitat qualities for coho and other salmonids in Jacoby Creek.

Sigler, et al (1984), concludes that "as little as 25 ntu's of turbidity caused a reduction in fish growth". The Salmon Forever sediment monitoring data shows that 25 ntu's of turbidity is often exceeded, even at relatively low flows. We believe that when Jacoby Creek turbidity is compared to severity indexes for impacts on salmonids, it paints a picture of impairment.

We have provided Pillsbury's thesis, 1972, which measured turbidity in Jacoby Creek old growth, which might help establish some background levels.

The 1978-79 total sediment sediment readings by Tom Lisle of Redwood Sciences Lab and the 1983-2001 cross section surveys at Brookwood Bridge compiled by Andre Lehre, Humboldt State University geology professor, are included. Professor Lehre has been taking classes to Jacoby Creek since 1982, and has seen significant and substantial changes. His 1992-2001 surveys of cross sections above, under and downstream of the bridge show 1 to 1.6 feet of aggradation, mostly since 1995 (personal communication and attached data). It is interesting to note the corresponding increase in timber harvest plan acreage during this time frame.

Many people are concerned that we have not yet seen all of the possible sediment effects from the recent dramatic increase in THP acreage (Smith's silvicultural summaries), due to light rainfall winters. Ziemer, et al (1991), reports that excess sediment is often stored in tributaries, resulting in a time lag between the erosion event and the transport of that material to the main channel.

The attached geomorphological map shows the instability of much of the Jacoby Creek watershed. Almost 24% is considered geologically unstable, 14% is considered earthflow--partially destablized, saturated soils that could contiuously move seasonally, and 7% of the watershed is at over 65% grade--steep, unstable slopes that have experienced repeated slides (Jacoby Creek Land Trust Strategy, 1999).

Such geological instability, especially coupled with increasing land use activities and roads, has resulted in sedimentation and adverse impacts to Jacoby Creek, and creates the potential for more. Many people in the area are familiar with an earthflow below the Plunkett Road subdivision, and the infamous "Blue Slide" further upvalley, a considerable source of sediment into the creek and site of restoration and stablization efforts (letters from Erich Schimp and Robert Wunner, and Wunner's 1980, '88 and '96 reports).

The increased intensity of timber harvesting in the Jacoby Creek watershed, especially the associated roads and tractor yarding (as reflected in the attached silvicultural area summary statistics and maps), are of great concern to many residents. The sedimentation that may result from such activities continues to be a threat to the water and salmonid habitat quality of the creek.

According to the silvicultural summaries, twenty-six percent of Jacoby Creek watershed was under timber harvest between 1986 and 2000. Reeves, Everest and Sedell (1993) report a diverse assemblage of salmonids in watersheds with less than 25% timber harvesting, and a monotypic population where more than 25% is cut. Protecting and restoring habitat to ensure diversity of salmon populations is critical for a healthy functioning watershed.

In 1993 Humboldt County Superior Court found that the California Department of Forestry had not required adequate assessment of potential adverse cumulative impacts of THP#01-91-065 HUM in conjunction with other past, present and foreseeable land use activities. Are the cumulative impacts being thoroughly assessed and mitigated on other timber harvest plans? If not, how could this adversely affect the beneficial uses of water in Jacoby Creek due to possible results such as erosion and sedimentation, especially in combination with other land uses?

We are very concerned about the herbicides that are frequently applied after clearcutting. Just a few weeks ago, while driving on a county road, I came across an active herbicide spray operation in a clearcut near the headwaters of Jacoby Creek. It was easy to see that the application was rather haphazard, evidenced by the bright purple dye in sporadic patches and on slash piles. I was very concerned for the health and safety of my three year-old son who was with me (and of the workers), as both sides of the road were saturated, with some overspray on the road. The dyed herbicide had sloshed into the back of the workers' truck, with some leaking out of the truck bed. With such sloppy application, usually unseen by the public or agencies, I believe the chemicals could easily get into our streams, with potentially drastic results.

Atrazine, one of the herbicides commonly used on industrial forestlands, is toxic to aquatic invertebrates and salmonids, able to travel through soil and enter groundwater, is carcinegenic, and has a relatively long half-life. Considering the potential effects on domestic, agricultural and biological values, herbicide use should be considered as an adverse chemical impact. A map of herbicide use in the watershed and possible impacts are available on request (compiled by Californians for Alternatives to Toxics). The use of herbicides at the Baywood Golf Course may also adversely affect the creek's water quality (Wunner, 1996).

Development in the watershed is an issue in regards to impaired beneficial uses and sedimentation. For example, five of 13 subwatersheds are zoned at development densities which upon full build-out at the levels of the 1982 Jacoby Creek Land Use Plan are expected to cause wetland sedimentation to accelerate beyond that experienced historically (many sources, e.g. Tuttle, 1985).

Ongoing interest and concern with Jacoby Creek is evidenced by efforts such as a new staff plate installed at Brookwood Bridge for monitoring by Jacoby Creek School students. Professor Lehre's recent cross section resurveying, and the installation of a new gauging station by Redwood Sciences Lab in the upper watershed at an old USGS site.

Please list Jacoby Creek as impaired to help us safeguard and restore the water quality and beneficial uses of our creek.

Thank you very much for your consideration of this petition.

Sincerely,

Elizabeth Finger

Elizabeth Finger
Jacoby Creek Protection Association

Please call me at (707) 826-0128 [June 7-27, 2001 at (801) 293-3666] or write 137 Nature Lane, Arcata 95521 for questions about this petition. We did not include copies of all of the sources/publications cited; they are available on request.

Contents:

Data--(Items A-C included as hard copy and electronically)

A) Jacoby Creek Salmon Forever Citizen Turbidity and TSS Monitoring with SOP for HY '99 and 2001

B) Jacoby Creek Cross-Sections Brookwood Reach 1983-1986, 1992, 1995, 1997 & 2001 by Andre Lehre

C) Jacoby Creek Suspended Sediment Data 1978-1979 at Brookwood Bridge by Tom Lisle

Jacoby Creek Silvicultural Summary 1988-2000 by Doug Smith

Jacoby Creek Residents' Accounts of the Watershed, written and on videotape

Photos of Floods and Sedimentation

Maps of: Geomorphic Features Related to Landsliding in Jacoby Creek Watershed and Riparian Buffer Zones and Topography in Jacoby Creek Watershed and Vicinity

Copies of relevant Literature and Documents - in other folder

List of Literature and other information Resources

HUMBOLDT BAY WATERSHEDS

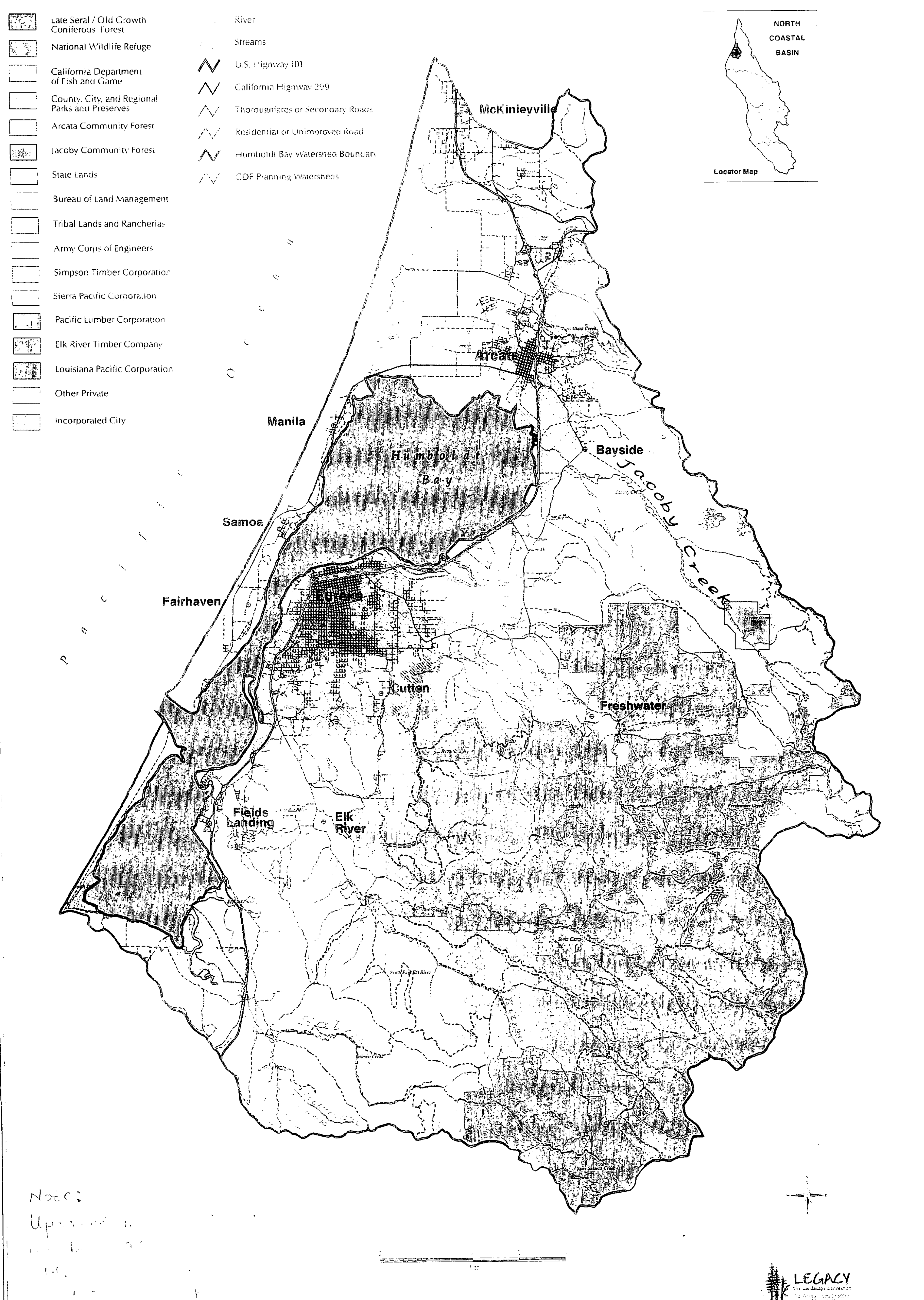
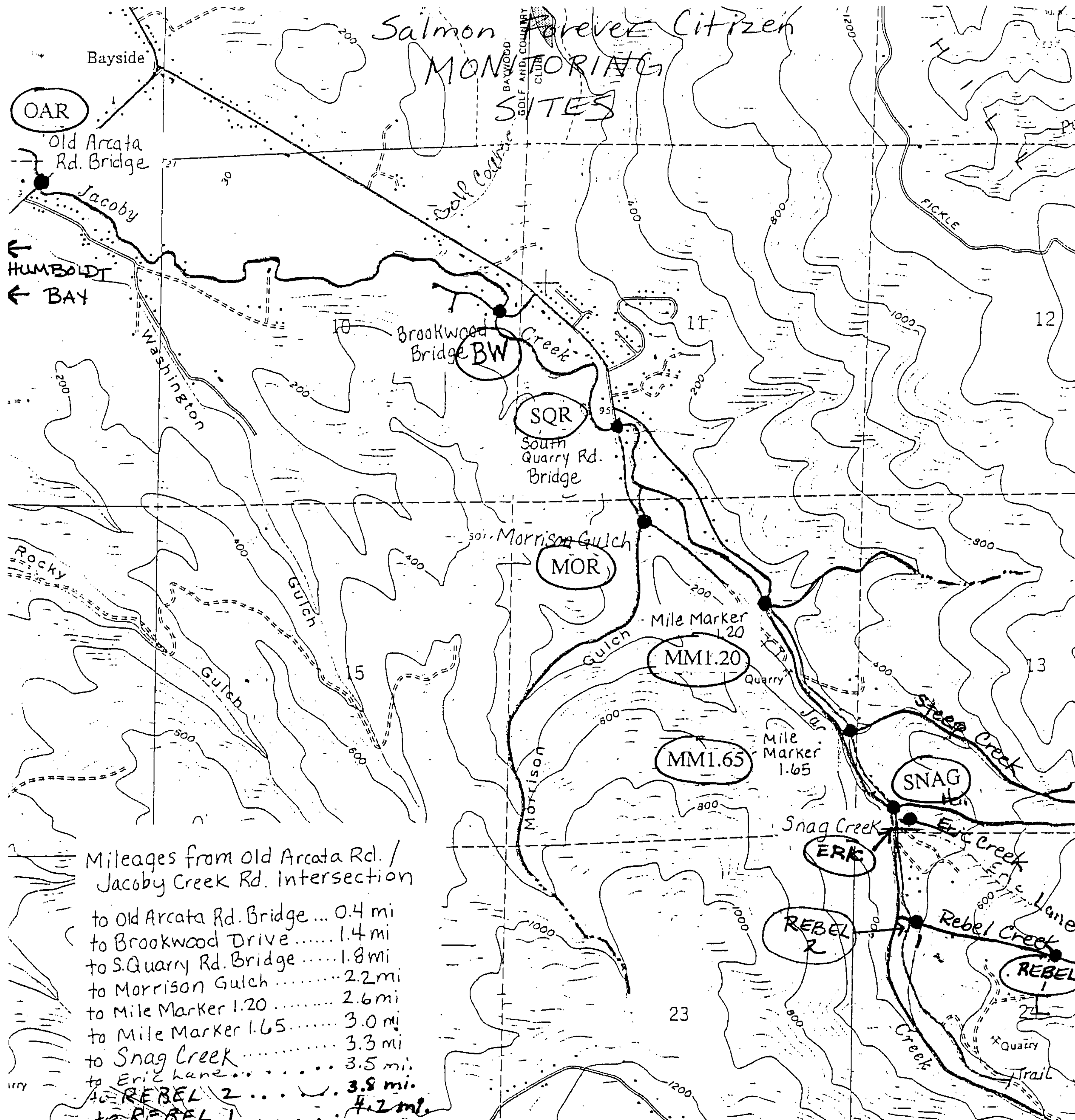


Figure 1

JACOBY CREEK
SALMON FOREVER
CITIZEN TURBIDITY AND TSS MONITORING
WITH SOP
FOR HY '99 AND 2001



<u>Jacoby Creek</u>

OAR	Jacoby Crk.@ Old Arcata Road Bridge/Old Arcata Rd.(F3K300)PM
BW	Jacoby Crk.@Brookwood Bridge@Brkwd Dr.(4K250) PM 0.12
SQR	Jacoby Crk.@South Quarry Rd. Bridge(4K250) PM
MOR	Morrison Gulch@S. Quarry Rd.(4K250) PM
MM1.20	Jacoby Crk.@Jacoby Creek Rd. PM 1.20
MM1.65	Jacoby Crk.@Jacoby Creek Rd. PM1.65
SNAG	Snag Crk.@Jacoby Creek Rd PM
ERIC	Jacoby Crk@Eric Lane PM
Rebel 1	Rebel Crk.@ Jacoby Crk.
Rebel 2	Rebel Crk. on Upper Crk. Rd.

USGS ARCATA SOUTH QUAD

Jacoby Creek at Old Arcata Road Bridge (OAR)

Old Arcata Road (F3K300) PM 7.49 Bridge # 4C-0182

compiled by Nate Lomba and Clark Fenton

Checked By C. Fenton

Humboldt County, California

Hydrologic Year 01

Grab Sampling: Turbidity / Suspended Sediment Data - provisional raw stage is depth of flo

Salmon Forever / Sunny Brae Sediment Lab Floating object

Stage is measured down from deck upstream at center?

Sign in page #	Datasheet #	Location Sampled	Date Sampled	Time Sampled	Sampled By	Turbidity FTU	Tur. Code	Container Type	Turbidity Date run	Turbidity Time run	Turbidity By	TUM S/N	Tare Bottle Weight g	Total Bottle Weight g	Volume/ Bottle Wt.	Filter Total	Filter ID	Initial Filter Weight g	Final Filter Weight g	Sediment Wt.	Lab Code		Total Mg/L	Turbidity FTU	Raw Stage	Stage	Discharge CFS	Vel. Str. hi or lo	Vel. dist.	Vel. sec.	Comments
2		OAR	11/17/98	9:56	J. Frincke	122	0	2x6			J. Frincke	9614												122							
4	12	OAR	11/21/98	7:50	J. Frincke	846	0	Hach Cell	11/21/98		J. Frincke	9614	18.0	35.5	17.5	1 1	205	0.11748	0.12792	0.01044	0		596.8	846		12" (1)					(1) "from bottom of bridge"
7		OAR	11/21/98	0:40	S. Kett	359	0	Hach Cell	11/22/98		S. Kett	9614												359		10'4"					"high tide"
10		OAR	11/23/98	11:15	J. Noell	188	0	DIS	11/25/98	15:20	J. Noell	9614												188							"All sta." "fine sand bottom of DIS Bottle"
10		OAR	11/24/98	11:15	J. Noell	186	0	Hach Cell	11/24/98	21:45	J. Noell	9614												186	28" depth ?	28 / 47 (1)					(1) "under bridge"
10	24	OAR	11/26/98	11:45	J. Noell	305	0	DIS	02/27/99	15:14	J. Noell	9614	376.3	731.6	355.3	1 2	414	0.11490	0.27162	0.15672	0		441.2	305		(1)					(1) "every 5' for 70'
	24												376.3	731.6	355.3	2 2	415	0.11645	0.16037	0.04392	0		123.6								
	24																					Total	564.8								
11		OAR	11/26/98	10:28	J. Frincke	467	0	Hach Cell	11/27/98		J. Frincke	9614	18.0	35.3	17.3	1 1	434	0.11266	0.12168	0.00902	0		521.6	467		dn 21.0"			15'	3.01	(1) 3.01 - 2.97 - 3.41 sec.
																														2.97	
																														3.41	
12	26	OAR	11/30/98	8:09	J. Frincke	171	0	Hach Cell	11/30/98		J. Frincke	9614	17.9	31.7	13.8	1 1	453	0.12334	0.12766	0.00432	0		313.1	171		dn 5.0' (1)			36'	8.68	(1) "taken off bridge"
16	31	OAR	12/13/98	21:01	J. Noell	191	0	DIS	12/13/98	21:36			370.0	798.7	428.7	1 2	560	0.12615	0.18988	0.06373	0		148.7	191	dn 29 mp	dn 50"				8.31	mp = crest stage gage dnstrm RL
	31												370.0	798.7	428.7	2 2	561	0.12709	0.20180	0.07471	0		174.3							7.91	
	31																					Total	323.0								
21	38	OAR	11/30/98	16:03	J. Frincke	129	0	PB 2x6	01/17/99	11:31	J. Frincke	9614	24.4	235.8	211.4	1 1	711	0.11372	0.15005	0.03633	0		171.9	129		dn 46"			15'	3.79	
27	46	OAR	1/14/99	19:00	B. Russell	3	0	glass jar	01/22/99	17:27	S. Kett	9614	236.6	348.3	111.7	1 1	887	0.11349	0.11502	0.00153	0		13.7	3		n/a			n/a		
27	46	OAR	1/15/99	10:30	B. Russell	73	0	glass jar	01/22/99	17:30	S. Kett	9614	473.8	992.9	519.1	1 1	888	0.11471	0.15001	0.03530	0		68.0	73		89.5"			36'	10.00	
27	46	OAR	1/19/99	9:30	B. Russell	34	0	glass jar	01/22/99	17:37	S. Kett	9614	238.4	419.9	181.5	1 1	889	0.11259	0.12154	0.00895	0		49.3	34		7'4"			n/a		
27	46	OAR	1/21/99	17:00	B. Russell	33	0	glass jar	01/22/99	17:41	S. Kett	9614	283.5	615.8	332.3	1 1	890	0.11511	0.12435	0.00924	0		27.8	33		7'4"			36'	8.00	
44	59	OAR	2/6/99	10:30	B. Russell	143	0	glass jar	02/21/99	14:22	S. Kett	9614	245.9	562.3	316.4	1 2	1221	0.10971	0.21455	0.10484	0		331.4	143		n/a			36'	8.40	
	59												245.9	562.3	316.4	2 2	1222	0.10747	0.12748	0.02001	0		63.2								
																						Total	394.6								
44	59	OAR	2/7/99	17:45	B. Russell	142	0	glass jar	02/21/99	14:33	S. Kett	9614	278.5	573.9	295.4	1 1	1226	0.10690	0.15628	0.04938	0		367.2	142		7'			36'	8.60	
46	55	OAR	2/18/99	11:00	B. Russell	93.6	0	glass jar	02/25/99	15:10	S. Kett	9614	255.5	573.6	318.1	1 2	1153	0.10187	0.13929	0.03742	0		117.6	93.6						8.50	
	55												255.5	573.6	318.1	2 2	1154	0.10720	0.11442	0.00722	0		22.7								
46	56	OAR	2/24/99	17:45	B. Russell	36.7	0	glass jar	02/25/99	15:22	S. Kett	9614	165.6	410.1	244.5	1 1	1218	0.10687	0.11826	0.01139	0		46.6	36.7		5'4"				10.58	

Jacoby Creek at Old Arcata Road Bridge (OAR)

Compiled by Eric Nyman and Clark Fenton — **Humboldt County, California**

Checked By C. Fenton — **Hydrologic Year 01**

Grab Sampling: Turbidity / Suspended Sediment Data - provisional

NS=Not Stated — **Salmon Forever / Sunny Brae Sediment Lab**

depth of flo is measured at bridge rail

Bridge width 36"

top of rail to creek bed 160" 1-11-01

Raw stage is measured as inches down from e-side/ upstream top of br. Rail / black tape mark - top rail

Stage is measured as depth of flo

Sign in page #	Datasheet #	Sample ID #	Location Sampled	Date Sampled	Time Sampled	Sampled By	Turbidity FTU	Tur. Code	Container Type	Turbidity Date run	Turbidity Time run	Turbidity By	TUM S/N	Raw Stage - inches	Stage inches	Discharge CFS	Vel. Str. hi or lo	Vel. dist. Ft.	Vel. sec.	Comments
20		01GR0400	OAR	1/12/01	9:55	B. Thompson	10.4	0	Hach Cell	1/27/01	16:56	C. Fenton	22441	148	12"			10	3.30	E-side measure stage - clear
																			3.15	
																			3.28	
20		01GR0409	OAR	1/24/01	9:55	B. Thompson	26.5	0	Hach Cell	1/27/01	17:24	C. Fenton	22441		14"			10	2.59	light rain
																			2.77	
																			2.77	
21		01GR0411	OAR	1/25/01	11:20	B. Thompson	56	0	Hach Cell	1/27/01	17:37	C. Fenton	22441		17"			10	2.51	light rain
																			2.60	
																			2.60	
21		01GR475	OAR	1/25/01	14:40	B. Thompson	300+-	0	Hach Cell	1/27/01	18:12	C. Fenton	22441		17.5"			10	2.30	raining - lo cell vol.
																			2.19	
																			2.07	
51		01GR0267	OAR	2/19/01	7:35	B. Thompson	10.3	0	Hach Cell	2/22/01	20:25	CF/EN	22423		13"			10	17.53	
																			17.68	
																			18.01	
58		01GR0283	OAR	2/21/01	10:50	B. Russell	31	0	Hach Cell	3/1/01	10:30	DVD		146"				Br. Width	9.00	Sunny - storm passed a few hrs ago
																			9.10	
																			9.10	
52		01GR0577	OAR	2/21/01	11:30	B. Thompson	103	0	Hach Cell	2/22/01	21:04	CF/EN	22423		18.5"			10	1.54	organics
																			1.57	
																			1.52	
52		01GR0581	OAR	2/22/01	9:20	B. Thompson	125	0	Hach Cell	2/22/01	21:08	CF/EN	22423		41"			10	1.53	dl
																			1.43	
																			1.72	
52		01GR 0580	OAR	2/22/01	7:05	B. Thompson	lo vol.								44.5			10	1.72	light rain
																			1.59	
																			1.65	
52		01GR0584	OAR	2/22/01	10:10	B. Thompson	100	0	Hach Cell	2/22/01	21:16	CF/EN	22423		40"dl			10	1.68	overcast
																			1.77	
																			1.20	
58		01GR0291	OAR	2/23/01	10:30	B. Russell	67.4	0	Hach Cell	3/2/01	10:33	DVD	9614	122"				Br. Width	6.20	peak stage 1 hour ago
																			7.80	
																			6.80	
94		01GR 0595	OAR	4/6/01	16:00	B. Thompson	25.1	0	Hach Cell	4/13/01	23:05	C. Fenton	9614	146"	14"			10	1.92	water 14" deep - rising limb - raining
																			2.04	
																			1.94	

Jacoby Creek - Brookwood Bridge (BW)

Brookwood Drive (4K250) PM 0.12 Bridge # 4C-0124

Humboldt County, California

Hydrologic Year 99

Grab Sampling: Turbidity / Suspended Sediment Data - provisional

Salmon Forever / Sunny Brae Sediment Lab

Compiled by Nate Lomba and Clark Fenton

Checked By C. Fenton

Grab samples are taken RR from bank at USGS staff gage

Floating object vel. is measured at upstream or dn stream of bridge RR

Stage is measured as inches on crest stage gage/ metal pipe RR

Stage is measured as ft above sea level form USGS staff gage RR

Sign in page #	Datasheet #	Location Sampled	Date Sampled	Time Sampled	Sampled By	Turbidity FTU	Tur. Code	Container Type	Turbidity Date run	Turbidity Time run	Turbidity By	Tare Bottle Weight g	Total Bottle Weight g	Volume/ Bottle Wt.	Filter Total	Filter ID	Initial Filter Weight g	Final Filter Weight g	Sediment Wt.	Lab Code	Total Mg/l	Stage	Discharge CFS	Vel. dist.	Vel. sec.	Comments
4		BW	11/21/98	07:25	J. Frincke	712	0	Hach Cel	11/21/98		J. Frincke	18.2	35.3	17.1	1 1	203	0.11542	0.13047	0.01505	0	880.1			15'	2.41	
11		BW	11/26/98	10:15	J. Frincke	413	0	Grab 2x6	11/27/98		J. Frincke											dn10'4"		25'	4.00	(1) 4.0 - 3.53 - 3.67 - 3.69 sec.
																									3.53	
																									3.67	
																									3.69	
12	26	BW	11/30/98	08:00	J. Frincke	249	0	Hach Cel	11/30/98		J. Frincke	17.9	35.8	17.9	1 1	452	0.12234	0.12794	0.0056	0	312.9	dn 12'1" (1)		25'	7.72	(1) "taken off bridge"
21	38	BW	11/30/98	15:53	J. Frincke	115	0	PB 2x6	01/17/99	11:33	J. Frincke	24.3	248.1	223.8	1 1	712	0.11616	0.15026	0.0341	0	152.4	dn 12'1"		25'	7.46	
24	39	BW	01/17/99	15:13	J. Frincke	29.7	0	Hach Cel	01/19/99	15:36	J. Frincke	18.2	36.4	18.2	1 1	752	0.11352	0.1137	0.00018	0	9.9	8" (1)		25'	21.13	(1) "taken off guage"
25	43	BW	01/13/99	17:36	B. Thompson	3.86	0	Hach Cel	01/20/99	15:22	J. Frincke	17.9	37.4	19.5	1 1	806	0.11269	0.11232	-0.00037	1	-19.0	n/a		n/a		
25	43	BW	01/14/99	22:00	B. Thompson	44.5	0	Hach Cel	01/20/99	15:24	J. Frincke	18.2	35.8	17.6	1 1	807	0.11456	0.11491	0.00035	0	19.9	5.5"		25'	27.93	
25	43	BW	01/15/99	22:00	B. Thompson	54.5	0	Hach Cel	01/20/99	15:26	J. Frincke	18	32.4	14.4	1 1	809	0.1142	0.11447	0.00027	0	18.6	0		25'	11.00	
25	43	BW	01/16/99	05:30	B. Thompson	61.2	0	Hach Cel	01/20/99	15:27	J. Frincke	18.1	33.1	15.0	1 1	814	0.11314	0.11357	0.00043	0	28.7	10"		25'	9.24	
25	43	BW	01/19/99	15:15	B. Thompson	71.5	0	Hach Cel	01/20/99	15:28	J. Frincke	18.2	31.4	13.2	1 1	818	0.11244	0.11298	0.00054	0	40.9	13"		n/a		
25	43	BW	01/20/99	06:30	B. Thompson	38.3	0	Hach Cel	01/20/99	15:29	J. Frincke	18	35.4	17.4	1 1	822	0.11541	0.11499	-0.00042	1	-24.1	11"		25'	7.00	
44	51	BW	01/22/99	10:00	B. Thompson	22.5	0	Hach Cel	02/21/99	14:04	J. Frincke	18	35.1	17.1	1 1	1010	0.10791	0.10806	0.00015	0	8.8	(1)		15'	13.00	(1) 1" below lowest mark
44	51	BW	01/22/99	23:30	B. Thompson	190	0	Hach Cel	02/21/99	14:06	J. Frincke	18	32.7	14.7	1 1	1012	0.10865	0.11206	0.00341	0	232.0	19"		15'	4.00	
44	51	BW	01/22/99	07:30	B. Thompson	137	0	Hach Cel	02/21/99	14:08	J. Frincke	17.8	34	16.2	1 1	1013	0.10748	0.10946	0.00198	0	122.2	18"		15'	4.50	
44	51	BW	01/24/99	06:30	B. Thompson	46.7	0	Hach Cel	02/21/99	14:14	J. Frincke	17.9	35.1	17.2	1 1	1014	0.10634	0.10705	0.00071	0	41.3	13"		15'	7.00	
44	51	BW	01/31/99	06:30	B. Thompson	12.5	0	Hach Cel	02/21/99	14:16	J. Frincke	18	35.2	17.2	1 1	1015	0.10764	0.10764	0	0	0.0	11.5"		15'	9.50	
44		BW	02/06/99	06:00	B. Thompson	14.3	0	ach Cell (	02/21/99	14:19	J. Frincke											11.5"		15'	19.00	(1) half full bottle
44	59	BW	02/08/99	12:30	B. Thompson	38.5	0	(1)	02/21/99	14:37	J. Frincke	20.2	119.7	99.5	1 1	1227	0.10686	0.11338	0.00652	0	65.5	11"		15'	5.00	(1) plastic bottle, probably 6 oz.
45	59	BW	02/08/99	14:30	B. Thompson	200	0	(1)	02/21/99	14:42	J. Frincke	17.2	91.6	74.4	1 1	1228	0.10778	0.12671	0.01893	0	254.5	19"		15'	4.00	(1) plastic bottle, probably 6 oz.
45		BW	02/13/99	15:30	B. Thompson	19.2	0	Hach Cel	02/21/99	15:03	J. Frincke											3.5" (1)		15'	8.00	(1) below 11 mark

Jacoby Creek - Brookwood Bridge (BW)

Humboldt County, California

Hydrologic Year 01

Grab Sampling: Turbidity / Suspended Sediment Data - provisional

Salmon Forever / Sunny Brae Sediment Lab

Compiled by Eric Nyman and Clark Fenton

Checked by C. Fenton

NS=Not Stated

Brookwood Drive (4k250 PM) bRIDGE #

Vel. Is measured at upstream or dn stream of bridge RR

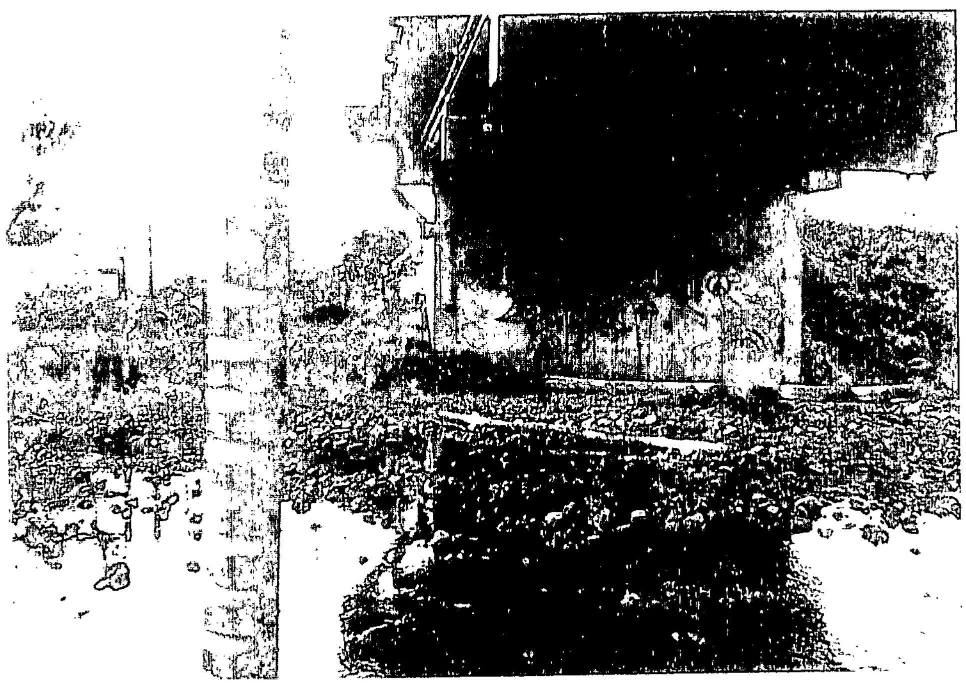
width of support to support is

Stage is measured as inches on crest stage gage/ metal pipe RR

Stage is measured as ft above sea level fom USGS staff gage RR

Sign-in Page #	Datasheet #	Sample ID #	Location Sampled	Date Sampled	Time Sampled	Sampled By	Turbidity FTU	Tur. Code	Container Type	Turbidity Date run	Turbidity Time run	Turbidity By	TUM S/N	Raw Stage	Stage	Discharge CFS	Vel. Str. hi or lo	Vel. dist. ft.	Vel. sec.	Comments
5		O1GR0263	BW	11/24/00	09:10	B. Thompson	15.9	O	Hach Cell	12/17/00	19:45	C. Fenton	22423		52.66			10	5.14	PEAK STAGE 3.5' CORK
5		01GR0268	BW	11/29/00	17:30	B. Thompson	110	0	Hach Cell	12/17/00	19:48	C. Fenton	22423		53.02			10	8.00	6.5' cork
7		01GR0266	BW	12/13/00	21:30	B. Thompson	3.16	0	Hach Cell	12/23/00	15:00	B. Thompson	22423	6 cork	52.6			10	6.41	Upstream side of bridge
																			5.66	
																			6.43	
7		01GR 0303	BW	12/14/00	09:00	B. Thompson	26.9	0	Hach Cell	12/23/00	15:02	B. Thompson	22423	6.5 cork	52.94			10	3.90	cloudy
																			3.53	
																			3.73	
7		01GR0287	BW	12/15/00	07:40	B. Thompson	16.2	0	Hach Cell	12/23/00	15:12	B. Thompson	22423	5.5 cork	52.84			10	3.96	scattered clouds
																			3.99	
																			4.15	
7		01GR0264	BW	12/11/00	10:00	B. Thompson	2.95	0	Hach Cell	12/23/00	15:15	B. Thompson	22423	5.5 cork	52.42			10	11.09	lt. Rain
																			11.02	
																			10.52	
8		01GR0296	BW	12/23/00	15:50	B. Thompson	3.85	0	Hach Cell	12/23/00	16:18	B. Thompson	22423		52.56			10	7.56	
																			7.21	
																			7.26	
12		01GR0395	BW	01/09/01	16:20	B. Thompson	15.4	0	Hach Cell	1/11/01	18:08	J. Noel			7.5"			10	3.99	off/on rain
																			3.96	
																			3.58	
17		01GR0332	BW	01/18/01	10:55	B. Thompson	4.57	0	Hach Cell	1/21/01	17:12	J. Noel			5"			10	4.89	intermittent rain
																			5.12	
																			4.50	
20		01GR0399	BW	01/23/01	15:25	B. Thompson	3.86	0	Hach Cell	1/27/01	17:03	C. Fenton	22441		4.5"			10	7.77	36' flo width - raining
																			7.29	
																			8.00	
20		01GR0425	BW	01/23/01	17:15	B. Thompson	15	0	Hach Cell	1/27/01	17:21	C. Fenton	22441		7"			10	6.79	light rain 38' width
																			7.15	
																			6.56	
20		01GR0408	BW	01/24/01	10:15	B. Thompson	22.4	0	Hach Cell	1/27/01	17:26	C. Fenton			8"			10	4.42	light rain
																			3.95	
																			3.81	
21		01GR0498	BW	01/25/01	12:55	B. Thompson	363	0	Hach Cell	1/27/01	17:56	C. Fenton	22441		15"			10	2.39	sunny - flo is width of bridge supports
																			2.14	
																			2.86	
51		01GR0487	BW	02/19/01	07:40	B. Thompson	12.1	0	Hach Cell	2/22/01	20:29	CF/EN	22423		8"			10	4.71	
																			5.03	
																			4.45	
52		01GR0576	BW	02/21/01	11:05	B. Thompson	38.3	0	Hach Cell	2/22/01	21:02	CF/EN	22423		12"			10	2.91	
																			3.01	
																			2.93	
52		01GR0582	BW	02/22/01	09:30	B. Thompson	96.3	0	Hach Cell	2/22/01	21:10	CF/EN	22423		16"			10	1.81	overcast
																			1.27	
																			1.82	
52		01GR0585	BW	02/22/01	11:00	B. Thompson	69.1	0	Hach Cell	2/22/01	21:17	CF/EN	22423		14.5"dl			10	1.85	overcast
																			1.85	
																			1.63	
94		01GR 0594	BW	04/06/01	16:08	B. Thompson	35.4	0	Hach Cell	4/13/01	23:06	C. Fenton	9614		9.5			10	3.10	rising limb
																			2.75	
																			3.05	

BROOKWOOD BRIDGE MONITORING SITE BW



Return-Path: <clarkstr@humboldt1.com>
X-Sender: clarkstr@mail.humboldt1.com
Date: Thu, 10 May 2001 20:41:01 -0700
To: russell-ms450700 <comwiz@mindspring.com>
From: clarkfenton <clarkstr@humboldt1.com>
Subject: Re: Jacoby data

Hi Russell,

I don't have any discharges or rating curves for Jacoby at all.

The 2 different stage numbers at BW are USGS staff gage sea level 53.xxx and inches on Janna's metal pipe pounded into the stream bed next to the USGS staff gage. I do not know the correlation between the 2. Somebody put it in in 98/99 and the 2 are comparable if you know the correlation.
Liz and I talked a little about this.

As far as stage measured from the bridge I don't know where. What do Bill's notes say?

We have not gotten to any Jacoby SSC data so far this year.

Velocities were measured with any floating object. Usually just upstream of the bridge by the staff gages

Usually when you talk about cork it's in reference to cork inside a crest stage gage where the cork rises inside the pipe and clings to an inner pipe which you lift out after the peak stage has passed and can tell how high it was by the cork left on the inner pipe.

Clark

>Clark,
>
>We're trying to get flow rates from the data you sent. Particularly, we
>are interested in the Brookwood Site as we have dug up some historic data
>there also. Can you clarify how flows were measured at this site. It
>looks like velocities were measured with a cork at the bridge and stage was
>measured from both the bridge and the staff plate(s). Are all staff plate
>readings comparable? I thought that the plate was recently replaced at the
>site. Please clarify. Also, please let me know if know where on the
>bridge stage was measured.
>
>Do you have or know of any rating curves for 99-01' for this site?
>
>I was also wondering if you will have the 2001 TSS data for the monitoring
>before friday.
>
>Thanks for your help!!!!
>
>Russell

Jacoby Creek - S. Quarry Road (SQR)

South Quarry Road Bridge (4K240) PM 0.05 Bridge # 4C-006

Humboldt County, California

Hydrologic Year 99

Grab Sampling: Turbidity / Suspended Sediment Data - provisional

Salmon Forever / Sunny Brae Sediment Lab

Compiled by Nate Lomba and Clark Fenton

Checked By C. Fenton

Hand grab sample is taken RR upstream of bridge

Floating object velocity is measured

Stage is measured as distance down from bridge

Sign in page #	Datasheet #	Location Sampled	Date Sampled	Time Sampled	Sampled By	Turbidity FTU	Tur. Code	Container Type	Turbidity Date run	Turbidity Time run	Turbidity By	TUM S/N	Tare Bottle Weight g	Total Bottle Weight g	Volume/ Bottle Wt.	Filter Total	Filter ID	Initial Filter Weight g	Final Filter Weight g	Sed. Wt.	Lab Code		Total Mg/L	Stage	Discharge CFS	Vel. dist.	Vel. sec.	Comments
4		SQR	11/21/98	7:19	J. Frincke	751	0	Hach Cell	11/21/98		J. Frincke	9614	18.2	35.9	17.7	1 1	206	0.11656	0.13046	0.01390	0		785.7					
5		SQR	11/21/98	12:58	J. Noell			Hach Cell																				
11	25	SQR	11/26/98	10:02	J. Frincke	361	0	Grab 2x6	11/27/98		J. Frincke	9614	23	248.1	225.1	1 2	432	0.11700	0.20009	0.08309	0		369.2	dn 20'		14'6"	3.27	
	25												23	248.1	225.1	2 2	433	0.11210	0.14899	0.03689	0		163.9				3.1	
	25																					Total	533.1					
12	26	SQR	11/30/98	7:51	J. Frincke	266	0	Hach Cell	11/30/98		J. Frincke	9614	17.9	37.3	19.4	1 1	451	0.12036	0.12752	0.00716	0		369.2	dn 20'10" (1)		14'6"	2.68	(1) "taken off bridge"
21	38	SQR	11/30/98	16:33	J. Frincke	111	0	PB 2x6	1/17/99	11:36	J. Frincke	9614	24.3	247.6	223.3	1 1	713	0.11314	0.14102	0.02788	0		124.9	dn 21.0'		14'6"	3.16	
22	39	SQR	01/14/99	19:35	J. Frincke	20	0	glass jar	1/17/99	12:32	J. Frincke	9614	177.9	344.7	166.8	1 1	734	0.11576	0.11838	0.00262	0		15.7	dn 21'9"		14'6"	14.87	(1) "half pint jam jar"
24	39	SQR	01/17/99	15:26	J. Frincke	31.9	0	Hach Cell	1/19/99	15:37	J. Frincke	9614	18.1	36.5	18.4	1 1	753	0.11214	0.11247	0.00033	0		17.9	20'11"		14'6"	4.81	
27	46	SQR	01/22/99	16:20	J. Frincke	124	0	Hach Cell	1/22/99	17:50	J. Frincke	9614	18	35.8	17.8	1 1	875	0.11515	0.11836	0.00321	0		180.4	20'6"		14'6"	3.62	
28	46	SQR	01/23/99	7:29	J. Frincke	145	0	Hach Cell	1/23/99	16:11	J. Frincke	9614	18	34.2	16.2	1 1	877	0.11067	0.11376	0.00309	0		190.3	19'5"		14'6"	3.02	
45		SQR	02/08/99	15:08	J. Frincke	60.6	0	2x6	2/21/99	14:54	J. Frincke	9614												20'1"		14'6"	3.77	
46	55	SQR	02/24/99	15:55	J. Frincke	34.9	0	2x6	2/25/99	15:12	J. Frincke	9614	22.6	264.4	241.8	1 1	1155	0.10373	0.10777	0.00404	0		16.7	(1)		(1)	(1)	(1) "in notes"
47	56	SQR	02/24/99	19:51	J. Frincke	106	0	(1)	2/25/99	15:30	J. Frincke	9614	168.5	321.4	152.9	1 1	1219	0.10884	0.13655	0.02771	0		161.3	(1)		(1)	(1)	(1) "in notes"

Jacoby Creek - Morrison Gulch (MOR)

South Quarry Road (4K240) - 2.2 miles east of Old Arcata Road

Compiled by Nate Lomba and Clark Fenton

Checked By C. Fenton

Humboldt County, California

Hydrologic Year 01

Grab Sampling: Turbidity / Suspended Sediment Data - provisional

Salmon Forever / Sunny Brae Sediment Lab

There is an existing dn stream staff plate not used

Floating object velocity is measured at culvert lip 10' into culvert

stage is measured as flo in bottom of 5'culvert

Sign in page #	Datasheet #	Location Sampled	Date Sampled	Time Sampled	Sampled By	Turbidity FTU	Tur. Code	Container Type	Turbidity Date run	Turbidity Time run	Turbidity By	TUM S/N	Tare Bottle Weight g	Total Bottle Weight g	Volume/ Bottle Wt.	Filter Total	Filter ID	Initial Filter Weight g	Final Filter Weight g	Sediment Wt.	Lab Code	Total Mg/L	Raw Stage	Stage	Discharge CFS	Vel. Str. hi or lo	Vel. dist.	Vel. sec.	Comments
4		MOR	11/21/98	07:02	J. Frincke	367	0	Hach	11/21/98		J. Frincke	9614	18.1	35.4	17.3	1 1	202	0.11855	0.12493	0.00638	0	368.9							
11		MOR	11/26/98	09:53	J. Frincke	123	0	Grab 2x6	11/27/98		J. Frincke	9614	22.9	246.2	223.3	1 1	429	0.1123	0.14999	0.03769	0	168.8		dn 39.5"			18'8"	4.24	
12	26	MOR	11/30/98	07:41	J. Frincke	67.1	0	Hach	11/30/98		J. Frincke	9614	17.9	37.2	19.3	1 1	450	0.12347	0.12433	0.00086	0	44.6		dn 48"			18'8"	4.85	
21	38	MOR	11/30/98	16:24	J. Frincke	39.8	0	PB 2x6	01/17/99	11:45	J. Frincke	9614	27.1	217.9	190.8	1 1	714	0.11646	0.1217	0.00524	0	27.5		dn 47"			18'8"	4.37	
21	39	MOR	12/02/98	14:05	B. Hanley	122	0	PB 2x6	01/17/99	12:02	J. Frincke	9614	24.7	271.5	246.8	1 1	725	0.1145	0.16388	0.04938	0	200.1		dn 32"			18'8"	3.90	
24	39	MOR	01/17/99	15:34	J. Frincke	24	0	PB 2x6	01/19/99	15:40	J. Frincke	9614	23.4	269.1	245.7	1 1	754	0.11362	0.11655	0.00293	0	11.9		54"			18'8"	7.76	
27	46	MOR	01/22/99	16:28	J. Frincke	48	0	PB 2x6	01/22/99	17:52	J. Frincke	9614	26.9	271.2	244.3	1 1	871	0.1146	0.12264	0.00804	0	32.9		49"			18'8"	6.80	
28	46	MOR	01/23/99	07:37	J. Frincke	33	0		01/23/99	16:11	J. Frincke	9614	168.7	393.9	225.2	1 1	886	0.11611	0.12148	0.00537	0	23.8		46"			18'8"	4.95,4.30	
45	59	MOR	02/08/99	15:18	J. Frincke	45.2	0	2x6	02/21/99	14:56	J. Frincke	9614	23	269.7	246.7	1 1	1233	0.10989	0.11458	0.00469	0	19.0		49.5"			18'8"	8.50,5.92	
46	55	MOR	02/24/99	16:02	J. Frincke	21	0	2x6	02/25/99	15:14	J. Frincke	9614	23.7	268.9	245.2	1 1	1156	0.10614	0.10792	0.00178	0	7.3		(1)			(1)	(1)	(1) "in notes"
47	60	MOR	02/24/99	20:01	J. Frincke	69.7	0	2x6	02/25/99	15:32	J. Frincke	9614	22.8	269.9	247.1	1 1	1251	0.10688	0.11786	0.01098	0	44.4		(1)			(1)	(1)	(1) "in notes"

Jacoby Creek - Morrison Gulch (MOR)

Compiled by Eric Nyman and Clark Fenton — ***Humboldt County, California***

Checked By C. Fenton — **Hydrologic Year 01**

Grab Sampling: Turbidity / Suspended Sediment Data - provisional

NS=Not Stated — **Salmon Forever / Sunny Brae Sediment Lab**

s. qUARRY rD
4' 11 TALL X 4' 3" WIDE
There is an existing dn stream staff plate not used by us
VEL IS MEASURED AT LIP OF CV 10' INTO CV

stage is measured as flo in bottom of 5' culvert

Sign in page #	Datashee #	Sample ID #	Location Sampled	Date Sampled	Time Sampled	Sampled By	Turbidity FTU	Tur. Code	Containe Type	Turbidity Date run	Turbidity Time run	Turbidity By	TUM S/N	Raw Stage	Stage inches	Discharge CFS	Vel. Str. hi or lo	Vel. dist. Ft.	Vel. sec.	Comments
17		01GR0299	MOR	01/08/01	10:00	B. Thompson	49.2	0	Hach Cel	01/21/01	17:14	J. Noel			5"			10	4.26	raining 5' cv dia.
																			5.44	
																			4.55	
12		01GR0396	MOR	01/09/01	16:45	B. Thompson	21.4	0	Hach Cel	01/11/01	18:10	J. Noel			4"			10	4.24	light rain
																			4.72	
																			4.12	
20		01GR0401	MOR	01/23/01	15:45	B. Thompson	11.5	0	Hach Cel	01/27/01	17:06	C. Fenton	22441		3.5"			10	3.02	raining
																			3.27	
																			3.01	
20		01GR0410	MOR	01/24/01	10:30	B. Thompson	27.6	0	Hach Cel	01/27/01	17:28	C. Fenton	22441		7"			10	2.10	lo vol. 5' cv - break in rain
																			2.41	
																			2.05	
21		01GR 0497	MOR	01/25/01	12:45	B. Thompson	200+	0	Hach Cel	01/27/01	18:14	C. Fenton								lo cell vol. No field form
		01GR 0476	MOR	02/19/01	11:15	B. Thompson	-	O VOL.							5.5			10	2.61	lo cell vol no turb.
																			2.83	
																			2.89	
52		01GR0575	MOR	02/21/01	10:55	B. Thompson	42.3	0	Hach Cel	02/22/01	21:00	CF/EN	22423		8.5"			10	1.71	sunny
																			1.50	
																			1.60	
		01GR 0583	MOR	02/22/01	9:45	B. Thompson	lo vol.								13.5			10	1.26	overcast
																			1.83	
																			1.48	
94		01GR 0593	MOR	04/06/01	16:21	B. Thompson	36.8	0	Hach Cel	04/13/01	23:07	C. Fenton	9614		7"			10	1.78	
																			1.78	
																			1.83	

Jacoby Creek - MM1.20 (MM1.20)

By Eric Nyman and Clark Fenton

Checked By C. Fenton

Humboldt County, California

Hydrologic Year 01

Grab Sampling: Turbidity / Suspended Sediment Data - provisional

NS=Not Stated

Salmon Forever / Sunny Brae Sediment Lab

PM 2.20

VEL IS MEASURED AT INSIDE OF CV 10 UPSTREAM TO DNSTEAM END

Stage is measured as culvert flow depth DNSTRM

Sign in page #	Datasheet #	Sample ID #	Location Sampled	Date Sampled	Time Sampled	Sampled By	Turbidity FTU	Tur. Code	Container Type	Turbidity Date run	Turbidity Time run	Turbidity By	TUM S/N	Raw Stage	Stage	Discharge CFS	Vel. Str. hi or lo	Vel. dist. Ft.	Vel. sec.	Comments
7		01GR0331	MM1.20	12/15/00	17:15	J. Dixon	28	0	Hach Cell	12/23/00	15:20	B. Thompson	22423					10	11.50	dry-rain 12-13-01 timing measurement taken on s. side of culvert- where pool stands - no depth marked yet
7		01GR0282	MM1.20	12/20/00	10:00	B. Thompson	6.86	0	Hach Cell	12/23/00	14:50	B. Thompson	22423		3					N. side of culvert - flo too low to time - 8.5x7.5 oval cv
17		01GR0355	MM1.20	01/08/01	10:15	B. Thompson	11.8	0	Hach Cell	01/21/01	17:15	J. Noel			7"					Yl. Brn. Sediment from road fill flowing into cv. UPSTREAM FILL SLOPE - light rain - flo too rocky to measure yet
12		01GR0398	MM1.20	01/09/01	16:53	B. Thompson	22.2	0	Hach Cell	01/11/01	18:12	J. Noel			4"			10	5.14	raining
																			4.92	
																			5.20	
20		01GR0420	MM1.20	01/23/01	16:05	B. Thompson	391	0	Hach Cell	01/27/01	17:09	CF	22441		3"			10	3.37	raining - sample from s-end / sed entering cv e-side not main flo - some researcher
																			3.76	has walked this feeder stream with a marker stream since last visit 1-9-01
																			3.12	
21		01GR0496	MM1.20	01/25/01	12:35	B. Thompson	567	0	Hach Cell	01/27/01	17:52	CF	22441		9"			10	1.08	8'6"x7'6" cv
																			1.40	
																			1.20	
51		01GR0490	MM1.20	02/19/01	08:25	B. Thompson	22.3	0	Hach Cell	02/22/01	20:35	CF/EN	22423		2"			10	2.90	
																			2.70	
																			2.67	
52		01GR0574	MM1.20	02/21/01	10:35	B. Thompson	86.9	0	Hach Cell	02/22/01	20:56	CF/EN	22423		5.5			10	1.56	cv size 8'6" x 7' 6"
																			1.53	
																			1.60	
94		01GR 0592	MM 1.20	04/06/01	16:35	B. Thompson	159	0	Hach Cell	04/13/01	23:08	C. Fenton	9614		6.5			10	1.45	RL
																			1.45	
																			1.42	

Jacoby Creek MM 1.65 (MM1.65)

Humboldt County, California

Hydrologic Year 98 - 99

Grab Sampling: Turbidity / Suspended Sediment Data - provisional

Salmon Forever / Sunny Brae Sediment Lab

Compiled by Nate Lomba and Clark Fenton

Checked By C. Fenton

Stage is measured at ...

