Appendix E
Hydrologic Analysis Technical Memorandum

CH:CDM

Santa Monica Bay Beaches Wet Weather Bacteria TMDL Implementation Plan

Technical Memorandum Task 4: Hydrologic Analysis

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1.0 Introduction

Background

The CH:CDM team is assisting Jurisdiction groups 2 and 3, which consist of the Cities of Los Angeles, Santa Monica, and El Segundo, the County of Los Angeles, and Caltrans in developing an Implementation Plan to address the requirements of Santa Monica Bay (SMB) Beaches Wet Weather Bacteria Total Maximum Daily Load (TMDL). The Implementation Plan will incorporate input from multiple cities, and agencies, as well as other affected stakeholders; and will consider and build on other planning efforts that are currently in progress with the City of Los Angeles' Integrated Resources Plan (IRP). The Implementation Plan will use an integrated water resources management approach which will address multiple pollutants, identify beneficial use opportunities, and integrate multiple agencies in its overall solution. Utilizing this approach, the Regional Board may allow the Jurisdiction group up to 18 years for implementation and compliance with the TMDL.

There are seven jurisdictions, organized by watersheds, which are impacted by this TMDL. Of these seven jurisdictions, the City of Los Angeles is the lead agency for Jurisdiction 2 and is a significant participant in three other Jurisdictions (1, 3, and 7). City of Santa Monica is the lead in Jurisdiction 3 and is a participant in Jurisdiction 2. This technical memorandum (TM) pertains to the joint implementation planning effort for Jurisdictions 2 and 3 (see Figure 1).

In support of the City of Los Angeles' efforts to prepare the Implementation Plan, the CH:CDM team is under contract with the City to provide the following 11 tasks. These tasks are:

Task 1: Assist with TMDL Development Planning

Task 2: Provide Staff Support for the Development of an Integrated Implementation Plan

Task 3: Regulatory Requirements

Task 4: Detailed Hydrologic Study

Task 5: Beneficial Use Evaluation

Task 6: Treatment and Management Options Evaluation

Task 7: Coastal Collection System Evaluation and Conceptual Alternatives

Task 8: Research Potential Sites for Collection, Treatment and Diversion Facilities

Task 9: Analysis of Implementation Alternatives

Task 10: Prepare TMDL Implementation Plan

Task 11: Task Management

Currently the CH:CDM team is also involved in the preparation of the City of Los Angeles' Integrated Resources Plan (IRP). As part of the IRP, the CH:CDM team and the City of Los Angeles developed a number of Interim Deliverable reports. This technical memorandum builds upon Volume 3, Runoff Management, which was prepared by the CH:CDM team and the City of Los Angeles and released in August 2003.

Purpose

The purpose of this analysis is to satisfy the requirements of Task 4, the detailed Hydrologic Study, which aims to estimate the capture volumes of stormwater runoff that must be managed to meet the TMDL requirements. In addition, this analysis will assist the agencies and stakeholders with the establishment of levels of confidence and risk in estimating stormwater runoff volumes and evaluating potential Implementation Plan alternatives.

Under most conditions, stormwater runoff typically exceeds bacteria criteria resulting in exceedances of water quality objectives. This analysis focuses on the determination of runoff capture volumes, or operational storage volumes, as a method of limiting the number of days water quality objectives are exceeded. Management of these storage volumes may include the treatment and discharge, diversion, or treatment and reuse of captured flows.

Scope

The scope of this effort included a detailed hydrologic study for the coastal drainage areas of the cities and other agencies within Jurisdictions 2 and 3 that discharge to the Santa Monica Bay beaches. The study determines target runoff volumes and design hydrographic relationships for use in sizing operational storage, diversion and treatment facilities. The study also estimates each city's and agency's relative proportional contribution of runoff from individual watersheds compared to other jurisdictions' runoff contributions for purposes of estimating relative responsibilities for implementation in the future. This task builds on the work previously performed by the CH:CDM team, the City of Los Angeles, and other agencies on the IRP task of analyzing water quantity data for major drainage areas by applying the approach to individual coastal watersheds.

