Marina del Rey and Ballona Creek
Feasibility Study

Ballona Creek Sediment Control
Management Plan

Final Draft F4 Documentation

Hydrology and Hydraulics Analyses for Sediment Basin

U.S. Army Corps of Engineers
Los Angeles District

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1. Introduction

The Marina del Rey Harbor entrance channel suffers from sediment accretion, which inhibits navigation and necessitates periodic maintenance dredging. The deposited sediment is contaminated with pollutants believed to originate in the Ballona Creek Watershed. This causes problems in the disposal of the dredged sediments as well as re-suspension of the material during the dredging operations. Thus, the United States Army Corps of Engineers (USACE) engaged in a reconnaissance study in 1995, and determined that there was a federal interest in sediment control. A feasibility study was initiated to investigate the without-project condition and potential alternatives for sediment control.

In order to reduce the sediment loading to the harbor entrance, three alternatives besides the no-action alternative were developed and evaluated. These three alternatives are as follows:

Alternative 2 – In-stream Sediment Basin. This alternative includes the evaluation of an in-stream sediment basin to capture sediment loads.

Alternative 3B – Jetty Extension. This alternative evaluates the modification of the middle jetty in Marina del Rey Harbor entrance channel. Alternative 3B was selected out of four jetty extension alternatives that are discussed in the Coastal Engineering Appendix.

Alternative 4 – Combination of In-stream Sediment Basin and Jetty Extension. This alternative evaluates a combination of Alternative 2 and Alternative 3B. For this combination alternative, a sediment basin and a jetty extension will both be constructed.

This hydrology and hydraulics study is performed for Alternatives 2 and 4 to evaluate different sediment basin options. The objectives of this hydraulic and sediment analyses are to develop three sediment basin options and to select a preferred option for the control of contaminated sediments from Ballona Creek upstream of Marina del Rey Harbor.

The scope of this hydrology and hydraulics study includes data investigation, criterion development, hydrologic analysis, hydraulic analysis, and sediment basin sizing. The hydraulic analyses were conducted through the use of the HEC-RAS (Hydrologic Engineering Center River Analysis System) hydraulic modeling program. After the HEC-RAS analyses were completed, the results were used for the analysis of the sediment basin. The analysis of the basin alternative includes the use of a sediment-settling program to estimate the sediment amount that would be trapped at each basin site. Various basin sizes for each site were analyzed to establish efficiency and economical feasibility.

2. Data Collection

Ballona Creek was originally constructed in 1937 as a soft-bottom channel with plain riprap on 3 (horizontal) to 1(vertical) sideslopes. In order to improve the channel flow capacity and avoid channel erosion, the Los Angeles County Department of Public Works (LACDPW) has constructed several channel improvements. Sometime before 1961, the riprap on the channel sideslopes was grouted upstream of Bay Street, and in 1961 the channel bottom was concrete-lined upstream from Centinela Avenue. Major channel information is summarized in Appendix A in the original imperial units, which was based on as-built drawings collected from LACDPW and was confirmed during the field investigation. Table 1 is the metric-unit version that is used in the hydraulic modeling.

As-built drawings of two major tributaries of the lower Ballona Creek - Centinela Creek and Sepulveda Channel - were also collected from LACDPW. Centinela Creek is a concrete-lined channel built in 1965. Most of the channel is a 21.3-meters (m) wide rectangular channel, except for the portion that transitions into a trapezoidal channel near the confluence with Ballona Creek. Sepulveda Channel is the downstream reach of the Sawtelle-Westwood Flood Control System. Near the confluence with Ballona Creek, it is a 11.6-m wide rectangular channel built in 1949.

There are two stream gaging stations in Ballona Creek, both located in the lower watershed and operated by LACDPW. These two stations are No. F38C-R at Ballona Creek near Sawtelle Boulevard and No. F301-R at Sepulveda Channel near Culver Boulevard. Both stations recorded maximum daily flow rates. Station No. F301-R is no longer operating, but data from 1952 to 1990 (water year) is available. Station No. F38C-R is operational from 1928 to date. Annual peak flow records of Station No. F38C-R and frequency analysis reports on both stream gages prepared by LACDPW are presented in Appendix A.