Sign in page #	Datasheet #	Location Sampled	Date Sampled	Time Sampled	Sampled By	Turbidity FTU	Tur. Code	Container Type	Turbidity Date run	Turbidity Time run	Turbidity By	TUM S/N	Tare Bottle Weight g	Total Bottle Weight g	Volume/ Bottle Wt	Filter Total	Filter ID	Initial Filter Weight g	Final Filter Weight g	Sediment Wt.	Lab Code		Total Mg/L	Stage	Discharge CFS	Vel. dist.	Vel. sec.	Comments
4		MM1.65	11/21/98	6:55	J. Frincke	532	0	Hach Cell	11/21/98		J. Frincke	9614	18.6	38.2	19.6	1 1	204	0.11722	0.13081	0.01359	0		693.7	10.5"				
11		MM1.65	11/26/98	9:44	J. Frincke	279	0	Grab 2x6	11/27/98		J. Frincke	9614	24.4	187.1	162.7	1 1	428	0.11693	0.17191	0.05498	0		338.0	dn 28.0"		15'	2.86	
																											3.13	
12	26	MM1.65	11/30/98	7:33	J. Frincke	254	0	Hach Cell	11/30/98		J. Frincke	9614	18.3	37.2	18.9	1 1	449	0.12313	0.12676	0.00363	0		192.1	dn 37"		15'	2.66	
21	38	MM1.65	12/02/98	14:20	B. Hanley	244	0	PB 2x6	01/17/99	12:04	J. Frincke	9614	24.8	237.3	212.5	1 1	715	0.11413	0.12545	0.01132	0		53.3	dn 32"		15'	2.31	
24	39	MM1.65	01/17/99	16:18	J. Frincke	31.9	0	PB 2x6	01/19/99	15:44	J. Frincke	9614	24	261	237	1 1	755	0.11405	0.11666	0.00261	0		11.0	45.5"		15'	4.33	
27		MM1.65	01/22/99	16:11	J. Frincke	171	0	PB 2x6	01/22/99	17:48	J. Frincke	9614	22.6	270.8	248.2	1 2	869	0.1108	0.12625	0.01545	0		42.3	36.5"		15'	2.56	
													22.6	270.8	248.2	2 2	870	0.11582	0.11578	-0.00004	1		-0.2					
																						Total	42.1					
28	46	MM1.65	01/23/99	7:18	J. Frincke	60	0	PB 2x6	01/23/99	16:11	J. Frincke	9614	23.1	264.4	241.3	1 1	872	0.11576	0.12415	0.00839	0		34.8	33.5"		15'	8.2.98.2.14	
45	59	MM1.65	02/08/99	14:59	J. Frincke	40.7	0	PB 2x6	02/21/99	14:52	J. Frincke	9614	22.9	269.4	246.5	1 1	1230	0.10736	0.11176	0.00440	0		17.9	41"		15'	2.98	
45		MM1.65	02/18/99	13:11	J. Frincke	54.8	0	PB 2x6	02/21/99	15:09	J. Frincke	9614												36"		15'	3.19	
45	60	MM1.65	02/18/99	16:43	J. Frincke	42.8	0	---	02/21/99	15:16	J. Frincke	9614	18.1	36.8	18.7	1 1	1241	0.1092	0.10935	0.00015	0		8.0	36"		15'	2.63	
46	55	MM1.65	02/24/99	16:11	J. Frincke	22.9	0	PB 2x6	02/25/99	15:16	J. Frincke	9614	24	269.7	245.7	1 1	1157	0.10516	0.10822	0.00306	0		12.5	(1)		(1)	(1)	(1) "in notes"
46	56	MM1.65	02/24/99	19:42	J. Frincke	84.8	0	PB 2x6	02/25/99	15:27	J. Frincke	9614	25.6	270	244.4	1 1	1220	0.10672	0.12503	0.01831	0		74.9	(1)		(1)	(1)	(1) "in notes"
21		MM1.65	11/30/98	14:40	B. Hanley	74.4	0	PB 2x6	01/17/99	11:38	J. Frincke	9614												dn 33"		15'	2.62	

Jacoby Creek - MM1.65 (MM1.65)

Compiled by Eric Nyman and Clark Fenton

Humboldt County, California

Checked By C. Fenton

Hydrologic Year 01

Grab Sampling: Turbidity / Suspended Sediment Data - provisional

NS=Not Stated

Salmon Forever / Sunny Brae Sediment Lab

MAIN CV AND FLOOD CV NEED TO BE OVER 1,5' STAGE TO SECOND CV

VEL IS MEASURED UPSTREAM 10' OF CV

Stage is measured as depth of flo in b[illegible] Floating Obj.

Sign in page #	Datashee #	Sample ID #	Location Sampled	Date Sampled	Time Sampled	Sampled By	Turbidity FTU	Tur. Code	Container Type	Turbidity Date run	Turbidity Time run	Turbidity By	TUM S/N	Raw Stage	Stage inches	Discharge CFS	Vel. Str. hi or lo	Vel. dist. Ft	Vel. sec.	Comments
17		01GR0054	MM 1.65	01/08/01	10:30	B. Thompson	92.3	0	Hach Cell	01/21/01	17:10	J. Noel			2.5					36" cv
13		01GR0397	MM 1.65	01/09/01	17:00	B. Thompson	15.2	0	Hach Cell	01/11/01	18:11	J. Noel			4"			10	5.92	raining
																			4.25	
																			5.29	
20		01GR0421	MM 1.65	01/23/01	16:25	B. Thompson	183	0	Hach Cell	01/27/01	17:13	C. Fenton	22441		3.5"			5	1.86	raining - vel. Is going into cv from 10' upstream
																			1.59	
																			1.84	
21		01GR0495	MM 1.65	01/25/01	12:25	B. Thompson	158	0	Hach Cell	01/27/01	17:50	C. Fenton	22441		12"			10	1.82	raining 36" cv
																			2.12	
																			2.02	
52		01GR0489	MM 1.65	02/21/01	10:18	B. Thompson	35.1	0	Hach Cell	02/22/01	20:53	CF/EN	22423		6"			10	1.21	cv size 3'
																			1.41	
																			1.43	
94		01GR 0578	MM 1.65	04/06/01	16:48	B. Thompson	51.5	0	Hach Cell	04/13/01	23:09	C. Fenton	9614		3"			10	1.04	3' cv
																			1.10	
																			1.07	

Jacoby Creek - Snag Creek (SNAG)

Jacoby Creek Road (C4K230) 3.3 miles east of Old Arcata Road

Compiled by Nate Lomba and Clark Fenton

Humboldt County, California

Checked By C. Fenton

Hydrologic Year 01

Grab Sampling: Turbidity / Suspended Sediment Data - provisional

DH/TH = Tom and Debbie Hartman

Salmon Forever / Sunny Brae Sediment Lab

Sample is taken at upstream end of 84" round metal pipe culvert under Jacoby Creek Road

Jacoby Creek - Snag Creek (SNAG)

Jacoby Creek Road (C4K230) 3.3 miles east of Old Arcata Road

Humboldt County, California

Hydrologic Year 01

Grab Sampling: Turbidity / Suspended Sediment Data - provisional

Salmon Forever / Sunny Brae Sediment Lab

GAGE is a metal pipe in streambed in Debbie Hartman's back yard

Velocity is floating object measured 10' above culvert

Stage is depth of flo in bottom of 84" culvert at upstream edge of culvert

Sign in page #	Datasheet #	Location Sampled	Date Sampled	Time Sampled	Sampled By	Turbidity FTU	Tur. Code	Container Type	Turbidity Date run	Turbidity Time run	Turbidity By	TUM S/N	Tare Bottle Weight g	Total Bottle Weight g	Volume/ Bottle Wt.	Filter Total	Filter ID	Initial Filter Weight g	Final Filter Weight g	Sediment Wt.	Lab Code		Total Mg/L	Raw Stage	Stage	Discharge CFS	Vel. Str. hi or lo	Vel. dist.	Vel. sec.	Comments
4		SNAG	11/21/98	06:50	J. Fricke	809	0	Hach	11/21/98		J. Fricke	9614	18.3	37.7	19.4	1 1	207	0.11538	0.14399	0.02861	0		1476.1		58.5"					
11	25	SNAG	11/26/98	09:37	J. Fricke	661	0	Grab 2x6	11/27/98		J. Fricke	9614	23.1	223.8	200.7	1 2	426	0.11251	0.26604	0.15353	0		765.3		dn 67.0"			10'	2.99	
	25												23.1	223.8	200.7	2 2	427	0.11561	0.15304	0.03743	0		186.5						1.63	
	25																					Total	951.8						2.52	
12	26	SNAG	11/30/98	07:23	J. Fricke	543	0	Hach	11/30/98		J. Fricke	9614	18	36.1	18.1	1 1	448	0.12127	0.13108	0.00981	0		542.2		dn 77"			10'	2.52	
21	38	SNAG	11/30/98	16:52	J. Fricke	207	0	PB 2x6	01/17/99	11:47	J. Fricke	9614	23.5	248.7	225.2	1 1	716	0.11592	0.17390	0.05798	0		257.5		dn 77" cv			10'	3.30	
22	39	SNAG	12/02/98	14:35	DH/TH	428	0	PB 2x6	01/17/99	12:27	J. Fricke	9614	23.9	252.4	228.5	1 3	729	0.11594	0.22343	0.10749	0		470.6	hi/peak 24"	14"			16'	2.19	"note: all Snag Creek stages now done on stage gage
	39												23.9	252.4	228.5	2 3	730	0.11377	0.17620	0.06243	0		273.3							hence high and current readings"
	39												23.9	252.4	228.5	3 3	731	0.11505	0.14133	0.02628	0		115.0							
	39																					Total	858.9							
22	39	SNAG	12/13/98	11:45	DH/TH	19.3	0	PB 2x6	01/17/99	12:29	J. Fricke	9614	24.2	162.7	138.5	1 1	732	0.11413	0.11613	0.00200	0		14.4		0 (1)			16'	16.68	(1) "not registering"
22	39	SNAG	01/14/99	22:10	DH/TH	131	0	PB 2x6	01/17/99	12:30	J. Fricke	9614	23.3	221.2	197.9	1 1	733	0.11445	0.13985	0.02540	0		128.4		1"			16'	14.02	
27	46	SNAG	01/17/99	16:30	DH/TH	69	0	PB 2x6	01/22/99	17:34	J. Fricke	9614	24.5	232.5	208	1 1	866	0.11569	0.12522	0.00953	0		45.8		0			16'	8.88	
44	59	SNAG	01/23/99	13:00	DH/TH	51.4	0	2x6	02/21/99	14:11	J. Fricke	9614	23.4	268.3	244.9	1 1	1235	0.10653	0.12401	0.01748	0		71.4		5.0"			16'	4.19	PVC high mark = 23"
44	59	SNAG	02/06/99	11:20	DH/TH	340	0	2x6	02/21/99	14:26	J. Fricke	9614	27.7	230.7	203	1 2	1223	0.10814	0.18302	0.07488	0		369.0		6" (1)			16'	3.69	(1) high mark = 13"
	59												27.7	230.7	203	2 2	1224	0.10700	0.19981	0.09281	0		457.3							
	59																					Total	826.3							
44	59	SNAG	02/07/99	11:45	DH/TH	111	0	2x6	02/21/99	14:30	J. Fricke	9614	25	246.3	221.3	1 1	1225	0.10933	0.15214	0.04281	0		193.5		7" (1)			16'	3.21	(1) high mark = 17"
45	59	SNAG	02/08/99	17:20	DH/TH	66.6	0	2x6	02/21/99	15:00	J. Fricke	9614	23.9	260.1	236.2	1 1	1234	0.10719	0.21937	0.11218	0		475.1		2.5"			16'	8.23	
45	59	SNAG	01/20/99	12:00	DH/TH	45.6	0	2x6	02/21/99	15:19	J. Fricke	9614	26.2	268.3	242.1	1 1	1232	0.10719	0.11507	0.00788	0		32.5		1" (1)			16'	5.87	(1) high mark = 16"
45	59	SNAG	02/13/99	16:15	DH/TH	29	0	2x6	02/21/99	15:05	J. Fricke	9614	25	263.8	238.8	1 1	1236	0.10739	0.11120	0.00381	0		16.0		0			16'	6.00	
46		SNAG	02/24/99	16:17	J. Fricke	29	0	2x6	02/25/99	15:18	J. Fricke	9614													(1)			(1)	(1)	(1) "in notes"
46	56	SNAG	02/24/99	19:36	J. Fricke	97	0	2x6	02/25/99	15:24	J. Fricke	9614	24.1	265.8	241.7	1 1	1217	0.10908	0.14489	0.03581	0		146.2		(1)			(1)	(1)	(1) "in notes"

Jacoby Creek - Snag Creek (SNAG)

By Eric Nyman and Clark Fenton

Checked By C. Fenton

Humboldt County, California

Hydrologic Year 01

Grab Sampling: Turbidity / Suspended Sediment Data - provisional

NS=Not Stated

Salmon Forever / Sunny Brae Sediment Lab

RMP

GAGE IS MMEASURED DEBBIES BK YD

VEL MEASURED 10' INTO CV AT UPSTREAM END WATCH GO INTO CV

Raw stage is depth of flo in bottom of 7' culvert UPSTREAM EDGE OF CV

Stage is measured at gauge

Sign in page #	Datasheet #	Sample ID #	Location Sampled	Date Sampled	Time Sampled	Sampled By	Turbidity FTU	Tur. Code	Container Type	Turbidity Date run	Turbidity Time run	Turbidity By	TUN S/N	Raw Stage	Stage	Discharge CFS	Vel. Str. hi or lo	Vel. dist. Ft.	Vel. sec.	Comments
8		01GR0258	SNAG	12/23/00	14:35	G. Blue	6.92	0	Hach Cell	12/23/00	16:12	B. Thompson			9.5			10	18.10	width at waterline 47" - need to relocate gage- used tape measure
17		01GR0394	SNAG	01/08/01	10:40	G. Blue	13.8	0	Hach Cell	01/21/01	17:11	J. Noel			2.5"					7' cv no new dings
20		01GR0422	SNAG	01/23/01	16:35	B. Thompson	13.5	0	Hach Cell	01/01/01	17:15	C. Fenton	22441	2.5				10	2.03	7"cv vel. From interior of cv - 2" of concrete on bottom of culvert
																			1.16	
																			1.34	
21		01GR0494	SNAG	01/25/01	12:15	B. Thompson	206	0	Hach Cell	01/27/01	17:47	C. Fenton	22441	9.5				10	1.21	7' cv sunny
																			1.01	
																			1.16	
19		01GR0259	SNAG	01/25/01	12:55	G. Blue	246	0	Hach Cell	01/27/01	16:26	C. Fenton		74cvinv 10" flo	3"			10	2.59	84"cv?
																			2.51	
																			2.63	
52		01GR0480	SNAG	02/21/01	10:00	B. Thompson	58.3	0	Hach Cell	02/22/01	20:49	CF/EN	22423	7				10	1.34	cv size 7'
																			1.59	
																			1.33	
95		01GR 0687	SNAG	04/06/01	17:05	B. Thompson	202	0	Hach Cell	04/13/01	23:11	C. Fenton	9614	6.5				10	1.27	7' cv
																			1.29	
																			1.41	

Jacoby Creek -Eric Lane (ERIC)

Humboldt County, California

Hydrologic Year 98 - 99

Grab Sampling: Turbidity / Suspended Sediment Data - provisional

Salmon Forever / Sunny Brae Sediment Lab

Compiled by Nate Lomba and Clark Fenton

Checked By C. Fenton

Eric Lane Jacoby

Stage is measured at ...

Sign in page #	Datasheet #	Location Sampled	Date Sampled	Time Sampled	Sampled By	Turbidity FTU	Tur. Code	Container Type	Turbidity Date run	Turbidity Time run	Turbidity By	TUM S/N	Tare Bottle Weight g	Total Bottle Weight g	Volume/ Bottle Wt.	Filter Total	Filter ID	Initial Filter Weight g	Final Filter Weight g	Sediment Wt.	Lab Code	Sand Fr. Mg/L	Total Mg/L	Stage	Discharge CFS	Vel. dist.	Vel. sec.	Comments
4		ERIC	11/21/98	06:42	J. Frincke	1000+	1	Hach Cell	11/21/98		J. Frincke	9614	18.2	37.4	19.2	1 1	201	0.11126	0.14781	0.03655	0		1905.9					
11		ERIC	11/26/98	09:32	J. Frincke	441	0	PB 2x6	11/27/98		J. Frincke	9614	24	244.1	220.1	1 1	425	spilled			0		0.0	dn 22.0"		15'	3.45	
12	26	ERIC	11/30/98	07:17	J. Frincke	1000 +	1	Hach Cell	11/30/98		J. Frincke	9614	17.9	36.9	19.0	1 1	447	0.12045	0.15418	0.03373	0		1777.0	dn 24.5"		15'	4.52	
21	38	ERIC	11/30/98	16:58	J. Frincke	1000+	1	PB 2x6	01/17/99	11:50	J. Frincke	9614	22.6	247.1	224.5	1 3	717	0.11453	0.16782	0.05329	0		237.4	dn 24"		15'	3.95	
	38												22.6	247.1	224.5	2 3	718	0.11517	0.17120	0.05603	0		249.6				4.39	
	38												22.6	247.1	224.5	3 3	719	0.11454	0.32927	0.21473	0		957.1					
	38																					Total	1444.1					
24		ERIC	01/17/99	16:25	J. Frincke	1000+	1	PB 2x6	01/19/99	15:46	J. Frincke	9614												29"		15'	4.35	
27	46	ERIC	01/22/99	15:59	J. Frincke	454	0	PB 2x6	01/22/99	17:46	J. Frincke	9614	25.3	273.5	248.2	1 2	867	0.11328	0.20374	0.09046	0		364.5	26"		15'	3.43	
	46												25.3	273.5	248.2	2 2	868	0.11531	0.11795	0.00264	0		10.6					
																						Total	375.1					
28	46	ERIC	01/23/99	07:09	J. Frincke	177	0	PB 2x6	01/23/99	16:11	J. Frincke	9614	23.8	262.6	238.8	1 2	873	0.11664	0.12807	0.01143	0		47.9	29"		15'	4.09	
	46												23.8	262.6	238.8	2 2	874	0.11661	0.13400	0.01739	0		72.8					
																						Total	120.7					
45	59	ERIC	02/08/99	14:51	J. Frincke	234	0	PB 2x6	02/21/99	14:48	J. Frincke	9614	23.4	265.4	242.0	1 1	1229	0.10845	0.14335	0.03490	0		144.2	41"		15'	9.02	
45	59	ERIC	02/18/99	13:51	J. Frincke	101	0	PB 2x6	02/21/99	15:12	J. Frincke	9614	22.3	267.1	244.8	1 2	1238	0.10851	0.10814	-0.00037	1		-1.5	29"		15'	7.80,8.13	
	59												22.3	267.1	244.8	2 2	1239	0.10700	0.12266	0.01566	0		64.0					
	59																					Total	62.5					
45	59	ERIC	02/18/99	16:34	J..Frincke	122	0	Hach Cell	02/21/99	15:14	J. Frincke	9614	18.3	36.5	18.2	1 1	1240	0.10647	0.12266	0.01619	0		890.1	28"		15'	6.10	

Jacoby Creek - Eric Creek (ERIC)

Compiled by Eric Nyman and Clark Fenton

Checked By C. Fenton

NS=Not Stated

Humboldt County, California

Hydrologic Year 01

Grab Sampling: Turbidity / Suspended Sediment Data - provisional

Salmon Forever / Sunny Brae Sediment Lab

RMP

gERRY'S GAGE 20' UPSTREAM OF CV - YARDSTICK TIED TO MP

VEL IS MEASURED GAGE DNSTRM OR 10' UPSTRM OF CV TO CV | floating object

DEPTH FROM ROCK W/YL MARK TO CV BASE IS 46.5"

Raw stage is measured as inches down(culvert invert) in a 36" culvert

Stage is measured as inches of flow in bottom of culvert

Sign in page #	Datasheet #	Sample ID #	Location Sampled	Date Sampled	Time Sampled	Sampled By	Turbidity FTU	Tur. Code	Container Type	Turbidity Date run	Turbidity Time run	Turbidity By	TUM S/N	Raw Stage	Stage	Discharge CFS	Vel. Str. hi or lo	Vel. dist. ft.	Vel. sec.	Comments
8		01GR0255	ERIC	12/23/00	14:00	G. Blue	237	0	Hach Cell	12/23/00	16:05	B. Thompson		5.75'@gage				10	9.57	1st sample moderate rain
12		01GR0257	ERIC	01/08/01	14:30	G. Blue	174	0	Hach Cell	1/11/01	18:06	J. Noel		31" cv inv. 7" @gage	5			10	5.19	cloudy - 2 depth measurements yardstick/culvert
																			5.00	
																			6.10	
17		01GR0354	ERIC	01/08/01	10:50	G. Blue	545	0	Hach Cell	1/21/01	17:12	J. Noel		8.5gb gage 31" cv in	5"			10	3.27	sample is free of eric ln /junction runoff
																			3.66	
																			3.72	
12		01GR0301	ERIC	01/09/01	15:30	G. Blue	172	0	Hach Cell	1/11/01	18:07	J. Noel		5.75" @gage	3"			10	9.44	lite rain raining last 36 hours on/off
																			12.10	
																			10.62	
19		01GR0261	ERIC	01/10/01	18:45	G. Blue	211	0	Hach Cell	1/27/01	16:20	C. Fenton		8.5"@gage 30" inv.	6			10	3.94	drizzle - 36" culvert - taking readings at original site next to gage
																			3.97	
																			3.25	
20		01GR0423	ERIC	01/23/01	16:50	G. Blue	1000+	1	Hach Cell	1/27/01	17:19	C. Fenton			8"			10	2.79	break in rain
																			2.48	
																			2.82	
19		01GR0262	ERIC	01/25/01	12:45	G. Blue	640	0	Hach Cell	1/27/01	16:23	C. Fenton		11.25@gage 26.5inv.	9.5			10	2.16	sunny
																			2.31	
																			2.32	
21		01GR0493	ERIC	01/25/01	12:05	G. Blue	1000+	1	Hach Cell	1/27/01	17:44	C. Fenton	22441	12"@gage	6"			10	1.78	3' cv 12" on gb gauge light rain
																			1.90	
																			2.01	
51		01GR 0491	ERIC	02/19/01	07:55	B. Thompson	-													lo cell vol.
52		01GR0479	ERIC	02/21/01	09:50	G. Blue	148	0	Hach Cell	2/22/01	20:47	CF/EN	22423	7"@gage	5.5			10	4.06	sunny
																			3.95	
																			3.29	
56		01GR0297	ERIC	02/22/01	09:00	G. Blue	86.5	0	Hach Cell	2/27/01	11:58	D. Vdyke		8.5"@gage - 28"inv.	8"			10	5.17	drizzle
																			4.68	
																			5.40	
56		01GR0300	ERIC	02/23/01	13:45	G. Blue	53.8	0	Hach Cell	2/27/01	12:01	D. Vdyke		6"gage - 32.5"inv.	3.5"			10	7.90	
																			8.60	
																			8.56	
76		01GR 0596	FAILED CV	03/05/01	11:00	B. Thompson	53.1	0	Hach Cell	3/19/01	11:55	DVD	9614							Water flows in one end of cv and out
			ERIC LN																	along it's side on downstream side - upstream sample
76		01GR 0597	FAILED CV	03/05/01	11:00	B. Thompson	56.5	0	Hach Cell	3/19/01	11:58	DVD	9614							no water thru 32' culvert
			ERIC LN																	
94		01GR 0579	ERIC	04/06/01	16:58	B. Thompson	427	0	Hach Cell	4/13/01	23:10	C. Fenton	9614	9" on gage				10	1.12	R.L.
																			1.08	
																			1.32	

Jacoby Creek - Rebel Creek (Rebel)

Compiled by Nate Lomba and Clark Fenton

Checked By C. Fenton

Humboldt County, California

Hydrologic Year 99

Grab Sampling: Turbidity / Suspended Sediment Data - provisional

Salmon Forever / Sunny Brae Sediment Lab

Stage is measured at ...

Sign in page #	Datasheet #	Location Sampled	Date Sampled	Time Sampled	Sampled By	Turbidity FTU	Tur. Code	Container Type	Turbidity Date run	Turbidity Time run	Turbidity By	TUM S/N	Tare Bottle Weight g	Total Bottle Weight g	Volume/ Bottle Wt.	Filter Total	Filter ID	Initial Filter Weight g	Final Filter Weight g	Sediment Wt.	Lab Code	Total Mg/L	Stage	Discharge CFS	Vel. Str. hi or lo	Vel. dist.	Vel. sec.	Comments
22	39	Rebel	12/2/98	15:10	B. Hanley	54	0	PB 2x6	1/17/99	12:06		9614	27.2	269.1	241.9	1 1	728	0.11414	0.15638	0.04224	0	174.6	24"			20'	3.53	

Jacoby Creek - Rebel 1 and 2 (RC1 / RC2)

By Eric Nyman and Clark Fenton

Humboldt County, California

Checked By C. Fenton

Hydrologic Year 01

Grab Sampling: Turbidity / Suspended Sediment Data - provisional

NS=Not Stated

Salmon Forever / Sunny Brae Sediment Lab

REBEL1 IS UPSTREAM 1/10 MI OF REB 2 ON UPPER CREEK RD VEL MEASURED AT FROM UPSTREAM OF CV TO CV LIP STGAE FROM TOP OF CV RMP

REB 2 IS ON jAC cRK RD RMP 3" BOTTOM FILLER OF CONCRET VEL 10' UPSTREAM TO CV LIP

Stage is measured as inches flo in bottom of 4' concrete culvert-rebel 1

Stage is measured as inches flo in bottom of 6' concrete culvert-rebel 2

Sign in page #	Datasheet #	Sample ID #	Location Sampled	Date Sampled	Time Sampled	Sampled By	Turbidity FTU	Tur. Code	Container Type	Turbidity Date run	Turbidity Time run	Turbidity By	TUM S/N	Raw Stage	Stage inches	Discharge CFS	Vel. Str. hi or lo	Vel. dist. ft.	Vel. sec.	Comments
7		01GR0334	REBEL	12/13/00	21:30	J. Dixon	9.29	0	Hach Cel	12/23/00	15:28	B. Thompson	22423							at culvert drizzling - rain start this afternoon - at peak stage - no depth marked yet
7		01GR0329	Rebel	12/13/00	09:00	J. Dixon	6.48	0	Hach Cel	12/23/00	15:35	B. Thompson	22423							clear
7		01GR0330	Rebel	12/14/00	10:40	J. Dixon	33.10	0	Hach Cel	12/23/00	15:31	B. Thompson	22423							7' cv clear rain start 12-13-01 - no depth marked yet
41		01GR0357	REBEL 1	01/09/01	11:30	J. Dixon	23.30	0	Hach Cel	2/14/01	19:00	CF/DVD						10	7.50	raining - measure vel. thru congested area?
41		01GR0360	REBEL 1	01/12/01	11:00	J. Dixon	19.60	0	Hach Cel	2/14/01	19:14	CF/DVD			4"			10	13.33	placed measurement marker in stream today.
21		01GR0412	REBEL 1	01/25/01	11:45	B. Thompson	94.90	0	Hach Cel	1/27/01	17:39	C. Fenton	22441		6"			10	1.96	4' cv light rain
																			1.86	
																			1.82	
55		01GR0274	REBEL 1	02/17/01	12:15	J. Dixon	12.90	0	Hach Cel	2/27/01	11:37	DVD			2.5"			10	13.00	cv size 3.5'
51		01GR0477	REBEL 1	02/21/01	09:15	B. Thompson	39.40	0	Hach Cel	2/22/01	20:40	CF/EN	22423		6"			10	2.42	cv size 4'
																			2.77	
																			2.55	
55		01GR0273	REBEL 1	02/21/01	14:00	J. Dixon	39.10	0	Hach Cel	2/27/01	11:41	DVD			7"			10	4.00	cv size 3.5' hi vel width 30"
56		01GR0270	REBEL 1	02/21/01	17:00	J. Dixon	34.10	0	Hach Cel	2/27/01	11:46	DVD			7"			10	3.00	cv size 3.5' rain just starting
76		01GR 0712	REBEL 1	03/02/01	16:00	J. Dixon	27.30	0	Hach Cel	3/19/01	11:40	DVD	9614		5			10	6.50	hi vel width 22"
76		01GR 0713	REBEL 1	03/03/01	13:00	J. Dixon	43.70	0	Hach Cel	3/19/01	11:45	DVD	9614		8.5			10	3.50	hi vel width 33" - sprinle
95		01GR 0688	REBEL 1	04/06/01	17:20	B. Thompson	51.30	0	Hach Cel	4/13/01	23:12	C. Fenton	9614		4			10	1.20	4' cv
																			1.34	
																			1.29	
103		01GR 0715	REBEL 1	04/20/01	11:00	J. Dixon	17.20	0	Hach Cel	4/27/01	8:57	C. Fenton	9614		3			10	10.00	width 19" - 3' cv
41		01GR0356	Rebel 2	01/08/01	16:40	J. Dixon	34.20	0	Hach Cel	2/14/01	18:52	CF/DVD						10	3.50	at cv - moved measurement of vel. To cv from rocks
41		01GR0361	Rebel 2	01/09/01	11:12	J. Dixon	20.10	0	Hach Cel	2/14/01	19:17	CF/DVD			3.5			10	2.00	raining - started 11 am
41		01GR0358	Rebel 2	01/10/01	21:16	J. Dixon	38.20	0	Hach Cel	2/14/01	19:06	CF/DVD			7.5			10	2.00	
20		01GR0424	REBEL2	01/22/01	17:00	B. Thompson	58.30	0	Hach Cel	1/27/01	17:00	C. Fenton			2"			10	1.76	vel. Taken 10' inside cv
																			1.94	
																			1.54	
21		01GR0413	Rebel 2	01/25/01	11:55	B. Thompson	256.00	0	Hach Cel	1/27/01	17:41	C. Fenton	22441		10"			10	1.11	light rain
																			1.15	
																			1.03	
56		01GR0271	Rebel 2	02/07/01	12:18	J. Dixon	10.90	0	Hach Cel	2/27/01	11:49	DVD			2"			10	7.00	cv size 6'
41		01GR0359	Rebel 2	02/11/01	12:00	J. Dixon	38.50	0	Hach Cel	14-Feb	19:11	CF/DVD			5.5			10	3.00	measured 64.5 in from culvert top - 2 inches of concrte?
56		01GR0269	Rebel 2	02/18/01	01:30	J. Dixon	28.00	0	Hach Cel	2/27/01	11:51	DVD			5"			10	5.00	cv size 6'
52		01GR 0478	Rebel 2	02/21/01	09:30	B. Thompson	59.10	0	Hach Cel	2/22/01	20:43	CF/EN	22423		3.5			10	1.31	
																			1.29	
																			1.13	
56		01GR0272	Rebel 2	02/21/01	17:00	J. Dixon	36.50	0	Hach Cel	2/27/01	11:54	DVD			6.5"			10	2.75	cv size 6'
76		01GR 0714	Rebel 2	03/03/01	13:30	J. Dixon	95.50	0	Hach Cel	3/19/01	11:50	DVD	9614		9			10	3.00	hi vel. Width 48" at cv
																			2.00	
102		01GR 0716	REBEL 2	03/28/01	12:00	J. Dixon	5.27	0	Hach Cel	4/27/01	8:51	C. Fenton	9614		6				4.00	rain last night - currentl dry
102		01GR 0717	REBEL 2	3/28 TO 4/2		J. Dixon	33.70	0	Hach Cel	4/27/01	8:53	C. Fenton	9614							
102		01GR 0728	REBEL 2	04/02/01	21:00	J. Dixon	18.30	0	Hach Cel	4/27/01	8:54	C. Fenton	9614		5			10	4.50	6' cv
																			5.00	
103		01GR 0731	REBEL 2	04/04/01	12:45	J. Dixon	42.00	0	Hach Cel	4/27/01	8:55	C. Fenton	9614		6			10	2.50	STRAND WIDTH 46"
																			3.00	
95		01GR 0689	REBEL 2	04/06/01	17:35	B. Thompson	162.00	0	Hach Cel	4/13/01	23:13	C. Fenton	9614		8			10	1.11	light rain
																			1.09	
																			1.02	
103		01GR 0729	REBEL 2	04/20/01	11:00	J. Dixon	15.80	0	Hach Cel	4/27/01	8:56	C. Fenton	9614		4			10	6.00	strand width 37" rain just started overcast now

SALMON FOREVER
Watershed Watch Grab Sampling Protocols
Turbidity and Suspended Sediment
How-to Guide for Volunteers
9-4-99

A. SAFETY FIRST!

1. Establish a safe path to the site: streambanks are soft and slippery.
2. Be careful! Please don't wade when you sample. We want all the grab samples to be consistently from the streambank. Remember, when you go out in the field, you do so as a volunteer and must assume responsibility for your own safety. Please take your time and be careful.

Before the rainy season:

B. PREPARING SAMPLE CONTAINERS

Sample containers and glassware must be cleaned and rinsed before the first sampling run and after each run. The lab may prep containers for volunteers beforehand. If there are dirty bottles in the lab when you sign-in your samples, please try to clean some for everyone else.

The following method should be used when preparing all sample containers and glassware for monitoring.

1. Wash each sample bottle with a brush and phosphate-free detergent.
2. Rinse three times with cold tap water.
3. Rinse twice with distilled or de-ionized water.

C. MATERIALS AND TOOLS NEEDED

Sample bottles
Stopwatch
Rite in the Rain note paper or book w/pencil
Tape measure
Orange peel or floating object for velocity
Bottle of HCL solution (for sterilizing sample after turbidity is run)
Waterproof boots and raingear
Flashlight or headlamp
Staff Gauge for measuring water depth. This can be:

1. 1- 1/4" or 1- 1/2" metal pipe staff gauge (to be driven into streambed in flatwater just upstream or downstream of the velocity gauging section)
2. Rod with markings driven in streambed
3. Marks on bridge piers or culverts

D. ESTABLISHING THE SITE

Before the rainy season begins, new sites need to be established. Existing sites must be checked for maintenance issues and accessibility. Know the route to your site and establish an alternate route and/or somebody else to sample in case of road flooding. Ask permission if a site is to be established on private property.

1. Locate a safe water-sampling site and give it a short name. (HH, SFELK, GG etc..)
2. Locate the appropriate site to measure water height. Measure down from a bridge guardrail, or measure water level on staff/stage gauge. Find a spot safe from flooding and one you can read at high water level.
3. Establish the velocity gauging section of the creek (straight, uniform stream reach, long enough to give velocities in the 6-12 second range at high flow if possible).
4. Measure the cross sectional area at the velocity gauging section. This can be accomplished during the flow by measuring flow depth at 1.0-foot intervals as you cross the stream but must also be correlated to the stream gauge. This needs to be established once or twice a year or more often if the creek bed or banks change. Others can help with this.
5. Photograph the site and make a location map. Make a photocopy of a topographic map of the area with the sampling location marked if possible and give to the your watershed coordinator or the SunnyBrae Lab.

E. WHEN TO MONITOR

Try to sample as the creek rises and throughout the storm event and as the water begins to go down. The goal is to collect representative samples that illustrate the full range of stream flow. A hydrograph, showing the rise and fall of water level in a creek, and the corresponding rise and fall of turbidity levels and PPM of sediment during a storm event will be produced with this data. The data will also show when turbidity levels that are injurious or lethal to salmonids are occurring and what sediment loads the individual creek is carrying. It is most useful to sample near the peak of the flows to get a good representation of the highest discharges (up to 90% of sediment transport may occur during high flow events). Photograph at the high stage!

1. Sample after the rain starts
2. As the creek rises (for long storms, sample at several stages.)
3. Sample at the **peak**, if at all possible
4. Sample as the creek falls (if it is a long duration storm, sample at several stages.)
5. During quiet times between storms you can minimize your samples and save the bottles for the next storm.

F. INFORMATION NEEDED FOR EACH SAMPLE

1. Location, date, time, who sampled and the approximate elapsed time since start of the storm
2. Record the staff/stage gauge water level (or distance down from the bridge guardrail) to the **nearest 1/2 an inch.**
3. Measure velocity (elapsed time for a floating object to pass through a measured section) to the **nearest tenth of a second and nearest 1/2 an inch.** If there is a high velocity strand and a low velocity strand, estimate width, depth and velocity for each. Note backwater eddies at the creek banks
4. Record width of flow in velocity section and width of creek

We are trying to get an estimate of water volume traveling down a point on the creek. Therefore you must provide width, depth (stage), and the velocity for each sample to be usable. One velocity measurement and depth is the minimum for each sample.

G. HOW TO MEASURE STAGE

Locate an appropriate site to measure creek water height (measure down from bridge guard rail, or measure water level on staff/stage gauge or distance down from the top of a culvert) to the **nearest 1/2 an inch.**

If there is a bridge available record the height of the creek from the bridge. One does this by measuring the distance between the water's surface and a fixed point on the bridge (top of guardrail) to the nearest 1/2 inch. The fixed point must be correlated to a spot on the stream bank and your x-section.

Measure cross sectional area at the velocity gauging section. This can be accomplished during the flow by measuring flow depth in 1-foot horizontal segments as you cross the stream or with a builder's level at low flow. This must also be correlated to the stream gauge. This needs to be established once or twice a year or more often if the creek bed or banks change.

H. HOW TO MEASURE STREAM VELOCITY.

Set up a known measured length (to the **nearest 1/2 an inch**) beforehand (For example inserting two colored sticks in the ground 20 feet apart above the bank and out of flood levels). Time an orange peel or floating object as it travels between the two sticks to the **nearest tenth of a second** using your stopwatch. Velocity is the distance your orange peel travels divided by the time it took to travel that distance.

A volunteer releases an orange peel (or a stick, leaf, etc.) at one side of a bridge and records to the **nearest tenth of a second** how long it takes to go a measured number of feet to the other side of the bridge. For example, say it takes 10.0 seconds for the orange peel to reach the other side of a 20.0-foot bridge. That means the water is flowing 2 feet per second. Incidentally, Winnie the Pooh invented this method...

With other simple measurements done at low flow, Salmon Forever can estimate the discharge (creek volume). Using discharge and the grams/liter of sediment in a sample, we can estimate the amount of sediment travelling down your creek. This tells us how quickly your watershed is eroding. Erosion is a natural activity, however accelerated erosion is generally due to human activities. Sampling creeks without any obvious impacts is an important way to establish baseline information

During the storms:

I. TAKING THE GRAB SAMPLE FROM THE STREAM

Use the same location each time and take a sample by standing on the bank and holding a bottle in your hand and reach into the water. You can also sample from a bridge by tying a bottle to a string and lowering it into the water or set up a pole to hold a bottle and lower it into the water that way. If you sample from a bridge always sample at the same spot. You can put a mark on the bridge where you sample. Volunteers may be trained in other sampling methods as needs arise. Please keep your coordinator informed of changes in your schedule.
Occasionally, video footage is recorded. Let us know if you are camera shy.

In general, sample away from the riverbank in the main current. Never sample stagnant water or backwater eddies. The outside curve of the river is often a good place to sample since the main current tends to hug this bank.
To collect water samples using screw-cap sample bottles, use the following procedures.

1. Label the bottle with the site name, date and time. Use a piece of tape to write on the plastic bottles and use a pencil only to write on the white portion of the glass HACH cell.
2 Remove the cap from the bottle just before sampling. Avoid touching the inside of the bottle or the cap.
3. Hold the bottle near its base and plunge it (opening downward) below the water surface. Collect a water sample 4 to 6 inches beneath the surface or mid-way between the surface and the bottom if the river reach is shallow.
4. Turn the bottle underwater into the current. In slow-moving river reaches, push the bottle underneath the surface and away from you in an upstream direction.
5. Leave an air space. Do not fill the bottle completely (2/3 is fine so that the sample can be shaken, just before analysis). HACH cells must be filled to above the white line. Recap the bottle
6. LABEL THE SAMPLE BOTTLE ! Label the bottle with, date, time, location, stage, velocity. Mark the water level in the bottle at the time of sampling with a mark on a piece of tape on the outside of all sample bottles, except the HACH cells. We can tell if the bottle leaked if the water level is different when we receive them in the lab. Incomplete labeling often creates wasted effort. Use only a pencil to mark HACH Turbidity cells. Check legibility because wet bottles can turn good information into mud.
7. WRITE IN YOUR NOTEBOOK: date, time, location, stage, stream width, and velocity at least for each sample

J. STORING THE SAMPLE

Keep in a dark and cool place and / or refrigerate. Return to your Watershed coordinator or the Sunny Brae Sediment Lab ASAP. Make sure all samples are labeled. Ideally the turbidity(NTU's) should be run within 48 hours. If you take the turbidity reading put a drop of HCL in the sample afterwards to retard algae. Turbidity reading protocols will be on a separate sheet. Dump the lowest flow samples if you run out of bottles. The peak flow is the most important! Call your coordinator for directions or answers to questions.

Important Phone #'s **Emergency 911**

Watershed Coordinator ____________ Jesse Noell 839-7552

Clark Fenton 826-2978 Anita Andazola 822-8576

Department of Water Resources / Eureka Flood Center
Roads 445-6576
River Info 445-7855

Standard Operating Procedures

Field Water Sampling
For
Determining
Turbidity and Suspended Sediment Levels

In
Rivers and Streams
Of
Humboldt, Trinity and Mendocino Counties
California

Salmon Forever
9-20-00
Draft

Prepared By ______________________ **Date** ______________

Approved By ______________________ **Date** ______________

Table of Contents

1. Scope:

This Standard Operating Procedure covers the proper way to collect water samples from various sites for representative turbidity and suspended sediment concentration determination. Grab Sampling provides only a single point representation of turbidity and suspended sediment concentration in a stream. Where possible samples will be compared with Depth-Integrated samples taken at the same time to provide a more representative understanding of the sediment distribution at a given point in time.

2. Apparatus:

Sample Containers - HACH Sample Cells, Plastic Bottles (various sizes), Glass Bottles (various sizes)
Stopwatch
Rite in the Rain note paper or book w/pencil
Tape measure
Orange peel or floating objects for velocity
Bottle of HCL solution (for sterilizing sample after turbidity is run)
Waterproof boots and raingear
Flashlight or headlamp
Staff Gauge for measuring water depth.
This can be:
1. 1- 1/4" or 1- 1/2" metal pipe staff gauge (to be driven into streambed in flatwater just upstream or downstream of the velocity gauging section)
2. Rod with markings driven in streambed
3. Marks on bridge piers or culverts

Sampling Equipment Suppliers

HACH Company:
PO Box 389
Loveland Colorado 80539
1-800-227-4224
www.hach.com

Turbidity Sample Cells # 24347
6 packs of cells $16

Turbidimeters: 2100P

Rickley Hydrological Co.
2710 Joyce Avenue
Columbus, Ohio 43211
614-475-0717
www.rickley.com

Sediment Sampling, Stream Gaging

DH-48 Depth Integrated Sampler
Glass Pint Bottles Current Meters

All supplies used in the South Fork Trinity Study will be either ordered from the manufacturer or through a scientific supply house. Supplies will not be accepted unless in proper working order. All supplies and equipment are purchased and inspected under the supervision of the Lab and Field Leader. Lab water shall be retail distilled water purchased locally. The Lab Manager before use shall inspect sample bottles cleaned in the lab and affix a unique ID # sticker to each bottle before it is used in the field. Copies of equipment invoices shall be kept in the Sediment Lab and Salmon Forever Offices.

3. Calibration:

None of the sampling equipment requires calibration.

4. Sample Collection:

A. SAFETY FIRST!
1. Establish a safe path to the site: streambanks are soft and slippery.
2. Be careful! Please don't wade when you sample. We want all the grab samples to be consistently from the streambank. Remember, when you go out in the field, you do so as a volunteer and must assume responsibility for your own safety. Please take your time and be careful.

B. ESTABLISHING THE SITE
Before the rainy season begins, new sites need to be established. Existing sites must be checked for maintenance issues and accessibility. Know the route to your site and establish an alternate route and/or somebody else to sample in case of road flooding. Ask permission if a site is to be established on private property.
1. Locate a safe water-sampling site and give it a short name. (HH, SFELK, GG etc.)
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5. Photograph the site from identifiable site and make a location map. Describe the lens and focal length used for future use. Make a photocopy of a topographic map of the area with the sampling location marked if possible and give to the your watershed coordinator or the Sunny Brae Lab.

C. WHEN TO MONITOR
Aim to sample as the creek rises and throughout the storm event and as the water begins to go down. The goal is to collect representative samples that illustrate the full range of stream flow. A hydrograph, showing the rise and fall of water level in a creek, and the corresponding rise and fall of turbidity levels and PPM of sediment during a storm event will be produced with this data. The data will also show when turbidity levels that are injurious or lethal to salmonids are occurring and what sediment loads the individual creek is carrying. It is most useful to sample near the peak of the flows to get a good representation of the highest discharges (up to 90% of sediment transport may occur during high flow events). Photograph at the high stage!
1. Sample after the rain starts
2. As the creek rises (for long storms, sample at several stages.)
3. Sample at the **peak**, if at all possible
4. Sample as the creek falls (if it is a long duration storm, sample at several stages.)
5. During quiet times between storms you can minimize the number of samples taken to save the bottles for the next storm.

To collect water samples using screw-cap sample bottles, use the following procedures.

1. Label the bottle with the site name, date and time. Use a piece of tape to write on the plastic bottles and use a pencil only to write on the white portion of the glass HACH cell. Note site on ID # label if possible.
2 Remove the cap from the bottle just before sampling. Avoid touching the inside of the bottle or the cap.
3. Hold the bottle near its base and plunge it (opening downward) below the water surface. Collect a water sample 4 to 6 inches beneath the surface or mid-way between the surface and the bottom if the river reach is shallow.
4. Turn the bottle underwater into the current. In slow-moving river reaches, push the bottle underneath the surface and away from you in an upstream direction.
5. Leave an air space. Do not fill the bottle completely (2/3 is fine so that the sample can be shaken, just before analysis). HACH cells must be filled to above the white line. Recap the bottle
6. **LABEL THE SAMPLE BOTTLE!** Label the bottle with, date, time, location, stage, and velocity. Mark the water level in the bottle at the time of sampling with a mark on a piece of tape on the outside of all sample bottles, except the HACH cells. We can tell if the bottle leaked if the water level is different when we receive them in the lab. Incomplete labeling often creates wasted effort. Use only a pencil to mark HACH Turbidity cells. Check legibility because wet bottles can turn good information into mud.
7. **WRITE IN YOUR NOTEBOOK**: date, time, location, the sample ID #, stage, stream width, and velocity at least for each sample

5. Handling Preservation:

A. PREPARING SAMPLE CONTAINERS

Sample containers and glassware must be cleaned and rinsed before the first sampling run and after each run. The lab may prep containers for volunteers beforehand. If there are dirty bottles in the lab when you sign-in your samples, please try to clean some for everyone else. Alconox soap shall be used.

The following method should be used when preparing all sample containers and glassware for monitoring.

1. Wash each sample bottle with a brush and phosphate-free detergent.
2. Rinse three times with cold tap water.
3. Rinse twice with distilled or de-ionized water.

B. STORING THE SAMPLE

Keep in a dark and cool place and / or refrigerate. Return to your Watershed coordinator or the Sunny Brae Sediment Lab ASAP**.** Make sure all samples are labeled. Ideally the turbidity (NTU's) should be run within 48 hours. If you take the turbidity reading put a drop of HCL in the sample afterwards to retard algae. Turbidity reading protocols will be on a separate sheet. Dump the lowest flow samples if you run out of bottles. The peak flow is the most important! Call your coordinator for directions or answers to questions.

D. HOW TO MEASURE STAGE

Locate an appropriate site to measure creek water height (measure down from bridge guard rail, or measure water level on staff/stage gauge or distance down from the top of a culvert) to the **nearest 1/2 an inch.** OR 0.01 FOOT W/ STAFF PLATE

If there is a bridge available record the height of the creek from the bridge. One does this by measuring the distance between the water's surface and a fixed point on the bridge (top of guardrail) to the nearest 1/2 inch. The fixed point must be correlated to a spot on the stream bank and your x-section.

Measure cross sectional area at the velocity gauging section. This can be accomplished during the low flow by measuring flow depth in 1-foot horizontal segments as you cross the stream or with a builder's level at low flow. This must also be correlated to the stream gauge. This needs to be established once or twice a year or more often if the creek bed or banks change.

E. HOW TO MEASURE STREAM VELOCITY. nearest foot

Set up a known measured length (to the **nearest ~~1/2 an inch~~**) beforehand (For example inserting two colored sticks in the ground 20 feet apart above the bank and out of flood levels). Time an orange peel or floating object as it travels between the two sticks to the **nearest tenth of a second** using your stopwatch. Velocity is the distance your orange peel travels divided by the time it took to travel that distance.

A volunteer releases an orange peel (or a stick, leaf, etc.) at one side of a bridge and records to the **nearest tenth of a second** how long it takes to go a measured number of feet to the other side of the bridge. For example, say it takes 10.0 seconds for the orange peel to reach the other side of a 20.0-foot bridge. That means the water is flowing 2 feet per second. Incidentally, Winnie the Pooh invented this method...

With other simple measurements done at low flow, Salmon Forever can estimate the discharge (creek volume). Using discharge and the grams/liter of sediment in a sample, we can estimate the amount of sediment travelling down your creek. This tells us how quickly your watershed is eroding. Erosion is a natural activity, however accelerated erosion is generally due to human activities. Sampling creeks without any obvious impacts is an important way to establish baseline information

F. TAKING THE GRAB SAMPLE FROM THE STREAM

Use the same location each time and take a sample by standing on the bank and holding a bottle in your hand and reach into the water. You can also sample from a bridge by tying a bottle to a string and lowering it into the water or set up a pole to hold a bottle and lower it into the water that way. If you sample from a bridge always sample at the same spot. You can put a mark on the bridge where you sample. Volunteers may be trained in other sampling methods as needs arise. Please keep your coordinator informed of changes in your schedule.

In general, sample away from the riverbank in the main current. Never sample stagnant water or backwater eddies. The outside curve of the river is often a good place to sample since the main current tends to hug this bank.

6. Troubleshooting:

Try to keep field forms and bottles dry when writing down information.