2.0 Methodology

The first part of the analysis deals with potential design criteria, involves a review of Draft Interim Deliverable (Volume 3) results, establishes and refines initial runoff volume estimates for each subwatershed within Jurisdiction 2 and 3, and identifies potential adjustments for hydrologic conditions.

The second part of the analysis relates to the establishment of confidence and risk and involves rainfall-runoff modeling. The fundamental assumption of these analyses is that exceedances (and violations) are directly correlated with rainfall-runoff events, and does not address the impacts of Ballona Creek, wave wash, or other elements associated with the compliance monitoring locations.

Preliminary Sizing Criteria

The Runoff Draft Interim Deliverable presented general sizing guidelines based on basin-wide parameters and the initial draft of the TMDL. The report presents a review of 50 years of precipitation data recorded at Los Angeles International Airport (LAX) and the observed daily volume of the 18^{th} largest rain day for each year of the 50-year period. The TMDL allows for 17 exceedance days in a given wet season. Based on this volume, the 90-percentile precipitation amount was calculated to be 0.45 inches. The implication is that having the capacity to manage a 0.45-inch rainfall will maintain exceedences to 17 or less each year, over 90 percent of the time. A TMDL capture volume was calculated based on the 0.45-inch daily event and a general runoff coefficient of 0.47. Using these estimated criteria, for Jurisdiction 2 only (28,000 acres), an approximate management capacity of 160 MG was estimated. Including Jurisdiction 3, and with identical generation rates, the total area (34,500 acres) would require approximately 200 MG of capacity.

The two subject Jurisdictions are subdivided into 7 smaller subwatersheds. Each subwatershed is within the greater Santa Monica Bay watershed, so while there are no significant regional differences in topographic features, there are significant differences in elevation across subwatersheds. There are also significant differences in land use as the northern subwatersheds include large undeveloped open spaces, while the smaller coastal subwatersheds are largely developed.

Therefore, the initial criteria for estimating operational storage volumes were adjusted on the basis of:

- Subwatershed area
- Land use, and
- Precipitation distribution.

Land uses are based on Southern California Association of Governments (SCAG) data, which provide estimates of percent impervious (%IMP) for each land use. A review of Los Angles County-defined soil types within the Santa Monica Bay watershed indicates that for most of the subject area, given the anticipated levels of precipitation (i.e., on the order of one-half inch in 24 hours), undeveloped soils are anticipated to have a base infiltration rate of 0.1 inch/hour. Using this estimate of soil conditions and composite %IMP values for each subwaterhed, the estimated runoff rate was calculated using the following equation:

Runoff coefficient, Rc = 0.9*(%IMP) + 0.1*(1-%IMP)

Estimates for runoff volumes were made using the following equation:

Runoff volume (MG) = Rc * P * A * Cf

Where,

Rc is dimensionless
P is daily precipitation volume in inches
A is area of subwatershed in acres
Cf is a conversion factor equal to 0.65 MG/acre-ft

Table 1 lists subwatershed areas, acreages, %IMP estimates, and runoff coefficients for Jurisdictions 2 and 3. Impervious values based on land use within each subwatershed are shown in Figure 1.

Table 1
Subwatershed Characteristics

Subwatershed	Area (Acres)	Predominant Land Use/Percentage	% Impervious	Runoff Coefficient
Castle Rock	4,982	Natural Open / 82%	9%	0.17
Santa Ynez	1,226	Single Family / 45%	26%	0.31
Pulga Canyon	1,984	Natural Open / 74%	13%	0.20
Santa Monica Canyon	10,125	Natural Open / 77%	8%	0.17
Santa Monica	9,152	Single Family / 40%	53%	0.52
Venice Beach	109	Beach Parks / 91%	16%	0.23
Dockweiler	6,879	Transportation / 30%	65%	0.62
Totals	**34,457**			