TABLE 1. CHANNEL SUMMARY OF BALLONA CREEK								
Station (km)	**Invert Elev. (m)**	**Top of Bank Elev. (m)**	**Bank Height (m)**	**Channel Slope**	**BW (m)**	**Bottom Material**	**Side Slope Material**	**Description**
0+00.00	-5.18	2.44	7.62	N/A	79.25	Soil	Riprap	Ocean at Begin of South Jetty
0+31.15	-3.44	2.74	6.18	0.0016	79.25	Soil	Riprap	Begin BW Transition
0+37.34	-3.34	2.80	6.15	0.0016	60.96	Soil	Riprap	End BW Transition
0+39.65	-3.31	3.17	6.477	GB	60.96	Soil	Riprap	Grade Break
0+47.61	-3.25	N/A	N/A	0.0007493	60.96	Soil	Riprap	Pacific Ave Br. W=34' with 3 Piers
2+69.75	-1.58	N/A	N/A	0.0007493	60.96	Soil	Grouted Riprap	Culver Blvd. Br. W=64' with 3 Piers
2+84.29	-1.48	N/A	N/A	0.0007493	60.96	Soil	Grouted Riprap	Lincoln Blvd. Br. W=110' with 3 Piers
3+32.23	-1.12	5.94	7.06	0.0007493	60.96	Soil	Grouted Riprap	Begin BW Transition
3+60.09	-0.91	6.32	7.22	0.0007493	54.25	Soil	Grouted Riprap	d/s Confluence of Centinela Creek
3+72.92	-0.81	6.41	7.22	0.0007493	51.21	Soil	Grouted Riprap	u/s Confluence of Centinela Creek
3+77.07	-0.78	N/A	N/A	0.0007493	50.29	Soil	Grouted Riprap	Abn Railroad br. W=17.5' w/ 3 piers
3+88.16	-0.69	N/A	N/A	0.0007493	47.55	Soil	Grouted Riprap	Hwy 90 Br.
4+84.63	0.03	6.52	6.49	GB	24.38	Concrete	Grouted Riprap	End BW Transition.
4+85.97	0.05	N/A	N/A	0.002011	24.38	Concrete	Grouted Riprap	Centinela Blvd. Br. W=44' with 2 piers
5+35.93	1.06	N/A	N/A	0.002011	24.38	Concrete	Grouted Riprap	Inglewood Blvd. Br. W=60' with 2 Piers
5+73.63	1.82	10.16	8.34	0.002011	24.38	Concrete	Grouted Riprap	Confluence of Sepulveda Ch.
6+19.35	2.73	N/A	N/A	0.002011	24.38	Concrete	Grouted Riprap	Hwy 405 Br.

3. Field Investigation

The project team conducted field investigations throughout the channel system on November 20, 2000 and July 16, 2001. The investigation focused on pollutant and sediment sources, potential basin sites, and the existing channel conditions that are significant to the project. The investigation was conducted together with the USACE representatives, and the acquired channel drawings were compared to field conditions.

It appears that there is constant urban runoff in the channel from the watershed even without rainfall. In general, Ballona Creek was observed to be relatively free of floating debris in the channel. Significant amounts of trash were observed at stormdrain outfalls. There is a significant sand bar deposition at the confluence of Centinela Creek where the channel is wider and the velocity is lower. Vegetation was noticed on the sand bar at the downstream end of Centinela Creek. The sand bar is expected to be washed out during a major event.

Upstream of Centinela Creek, a small amount of sediment was observed on the concrete-lined bottom. This could be because sediment has been washed out by the storm one week prior to the field investigation or because of the potential higher velocity in that reach. Sepulveda Channel is relatively cleaner than Centinela Creek. The constant channel width, lined rectangular channel, and better confluence design may be the reasons why Sepulveda Channel is generally free of sediment accumulation.

4. Potential Basin Sites

To intercept most of the sediment, the proposed sediment basin should be placed as close to the downstream end of the channel or near the ocean as possible. It is preferred to locate the basins outside of the tidal zone because chloride contamination of the sediment in the tidal zone will limit which landfills disposal of the dredged sediments can be taken to. Based on the investigation in the dredging study (USACE, 1998), the average tidal limit was estimated near Lincoln Boulevard Bridge. The extent of the tidal zone may extend upstream of Lincoln Boulevard Bridge. Additional modeling and testing of sediments north of Lincoln Boulevard was performed and is discussed in the next section of this study in order to better estimate the limits of the tidal zone.