7. Data Acquisition, Calculations & Data Reduction:

F. INFORMATION NEEDED FOR EACH SAMPLE ON THE FIELD FORM

1. Location, date, time, ID #, who sampled and the approximate elapsed time since start of the storm
2. Record the staff/stage gauge water level (or distance down from the bridge guardrail) to the **nearest 1/2 an inch.**
3. Measure velocity (elapsed time for a floating object to pass through a measured section) to the **nearest tenth of a second and nearest 1/2 an inch**. If there is a high velocity strand and a low velocity strand, estimate width, depth and velocity for each. Note backwater eddies at the creek banks
4. Record width of flow in velocity section and width of creek

We are trying to get an estimate of water volume traveling down a point on the creek. Therefore you must provide width, depth (stage), and the velocity for each sample to be usable. One velocity measurement and depth is the minimum for each sample.

Volunteers will record field-sampling data using ready-made sheets in binders or Rite in the Rain Notebooks. The Field Managers or Watershed coordinator makes copies and returns the binder to samplers. Field sheets are archived for 10 years by sampler. Originals of Lab Sheets will be kept in the Sunny Brae Sediment lab. Copies of Field Sheets and Lab sheets will be kept in Salmon Forever Offices. Hard copies of all data as well as computer back-up disks will be maintained by Salmon Forever for at least 10 years. QA/QC sheets will maintained by Salmon Forever for 10 years. All Sediment Lab data to be maintained by Salmon Forever for 10 years. Originals of ISCO Automatic Sampler field sheets will be maintained for 10 years at the Salmon Forever Sediment Lab location. Copies will be given to RSL.

All ISCO and Depth Integrated sample bottles and grab sample bottles shall be labeled in the field with the pertinent data and logged in a logbook at the time of sampling. ISCO Sample bottles shall be labeled at the time they are taken from the sampler. Grab Sample labels shall at least include a sample location, sampling time and date. Data recorded shall at least include time and date, location, person sampling, velocity, and stage.

The chain-of-custody for these samples is as follows:
The Volunteer is responsible for samples until they are picked up or measurements recorded by a Field Leader or Watershed Coordinator. The Field Leader or Watershed Coordinator is responsible for samples until they are checked into the lab. The Field Leader or Watershed Coordinator is responsible for collecting and checking the completeness of field samples and data. The Lab Leader is responsible for processing samples. The date and time of arrival at the Sediment Lab is recorded on the Lab Sign In sheet by whoever brings the sample into the lab. Samples at the lab shall be kept in a cool dark place until processing. The lab sign-in sheet is in Appendix 2.

Volunteer grab samples will be analyzed for turbidity with a HACH 2100P Turbidimeter and then processed for suspended sediment concentrations through tared 1.0-micron filters on a vacuum assembly. ISCO samples will not be run on the HACH Turbidimeter but will be

Velocity of water = distance / time

8. Computer Hardware and Software Used:

No special hardware is needed for suspended sediment concentration determination, calculations and data analysis. Software used will primarily be Microsoft Word and Excel programs. Software may also include specialized statistical and graphing programs. Redwood Sciences Lab uses Pearl and S+ database and analysis software.

9. Data Management & Records Management:

Data is entered on data sheets in the field. Sample information is recorded on standardized field and data sheets. See Appendix 2 for examples of all data sheets. The Volunteer, Watershed Coordinator and Field Manager are responsible to double check and copy Field Data sheets and deliver them to the Project Manager. Salmon Forever and/or Watershed Coordinators will keep the originals. Reports and data will be transferred to Excel spreadsheets and Word documents and copies kept at the Sunny Brae Sediment Lab and Salmon Forever Offices.

All data sheets will have the Hydrologic Year, initials of the person entering data, the date of data entry and the date of copying. Sign-in sheets will be numbered sequentially.

Data will be examined and rated on the basis of field codes pertaining to the quality of data. Any outliers or nonsensical data will be detected during calculations and transfer to electronic spreadsheet and documented. Data will be in a format acceptable to EPA, RSL and NCRWQCB. Data and calculations will be checked at the time of transfer from paper to spreadsheets.

Appendix 2: Data Forms

Sample Sign-In Sheet
Field Sampling Data Sheet
Training Sign-in

10. QA / QC:

Quality control (QC) measures are those activities undertaken to demonstrate the accuracy (how close to the real result you are) and precision (how reproducible your results are) of your monitoring. Quality Control consists of the steps you will take to determine the validity of specific sampling and analytical procedures. The Quality Assurance Manager will be responsible for implementing and recording and analyzing these measures. Quality Control measures will make up at least 10% of the data collected in this study. Most measures will be taken after every 9th sample or measurement. Some will be done on every sample. Results of analysis and corrective actions shall be reported to the Project Manager. Precision calculations are described in A7 data quality objectives.

1. Grab Sampling
A. Internal QC:
Unique ID # on bottle - codes are in QAPP section B3
External QC: None

2. Floating Object Velocity Measurement

Internal QC: None
External QC: None

3. Manual Stage Measurement

Internal QC: None
External QC: None

Quality Assessment/Assurance (QA) generally refers to a broad plan for maintaining quality in all aspects of a program. Quality assurance/assessment is your assessment of the overall precision and accuracy of your data, after you've run the analyses. QA activities include training of staff, documentation and development of methods and standard operating procedures, equipment maintenance, and appropriate handling, processing, and tracking of all data and samples collected. These activities are designed to ensure that study objectives are met.

1. Grab Sampling - including velocity and stage measurements

A. Internal QA: Proficiency Checklist Twice a season

B. External QA - None

Proficiency checklists (Appendix 3), listing the sequence of sampling and data collection tasks, and notes on proper execution of methods, have been prepared for evaluating implementation of methods by individuals and teams. These checklists will be used by the QA Manager, Field Manager, Lab Manager, Watershed Coordinators during training and field data collection, and possibly by HSU/EPA/RSL staff.

The Field Manager, Lab Manager, QA Manager and Watershed Coordinators during training will use these checklists to document volunteer proficiency.

The Field Manager, QA/QC manager or Watershed Coordinator shall observe each volunteer at the beginning of the project and again at least once a year conducting sampling using a proficiency checklist. Any problems shall be discussed and corrected at that time. During training, we will note any methods that the volunteers find confusing, and discuss modification of the method, the training schedule and the checklist. Volunteers will be required to perform all sampling procedures correctly for their data to be used. Volunteers will be rated on a scale as to the quality of data collection for later data quality evaluation. All field protocols will be re-evaluated following the training. All volunteers will be required to pass proficiency criteria during training. If volunteers do not pass the proficiency criteria, they will receive additional training until they are proficient or they will not be utilized in this study. The Field Manager, QA/QC Manager or Watershed Coordinator is responsible for implementing these assessments and to document and file these checklists. Results shall be reported to the Project Manager

The Field Manager and QA Manager and Watershed Coordinators will conduct all field training. All volunteers will be assembled in various groups at least twice during the field season, for "calibration" in the collection of depth, velocity, crossection and grab sampling measurements.

Personnel from Salmon Forever will initially conduct training. As the study progresses volunteer samplers will become proficient to train others. Field training will take place in at least the Freshwater Creek or Elk River or South Fork Trinity or South Fork Eel watersheds at various locations. Training will consist of day or half-day sessions in the field and laboratory.

Safety procedures for sampling and taking measurements in stormy or hazardous conditions will be explained at every training session. High stream flows during storm events will be the main hazard the volunteers will encounter. Sampling points will be designed for safety at all times. Under no circumstances is anyone to risk injury for data. Back-up plans for volunteers to cover for each other will be developed. If volunteers cannot conduct the scheduled sampling, they are instructed to contact the field leader as soon as possible so an alternative monitor can be found.

Requirements for volunteers include good physical health, the ability to consistently repeat sampling procedures and time to spend sampling and analyzing data. Most of the procedures are not physically demanding. No special certification is required but all volunteers will go through training before sampling. The goal of training is to educate volunteers so their estimates of subjective variables meets the DQO's in Table A7b.

Back-up plans for volunteers to cover for each other will be developed. If volunteers cannot conduct the scheduled sampling, they are instructed to contact the field leader as soon as possible so an alternative monitor can be found.

QA Watershed Coordinator checks:
Watershed Coordinators will meet every 2 months to compare progress, to discuss and resolve problems that they may have encountered, and to address any issues brought to their attention by the external audits of internal QA checks. These meetings will be extremely important in terms of preventing data quality problems, variation in execution of sampling procedures. Topics for discussion may include:

A. Progress in the field sampling and laboratory analyses or activities.
B. Identify problems with sampling procedures or logistics in the field. Discuss difficulties encountered in specific situations and adopt corrective actions. Develop and adopt appropriate modifications for standardizing use of methods among crews.
C. Discuss personnel performance problems

11. References:

EPA:

Volunteer Stream Monitoring: A Methods Manual EPA 841D 95001 April 1995
EPA QA/G-5 Guidance for Quality Assurance Project Plans
EPA QA/G-6 Guidance for the Preparation of Standard Operating Procedures (SOP's) for Quality Related Documents
EPA QA/R-5 EPA Requirements for Quality Assurance Project Plans for Environmental Data Operations

USGS

Techniques of Water-Resources Investigations of the USGS:

Stage Measurements at Gaging Stations Book 3 Chapter A7
Discharge Measurements at Gaging Stations Book 3 Chapter A8
Laboratory Theory and Methods for Sediment Analysis Chapter C1 Book 5
Field Methods for Measurement of Fluvial Sediment Chapter C2 Book 3

Surface Water Techniques:

Discharge Ratings at Gaging Stations - Hydraulic Measurement and Computation Book 1 Chapter 12 1965

Others:

Laboratory Procedure for Total Suspended Solids, Redwood Sciences Laboratory, USDA Forest Service, Arcata Ca, Rand Eads, 12-10-98

Harrellson, C. C., 1994, Stream Channel Reference Sites: An Illustrated Guide to Field Technique: USFS, Rocky Mountain Forest and Range Experiment Station, General Technical Report RM-245.

SOP Field Sampling9-20-00/word98/cf/9-20-00

Location__________ Sampled by__________ Date__________
Rain start time __________ Current weather __________ Time__________
Peak stage __________ Current stage __________
Culvert size__________ Culvert flow depth__________ Culvert invert__________
High-velocity width __________ Low-velocity width __________
Dist.#1__________ Time #1__________ Dist.#1__________ Time #1__________
Dist.#2__________ Time #2__________ Dist.#2__________ Time #2__________
Dist.#3__________ Time #3__________ Dist.#3__________ Time #3__________
Sketch map of high and low velocity strands: Sketch cross-section of channel:

Comments:

Turbidity__________NTU's
Measured by __________
Date/time__________

Location__________ Sampled by__________ Date__________
Rain start time __________ Current weather __________ Time__________
Peak stage __________ Current stage __________
Culvert size__________ Culvert flow depth__________ Culvert invert__________
High-velocity width __________ Low-velocity width __________
Dist.#1__________ Time #1__________ Dist.#1__________ Time #1__________
Dist.#2__________ Time #2__________ Dist.#2__________ Time #2__________
Dist.#3__________ Time #3__________ Dist.#3__________ Time #3__________
Sketch map of high and low velocity strands: Sketch cross-section of channel:

Comments:

Turbidity__________NTU's
Measured by __________
Date/time__________

Location__________ Sampled by__________ Date__________
Rain start time __________ Current weather __________ Time__________
Peak stage __________ Current stage __________
Culvert size__________ Culvert flow depth__________ Culvert invert__________
High-velocity width __________ Low-velocity width __________
Dist.#1__________ Time #1__________ Dist.#1__________ Time #1__________
Dist.#2__________ Time #2__________ Dist.#2__________ Time #2__________
Dist.#3__________ Time #3__________ Dist.#3__________ Time #3__________
Sketch map of high and low velocity strands: Sketch cross-section of channel:

Comments:

Turbidity__________NTU's
Measured by __________
Date/time

HY 2001 **Salmon Forever — Sample Sign-in Log — Sunnybrae Sediment Lab** PAGE 22

Copied 1-28-01 *For NTU > 1000, use NTU Dilution sheet* *NTU < 1000, Code = 0 NTU ≥ 1000, Code = 1* *Type: Hach, 2x6, 2x6P, 3x7, 3x7P, Other*

BROUGHT TO LAB		SAMPLE					TURBIDITY						STAGE	VELOCITY 'V'		REMARK
BY	DATE	ID No.	LOCATION	DATE	TIME	BY	NTU	CODE	TYPE	DATE	TIME	BY	'S'	Sec.	Dist.	
JN	*3/6/00*	*GB012*	*HH*	*2/18/00*	*14:50*	*BL*	*180*	*0*	*Hach*	*2/19/00*	*22:15*	*CF*	*112"*	*5.50*	*10.0'*	***Example***
JN	1/26/01	01IS 0186	SF MRB	1/20/01	23:25 CF	CF JN SF	4.98	0	ISCO	1/26/01	:	JN				BOTTLE #1 OF 11 01SFMRB01
JN	1/26/01	01IS 0180	SF MRB	1/21/01	05:25		4.26	0	ISCO	1/26/01	:	JN				01SFMRB02
JN	1/26/01	01IS 0181	SF MRB	1/21/01	11:25		5.43	0	ISCO	1/26/01	:	JN				01SFMRB03
JN	1/26/01	01IS 0182	SF MRB	1/21/01	17:25		4.47	0	ISCO	1/26/01	:	JN				01SFMRB04
JN	1/26/01	01IS 0184	SFMRB	1/21/01	23:25		4.19	0	ISCO	1/26/01	:	JN				01SFMRB05
JN	1/26/01	01IS 0185	SF MRB	1/22/01	05:25		4.12	0	ISCO	1/26/01	:	JN				01SFMRB06
JN	1/26/01	01IS 0225	SF MRB	1/22/01	11:25		3.07	0	ISCO	1/26/01	:	JN				01SFMRB07
JN	1/26/01	01IS 0226	SF MRB	1/22/01	17:25		3.23	0	ISCO	1/26/01	:	JN				01SFMRB08
JN	1/26/01	01IS 0228	SF MRB	1/22/01	23:25		3.16	0	ISCO	1/26/01	:	JN				01SFMRB09
JN	1/26/01	01IS 0235	SF MRB	1/24/01	10:00		30.4	0	ISCO	1/26/01	:	JN				RESTART 01SFMRB10
JN	1/26/01	01IS 0166	SF MRB	1/24/01	16:00		22.6	0	ISCO	1/26/01	:	JN				11 OF 11 01SFMRB11
JN	1/26/01	01IS 0206	NF ELK	1/26/01	18:00	JN	48.3	0	H	1/26/01	20:13	JN	5.81			NO RAIN 24 HRS

WorksheetLabSign-inHY2001/EXCELL98/NSL/9-00 *Time notes: Noon = 12:00, Midnight = 24:00*

FOR BILL THOMPSON 1-28-01 // 1/31 Ckd entre w/ field book + started site register for ea site

JACOBY CREEK CROSS-SECTIONS

BROOKWOOD REACH

1983-1986,1992, 1995, 1997, & 2001

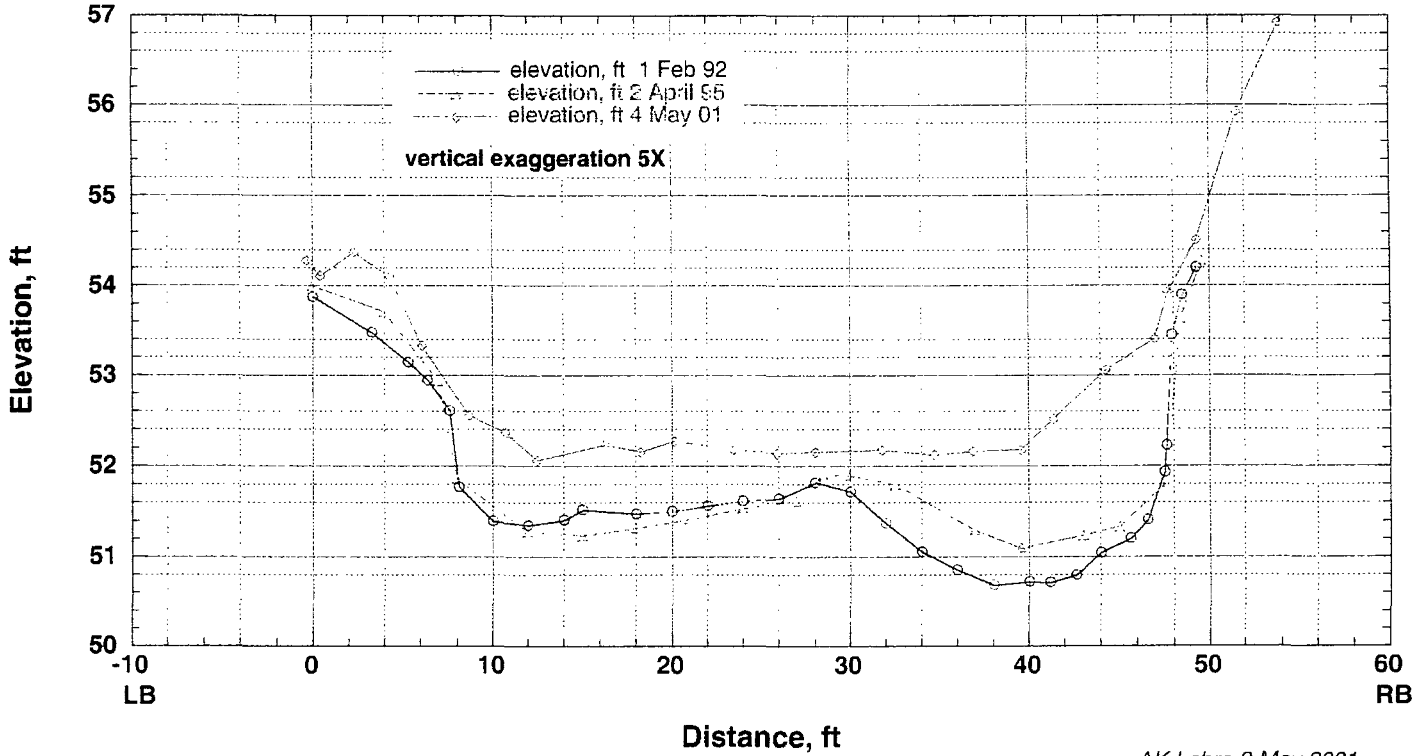
By

ANDRE LEHRE

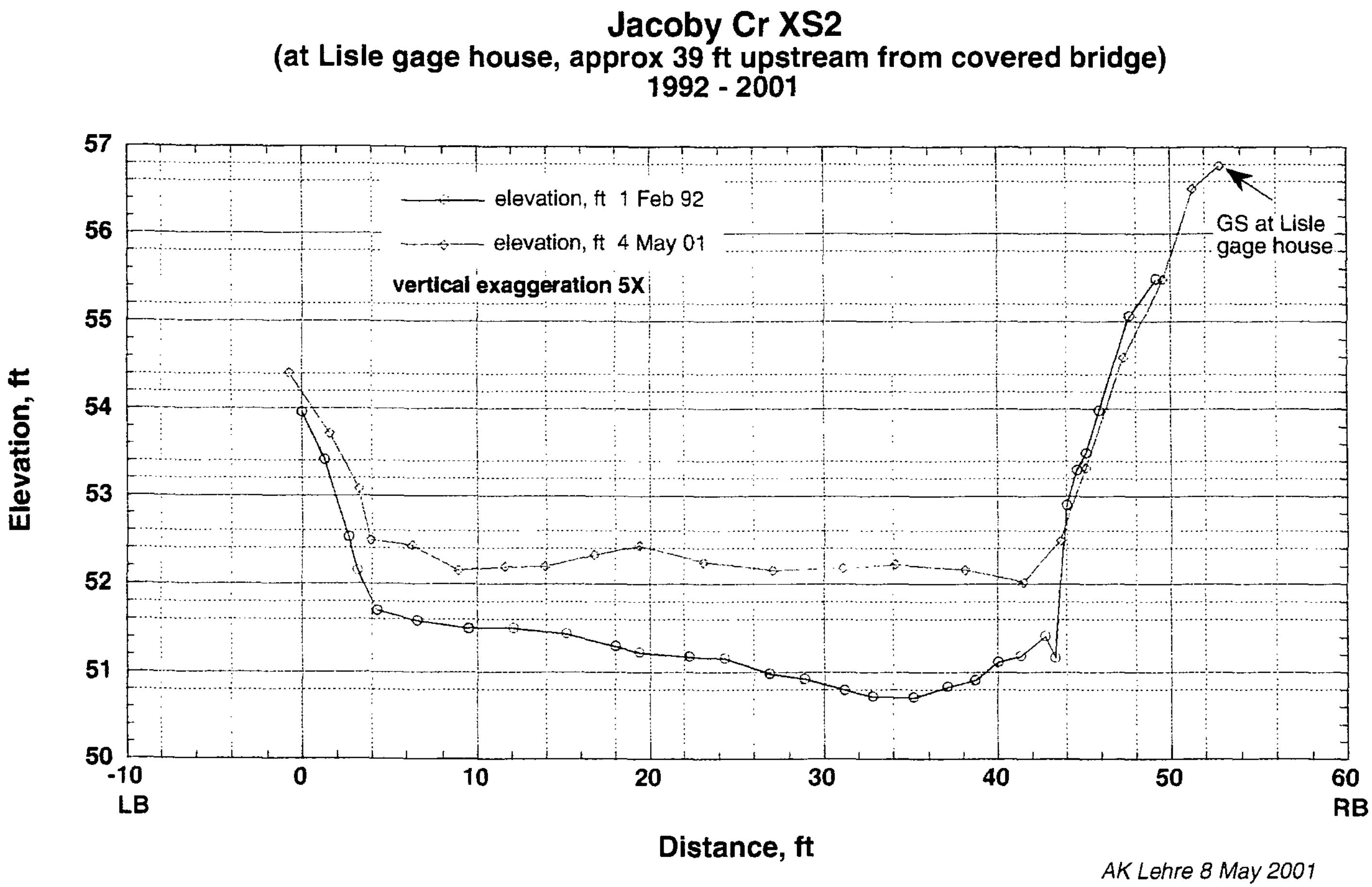
AK11@AXE.HUMBOLDT.EDU

DEPT. OF GEOLOGY
HUMBOLDT STATE UNIVERSITY
ARCATA, CALIFORNIA 95521

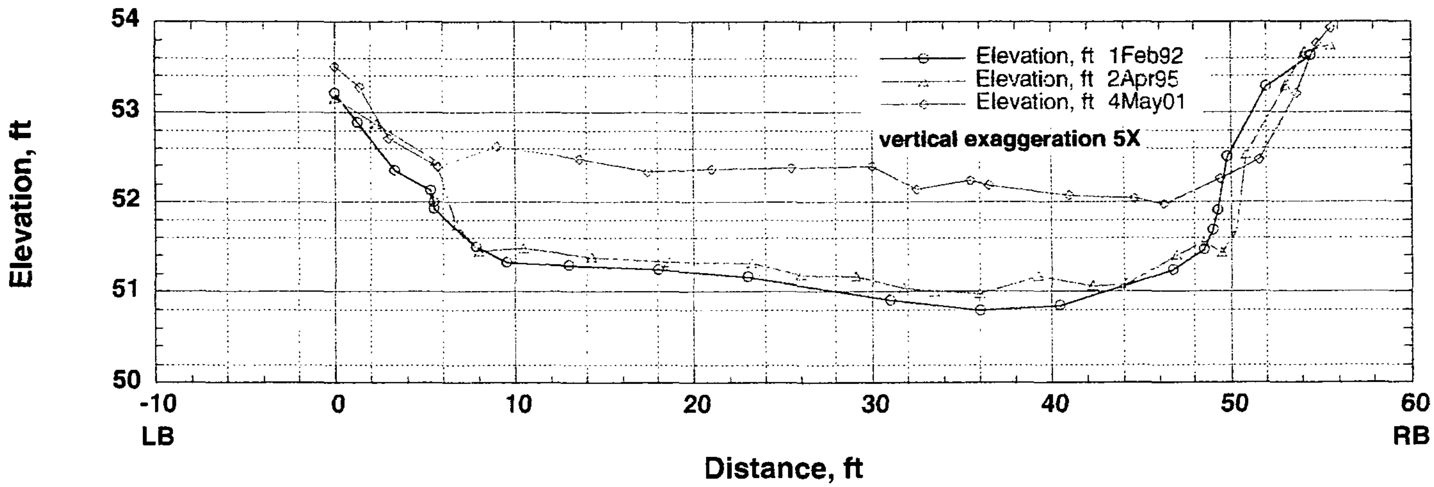
Jacoby Cr XS1
(approximately 75 ft upstream from covered bridge)
1992 - 2001



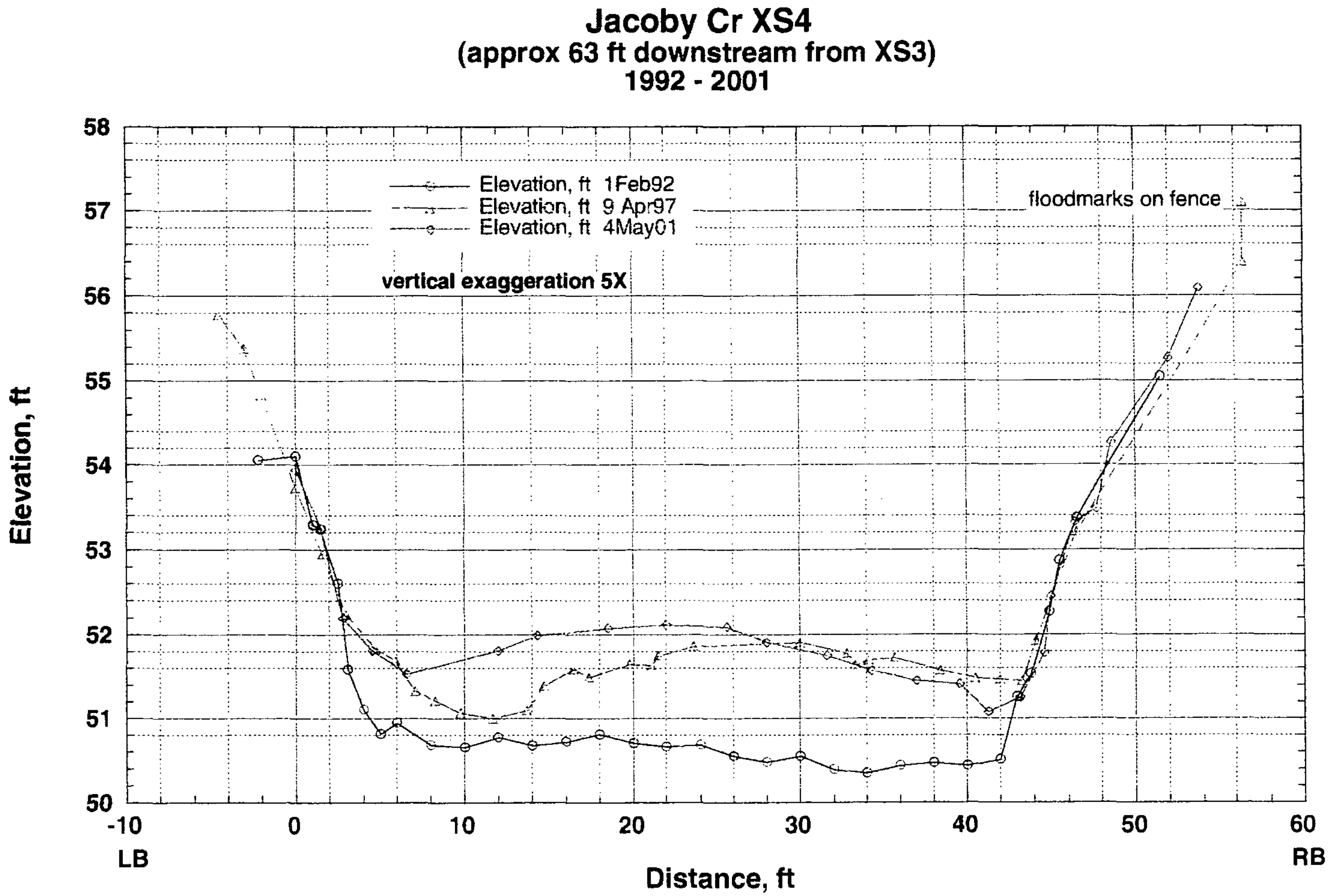
AK Lehre 8 May 2001


Jacoby Cr XS2
(at Lisle gage house, approx 39 ft upstream from covered bridge)
1992 - 2001
elevation, ft 1 Feb 92
elevation, ft 4 May 01
vertical exaggeration 5X
GS at Lisle gage house
Elevation, ft
57
56
55
54
53
52
51
50
-10
LB
0
10
20
30
40
50
60
RB
Distance, ft
AK Lehre 8 May 2001

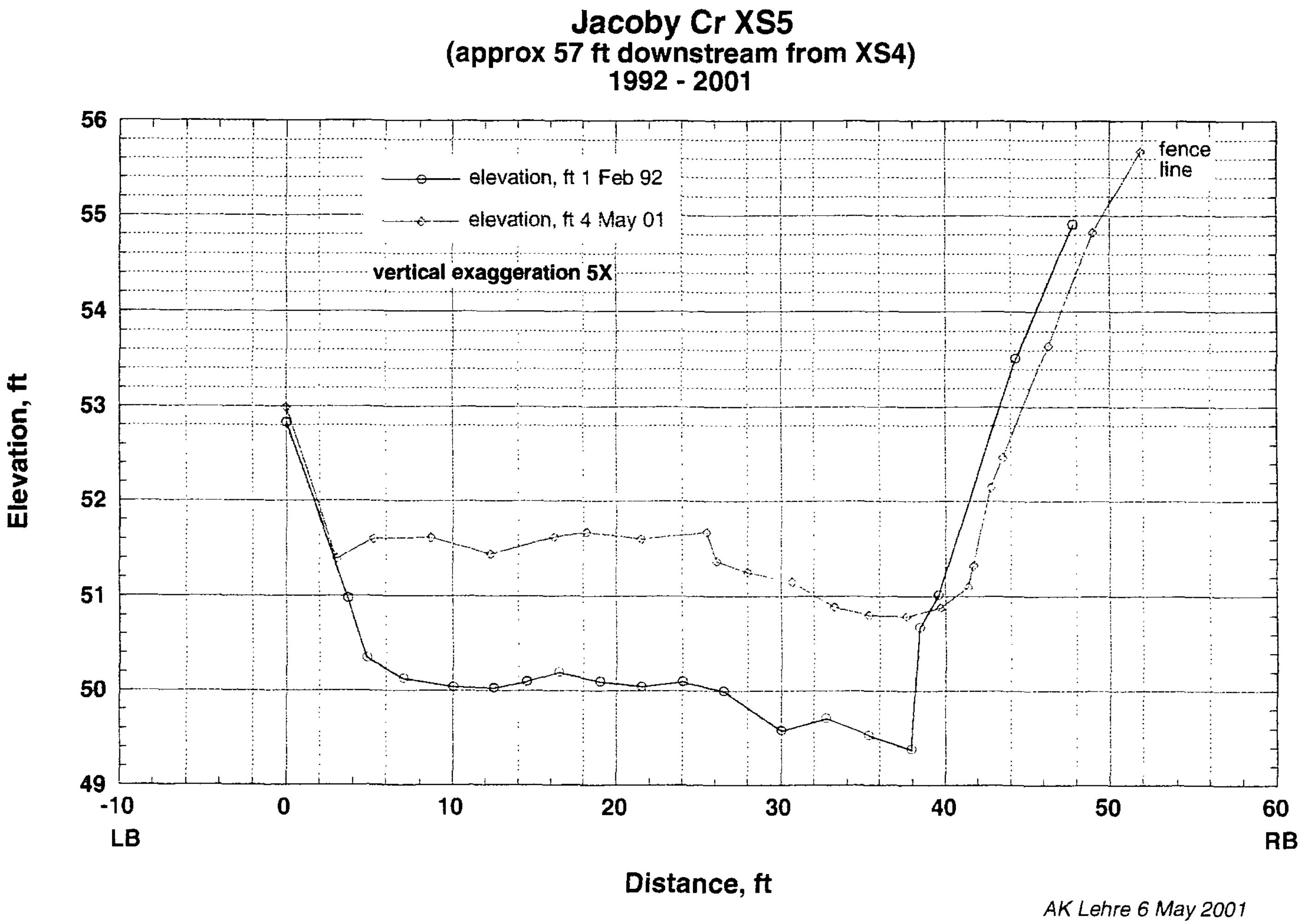
Jacoby Cr XS3
(under covered bridge)
1992 - 2001



AK Lehre 4 May 2001

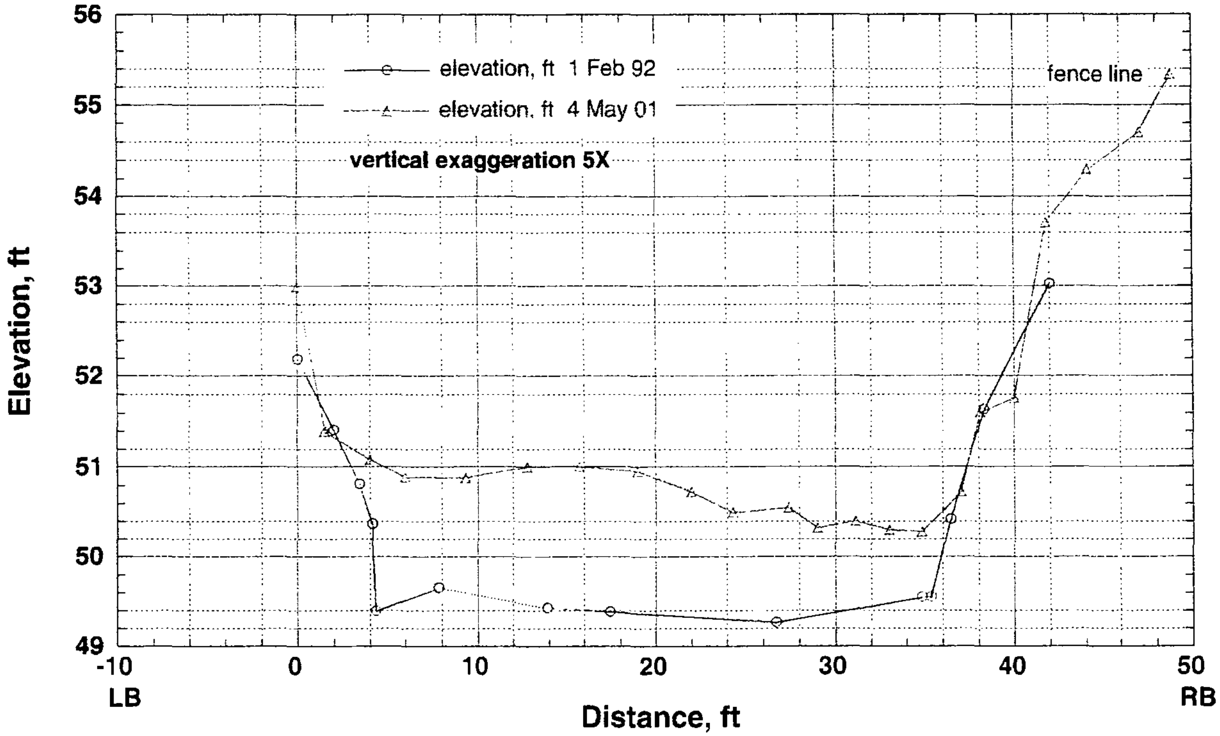


AK Lehre 4 May 2001



Jacoby Cr XS5
(approx 57 ft downstream from XS4)
1992 - 2001
elevation, ft 1 Feb 92
elevation, ft 4 May 01
vertical exaggeration 5X
fence line
Elevation, ft
56
55
54
53
52
51
50
49
-10
LB
0
10
20
30
40
50
60
RB
Distance, ft
AK Lehre 6 May 2001

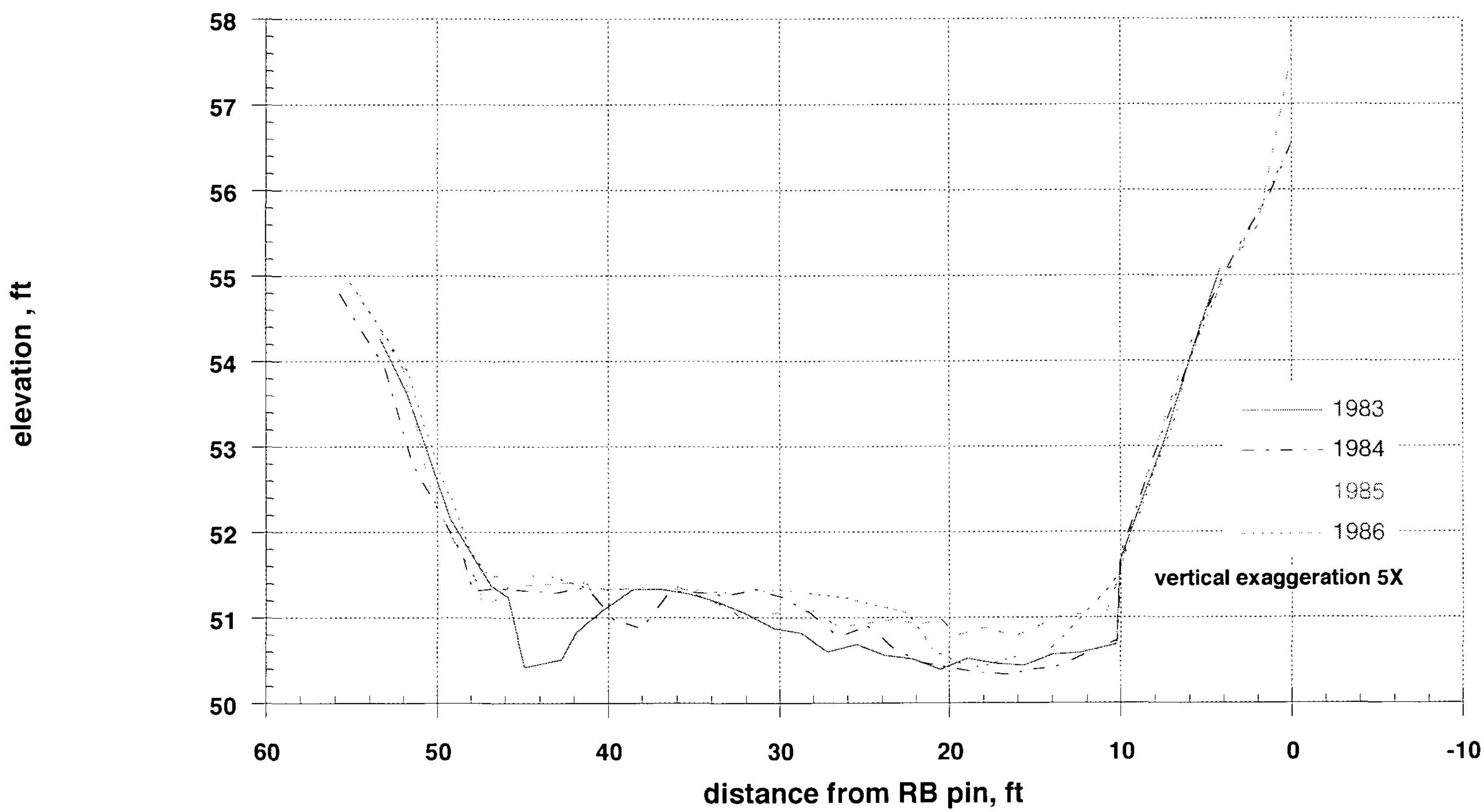
Jacoby Cr XS6
(approx 57 feet downstream from XS5)
1992 - 2001



AK Lehre 6 May 2001

* see attached e-mail

Jacoby XS1 1983-1986
at Lisle's gage
surveys by HSU Geology 531 and 550 classes



A K Lehre 1 May 2001

Return-Path: <akl1@humboldt.edu>
Date: Thu, 10 May 2001 09:47:26 -0700
To: russell-ms450700 <comwiz@mindspring.com>
From: Andre Lehre <akl1@humboldt.edu>
Subject: Re: Jacoby Cr XSS

>Andre,
>
Thanks for the data!

>Are the 1983-1986 XSS at Lisle's gage comparable to the 1992-2001 XSS? If
>so, would it be possible to get a composite PDF with the six XSS on it?

At the present time I can't tie them together. The 1983-86 ones didn't have any permanent rebar endpoints. It would take a fair bit of messing about with them to see if they could be tied to the later ones. (I believe they are not at exactly the same location.)

>Do you have, or know if any one has, rating curves for the Brookwood Reach
>for 1999-2001?

No. Randy Klein did one gaging there this year with Jacoby Cr school students, I believe. I don't have the data. I can tell you, however, that the BED is currently at 52.0 on Lisle's gage plate, and that according to my pre-1992 rating curve that would correspond to 150 cfs! Clearly there has been significant filling, for that would no correspond to zero cfs.

>Thanks again!!!

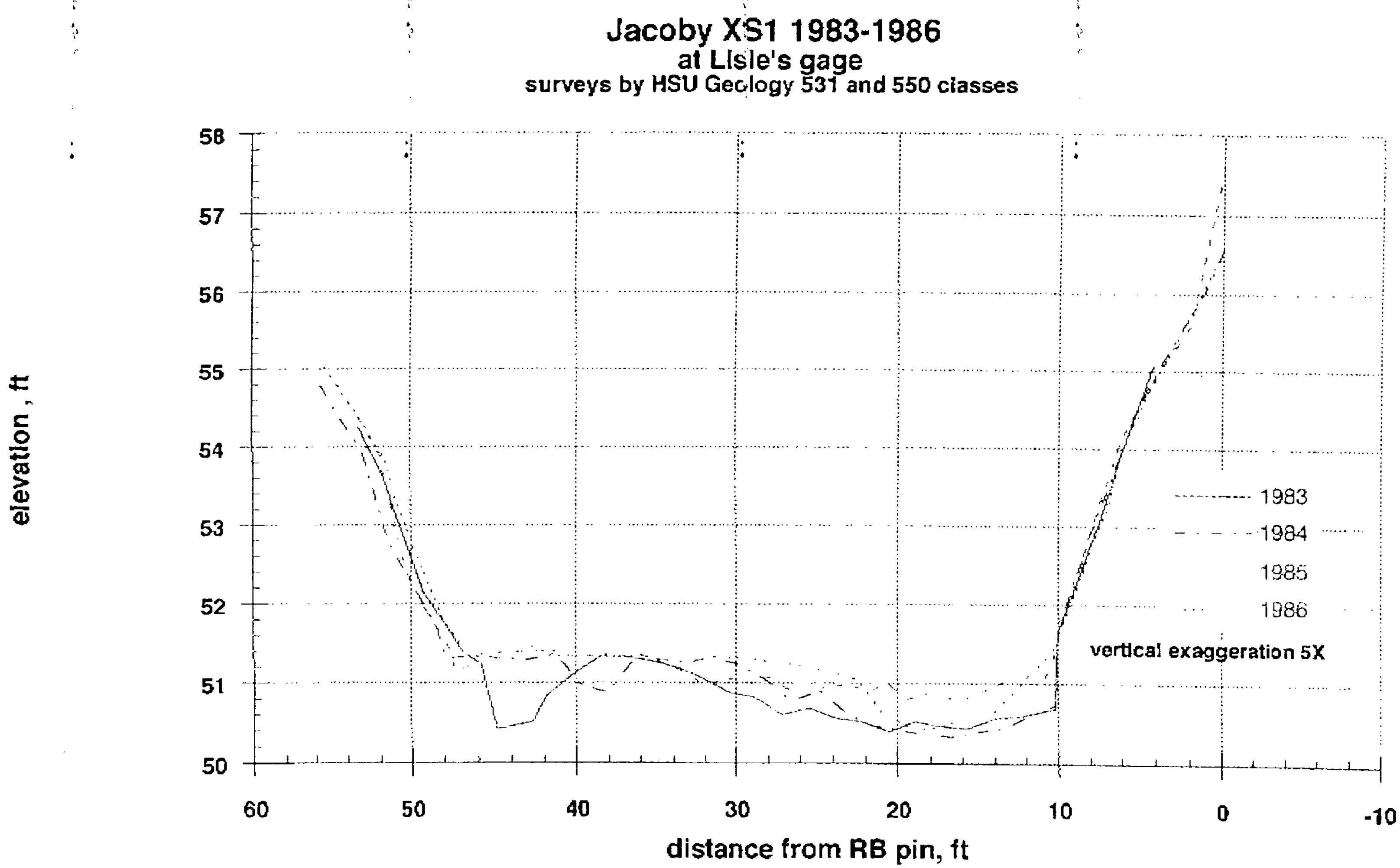
My pleasure.

Andre

--

Andre Lehre \\ akl1@axe.humboldt.edu
Department of Geology \\ 707-839-3526
Humboldt State University \\
Arcata, CA 95521 \\

* see attached e-mail



A K Lehre 1 May 2001

Andre Lehre, 09:47 AM 5/10/01 , Re: Jacoby Cr XSS

Return-Path: <akl1@humboldt.edu>
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>Thanks again!!!

My pleasure.