The Runoff Draft Interim Deliverable applies anticipated precipitation volumes throughout the Santa Monica Bay watershed. In order to better assess site-specific differences, it was desired to estimate a representative precipitation volume for each subwatershed. Two sets of precipitation data were considered and reviewed:

- County of Los Angeles data (27 stations) 1996-2001
- Western Regional Climate Center data (5 stations) 1948-2001

Both data sets showed clear correlation trends with elevation being the factor impacting precipitation. For the purposes of initial evaluation of applicability of data, annual precipitation volumes were examined from the two sources. The County of Los Angeles data had greater spatial coverage. On the other hand, the Western Regional Climate Center (WRCC) data had significantly longer durations. Plots of annual runoff versus elevation for each data set are presented in Figures 2 and 3.

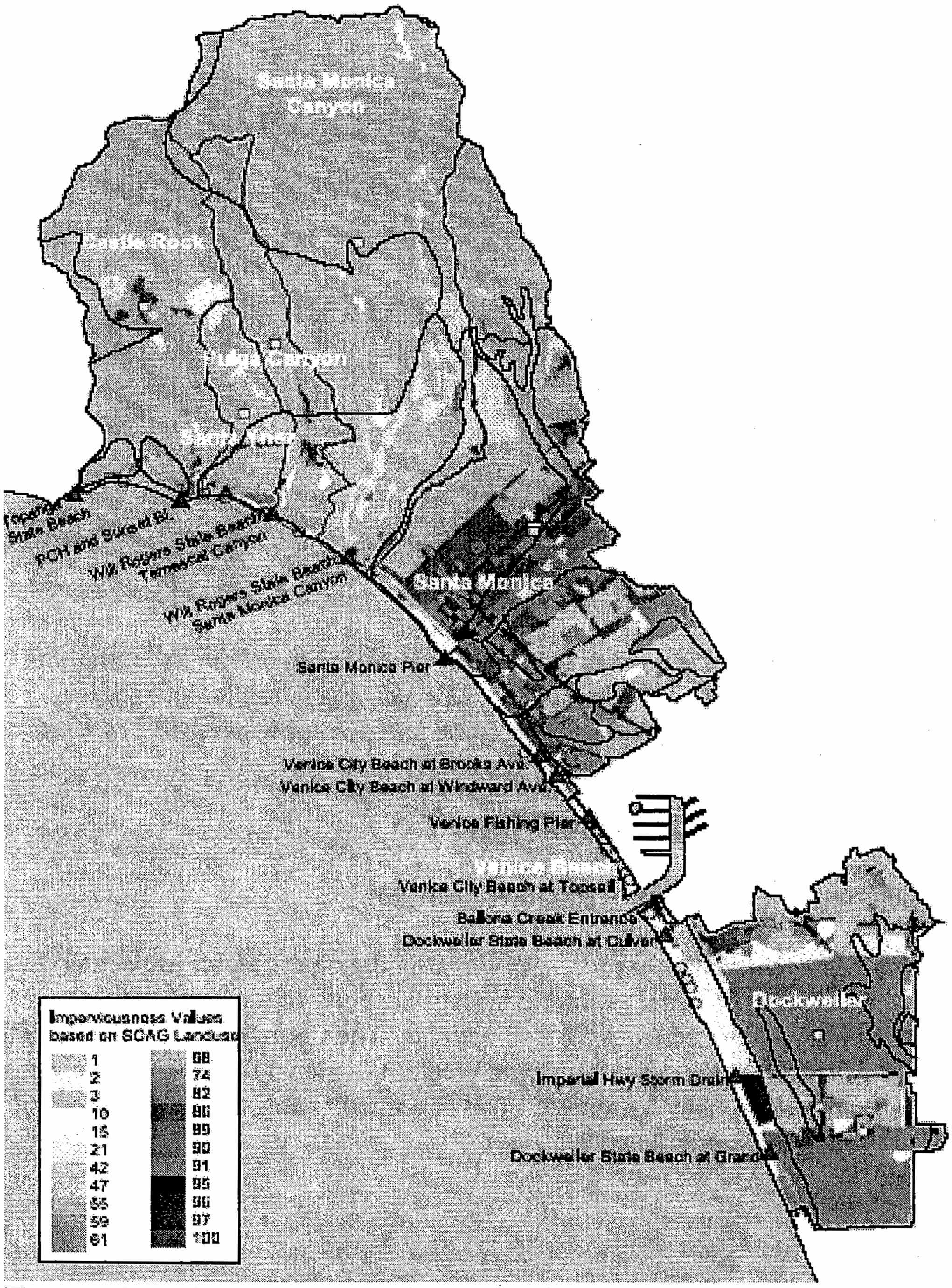

Figure 1. Jurisdiction 2 and 3 Subwatersheds and Land Uses

Figures 2 and 3 indicate that the WRCC gage data correlated much better than County gage data (R-squared of 0.91 vs. 0.48). This is primarily attributable to 1996-2001 time frame (which included at least two El Nino events) and is confirmed when reviewing the WRCC data for the same time frame. On this basis, long-term WRCC data were used to form a relational model between precipitation and elevation. The WRCC station names are listed below:

- Santa Monica Pier (Elevation 2 ft)
- Culver City (Elevation 80 ft)
- LA Airport (Elevation 120 ft)
- Civic Center (Elevation 360 ft)
- UCLA (Elevation 430 ft)

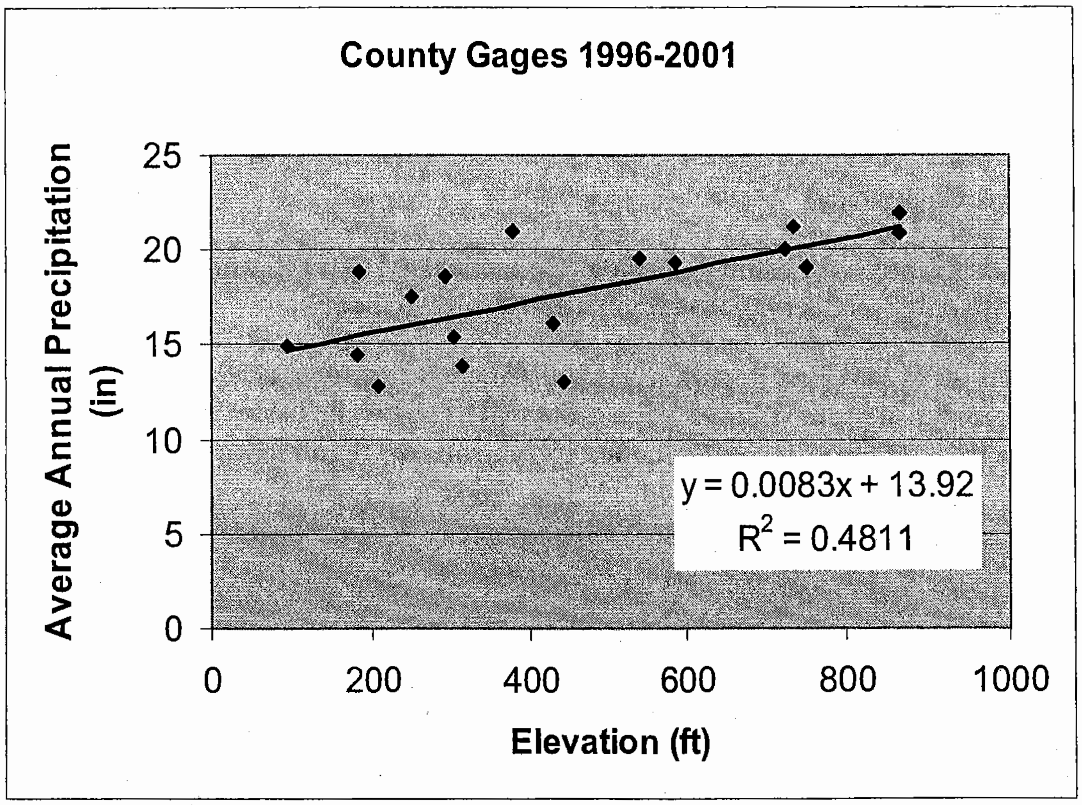

Figure 2. Los Angeles County Gage Data[1]