Five potential sites for the placement of the sediment basin were selected, as shown in Figure 1. Factors for selecting an ideal basin site include the bottom width of the channel, channel slope, and the bottom material of the channel.

Sites 2 and 4, located within Sepulveda Channel and Centinela Creek, respectively, are not considered good candidates because sediment is less contaminated from these two tributaries (based on the Sediment Sampling and Analysis). The sediment yield of these sites is also expected to be less than that of other sites because of their smaller watersheds. The concrete rectangular channel and urban development close to the channel right of way also makes the construction of basins less feasible at these locations.

Site 1, located at Ballona Creek upstream of Inglewood Boulevard, is not very ideal due to the relatively steep channel slope. The narrower 24.4 m wide channel and concrete-lined bottom also make the basin less desirable. However, the site is likely to be out of the tidal influence zone and free of chloride contamination.

Implementing a sediment basin near the confluence of Ballona Creek and Centinella Creek is determined to be a good potential location where the channel slope is a relatively flat 0.075 percent. There are earthen bottoms upstream (Site 3) and downstream (Site 5) of the confluence, which would alleviate difficulties during construction. The bottom width at Site 5 varies between 61.0-m and 54.3-m and is much wider than the 24.4-m bottom width at Site 1. Site 5 would be the most ideal location because it is located at the downstream end of the channel, and, therefore, theoretically would catch most of the sediment heading toward Marina del Rey Harbor. The current sand bar deposition at this location also indicates that Site 5 would be a good location.

Sites 1 and 3 should also be considered for hydraulic and sediment evaluation. Site 1 has the advantage of being free of chloride contamination. Site 3 still provides some good features, such as a flat slope and soft bottom, although the bottom width is narrower than Site 5. Sites 2 and 4 will be eliminated from further study. Therefore, Sites 1, 3, and 5 will be evaluated as discussed in the following sections.

Figure 1 Potential Sites for Sediment Basin in Ballona Creek

5. Tidal Influence

The RMA2-WES model was used to determine whether the proposed sediment basins at Sites 3 and 5 are subjected to tidal influence. The RMA2-WES model is a two-dimensional depth-averaged hydrodynamic model developed by the USACE Waterways Experiment Station (WES). The same model was used for an accompanying study to evaluate tidal circulation and subsequent sedimentation near the Marina del Rey (MDR) Harbor entrance for different jetty alternatives.

The numerical model grid used for this study is shown in Figure 2. The creek portion of the model grid extended upstream to the Sepulveda Channel (Mesmer Ave) which has an invert elevation higher than the Mean Higher High Water (MHHW), hence, it is outside the tidal influence zone. Details of the numerical model grid for the creek are shown in Figure 3. The sediment basin sites, as well as some landmarks along the creek are also shown in the figure. In setting up the model, bathymetry of the creek was based on as-built drawings.

A 72-hour tide varying between the Mean Lower Low Water (MLLW) and MHHW (1.7 m, MLLW) was specified at the ocean boundary. Tidal responses at nine locations along Ballona Creek were analyzed. These locations and their corresponding node numbers, station locations, as well as their invert elevations are shown in Table 2.

Table 2. Locations for Tidal Influence Analysis

Location	Node Number	Station (ft)	Bottom Elevation (m, MLLW)
	14	176+44	2.00
Inglewood Blvd	30	175+83	1.96
Basin Site 3	58	159+44	0.95
	100	127+35	0.21
Basin Site 5	128	122+35	0.09
	170	94+36	-0.58
Culver Blvd	184	88+50	-0.68
Pacific Ave	240	15+62	-2.35
Ocean @ South Jetty	338	0+00	-4.28

Figure 4 shows the changes in water surface elevations with time at the two sediment basin sites together with the ocean tide. It appears that during high tide, the water surface elevations at the two basin sites are practically the same as that of the ocean tide (i.e., there is no attenuation of the tide along the creek). Minor fluctuations of the peak water elevations shown in the figure are the results of numerical errors. During low tide, the lowest water elevations at the basin sites, shown in Figure 4, are controlled by the invert elevations.

The results of the tidal analyses indicate that both the sediment basins are subject to tidal influence. There is practically no reduction in tidal elevations along the creek (i.e., tidal flows along Ballona Creek will reach an upstream location where the invert elevation is higher than the highest tide for the project location, which is about Inglewood Boulevard Bridge).