Andre

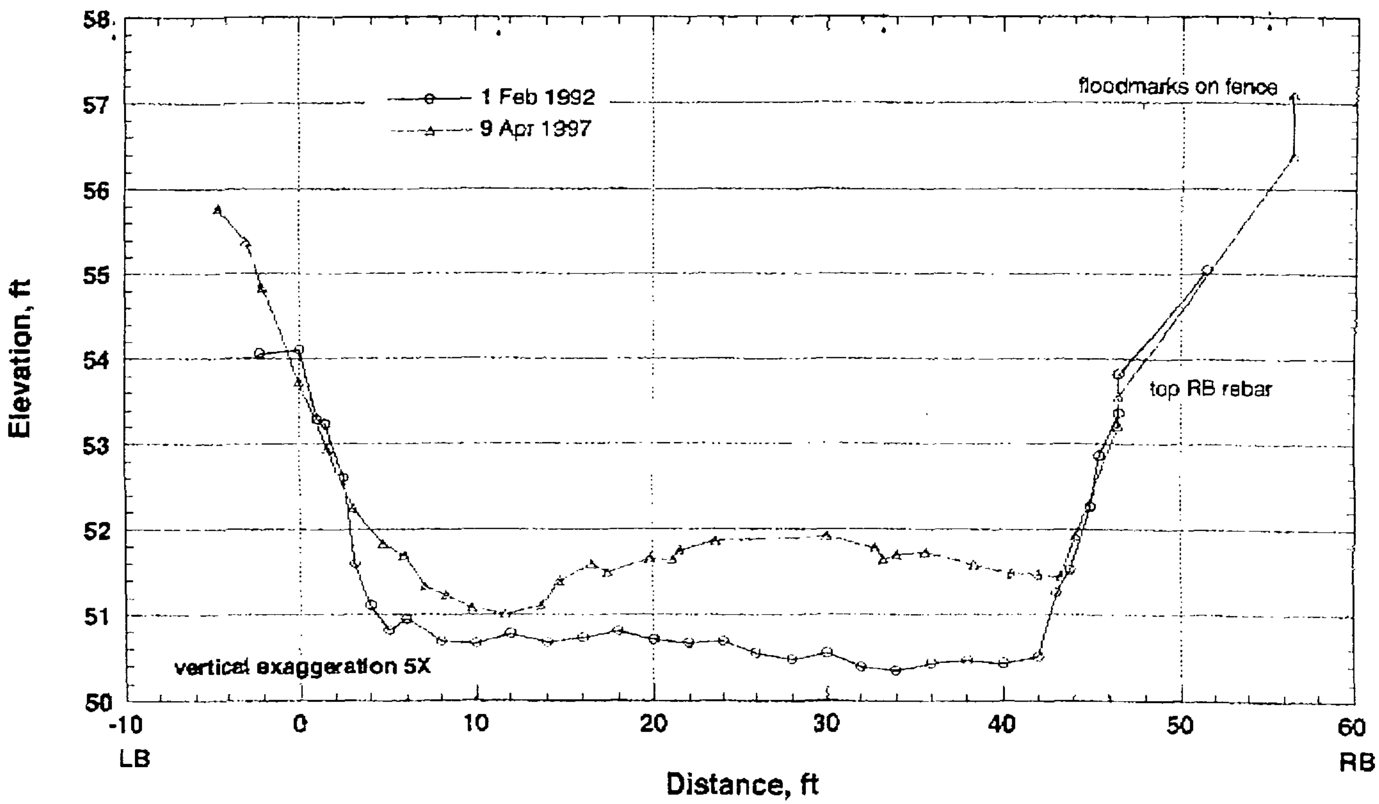
--

Andre Lehre \\ akl1@axe.humboldt.edu
Department of Geology \\ 707-839-3526
Humboldt State University \\
Arcata, CA 95521 \\

Jacoby Cr XS4 1992-1997

about 50 ft downstream from bridge

surveyed by HSU Geology 531 and 550 classes



A K Lehre 1 May 2001

JACOBY CREEK SUSPENDED SEDIMENT DATA
1978 - 1979

By

TOM LISLE

REDWOOD SCIENCES LAB
(707) 825-2930

Jacoby Creek at Covered Bridge (Dec '78 - Nov '79)						Data formatted for plotting			
Data supplied by Tom Lisle, USFS PSWFRES Redwood Lab						sediment concentation graph			
Date	Time	Q	C	Qsusp	stage	Date Time	Cum hr	Q	C
		m3/s	mg/l	t/day			from start	m3/s	mg/l
12/01/78	850	1.870	60	9.69	falling	12/1/78 8:50	0.00	1.870	60
12/01/78	1000	1.700	44	6.46	falling	12/1/78 10:00	1.17	1.700	44
12/01/78	1115	1.390	25	3.00	falling	12/1/78 11:15	2.42	1.390	25
12/05/78	930	1.560	20	2.70	falling	12/5/78 9:30	0.00	1.560	20
12/05/78	1055	1.330	18	2.07	falling	12/5/78 10:55	1.42	1.330	18
12/17/78	830	0.740	81	5.18	rising	12/17/78 8:30	0.00	0.740	81
12/17/78	900	0.790	79	5.39	rising	12/17/78 9:00	0.50	0.790	79
12/17/78	945	0.850	71	5.21	rising	12/17/78 9:45	1.25	0.850	71
12/17/78	1015	0.880	81	6.16	rising	12/17/78 10:15	1.75	0.880	81
12/17/78	1040	0.880	73	5.55	rising	12/17/78 10:40	2.17	0.880	73
12/17/78	1120	0.930	69	5.54	rising	12/17/78 11:20	2.83	0.930	69
12/17/78	1145	0.930	68	5.46	rising	12/17/78 11:45	3.25	0.930	68
1/10/79	1535	0.510	44	1.94	rising	1/10/79 15:35:00	0.00	0.510	44
1/10/79	1625	0.650	60	3.37	rising	1/10/79 16:25:00	0.83	0.650	60
1/10/79	1705	0.820	88	6.23	rising	1/10/79 17:05:00	1.50	0.820	88
1/10/79	1750	1.160	166	16.64	rising	1/10/79 17:50:00	2.25	1.160	166
1/10/79	1908	1.920	233	38.65	rising	1/10/79 19:08:00	3.55	1.920	233
1/10/79	2105	2.290	347	68.66	rising	1/10/79 21:05:00	5.50	2.290	347
1/11/79	225	2.350	109	22.13	rising	1/11/79 2:25:00	10.83	2.350	109
1/11/79	341	5.090	356	156.56	rising	1/11/79 3:41:00	12.10	5.090	356
1/11/79	920	16.400	777	1100.98	rising	1/11/79 9:20:00	17.75	16.400	777
1/11/79	1420	9.340	327	263.88	falling	1/11/79 14:20:00	22.75	9.340	327
1/11/79	1640	7.920	214	146.44	falling	1/11/79 16:40:00	25.08	7.920	214
1/11/79	2100	10.200	387	341.06	rising	1/11/79 21:00:00	29.42	10.200	387
1/11/79	2350	8.350	206	148.62	falling	1/11/79 23:50:00	32.25	8.350	206
1/12/79	1310	9.060	184	144.03	falling	1/12/79 13:10:00	45.58	9.060	184
1/15/79	1105	1.080	41	3.83	falling	1/15/79 11:05:00	0.00	1.080	41
2/12/79	2150	1.020	78	6.87	rising	2/12/79 21:50:00	0.00	1.020	78
2/12/79	2235	1.440	170	21.15	rising	2/12/79 22:35:00	0.75	1.440	170
2/12/79	2330	2.260	293	57.21	rising	2/12/79 23:30:00	1.67	2.260	293
2/13/79	20	3.760	424	137.74	rising	2/13/79 0:20:00	2.50	3.760	424
2/13/79	105	4.190	332	120.19	rising	2/13/79 1:05:00	3.25	4.190	332
2/13/79	220	5.320	440	202.25	rising	2/13/79 2:20:00	4.50	5.320	440
2/13/79	430	8.770	519	393.26	rising	2/13/79 4:30:00	6.67	8.770	519
2/13/79	535	15.300	642	848.67	rising	2/13/79 5:35:00	7.75	15.300	642
2/13/79	645	17.800	861	1324.15	rising	2/13/79 6:45:00	8.92	17.800	861
2/13/79	840	19.000	631	1035.85	rising	2/13/79 8:40:00	10.83	19.000	631
2/13/79	1240	14.600	303	382.22	falling	2/13/79 12:40:00	14.83	14.600	303
2/13/79	1645	10.500	237	215.01	falling	2/13/79 16:45:00	18.92	10.500	237
2/13/79	2020	7.360	174	110.65	falling	2/13/79 20:20:00	22.50	7.360	174
2/13/79	2250	6.230	139	74.82	falling	2/13/79 22:50:00	25.00	6.230	139
2/14/79	0	5.800	130	65.15	falling	2/14/79 0:00:00	26.17	5.800	130
2/14/79	115	5.240	142	64.29	falling	2/14/79 1:15:00	27.42	5.240	142
2/14/79	230	5.090	83	36.50	falling	2/14/79 2:30:00	28.67	5.090	83
2/14/79	405	4.810	39	16.21	falling	2/14/79 4:05:00	30.25	4.810	39
2/14/79	610	4.390	66	25.03	falling	2/14/79 6:10:00	32.33	4.390	66
2/14/79	830	3.820	56	18.48	falling	2/14/79 8:30:00	34.67	3.820	56
2/14/79	1035	3.590	51	15.82	falling	2/14/79 10:35:00	36.75	3.590	51
2/20/79	1400	1.160	16	1.60	falling	2/20/79 14:00:00	0.00	1.160	16
2/23/79	1015	4.530	130	50.88	falling	2/23/79 10:15:00	0.00	4.530	130
2/23/79	1330	4.730	99	40.46	falling	2/23/79 13:30:00	3.25	4.730	99
2/23/79	1430	4.730	101	41.28	falling	2/23/79 14:30:00	4.25	4.730	101
2/23/79	2012	4.670	74	29.86	falling	2/23/79 20:12:00	9.95	4.670	74
2/26/79	915	5.800	122	61.14	falling	2/26/79 9:15:00	0.00	5.800	122
2/28/79	1110	8.778	430	326.13	falling	2/28/79 11:10:00	0.00	8.778	430
2/28/79	1445	7.221	207	129.14	falling	2/28/79 14:45:00	3.58	7.221	207

2/28/79	1725	6.230	219	117.88	falling		2/28/79 17:25:00	6.25	6.230	219
4/11/79	115	25.202	1944	4232.97	rising		4/11/79 1:15:00	0.00	25.202	1944
4/11/79	430	26.901	1276	2965.74	rising		4/11/79 4:30:00	3.25	26.901	1276
4/11/79	740	18.406	1565	2488.79	falling		4/11/79 7:40:00	6.42	18.406	1565
4/11/79	1120	14.442	990	1235.28	falling		4/11/79 11:20:00	10.08	14.442	990
4/11/79	1424	9.061	1058	828.31	falling		4/11/79 14:24:00	13.15	9.061	1058
4/11/79	1655	7.929	635	435.00	falling		4/11/79 16:55:00	15.67	7.929	635
4/11/79	1950	6.088	343	180.42	falling		4/11/79 19:50:00	18.58	6.088	343
4/17/79	1230	6.230	276	148.56	falling		4/17/79 12:30:00	0.00	6.230	276
4/17/79	1400	5.947	213	109.44	falling		4/17/79 14:00:00	1.50	5.947	213
10/19/79	1005	0.481	76	3.16	falling		10/19/79 10:05:00	0.00	0.481	76
10/20/79	1415	1.501	95	12.32	rising		10/20/79 14:15:00	0.00	1.501	95
10/20/79	1425	1.529	226	29.86	rising		10/20/79 14:25:00	0.17	1.529	226
10/20/79	1455	1.869	266	42.95	rising		10/20/79 14:55:00	0.67	1.869	266
10/20/79	1510	2.350	457	92.80	rising		10/20/79 15:10:00	0.92	2.350	457
10/20/79	1550	2.605	517	116.37	rising		10/20/79 15:50:00	1.58	2.605	517
10/20/79	1615	3.002	321	83.25	rising		10/20/79 16:15:00	2.00	3.002	321
10/20/79	1705	3.455	542	161.78	rising		10/20/79 17:05:00	2.83	3.455	542
10/20/79	1818	3.681	337	107.18	rising		10/20/79 18:18:00	4.05	3.681	337
10/20/79	2040	3.002	134	34.75	falling		10/20/79 20:40:00	6.42	3.002	134
10/20/79	2240	2.690	92	21.38	falling		10/20/79 22:40:00	8.42	2.690	92
10/21/79	15	2.095	54	9.78	falling		10/21/79 0:15:00	10.00	2.095	54
10/24/79	1750	2.888	334	83.35	rising		10/24/79 17:50:00	0.00	2.888	334
10/24/79	1830	5.154	929	413.66	rising		10/24/79 18:30:00	0.67	5.154	929
10/24/79	1945	6.598	316	180.14	rising		10/24/79 19:45:00	1.92	6.598	316
10/24/79	2050	6.513	449	252.66	falling		10/24/79 20:50:00	3.00	6.513	449
10/24/79	2245	6.088	196	103.10	falling		10/24/79 22:45:00	4.92	6.088	196
10/24/79	2320	6.088	248	130.45	falling		10/24/79 23:20:00	5.50	6.088	248
10/25/79	25	10.534	1444	1314.23	rising		10/25/79 0:25:00	6.58	10.534	1444
10/25/79	150	19.539	1393	2351.57	rising		10/25/79 1:50:00	8.00	19.539	1393
10/25/79	425	23.645	955	1950.96	rising		10/25/79 4:25:00	10.58	23.645	955
10/25/79	630	15.008	629	815.61	falling		10/25/79 6:30:00	12.67	15.008	629
10/25/79	745	10.137	401	351.22	falling		10/25/79 7:45:00	13.92	10.137	401
10/25/79	900	7.787	347	233.46	falling		10/25/79 9:00:00	15.17	7.787	347
10/25/79	1030	6.938	379	227.18	falling		10/25/79 10:30:00	16.67	6.938	379
10/25/79	1327	5.267	136	61.89	falling		10/25/79 13:27:00	19.62	5.267	136
10/25/79	1435	4.701	112	45.49	falling		10/25/79 14:35:00	20.75	4.701	112
10/25/79	1558	4.248	98	35.96	falling		10/25/79 15:58:00	22.13	4.248	98
10/25/79	1910	3.511	66	20.02	falling		10/25/79 19:10:00	25.33	3.511	66
10/25/79	1950	3.256	61	17.16	falling		10/25/79 19:50:00	26.00	3.256	61
11/03/79	1109	7.306	262	165.38	rising		11/3/79 11:09:00	0.00	7.306	262
11/03/79	1240	6.173	178	94.94	falling		11/3/79 12:40:00	1.52	6.173	178
11/03/79	1330	5.663	160	78.29	falling		11/3/79 13:30:00	2.35	5.663	160
11/03/79	1432	5.267	105	47.78	falling		11/3/79 14:32:00	3.38	5.267	105
11/03/79	1540	4.842	114	47.69	falling		11/3/79 15:40:00	4.52	4.842	114
11/03/79	1620	4.587	92	36.46	falling		11/3/79 16:20:00	5.18	4.587	92
11/03/79	1710	4.389	73	27.68	falling		11/3/79 17:10:00	6.02	4.389	73
11/03/79	1840	4.163	136	48.91	falling		11/3/79 18:40:00	7.52	4.163	136
11/03/79	1945	4.304	71	26.40	falling		11/3/79 19:45:00	8.60	4.304	71
11/03/79	2045	5.097	289	127.27	falling		11/3/79 20:45:00	9.60	5.097	289
11/03/79	2230	6.173	259	138.14	falling		11/3/79 22:30:00	11.35	6.173	259
11/05/79	740	3.171	39	10.69	falling		11/5/79 7:40:00	0.00	3.171	39
11/05/79	855	3.115	44	11.84	falling		11/5/79 8:55:00	1.25	3.115	44

JACOBY CREEK SILVICULTURAL SUMMARY
1988 – 2000

By
DOUG SMITH

(707) 677-3196
das16@humboldt.edu

From
CDF Data - Coast Cascade GIS

JACOBY CREEK Silviculture
AREA SUMMARY STATISTICS

HARVEST METHOD	YEAR 1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	% WA	Total	Silviculture
Alturnative Perscription	0	9	0	0	0	0	0	0	44	0	48	0	0	1%	100	ALPR
Clearcut	97	259	3	0	96	26	28	4	47	70	42	213	82	7%	968	CLCT
Shelterwood Seed Cut	0	0	0	0	0	29	0	0	0	0	0	0	0	0.2%	29	SHSC
Shelterwood Prep	0	8	0	0	0	17	0	0	0	0	0	0	0	0.2%	25	SHPC
Sanitation Salvage	0	2	0	0	0	0	0	0	0	0	0	0	0	0%	2	SASV
Shelterwood Removal	225	168	0	15	0	99	0	55	8	0	2	26.03	0	5%	597	SHRC
Select Cut	0	3	10	0	0	0	13	56	95	66	157	69	11	4%	480	SLCN
Transition	0	0	0	0	0	0	0	0	0	0	0	0	0	0%	0	TRAN
Comercial Thin	0	0	0	0	0	28	0	12	16	4	354	202	0	5%	615	CMTH
Seed Tree Remoal	0	0	0	0	0	99	51	164	179	0	0	0	0	4%	492	STRC
Seed Tree Step	0	0	0	0	0	0	0	0	0	0	39	0	0	0.3%	39	STSC
Rehabilitation	0	0	0	0	0	0	0	4	0	0	0	0	0	0.0%	4	REHB
DATA GAPS	3	0	0	0	0	0	0	0	0	0	16	0	0	0.1%	18	THP BLANK
Annual Totals	**324**	**450**	**13**	15	96	297	93	295	388	140	642	509	93		3370	THP TOTAL
TOTAL ANNUAL PERCENTAGE	2%	3%	0.1%	0.1%	1%	2%	1%	2%	3%	1%	5%	4%	0.7%	26%		TOTAL ANNUAL %
Tractor Yarding	316	355	13	15	91	283	22	295	366	124	411	294	72	20.4%	2656	TR
Cable Yarding	9	95	0	0	5	14	71	0	22	16	215	215	21	5.2%	683	CS
Data Gaps	0	0	0	0	0	0	0	0	0	0	16	0	0	0.1%	16	Yarding Blank
Ballon Helecopter Yarding	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0%	0	BH
	126	142	5	6	36	113	9	118	146	50	164	310			1226	Total Compacted

By Doug Smith Intern 3/24 /2001 Compiled from CDF data from Coast Cascade GIS. 0.00025 conversion factor

13031	Total Acres
20%	% area Tractored
9%	Compacted

Compaction of % equals 40% multiplied by the total area tractor yarded.

Tractor "logging can compact and disturb 40% of the logged area. Sediment discharge of 19% for each percent area logged." Patricia Datzman 6/1978 P. 40

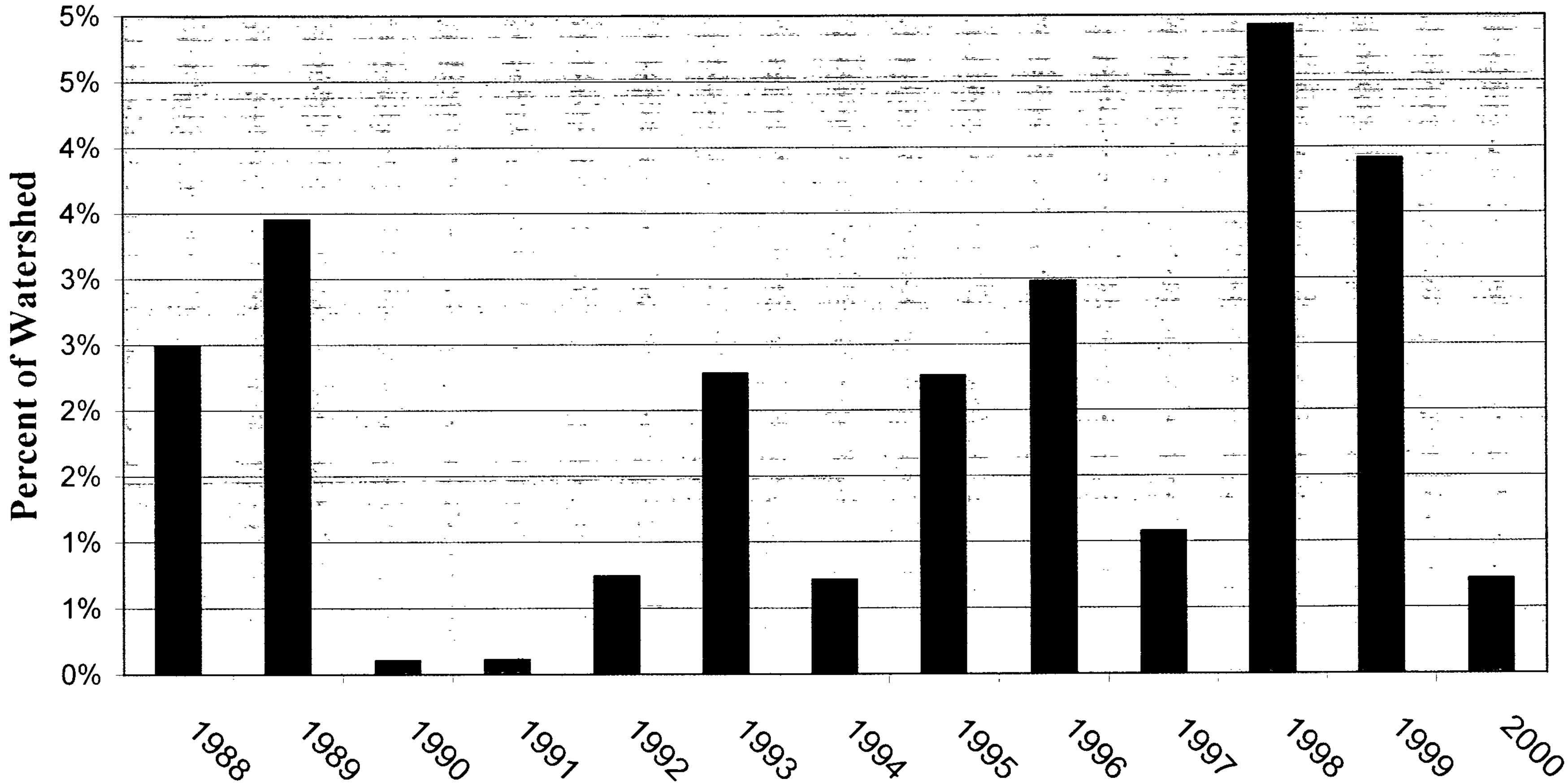
Total THP area divided by the JACOBY CREEK watershed area equals percent or timber harvest plan area in the ten years.

This watershed has 9% of the ground area compacted in a ten year period, where 20% of the total watershed area was operated on by tractors.

This watershed has 26 percent of the area timber harvest plan activity in 13 years.

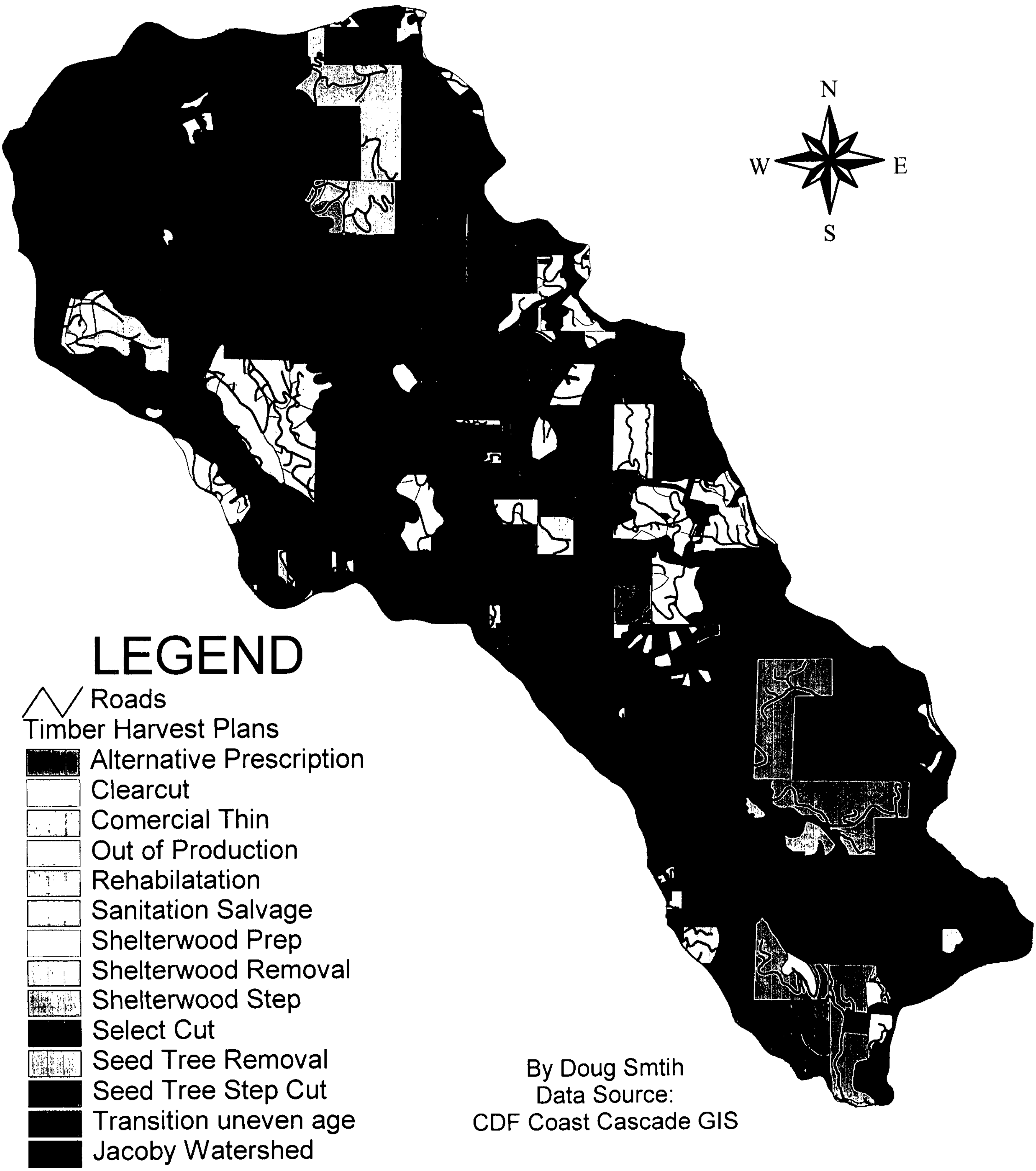
US_MADR	US_hemlok	US_abies	US_MANz	US_rhody	US_ehuck	US_rhuck	US_Tobacco	US_Bbloss	US_coyoteB	US_Alder
1.14	0.00	0	0	0	0	0	29.571	0	0	0
0.00	0.00	0	0	0	0	0	0	4.429	0.714	3.143
0.71	0.00	0	0	0	0	0	0	0	0	0
0.00	0.00	0.14	0	0	0	3	0	4.143	0.571	0
0.86	0.00	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0.428	0	0	0	0.857	1.857	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0.143	0	0	0	0	0
0	0.143	0	0	0	0	0	0	0	0	0

Timber Harvest Plan Acreage in Jacoby Creek 1988 to 2000 A Total Harvest of 26%

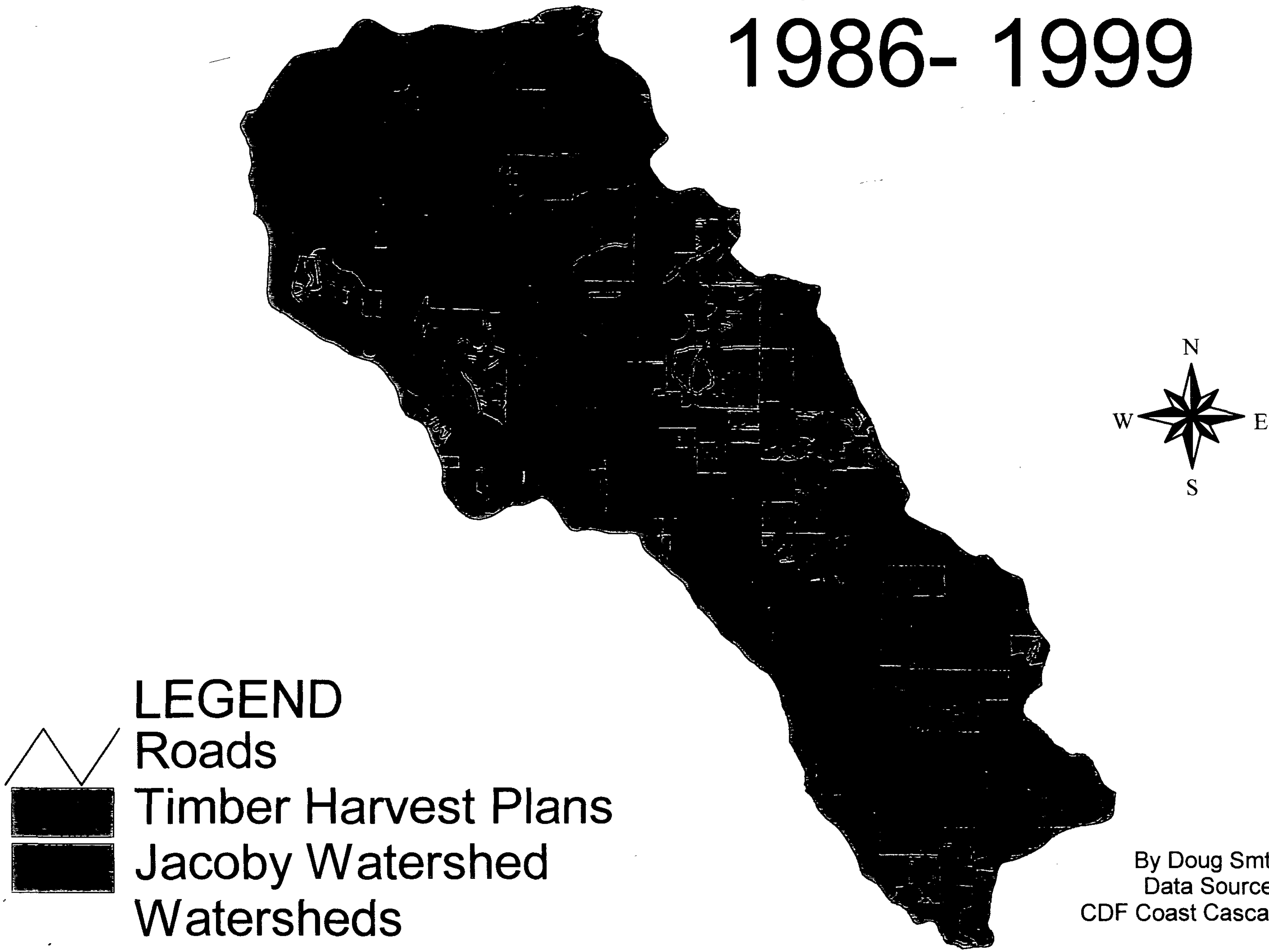


By Doug Smith 3/26/2001 Compiled from CDF data from Coast Cascade GIS.

Jacoby Creek THPs 1986- 1999

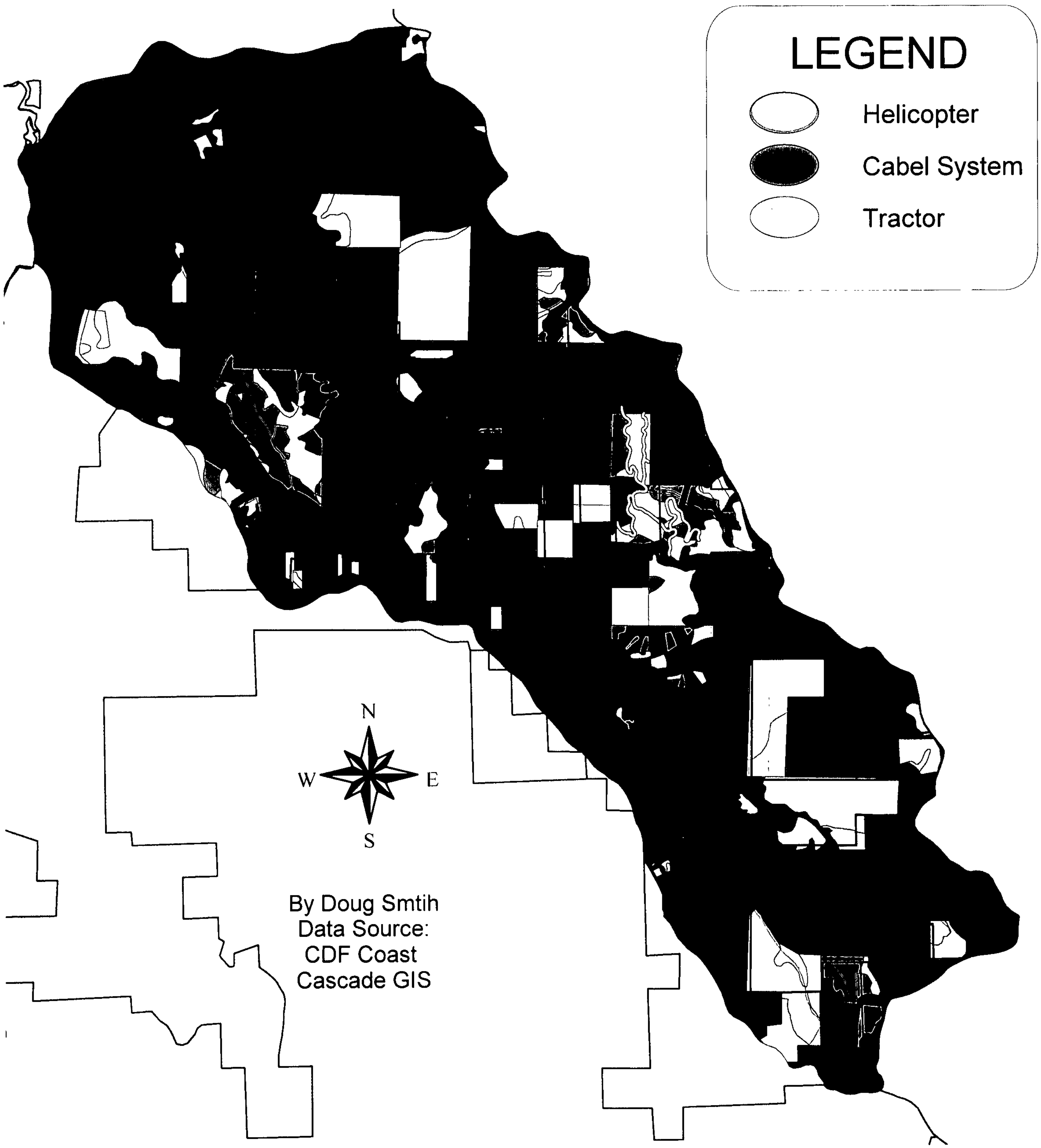


Jacoby Creek THPs 1986- 1999

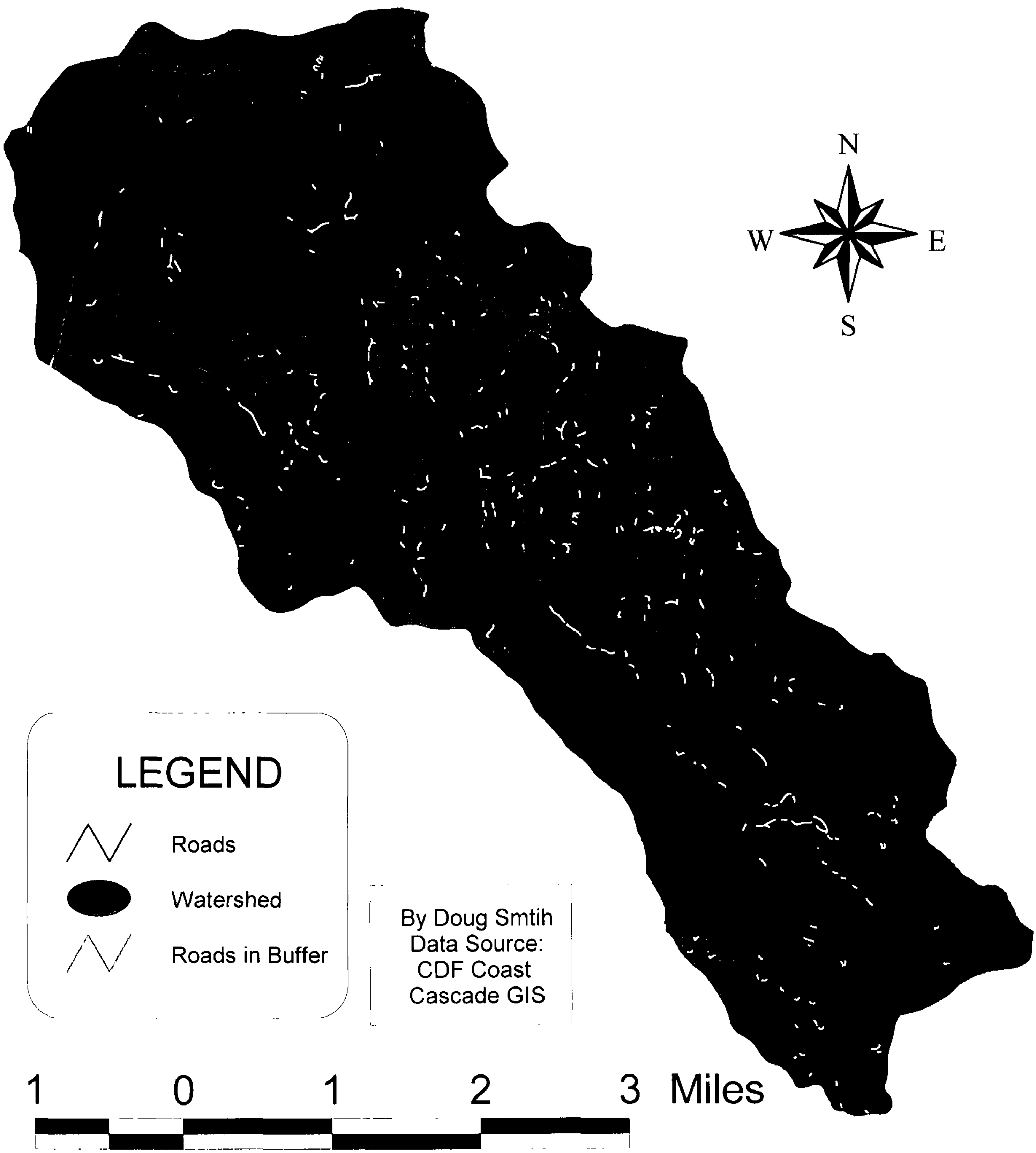


By Doug Smtih
Data Source:
CDF Coast Cascade GIS

JACOBY CREEK
Yarding Method



JACOBY CREEK ROADS
In 75' Stream Buffer



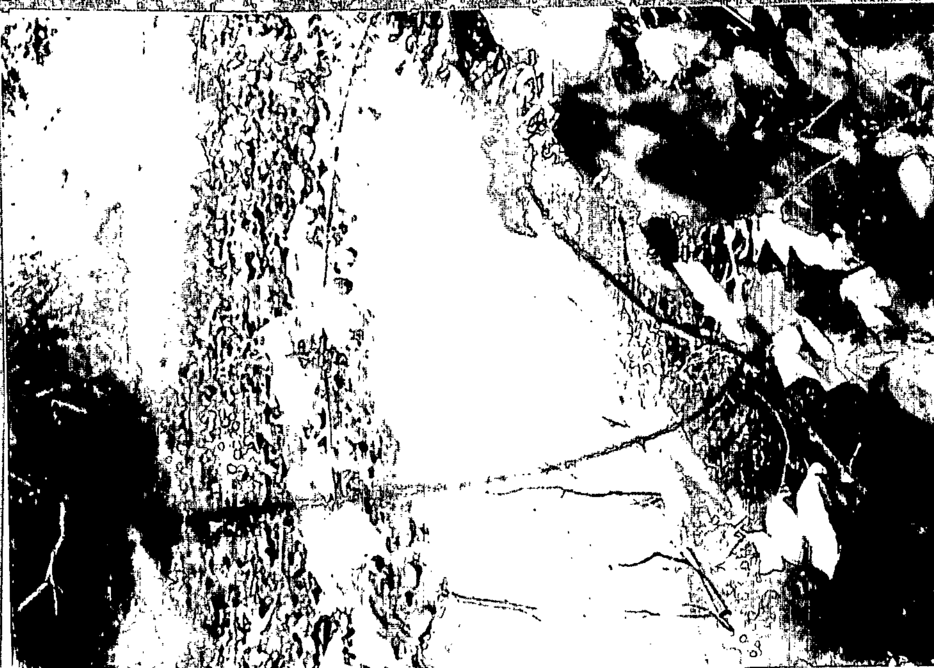
PHOTOS OF FLOODING AND SEDIMENTATION

9/12/91

Creek loaded with clay and sediment

←up

9/12/91



←up

9/12/91

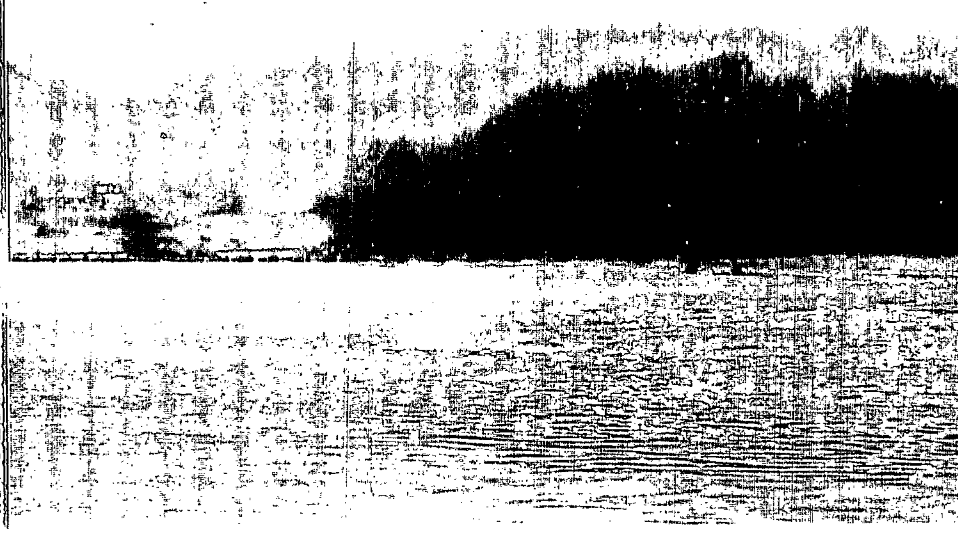
↑up

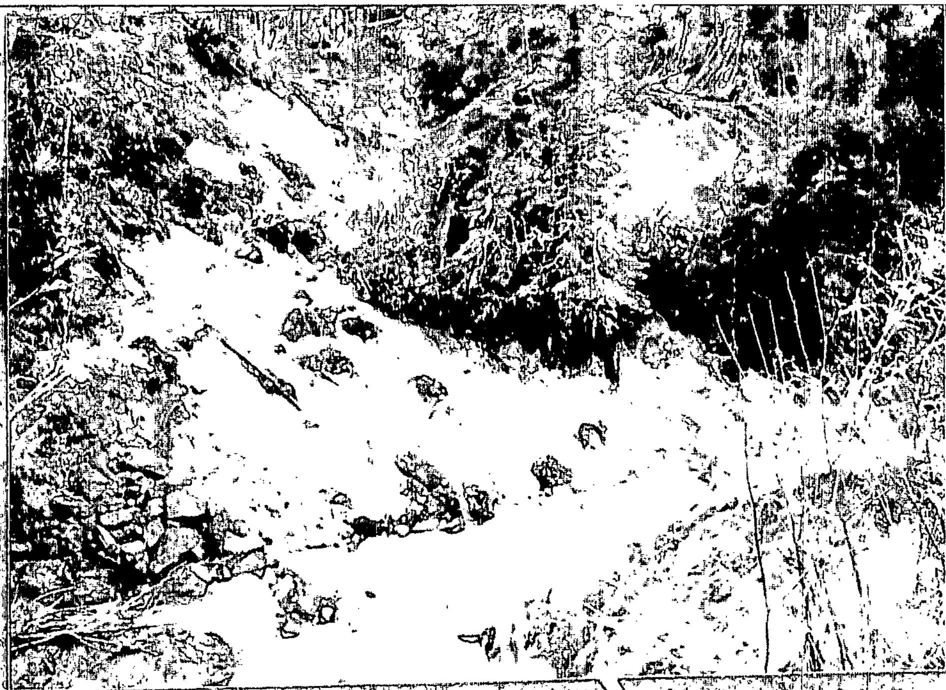
Winter Floods '95 & '96

7am 12/30/95
Looking East across Alexander pasture, presently a fast flowing river.

7am 12/30/95
Looking South at the remaining fence section of the old cattle pens.

7am 12/30/95
Looking NE across flooded plain to Alexander pasture under water





Blue Slide below Rebel Creek 6' Culvert w/concrete bottom

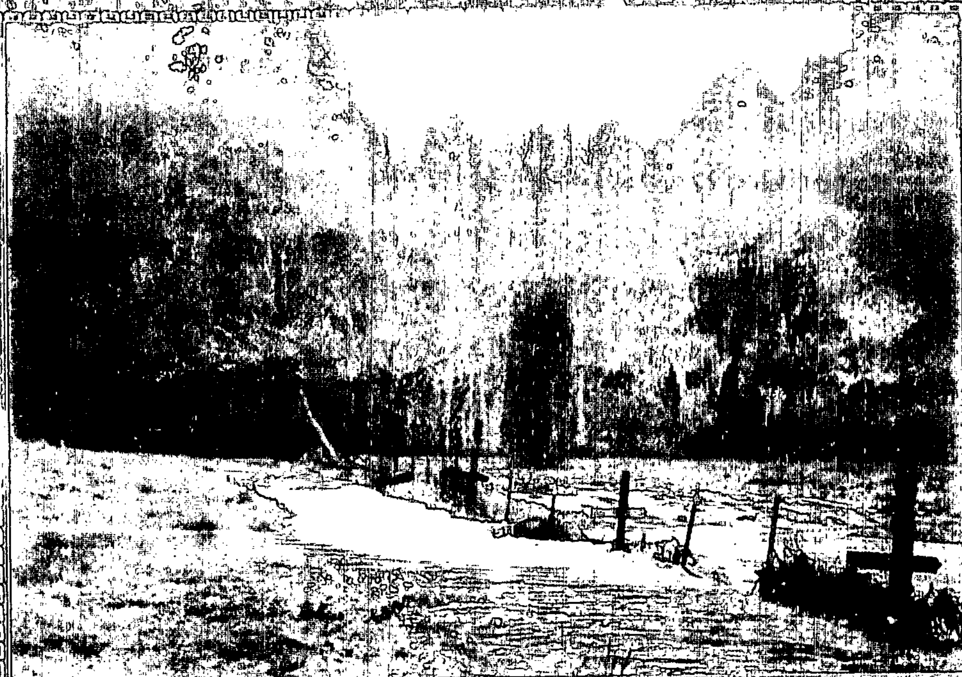
95-96 Flood Private road culvert just past Eric Lane on Jacoby Creek Road. Blocked Culvert

12/30/95 Flood waters went over Craig Lord's fence

Looking South across Jacoby Creek to floating trailer

Jam 12/30/95

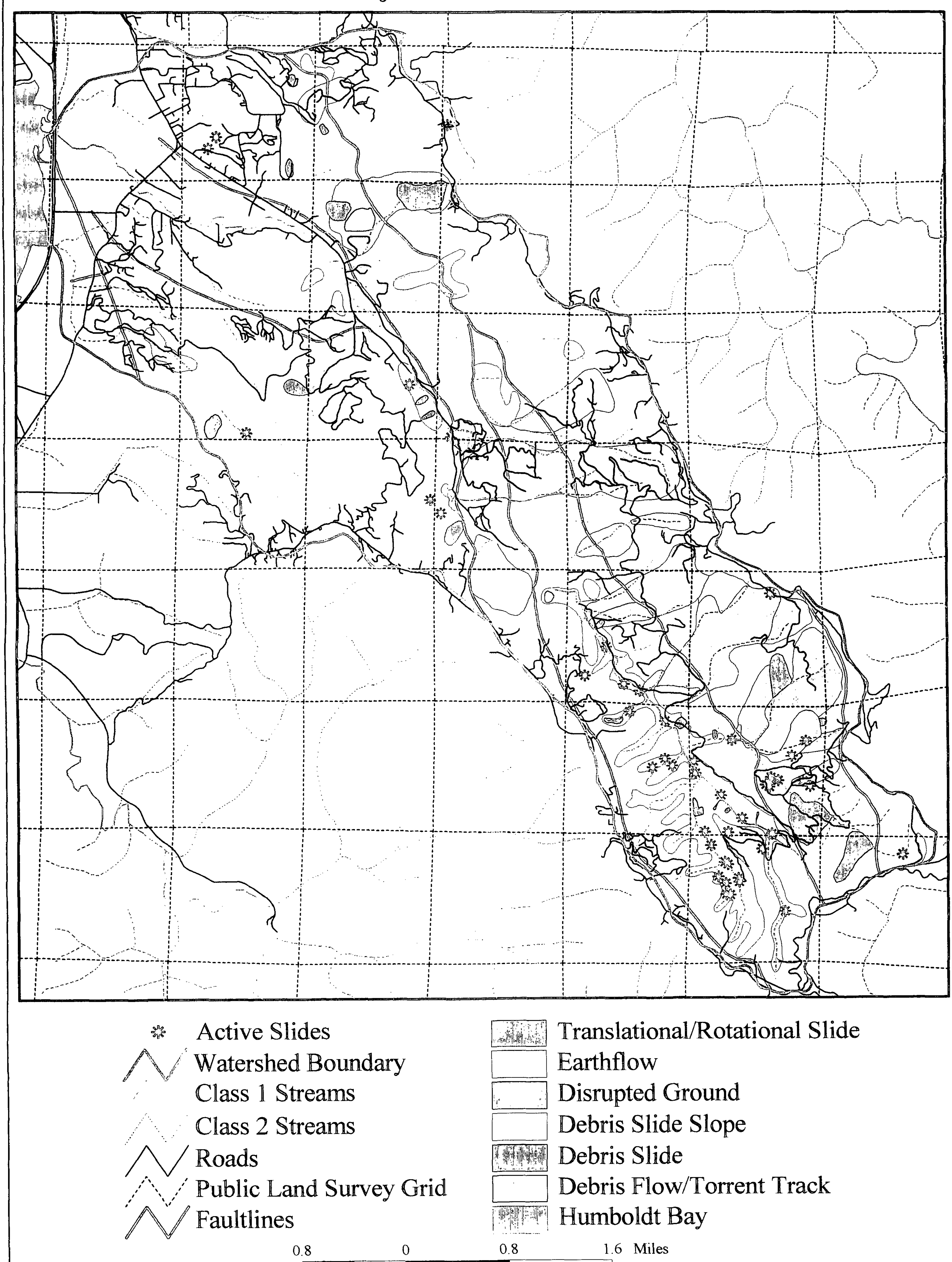
1995 Flooding crossing Parcel 3 overflowing Corp. of Eng. ditch



12/30/95 3626 Brookwood Dr., near Brookwood bridge Looking West

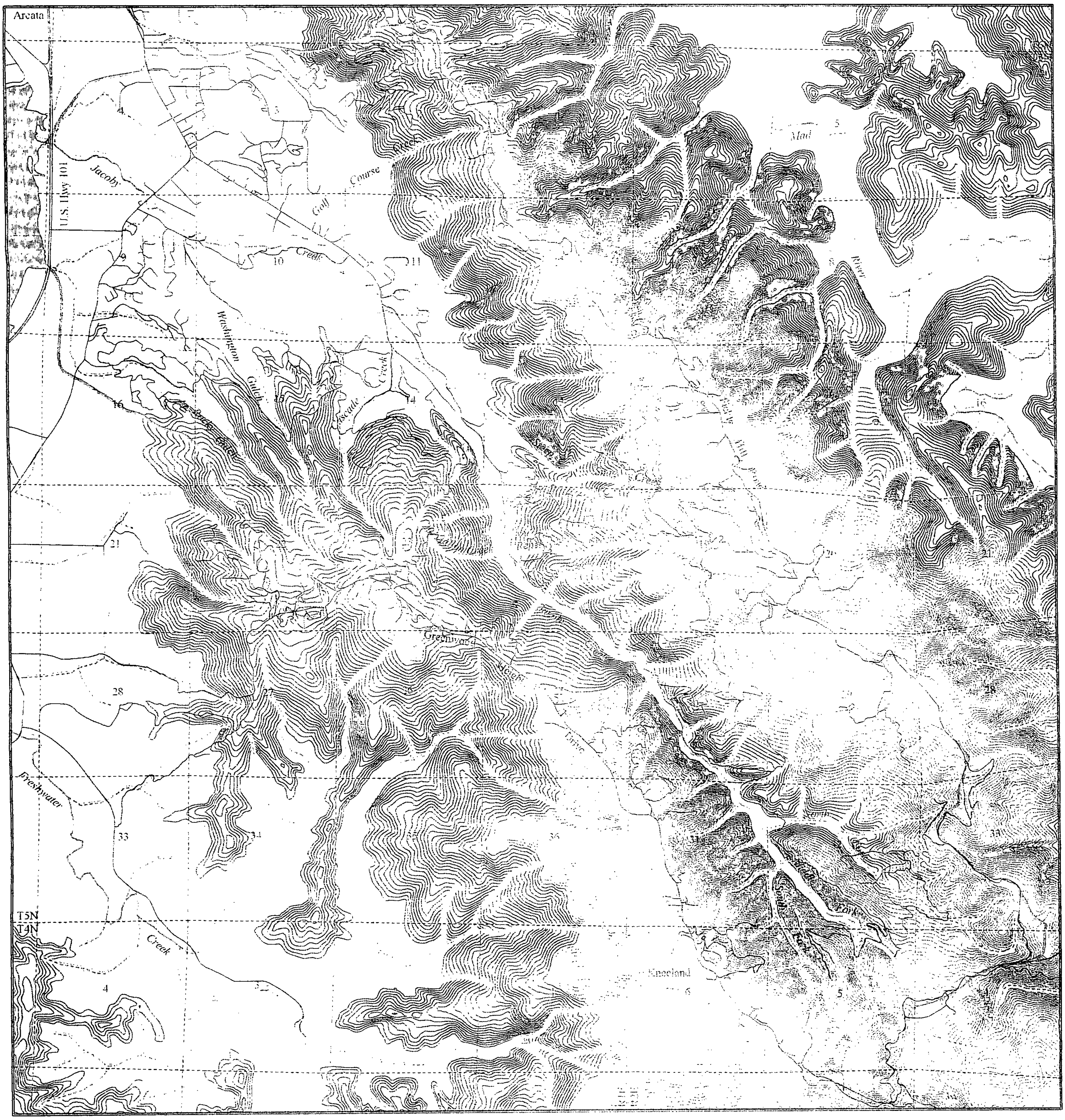
Geomorphic Features Related to Landsliding

Jacoby Creek Watershed



Map Composition by: Chris Trudel for the Jacoby Creek Land Trust in cooperation with Legacy - The Landscape Connection and the Environmental Services Department, City of Arcata.
Date: November 1998.

Riparian Buffer Zones and Topography
In Jacoby Creek Watershed and Vicinity



10-meter Contour Intervals
- 0 - 120 meters
- 130 - 240 meters
- 250 - 370 meters
- 380 - 500 meters
- 510 - 720 meters

Roads
Public Land Survey Grid
Jacoby Creek Watershed Boundary
Class 1 Streams
Class 2 Streams
Riparian Buffer Zones
Humboldt Bay

1 0 1 2 3 Miles

N W E S

Map Compiled by: Anthony Ambrose for the Jacoby Creek Land Trust in cooperation with the Environmental Services Department, City of Arcata.
Date: September 1998.

Figure 2

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in other folder

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Murray & Wunner, 1988, *The Jacoby Creek Watershed, Past, Present, and Future.* Natural Resources Division, Redwood Community Action Agency
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Sigler, 1984, *Effects of Chronic Turbidity on Density and Growth of Steelhead Trout and Coho Salmon, Transactions of the American Fisheries Society, 113:142-150, 1984*
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Eggers, 1987, *Seasonal Fluctuations in Food Availability and Feeding of Juvenile Steelhead Trout in a Small Coastal Stream*
Described are the Jacoby Creek fish habitats and the need for suitable summer flow rates. Also discussed is the type of water conditions needed for healthy juvenile steelhead trout in Jacoby Creek. Thesis, Humboldt State University

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Frakes, 1989, *An Analysis of Two Water Quality Problems in the Jacoby Creek Watershed, California*
Gives a perspective of the public agencies roles in the Jacoby Creek watershed and shows the continuing problem of sediment in Jacoby Creek. Thesis, Humboldt State University

Johnson, 1972, *A Study of Some Water Quality Characteristics and Possible Logging Influences on a Small on the North Coast of California*
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2002 3-3(d) List Update
Ref. # 76

Chapter 4

Habitat Requirements of Salmonids in Streams

T. C. Bjornn and D. W. Reiser

Habitat needs of salmon, trout, and char in streams vary with the season of the year and stage of the life cycle. The major life stages of most salmonid species are associated with different uses of fluvial systems: migration of maturing fish from the ocean (anadromous fishes), lakes, or rivers to natal streams; spawning by adults; incubation of embryos; rearing of juveniles; and downstream migration of juveniles to large-river, lacustrine, or oceanic rearing areas. We present information from the literature and from our own research on the range of habitat conditions for each life stage that allow the various species to exist. When possible, we attempt to define optimum and limiting conditions. Anadromous salmonids of the Pacific drainages of North America are our primary focus, but we have included information on other salmonids to illustrate the ranges of temperature, water velocities, depths, cover, and substrates preferred by salmon, trout, and char in streams. The scientific names of species identified by common names here are listed in the book's front matter.

Upstream Migration of Adults

Adult salmonids returning to their natal streams must reach spawning grounds at the proper time and with sufficient energy reserves to complete their life cycles. Stream discharges, water temperatures, and water quality must be suitable during at least a portion of the migration season. Native stocks of salmon, trout, and char that have evolved in stream systems with fluctuations in flow, turbidity, and temperature have often developed behaviors that enable survival despite the occurrence of temporarily unfavorable conditions. Native salmonids usually have sufficient extra time in their maturation, migration, and spawning schedules to accommodate delays caused by normally occurring low flows, high turbidities, or unsuitable temperatures. When upstream migration is not delayed, the fish in some stocks that migrate long distances arrive in the spawning areas 1–3 months before they spawn. Some stocks of fish that migrate short distances may not move into natal streams until shortly before spawning, but they must often wait in the ocean, lake, or river for flows or temperatures in the spawning streams to become suitable.