1 Only stations with complete data shown

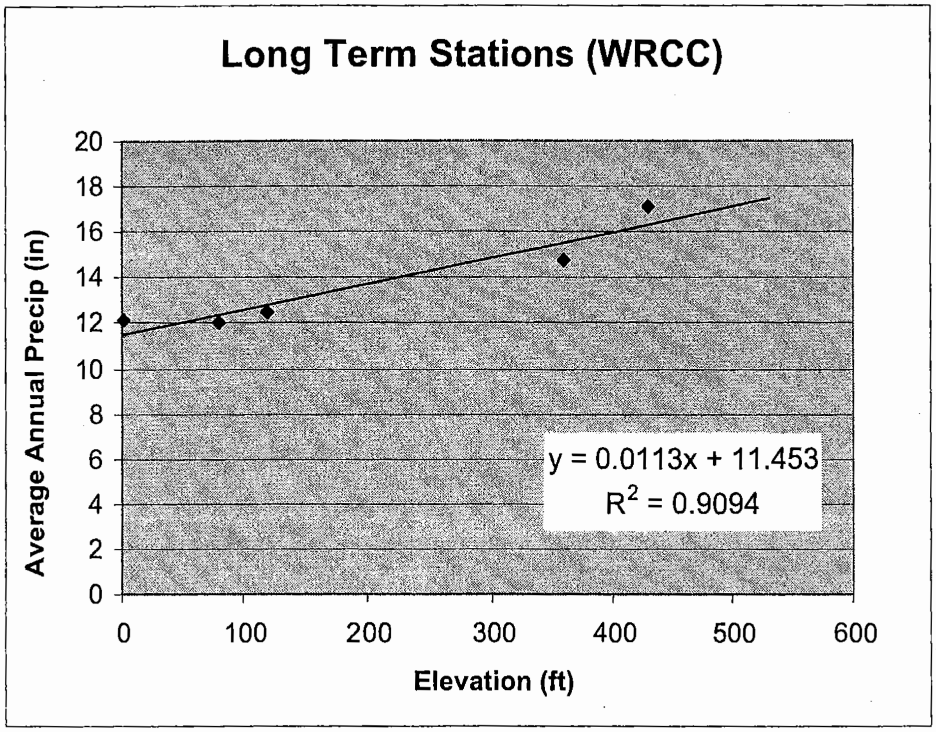

Figure 3. WRCC Gage Data

Representative elevations were estimated using two methods: 1) the elevation of the centroid of the subwatershed and 2) the mid-elevation within the watershed.

Using elevation data to select precipitation estimates and land use data to identify runoff coefficients, the design capture volumes were estimated as shown in Table 2. As Table 2 indicates, on the basis of the sizing criteria, the capture volumes required are significant.

Table 2

Preliminary Design Volumes

			Adjusted Precip.		Volume (MG)	
Subwatershed	**Centroid Elev**	**Midpoint Elev.**	**Low Estimate**	**High Estimate**	**Low Estimate**	**High Estimate**
Castle Rock	660	1025	0.68	0.82	16	19
Santa Ynez	350	835	0.55	0.75	6	8
Pulga Canyon	660	1020	0.68	0.82	7	9
Santa Monica Cyn	790	970	0.73	0.80	33	37
Santa Monica	170	815	0.48	0.74	63	96
Venice Beach	5	6	0.42	0.42	0.3	0.3
Dockweiler	20	90	0.42	0.45	49	52
Totals					**174**	**221**

Table 3 below illustrates how the factors described above (land use and precipitation) affect storage requirements as illustrated by storage requirement "rates" (in gallons of storage per acre). A comparison of Santa Monica Canyon to Santa Monica illustrates that the more urbanized Santa Monica subwatershed requires up to three times more storage per acre than the less-developed Santa Monica Canyon subwatershed.