Figure 2 RMA2 Mesh

Figure 3 Ballona Creek Mesh

Figure 4 Tidal Influence in Ballona Creek

6. Hydrologic Analysis

Because the proposed basins are along the main channel, only flows along the main channel are required for the project. The most recent frequency analysis conducted by LACDPW on Station No. F38C-R (near Sawtelle Boulevard) used peak flow data up to 1995. The analysis used the USACE Flood Frequency Analysis (HEC-FFA) Program, Bulletin 17B published by USGS in 1982. The complete results from this analysis are presented in Appendix A.

An updated analysis was conducted for this project by including flood years from 1996 to 1999. The analysis used the same HEC-FFA program. The analysis procedure followed the USGS guidelines (USGS, 1982), which suggest a generalized skew of – 0.45 for the Los Angeles County area. The update analysis evaluated 68 systematic events to determine the expected probabilities for floods with return periods from 1 year to 500 years. The complete results from Bulletin 17B are presented in Appendix A.

The HEC-FFA results of both the county and current analysis are summarized in Table 3. The results are slightly different due to the use of different generalized skews (-99.00 vs. –0.45) and numbers of data years (64 years vs. 68 years). The maximum difference is less than 3.3 percent and is considered insignificant. The updated FFA results will be used for the project.

In order to model the flow in the lower reach, other flow rates downstream of Sawtelle Boulevard will be required. Capital Flood information from LACDPW (flow map see Appendix A) was obtained. The *Capital Flood Protection*, recommended by LACDPW for a major regional flood-control design, uses a 50-year rainfall record. The Capital Flood Design Storm is patterned after actual major extratropical storms observed in the Los Angeles region. The 50-year frequency design storm occurs over a period of 4 days with the maximum rainfall occurring on the fourth day. In some cases, the 50-year rainfall can generate more than a 500-year runoff rate. The ratios of Capital Flood flows between reaches was used to estimate the various return period flows for downstream reaches. The design flood flows are summarized in Table 3.

TABLE 3. DESIGN FLOOD FLOWS IN LOWER BALLONA CREEK				
	County Results F38C-R (m^3)	**Lower Ballona Creek Reach (cms)**		
		Benedict to Sepulveda Ch. (F38C-R)	**Sepulveda Ch. to Centinella Ck.**	**Centinella Ck. to Ocean**
LACDPW Capital Flood Flow	1628	1628	1909	1974
Pro-Rate Factor	1	1.000	1.172	1.212
Return Period: 1 year	103	100	117	121
2 year	320	320	375	388
5 year	473	470	551	570
10 year	580	578	677	700
25 year	N/A	708	830	858
50 year	838	821	963	995
100 year	954	932	1092	1129
200 year	1079	1045	1225	1267
500 year	1254	1203	1411	1459

7. Criterion Development

At the three potential basin sites, the basin will be sized based on physical constraints in the vicinity, which include the existing right-of-way, bridges, major structures, and utility crossings. The basin size, within the limits of physical constraints, can be determined by optimal trapping efficiency (minimum cost/trapping rate) under a given hydraulic condition.

The sediment-trapping rate, for a given basin size, will decrease as the flow increases. This is because higher flows have higher velocities, which will make the sediment settling and trapping more difficult. It appears infeasible to size the basin using high flows, such as a 100-year flood. The 100-year flow basin could be too long to fit into the existing physical constraints. A low flow, such as a 1-year flow, must also be avoided because the small basin could be easily filled up and require frequent maintenance clean-up.

A mid-sized 10-year flow was selected for the hydraulic criterion. This is because of the above discussion, and the fact that most of the pollutants from a urban watershed are from a non-point source on street pavement. As city streets are typically designed for carrying a 10-year flow, a 10-year flow would wash most sediments and pollutants into the storm drains, and then into the creek where they would then be trapped in the sediment basin. Note that the 10-year flow is only used for optimal basin sizing. All other flows will also be evaluated once the basin size is determined. Annual sediment trapping rate and volume will be estimated for the maintenance plan.