The flexibility in maturation and migration schedules observed in many stocks of native salmonids is not unlimited and has evolved for the specific environment

Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats
American Fisheries Society Special Publication 19:83–138, 1991

Transactions of the American Fisheries Society 113:142–150, 1984

Effects of Chronic Turbidity on Density and Growth of Steelheads and Coho Salmon[1]

JOHN W. SIGLER,[2] T. C. BJORNN, AND FRED H. EVEREST[3]

Idaho Cooperative Fishery Research Unit[4]
University of Idaho, Moscow, Idaho 83843

Abstract

Chronic turbidity in streams during emergence and rearing of young anadromous salmonids could affect the numbers and quality of fish produced. We conducted laboratory tests to determine the effect of chronic turbidity on feeding of 30–65 mm long steelheads *Salmo gairdneri* and coho salmon *Oncorhynchus kisutch* in straight and oval channels. Fish subjected to continuous clay turbidities grew less well than those living in clear water, and more of them emigrated from channels during the experiments.

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Yearling and older salmonids can survive high concentrations of suspended sediment for considerable periods, and acute lethal effects generally occur only if concentrations exceed 20,000 mg/liter (see reviews by Cordone and Kelly 1961; Sorenson et al. 1977), but little is known about the effects of turbidity on newly emerged young. Many streams used by salmonids for spawning in disturbed watersheds are subject to chronic turbidity. Fish reared in such streams might not grow as rapidly, or be as socially fit, as those produced in clear streams. In our paper, we evaluated the effects of chronic turbidity on growth and densities of young steelheads *Salmo gairdneri* and coho salmon *Oncorhynchus kisutch*.

Methods

Physical Facilities

We used two types of laboratory streams to insure that results were not artifacts of a single apparatus. We conducted replicate pairs of tests in 1978 and 1979 in (1) a pair of indoor oval channels, 3.7 m wide × 4.9 m long, located at the University of Idaho, and (2) two pairs of linear raceways, 1.2 m wide × 21 m long, on a translucent plastic-covered area at the Hayden Creek Research Station.

The four raceway channels at Hayden Creek Research Station had substrate arranged in riffle–pool configurations with large (10–15-cm) cobble distributed in a set pattern throughout each channel unit. A trap was attached to the downstream ends of each section (Fig. 1). Each pair of upper and lower channels was operated as a test unit.

The oval channels consisted of two essentially identical units, one above the other (Hahn 1977) (Fig. 1). Rearing space in each channel was about 10 m long and 60 cm wide (usable space, 6 m^2); pools were 30 cm deep and riffles 7–15 cm deep. Substrate was arranged in riffle–pool configuration with cobble placed in a set pattern throughout the substrate. A paddlewheel was used to maintain water velocities. Fine-mesh screen separated the paddlewheel from the rearing section. Free egress from the channels was provided by downstream and upstream traps.

We regulated turbidity, water velocity, temperature, and photoperiod in the oval channels. Carrying capacity of each was about 30 young fish, 30–55 mm long, in clear water. The Hayden Creek raceways were larger, enabling us to use larger numbers of fish, and we controlled turbidity, flow rate (velocity), and, to some extent, temperature. Photoperiod was natural.

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[4] The Unit is jointly supported by University of Idaho, Idaho Department of Fish and Game, and the United States Fish and Wildlife Service.

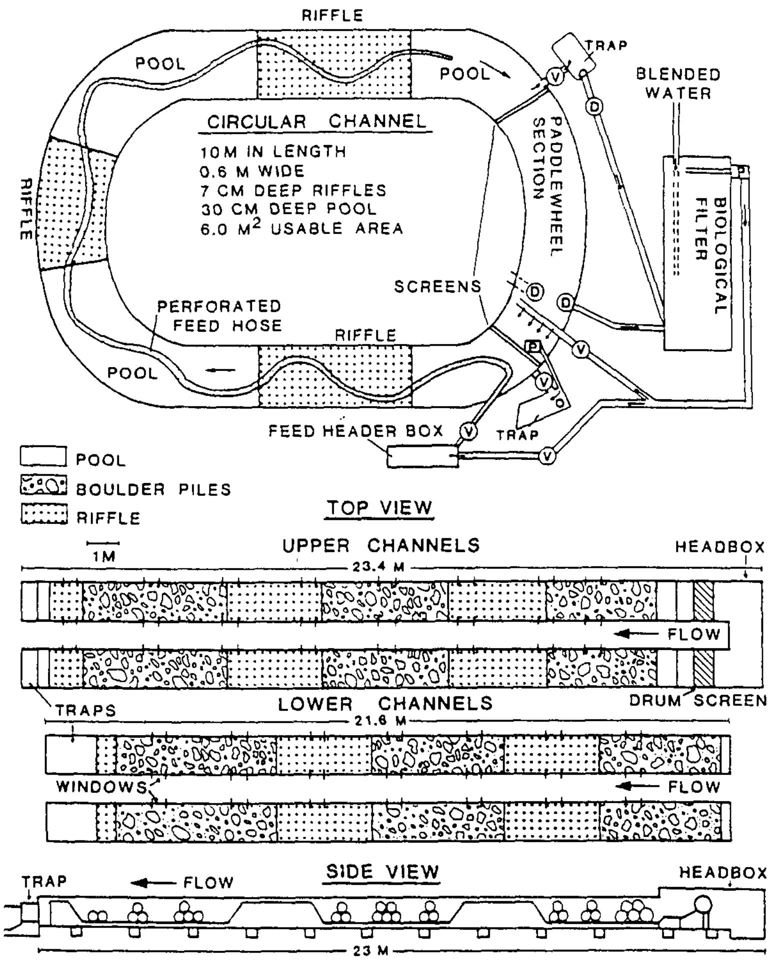

FIGURE 1.—*Generalized schematic of raceway channels at Hayden Creek Research Station and oval channels at University of Idaho showing the channel configurations, location of riffle and pool areas, and traps. (V = valve, D = drainline or drain, and P = pump.)*

Turbidity

We used clays, fireclay and bentonite, to create :urbidity in the tests. Fireclay used in the 1978 :ests, largely kaolinite as determined by X-ray iiffractograms, was distinctively different from he montmorillonite-based bentonite clay in size, :ohesion, and cation exchange capacity. Ben-onite clay used in the 1979 tests, as indicated ɔy X-ray analysis, had a structure that more :losely resembled the vermiculite structure of ıatural west-coast clays.

Clay was mechanically dispensed to all test :hannels. We added fireclay as a dry powder in the 1978 tests, using a modified lawn fertilizer spreader to achieve a near constant delivery. In the 1979 tests with bentonite clay, we pumped a wet slurry into the channels through a series of time clocks and valves that enabled us to maintain nearly constant turbidity in the channels.

Turbidity, in nephelometric turbidity units (NTUs), was significantly correlated with suspended material (mg/liter) filtered from the water (NTU = 10.0 + 0.178[mg/liter]; r^2 = 0.764) and with bentonite clay (mg/liter) added to the water (NTU = 5.49 + 0.162[mg/liter];

TABLE 1.—*Results of turbidity tests with steelheads in two oval channels, 1978 and 1979. Beginning mean weights and lengths for both turbid- and clear-water channels are based on a separate sample of 25 fish taken at time fish were placed in channels.*

Test (duration) Turbidity (NTUs)[a]	Fish: Released	Fish: Entering trap	Fish: Removed at end of test	Mean size of fish released: Length (mm)	Mean size of fish released: Weight (g)	Mean size at end of test: Length (mm)	Mean size at end of test: Weight (g)	Mean daily length increase (mm)	Mean daily weight increase (g)	Density at end of test: Fish/m^2	Density at end of test: g/m^2
Test 1 (14 days)											
Clear water	299	180	32	30.2	0.25	41.3	0.63	0.79	0.027	5.3	3.9
Clear water	305	162	27	29.7	0.26	40.6	0.62	0.74	0.026	4.5	2.8
Test 2 (14 days)											
Turbid water (143)	100	58	35	30.8	0.26	38.5	0.52	0.55	0.019	5.8	3.0
Turbid water (192)	100	63	3	30.9	0.27	35.3	0.38	0.32	0.008	0.5	0.2
Test 3 (14 days)											
Turbid water (167)	110	71	0	31.4	0.29					0.0	0.0
Turbid water (241)	110	61	0	31.4	0.29					0.0	0.0
Test 4 (14 days)											
Turbid water (232)	200	147	1	27.3	0.24	30.0	0.32	0.19	0.006	0.2	0.1
Turbid water (265)	160	121	1	27.3	0.29	29.0	0.20	0.12	0.003	0.2	0.0
Test 5 (14 days)											
Turbid water (77)	130	90	40	29.9	0.25	35.8	0.38	0.42	0.009	6.7	2.5
Turbid water (57)	130	103	33	29.9	0.25	36.3	0.38	0.46	0.009	5.5	2.1
Test 6 (21 days)											
Clear water	110	76	23	38.2	0.44	46.9	0.84	0.42	0.019	3.8	3.2
Turbid water (80)	110	68	24	38.2	0.44	45.8	0.77	0.36	0.016	4.0	3.1
Test 7 (15 days)											
Clear water	120	110	8	29.1	0.21	31.6	0.23	0.19	0.002	1.3	0.3
Turbid water (72)	120	105	2	29.1	0.21	34.0	0.20	0.15	−0.001	0.3	0.1
Test 8 (19 days)											
Clear water	120	102	6	31.5	0.26	36.8	0.40	0.53	0.014	1.0	0.4
Turbid water (51)	120	96	2	31.5	0.26	34.0	0.26	0.25	0.000	0.3	0.1
Test 9 (17 days)											
Clear water	100	92	4	43.0	0.65	50.3	0.87	0.56	0.017	0.7	0.6
Turbid water (59)	100	66	32	43.0	0.65	43.5	0.68	0.04	0.002	5.3	3.6
Test 10 (19 days)											
Clear water	130	114	10	45.7	0.72	49.6	0.93	0.19	0.010	1.7	1.6
Turbid water (45)	120	95	15	45.7	0.72	45.4	0.72	−0.01	0.000	2.5	1.8

[a] NTU = nephelometric turbidity unit.

$r^2 = 0.926$). We first created turbidities of 100–300 NTUs, but fish either left the channels or died. Subsequently we created turbidities mostly in the 25–50-NTU range. At 50 NTUs, visibility was limited to 2–5 cm.

Fish and Feeding

Steelhead and coho salmon were used in the tests to determine interspecific differences in reactions to turbidity. Steelhead eggs and juveniles were from Dworshak National Fish Hatchery, Ahsahka, Idaho, and coho salmon eggs were from the Sandy State Fish Hatchery, Oregon.

At the start of each growth test, we introduced 100–160 fish into each oval channel and 135–1,200 into each raceway channel. Migration traps were kept closed 24–48 hours after the first fish were introduced. Initial mean weights and lengths were determined from a

LE 2.—*Results of turbidity tests with steelheads in four raceway channels, 1979. Beginning mean weights and lengths ? based on a separate sample of 25 fish taken at time fish were placed in channels.*

(duration) ırbidity (NTUs)[a]	Fish: Re-leased	Fish: Enter-ing trap	Fish: Re-moved at end of test	Mean size of fish released: Length (mm)	Mean size of fish released: Weight (g)	Mean size at end of test: Length (mm)	Mean size at end of test: Weight (g)	Mean daily length in-crease (mm)	Mean daily weight increase (g)	Density at end of test: Fish/m²	Density at end of test: g/m²
1 (14 days)				27.6	0.23						
ear water											
Upper channel	950	452	357			33.5	0.41	0.39	0.012	17.1	7.0
Lower channel	425	128	208			35.0	0.46	0.49	0.015	8.4	2.1
ırbid water (48)											
Upper channel	950	636	176			31.0	0.25	0.23	0.002	8.5	3.9
Lower channel	425	480	4			33.5	0.39	0.39	0.011	0.2	0.1
t 2 (19 days)				29.4	0.22						
lear water											
Upper channel	1,200	448	498			37.1	0.56	0.41	0.018	23.8	13.4
Lower channel	800	188	352			37.5	0.62	0.43	0.021	4.0	1.4
'urbid water (38)											
Upper channel	1,200	913	84			33.6	0.36	0.22	0.007	14.5	8.9
Lower channel	800	839	20			34.2	0.37	0.25	0.008	0.8	0.3
st 3 (17 days)				26.8	0.20						
:lear water											
Upper channel	1,000	314	386			38.0	0.62	0.66	0.024	18.4	11.3
Lower channel	700	236	540			37.4	0.58	0.62	0.023	9.9	3.6
Turbid water (49)											
Upper channel	1,000	570	208			33.4	0.36	0.39	0.009	22.2	12.9
Lower channel	700	263	230			32.8	0.35	0.35	0.009	9.5	3.3
:st 4 (19 days)				37.9	0.56						
Clear water											
Upper channel	900	119	697			47.8	1.44	0.52	0.046	33.3	48.0
Lower channel	585	14	531			46.6	1.33	0.46	0.040	5.8	4.7
Turbid water (42)											
Upper channel	900	467	122			42.0	0.94	0.22	0.020	21.8	29.0
Lower channel	585	345	235			41.6	0.93	0.22	0.019	9.7	9.0

[a] NTU = nephelometric turbidity unit.

:parate sample of fish randomly selected from ıe holding tank.

Frozen brine shrimp were fed to the fish in ıceways in 1978 and in oval channels in 1978 nd 1979. Oregon Moist Pellet of appropriate .ze was fed to fish in raceways in 1979. Un-tressed fish took these foods readily. Food was ırovided at a daily rate of 10–15% of body veight, and was adjusted every 3–4 days to ac-ount for emigration and assumed weight gain. The ration was divided into three daily feed-ngs. Food was dispensed to each raceway by ıand in 1978 and by automatic feeding in 1979. For oval channels, brine shrimp were slowly dis-tributed to the channel through a perforated ıose in the substrate (Fig. 1). Food entering the channels peaked shortly after feeding, and de-creased exponentially until the next feeding.

Experimental Procedures

At the start of each test, fish were counted into three containers: one for the turbid-water channel; one for the clear-water channel; and one for measurement of beginning lengths and weights. Fish were introduced into the channels in two ways: (1) placed in a screen cage open on the bottom and forced to go down into the grav-el and emerge outside the box if the fish were near the size of emergence; and (2) poured into the head of raceway channels or middle of oval channels. Water in the turbid-water channel was usually turbid when fish were placed in the

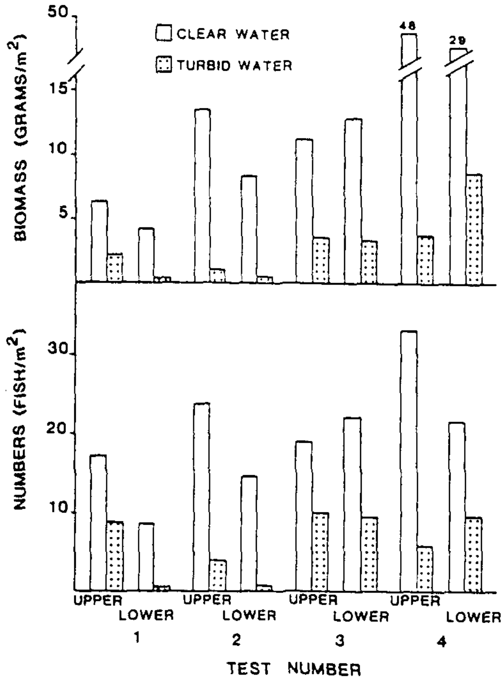

FIGURE 2.—*Densities at end of tests with steelheads in upper and lower raceway channels with clear and turbid water, 1979.*

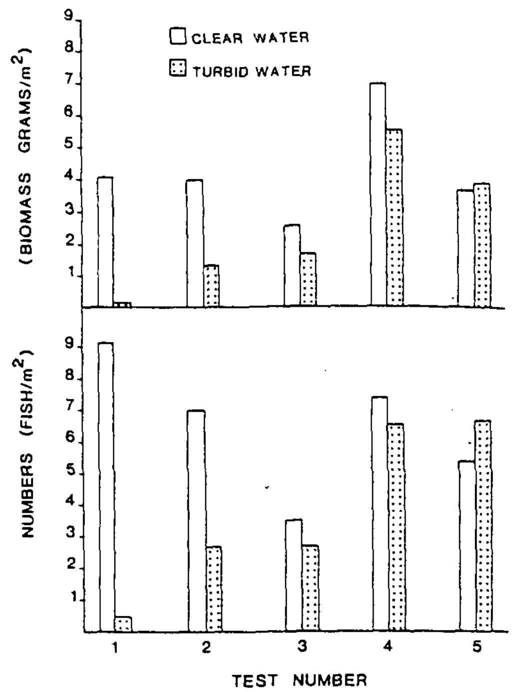

FIGURE 3.—*Densities at end of tests with coho salmon in oval channels with clear and turbid water, 1979.*

channels. Traps that fish could enter to leave the channels were not opened until 24–48 hours after fish were placed in the channel to provide time for the fish to acclimate to the channels. Additional small numbers of fish were added to each channel on the second and third day of tests to help insure the channels were fully seeded. At the end of each test, fish were removed from the channels first by electrofishing and then by killing any remaining fish with chlorine bleach. Fish were preserved in 10% neutral buffered formalin and later measured and weighed.

All fish could not be accounted for at the end of most tests, either as having left the channels through the traps or as having been recovered at the end of the test. The fate of the unrecovered fish is unknown, but we suspect that some died and settled into the gravel interstices. In any event, fish that took up residence in the channels and were recovered at the end of the test were the most important for evaluating the effects of turbidity on densities and growth.

Results

Steelhead

Oval Channels

In our first test in 1978 to determine the approximate carrying capacity of the channels with clear water, we released in each channel about 300 fish that averaged 29.7 and 30.2 mm total length, and 0.25 and 0.26 g. After 14 days, 32 and 27 fish remained in the channels (Table 1). Most fish that left the channel did so in the first 2–3 days; there was little or no emigration during the last 2–3 days. Densities at the end of the test were 4.5 and 5.3 fish/m², and 2.8 and 3.9 g/m². Fish in the channels at the end of the test grew an average of about 0.75 mm/day and 0.026 g/day, if they were representative of fish placed in the channel at the start.

We then conducted four tests to determine the range of turbidities we should use in growth tests. We placed 100–200 fish in each channel and then added the powdered clay to both channels to create turbidities that ranged from 57 to 265 NTUs (tests 2–5, Table 1). In tests 2–4

TABLE 3.—*Results of turbidity tests with coho salmon in two oval channels, 1979. Beginning mean weights and lengths are based on a separate sample of 25 fish taken at time fish were placed in channels.*

Test (duration) Turbidity (NTUs)[a]	Fish: Re-leased	Fish: Enter-ing trap	Fish: Re-moved at end of test	Mean size of fish released: Length (mm)	Mean size of fish released: Weight (g)	Mean size at end of test: Length (mm)	Mean size at end of test: Weight (g)	Mean daily length in-crease (mm)	Mean daily weight increase (g)	Density at end of test: Fish/m²	Density at end of test: g/m²
Test 1 (14 days)				33.4	0.34						
Clear water	130	70	55			38.6	0.46	0.37	0.007	9.2	4.2
Turbid water (86)	130	91	3			35.7	0.30	0.16	−0.005	0.5	0.2
Test 2 (13 days)				37.1	0.40						
Clear water	160	105	41			42.0	0.57	0.38	0.013	7.0	4.0
Turbid water (45)	160	136	16			40.6	0.49	0.27	0.007	2.7	1.3
Test 3 (11 days)				42.4	0.53						
Clear water	140	118	21			46.3	0.75	0.36	0.020	3.5	2.6
Turbid water (22)	120	104	16			44.1	0.65	0.16	0.011	2.7	1.7
Test 4 (14 days)				45.2	0.77						
Clear water	120	71	44			49.6	0.94	0.31	0.006	7.3	6.9
Turbid water (31)	120	73	39			48.5	0.87	0.24	0.011	6.5	5.6
Test 5 (15 days)				41.1	0.57						
Clear water	120	86	32			45.4	0.70	0.31	0.009	5.3	3.7
Turbid water (23)	120	67	40			42.0	0.58	0.13	0.000	6.7	3.9

[a] NTU = nephelometric turbidity unit.

with mean turbidities of 167 NTUs or higher, almost no fish could be found in the channels after 14 days. In test 2, with a mean turbidity of 143 NTUs in one channel, we removed 35 fish at the end of the test. We then tested much lower turbidities (57 and 77 NTUs) in test 5 and found that small fish could survive in those turbidities, and numbers near the carrying capacity (33 and 40 fish, 35 mm long) would stay in the channels. In all subsequent tests, mean turbidities were less than 86 NTUs.

We then conducted one additional test in 1978 with steelheads to compare growth of fish in turbid versus clean water (test 6, Table 1). Of the 110 fish (38.2 mm long, 0.44 g) released in each channel, 23 were removed from the one with clear water and 24 from the one with turbid water (80 NTUs). Density at the end of the 21-day test was near carrying capacity (3 g/m²) in both channels and growth rates of the fish of the fish were not significantly different between channels.

In 1979, we conducted four turbidity-versus-growth tests with steelheads in the oval channels (tests 7–10, Table 1). In all four tests, the numbers of fish remaining in the channels at the end were less than half the carrying capacity, except for the turbid water channel in test 9. Because of the small number of fish at the end of the tests, comparisons of fish growth between clear and turbid water channels are of limited value. There is some evidence of slower growth of steelheads in turbid water versus clear water, but it is not conclusive.

Raceway Channels

Four tests of steelhead growth versus turbidity were conducted in the raceway channels in 1979 (Table 2). In all tests, more fish stayed in the clear-water channels than in those with turbid water (Fig. 2). The number and biomass of fish remaining in each channel somewhat depended on the number and size of fish released. In general, numbers of fish and biomass in either clear- or turbid-water channels at the end of the test were larger when larger numbers or larger-size fish were released.

Steelheads that stayed in the clear-water channels were consistently larger than fish in the turbid-water channels and they grew at fast-

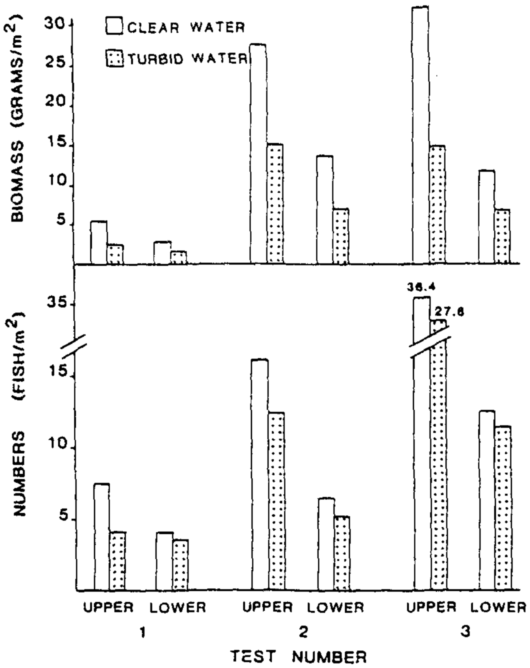

FIGURE 4.—*Densities at end of tests with coho salmon in upper and lower raceway channels with clear and turbid water, 1979.*

er daily rates of both weight and length (Table 2). Differences in growth and density between fish in clear and turbid water were statistically significant for the combined upper and lower channels: final weight (F = 31.67; P = 0.003); final length (F = 36.64; P = 0.0002); and mean daily length gain (F = 46.61; P = 0.0001).

Coho Salmon

Oval Channels

In four of the five tests of coho salmon growth versus turbidity in the oval channels, fewer fish had stayed in the turbid water channels by the end of each test than had stayed in the channels with clear water (Table 3; Fig. 3). Largest differences in ending densities occurred in tests 1 and 2 when the fish released were relatively small (33 and 37 mm mean length). In later tests, fish averaged 41 mm or more in length when released and differences in ending densities between clear and turbid water channels were not large. In all tests, ending densities in at least the clear-water channel were near carrying capacity.

Fish that stayed in the clear-water channe were significantly larger at the end of each test than fish in turbid water (Table 3) in both weight (F = 31.52; P = 0.005) and length (F = 35.09; P = 0.004). Mean daily weight and length increases of fish were significantly larger in the clear-water channels than in the turbid-water channels (Table 3): weight increase, F = 30.87; P = 0.005; length increase, F = 35.18; P = 0.004.

Raceway Channels

Fewer fry remained in raceway channels with turbid water than in those with clear water at the end of all three tests with coho salmon (Table 4; Fig. 4). Differences in fish numbers for the combined upper and lower channels between clear and turbid water were not statistically significant (F = 1.01; P = 0.35), but differences in biomass were significant (F = 7.21; P = 0.036). As in raceway-channel tests with steelheads, ending densities of coho salmon were influenced some by the number and perhaps size of fish released: higher ending densities resulted from larger numbers released.

Coho salmon that stayed in clear water were consistently larger in weight and length than fish that stayed in turbid water channels (Table 4). Mean daily weight and length increases were up to six times larger for fish in clear water versus those in turbid water. Weights and lengths of clear- versus turbid-water fish at the end of the tests differed significantly (F = 16.33; P = 0.006; and F = 19.91; P = 0.004), as did mean daily length increase (F = 38.54; P = 0.001).

Discussion

In general, more fish stayed in channels with clear water than with turbid water, and weight and length of both steelheads and coho salmon increased faster in clear water. In most tests, there was a significant difference in growth rates between fish in clear versus turbid water. Fish reared in clear water were not always significantly larger than fish in turbid water, but were growing at faster rates. After longer periods of growth, greater divergences of weight and length between fish in clear versus turbid water presumably would have occurred.

Densities of fish in the clear-water channels, although not always statistically different, were consistently higher than those in the turbid-

TABLE 4.—*Results of turbidity tests with coho salmon in four raceway channels, 1979. Beginning mean weights and lengths are based on a separate sample of 25 fish taken at time fish were placed in channels.*

Test (duration) Turbidity (NTUs)[a]	Fish: Released	Fish: Entering trap	Fish: Removed at end of test	Mean size of fish released: Length (mm)	Mean size of fish released: Weight (g)	Mean size at end of test: Length (mm)	Mean size at end of test: Weight (g)	Mean daily length increase (mm)	Mean daily weight increase (g)	Density at end of test: Fish/m²	Density at end of test: g/m²
Test 1 (14 days)				35.1	0.45						
Clear water											
Upper channel	314	15	153			41.9	0.75	0.49	0.022	7.3	5.5
Lower channel	135	26	98			41.5	0.73	0.45	0.020	4.1	2.5
Turbid water (11–32)											
Upper channel	314	45	86			40.4	0.60	0.38	0.011	4.0	2.9
Lower channel	135	48	76			39.3	0.55	0.30	0.007	3.1	1.7
Test 2 (31 days)				38.2	0.52						
Clear water											
Upper channel	600		330			53.8	1.76	0.50	0.040	15.8	27.7
Lower channel	187	13	161			57.0	2.07	0.61	0.050	12.7	15.0
Turbid water (41)											
Upper channel	600	215	266			47.3	1.18	0.29	0.021	6.6	13.7
Lower channel	188	60	128			49.0	1.30	0.35	0.025	5.3	7.0
Test 3 (21 days)				37.2	0.45						
Clear water											
Upper channel	900	19	761			44.5	0.89	0.35	0.021	36.4	32.4
Lower channel	400	20	314			43.9	0.93	0.32	0.023	27.6	14.9
Turbid water (49)											
Upper channel	1,000	347	578			38.4	0.54	0.06	0.004	12.9	11.9
Lower channel	400	159	284			38.6	0.59	0.07	0.007	11.7	6.9

[a] NTU = nephelometric turbidity unit.

water channels (Figs. 2, 3, 4) and were somewhat smaller than those reported by Reiser and Bjornn (1979) for natural streams. Conditions in the turbid-water channels were less desirable or suitable for habitation than in the clear-water channels, perhaps because fish could not feed normally or suffered stresses resulting from the turbidity. Small fish (<40 mm) were less likely to stay in the turbid-water channels than larger fish.

Larger numbers of fish emigrated from the channel with turbid water than from the one with clear water during the first two diel cycles in each test. This early emigration by large numbers of fish is evidence that the turbidity was stressful to the fish. Some fish that still had a portion of yolk sac left the turbid water, indicating that inability to obtain sufficient food was not the principal reason for emigration.

Anadromous salmonids use many small west-coast streams with seasonally intermittent flow for spawning and early rearing. Summer-run steelheads in the Rogue River basin, Oregon, spawn primarily in streams that become intermittent or dry in summer (Everest 1973). Fall-run chinook salmon *Onchorhynchus tshawytscha* and coho salmon also spawn in small intermittent streams of the Rogue basin. Resident rainbow trout *Salmo gairdneri* in the Sagehen Creek basin, California, often spawned in an intermittent tributary (Erman and Hawthorne 1976). Young salmonids live in the intermittent streams for a few days to several weeks, after which they migrate downstream and enter larger streams where they must compete with other fish for food and space.

If fish in natural streams are subjected to turbidity soon after emergence, we would expect substantial emigration. Such downstream migration could reduce production in those tributaries if the emigrants did not secure suitable habitat in downstream areas. Fish rearing in chronically turbid intermittent streams eventually would be forced by declining space to emigrate to downstream waters or perish. Those that did emigrate after rearing in turbid water would be smaller than downstream cohorts reared in clear water and probably less able to compete for living space. Because the outcome of aggressive encounters usually is decided by size (Chapman 1962), survival to smolt for such emigrants would probably be reduced.

The higher rate of emigration by fish in turbid water is in contrast to the findings of Noggle (1978). He found a strong tendency for fish to stay in their initial territory when exposed for short periods to turbid water rather than leave, even when a less adverse condition (clear water) was accessible. Noggle's fish were larger than those in our tests and may have been better able to handle stress from turbid water.

In our study, gill-tissue damage was not readily observable in any of the fish examined until after 3 to 5 days of exposure to the test turbidities. Herbert and Merkens (1961) observed gill-epithelial thickening in six fish exposed for several weeks to 270 to 810 mg/liter diatomaceous earth, yet one fish surviving in 810 mg/liter had normal gills. Other studies cited by Noggle (1978) reported no damage to gills of fish exposed to high concentrations of the type of sediment used in our studies.

In our studies, as little as 25 NTUs of turbidity caused a reduction in fish growth. The slower growth, presumably from a reduced ability to feed, could be related to a mechanism more complex than inability to see prey (such as insufficient light). Brett and Groot (1963) reported that Pacific salmon could feed at light levels equivalent to $\frac{1}{500}$ of bright moonlight (0.001 lux), much darker than in our turbid-water channels. Quality of light may be a factor. Large amounts of suspended particles may intercept the wavelengths used by fish, thereby reducing their ability to see and secure food.

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Transactions of the American Fisheries Society

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Increased pressures on our and concern for the environ past couple of decades has b history work to the forefront management and impact-asses Studies related to siting and ir fossil-fueled, and hydroelectr have become particularly pro land and coastal waters. Couple in early-life-history work has b of information. Still, our knowl life history of fish generally lag of adults. Much potentially va tion may be buried forever in dustry, and consulting-firm rep

A series of annual larval-fish evolved in response to the need and effective exchanges of info promote interaction among ot researchers. Beginning with a water-oriented symposium spo power industry in 1977, the co grown to become major North A encompassing nearly all facets c tory work. Each successive, ind ganized conference has built up of the past and expanded acco and contributions of its particip

The Early Life History Sectio ican Fisheries Society has assume coordinating role with these cc advisory committee of present, f ture conference chairmen assure of well-organized annual confere conference, the eighth, will be h 1984 in conjunction with an Inter posium on the Early Life Histor Vancouver, British Columbia. T ference is scheduled for Port Ar and the tenth for Miami, Florida

The Seventh Annual Larval Fis was hosted by the Larval Fish La Department of Fishery and Wildl Colorado State University, 16–19 The number and variety of pape subjects discussed, and materials worked with during this confere

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Newcomb & Jensen

COMMENTS

Canadian Journal of Fisheries and aquatic Sci

Comment: Utility of the Stress Index for Predicting Suspended Sediment Effects

Newcombe and MacDonald (1991) present a concentration–duration response model intended to be a convenient tool for assessing environmental effects caused by suspended sediment. As a much-needed synthesis of the available literature on the impacts of suspended sediment on salmonid fishes, their work is commendable. However, as an accurate predictive management tool, we find their stress index model is unreliable. These authors conclude that their stress index, $\log_e$ (concentration × duration), will be useful in assessing the severity of suspended sediment effects when there is a lack of either time or resources to complete a detailed environmental assessment. Because such instances are commonplace, the appeal of an effective tool developed for this purpose is obvious. The stress index model is seductively simple.

Our concerns have been prompted by the queries of salmon stock and habitat managers and hatchery operators in British Columbia, alarmed at the effects the model predicts for specific habitats. We have examined the information reviewed by Newcombe and MacDonald (1991) and have found that the data were highly variable, making the predictive power of their stress index low. Applying a general model, such as the stress index, to a stock-specific problem is a speculative prospect. We agree that duration of exposure as well as concentration must be considered in any assessment of the effect of suspended sediment on aquatic life. However, the stress index model is unrealistically simplistic. Without more detailed knowledge of specific stocks and habitats than the authors imply to be necessary, their stress index model has limited usefulness.

We have several concerns about the paper's treatment of data from the literature and the conclusions Newcombe and MacDonald (1991) presented. First, contrary to claims in the paper, the stress index model cannot be used to predict unquantifiable and subjectively ranked effects (Table 1, ranks 1–7, *in* Newcombe and MacDonald 1991). The model also omits concentration and duration thresholds, beyond which impacts will not occur; therefore, many predictions will be exaggerated. Second, although the authors attempted to cove a wide spectrum of aquatic animal and plant taxa data from relevant fish species were not considere (e.g., nonsalmonid fishes). Considering the abundance of suspended sediment literature on these other fish species, we are surprised none of these studies were included in their analysis. Third, the model ignores the effects of additional variables normally associated with suspended sediment. Fourth, no statistical or practical validation procedure was performed on the model. Effects were substantially over- or underestimated relative to the observed effects in a high proportion of cases. Their stress index model fails to provide sufficiently accurate predictions of the effects of suspended sediment to be reliably used by managers of fish stocks (salmonid stocks in particular). In this paper, we reveal how each of these points affects the usefulness of the stress index model. We also demonstrate, through examples from our own research as well as from the published literature, that reliance on the stress index might lead fish habitat managers to suggest inappropriate policies for the protection of many fish stocks.

Other than quantifiable metabolic, physiological, and lethal stresses (Table 1, ranks 8–14, *in* Newcombe and MacDonald 1991), the relative ranks of the effects of suspended sediment presented by the authors were subjective and often of debatable biological significance. For example, suspended sediment "avoidance response" (rank 2) could simply have represented a short-term reaction to novel stimuli. Berg (1983) reported that initial observations indicating such avoidance behavior passed quickly in young coho salmon *Oncorhynchus kisutch*. Similarly, the "abandonment of cover" (rank 3) may not be a detrimental effect either. Turbidity may act as a form of cover from predators, affecting predator avoidance and feeding behavior of salmonids (Gregory 1990, 1993; Gregory and Northcote 1993). We also see no empirical support for the order of the sublethal and behavioral effects observed (ranks 1–9). Therefore, the variance their model accounted for (64%) was likely to have been overestimated.

The stress index model uses an open-ended time horizon, which will serve to exaggerate predicted impacts. According to the model, suspended sediment loads as low as 5 mg·L^{-1} over a year ($\log_e$(S

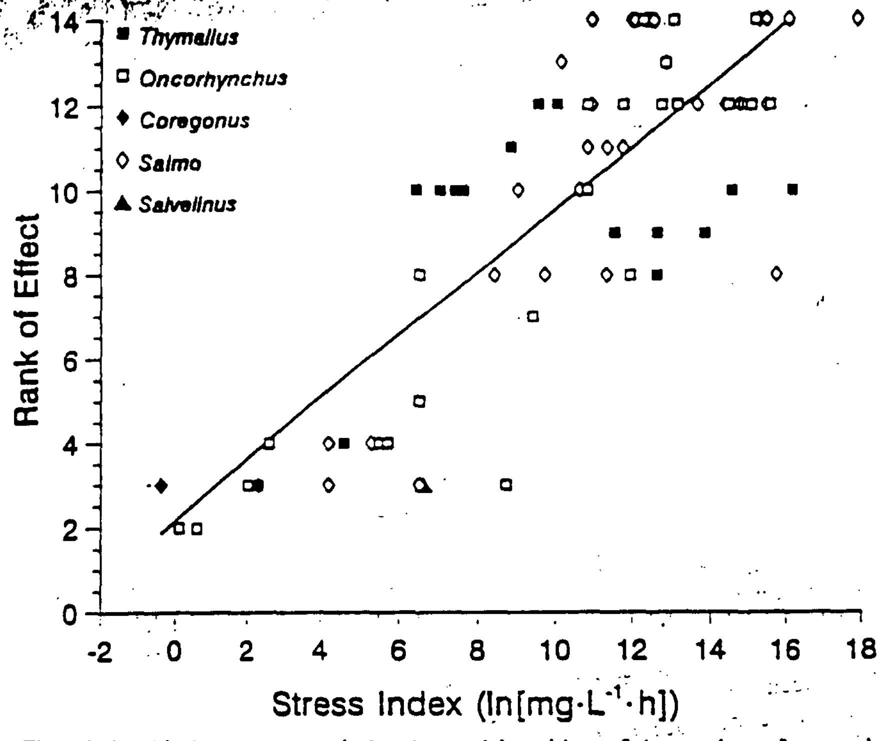

FIGURE 1.—The relationship between stress index (natural logarithm of the product of suspended sediment concentration and duration of exposure) and the observed severity of impact (rank of effect) on salmonids (after Newcombe and MacDonald 1991). Line indicates the prediction of the stress index model (rank effect = 0.738 $\log_e$[concentration × duration] + 2.179). We have removed data on aquatic invertebrates and data on "sediments" with confounding toxic effects (e.g., coal dust—see text) from our reanalysis.

tant topics, we believe their inclusion in Newcombe and MacDonald's (1991) survey was inappropriate. The confounding toxic effects of coal dust and iron hydroxide were likely manifested in the relevant investigations. Although providing valuable information, these studies were not designed to separate the toxicity from the more "inert" particle effects (e.g., angularity, turbidity, etc.). For example, given the abrasive characteristics of silicon particles, the observed effects of diatomaceous earth were (not surprisingly) higher than the model's predictions. Again, the presentation of "generalized" data on particle concentration is not appropriate for inclusion into a model purporting to isolate the effects of suspended sediment.

Effect thresholds receive no treatment in the stress index model, although such threshold values are common in studies on the influence of toxins on fish (e.g., see Sprague 1970). Threshold responses also appear in investigations on suspended sediment effects (Vinyard and O'Brien 1976; Confer et al. 1978; Breitburg 1988). Even when suspended sediment is acutely lethal to juvenile coho salmon, mortality generally occurs within the first few days (J. A. Servizi and D. W. Martens, unpublished data). Such results suggest a duration threshold response. Similar effects were suggested by our reanalysis (Figures 1, 2) of the data compiled by Newcombe and MacDonald (1991). Therefore, the logarithmic response assumed by the model is probably unrealistic.

At both high and low stress index values, predictions of the Newcombe and MacDonald (1991) model were unreliable estimators of observed responses. At low values (≤6), the effects of suspended sediment on salmonids were consistently overestimated (Figure 1). Our analysis of the model residuals (Figure 2) indicated that departures from the predicted effects were significant at these low index values (analysis of variance: $P < 0.001$, $N = 16$). At any given high stress index value (>6), the range of effects reported in the literature surveyed by Newcombe and MacDonald (1991) was excessively large, spanning from five to seven effect categories (Figure 1). Standard deviation of the model residuals was 2.3 rank effect units, indicating that about 40% of predicted impacts would be in error by at least 2.0 rank effect units. Figure

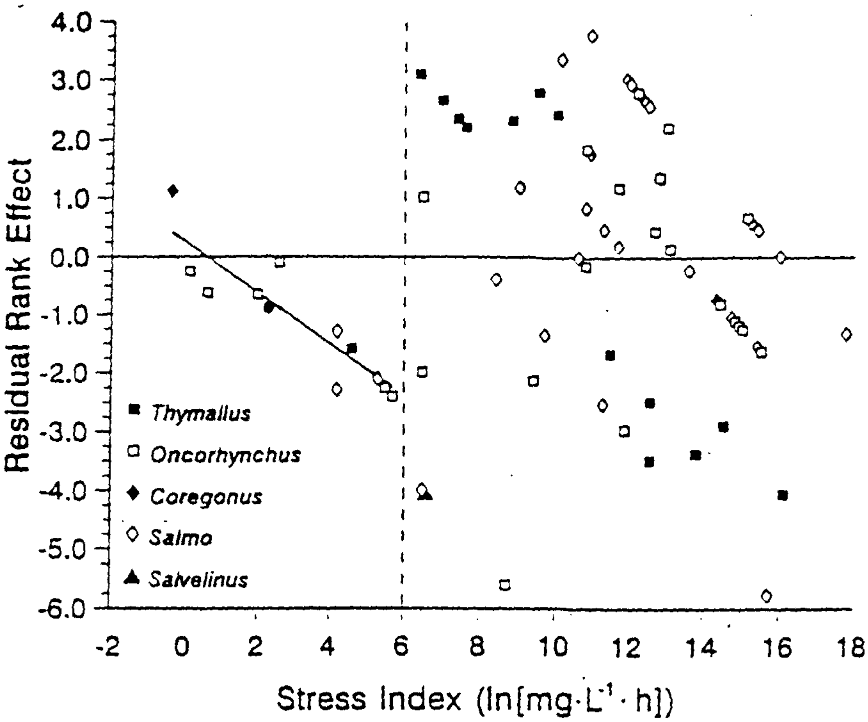

FIGURE 2.—The residuals from the stress index model (Newcombe and MacDonald 1991) calculated from data presented in Figure 1. Solid line indicates the relationship between low stress index values (<6) and the model residuals ($Y = 0.250 - 0.436X$; $r^2 = 0.827$, $N = 16$).

2 also suggests that the degree of error increases with the value of the stress index. We believe that the observed effects depart so frequently from the predictions of the model that the stress index is unreliable for management use.

Suspended sediment loads in the Fraser River can range up to 1,050 mg·L⁻¹ (Servizi and Gordon 1989; Servizi and Martens 1992) during the peak of the juvenile salmonid outmigration and turbidity ranges from 30 to more than 100 Jackson turbidity units from May to August (Northcote and Larkin 1989). The stress index model suggests that as few as 2 d of exposure to these concentrations would be sufficient to cause 20% mortality (stress index = 10.8). We have observed suspended sediment concentrations greater than 50 mg·L⁻¹ in side channels where underyearling chinook salmon rear for up to 2 months (Levy et al. 1979; Levy and Northcote 1982). Even in these relatively "clear" habitats, the stress index model predicts that mortality could reach 20% during such a residency period (stress index = 11.2). By definition, the survivors would also be subjected to all (or most) of the lower-ranked effects as well (e.g., negative growth, physiological damage, and population decline). However, both growth rate (Levy and Northcote 1982) and feeding rate (Gregory 1990; Gregory and Northcote 1993) of underyearling chinook salmon are high in such "stressful" conditions. Although these fish are exposed to numerous other environmental factors during their estuarine residency, the stress index model is clearly not supported by these latter investigations. On the contrary, the historical evidence for large salmon runs in the Fraser River (Northcote and Larkin 1989) strongly suggests that suspended sediment concentrations in the migratory and rearing portions of the river are nonlethal.

We find Newcombe and MacDonald's (1991) paper a timely addition to the literature because of the value of their synthesis of widely scattered published accounts of suspended sediment impacts on salmonid fishes. However, we maintain that the stress index model of Newcombe and MacDonald (1991) represents an oversimplification of the complex interaction of suspended sediment and the biology of salmonid fishes. At best, the predictions of the model lack the precision to be useful for salmon habitat management. At worst, underestimating potential effects may lead to serious damage of affected salmonid stocks by prompting incorrect habitat management actions (or inaction). Therefore, the use of the stress index model as a convenient predictive management tool would be inappropriate.

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North American Journal of Fisheries Management 13:873–876, 1993

Utility of the Stress Index for Predicting Suspended Sediment Effects: Response to Comment

Although there is general agreement that there is a need for a simple method to predict the adverse effects of suspended sediment in aquatic ecosystems, there is still some disagreement on the extent to which the existing information can be used to develop such a tool. It is useful, therefore, to recapitulate the recent history related to our understanding of the environmental toxicology of suspended sediments.

The pollution control strategies used during the 1970s and 1980s were based on the assumption that suspended sediments would cause little or no harm to fish and aquatic life at relatively low concentrations, regardless of the duration of exposure to those levels. In those days, concentrations in the order of 25 $mg \cdot L^{-1}$ were frequently accepted, for pollution control purposes, as the thresholds for adverse biological effects (e.g., USEPA 1973). The concept of exposure duration was not considered in the pollution control paradigm, and thus low-level pollution episodes were officially tolerated for indefinite periods of time.

In the past, the concentration–response model has provided a convenient compromise between administrative (i.e., regulatory) requirements and our relative lack of knowledge of the toxicological effects of suspended sediment as a function of duration of exposure. However, the time-dependent effects of suspended sediments are now better understood and the concentration–response model seems to be somewhat dated. A comparison of the traditional concentration–response model with a dose–response model (dose = concentration × duration) indicates that concentration alone is only weakly correlated with severity of ranked effects, whereas the dose is more strongly correlated with those same effects (Newcombe and MacDonald 1991).

As indicated above, the need for a dose–response model applicable to suspended sediments is not at issue. However, in their Comment, Gregory et al. have raised a number of questions regarding the reliability of the "model" presented in our article (Newcombe and MacDonald 1991). These indicate that they have misinterpreted the intent of the stress index (SI) "model" presented in our original publication. Therefore, the following discussion is offered to clarify the original intent of our paper and to present the stress index model that was developed in the course of our research on the impacts of suspended sediments on aquatic ecosystems (Newcombe 1986, 1993).

Aquatic ecosystems throughout North America are affected by pollution episodes that have the potential to adversely affect fish, invertebrates, and aquatic plants. Although many concerns have been raised in recent years regarding the impacts of toxic chemicals that are released into these systems, the mobilization of fine inorganic particles and their subsequent deposition in sensitive habitats are, arguably, the most pervasive problem facing aquatic environmental managers. However, until recently, researchers in this field have provided these managers with little practical guidance for making regulatory decisions. In the absence of effect-based water quality guidelines for suspended sediments, regulatory decisions have generally been either arbitrary or based on background conditions at the site. In either case, it was assumed that consideration of concentration of suspended sediments alone would provide an adequate basis for protecting the environment.

The effects of an environmental contaminant on aquatic organisms vary substantially depending on diverse factors, including species and life stage, ambient water quality conditions, temperature, and

TABLE 1.—Revised ranking of effects of suspended sediments on fish and aquatic life.

Rank	Description of effect
	Behavioral effects
0	No adverse effects observed
1	Alarm reaction
2	Abandonment of cover
3	Avoidance response; change in swimming behavior
4	Reduction in feeding rate
	Sublethal effects
5	Minor physiological stress; increased rate of coughing or respiration, or both
6	Moderate physiological stress
7	Moderate habitat degradation; impairment of homing
8	Severe physiological stress; poor condition
9	Reduced growth rate; reduced rate of development
	Lethal effects
10	0–20% mortality; increased rate of predation
11	20–40% mortality; reduced size of population
12	40–60% mortality; severe habitat degradation
13	60–80% mortality
14	80–100% mortality

the presence of disease organisms and other contaminants (see CCREM 1987 for comprehensive summaries of the available toxicological data for numerous substances). However, the concentration of the substance and the duration of exposure to that substance are probably two of the most important factors affecting the toxicity of the majority of environmental contaminants. It was surprising to see that much of the published research relating to the effects of suspended sediments has failed to include information on the duration of exposure. Together, the available data led us to believe either that exposure duration was not considered to be a relevant factor for assessing the impacts of suspended sediments or that there were operational difficulties associated with the collection of the required data. Regardless of which factors have precipitated this information deficiency, it is our belief that the concentration–response model implicit throughout the literature on suspended sediments is fundamentally flawed.

The primary objective of our article (Newcombe and MacDonald 1991) was to evaluate the applicability of the concentration–response model described above. As a basis of comparison, a dose–response model, consistent with those developed for other environmental contaminants, was also described. In this context, dose was considered to be a function of both concentration and duration of exposure. To support this evaluation, a listing of the effects that had been reported in the literature in association with pollution episodes with suspended sediments was created. Subsequently, each of these effects was subjectively ranked in increasing order of severity (considering the potential long-term impacts associated with each endpoint measured) to provide a basis for comparing the two models. The results of the regression analyses performed on these data indicated that concentration alone was only poorly correlated with severity of effects, whereas dose (measured as pollution intensity, $mg \cdot h \cdot L^{-1}$) was more strongly correlated with ranked effect. From this information, it was concluded that pollution intensity (which was converted to stress index by taking the natural logarithm) provides a much more reliable tool for assessing the severity of environmental effects of suspended sediment episodes than does concentration alone. However, the regression equation reported in this study was never meant to be used as a predictive model to precisely estimate the nature and severity of effects on aquatic ecosystems. Indeed, we explicitly stated that the considerable variability among the data in the literature was likely to limit the applicability of the stress index for predicting precise responses of aquatic biota to suspended sediment exposures.

Notwithstanding the foregoing discussion, we have developed a stress index model for assessing the potential impacts of suspended sediment pollution episodes in coldwater ecosystems. In contrast to the interpretation provided by Gregory et al., however, this model is not represented by the regression equation reported in Newcombe and MacDonald (1991). Rather, the stress index model (as reported in Newcombe 1986, 1993) was intended to identify ranges of pollution intensities that are generally associated with three broad categories of effects in fish and other aquatic organisms, as follows:

Stress index	General category of effect expected
$SI < 6$	Behavioral effects
$6 \leq SI \leq 12$	Sublethal effects
$SI > 12$	Lethal effects

Reliability was one of the central issues addressed by Gregory et al. For this reason, we have attempted to evaluate the predictive capability of our stress index model by using an expanded version of the database described in Newcombe and MacDonald (1991). This expanded database (which now contains 203 records) includes information on a diverse array of fish species and endpoints that are relevant to the assessment of suspended sediment impacts (Newcombe 1993). A revised ranking system has also been created to more adequately reflect the information that is currently contained in that database (Table 1). As such, a substantial quantity of data is available that relates suspended sediment intensity to severity of effect.

A preliminary evaluation on the reliability of the model was conducted by determining the incidence of each category of effect within the three ranges of pollution intensities identified (Table 2). The results of this evaluation indicate that the stress index model provides a reliable basis for predicting the potential of impacts associated with pollution episodes of various intensities. A very high incidence of behavioral effects (86.7%) was observed within the lowest range of pollution intensities ($SI < 6$); sublethal and lethal effects were observed only rarely within this range. At stress indices of greater than 12, lethal effects were observed with the greatest frequency (74.8%), and the incidences of behavioral (3.2%) and sublethal (22%) effects were relatively low. Therefore, the stress index model provides a reliable tool for estimating the potential impacts of suspended sediments within these two ranges of pollution intensities. However, both sublethal and lethal effects were observed between these two ranges, which indicates that the stress index model tends to underestimate the effects of suspended sediments within the intermediate range of pollution intensities ($6 \le SI \le 12$). Therefore, care should be exercised in applying this model when pollution intensities fall within this range. Similarly, care should be exercised in applying the model to situations outside of the range of conditions from which it was developed (i.e., from 7 to 300,000 $mg \cdot L^{-1}$ and from 1 min to 1 year).

TABLE 2.—Incidence of behavioral, sublethal, and lethal effects within the three ranges of pollution intensities identified by the stress index model. SI = $\log_e$(concentration × duration).