Table 3

Estimated Storage Requirement "Rate"

		Estimate storage requirements (gallons/acre)	
Subwatershed	**Area (Acres)**	**Low**	**High**
Castle Rock	4,982	3,100	3,800
Santa Ynez	1,226	4,700	6,300
Pulga Canyon	1,984	3,700	4,500
Santa Monica Cyn	10,125	3,300	3,600
Santa Monica	9,152	6,800	10,500
Venice Beach	109	2,600	2,600
Dockweiler	6,879	7,100	7,500
Total	**34,457**		

Hydrologic Modeling

While the initial assessment is helpful in understanding relative differences and overall target volumes, it is critical to have a more robust analysis method. Therefore, it was desired to assess the effectiveness and confidence levels associated with potentially major infrastructure requirements. There were a number of hydrologic conditions that required further examination:

- The 17 exceedance days that the TMDL stipulates are interpreted as allowable discharge days per year during wet weather, with each day theoretically subject to a discrete (e.g., midnight-to-midnight) period. Storms do not naturally mimic these timing patterns, so it is difficult to correlate the two events.
- Storms naturally exhibit variable *durations;* rarely are these durations 24 hours.
- Watershed response to precipitation is highly dependent on storm patterns, intensity, and antecedent conditions. That is, a 0.45-inch storm occurring after 3 consecutive rain days will produce more runoff than the first 0.45-inch storm of the year. For this reason it is necessary to capture actual events, so that assumed conditions over an extended duration are unbiased.

- Proposed control measures require transient storage capacity; therefore *inter-event* conditions must be appropriately considered. That is, if it is necessary to regulate outflows (for diversion or treatment), it is not appropriate to assume storage facilities are empty prior to the storm event. To properly model conditions, it is necessary to assume a rate of dewatering (or discharge) in conjunction with the dynamics of storm events. As with antecedent conditions, assuming average pre-storm storage is inappropriate due to the time-specific and irregular nature of storm events.

These conditions clearly indicate that the frequency of runoff and discharge events is not simply related to daily precipitation and that synthetic hydrograph approaches that are appropriate for design are not appropriate for estimating conditions relevant to establishing implementation criteria for TMDL compliance. Therefore, the following approach was implemented to address all of the complexities of the hydrologic cycle on a macro-scale.

Using the same precipitation weighting, current land use, and runoff criteria described above, a continuous simulation rainfall runoff model was developed. The baseline precipitation data includes 50 years of hourly data (1951-2001) at Los Angeles Airport rain gauge (near Los Angeles International Airport, LAX). After reviewing numerous candidate models and applications, the XP-SWMM rainfall-runoff model was selected to conduct the analysis. The Natural Resource Conservation Service (NRCS) Curve Number method was utilized assuming standard rainfall distributions and unit hydrograph characteristics. Initial estimates of vegetative cover were made based on a review of current aerial photographs (see Figure 4).

Hourly rainfall data was used as input, but because of the short lag times of some of the subwatersheds, in many cases time steps of less than 10 minutes were calculated. The model also considered each subwatershed as one basin.

Figure 4. Typical Aerial Photograph for Watershed Subarea

Order of magnitude calibration/verification of the XP-SWMM model was conducted using 5-, 10-, and 25-year data collected from the Western Regional Climate Center, and USGS regression equations for Coastal California. Peak flow rates calculated using the USGS equations were compared to comparable design storms calculated as follows:

For each of the 24-hour design storms, the corresponding Regional Regression equations are as follows:

- 5-year, $Q_5 = 0.40*A^{0.77}*P^{1.69}$
- 10-year, $Q_{10} = 0.63*A^{0.79}*P^{1.75}$
- 25-year, $Q_{25} = 1.10*A^{0.81}*P^{1.81}$

Watershed parameters were calibrated against more-frequent (e.g., 5-year) events to establish unbiased results that do not include any factors of safety. Typically, when designing storm drain and flood control systems, agencies use conservative estimates of precipitation, storm pattern, and watershed characteristics because the intent is to overestimate flows to provide for design safety. For purposes of TMDL compliance, it is desired to have an unbiased estimate of flows, and therefore use of factors of safety and standard approaches are not appropriate.