The following approach was used for the basin analysis:

- Select the 10-year flow and a representative sediment gradation curve
- Size the basin based on the design flow and sediment gradation curve per physical constraints at three potential locations
- Run sediment settling analysis to find trapping rate vs. basin size at three locations
- Select the preferred basin location and size per minimum cost/trapping rate at three locations
- Run other frequency floods to obtain annual sediment trapping rate and volume
- Develop maintenance plan and schedule based on basin size and annual yield
- Estimate basin construction and maintenance costs for preferred location (see Cost Estimate and Operation and Maintenance Appendixes)

8. Hydraulic Analysis

As-Built drawings of Ballona Creek and the bridge crossings were obtained from LACDPW and Caltrans. The as-built drawings describe the channel characteristics and dimensions of the creek. The hydraulic analysis was performed to determine the following parameters:

- Velocity of the channel during storm events
- Flow Area of the channel during storm events
- Flow depths at each cross section

The HEC-RAS computer modeling program was used to perform one-dimensional steady flow for the river system. This program, developed by the US Army Corps of Engineers, was used to model 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storm events in Ballona Creek. The resulting hydraulic characteristics will be used for the calculations of the settling basin.

Defining a Reach

Ballona Creek is defined as one reach to simplify the modeling. The physical characteristics of the channel were entered in cross-sections. Tributaries (Sepulveda Channel and Centinella Creek) were added along the main reach of the channel.

The cross-section dimensions were defined by the as-built plans. The cross-sections input into the program are the locations of significant changes in the channel. This includes grade breaks, sideslope changes, widening or narrowing of the bottom width of the channel, tributary confluence, and presence of bridges. Necessary items that define a cross section are as follows: river station identification, invert elevation, bank stations, downstream reach lengths, Manning's n value, and contraction and expansion coefficients.

River station is a numerical value used to define each cross section of the channel. River Stations are described in kilometers (km) with Station 0.00 located at the mouth of Ballona Creek (at the Pacific Ocean) and Station 5.791 located at the upstream end of the project area (downstream of the I-405 Bridge).

The sideslopes of Ballona Creek are 3:1 (horizontal to vertical) along the entire length of the project area. In order to obtain an average flow velocity, the bank points are placed at the top of each sideslope.

The distance to the following downstream reach should not be so long that it prevents an accurate computation from being achieved. If the channel characteristics do not change greatly between defined cross sections, the distance between two cross-sections may be increased. If the distance between cross section is too large, HEC-RAS has the ability of interpolating additional cross sections. Cross-sections were interpolated at the maximum distance of 50 m for increased accuracy of results.

Composite Manning's n-Values

Manning's n-values were used in HEC-RAS to determine friction loss within the channel. Reasonable coefficients of roughness must be used to obtain realistic results. Since the bottom width of Ballona Creek is comprised of a different material than the side slopes, a representative Manning's n-value was calculated.

With respect to material composition of the project area, the channel reach can be described as three sections:

- From Station 0.00 to Station 2.685, the bottom width is comprised of soil and the side slopes of riprap
- From Station 2.685 to Station 3.835, the bottom material is soil and the side slopes are grouted riprap.
- Upstream of Station 3.835, the bottom width is concrete lined and the side slopes are grouted riprap

The following equation is used to compute a composite Manning's n-value of each section:

$$n = \left(\frac{\left(P_1 n_1^{3/2} + P_2 n_2^{3/2} + P_N n_N^{3/2} \right)}{P} \right)^{2/3}$$

Where:

P: (with subscripts) the wetted perimeter for the various sections

n: (with subscripts) the coefficient of roughness for the various sections

P: the entire perimeter P.

The wetted perimeter is estimated from HEC-RAS results of a 100-year storm event. The Manning's n -values for each applicable material used in HEC-RAS are defined in Table 4.

TABLE 4. RELAVENT MANNING'S COEFFICIENTS OF ROUGHNESS

DESCRIPTION	MANNING'S "n"
Earthen Channels	0.030
Plain Riprap	0.035
Flush Grouted Riprap	0.020

Manning's n -values and channel dimensions used in HEC-RAS were confirmed by field evaluation. The summary of composite Manning's n -values is shown in Table 5.