Range of pollution intensity	Number of records	Incidence (%) of each type of effect: Behavioral	Sublethal	Lethal
$SI < 6$	30	86.7	13.3	0
$6 \le SI \le 12$	150	7.3	42.0	50.7
$SI > 12$	123	3.2	22.0	74.8

The stress index model is intended to provide resource and environmental managers with general guidance for assessing the impacts of suspended sediments in aquatic ecosystems. In this context, the model provides a convenient screening tool for predicting the severity of effects associated with pollution episodes of measured intensity. When pollution intensities fall within the lowest range identified by the model ($SI < 6$), only minor biological effects are likely to be observed. Therefore, generally it would not be necessary to initiate regulatory or remedial actions at the site under investigation. However, moderate and severe impacts on aquatic ecosystems are predicted when pollution intensities fall within the moderate (i.e., $6 \le SI \le 12$) and high (i.e., $SI > 12$) ranges, respectively. Under these conditions, it is rec-

TABLE 3.—Summary of recent information on the effects of suspended sediments on underyearling salmon.

Oncorhynchus species	Concentration ($mg \cdot L^{-1}$)	Duration (h)	Stress index ($mg \cdot h \cdot L^{-1}$)[a]	Effect	Rank of effect	Servizi and Martens (year)[b]
Coho salmon *O. kisutch*	20	0.05	0	No increase in coughing frequency	0	1992
	300	0.17	3.91	Avoidance behavior	3	1992
	2,460	0.05	4.81	Coughing frequency increased	5	1992
	240	24	8.66	Coughing frequency increased	5	1992
	530	96	10.84	Blood glucose concentrations increased	6	1992
	2,460	24	10.99	Fatigue of cough reflex	8	1992
	1,000	96	11.47	No mortality	10	1991
Sockeye salmon *O. nerka*	1,261	96	11.7	Body moisture content reduced	8	1987
	2,100	96	12.21	No mortality	10	1987
	3,148	96	12.62	Trauma in gill tissues evident	8	1987
Coho salmon	8,000	96	13.55	1% mortality	10	1991
	8,100	96	13.56	50% mortality	12	1991
Sockeye salmon	9,000	96	13.67	No mortality	10	1987
	13,000	96	14.3	90% mortality	14	1987
	17,560	96	14.34	50% mortality	12	1987
Coho salmon	22,700	96	14.59	50% mortality	12	1991
Sockeye salmon	23,900	96	14.65	90% mortality	14	1987

[a] Stress index = $\log_e$(concentration × duration).
[b] See references.

ommended that further investigations be conducted to evaluate the nature and extent of the impacts that are actually manifested at the site. This preliminary information will provide a relevant basis for determining the need for and developing a remedial action plan to protect aquatic biota.

We concur with Gregory et al. that there may be a need for a more precise model for assessing the impacts of suspended sediment pollution in certain situations (e.g., spawning channel cleaning operations, etc.). However, it is unlikely that the existing data would support the development of a more precise model that could be applied uniformly to fish, invertebrates, and aquatic plants. Moreover, the uncertainty inherent in most of the monitoring data collected on suspended sediment episodes in the field (limited numbers of grab samples are normally collected over short time periods) would restrict the application of a more precise model, even if the available toxicological data supported its development. Therefore, efforts in this area ought to be focused on the establishment of quantitative dose–response relationships for specific species and life stages of aquatic organisms.

To illustrate this process, a preliminary dose–response relationship specific to underyearling salmon has been derived. Regression analysis of the recent data on the effects of suspended sediments on these receptors (data that are independent of the original database: Table 3) results in the following relationship ($r^2 = 0.86$, $N = 17$, $P < 0.01$):

$$\text{severity of effect} = 0.849 \log_e i - 0.591;$$

i is intensity of exposure ($mg \cdot h \cdot L^{-1}$). These data confirm that the natural logarithm of suspended sediment intensity is strongly correlated with ranked effect in underyearling salmon. Although the slope of the quantitative relationship is similar to that reported by Newcombe and MacDonald (1991) for salmonids and aquatic invertebrates, the intercept is different (−0.591 compared to +2.179). These data validate the stress index model, but indicate that juvenile salmon are somewhat more resistant to the effects of suspended sediments than the species represented in the original data set. We believe that similar "models" can be developed for other species and life history stages and challenge researchers in this field to generate the necessary information.

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Effects of Suspended Sediments on Aquatic Ecosystems

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Abstract.—Resource managers need to predict effects of pollution episodes on aquatic biota, and suspended sediment is an important variable in considerations of freshwater quality. Despite considerable research, there is little agreement on environmental effects of suspended sediment as a function of concentration and duration of exposure. More than 70 papers on the effects of inorganic suspended sediments on freshwater and marine fish and other organisms were reviewed to compile a data base on such effects. Regression analysis indicates that concentration alone is a relatively poor indicator of suspended sediment effects ($r^2 = 0.14$, NS). The product of sediment concentration (mg/L) and duration of exposure (h) is a better indicator of effects ($r^2 = 0.64$, $P < 0.01$). An index of pollution intensity (stress index) is calculated by taking the natural logarithm of the product of concentration and duration. The stress index provides a convenient tool for predicting effects for a pollution episode of known intensity. Aquatic biota respond to both the concentration of suspended sediments and duration of exposure, much as they do for other environmental contaminants. Researchers should, therefore, not only report concentration of suspended sediment but also duration of exposure of aquatic biota to suspended sediments.

The effects of suspended sediments on fish and aquatic life have been studied intensively. The available information on suspended sediment effects has been collated and analyzed in numerous reviews of the literature (Cordone and Kelly 1961; Petticord 1980; Alabaster and Lloyd 1982). However, although these reviews are both detailed and synoptic, they have not established general principles characterizing environmental effects of suspended sediments.

In this paper, we review the available literature in an attempt to identify factors that contribute to effects of suspended sediments on fish and aquatic life. This information should provide researchers with guidance on which data ought to be collected to develop a verified model of the environmental effects of suspended sediment. Experience with environmental toxicants suggests that severity of effects is related not only to concentration of a substance, but also to duration of exposure. In addition, frequency of pollution episodes, ambient water quality, species and life history stage affected, and the presence of disease organisms and other environmental toxicants may all affect the toxicity of a substance. Much of the reported work on effects of inert suspended sediments fails to include information other than concentration and an organism's response. Apparently, many researchers in this field assume that effects are dependent only on concentration, or that the time frame (although not explicitly stated) is implied (e.g., the time required for eggs to develop into fry). We analyzed the information available to determine which model provides better predictive power, the implicit concentration–response model currently in use or a concentration–duration response model similar to those currently used to assess the effects of toxicants.

Data-Base Development

Our search for a relationship between the magnitude of suspended sediment pollution and severity of effect involved collation and analysis of relevant data scattered throughout the literature. Researchers have reported a diverse assortment of effects. For the purpose of this assessment, effects were grouped into one of three categories:

(1) *Lethal effects.*—Lethal effects kill individual fish, cause population reductions, or damage the capacity of the ecosystem to produce fish. This category also includes reductions in population size that are believed to be caused by sublethal or behavioral effects.

(2) *Sublethal effects.*—Sublethal effects injure the tissues or physiology of the organism, but are not severe enough to cause death.

(3) *Behavioral effects.*—Behavioral effects change

TABLE 1.—Ranking of effects of suspended sediments on fish and aquatic life.

Rank	Description of effect
14	>80 to 100% mortality
13	>60 to 80% mortality
12	>40 to 60% mortality, sev[illegible] habitat degradation
11	>20 to 40% [illegible]rtality
10	0 to 20% m[illegible]ty
9	Reduction [illegible]wth rates
8	Ph[illegible] and histological changes
7	Mo[illegible]itat degradation
6	Poor [illegible]ation of orga[illegible]m
5	Impaired homing
4	Reduction in feeding rates
3	Avoidance response, abandonment of cover
2	Alarm reaction, avoidance reaction
1	Increased coughing rate

activity patterns or alter the kinds of activity usually associated with an organism in an unperturbed environment.

Subsequently, effects were ranked according to severity of the effect on fish and aquatic life, as outlined in Table 1.

Although many articles deal with inert sediments and fisheries, we included in this analysis only those containing information on concentration of sediment in the water, length of time the organism was exposed to that sediment, and the nature of the effect. Many potentially useful articles lacked one or more pieces of essential information and were therefore excluded. In a few instances, missing information was supplied by the author of the original article or from a second published source.

Estimates of concentration and duration, or both, were used in some instances, but only when there were sufficient additional details in the original publication, or elsewhere, to do so with reasonable certainty. Many publications that provided no explicit measure of time of exposure did include a sufficiently detailed account of the context and circumstances of the pollution episode to permit useful estimates of exposure duration. In some instances, when information on the concentration of sediment in the water was not reported, information from authoritative sources other than the original reference was used. Typically, these outside sources provided correlations that permitted the conversion of turbidity measurements into concentrations of suspended sediment. In other instances, authors provided additional information in the form of personal communications. The rationale for each estimate of time and concentration are contained in Newcombe (1986).

Effects on Salmonid Fishes

There is a substantial body of knowledge about effects of suspended sediments on salmonid fishes. Previously published reviews (Cordone and Kelly 1961; Sorensen et al. 1977; Langer 1980; Alabaster and Lloyd 1982) indicate that salmonid fisheries can be affected by inert sediment (1) acting directly on free-living fish, either by killing them or by reducing their growth rate or resistance to disease, or both; (2) interfering with the development of eggs and larvae; (3) modifying natural movements and migrations of fish; (4) reducing the abundance of food organisms available to the fish; and (5) reducing the efficiency of methods used for catching fish. Tables 2–4 summarize the literature pertaining to lethal, sublethal, and behavioral responses of salmonid fishes to suspended sediment.

Effects of Aquatic Invertebrates

Benthic invertebrates in streams can be affected by elevated levels of suspended sediment in several ways. First, many benthic invertebrates are grazers and depend on periphyton for food. Any change in suspended sediment concentration that adversely affects algal growth, biomass, or species composition can adversely affect secondary production. Other invertebrates are filter feeders. Increases in suspended sediment levels tend to clog feeding structures, reduce feeding efficiency, and therefore reduce growth rates or stress or kill these organisms (Hynes 1970). Second, invertebrates that inhabit exposed streambed substrates are subject to scouring, which can damage exposed respiratory organs or make the organism more susceptible to predation through dislodgment (Langer 1980). Table 5 is a compilation of information on effects of suspended sediment on aquatic invertebrates. These data suggest that aquatic invertebrates are at least as sensitive to high levels of suspended sediment as salmonid fishes, and perhaps more so.

Effects on Periphyton

Effects of suspended sediment on algae are likely primarily related to its effect on light penetration. However, high levels of suspended sediment in conjunction with high flow rates can scour algae off streambed substrates and thereby reduce periphyton biomass (Alabaster and Lloyd 1982). In addition, increases in nutrients or toxic compounds, or both, adsorbed on suspended sediments can alter growth rates and biomass of algae.

TABLE 2.—Summary of data (in situ observations) on exposures to suspended sediment that resulted in lethal responses in salmonid fishes. Within species groups, stress indices are arranged in increasing order. For exposure, C = concentration (mg/L) and D = duration (h).

Species[a]	Exposure C	Exposure D	Stress index ($\log_e$ [$C \times D$])	Effect	Rank of effect	Source
			Arctic grayling			
Arctic grayling	25	24	6.397	6% mortality of sac fry	10	Reynolds et al. (1988)
	23	48	7.007	14% mortality of sac fry	10	Reynolds et al. (1988)
	65	24	7.352	15% mortality of sac fry	10	Reynolds et al. (1988)
	22	72	7.368	15% mortality of sac fry	10	Reynolds et al. (1988)
	20	96	7.560	13% mortality of sac fry	10	Reynolds et al. (1988)
	143	48	8.834	26% mortality of sac fry	11	Reynolds et al. (1988)
	185	72	9.497	41% mortality of sac fry	12	Reynolds et al. (1988)
	230	96	10.002	47% mortality of sac fry	12	Reynolds et al. (1988)
	20,000	96	14.468	10% mortality of age-0 fish	10	McLeay et al. (1987)
	100,000	96	16.077	20% mortality of age-0 fish	10	McLeay et al. (1987)
			Salmons			
Chinook salmon	488	96	10.755	50% mortality of smolts (high T°C)	12	Stober et al. (1981)
Coho salmon	509	96	10.797	50% mortality of smolts (high T°C)	12	Stober et al. (1981)
Chinook and sockeye salmon	1,400[b]	36	10.827	10% mortality of juveniles	10	Newcomb and Flagg (1983)
Coho salmon	1,200	96	11.654	50% mortality of juveniles	12	Noggle (1978)
	1,217	96	11.668	50% mortality of presmolts (high T°C)	12	Stober et al. (1981)
Chinook and sockeye salmon	207,000[b]	1	12.240	100% mortality of juveniles	14	Newcomb and Flagg (1983)
	9,400	36	12.732	50% mortality of juveniles	12	Newcomb and Flagg (1983)
Chum salmon	97	3,912[b]	12.847	77% mortality of eggs and alevins	13	Langer (1980)
	111	3,912[b]	12.981	90% mortality of eggs and alevins	14	Langer (1980)
Chinook and sockeye salmon	82,000	6	13.106	60% mortality of juveniles	12	Newcomb and Flagg (1983)
Coho salmon	18,672	96	14.400	50% mortality of presmolts	12	Stober et al. (1981)
Chinook salmon	19,364	96	14.436	50% mortality of smolts	12	Stober et al. (1981)
Chum salmon	28,000	96	14.804	50% mortality of juveniles	12	Smith (1939)
Coho salmon	28,184	96	14.811	50% mortality of smolts	12	Stober et al. (1981)
	29,580	96	14.859	50% mortality of smolts	12	Stober et al. (1981)
	35,000[b]	96	15.027	50% mortality of juveniles	12	Noggle (1978)
Chinook and sockeye salmon	39,400	36	15.145	90% mortality of juveniles	14	Newcomb and Flagg (1983)
Chum salmon	55,000	96	15.479	50% mortality of juveniles	12	Smith (1939)
			Whitefish			
Whitefish	16,613	96[b]	14.282	50% mortality of juveniles	12	Lawrence and Scherer (1974)
			Trouts			
Rainbow trout	200[c]	24	8.476	5% mortality of fry	10	Herbert and Richards (1963)
	7	1,152	8.995	17% reduction in egg-to-fry survival	10	Slaney et al. (1977b)
	21	1,152	10.094	62% reduction in egg-to-fry survival	13	Slaney et al. (1977b)
	200[c]	168	10.422	8% mortality of fry	10	Herbert and Richards (1963)
	90	456	10.622	5% mortality of subadults	10	Herbert and Merkens (1961)

TABLE 3.—Summary of data on exposures to suspended sediment that resulted in sublethal responses in salmonid fishes. Within species groups, stress indices are in increasing order. For exposure, C = concentration (mg/L) and D = duration (h).

Species[a]	Exposure C	Exposure D	Stress index ($\log_e [C \times D]$)	Effect	Rank of effect	Source
				Arctic grayling		
Arctic grayling	100	1	4.605	Reduction in feeding rate	4	McLeay et al. (1984)
	100	1,008	11.521	6% reduction in growth rate	9	McLeay et al. (1984)
	300	1,008	12.620	Physiological stress	8	McLeay et al. (1987)
	300	1,008	12.620	10% reduction in growth rate	9	McLeay et al. (1987)
	1,000	1,008	13.823	33% reduction in growth rate	9	McLeay et al. (1987)
				Salmons		
Coho salmon	14	1	2.639	Reduction in feeding efficiency	4	Berg and Northcote (1985)
	100	1[b]	4.605	45% reduction in feeding rate	4	Noggle (1978)
	250	1[b]	5.521	90% reduction in feeding rate	4	Noggle (1978)
	300	1[b]	5.704	Feeding ceased	4	Noggle (1978)
	53.5	12	6.465	Physiological stress, changes in behavior	8	Berg (1983)
Chinook salmon	1.5–2.0[c]	1,440	7.832	Gill hyperplasia, poor condition of fry	8	Anderson, U.S. Fish and Wildlife Service, personal communication
	6[c]	1,440	9.064	Reduction in growth rate	9	MacKinlay et al. (1987)
	75	168[b]	9.441	Harm to quality of habitat	7	Slaney et al. (1977a)
	84[d]	336	10.248	Reduction in growth rate	9	Sigler et al. (1984)
	1,547	96	11.908	Histological damage to gills	8	Noggle (1978)
				Trouts		
Cutthroat trout	35	2	4.248	Feeding ceased, cover sought	4	Bachmann (1958)
Rainbow trout	500	9	8.412	Physiological ill effects	8	Redding and Schreck (1980)
	171	96	9.706	Histological damage	8	Goldes (1983)
Steelhead	84[d]	336	10.248	Reduction in growth rate	9	Sigler et al. (1984)
Rainbow trout	50[e]	960[b]	10.779	Reduction in growth rate	9	Herbert and Richards (1963)
	50[f]	960[b]	10.779	Reduction in growth rate	9	Herbert and Richards (1963)
Trout	270	312[b]	11.341	Histological damage to gills	8	Herbert and Merkens (1961)
Rainbow trout	50[c]	1,848	11.434	Reduction in growth rate	9	Sykora et al. (1972)
	5,000–300,000	168	13.641–17.736	Fish survived, but gill epithelium harmed	8	Slanina (1962)
Brook trout	12[c]	5,880	11.164	Reduction in growth rate, reduced condition	9	Sykora et al. (1972)
	100[c]	1,176[b]	11.675	Reduction in growth rate	9	Sykora et al. (1972)
	24[c]	5,280	11.736	Reduction in growth rate	9	Sykora et al. (1972)

[a] Scientific names: cutthroat trout, *Oncorhynchus clarki*; steelhead = anadromous rainbow trout; brook trout, *Salvelinus fontinalis*.
[b] Estimated.
[c] Lime-neutralized iron hydroxide.
[d] Fire clay.
[e] Coal dust.
[f] Wood fiber.

poorly correlated with the ranked response of aquatic biota ($r^2 = 0.14$, NS). Regression of the natural logarithm of suspended sediment intensity against ranked response was more strongly correlated ($r^2 = 0.64$, $P < 0.01$). This analysis suggests that suspended sediment effects on aquatic ecosystems can be better predicted with a concentration–duration response model developed from the available information.

Stress Index

Pollution episodes reported in the primary literature span a wide range of suspended sediment concentrations and exposure times. The range of the product of these two variables (concentration and duration of exposure) is even larger, spanning many orders of magnitude. To compress this range and provide numbers of manageable size, the natural logarithm of the product was taken as an index of severity, which we refer to as a stress index.

The considerable variability among data in the literature limits our ability to test the stress index for predicting precise responses of aquatic biota to exposures to suspended sediment. Variables in the data include, but are certainly not limited to, species, life history stage and physiological con-

TABLE 5.—Summary of data on the effects of suspended sediment on aquatic invertebrates.

Taxon	Exposure C	Exposure D	Stress index ($\log_e$ [$C \times D$])	Effect	Rank of effect	Source
Zooplankton	24[a]	0.15	1.281	Reduced capacity to assimilate food	4	McCabe and O'Brien (1983)
Benthic invertebrates	8	2.5	2.996	Lethal: increased rate of drift	10	Rosenberg and Wiens (1978)
Macro invertebrates	53–92	24[a]	7.462	Lethal: reduction in population size	10	Gammon (1970)
Benthic invertebrates	1,700	2	8.132	Lethal: alteration in community structure and drift patterns	10	Fairchild et al. (1987)
Zoobenthos	10–15	720[a]	9.105	Lethal: reduction in standing crop	10	Rosenberg and Snow (1977)
Benthic invertebrates	8	1,440	9.352	Lethal: up to 50% reduction in standing crop	12	Rosenberg and Wiens (1978)
Cladocera	82–392	72[a]	9.745	Lethal: survival and reproduction harmed	12	Robertson (1957); from Alabaster and Lloyd (1982)
Benthic fauna	29	720[a]	9.947	Lethal: populations of Trichoptera, Ephemeroptera, Crustacea, and Mollusca, disappear	14	M.P. Vivier, personal communication in Alabaster and Lloyd (1982)
Benthic invertebrates	16	1,440	10.045	Lethal: reduction in standing crop	12	Slaney et al. (1977b)
Cladocera and Copepoda	300–500	72	10.268	Lethal: gills and gut clogged	14	Stephan (1953) cited in Alabaster and Lloyd (1982)
Benthic invertebrates	32	1,440	10.738	Lethal: reduction in standing crop	12	Slaney et al. (1977b)
Zoobenthos	>100	672[a]	11.115	Lethal: reduction in standing crop	12	Rosenberg and Snow (1977)
Benthic invertebrates	62	2,400	11.910	Lethal: 77% reduction in population size	13	Wagener and LaPerriere (1985)
	77	2,400	12.127	Lethal: 53% reduction in population size	12	Wagener and LaPerriere (1985)
Bottom fauna	261–390	720[a]	12.365	Lethal: reduction in population size	12	Tebo (1955)
Benthic invertebrates	390	720[a]	12.545	Lethal: reduction in population size	12	Tebo (1955)
	278	2,400	13.411	Lethal: 80% reduction in population size	13	Wagener and LaPerriere (1985)
Stream invertebrates	130[b]	8,760	13.945	Lethal: 40% reduction in species diversity	14	Nuttall and Bielby (1973)
Benthic invertebrates	743	2,400	14.394	Lethal: 85% reduction in population size	14	Wagener and LaPerriere (1985)
	5,108	2,400	16.322	Lethal: 94% reduction in population size	14	Wagener and LaPerriere (1985)
Stream invertebrates	25,000[b]	8,760	19.204	Lethal: reduction or elimination of populations	14	Nuttall and Bielby (1973)

[a] Estimated.
[b] China clay.

improve as more and better information on effects of suspended sediment on aquatic biota become available.

Future research in this field ought to be reported in terms of concentration of suspended sediment, duration of exposure, and response. In this way our ability to predict the environmental effects of pollution events will be improved. In addition, studies ought to concentrate on dissociating the effects of exposures to suspended sediment from the confounding effects of other variables.

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Channel Suspended Sediment and Fisheries: A Synthesis for Quantitative Assessment of Risk and Impact

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Abstract.—Our meta-analysis of 80 published and adequately documented reports on fish responses to suspended sediment in streams and estuaries has yielded six empirical equations that relate biological response to duration of exposure and suspended sediment concentration. These equations answer an important need in fisheries management: quantifying the response of fishes to suspended sediment pollution of streams and estuaries has been difficult historically, and the lack of a reliable metric has hindered assessment for risk and impact for fishes subjected to excess sedimentation. The six equations address various taxonomic groups of lotic, lentic, and estuarine fishes, life stages of species within those groups, and particle sizes of suspended sediments. The equations all have the form

$$z = a + b(\log_e x) + c(\log_e y);$$

z is severity of ill effect, x is duration of exposure (h), y is concentration of suspended sediment (mg SS/L), a is the intercept, and b and c are slope coefficients. The severity of ill effect (z) is delineated semiquantitatively along a 15-point scale on which is superimposed four "decision" categories ranging from no effect through behavioral and sublethal effects to lethal consequences (a category that also includes a range of paralethal effects such as reduced growth rate, reduced fish density, reduced fish population size, and habitat damage). The study also provided best available estimates of the onset of sublethal and lethal effects, and it supported the hypothesis that susceptible individuals are affected by sediment doses (concentration × exposure duration) lower than those at which population responses can be detected. Some species and life stages show "ultrasensitivity" to suspended sediment. When tested against data not included in the analysis, the equations were robust. They demonstrate that meta-analysis can be an important tool in habitat impact assessment.

While it is now generally accepted that the severity of effect of suspended sediment pollution on fish increases as a function of sediment concentration and duration of exposure, or dose (the product of concentration and exposure time), attempts to document the dose–response relationship for sediment and aquatic organisms have been limited in several ways. First, initial analyses were based on pooled data (Newcombe 1986; Newcombe and MacDonald 1991). Second, the database available for those analyses embraced a wide taxonomic range from phytoplankton to fish. Third, the database contained little information about particular species and life stages. The resulting dose–response model for aquatic ecosystems (Newcombe 1986; Newcombe and MacDonald 1991) established a general principle, but this model was held to be too imprecise to help fishery and habitat managers address local sediment problems (Gregory et al. 1993).

In an effort to refine the general dose–response model, MacDonald and Newcombe (1993) extracted and analyzed data for juvenile salmon from the recent literature. These data yielded an equation similar to the one for pooled data, but the two curves differed in important ways. This finding established a need to revisit the dose–response database so that models could be tailored to particular groups of fishes as functions of taxonomic group, natural history, life history phase, and predominant sizes of the sediment particles responsible for ill effects (Newcombe 1994). We have endeavored to meet this need and present a meta-analytic synthesis of dose–response data in this paper. Insofar as this research provides new understanding of channel sediment impacts, it leads to discussion of potential changes in the methods and goals of quantitative impact assessment. Specifically, the results (i) suggest the need to change the methods of data collection for environmental law enforcement, (ii) demonstrate the value of meta-analysis as a research method in fisheries habitat impact assessment, and (iii) prompt an expression of concern about land use practices and protection of instream, riparian, and upland zones.

Methods

This study is based on 264 data triplets consisting of (i) suspended sediment concentration, (ii) duration of exposure, and (iii) severity of ill effect for fishes. These data were taken from a comprehensive literature review (Newcombe 1994; Newcombe et al. 1995). Supporting data extracted from the review included taxonomic group, species of fish, natural history, life history phase, and sediment particle size range.

We define dose as concentration of suspended sediment (SS) times duration of exposure; dose has the units mg $SS \cdot h \cdot L^{-1}$. The natural logarithm of dose is termed the stress index (Newcombe 1986, 1994; Newcombe and MacDonald 1991; MacDonald and Newcombe 1993). Response is the severity of ill effect, described below. The dose–response matrix, which is the basis of data presentation in this report, encompasses all combinations of sediment concentration (1–500,000 mg SS/L) and exposure duration (1–35,000 h). Except when it refers specifically to duration, we use "exposure" broadly to include dose, particle size, and other potential contributors to stress on fishes. In most cases, data on particle shape and roughness and on water temperature were lacking.

TABLE 1.—Scale of the severity (SEV) of ill effects associated with excess suspended sediment.

SEV	Description of effect
	Nil effect
0	No behavioral effects
	Behavioral effects
1	Alarm reaction
2	Abandonment of cover
3	Avoidance response
	Sublethal effects
4	Short-term reduction in feeding rates; short-term reduction in feeding success
5	Minor physiological stress; increase in rate of coughing; increased respiration rate
6	Moderate physiological stress
7	Moderate habitat degradation; impaired homing
8	Indications of major physiological stress; long-term reduction in feeding rate; long-term reduction in feeding success; poor condition
	Lethal and paralethal effects
9	Reduced growth rate; delayed hatching; reduced fish density
10	0–20% mortality; increased predation; moderate to severe habitat degradation
11	>20–40% mortality
12	>40–60% mortality
13	>60–80% mortality
14	>80–100% mortality

Severity-of-Ill-Effect Scale

As before (MacDonald and Newcombe 1993; Newcombe 1994) and in a nearly identical way, we scored qualitative response data along a semi-quantitative ranking scale (Table 1). Superimposed on a 15-point scale (0–14) were four major classes of effect: (i) nil effect, (ii) behavioral effects, (iii) sublethal effects (a category that also includes effects such as short-term reduction in feeding success), and (iv) lethal effects (direct mortality, or its paralethal surrogates—reduced growth, reduced fish density, habitat damage such as reduced porosity of spawning gravel, delayed hatching, and reduction in population size). When these various effects could be compared directly, pollution episodes associated with sublethal or lethal effects

also degraded habitat and reduced population siz
which is why these seemingly disparate ill effe
are grouped together in the hierarchy. For ever
between the extremes of nil effect and 100% mo
tality, we assumed for modeling purposes that t
severity-of-ill effects (SEV for "severity") sca
represents proportional differences in true effec
We now incorporate all feeding reductions
the class of sublethal effects, and we set the boun
ary between short-term and long-term reductio
in feeding success at 2 h. In practice, reports
long-term disruption of feeding rates encomp
800 h and more. We consider all feeding reductio
to be sublethal effects (unless feeding reductio
can be linked to slow growth when we t
as paralethal effects) because they reflec
change in fish behavior than reduced availabi
of food and reduced visual hunting range.

Along the SEV scale, habitat damage ran
from moderate to severe. Habitat damage can
characterized in biological or physical terms
both of these in conjunction. Biological manif
tations of habitat damage include underutilizat
of stream habitat (Birtwell et al. 1984), aband
ment of traditional spawning habitat (Hamil
1961), displacement of fish from their hab
(McLeay et al. 1987), and avoidance of hab
(Swenson 1978). Physical manifestations incl
degradation of spawning habitat (Slaney et
1977b; Cederholm et al. 1981), damage to hab
structure (Newcomb and Flagg 1983; Menze
al. 1984), and loss of habitat (Menzel et al. 19
Coats et al. 1985). Biophysical manifestation
excess SS are reported (in one typical example
habitat degradation that reduces the relative
cess of one or more fish species that depend
low siltation rates and silt-free (<3% silt) ri
(Berkmann and Rabeni 1987).

Habitat degradation can be inferred by (i)
dence of increased mortality at any stage in a f
life cycle (egg-to-fry survival may decrease
result of increased sedimentation: J. LaPerr
University of Alaska, personal communicat
(ii) avoidance behavior by fishes (Suchanek
1984a, 1984b), (iii) reduced abundance of in
and reduced quality of rearing habitat (Slan
al. 1977b), (iv) decreased size of zoobenthic
ulations (Gammon 1970; Rosenberg and S
1977), (v) reduced utility of spawni
(Hamilton 1961), (vi) delayed hatchin
and Wang 1973), and (vii) disruption of ho
behavior and home water preference (Brann
al. 1981; Whitman et al. 1982).

Relative severity of habitat damage is a co also degraded habitat and reduced population size, which is why these seemingly disparate ill effects are grouped together in the hierarchy. For events between the extremes of nil effect and 100% mortality, we assumed for modeling purposes that the severity-of-ill effects (SEV for "severity") scale represents proportional differences in true effects.

We now incorporate all feeding reductions in the class of sublethal effects, and we set the boundary between short-term and long-term reductions in feeding success at 2 h. In practice, reports of long-term disruption of feeding rates encompass 800 h and more. We consider all feeding reductions to be sublethal effects (unless feeding reductions can be linked to slow growth when we treat them as paralethal effects) because they reflect less a change in fish behavior than reduced availability of food and reduced visual hunting range.

Along the SEV scale, habitat damage ranges from moderate to severe. Habitat damage can be characterized in biological or physical terms or both of these in conjunction. Biological manifestations of habitat damage include underutilization of stream habitat (Birtwell et al. 1984), abandonment of traditional spawning habitat (Hamilton 1961), displacement of fish from their habitat (McLeay et al. 1987), and avoidance of habitat (Swenson 1978). Physical manifestations include degradation of spawning habitat (Slaney et al. 1977b; Cederholm et al. 1981), damage to habitat structure (Newcomb and Flagg 1983; Menzel et al. 1984), and loss of habitat (Menzel et al. 1984; Coats et al. 1985). Biophysical manifestations of excess SS are reported (in one typical example) as habitat degradation that reduces the relative success of one or more fish species that depend on low siltation rates and silt-free (<3% silt) riffles (Berkmann and Rabeni 1987).

Habitat degradation can be inferred by (i) evidence of increased mortality at any stage in a fish's life cycle (egg-to-fry survival may decrease as a result of increased sedimentation: J. LaPerriere, University of Alaska, personal communication), (ii) avoidance behavior by fishes (Suchanek et al. 1984a, 1984b), (iii) reduced abundance of insects and reduced quality of rearing habitat (Slaney et al. 1977b), (iv) decreased size of zoobenthic populations (Gammon 1970; Rosenberg and Snow 1977), (v) reduced utility of spawning habitat (Hamilton 1961), (vi) delayed hatching (Schubel and Wang 1973), and (vii) disruption of homing behavior and home water preference (Brannon et al. 1981; Whitman et al. 1982).

Relative severity of habitat damage is a continuum on a two-dimensional plane (SS concentration × duration of SS exposure) in which an event may be minor (ephemeral or low SS concentration or both), or major (long term or high SS concentration or both), or anywhere between these extremes. Severe habitat damage has been described by various authors, some of whom used aquatic invertebrates as indicators (Herbert and Richards 1963; Vaughan 1979; Vaughan et al. 1982; Menzel et al. 1984; Wagener and LaPerriere 1985). Severity of habitat damage caused by excess SS sometimes has been reported in terms of the length of time required for the stream to return to its natural state—sometimes as long as 15–20 years (estimated) after extensive coal mining (Vaughan et al. 1982).

The distinction between moderate and severe habitat damage is a matter of degree that still has not been delineated exactly. Severe habitat damage can be characterized in its extreme by the absence of fish where fish normally are found or by substantial reduction in fish population size, as was documented for brown trout by Herbert et al. (1961). (Scientific names of fish species are given in Table 2.) A pollution event that results in the deposition of suspended sediment in or on spawning habitat during egg incubation might be considered "moderately severe" if the area affected were a small portion of the total available. On the other hand, chronic or acute SS pollution that causes substantial reduction in the size of riverine fish populations (Herbert et al. 1961; Stober et al. 1981) should be considered to represent "severe" habitat damage. Likewise, major SS pollution that results in extensive deposition of sediment on spawning grounds should be characterized as severe habitat damage because its effects could reduce the strength of an entire year-class.

Habitat damage is a valid description of the harm caused by SS pollution, but it is probably an abstraction insofar as ill effects operate on one or more life stages of a fish's life cycle. Age-specific morbidity and mortality rates are fundamental to the notion of habitat damage. For example, habitat damage may manifest itself as foregone opportunity for fish to use a portion of a stream. Reduced suitability of habitat could result in increased age-specific morbidity and mortality rates, or both, depending on the focus and methods of a study. Habitat damage, therefore, should be seen as an accumulative measure of numerous (potentially undocumented) ill effects at various stages in a fish's life cycle. It is a unique phenomenon in that it can only be studied in the field (in contrast to direct effects—age-specific morbidity and mortality, for example—that can be studied in the laboratory as well as in the field). Thus the documented harm caused by excess *SS*—especially when it is not known by direct observation to have caused an increase in morbidity or mortality rates—can reasonably be characterized in more general terms as habitat damage.

Model Formulation

From the expanded database (see Appendix Table A.1), six groupings of fish data were identified for which sample sizes were large enough to support modeling. The six groupings arose from various combinations of four attributes: taxonomic group, life stage, life history, and particle size of suspended sediment.

Taxonomy.—Salmonids (family Salmonidae) were distinguished from nonsalmonids, although several groupings were not exclusively one or the other.

Life stage.—Life stages were allocated among four categories: *eggs, larvae* (recently hatched fish, including yolk-sac fry, that had not passed through final metamorphosis); *juveniles* (fish, including fry, parr, and smolts, that had passed through larval metamorphosis but were sexually immature), and *adults* (mature).

Life history.—Estuarine species were categorized separately from anadromous and freshwater species, although these two groups were combined for early life stages.

Sediment particle size.—The predominant sizes of suspended sediment particles reported in the database literature ranged up to 250 μm. We collated sizes into two categories separated at 75 μm. *Fine* particles were smaller than 75 μm, small enough to pass through gill membranes into interlamellar spaces of gill tissue. This category includes clay, silt, and very fine sand particles (Agriculture Canada 1974). *Coarse* particles were 75–250 μm in diameter, large enough to cause mechanical abrasion of gills. This size range includes very fine to fine sand particles.

The six data groups for which we developed models follow. Species in each group are listed in Table 2.

Group 1: juvenile and adult salmonids; particle sizes 0.5–250 μm.—Group 1 (N = 171 studies or experimental units) includes Atlantic and Pacific salmon, trout, Arctic grayling, mountain whitefish, and rainbow smelt (a nonsalmonid). Some studies dealt with fine sediment as categorized above, some with coarse sediment, and some with both.

TABLE 2.—Common and scientific names of fish species and other taxa mentioned in this paper and the sediment effects model(s) to which they contributed. Species without a model number were not used in any model.

Common name	Scientific name	Model
Anchovy (bay)	*Anchoa mitchilli*	5[a]
Bass (largemouth)	*Micropterus salmoides*	6
Bass (smallmouth)	*Micropterus dolomieu*	
Bass (striped)	*Morone saxatilis*	4,5
Bluegill	*Lepomis macrochirus*	6
Carp (common)	*Cyprinus carpio*	6
Cunner	*Tautogolabrus adspersus*	5
Darters	Percidae; includes *Semotilus atromaculatus*[b]	6
Fish	(Genus and species obscure)	5
Fish (warmwater)	(Genus and species obscure)	5,6
Goldfish	*Carassius auratus*	6
Grayling (Arctic)	*Thymallus arcticus*	1–4
Herring (Atlantic)	*Clupea harengus*	4,5[a]
Herring (lake)	*Coregonus artedi*	4
Herring (Pacific)	*Clupea pallasi*	4
Hogchoker	*Trinectes maculatus*	5
Killifish (striped)	*Fundulus majalis*	5
Menhaden (Atlantic)	*Brevoortia tyrannus*	5[a]
Minnow (sheepshead)	*Cyprinodon variegatus*	5[a]
Mummichog	*Fundulus heteroclitus*	5
Perch (white)	*Morone americana*	4,5
Perch (yellow)	*Perca flavescens*	4
Rasbora (harlequin)	*Rasbora heteromorpha*	5
Salmon	(Genus and species obscure)	1,2,4
Salmon (Atlantic)	*Salmo salar*	1,2
Salmon (chinook)	*Oncorhynchus tshawytscha*	1–3
Salmon (chum)	*Oncorhynchus keta*	1,3,4
Salmon (coho)	*Oncorhynchus kisutch*	1,3,4
Salmon (Pacific)	*Oncorhynchus* spp.	1,2
Salmon (sockeye)	*Oncorhynchus nerka*	1–3
Shad (American)	*Alosa sapidissima*	4,5
Silverside (Atlantic)	*Menidia menidia*	5[a]
Smelt (rainbow)	*Osmerus mordax*	1,2
Spot	*Leiostomus xanthurus*	5[a]
Steelhead	*Oncorhynchus mykiss* (anadromous)	1–4
Stickleback (fourspine)	*Apeltes quadracus*	5[a]
Stickleback (threespine)	*Gasterosteus aculeatus*	5
Sunfish (green)	*Lepomis cyanellus*	6
Sunfish (redear)	*Lepomis microlophus*	6
Toadfish (oyster)	*Opsanus tau*	5
Trout	(Genus and species obscure)	1,2,4
Trout (brook)	*Salvelinus fontinalis*	1–3
Trout (brown)	*Salmo trutta*	1,2
Trout (cutthroat)	*Oncorhynchus clarki*	1,2
Trout (lake)	*Salvelinus namaycush*	1,2
Trout (rainbow)	*Oncorhynchus mykiss*	1–4
Trout (sea)	(Genus and species obscure)	1,2
Whitefish (lake)	*Coregonus clupeaformis*	1,2
Whitefish (mountain)	*Prosopium williamsoni*	1,2

[a] A relatively sensitive species used in the empirical model for estuarine species.

[b] Creek chubs are included with darters here because the relevant study (Vaughan et al. 1978) referred to reduced fish abundance in streams where chubs and darters were reported to live.

TABLE 3.—Attributes, slopes and coefficients, and statis (z, 15-point scale) to duration of exposure (x, h) and conce. + b(log$_e$x) + c(log$_e$y).

Term	1	2
		Attri
Taxon[a]	S	S
Life stage[b]	J + A	A
Life history[c]	FW	FW
Sediment particle size[d]	F to C	F to C
		Slopes and
Intercept (a)	1.0642	1.6814
Slope of log$_e$x (b)	0.6068	0.4769
Slope of log$_e$y (c)	0.7384	0.7565
		Statis
Coefficient of determination[e] (r^2)	0.6009	0.6173
F-statistic	130.28	52.37
Probability (P)	<0.01	<0.01
Sample size (N)	171	63

[a] S = salmonids (predominantly); N = nonsalmonids.

[b] A = adults; J = juveniles; L = larvae; E = eggs.

[c] FW = freshwater and anadromous; ES = estuarine.

[d] F = fine (predominantly <75 μm); C = coarse (75–250 μm).

[e] Corrected for degrees of freedom.

Group 2: adult salmonids; particle sizes 0.5–250 μm.—Group 2 (N = 63) is a subset of group 1.

Group 3: juvenile salmonids; particle sizes 0.5–75 μm.—Group 3 (N = 108) is a subset of group 1. In a few cases, sediment sizes were as large as 150 μm.

Group 4: eggs and larvae of salmonids and nonsalmonids; particle sizes 0.5–75 μm.—Group 4 (N = 43) includes salmonids that do not bury their eggs. Nonsalmonids comprise species that spawn in rivers, lakes, and estuaries. Sediment sizes exceeded 75 μm in a few studies.

Group 5: adult estuarine nonsalmonids; particle sizes 0.5–75 μm.—Group 5 (N = 28) includes several species believed to be particularly sensitive to the effects of suspended sediment; these are footnoted in Table 2. Some test sediments exceeded 75 μm.

Group 6: adult freshwater nonsalmonids; particle sizes 0.5–75 μm.—Group 6 (N = 22) includes both lentic and lotic species. Particle sizes exceeded 75 μm in some cases.

For each group, the severity of effect (SEV, 15-point scale, 0–14) was regressed on suspended sediment dose (exposure duration [ED, h] and suspended sediment concentration [mg SS/L]). Pr liminary analyses indicated that logarithmic transformations of ED and concentration provided suitably linear relations of the form

TABLE 3.—Attributes, slopes and coefficients, and statistics of six models that relate severity of ill effect on fishes (z, 15-point scale) to duration of exposure (x, h) and concentration of suspended sediment (y, mg/L) in the form $z = a + b(\log_e x) + c(\log_e y)$.

Term	Model 1	2	3	4	5	6
Attributes						
Taxon[a]	S	S	S	S + N	N	N
Life stage[b]	J + A	A	J	E + L	A	A
Life history[c]	FW	FW	FW	FW + ES	ES	FW
Sediment particle size[d]	F to C	F to C	F	F	F	F
Slopes and coefficients						
Intercept (a)	1.0642	1.6814	0.7262	3.7466	3.4969	4.0815
Slope of $\log_e x$ (b)	0.6068	0.4769	0.7034	1.0946	1.9647	0.7126
Slope of $\log_e y$ (c)	0.7384	0.7565	0.7144	0.3117	0.2669	0.2829
Statistics						
Coefficient of determination[e] (r^2)	0.6009	0.6173	0.5984	0.5516	0.6200	0.6998
F-statistic	130.28	52.37	82.00	28.03	24.50	27.42
Probability (P)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Sample size (N)	171	63	108	43	28	22

[a] S = salmonids (predominantly); N = nonsalmonids.
[b] A = adults; J = juveniles; L = larvae; E = eggs.
[c] FW = freshwater and anadromous; ES = estuarine.
[d] F = fine (predominantly <75 μm); C = coarse (75–250 μm).
[e] Corrected for degrees of freedom.

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For each group, the severity of effect (SEV, 15-point scale, 0–14) was regressed on suspended sediment dose (exposure duration [ED, h] and suspended sediment concentration [mg SS/L]). Preliminary analyses indicated that logarithmic transformations of ED and concentration provided suitably linear relations of the form

$$\text{SEV} = a + b(\log_e \text{ED}) + c(\log_e \text{mg SS/L});$$

intercepts (a) and slope coefficients (b and c) emerged from the fitting exercise. Commercial software was used for the regressions (TableCurve 3D; Jandel Scientific). Coefficients of determination (r^2) were adjusted for degrees of freedom (r^2 = 1 − [sum of squares due to error]/[sum of squares around the mean]). The software also generated F-statistics, P-values, and 95% confidence intervals around the SEVs. Although arithmetic values for exposure duration and concentration are also given in the Results and in the Appendix, the models we present are based on logarithmic transformations.

The regressions, having been fitted to the data, become predictive models of the form

$$z = a + b(\log_e x) = c(\log_e y),$$

for which z is calculated severity of ill effect (SEV), x is an estimate of exposure duration (ED), and y is the concentration of the (estimated) predominant suspended sediment size (mg SS/L). These predictive models are numbered 1–6 to correspond with the data groupings already described. Because of scatter even in the fitted data, the predictive equations can yield severity-of-ill-effect (z) values greater than 14, which already includes the

Juvenile and Adult Salmonids

Duration of exposure to SS ($\log_e$ hours)

(A) Average severity-of-ill-effect scores (empirical)

Concentration (mg SS/L)	0	1	2	3	4	5	6	7	8	9	10	($\log_e$ mg SS/L)
162755	14	-	-	14	-	-	-	-	-	-	-	12
59874	-	-	12	10	14	12	-	-	-	-	-	11
22026	[illegible]	-	-	-	-	11	-	-	-	-	-	10
8103	3	[illegible]	-	10	12	10	-	11	-	14	-	9
2981	6	[illegible]	[illegible]	9	11	8	9	13	-	-	-	8
1097	4	-	[illegible]	[illegible]	10	9	11	8	-	14	8	7
403	4	5	8	[illegible]	[illegible]	[illegible]	10	9	10	-	-	6
148	4	-	6	[illegible]	[illegible]	[illegible]	9	9	-	-	-	5
55	[illegible]	4	5	-	-	[illegible]	10	9	10	-	-	4
20	3	4	-	4	-	-	[illegible]	10	-	9	-	3
7	-	[illegible]	[illegible]	[illegible]	[illegible]	3	[illegible]	9	-	9	-	2
3	-	-	-	-	[illegible]	5	-	[illegible]	[illegible]	[illegible]	-	1
1	3	-	-	-	-	-	-	-	-	-	-	0
	1	3	7	1	2	6	2	7	4	11	30	
	Hours			Days			Weeks		Months			

FIGURE 1.—(A) Average empirical severity-of-ill-effect scores for juvenile and adult salmonids (freshwater, group 1) in the matrix of suspended sediment (SS) concentration and duration of exposure. Both matrix axes are expressed in logarithmic and absolute terms. Dashes mean "no data." Shaded bands denote inferred (by manual interpolation) thresholds of sublethal effects (shading without a border) and lethal effects (shading with a border; see Table 1 for criteria). (B, upper matrix) Severity-of-effect scores calculated by model (1) (Table 3). Severity-of-ill-effect calculations are based on the logarithmic values shown on the axes of the matrix. Shaded areas represent extrapolations beyond empirical data; extrapolations have been capped at 14 (upper limit of the effects scale: Table 1), although higher values are possible. Diagonal terraced lines denote thresholds of sublethal effects (lower left) and lethal effects (middle diagonal) delineated by the model with reference to Table 1. (B, lower matrix) Half-95% confidence intervals around calculated severity-of-effect scores. Shaded areas denote half-intervals greater than 1.0.

most serious effects to be measured (100% mortality; catastrophic habitat degradation).

Data Presentation

Empirical data.—Severity-of-ill-effect values for each of the six data groups are presented as rounded averages in the cells of dose matrixes whose axes are concentration of suspended sediment and duration of exposure (panel A of the figure for each group). Maximum possible duration of exposure in the matrix is 48 months ($\log_e$[hours] = 10.4999). All but one of the matrixes show a maximum possible suspended sediment concentration of 268,337 mg/L ($\log_e$[mg SS/L] = 12.4999). The exception—adult estuarine fishes—has a maximum possible concentration of 729,416 mg SS/L ($\log_e$[mg SS/L] = 13.4999).

Displayed logarithmic values of duration and concentration are the midrange values. Thus the range of logarithmic values represented by a row or a column in the figures is approximately the value ± 0.4999 in logarithmic units (take antilogarithms for absolute values and their ranges). The accompanying confidence values are one-half the 95% confidence intervals around z.

Cells of a matrix that contain data form a cluster of "populated" cells. The imaginary "tight-string" polygon that encompasses all the populated cells in a matrix is the "data envelope." Typically, some cells within a data envelope are unpopulated. For predictive purposes, values are assigned to these cells by interpolation. Empty cells outside the envelope are given values by extrapolation. Interpolations are considered to have greater intrinsic reliability than extrapolations because they can be compared more easily with known data.

Juvenile and

Duration of expos

(B) Average severity-of-ill-

Concentration (mg SS/L)	0	1	2	3	4
162755	10	11	11	12	[illegible]
59874	9	10	10	11	12
22026	8	9	10	10	11
8103	8	8	9	10	10
2981	7	8	8	9	
1097	6	7	7	8	
403	5	6	7	7	8
148	5	5	6	7	7
55	4	5	5	6	6
20	3	4	4	5	6
7	3	3	4	4	5
3	2	2	3	4	4
1	1	[illegible]	[illegible]	[illegible]	[illegible]
	1	3	7	1	2
	Hours			Days	

Half-95% confide
around calculated severity-

162755	0.9	0.8	0.8	0.8	0.7	0.7
59874	0.8	0.7	0.7	0.6	0.6	0.6
22026	0.7	0.6	0.6	0.5	0.5	0.5
8103	0.6	0.6	0.5	0.4	0.4	0.4
2981	0.6	0.5	0.4	0.4	0.4	0.4
1097	0.6	0.5	0.4	0.3	0.3	0.3
403	0.6	0.5	0.4	0.3	0.3	0.3
148	0.6	0.5	0.4	0.4	0.4	0.4
55	0.6	0.6	0.5	0.5	0.5	0.5
20	0.7	0.7	0.6	0.6	0.6	0.6
7	0.8	0.7	0.7	0.7	0.7	0.7
3	0.9	0.8	0.8	0.8	0.8	0.8
1	1.0	1.0	0.9	0.9	0.9	0.9
	1	3	7	1	2	6
	Hours			Days		

FIGURE 1.—C

Thresholds of ill effect.—Display of empiri- severity-of-effect scores in the dose matrix peri estimation of the minimum concentrations and durations that trigger sublethal and lethal effects (panel A of the figure for each group). For this purpose, unpopulated cells within the data envelope are assigned values by manual interpolation. Thresholds thus estimated from empirical data of-

Juvenile and Adult Salmonids

Duration of exposure to SS ($\log_e$ hours)

(B) Average severity-of-ill-effect scores (calculated)

Concentration (mg SS/L)	0	1	2	3	4	5	6	7	8	9	10	($\log_e$ mg SS/L)
162755	10	11	11	12	12	13	14	14	[illegible]	[illegible]	[illegible]	12
59874	9	10	10	11	12	12	13	13	14	[illegible]	[illegible]	11
22026	8	9	10	10	11	11	12	13	13	14	[illegible]	10
8103	8	8	9	10	10	11	11	12	13	13	14	9
2981	7	8	8	9	9	10	11	11	12	12	13	8
1097	6	7	7	8	9	9	10	10	11	12	12	7
403	5	6	7	7	8	9	9	10	10	11	12	6
148	5	5	6	7	7	8	8	9	10	10	11	5
55	4	5	5	6	6	7	8	8	9	9	10	4
20	3	4	4	5	6	6	7	8	8	9	9	3
7	3	3	4	4	5	6	6	7	7	8	9	2
3	2	2	3	4	4	5	5	6	7	7	8	1
1	1	2	2	3	3	4	5	5	6	7	7	0
	1	3	7	1	2	6	2	7	4	11	30	
	Hours			Days			Weeks		Months			

Half-95% confidence intervals (±)
around calculated severity-of-ill-effect scores (above)

Concentration (mg SS/L)	0	1	2	3	4	5	6	7	8	9	10	($\log_e$ mg SS/L)
162755	0.9	0.8	0.8	0.8	0.7	0.7	0.8	0.8	-	-	-	12
59874	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.7	0.7	-	-	11
22026	0.7	0.6	0.6	0.5	0.5	0.5	0.6	0.6	0.7	0.7	-	10
8103	0.6	0.6	0.5	0.4	0.4	0.4	0.5	0.5	0.6	0.7	0.8	9
2981	0.6	0.5	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.6	0.7	8
1097	0.6	0.5	0.4	0.3	0.3	0.3	0.4	0.4	0.5	0.6	0.7	7
403	0.6	0.5	0.4	0.3	0.3	0.3	0.4	0.5	0.5	0.6	0.7	6
148	0.6	0.5	0.4	0.4	0.4	0.4	0.4	0.5	0.6	0.7	0.8	5
55	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.7	0.8	4
20	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.8	0.9	3
7	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.8	0.8	0.9	1.0	2
3	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.9	0.9	1.0	1.0	1
1	1.0	1.0	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.1	1.1	0
	1	3	7	1	2	6	2	7	4	11	30	
	Hours			Days			Weeks		Months			

FIGURE 1.—Continued.