As expected, a comparison with regional regression equations resulted in the XP-SWMM model overestimating flows in developed (more impervious) conditions with short lag times, and underestimating flows in undeveloped (more pervious) subwatersheds with long lag times. The net effect, however, is a model that shows little bias and that is consistent with model assumptions. Model parameters are listed below in Table 4.

Table 4
XP-SWMM Watershed Model Parameters

Subwatershed	Area (Acres)	Curve Number	Lag Time (min)	UH Factor
Castle Rock	4,982	48	69	484
Santa Ynez	1,226	63	37	484
Pulga Canyon	1,984	48	72	484
Santa Monica Canyon	10,125	53	122	484
Santa Monica	9,152	69	146	256
Venice Beach	109	50	13	256
Dockweiler	6,879	70	178	256
Totals	**34,457**			

To simulate the effectiveness of the various target volume criteria, transient storage facilities were modeled as "reservoirs" with low level discharge rates corresponding to 24-hour dewatering times. If inflow volumes were less than the storage volume, or if the inflow rates were such that storage volumes were allowed to decrease over time, the entire runoff event was modeled to remain within the storage facility. Exceedances, or violations, were simulated when the available storage (and inflow rate) was exceeded and there was a discharge from a hypothetical "spillway." This allows the model to account for inter-event timing, inflow and outflow rates, and transient storage. For each subwatershed, the theoretical storage facility was modeled using the "low estimate" shown in Table 2. The number of hypothetical violations/spillway discharges were then tabulated.

Violations were tabulated on a yearly (number of years with violations) and daily violation (number of violations in a given year) basis.

Initial model runs indicated that the previously developed storage volumes would provide, for the most part, better-than-expected results. Therefore, for purposes of analysis, the "low estimate" and one-half the low estimate were considered. The latter was evaluated because, although penalties/fines for violations have not been established, the magnitude of infrastructure requirements may dictate a cost-benefit, cost-minimizing approach that allows for some risk/exposure to TMDL violations and that is consistent with the appropriate use of public funds.

3.0 Results

The preliminary results are consistent with expectations. Smaller, more highly developed watersheds require greater proportional storage volumes. Longer lag times and infiltration attributes of the larger, undeveloped watersheds reduce demands on storage facilities.

For the 50-year simulation, the frequency of hypothetical violations are listed below in Tables 5 and 6; Table 5 lists results in years and Table 6 lists results in days. Both tables use the "low estimate" volumes from Table 2. A "violation" is noted where modeling results show that there is an 18th exceedance day, thereby exceeding the 17 days allowed in the TMDL. Tables 7 and 8 lists hypothetical historical frequencies of violation years and days, respectively.

Table 5

Hypothetical Number of Years with Violations Over a 50-year Period

Subwatershed	Half Storage Assumed	Full Storage Assumed
Castle Rock	0	0
Santa Ynez	2	1
Pulga Canyon	0	0
Santa Monica Canyon	1	0
Santa Monica	9	6
Venice Beach	0	0
Dockweiler	11	6

Table 6

Hypothetical Number of Days with Violations Over a 50-year Period

Subwatershed	Half Storage Assumed	Full Storage Assumed
Castle Rock	0	0
Santa Ynez	4	1
Pulga Canyon	0	0
Santa Monica Canyon	4	0
Santa Monica	54	17
Venice Beach	0	0
Dockweiler	73	13