TABLE 5. COMPOSITE MANNING'S "n" FOR BALLONA CREEK	
SUB-REACH (km)	MANNING'S "n"
0.00 – 2.685	0.032
2.865 – 3.835	0.026
3.835 – 5.729	0.018

Bridge Characteristics

There are six bridges within the modeling reach. Inglewood Boulevard Bridge is the most upstream bridge (see Table 1) and Pacific Avenue Bridge located near the ocean is the most downstream bridge. The bridge characteristics were entered into HEC-RAS using the bridge-editor function. Information needed in this section includes the following:

- Width of the bridge deck
- Number of piers
- Elevations of piers
- Width and length of piers at low elevation and high elevation
- Elevation of bridge soffit - determines the maximum height the water level can reach without overflowing onto the bridge deck
- Angle of the piers to direction of flow

Table 6 summarizes the bridge information that was input into the modeling program. A "debris factor" is used to simulate the effect of debris build-up on piers. A debris factor of 0.3 m was added to the width of each pier on each bridge within the channel to account for this effect.

TABLE 6. BRIDGE CHARACTERISTICS				
BRIDGE NAME	STATION (km)	WIDTH OF DECK (m)	NUMBER OF PIERS	ELEVATION OF PIERS (m)
Inglewood Blvd.	5.359	18.53	2	9.78
Centinella Blvd.	4.860	13.41	2	8.6
Highway 90	3.882	24.99	3	13.22
Abandoned Railroad	3.774	N/A	3	N/A
Lincoln Blvd.	2.843	33.53	3	7.34
Culver Blvd.	2.697	19.51	3	7.79
Pacific Ave.	0.472	13.92	3	5.78

An “ineffective” area was used to model the abandoned railroad piers at Station 3.774 located just downstream of the Highway 90 Bridge. The railway does not have a bridge deck, and, thus, cannot be defined in the bridge section. In this case, the piers were modeled by blocking out three sections of the channel with the same dimensions as each pier.

Once the channel and bridge data were coded into the program file, the steady state flow analysis was conducted for the return periods of 1-, 2-, 5-, 10-, 25-, 50-, and 100-years. Velocity, flow area, water surface elevations, and many other hydraulic characteristics at each cross section were determined for each storm event. The completed HEC-RAS summary is presented in Appendix B.

9. Sediment and Settling Analysis

Sediment Analysis

Sediment samples were collected and analyzed by a laboratory for sieve size and percentage of sediment passing. The samples were collected from 20 different locations along Ballona Creek and its tributaries during the F3 study in the summer of 2000. Figure 5 shows a graphical summary of the analysis. Based on this available data, an average gradation has been calculated and inserted into the figure to depict a representative sediment characteristic for the main channel of Ballona Creek. The average gradation, which consists of 8 sediment classes, is used in the sediment analysis. Given the significant and inherent uncertainly in sediment transport data and theory (in many cases errors can be on the order 100 percent) utilizing a representative average is an acceptable practice.

The categories for Ballona Creek range from silt to fine gravel. Table 7 shows the relationship of grain size to classification used in the analysis. The representative particle size is the geometric mean size, which is calculated by using the following equation:

$$d_g = \sqrt{d_{\max} \times d_{\min}}$$

TABLE 7. BALLONA CREEK SEDIMENT GRADATION

	SEDIMENT CLASS	GRAIN SIZE (mm)	d_g (mm)	PERCENT FINER	CLASS PERCENTAGE
1	Silt	0.004 TO 0.0625	0.0158	20.0%	20.0%
2	Very Fine Sand	0.0625 TO 0.125	0.0884	25.0%	5.0%
3	Fine Sand	0.125 TO 0.25	0.1768	40.0%	15.0%
4	Medium Sand	0.25 TO 0.50	0.3536	56.0%	16.0%
5	Coarse Sand	0.50 TO 1.0	0.7071	72.5%	16.5%
6	Very Coarse Sand	1.0 TO 2.0	1.4142	85.0%	12.5%
7	Very Fine Gravel	2.0 TO 4.0	2.8284	95.0%	10.0%
8	Fine Gravel	4.0 TO 8.0	5.6569	100.0%	5.0%