Thresholds of ill effect.—Display of empirical severity-of-effect scores in the dose matrix permits estimation of the minimum concentrations and durations that trigger sublethal and lethal effects (panel A of the figure for each group). For this purpose, unpopulated cells within the data envelope are assigned values by manual interpolation. Thresholds thus estimated from empirical data often are lower than thresholds predicted by regressions fit to meta-analytical data. We interpret "empirical thresholds" as an approximated response of the more "sensitive" individuals within a species group.

Predictions of ill effect.—The regression equation fitted to each of the six data groups provides predictions of response within the matrix of con-

Adult Salmonids

Duration of exposure to SS (log$_e$ hours)

(A) Average severity-of-ill-effect scores (empirical)

Concentration (mg SS/L)	0	1	2	3	4	5	6	7	8	9	10	(log$_e$ mg SS/L)
162755	14	-	-	14	-	-	-	-	-	-	-	12
59874	-	-	12	10	-	12	-	-	-	-	-	11
22026	-	-	-	-	-	10	-	-	-	-	-	10
8103	[illegible]	[illegible]	[illegible]	10	-	-	-	-	-	14	-	9
2981	-	[illegible]	[illegible]	10	-	-	12	13	-	-	-	8
1097	-	-	[illegible]	[illegible]	[illegible]	[illegible]	9	-	-	14	8	7
403	5	5	[illegible]	[illegible]	[illegible]	[illegible]	9	12	10	-	-	6
148	4	-	-	[illegible]	[illegible]	[illegible]	[illegible]	9	-	-	-	5
55	[illegible]	4	-	[illegible]	[illegible]	[illegible]	[illegible]	9	10	-	-	4
20	-	4	-	4	-	-	-	10	-	-	-	3
7	-	[illegible]	[illegible]	[illegible]	[illegible]	3	-	[illegible]	-	-	-	2
3	-	-	-	-	-	5	-	-	-	-	-	1
1	3	-	-	-	-	-	-	-	-	-	-	0
	1	3	7	1	2	6	2	7	4	11	30	
	Hours			Days			Weeks		Months			

FIGURE 2.—Empirical severity-of-ill-effect scores for adult salmonids (freshwater, group 2) and scores (with half-95% confidence intervals) predicted by model (2). Conventions are those of Figure 1.

centration and duration of exposure (panel B of the figure for each group). Each prediction is accompanied by half-95% confidence intervals.

Each prediction matrix is divided into a maximum of three zones by terraced lines separating behavioral, sublethal, and lethal responses. We compare these modeled thresholds to empirical ones to discern responses of "sensitive" individuals within each species group.

Results

Dose–response models fitted to the empirical data groups were all highly significant ($P < 0.01$) and accounted for 55–70% of the variances (Table 3). Averaged empirical data on which the models are based are displayed in panel A of Figures 1–6. Panel B of Figures 1–6 gives the model-generated responses (and confidence intervals) for each cell of the dose–response matrixes. These panels provide a set of "look-up tables" suitable for field use in impact assessment. Superimposed on them are predicted thresholds of sublethal and lethal effects based on the response categories in Table 1. Response surfaces resulting from the models are shown in Figures 7–12. Data are derived from sources listed in the Appendix.

Group 1: Juvenile and Adult Salmonids

Average empirical severity-of-ill-effect data for group 1 fill 56 of the 143 available cells (Figure 1A). Data are widely distributed, but thresholds for the onset of sublethal and lethal ill effects can be inferred within broad limits, based on manual interpolations within the data envelope (see gray-shaded zones without and with borders).

The full matrix array of severity scores predicted by model 1 (Table 3, Figure 1B) shows regular increases of response intensity with sediment dose, as expected. Predicted thresholds of sublethal and lethal effects (terraced diagonals) have similar orientations to those inferred from empirical data, but they generally occur at higher sediment doses.

Group 2: Adult Salmonids

Group 2 data fill 36 widely scattered cells of the 143 available in the empirical matrix (Figure 2A). The thresholds of lethal effect predicted by model 2 (Table 3; Figure 2B) are similar to the empirically inferred threshold (Figure 2A), but predicted sublethal effects emerge at slightly lower sediment doses than implied by empirical data.

Adult Sal

Duration of exposure

(B) Average severity-of-ill-effe

Concentration (mg SS/L)	0	1	2	3	4	5
162755	11	11	12	12	[illegible]	[illegible]
59874	10	10	11	11	12	12
22026	9	10	10	11	11	12
8103	8	9	9	10	10	11
2981	8	8	9	9	10	[illegible]
1097	7	7	8	8	9	[illegible]
403	6	7	7	8	8	9
148	5	6	6	7	7	8
55	5	5	6	6	7	7
20	4	4	5	5	6	6
7	3	4	4	5	5	6
3	2	3	3	4	4	5
1	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	1	3	7	1	2	6
	Hours			Days		

Half-95% confidence
around calculated severity-of-i

Concentration (mg SS/L)						
162755	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
59874	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
22026	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8103	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2981	1.0	1.0	1.0	1.0	1.0	1.0
1097	1.0	1.0	1.0	1.0	1.0	1.0
403	0.9	0.9	0.9	0.9	0.9	0.9
148	1.0	1.0	1.0	1.0	1.0	1.0
55	1.0	1.0	1.0	1.0	1.0	1.0
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	1	3	7	1	2	6
	Hours			Days		

FIGURE 2.—Contin

Group 3: Juvenile Salmonids

Average severity-of-effect scores for group 3 fill 37 cells, most of them clustered at exposure durations of 1 h and 2 d to 7 weeks (Figure 3A). As for adult salmonids, predicted thresholds (model 3; Table 3; Figure 3B) were similar to empirical thresholds for lethal effects but lower than empirical ones for sublethal effects.

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Adult Salmonids

Duration of exposure to SS (log_e hours)

(B) Average severity-of-ill-effect scores (calculated)

Concentration (mg SS/L)	0 (1 h)	1 (3 h)	2 (7 h)	3 (1 d)	4 (2 d)	5 (6 d)	6 (2 wk)	7 (7 wk)	8 (4 mo)	9 (11 mo)	10 (30 mo)	(log_e mg SS/L)
162755	11	11	12	12	13	13	14	14	[illegible]	[illegible]	[illegible]	12
59874	10	10	11	11	12	12	13	13	14	14	[illegible]	11
22026	9	10	10	11	11	12	12	13	13	14	14	10
8103	8	9	9	10	10	11	11	12	12	13	13	9
2981	8	8	9	9	10	10	11	11	12	12	13	8
1097	7	7	8	8	9	9	10	10	11	11	12	7
403	6	7	7	8	8	9	9	10	10	11	11	6
148	5	6	6	7	7	8	8	9	9	10	10	5
55	5	5	6	6	7	7	8	8	9	9	9	4
20	4	4	5	5	6	6	7	7	8	8	9	3
7	3	4	4	5	5	6	6	7	7	7	8	2
3	2	3	3	4	4	5	5	6	6	7	7	1
1	2	2	3	3	4	4	5	5	5	6	6	0

Half-95% confidence intervals (±)
around calculated severity-of-ill-effect scores (above)

Concentration (mg SS/L)	1 h	3 h	7 h	1 d	2 d	6 d	2 wk	7 wk	4 mo	11 mo	30 mo	(log_e mg SS/L)
162755	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	[illegible]	[illegible]	[illegible]	12
59874	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	[illegible]	11
22026	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.3	10
8103	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	9
2981	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	8
1097	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	7
403	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.1	6
148	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	5
55	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	4
20	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.2	3
7	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.3	2
3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1
1	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.5	0

FIGURE 2.—Continued.

Group 3: Juvenile Salmonids

Average severity-of-effect scores for group 3 fill 37 cells, most of them clustered at exposure durations of 1 h and 2 d to 7 weeks (Figure 3A). As for adult salmonids, predicted thresholds (model 3: Table 3; Figure 3B) were similar to empirical thresholds for lethal effects but lower than empirical ones for sublethal effects.

Group 4: Eggs and Larvae of Salmonids and Nonsalmonids

Average severity scores for eggs and larvae of salmonids and freshwater and estuarine nonsalmonids fill 23 cells (Figure 4A). Most data are clustered in the exposure interval of 1 d to 7 weeks. Sublethal effects thresholds were estimated empirically, but they were not recognized by model

Juvenile Salmonids

Duration of exposure to SS (log$_e$ hours): 0 1 2 3 4 5 6 7 8 9 10

(A) Average severity-of-ill-effect scores (empirical)

Concentration (mg SS/L)	1 Hours	3 Hours	7 Hours	1 Days	2 Days	6 Days	2 Weeks	7 Weeks	4 Months	11 Months	30 Months	(log$_e$ mg SS/L)
162755				-	-	-	-	-	-	-	-	12
59874				-	14	12	-	-	-	-	-	11
22026	[illegible]	[illegible]	-	-	-	11	-	-	-	-	-	10
8103	3		[illegible]	[illegible]	12	10	-	11	-	-	-	9
2981	6			[illegible]	11	8	8	13	-	-	-	8
1097	4			[illegible]	10	10	12	8	-	-	-	7
403	4			-	[illegible]	10	12	9	-	-	-	6
148	4	-	8	6	-	[illegible]	9	9	-	-	-	5
55	[illegible]	[illegible]	5	-	-	[illegible]	10	-	9	-	-	4
20	3		[illegible]	[illegible]	-	-	[illegible]	-	-	9	-	3
7				-	-	-	[illegible]	9	-	9	-	2
3				-	-	-	-	-	-	-	-	1
1				-	-	-	-	-	-	-	-	0

FIGURE 3.—Empirical severity-of-ill-effect scores for juvenile salmonids (freshwater, group 3) and scores (with half-95% confidence intervals) predicted by model (3). Conventions are those of Figure 1.

4 (Table 3; Figure 4B), which generated no severity score lower than 4. Empirical and predicted thresholds of lethal effect agreed well and occurred at relatively low doses.

Group 5: Adult Estuarine Nonsalmonids

Average severity-of-effect scores for at least 15 species of estuarine fishes filled 23 of the available 154 matrix cells (Figure 5A). Most of the data represent 1–6-d exposures.

Model 5 (Table 3) was developed for only the seven species represented by adequate data. These seven are believed to be relatively more sensitive to the ill effects of suspended sediment than the other species in the database (Table 2). Predicted thresholds of lethal effect (Figure 5B) tracked empirical thresholds well for exposure durations less than 1 d; both estimates indicated that lethal effects on those sensitive species result from short exposures to a wide range of sediment concentrations. Sublethal effect thresholds were considerably closer the origin in the predictive matrix than in the empirical matrix.

Group 6: Adult Freshwater Nonsalmonids

A relatively small sample of stream and stillwater fishes in cold, temperate, and warmwater environments provided average severity scores for 15 scattered matrix cells of the 143 available (Figure 6A). Model 6 (Table 3) generated lethal effects thresholds that agreed well with interpolations of empirical data for exposures of 7 d to 7 weeks (Figure 6B). Although sublethal thresholds could be inferred from empirical data, the model indicated that they lay beyond the matrix—below concentrations of 1 mg/L, exposure durations of 1 h, or both.

Response Surfaces

Dose–response surfaces based on models 1–6 are shown in Figures 7–12. We think it important to emphasize that only models (1), (3), and (4) address early life stages in some form. Many studies have shown that early stages (some stages of egg development through young juveniles) are more susceptible to toxicants and other pollutants than older juveniles and adults. The response surfaces (and prediction matrixes) should be judged by the data available to develop them.

Discussion

Fisheries biologists, habitat protection specialists, and enforcement officers in many parts of the world may find that the dose–response equations

Juvenile Sa

Duration of exposure: 0 1 2 3 4 5

(B) Average severity-of-ill-effe

Concentration (mg SS/L)	1 Hours	3 Hours	7 Hours	1 Days	2 Days	6 Days
162755	9	10	11	11	[illegible]	[illegible]
59874	9	9	10	11	11	12
22026	8	9	9	10	11	11
8103	7	8	9	9	10	11
2981	6	7	8	9	9	10
1097	6	8	7	8	9	9
403	5	6	6	7	8	[illegible]
148	4	5	6	6	7	[illegible]
55	4	4	5	6	6	[illegible]
20	3	4	4	5	6	6
7	[illegible]	[illegible]	[illegible]	[illegible]	5	6
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Half-95% confidenc
around calculated severity-of-

Concentration (mg SS/L)	1 Hours	3 Hours	7 Hours	1 Days	2 Days	6 Days
162755	[illegible]	[illegible]	[illegible]	[illegible]	1.0	1.0
59874	1.1	1.0	0.9	0.9	0.9	0.8
22026	1.0	0.9	0.8	0.7	0.7	0.7
8103	0.9	0.7	0.7	0.6	0.5	0.6
2981	0.8	0.7	0.6	0.5	0.4	0.5
1097	0.7	0.6	0.5	0.4	0.4	0.4
403	0.7	0.6	0.5	0.5	0.4	0.5
148	0.8	0.7	0.6	0.6	0.5	0.6
55	0.9	0.8	0.7	0.7	0.7	0.7
20	1.0	0.9	0.9	0.8	0.8	0.9
7	[illegible]	[illegible]	1.0	1.0	1.0	1.0
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

FIGURE 3.—Con:

generated in this study are useful additions to their daily work. The discussion below focuses on (i) validation of the models, (ii) the dose–response patterns of ultrasensitive species and life stages, (iii) potential new options in environmental law enforcement, (iv) the role of meta-analysis in the findings of this study, (v) possible directions of

Juvenile Salmonids

Duration of exposure to SS (log_e hours)

(B) Average severity-of-ill-effect scores (calculated)

Concentration (mg SS/L)	0 (1 h)	1 (3 h)	2 (7 h)	3 (1 d)	4 (2 d)	5 (6 d)	6 (2 wk)	7 (7 wk)	8 (4 mo)	9 (11 mo)	10 (30 mo)	(log_e mg SS/L)
162755	9	10	11	11	12	13	14	14	[illegible]	[illegible]	[illegible]	12
59874	9	9	10	11	11	12	13	14	14	[illegible]	[illegible]	11
22026	8	9	9	10	11	11	12	13	13	14	[illegible]	10
8103	7	8	9	9	10	11	11	12	13	13	14	9
2981	6	7	8	9	9	10	11	11	12	13	13	8
1097	6	6	7	8	9	9	10	11	11	12	13	7
403	5	6	6	7	8	9	9	10	11	11	12	6
148	4	5	6	6	7	8	9	9	10	11	12	5
55	4	4	5	6	6	7	8	8	9	10	11	4
20	3	4	4	5	6	6	7	8	8	9	10	3
7	2	3	4	4	5	6	6	7	8	8	9	2
3	1	2	3	4	4	5	6	6	7	8	8	1
1	1	1	2	3	4	4	5	6	6	7	8	0

Half-95% confidence intervals (±) around calculated severity-of-ill-effect scores (above)

Concentration (mg SS/L)	1 Hours	3 Hours	7 Hours	1 Days	2 Days	6 Days	2 Weeks	7 Weeks	4 Months	11 Months	30 Months	(log_e mg SS/L)
162755	1.3	1.2	1.1	1.1	1.0	1.0	1.0	1.1	[illegible]	[illegible]	[illegible]	12
59874	1.1	1.0	0.9	0.9	0.9	0.8	0.9	0.9	1.0	[illegible]	[illegible]	11
22026	1.0	0.9	0.8	0.7	0.7	0.7	0.7	0.8	0.9	1.0	[illegible]	10
8103	0.9	0.7	0.7	0.6	0.5	0.6	0.6	0.7	0.8	0.9	1.0	9
2981	0.8	0.7	0.6	0.5	0.4	0.5	0.5	0.6	0.7	0.8	1.0	8
1097	0.7	0.6	0.5	0.4	0.4	0.4	0.5	0.6	0.7	0.8	1.0	7
403	0.7	0.6	0.5	0.5	0.4	0.5	0.5	0.6	0.7	0.9	1.0	6
148	0.8	0.7	0.6	0.6	0.5	0.6	0.6	0.7	0.8	1.0	1.1	5
55	0.9	0.8	0.7	0.7	0.7	0.7	0.8	0.9	0.9	1.1	1.2	4
20	1.0	0.9	0.9	0.8	0.8	0.9	0.9	1.0	1.1	1.2	1.3	3
7	1.1	1.1	1.0	1.0	1.0	1.0	1.1	1.2	1.2	1.3	1.4	2
3	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.4	1.5	1.6	1
1	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.5	1.6	1.6	1.7	0

FIGURE 3.—Continued.

generated in this study are useful additions to their daily work. The discussion below focuses on (i) validation of the models, (ii) the dose–response patterns of ultrasensitive species and life stages, (iii) potential new options in environmental law enforcement, (iv) the role of meta-analysis in the findings of this study, (v) possible directions of future research, and (vi) implications of this study for ecosystem assessment.

Validation of the Models

Validation of the models in this study will rely on new studies that add to the data now available. Creation of new data—in sufficient volume for

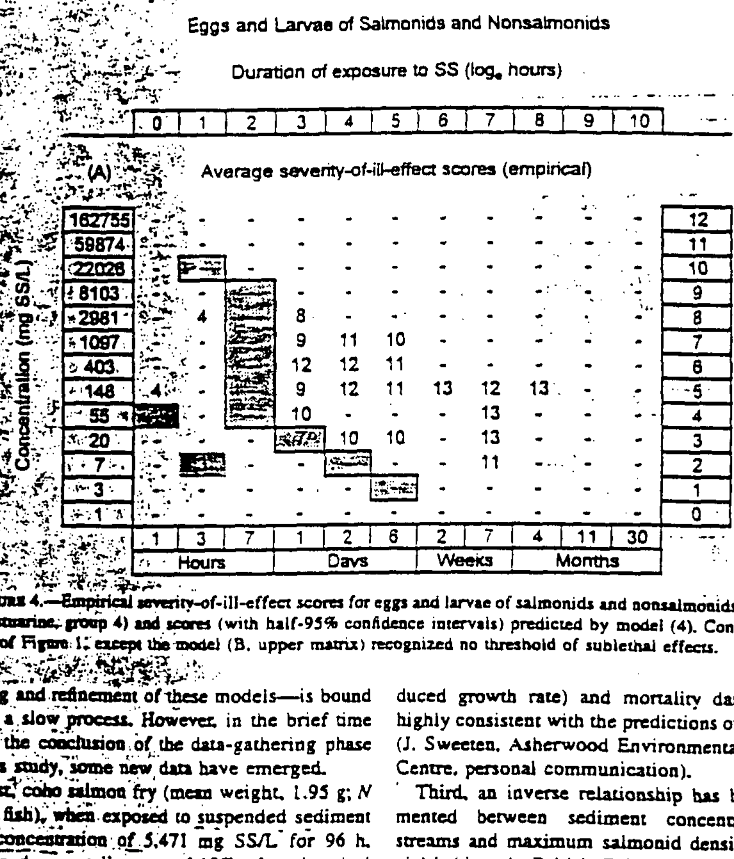

FIGURE 4.—Empirical severity-of-ill-effect scores for eggs and larvae of salmonids and nonsalmonids (freshwater and estuarine, group 4) and scores (with half-95% confidence intervals) predicted by model (4). Conventions are those of Figure 1, except the model (B, upper matrix) recognized no threshold of sublethal effects.

testing and refinement of these models—is bound to be a slow process. However, in the brief time since the conclusion of the data-gathering phase of this study, some new data have emerged.

First, coho salmon fry (mean weight, 1.95 g; N = 10 fish), when exposed to suspended sediment at a concentration of 5,471 mg SS/L for 96 h, sustained a mortality rate of 10% after they had been held in water at 18.7°C and 9.7 mg O_2/L (J.O.T.J., unpublished data). This mortality rate expressed as a severity of ill effect (with reference to Table 1) is SEV = 10. Severity of ill effect as predicted by model 1 (SEV = 0.7262 − 0.7034log$_e$[96 h] + 0.7144(log$_e$5,471 mg SS/L]) is 10.09. These values agree closely and tend to validate this model. Steelhead (N = 10), similarly exposed, had 0% mortality. This result too is consistent with the predictions of the model, because SEV = 10 represents 0–20% mortality, and the test fish exhibited behaviors of severe sublethal stress.

Second, a recent laboratory study of effects of suspended bentonite clay (1–5-μm diameters) on larval nonsalmonid fishes (smallmouth bass, largemouth bass, and bluegill) in warm water (20–25°C) has produced several sets of morbidity data (reduced growth rate) and mortality data that are highly consistent with the predictions of model (4) (J. Sweeten, Asherwood Environmental Learning Centre, personal communication).

Third, an inverse relationship has been documented between sediment concentrations in streams and maximum salmonid densities in fluvial habitats in British Columbia (Ptolemy 1993; R. A. Ptolemy, British Columbia Ministry of Environment, Lands and Parks, personal communication). For example, the density (number of fish per unit area) of juvenile chinook salmon and steelhead that rear in the turbid main stem of the Bella Coola River (British Columbia) is lower than would be expected in clear water. Rearing occurs in June, July, and August. During this time, turbidity averages 21 nephelometric units, suspended sediment concentration averages 61 mg SS/L, particle sizes are smaller than 75 μm, and the temperature range is 8–12°C). Reduced fish density is consistent with the range of ill effects—low paralethal rankings—predicted by the models. These results tacitly acknowledge the role of excess sediment exposure—particularly concentration and duration—as a factor in the productivity of salmon streams. Two extenuating factors—relatively

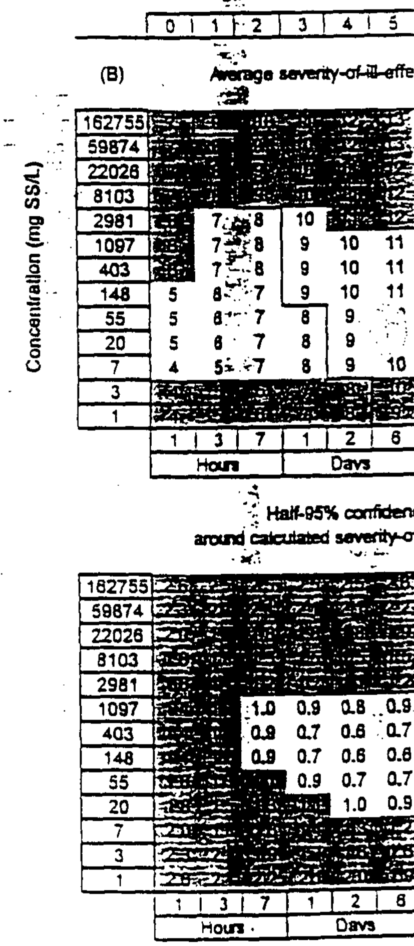

FIGURE 4.—Cor

small particle size and relatively cool water—could explain the absence of direct lethality in the Bella Coola.

Fourth, juvenile salmonids (chinook salmon, rainbow trout, and mountain whitefish) are thoug[illegible] to seek refuge—an average of 9 d for age-0 w[illegible] chinook salmon—in a small nonnatal tributary of the upper Fraser River, perhaps to avoid unsuitable

Eggs and Larvae of Salmonids and Nonsalmonids

Duration of exposure to SS ($\log_e$ hours)

(B) Average severity-of-ill-effect scores (calculated)

Concentration (mg SS/L)	0	1	2	3	4	5	6	7	8	9	10	($\log_e$ mg SS/L)
162755	[illegible]	9	10	[illegible]	12	13	14	[illegible]	[illegible]	[illegible]	[illegible]	12
59874	[illegible]	8	9	10	12	13	14	[illegible]	[illegible]	[illegible]	[illegible]	11
22026	[illegible]	8	9	10	[illegible]	12	13	[illegible]	[illegible]	[illegible]	[illegible]	10
8103	[illegible]	8	9	10	11	12	13	14	[illegible]	[illegible]	[illegible]	9
2981	[illegible]	7	8	10	11	12	13	14	[illegible]	[illegible]	[illegible]	8
1097	[illegible]	7	8	9	10	11	12	[illegible]	[illegible]	[illegible]	[illegible]	7
403	[illegible]	7	8	9	10	11	12	13	[illegible]	[illegible]	[illegible]	6
148	5	6	7	9	10	11	12	13	14	[illegible]	[illegible]	5
55	5	6	7	8	9	10	12	13	[illegible]	[illegible]	[illegible]	4
20	5	6	7	8	9	10	11	12	[illegible]	[illegible]	[illegible]	3
7	4	5	7	8	9	10	11	12	[illegible]	[illegible]	[illegible]	2
3	[illegible]	[illegible]	[illegible]	[illegible]	8	10	11	12	[illegible]	[illegible]	[illegible]	1
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10	[illegible]	[illegible]	[illegible]	[illegible]	0
	1	3	7	1	2	6	2	7	4	11	30	
	Hours			Days			Weeks		Months			

Half-95% confidence intervals (±)
around calculated severity-of-ill-effect scores (above)

Concentration (mg SS/L)	0	1	2	3	4	5	6	7	8	9	10	($\log_e$ mg SS/L)
162755	[illegible]	2.5	2.5	2.5	2.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12
59874	2.3	2.2	[illegible]	[illegible]	[illegible]	2.2	2.3	[illegible]	[illegible]	[illegible]	[illegible]	11
22026	2.1	1.9	1.8	1.8	1.8	1.9	2.0	2.1	[illegible]	[illegible]	[illegible]	10
8103	[illegible]	1.6	1.5	1.5	1.5	1.5	1.8	1.8	[illegible]	[illegible]	[illegible]	9
2981	[illegible]	[illegible]	1.2	1.2	1.1	1.2	1.3	1.5	[illegible]	[illegible]	[illegible]	8
1097	[illegible]	1.2	1.0	0.9	0.8	0.9	1.0	1.2	[illegible]	[illegible]	[illegible]	7
403	[illegible]	[illegible]	0.9	0.7	0.6	0.7	0.8	1.0	[illegible]	[illegible]	[illegible]	6
148	[illegible]	[illegible]	0.9	0.7	0.6	0.6	0.7	0.9	[illegible]	[illegible]	[illegible]	5
55	[illegible]	[illegible]	[illegible]	0.9	0.7	0.7	0.8	0.9	[illegible]	[illegible]	[illegible]	4
20	[illegible]	[illegible]	1.3	1.1	1.0	0.9	1.0	[illegible]	[illegible]	[illegible]	[illegible]	3
7	[illegible]	[illegible]	1.6	1.4	1.3	1.2	1.2	1.3	[illegible]	[illegible]	[illegible]	2
3	[illegible]	[illegible]	1.9	[illegible]	[illegible]	1.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1
1	2.6	2.4	2.2	2.1	2.0	[illegible]	1.9	1.9	2.0	2.1	[illegible]	0
	1	3	7	1	2	6	2	7	4	11	30	
	Hours			Days			Weeks		Months			

FIGURE 4.—Continued.

small particle size and relatively cool water—could explain the absence of direct lethality in the Bella Coola.

Fourth, juvenile salmonids (chinook salmon, rainbow trout, and mountain whitefish) are thought to seek refuge—an average of 9 d for age-0 wild chinook salmon—in a small nonnatal tributary of the upper Fraser River, perhaps to avoid unsuitable rearing conditions created by high, naturally occurring sediment loads found in the main stem (Scrivener et al. 1993).

Although these recent findings tend to support the predictions of the models, the well-documented good health (as indicated by acceptable rates of growth and survival) among salmon juveniles in turbid estuarine waters remains unexplained.

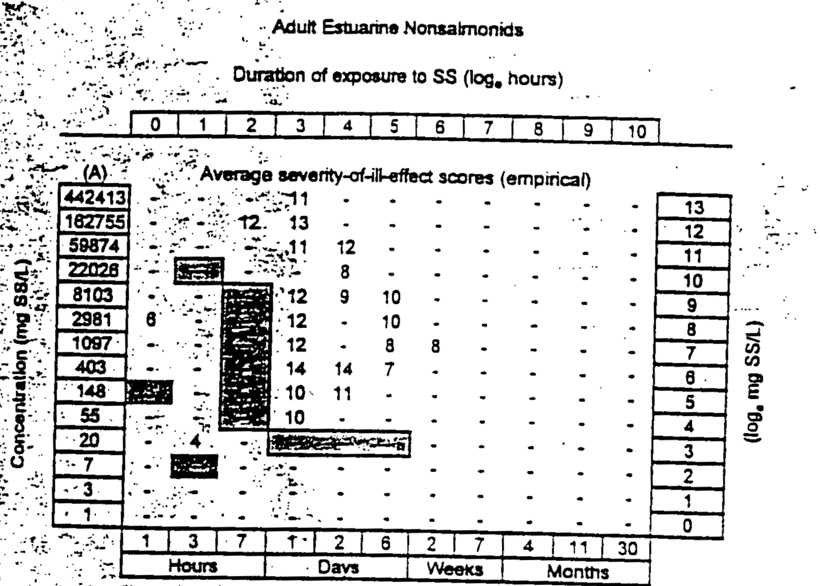

FIGURE 5.—Empirical severity-of-ill-effect scores for adult nonsalmonids (estuarine, group 5) and scores (with half-95% confidence intervals) predicted by model (5). Conventions are those of Figure 1.

Considerations relevant to this "anomaly" include (i) the extremely fine texture of suspended sediment (generally much smaller than 75 µm); (ii) the relatively cold water temperatures; (iii) the potential for favorable physicochemical effects such as flocculation, which could be enhanced by the chemistry of brackish water; (iv) beneficial behavioral adaptations of juvenile salmonids; and (v) the suitability of reedy habitat, where average sediment concentrations and average particle size may be further reduced below those found in traditional sampling sites.

Ultrasensitivity of Some Species and Life Stages

Rapid escalation of ill effects on eggs, larvae, and fry (Figures 4, 10) and on some adult fishes of the estuary (Figures 5, 11) as duration of sediment exposure increases suggests that the mechanisms of self-preservation in at least some estuarine fishes are easily overwhelmed by the presence of suspended sediment. This pattern implies the existence of an abrupt threshold concentration of suspended sediment leading to ill effects in ultrasensitive species and life stages.

If this inference is correct, these dose–response patterns might be explained in terms of the time required to reach an end point (e.g., lethality), and might indicate that the physiological and physical processes involved in homeostasis are more sensitive to exposure time than to suspended sediment concentrations. It is reasonable to speculate further that the sequence of events leading to a lethal end point (for example, severely abraded gill tissue and associated loss of capacity for ion regulation), once triggered, would not easily be halted or reversed.

Environmental Enforcement Issues

Fisheries biologists and enforcement personnel can, as part of an investigation, document the sediment concentration and duration of exposure, and they can use these data to infer the most probable severity of impact. The dose–response equations alone are sufficient for this task. But the "look-up" tables (here, Figures 1–6, panels B) simplify the task even more; they are based on the equations, and they supply ranges of interpolation and extrapolation and confidence intervals. They make it possible for field workers readily to distinguish between minor and major events in the broad context established by the dose–response matrixes. This knowledge can contribute to decisions about

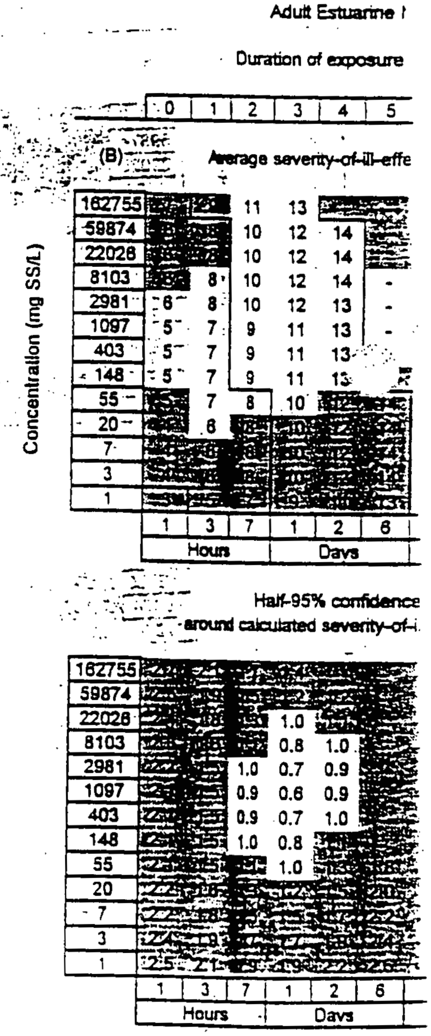

FIGURE 5.—Contin

the need for additional field work by which to gather physical evidence about the nature and severity of the ill effects. This new capacity to make inferences—an unprecedented development in the field of channel sediment impacts—might also influence the goals of a prosecution.

Impacts on fish populations exposed to episodes of excess sediment may vary according to the cir-

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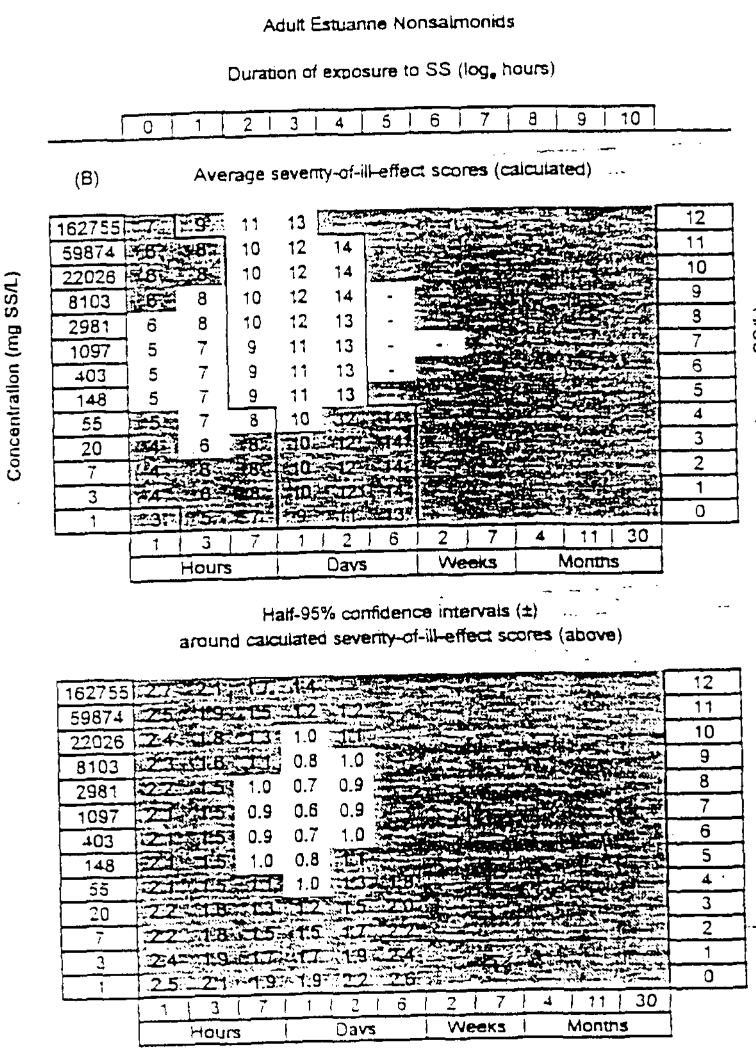

FIGURE 5.—Continued.

the need for additional field work by which to gather physical evidence about the nature and severity of the ill effects. This new capacity to make inferences—an unprecedented development in the field of channel sediment impacts—might also influence the goals of a prosecution.

Impacts on fish populations exposed to episodes of excess sediment may vary according to the circumstances of the event. For example, fish tend to avoid high concentrations of suspended sediment when possible. Thus, a pollution episode capable of causing high mortality (e.g., of sac fry) or gill damage or starvation or slowed maturation (e.g., of age-0 fingerlings and age-2 juveniles) among caged fish (Reynolds et al. 1989) might not cause any of these direct effects in a wild population that

Adult Freshwater Nonsalmonids

Duration of exposure to SS ($\log_e$ hours)

(A) Average severity-of-ill-effect scores (empirical)

Concentration (mg SS/L)	0	1	2	3	4	5	6	7	8	9	10	($\log_e$ mg SS/L)
162755	10	-	-	-	-	-	10	-	-	-	-	12
59874	-	-	-	-	-	-	-	-	-	-	-	11
22028			-	-	-	-	10	-	-	-	-	10
8103	5	-		-	-	-	-	-	-	-	-	9
2981	-	-		-	-	-	-	-	-	13	-	8
1097	-	-	-		-	-	-	12	-	-	-	7
403	4	-	-		10	-	-	-	-	-	-	6
148	-	-	-	-		-	10	11	-	-	-	5
55	-	-	-	-			-	9	-	-	-	4
20			-	-	-	-			-	12	-	3
7	-			-	-	-	-	-		-	-	2
3	-	-	-	-	-	-	-	-	-	-	-	1
1	-	-	-	-	-	-	-	-	-	-	-	0
	1	3	7	1	2	6	2	7	4	11	30	
	Hours			Days			Weeks		Months			

FIGURE 6.—Empirical severity-of-ill-effect scores for adult nonsalmonids (freshwater, group 6) and scores (with half-95% confidence intervals) predicted by model (6). Conventions are those of Figure 1, except the model (B, upper matrix) recognized no threshold of sublethal effects.

is free to move elsewhere in the stream system. Absence of dead fish (notwithstanding reduced egg-to-fry survival) is, however, not necessarily an indication of absence of harm. Indirect effects of sedimentation—loss of summer habitat for feeding and reproduction—may outweigh the direct effects seen in caged fish (Reynolds et al. 1989). This dichotomy has practical implications for enforcement. An investigation during a pollution event should attempt to document suspended sediment concentrations and durations for possible use with the models given here.

However, in the aftermath of a sediment pollution event, the investigation should switch its focus and gather evidence of sediment deposition. Changes in streambed composition resulting from excess sediment are usually manifested as changes in particle size composition. Subjective methods for assessing the extent of sedimentation exist. Objective methods are being developed (Kondolf and Li 1992; Kondolf and Wolman 1993; Potyondy and Hardy 1995) and could be used in place of or in conjunction with the traditional methods. Photographic and videographic records are invaluable regardless of the streambed survey methods chosen.

Four provisions of existing legislation and four potential goals of prosecution are convictions, fines, compensatory damages, and remediation. When the state's purpose is to secure a conviction, a single water sample may be the only evidence required. In some jurisdictions, water quality criteria may be used to identify potential episodes of SS pollution by a tandem system of thresholds. Typically these guidelines state that SS concentrations should not exceed background by more than 10 mg SS/L when background is less than 100 mg SS/L and not more than 10% when background is equal to or greater than 100 mg SS/L (Singleton 1985a, 1985b). This tandem system of thresholds—based on literature reviews specifically intended to document the nature and severity of ill effect under these conditions—is commendable because it recognizes the seasonal patterns in suspended sediment load of natural streams. However, these guidelines do not purport to deal with the inherent nature of sediment as a deleterious substance in aquatic ecosystems as defined by an act of legislation. Nor do they purport to detect the least change in concentration capable of causing ill effects. Various researchers report ill effects when concentrations exceed

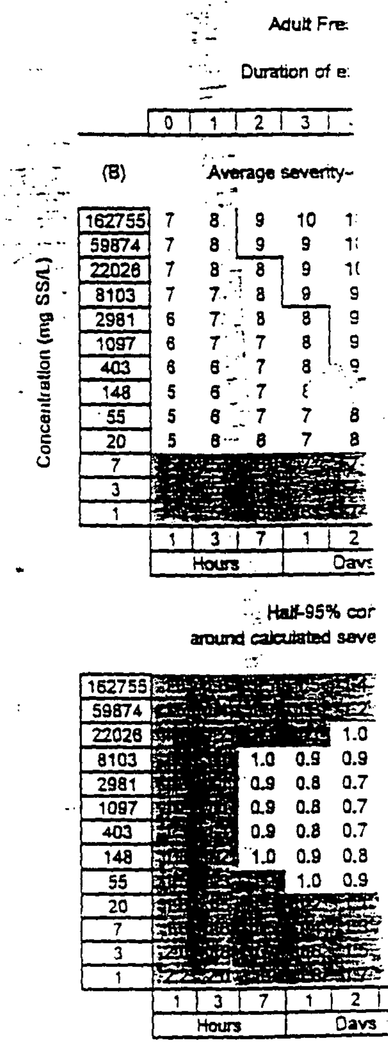

FIGURE 6

background levels by small amounts (see Lawrence and Scherer 1974; Swenson 1978; Gradal and Swenson 1982).

Prosecution based on these rules has bee cessful because the increased concentration known to harm aquatic life. Such evidenc abounds, but pertains largely to invertebrate populations (fish food) and primary production (phy

Adult Freshwater Nonsalmonids

Duration of exposure to SS ($\log_e$ hours)

(B) Average severity-of-ill-effect scores (calculated)

Concentration (mg SS/L)	0	1	2	3	4	5	6	7	8	9	10	($\log_e$ mg SS/L)
162755	7	8	9	10	10	11	12	12	13	[illegible]	[illegible]	12
59874	7	8	9	9	10	11	11	12	[illegible]	[illegible]	[illegible]	11
22026	7	8	8	9	10	10	11	12	[illegible]	[illegible]	[illegible]	10
8103	7	7	8	9	9	10	11	12	12	[illegible]	[illegible]	9
2981	6	7	8	8	9	10	11	11	12	13	[illegible]	8
1097	6	7	7	8	9	10	10	11	12	12	[illegible]	7
403	6	6	7	8	9	9	10	11	11	12	[illegible]	6
148	5	6	7	8	8	9	10	10	11	12	[illegible]	5
55	5	6	7	7	8	9	9	10	11	12	[illegible]	4
20	5	6	6	7	8	8	9	10	11	11	[illegible]	3
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
	1	3	7	1	2	6	2	7	4	11	30	
	Hours			Days			Weeks		Months			

Half-95% confidence intervals (±)
around calculated severity-of-ill-effect scores (above)

Concentration (mg SS/L)	0	1	2	3	4	5	6	7	8	9	10	($\log_e$ mg SS/L)
162755	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12
59874	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11
22026	[illegible]	[illegible]	[illegible]	[illegible]	1.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10
8103	[illegible]	[illegible]	1.0	0.9	0.9	0.9	0.9	1.0	[illegible]	[illegible]	[illegible]	9
2981	[illegible]	[illegible]	0.9	0.8	0.7	0.7	0.8	0.8	1.0	[illegible]	[illegible]	8
1097	[illegible]	[illegible]	0.9	0.8	0.7	0.6	0.7	0.7	0.9	1.0	[illegible]	7
403	[illegible]	[illegible]	0.9	0.8	0.7	0.6	0.6	0.7	0.8	1.0	[illegible]	6
148	[illegible]	[illegible]	1.0	0.9	0.8	0.7	0.7	0.7	0.8	1.0	[illegible]	5
55	[illegible]	[illegible]	[illegible]	1.0	0.9	0.9	0.8	0.9	0.9	1.0	[illegible]	4
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.0	1.0	1.0	[illegible]	[illegible]	[illegible]	3
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
	1	3	7	1	2	6	2	7	4	11	30	
	Hours			Days			Weeks		Months			

FIGURE 6.—Continued.

background levels by small amounts (see Lawrence and Scherer 1974; Swenson 1978; Gradall and Swenson 1982).

Prosecution based on these rules has been successful because the increased concentrations are known to harm aquatic life. Such evidence abounds, but pertains largely to invertebrate populations (fish food) and primary production (phytoplankton and periphyton, the source of energy on which invertebrates may depend) (Newcombe 1994).

However, to the extent that legislation emphasizes the existence of an impact, or the probability of an impact, its primary goal is to secure a conviction. Scope for additional penalty—fines, compensatory damages, and remediation—depends on

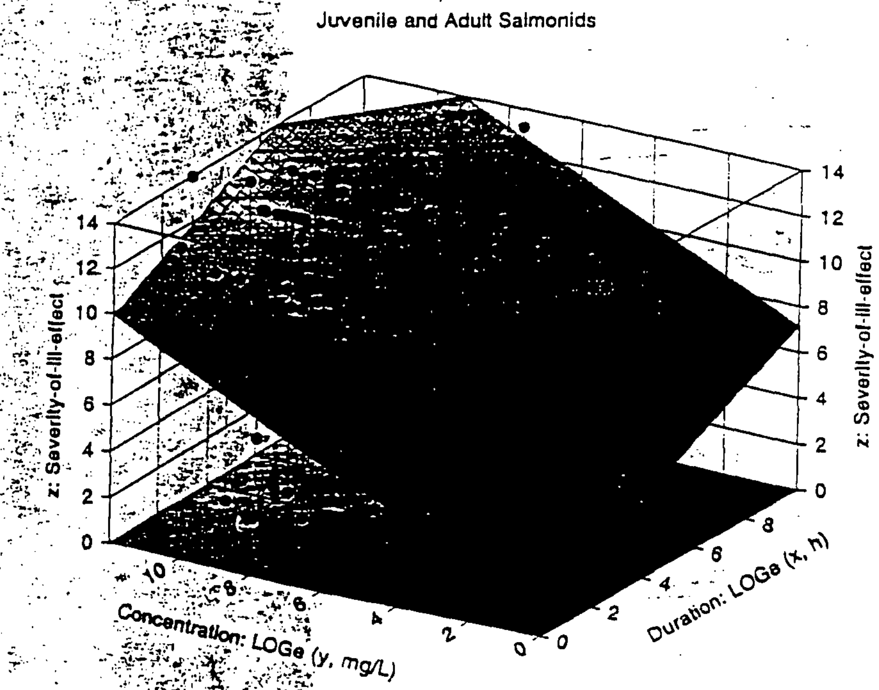

FIGURE 7.—Dose–response surfaces describing the severity of ill effect for juvenile and adult salmonids (freshwater, group 1) as a function of suspended sediment concentration and duration of exposure (model 1): $z = 1.0642 + 0.6068(\log_e x) + 0.7384(\log_e y)$.

an ability to demonstrate harmful effects. Dose–response models enhance this capability.

It is difficult to overstate the value of time series water quality data, but there are some kinds of pollution episodes in which other evidence might take precedence. These instances could be classed as catastrophic events in which one or more of the following conditions prevail: (i) the pollution damage is severe, or extensive and highly visible—blanketing by silt, for example; (ii) the extent of harm is to be confirmed by field studies designed and conducted for the purpose (especially relevant for streams on which previous work has been done); or (iii) the pollution event is detected after the fact, in which case the option to sample suspended sediment is foregone already. Notwithstanding these exceptions, efforts to collect sequential water samples during a pollution episode may be the most cost-effective option, especially when court fines, compensation, and remediation are high-priority goals.

In short, the dose–response equations proposed in this report make it possible not only to identify the existence of a pollution event—this information alone being sufficient to secure a conviction—but also to document the severity of ill effect in support of additional penalties.

Meta-analysis

No single researcher could have aspired to conduct all the field work represented in our database. However, the collective works have value beyond anything the original authors could have envisaged. To the extent that this synthesis informs the science, it demonstrates the utility of meta-analysis as a way to shed new light on old problems by using existing data. Limitations of the database can be overcome with further study.

Future Research

The dose–response models in this synthesis are only a beginning. Many gaps remain. Gaps are

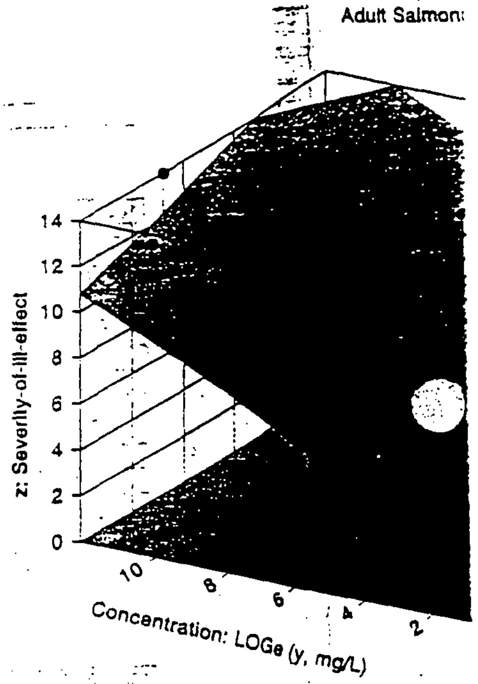

FIGURE 8.—Dose–response surface describing the severity of i
as a function of suspended sediment concentration and duration o
+ 0.7565(log$_e$ x).

especially conspicuous for the youngest age-classes (eggs through young juveniles). The pooling of life stages required for these models—eggs with larvae, young with old juveniles—doubtless masks important thresholds of susceptibility to suspended sediment. Each developmental stage should be identified and treated separately for the purpose of developing uniquely age-specific and size-specific dose–response profiles.

There are practical reasons to make such distinctions. For example, artificial spawning channels must be cleaned annually. Gravel cleaning, which raises a plume of silty water, therefore must be carefully timed to minimize the potential ill effects. Susceptibilities of resident life stages to sediment must be known.

Thresholds of sublethal and lethal effects must be known more precisely. Our analysis has shown, in particular, that sublethal effects thresholds are poorly delineated for most groups. Finding useable data is a challenge; we rejected many studies be-

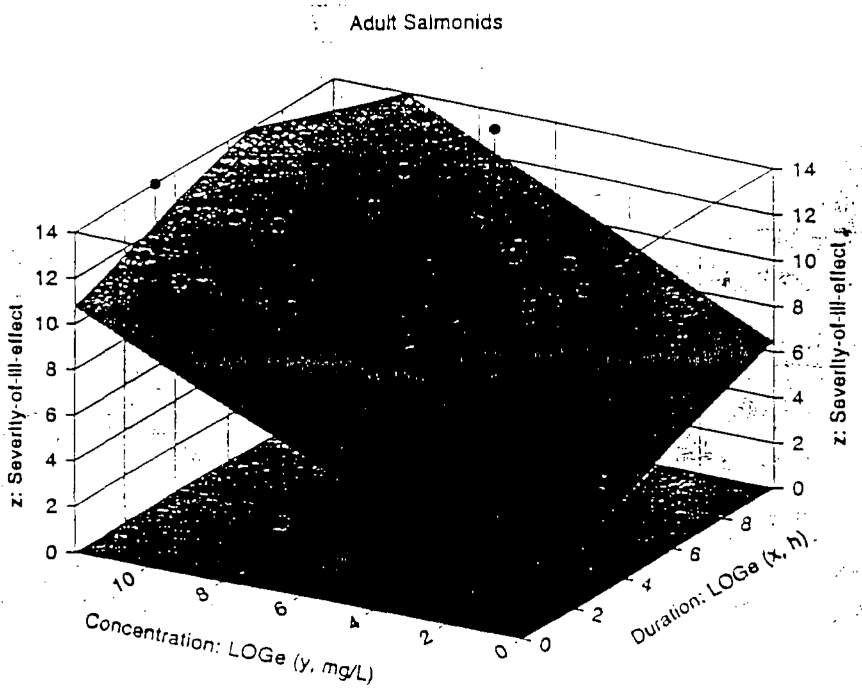

FIGURE 8.—Dose–response surface describing the severity of ill effect for adult salmonids (freshwater, group 2) as a function of suspended sediment concentration and duration of exposure (model 2): $z = 1.6814 + 0.4769(\log_e x) + 0.7565(\log_e y)$.

especially conspicuous for the youngest age-classes (eggs through young juveniles). The pooling of life stages required for these models—eggs with larvae, young with old juveniles—doubtless masks important thresholds of susceptibility to suspended sediment. Each developmental stage should be identified and treated separately for the purpose of developing uniquely age-specific and size-specific dose–response profiles.

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Thresholds of sublethal and lethal effects must be known more precisely. Our analysis has shown, in particular, that sublethal effects thresholds are poorly delineated for most groups. Finding useable data is a challenge; we rejected many studies because they were too vague about sediment concentration, duration of exposure, or the exact nature of the ill effect. We undoubtedly overlooked some reports, but more directed research is warranted. Research is especially needed into particle quality (particle size, angularity, and mineralogy), particle toxicity (toxicants in and adsorbed on sediments), and temperature effects.