Table 7 Summary of Hypothetical Historical Frequency of Violation in Years			
Predominant Watershed Type	**Subwatershed**	**Years with violations (half storage)**	**Years with violations (full storage)**
Natural, open	Castle Rock, Pulga, Santa Monica Cyn, Venice Beach	0 to 1 year in 50	0 years in 50
Open + Mixed Residential	Santa Ynez	2 years in 50	1 year in 50
Transportation/ Residential	Dockweiler, Santa Monica	9 to 11 years in 50	6 years in 50

Table 8 Summary of Hypothetical Historical Number of Violation Days per Year			
Predominant Watershed Type	**Subwatershed**	**Avg. Violation Days/year (half storage)**	**Avg. Violation Days/year (full storage)**
Natural, open	Castle Rock, Pulga, Santa Monica Cyn, Venice Beach	0 to 0.08 days/year (over 50 yrs)	0 days/year (over 50 yrs)
Open + Mixed Residential	Santa Ynez	0.08 days/year (over 50 yrs)	0.02 days/year (over 50 yrs)
Transportation/ Residential	Dockweiler, Santa Monica	1 to 1.5 days/year (over 50 yrs)	0.25 to 0.35 days/year (over 50 yrs)

Since the management option is to estimate required storage volume based on hypothetical exceedances, additional analyses were conducted. For each watershed, numerous additional storage volumes were considered in order to develop relationships between required storage volume and number of hypothetical violation days. In order to estimate, for example the storage volume required to allow 2 violations days in 50 years, interpolation and/or extrapolation of data was required. Because the storage-violation relationship is not linear, values were linearly interpolated only between adjacent points and extrapolated only between the last two points in a series. The results are presented in Table 9.

Table 9 Estimated Required Volume (MG) for Hypothetical Violation Days within a 50-year period.			
Subwatershed	1 violation in 50 yrs	2 violations in 50 yrs	5 violations in 50 yrs
Castle Rock	2.0	1.7	1.0
Santa Ynez	5.7	4.8	2.6
Pulga Canyon	2.8	0.9	0.5
Santa Monica Canyon	29.2	25.1	7.3
Santa Monica	76.0	75.2	72.7
Venice Beach	<0.1	<0.1	<0.1
Dockweiler	53.6	53.1	51.9
TOTAL	169.3	160.8	135.9

A comparison of the preliminary storage volume (total of 200 MG) to the total storage calculated using the continuous simulation model yield a reduction in required storage of 15% to over 30%, depending on the tolerance for risk.

4.0 Conclusions

The hydrologic study has yielded the following conclusions:

- The hydrologic analysis and methodology presented herein presents a useful means of predicting potential risk of TMDL exceedance and violation assuming a direct correlation of exceedances to runoff events. It can be used as a tool to develop infrastructure requirements and help establish cost-effectiveness.

- The analysis accounts for complex hydrologic conditions and the relationship with a calendar-based exceedance and regulatory criteria that can be applied elsewhere within the region.

- Sizing and design criteria should be reexamined to account for acceptable levels of risk and/or potential impacts and likely exceedances/violations in addition to perception and cost issues.

- Because this analysis is based on hypothetical representations of runoff and storage behavior, further investigation and probabilistic analyses could establish true confidence limits and probabilistic risk.

- Further examination of the relationship between the Santa Monica Bay, currents, other major tributaries, and TMDL exceedances at monitoring locations is required. While, given the size of Jurisdiction 2 and 3 watersheds, there may not be long-term residual effects, the relationship between runoff days and exceedance days should be examined in more detail.

- The method of analysis described herein provides a defensible relationship between infrastructure sizing and regulatory compliance and has significant applications to support the analysis of runoff management alternatives to be developed for the Implementation Plan.

5.0 References

City of Los Angeles Integrated Resources Plan Facilities Plan Interim Deliverable. Volume 3 Runoff Management, August 2003. Prepared by CH:CDM and City of Los Angeles Department of Public Works, Bureau of Sanitation

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