Particle quality and toxicology.—Ill effects increase as a function of increasing particle size (if other variables are kept constant). Pollution events often subject fish to particle sizes to which they are not normally exposed. Newcombe et al. (1995) documented that rainbow trout died rapidly when exposed to a silty water discharge (mortality, 80–100%; concentration, ~4,315 mg SS/L; duration, <57 h; particle sizes, 100–170 μm, water temperature, 10°C). These results differ from those from other pollution episodes in which the particle size was smaller; generally, the ill effects would be much less severe—on the order of 0–10% mor-

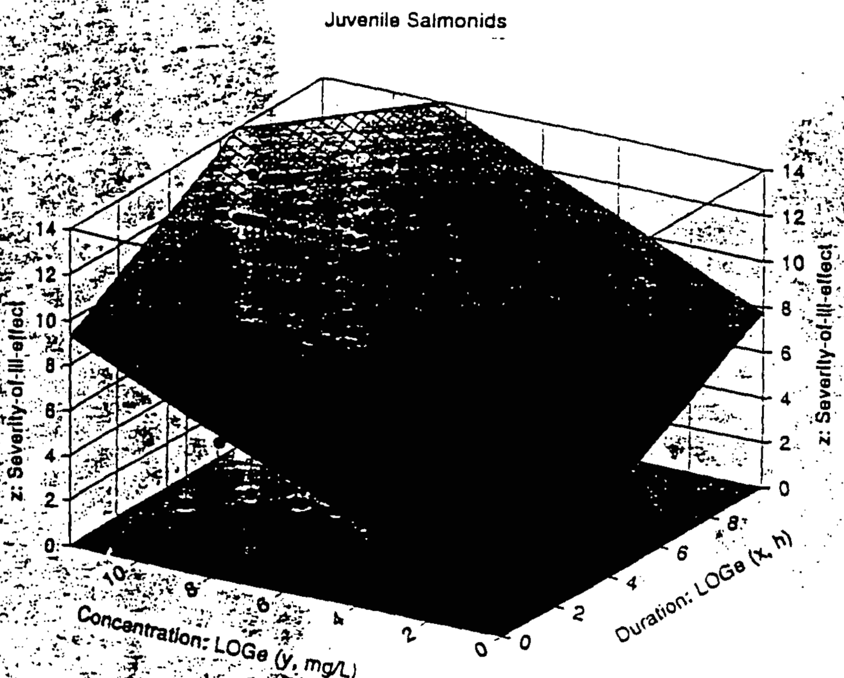

FIGURE 9.—Dose–response surface describing the severity of ill effect for juvenile salmonids (freshwater, group 3) as a function of suspended sediment concentration and duration of exposure (model 3): $z = 0.7262 + 0.7034(\log_e x) + 0.7144(\log_e y)$.

tality. Some research to quantify ill effect as a function of particle size has been done with several species of Pacific salmon (Servizi and Martens 1987, 1991, 1992). Further work should make it possible to create a set of dose–response models as functions of particle size range that are unique to each relevant life stage. The growing need to explore ill effects of suspended sediment as a function of particle size imposes an obligation among fisheries biologists to use a uniform nomenclature in reference to the particle grade scale. Suitable systems exist already so there is no need to invent a more specialized one. For example, soils scientists recognize three particle size-classes—sand, silt and clay (Agriculture Canada 1974)—with formalized subdivisions, names, and sizes as follows: very coarse sand, 2.0–1.0 mm; coarse sand, 1.0–0.5 mm; medium sand, 0.5–0.25 mm; fine sand, 0.25–0.10 mm; very fine sand, 0.10–0.05 mm; silt, 0.05–0.002 mm; and clay, ≤0.002 mm. Fisheries biologists would do well to adopt this or some similar particle grade scale.

The importance of particle angularity, especially in relation to gill abrasion, should be studied. The mineralogy of sediment particles may offer clues to the potential for toxicity and physiological effects. Likewise, the presence of innate or adsorbed toxicants may offer clues to latent effects on fish population health. Studies of the mineralogy and potential chemical activity of the particle itself, of particles in the colloidal size range capable of entering the fish's cells, and of particles with adsorbed toxicants may reveal common properties relating to fate and ill effect at the tissue and cellular level. If common properties do exist among these particular variables, there may be a unifying explanation in the phenomenon of phagocytosis.

Phagocytosis, the envelopment of fine particles by cells of the fish's gill and gut, transports the particles into the fish's body. Although these particles may end up in various tissues, the spleen is a major repository. The spleens of some fishes exposed to fine sediment become mineralized to the extent that the tissue damages the cutting edge of the glass microtome blades (Goldes 1983; S. Goldes, Malaspina College, personal communication). Thus, phagocytosis of fine suspended sediments could trigger a sequence of harmful events within the cells of a fish's body leading to ill effects that are only partially understood today. Invasive particles may be the biological equivalent of a Trojan horse: harmless when on the outside, devastating when on the inside. Tumorigenesis, especially among groundfish that dwell in harbors where sediments may be contaminated by stormwater runoff or by industrial effluent, may be one such latent ill effect yet to be linked to this phenomenon.

Water temperature.—Severity of ill effect as a function of ambient water temperature ought to be explored more fully. Ill effects are greater in sea-

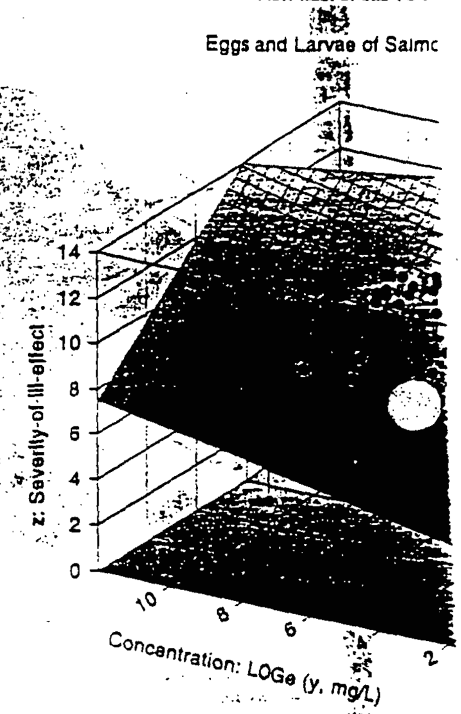

FIGURE 10.—Dose–response surface describing the sever nonsalmonids (freshwater and estuarine, group 4) as a functi of exposure (model 4): $z = 3.7466 + 1.0946(\log_e x) + 0.31$

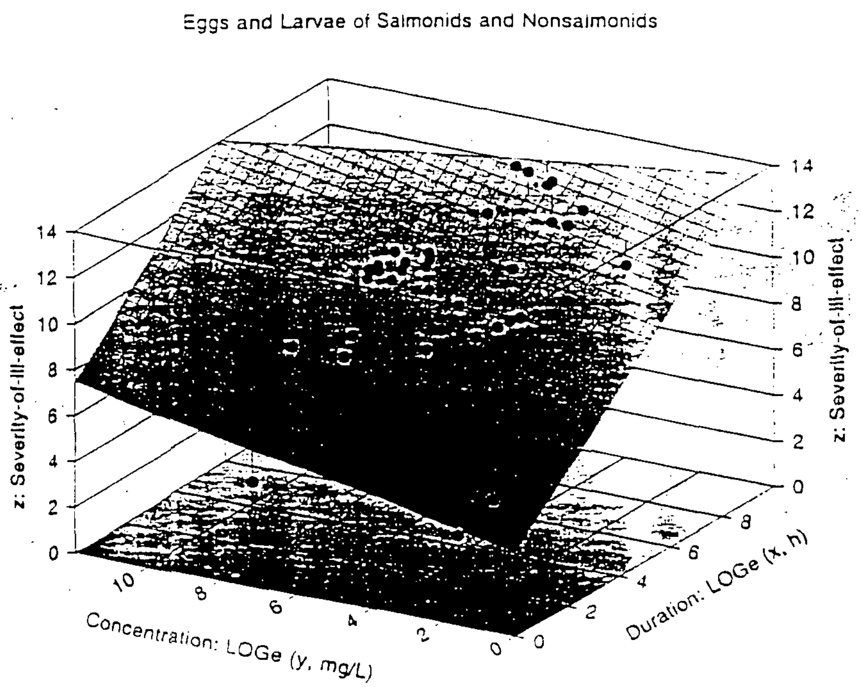

FIGURE 10.—Dose-response surface describing the severity of ill effect for eggs and larvae of salmonids and nonsalmonids (freshwater and estuarine, group 4) as a function of suspended sediment concentration and duration of exposure (model 4): $z = 3.7466 + 1.0946(\log_e x) + 0.3117(\log_e y)$.

ticles may end up in various tissues, the spleen is a major repository. The spleens of some fishes exposed to fine sediment become mineralized to the extent that the tissue damages the cutting edge of the glass microtome blades (Goldes 1983; S. Goldes, Malaspina College, personal communication). Thus, phagocytosis of fine suspended sediments could trigger a sequence of harmful events within the cells of a fish's body leading to ill effects that are only partially understood today. Invasive particles may be the biological equivalent of a Trojan horse: harmless when on the outside, devastating when on the inside. Tumorigenesis, especially among groundfish that dwell in harbors where sediments may be contaminated by stormwater runoff or by industrial effluent, may be one such latent ill effect yet to be linked to this phenomenon.

Water temperature.—Severity of ill effect as a function of ambient water temperature ought to be explored more fully. Ill effects are greater in seasonably warm water than would be the case for the same fishes in seasonably cold water. Mechanisms for this effect have not been systematically described. The dynamics of this variable probably have to do with the temperature-related patterns of oxygen saturation, respiration rate, and metabolic rate of fishes (slower in cool water, more rapid in warm)—all of which result in reduced risk of gill abrasion in cool water and increased risk in warm water. These mechanisms should be explored in the context of seasonal temperature ranges in a fish's natural habitat.

Ecosystem Considerations

Broad-based ecosystem research supporting stream protection is under way, but it is a relatively new science. Stream protection requires, among other things, quantitative linkages between impacts of channel sediment and the land use practices that generate the sediment. Leadership in this area will come from many disciplines, as exem-

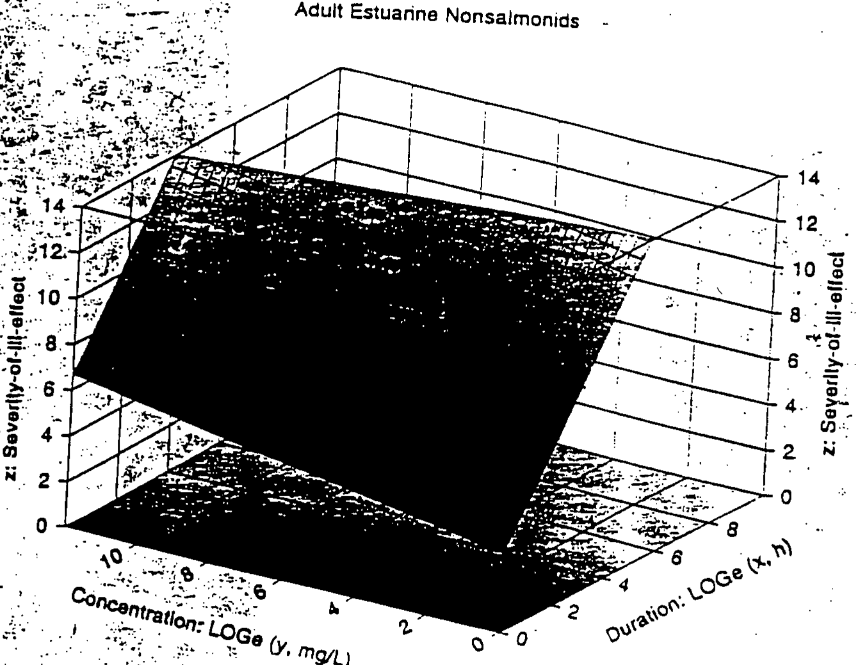

FIGURE 11.—Dose-response surface describing the severity of ill effect for adult nonsalmonids (estuarine, group 5) as a function of suspended sediment concentration and duration of exposure (model 5): $z = 3.4969 + 1.9647(\log_e x) + 0.2669(\log_e y)$.

plified by several important contributions dealing with water quality, resource roads, timber harvest, and channel sediment (Cederholm et al. 1981; Chamberlin 1988; Hartman 1988; Macdonald et al. 1992; Davies and Nelson 1993; Grayson et al. 1993; Macdonald 1994). This research emphasizes the consequences of land disturbance in the upland and riparian zones. It shows that the upland zone capable of impacts on stream quality may be much larger than previously supposed—especially in hilly terrain. The size of upland and riparian zones may be a function of the time scale used to view them. Latent impacts of land use practices—reduced slope stability, increased frequency and severity of flooding, more frequent and longer-lasting episodes of channel sediment pollution—may develop decades after the fact of land disturbance. Thus we should broaden our definition of the upland and riparian zones to accommodate latent ill effects from land disturbance. A broader definition, to the extent it is scientifically supported, can justify a wider legislated zone of protection that extends well into the upland, far away from the stream itself.

Suspended channel sediment is a major factor determining stream quality. Excess sediment is a serious but still underrated pollutant. Unless it is addressed, instream and riparian zones can not be reliably protected. Although the need for increased protection of instream environments might be publicly acceptable, the case for increased protection of upland and riparian areas in aid of stream protection has yet to be made.

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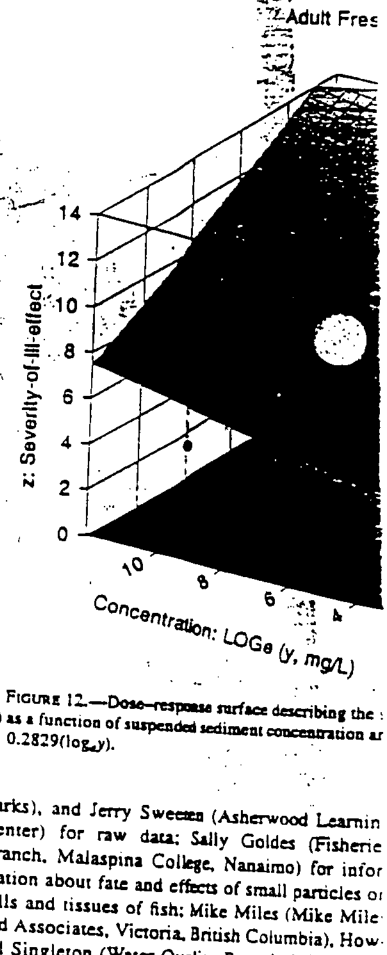

FIGURE 12.—Dose-response surface describing the 6) as a function of suspended sediment concentration ar + $0.2829(\log_e y)$.

Parks), and Jerry Sweeten (Asherwood Learnin Center) for raw data; Sally Goldes (Fisherie Branch, Malaspina College, Nanaimo) for infor mation about fate and effects of small particles o cells and tissues of fish; Mike Miles (Mike Mile and Associates, Victoria, British Columbia), Howard Singleton (Water Quality Branch, Ministry o Environment, Lands and Parks), and Mark Labelle (Institut Français de Recherche pour l'Exploitation de la Mer, Nantes Cedex) for various suggestions; Bill McLean (Qunisam River Hatchery, Campbel River, British Columbia) for field-testing some o the models; and American Fisheries Society reviewers and staff for their numerous improv nts to the manuscript.

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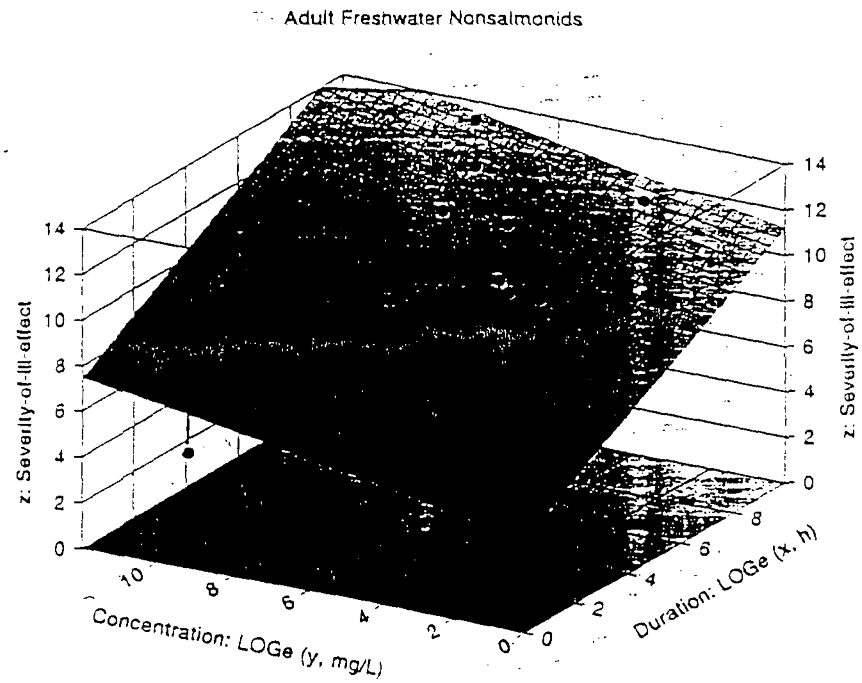

FIGURE 12.—Dose–response surface describing the severity of ill effect for adult nonsalmonids (freshwater, group 6) as a function of suspended sediment concentration and duration of exposure (model 6): $z = 4.0815 + 0.7126(\log_e x) + 0.2829(\log_e y)$.

Parks), and Jerry Sweeten (Asherwood Learning Center) for raw data; Sally Goldes (Fisheries Branch, Malaspina College, Nanaimo) for information about fate and effects of small particles on cells and tissues of fish; Mike Miles (Mike Miles and Associates, Victoria, British Columbia), Howard Singleton (Water Quality Branch, Ministry of Environment, Lands and Parks), and Mark Labelle (Institut Français de Recherche pour l'Exploitation de la Mer, Nantes Cedex) for various suggestions; Bill McLean (Quinsam River Hatchery, Campbell River, British Columbia) for field-testing some of the models; and American Fisheries Society reviewers and staff for their numerous improvements to the manuscript.

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Appendix: Dose–Response Database

TABLE A.1 Dose-response database for fishes exposed to suspended sediment.

Species	Life stage[a]	Sediment dose: Exposure concentration (mg/L)	Sediment dose: Exposure duration (h)	Fish response: SEV[b]	Fish response: Description[c]	Reference
			Adult salmonids and rainbow smelt (freshwater, groups 1 and 2)			
Grayling (Arctic)	A	100	0.10	3	Fish avoided turbid water	Suchanek et al. (1984a, 1984b)
Grayling (Arctic)	A	100	1,008	8	Fish had decreased resistance to environmental stresses	McLeay et al. (1984)
Grayling (Arctic)	A	100	1,008	9	Impaired feeding	McLeay et al. (1984)
Grayling (Arctic)	A	100	1,008	9	Reduced growth	McLeay et al. (1984)
Salmon	A	25	4	4	Feeding activity reduced	Phillips (1970)
Salmon	A	16.5	24	4	Feeding behavior apparently reduced	Townsend (1983); Ott (1984)
Salmon	A	1,650	240	7	Loss of habitat caused by excessive sediment transport	Coats et al. (1985)
Salmon	A	75	168	7	Reduced quality of rearing habitat	Slaney et al. (1977b)
Salmon	A	210	24	10	Fish abandoned their traditional spawning habitat	Hamilton (1961)
Salmon (Atlantic)	A	2,500	24	10	Increased risk of predation	Gibson (1933)
Salmon (chinook)	A	650	168	5	No histological signs of damage to olfactory epithelium	Brannon et al. (1981)
Salmon (chinook)	A	350	0.17	7	Home water preference disrupted	Whitman et al. (1982)
Salmon (chinook)	A	650	168	7	Homing behavior normal, but fewer test fish returned	Whitman et al. (1982)
Salmon (chinook)	A	39,300	24	10	No mortality (VA, <5–100 μm; median, <15 μm)	Newcomb and Flagg (1983)
Salmon (chinook)	A	82,400	6	12	Mortality rate 60% (VA, <5–100 μm)	Newcomb and Flagg (1983)
Salmon (chinook)	A	207,000	1	14	Mortality rate 100% (VA, <5–100 μm)	Newcomb and Flagg (1983)
Salmon (Pacific)	A	525	588	10	No mortality (other end points not investigated)	Griffin (1938)
Salmon (sockeye)	A	500	96	8	Plasma glucose levels increased 39%	Servizi and Martens (1987)
Salmon (sockeye)	A	1,500	96	8	Plasma glucose levels increased 150%	Servizi and Martens (1987)
Salmon (sockeye)	A	39,300	24	10	No mortality (VA, <5–100 μm; median, <15 μm)	Newcomb and Flagg (1983)
Salmon (sockeye)	A	82,400	6	12	Mortality rate 60% (VA, <5–100 μm; median, <15 μm)	Newcomb and Flagg (1983)
Salmon (sockeye)	A	207,000	1	14	Mortality rate 100% (VA)	Newcomb and Flagg (1983)
Smelt (rainbow)	A	3.5	168	7	Increased vulnerability to predation	Swenson (1978)
Steelhead	A	500	3	5	Signs of sublethal stress (VA)	Redding and Schreck (1982)
Steelhead	A	1,650	240	7	Loss of habit caused by excessive sediment transport	Coats et al. (1985)
Steelhead	A	500	9	8	Blood cell count and blood chemistry change	Redding and Schreck (1982)
Trout	A	16.5	24	4	Feeding behavior apparently reduced	Townsend (1983); Ott (1984)
Trout	A	75	168	7	Reduced quality of rearing habitat	Slaney et al. (1977b)
Trout	A	270	312	8	Gill tissue damaged	Herbert and Merkens (1961)
Trout	A	525	588	10	No mortality (other end points not investigated)	Griffin (1938)
Trout	A	300	720	12	Decrease in population size	Peters (1967)
Trout (brook)	A	4.5	168	3	Fish more active and less dependent on cover	Gradall and Swenson (1982)

TABLE A.1.—Continued.

Species	Life stage[a]	Sediment dose: Exposure concentration (mg/L)	Sediment dose: Exposure duration (h)	SEV[b]	
Trout (brown)	A	1,040	17,520	8	Gill …
Trout (brown)	A	1,210	17,520	8	Some … (VF
Trout (brown)	A	18	720	10	Abunc
Trout (brown)	A	100	720	11	Popula
Trout (brown)	A	1,040	8,760	14	Popula … expe
Trout (brown)	A	5,838	8,760	14	Fish m … expe
Trout (cutthroat)	A	35	2	4	… in
Trout (lake)	A	3.5	168	3	… av
Trout (rainbow)	A	66	1	3	Avoida … part c
Trout (rainbow)	A	665	1	3	Fish ar
Trout (rainbow)	A	100	0.10	3	Fish av … (avoi
Trout (rainbow)	A	100	0.25	5	Rate of
Trout (rainbow)	A	250	0.25	5	Rate of
Trout (rainbow)	A	810	504	8	Gills of … thicke
Trout (rainbow)	A	17,500	168	8	Fish surv … prolife
Trout (rainbow)	A	50	960	9	Rate of … (CWS
Trout (rainbow)	A	50	960	9	Rate of
Trout (rainbow)	A	810	504	10	Some fish
Trout (rainbow)	A	270	3,240	10	Survival r
Trout (rainbow)	A	200	24	10	Test fish … day (W
Trout (rainbow)	A	80,000	24	10	No morta
Trout (rainbow)	A	18	720	10	Abundance
Trout (rainbow)	A	59	2,232	10	Habitat da … of grave
Trout (rainbow)	A	4,250	588	12	Mortality r
Trout (rainbow)	A	49,838	96	12	Mortality r
Trout (rainbow)	A	3,500	1,488	13	Catastroph … populatio
Trout (rainbow)	A	160,000	24	14	Mortality r
Trout (sea)	A	210	24	10	Fish aband … spawning
Whitefish (lake)	A	0.66	1	3	Swimming
Whitefish (lake)	A	16,613	96	12	Mortality ra
Whitefish (mountain)	A	10,000	24	10	Fish died; s
			Juvenile salmonids (freshwater, gro		
Grayling (Arctic)	U	20	24	3	Fish avoided
Grayling (Arctic)	U	10,000	96	3	Fish swam n
Grayling (Arctic)	J	36	0.42	3	78% of fish … (NTU, >2
Grayling (Arctic)	U	100	1	4	C… re … ao
Grayling (Arctic)	U	100	1	4	Catch rate red … prey: tubifi
Grayling (Arctic)	U	300	1	4	Catch rate red … prey: droso
Grayling (Arctic)	U	1,000	1	4	Feeding rate r … prey: tubifc

TABLE A.1.—Continued.

Species	Life stage[a]	Sediment dose: Exposure concentration (mg/L)	Sediment dose: Exposure duration (h)	Fish response: SEV[b]	Fish response: Description[c]	Reference
Trout (brown)	A	1,040	17,520	8	Gill lamellae thickened (VFSS)	Herbert et al. (1961)
Trout (brown)	A	1,210	17,520	8	Some gill lamellae became fused (VFSS)	Herbert et al. (1961)
Trout (brown)	A	18	720	10	Abundance reduced	Peters (1967)
Trout (brown)	A	100	720	11	Population reduced	Scullion and Edwards (1980)
Trout (brown)	A	1,040	8,760	14	Population one-seventh of expected size (River Fal)	Herbert et al. (1961)
Trout (brown)	A	5,838	8,760	14	Fish numbers one-seventh of expected (River Par)	Herbert et al. (1961)
Trout (cutthroat)	A	35	2	4	Feeding ceased; fish sought cover	Cordone and Kelly (1961)
Trout (lake)	A	3.5	168	3	Fish avoided turbid areas	Swenson (1978)
Trout (rainbow)	A	66	1	3	Avoidance behavior manifested part of the time	Lawrence and Scherer (1974)
Trout (rainbow)	A	665	1	3	Fish attracted to turbidity	Lawrence and Scherer (1974)
Trout (rainbow)	A	100	0.10	3	Fish avoided turbid water (avoidance behavior)	Sucnanek et al. (1984a, 1984b)
Trout (rainbow)	A	100	0.25	5	Rate of coughing increased (FSS)	Hughes (1975)
Trout (rainbow)	A	250	0.25	5	Rate of coughing increased (FSS)	Hughes (1975)
Trout (rainbow)	A	810	504	8	Gills of fish that survived had thickened epithelium	Herbert and Merkens (1961)
Trout (rainbow)	A	17,500	168	8	Fish survived; gill epithelium proliferated and thickened	Slanina (1962)
Trout (rainbow)	A	50	960	9	Rate of weight gain reduced (CWS)	Herbert and Richards (1963)
Trout (rainbow)	A	50	960	9	Rate of weight gain reduced (WF)	Herbert and Richards (1963)
Trout (rainbow)	A	810	504	10	Some fish died	Herbert and Merkens (1961)
Trout (rainbow)	A	270	3,240	10	Survival rate reduced	Herbert and Merkens (1961)
Trout (rainbow)	A	200	24	10	Test fish began to die on the first day (WF)	Herbert and Richards (1963)
Trout (rainbow)	A	80,000	24	10	No mortality	D. Herbert, personal communication to Alabaster and Lloyd (1980)
Trout (rainbow)	A	18	720	10	Abundance reduced	Peters (1967)
Trout (rainbow)	A	59	2,232	10	Habitat damage; reduced porosity of gravel	Slaney et al. (1977b)
Trout (rainbow)	A	4,250	588	12	Mortality rate 50% (CS)	Herbert and Wakeford (1962)
Trout (rainbow)	A	49,838	96	12	Mortality rate 50% (DM)	Lawrence and Scherer (1974)
Trout (rainbow)	A	3,500	1,488	13	Catastrophic reduction in population size	Herbert and Merkens (1961)
Trout (rainbow)	A	160,000	24	14	Mortality rate 100%	D. Herbert, personal communication to Alabaster and Lloyd (1980)
Trout (sea)	A	210	24	10	Fish abandoned traditional spawning habitat	Hamilton (1961)
Whitefish (lake)	A	0.66	1	3	Swimming behavior changed	Lawrence and Scherer (1974)
Whitefish (lake)	A	16,613	96	12	Mortality rate 50% (DM)	Lawrence and Scherer (1974)
Whitefish (mountain)	A	10,000	24	10	Fish died; silt-clogged gills	Langer (1980)
					Juvenile salmonids (freshwater, groups 1 and 3)	
Grayling (Arctic)	U	20	24	3	Fish avoided parts of the stream	Birtwell et al. (1984)
Grayling (Arctic)	U	10,000	96	3	Fish swam near the surface	McLeay et al. (1987)
Grayling (Arctic)	J	56	0.42	3	78% of fish avoided turbid water (NTU, >20)	Scannell (1988)
Grayling (Arctic)	U	100	1	4	Catch rate reduced (unfamiliar prey: drosophila)	McLeay et al. (1987)
Grayling (Arctic)	U	100	1	4	Catch rate reduced (unfamiliar prey: tubificids)	McLeay et al. (1987)
Grayling (Arctic)	U	300	1	4	Catch rate reduced (unfamiliar prey: drosophila)	McLeay et al. (1987)
Grayling (Arctic)	U	1,000	1	4	Feeding rate reduced (unfamiliar prey: tubificids)	McLeay et al. (1987)

TABLE A.1.—Continued.

Species	Life stage[a]	Sediment dose: Exposure concentration (mg/L)	Sediment dose: Exposure duration (h)	Fish response: SEV[b]	Fish response: Description[c]	Reference
Trout (rainbow)	Y	90	456	10	Mortality rates 0–20% (DE)	Herbert and Merkens (1961)
Trout (rainbow)	Y	90	456	10	Mortality rates 0–15% (KC)	Herbert and Merkens (1961)
Trout (rainbow)	Y	270	456	11	Mortality rates 10–35% (KC)	Herbert and Merkens (1961)
Trout (rainbow)	Y	810	456	12	Mortality rates 35–85% (DE)	Herbert and Merkens (1961)
Trout (rainbow)	Y	810	456	12	Mortality rates 5–80% (KC)	Herbert and Merkens (1961)
Trout (rainbow)	Y	270	456	12	Mortality rates 25–80% (DE)	Herbert and Merkens (1961)
Trout (rainbow)	Y	7,433	672	11	Mortality rate 40% (CS)	Herbert and Wakeford (1962)
Trout (rainbow)	Y	4,250	672	12	Mortality rate 50%	Herbert and Wakeford (1962)
Trout (rainbow)	Y	2,120	672	14	Mortality rate 100%	Herbert and Wakeford (1962)
Trout (rainbow)	J	4,315	57	14	Mortality rate ~100% (CSS)	Newcombe et al. (1995)
			Salmonid eggs and larvae (freshwater, group 4)			
Grayling (Arctic)	SF	25	24	10	Mortality rate 5.7%	J. LaPerriere (personal communication)
Grayling (Arctic)	SF	22.5	48	10	Mortality rate 14.0%	J. LaPerriere (personal communication)
Grayling (Arctic)	SF	65	24	10	Mortality rate 15.0%	J. LaPerriere (personal communication)
Grayling (Arctic)	SF	21.7	72	10	Mortality rate 14.7%	J. LaPerriere (personal communication)
Grayling (Arctic)	SF	20	96	10	Mortality rate 13.4%	J. LaPerriere (personal communication)
Grayling (Arctic)	SF	142.5	48	11	Mortality rate 26%	J. LaPerriere (personal communication)
Grayling (Arctic)	SF	185	72	12	Mortality rate 41.3%	J. LaPerriere (personal communication)
Grayling (Arctic)	SF	230	96	12	Mortality rate of 47%	J. LaPerriere (personal communication)
Salmon	E	117	960	10	Mortality; deterioration of spawning gravel	Cederholm et al. (1981)
Salmon (chum)	E	97	2,808	13	Mortality rate 77% (controls, 6%)	Langer (1980)
Salmon (coho)	E	157	1,728	14	Mortality rate 100% (controls, 16.2%)	Shaw and Maga (1943)
Steelhead	E	37	1,488	12	Hatching success 42% (controls, 63%)	Slaney et al. (1977b)
Trout	E	117	960	10	Mortality; deterioration of spawning gravel	Cederholm et al. (1981)
Trout (rainbow)	EE	1,750	144	10	Mortality rate greater than controls (controls, 6%)	Campbell (1954)
Trout (rainbow)	E	6.6	1,152	11	Mortality rate 40%	Slaney et al. (1977b)
Trout (rainbow)	E	57	1,488	12	Mortality rate 47% (controls, 32%)	Slaney et al. (1977b)
Trout (rainbow)	E	120	384	13	Mortality rates 60–70% (controls, 38.6%)	Erman and Ligon (1988)
Trout (rainbow)	E	20.8	1,152	13	Mortality rate 72%	Slaney et al. (1977a)
Trout (rainbow)	E	46.6	1,152	14	Mortality rate 100%	Slaney et al. (1977b)
Trout (rainbow)	E	101	1,440	14	Mortality rate 98% (controls, 14.6%)	Turnpenny and Williams (1980)
			Nonsalmonid eggs and larvae (estuarine[d], group 4)			
Bass (striped)	L	200	0.42	4	Feeding rate reduced 40%	Breitburg (1988)
Bass (striped)	E	800	24	9	Development rate slowed significantly	Morgan et al. (1983)
Bass (striped)	E	100	24	9	Hatching delayed	Schubel and Wang (1973)
Bass (striped)	E	1,000	168	10	Reduced hatching success	Auld and Schubel (1978)
Bass (striped)	L	1,000	68	11	Mortality rate 35% (controls, 16%)	Auld and Schubel (1978)
Bass (striped)	L	500	72	12	Mortality rate 42% (controls, 17%)	Auld and Schubel (1978)
Bass (striped)	L	485	24	12	Mortality rate 50%	Morgan et al. (1973)

…V[b]	Fish response: Description[c]	Reference
10	Mortality rates 0–20% (DE)	Herbert and Merkens (1961)
10	Mortality rates 0–15% (KC)	Herbert and Merkens (1961)
11	Mortality rates 10–35% (KC)	Herbert and Merkens (1961)
12	Mortality rates 35–45% (DE)	Herbert and Merkens (1961)
12	Mortality rates 5–30% (KC)	Herbert and Merkens (1961)
12	Mortality rates 25–80% (DE)	Herbert and Merkens (1961)
11	Mortality rate 40% (CS)	Herbert and Wakeford (1962)
12	Mortality rate 50%	Herbert and Wakeford (1962)
14	Mortality rate 100%	Herbert and Wakeford (1962)
14	Mortality rate ~100% (CSS)	Newcombe et al. (1995)
…d larvae (freshwater, group 4)		
10	Mortality rate 5.7%	J. LaPerriere (personal communication)
10	Mortality rate 14.0%	J. LaPerriere (personal communication)
10	Mortality rate 15.0%	J. LaPerriere (personal communication)
10	Mortality rate 14.7%	J. LaPerriere (personal communication)
10	Mortality rate 13.4%	J. LaPerriere (personal communication)
11	Mortality rate 26%	J. LaPerriere (personal communication)
12	Mortality rate 41.3%	J. LaPerriere (personal communication)
12	Mortality rate of 47%	J. LaPerriere (personal communication)
10	Mortality; deterioration of spawning gravel	Cederholm et al. (1981)
3	Mortality rate 77% (controls, 6%)	Langer (1980)
4	Mortality rate 100% (controls, 16.2%)	Shaw and Maga (1943)
2	Hatching success 42% (controls, 63%)	Slaney et al. (1977b)
0	Mortality; deterioration of spawning gravel	Cederholm et al. (1981)
0	Mortality rate greater than controls (controls, 6%)	Campbell (1954)
1	Mortality rate 40%	Slaney et al. (1977b)
2	…ortality rate 47% (controls, …2%)	Slaney et al. (1977b)
	…rtality rates 60–70% (controls, 38.6%)	Erman and Ligon (1988)
	Mortality rate 72%	Slaney et al. (1977a)
	Mortality rate 100%	Slaney et al. (1977b)
	Mortality rate 98% (controls, 14.6%)	Turnpenny and Williams (1980)
…d larvae (estuarine[d], group 4)		
	Feeding rate reduced 40%	Breitburg (1988)
	Development rate slowed significantly	Morgan et al. (1983)
	Hatching delayed	Schubel and Wang (1973)
	Reduced hatching success	Auld and Schubel (1978)
	Mortality rate 35% (controls, 16%)	Auld and Schubel (1978)
	Mortality rate 42% (controls, 17%)	Auld and Schubel (1978)
	Mortality rate 50%	Morgan et al. (1973)

TABLE A.1.—Continued.

Species	Life stage[a]	Sediment dose: Exposure concentration (mg/L)	Sediment dose: Exposure duration (h)	Fish response: SEV[b]	Fish response: Description[c]	Reference
Herring	L	10	3	3	Depth preference changed	Johnson and Wildish (1982)
Herring (lake)	L	16	24	3	Depth preference changed	Swenson and Matson (1976)
Herring (Pacific)	L	2,000	2	4	Feeding rate reduced	Boehlert and Morgan (1985)
Herring (Pacific)	L	1,000	24	8	Mechanical damage to epidermis	Boehlert (1984)
Herring (Pacific)	L	4,000	24	8	Epidermis punctured; microridges less distinct	Boehlert (1984)
Perch (white)	E	800	24	9	Egg development slowed significantly	Morgan et al. (1983)
Perch (white)	E	100	24	9	Hatching delayed	Schubel and Wang (1973)
Perch (white)	E	1,000	168	10	Reduced hatching success	Auld and Schubel (1978)
Perch (white)	L	155	48	12	Mortality rate 50%	Morgan et al. (1973)
Perch (white)	L	373	24	12	Mortality rate 50%	Morgan et al. (1973)
Perch (white)	L	280	48	12	Mortality rate 50%	Morgan et al. (1973)
Perch (yellow)	L	500	96	11	Mortality rate 37% (controls, 7%)	Auld and Schubel (1978)
Perch (yellow)	L	1,000	96	11	Mortality rate 38% (controls, 7%)	Auld and Schubel (1978)
Shad (American)	L	100	96	10	Mortality rate 18% (controls, 5%)	Auld and Schubel (1978)
Shad (American)	L	500	96	11	Mortality rate 36% (controls, 4%)	Auld and Schubel (1978)
Shad (American)	L	1,000	96	11	Mortality rate 34% (controls, 5%)	Auld and Schubel (1978)
Adult nonsalmonids (estuarine or riverine–estuarine, group 5)						
Anchovy (bay)	A	231	24	10	Mortality rate 10% (FE)	Sherk et al. (1975)
Anchovy (bay)	A	471	24	12	Mortality rate 50% (FE)	Sherk et al. (1975)
Anchovy (bay)	A	960	24	14	Mortality rate 90%	Sherk et al. (1975)
Bass (striped)	A	1,500	336	8	Haematocrit increased (FE)	Sherk et al. (1975)
Bass (striped)	A	1,500	336	8	Plasma osmolality increased (FE)	Sherk et al. (1975)
Cunner	A	28,000	24	12	Mortality rate 50% (20.0–25.0°C)	Rogers (1969)
Cunner	A	133,000	12	12	Mortality rate 50% (15°C)	Rogers (1969)
Cunner	A	100,000	24	12	Mortality rate 50% (15°C)	Rogers (1969)
Cunner	A	72,000	48	12	Mortality rate 50% (15°C)	Rogers (1969)
Fish	A	3,000	240	10	Fish died	Kemp (1949)
Herring (Atlantic)	A	20	3	4	Reduced feeding rate	Johnson and Wildish (1982)
Hogchoker	A	1,240	24	8	Energy utilization increased	Sherk et al. (1975)
Hogchoker	A	1,240	120	8	Erythrocyte count increased	Sherk et al. (1975)
Hogchoker	A	1,240	120	8	Haematocrit increased	Sherk et al. (1975)
Killifish (striped)	A	960	120	8	Haematocrit increased	Sherk et al. (1975)
Killifish (striped)	A	3,277	24	10	Mortality rate 10% (FE)	Sherk et al. (1975)
Killifish (striped)	A	9,720	24	10	Mortality rate 10%	Sherk et al. (1975)
Killifish (striped)	A	3,819	24	12	Mortality rate 50%	Sherk et al. (1975)
Killifish (striped)	A	12,820	24	12	Mortality rate 50%	Sherk et al. (1975)
Killifish (striped)	A	16,930	24	13	Mortality rate 90%	Sherk et al. (1975)
Killifish (striped)	A	6,136	24	14	Mortality rate 90%	Sherk et al. (1975)
Menhaden (Atlantic)	A	154	24	10	Mortality rate 10% (FE)	Sherk et al. (1975)
Menhaden (Atlantic)	A	247	24	12	Mortality rate 50% (FE)	Sherk et al. (1975)
Menhaden (Atlantic)	A	396	24	14	Mortality rate 90% (FE)	Sherk et al. (1975)
Minnow (sheepshead)	A	200,000	24	10	Mortality rate 10% (15°C)	Rogers (1969)
Minnow (sheepshead)	A	300,000	24	11	Mortality rate 30% (10°C)	Rogers (1969)
Minnow (sheepshead)	A	100,000	24	14	Mortality rate 90% (19°C)	Rogers (1969)
Mummichog	A	300,000	24	10	No mortality (15°C)	Rogers (1969)
Mummichog	A	2,447	24	10	Mortality rate 10% (FE)	Sherk et al. (1975)
Mummichog	A	3,900	24	12	Mortality rate 50% (FE)	Sherk et al. (1975)
Mummichog	A	6,217	24	14	Mortality rate 90%	Sherk et al. (1975)
Perch (white)	A	650	120	6	Haematocrit increased	Sherk et al. (1975)
Perch (white)	A	650	120	6	Erythrocyte count increased	Sherk et al. (1975)
Perch (white)	A	650	120	6	Haemoglobin concentration increased	Sherk et al. (1975)
Perch (white)	A	305	120	8	Gill tissue may have been damaged	Sherk et al. (1975)
Perch (white)	A	650	120	8	Histological damage to gill tissue	Sherk et al. (1975)
Perch (white)	A	305	24	10	Mortality rate 10% (FE)	Sherk et al. (1975)
Perch (white)	A	985	24	12	Mortality rate 50%	Sherk et al. (1975)

TABLE A.1.—Continued.

Species	Life stage[a]	Sediment dose: Exposure concentration (mg/L)	Sediment dose: Exposure duration (h)	Fish response: SEV[b]	Fish response: Description[c]	Reference
Perch (white)	A	3,181	24	14	Mortality rate 90% (FE)	Sherk et al. (1975)
Rasbora (harlequin)	A	40,000	24	10	Fish died (BC)	Alabaster and Lloyd (1980)
Rasbora (harlequin)	A	6,000	168	10	No mortality	Alabaster and Lloyd (1980)
Shad (American)	A	150	0.25	3	Change in preferred swimming depth	Dadswell et al. (1983)
Silverside (Atlantic)	A	58	24	10	Mortality rate 10% (FE)	Sherk et al. (1975)
Silverside (Atlantic)	A	250	24	12	Mortality rate 50% (FE)	Sherk et al. (1975)
Silverside (Atlantic)	A	1,000	24	14	Mortality rate 90% (FE)	Sherk et al. (1975)
Spot	A	114	48	10	Mortality rate 10% (FE)	Sherk et al. (1975)
Spot	A	1,309	24	10	Mortality rate 10% (FE)	Sherk et al. (1975)
Spot	A	6,875	24	10	Mortality rate 10%	Sherk et al. (1975)
Spot	A	189	48	12	Mortality rate 50% (FE)	Sherk et al. (1975)
Spot	A	2,034	24	12	Mortality rate 50%	Sherk et al. (1975)
Spot	A	8,800	24	12	Mortality rate 50%	Sherk et al. (1975)
Spot	A	317	48	14	Mortality rate 90% (FE)	Sherk et al. (1975)
Spot	A	11,263	24	14	Mortality rate 90%	Sherk et al. (1975)
Stickleback (fourspine)	A	100	24	10	Mortality rate <1% (IA)	Rogers (1969)
Stickleback (fourspine)	A	10,000	24	10	No mortality (KS; 10–12°C)	Rogers (1969)
Stickleback (fourspine)	A	300	24	12	Mortality rate ~50% (IA)	Rogers (1969)
Stickleback (fourspine)	A	18,000	24	12	Mortality rate 50% (15.0–16.0°C)	Rogers (1969)
Stickleback (fourspine)	A	50,000	24	12	Mortality rate 50% (KS)	Rogers (1969)
Stickleback (fourspine)	A	53,000	24	12	Mortality rate 50% (10–12°C)	Rogers (1969)
Stickleback (fourspine)	A	330,000	24	12	Mortality rate 50% (9.0–9.5°C)	Rogers (1969)
Stickleback (fourspine)	A	500	24	14	Mortality rate 100%	Rogers (1969)
Stickleback (fourspine)	A	200,000	24	14	Mortality rate 95% (KS)	Rogers (1969)
Stickleback (threespine)	A	28,000	96	10	No mortality in test designed to identify lethal threshold	LeGore and DesVoigne (1973)
Toadfish (oyster)	A	3,360	1	6	Oxygen consumption more variable in prestressed fish	Neumann et al. (1975)
Toadfish (oyster)	A	14,600	72	8	Fish largely unaffected, but developed latent ill effects	Neumann et al. (1975)
Toadfish (oyster)	A	11,090	72	9	Latent ill effects manifested in subsequent test at low SS	Neumann et al. (1975)
Adult nonsalmonids (freshwater, group 6)						
Bass (largemouth)	A	62.5	720	9	Weight gain reduced ~50%	Buck (1956)
Bass (largemouth)	A	144.5	720	9	Growth retarded	Buck (1956)
Bass (largemouth)	A	144.5	720	12	Fish unable to reproduce	Buck (1956)
Bluegill	A	423	0.05	4	Rate of feeding reduced	Gardner (1981)
Bluegill	A	15	1	4	Reduced capacity to locate prey	Vinyard and O'Brien (1976)
Bluegill	A	144.5	720	9	Growth retarded	Buck (1956)
Bluegill	A	62.5	720	9	Weight gain reduced ~50%	Buck (1956)
Bluegill	A	144.5	720	12	Fish unable to reproduce	Buck (1956)
Carp (common)	A	25,000	336	10	Some mortality (MC)	Wallen (1951)
Darters	A	2,045	8,760	14	Darters absent	Vaughan (1979); Vaughan et al. (1982)
Fish	A	120	384	10	Density of fish reduced	Erman and Ligon (1988)
Fish	A	620	48	10	Fish kills downstream from sediment source	Hesse and Newcomb (1982)
Fish	A	900	720	12	Fish absent or markedly reduced in abundance	Herbert and Richards (1963)
Fish	A	2,045	8,760	12	Habitat destruction; fish populations smaller than expected	Vaughan (1979); Vaughan et al. (1982)
Fish (warmwater)	A	100,000	252	10	Some fish died; most survived	Wallen (1951)
Fish (warmwater)	A	200,000	1.125	10	Fish died; opercular cavities and gill filaments clogged	Wallen (1951)
Fish (warmwater)	A	22	8,760	12	Fish populations destroyed	Menzel et al. (1984)
Goldfish	A	25,000	336	10	Some mortality (MC)	Wallen (1951)

SEV[b]	Fish response: Description[c]	Reference
14	Mortality rate 90% (FE)	Sherk et al. (1975)
10	Fish died (BC)	Alabaster and Lloyd (1980)
10	No mortality	Alabaster and Lloyd (1980)
3	Change in preferred swimming depth	Dadswell et al. (1983)
10	Mortality rate 10% (FE)	Sherk et al. (1975)
12	Mortality rate 50% (FE)	Sherk et al. (1975)
14	Mortality rate 90% (FE)	Sherk et al. (1975)
10	Mortality rate 10% (FE)	Sherk et al. (1975)
10	Mortality rate 10% (FE)	Sherk et al. (1975)
10	Mortality rate 10%	Sherk et al. (1975)
12	Mortality rate 50% (FE)	Sherk et al. (1975)
12	Mortality rate 50%	Sherk et al. (1975)
12	Mortality rate 50%	Sherk et al. (1975)
14	Mortality rate 90% (FE)	Sherk et al. (1975)
14	Mortality rate 90%	Sherk et al. (1975)
10	Mortality rate <1% (IA)	Rogers (1969)
10	No mortality (KS; 10–12°C)	Rogers (1969)
12	Mortality rate ~50% (IA)	Rogers (1969)
12	Mortality rate 50% (15.0–16.0°C)	Rogers (1969)
12	Mortality rate 50% (KS)	Rogers (1969)
12	Mortality rate 50% (10–12°C)	Rogers (1969)
12	Mortality rate 50% (9.0–9.5°C)	Rogers (1969)
14	Mortality rate 100%	Rogers (1969)
14	Mortality rate 95% (KS)	Rogers (1969)
10	No mortality in test designed to identify lethal threshold	LeGore and DesVoigne (1973)
6	Oxygen consumption more variable in pretreated fish	Neumann et al. (1975)
8	Fish largely unaffected, but developed latent ill effects	Neumann et al. (1975)
9	Latent ill effects manifested in subsequent test at low SS	Neumann et al. (1975)
[illegible]monoids (freshwater, group 6)		
9	Weight gain reduced ~50%	Buck (1956)
9	Growth retarded	Buck (1956)
12	Fish unable to reproduce	Buck (1956)
4	Rate of feeding reduced	Gardner (1981)
4	Reduced capacity to locate prey	Vinyard and O'Brien (1976)
9	Growth retarded	Buck (1956)
[illegible]	Weight gain reduced ~50%	Buck (1956)
[illegible]	[illegible]ish unable to reproduce	Buck (1956)
[illegible]	Some mortality (MC)	Wallen (1951)
14	Darters absent	Vaughan (1979); Vaughan et al. (1982)
10	Density of fish reduced	Erman and Ligon (1988)
10	Fish kills downstream from sediment source	Hesse and Newcomb (1982)
12	Fish absent or markedly reduced in abundance	Herbert and Richards (1963)
12	Habitat destruction; fish populations smaller than expected	Vaughan (1979); Vaughan et al. (1982)
10	Some fish died; most survived	Wallen (1951)
10	Fish died; opercular cavities and gill filaments clogged	Wallen (1951)
12	Fish populations destroyed	Menzel et al. (1984)
10	Some mortality (MC)	Wallen (1951)

TABLE A.1.—Continued.

Species	Life stage[a]	Sediment dose: Exposure concentration (mg/L)	Sediment dose: Exposure duration (h)	SEV[b]	Fish response: Description[c]	Reference
Sunfish (green)	A	9,600	1	5	Rate of ventilation increased	Horkel and Pearson (1976)
Sunfish (redear)	A	62.5	720	9	Weight gain reduced ~50% compared to controls	Buck (1956)
Sunfish (redear)	A	144.5	720	9	Growth retarded	Buck (1956)
Sunfish (redear)	A	144.5	720	12	Fish unable to reproduce	Buck (1956)

[a] A = adult; E = egg; EE = eyed egg; F = fry; F* = swim-up fry; FF = young fry (<30 weeks old); FF* = older fry (>30 weeks old); J = juvenile; L = larva; PS = presmolt; S = smolt; SF = sac fry; U = underyearling; Y = approximate yearling; YY = young of the year.

[b] Severity-of-ill-effect ranging from 0 (no detectible effect) to 14 (maximum effect; see Table 1).

[c] Full response annotations are in Newcombe (1994). Particle sizes of suspended sediment (SS) sometimes were given categorically in source documents. As abbreviated here, VFSS = very fine (<15 μm); FSS = fine (15–74 μm); MFSS = medium to fine (75–149 μm); MCSS = medium to coarse (150–290 μm); and CSS = coarse (180–740 μm). Usual "sediments" used: BC = bentonite clay; CS = calcium sulfate; CWS = coal washery solids; DE = diatomaceous earth; DM = drilling mud (nontoxic); FC = fire clay; FE = fuller's earth; IA = incinerator ash; KC = kaolin clay; KS = Kingston silt; LNFH = lime-neutralized ferric hydroxide; MC = montmorillonite clay; VA = volcanic ash; WF = wood fibers. Other abbreviation: NTU = nephelometric turbidity units.

[d] Lake herring larvae were tested in freshwater.