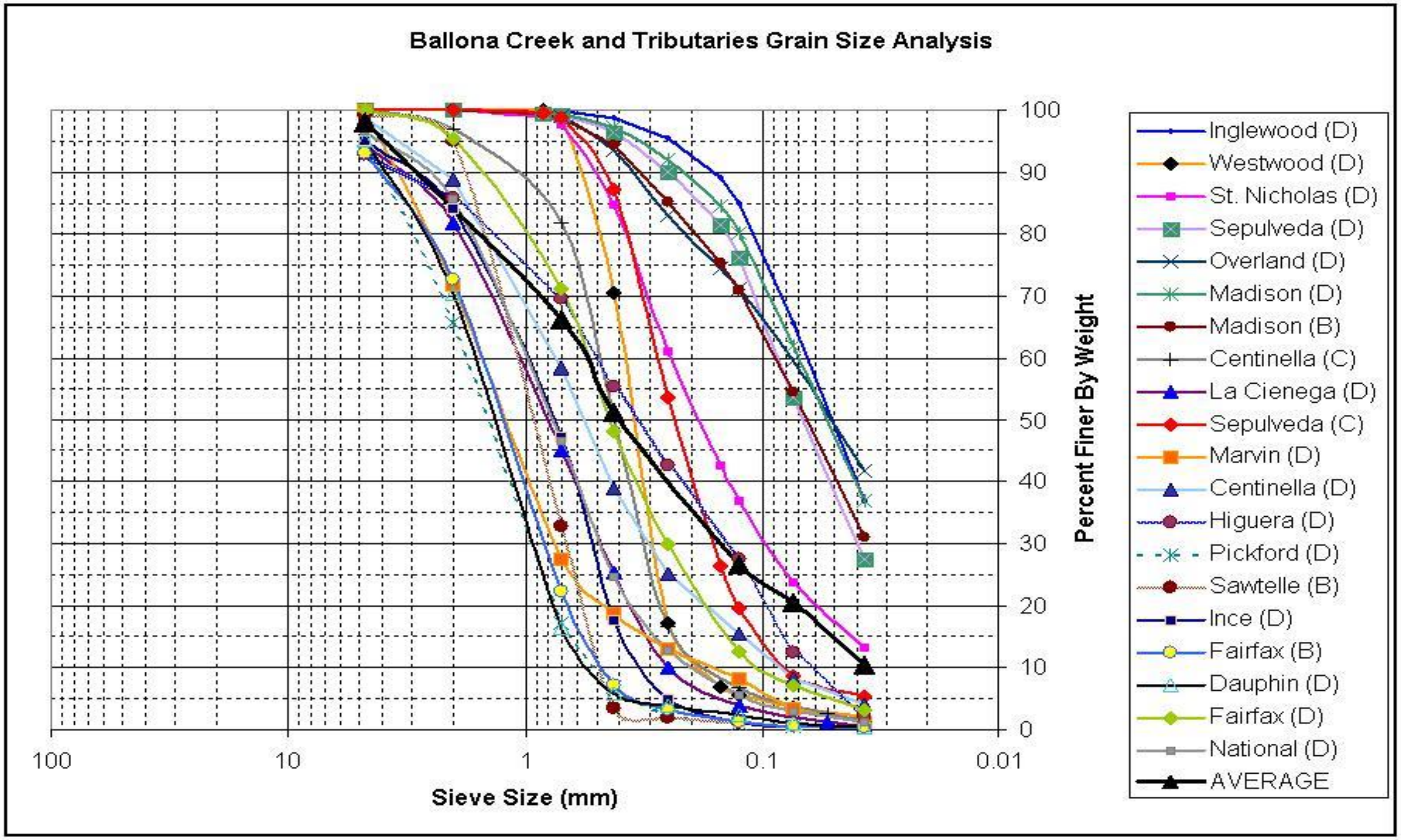

Figure 5. Grain Size Analysis Summary

Settling Analysis

It is desirable to make the length of the basin as long as possible without jeopardizing the integrity of any outlet structures, channel lining, and bridges within the channel. The safe distance from any bridge structure was assumed to be 15 m. The settling basin would be placed between the point 15 m downstream of an upstream bridge and the point 15 m upstream of the following (downstream) bridge. The three potential locations are as follows:

1. Site 1 - Between I-405 Bridge and Inglewood Boulevard Bridge. The length of the sediment basin would be 774 m
2. Site 3 - Between Centinela Boulevard Bridge and Highway 90 Bridge. The length of the sediment basin would be 927 m
3. Site 5 - Between abandoned railroad bridge and Lincoln Bridge. The length of the sediment basin would be 878 m

The sediment-settling program "Trapmix" was used to analyze the trapping efficiency. The program is based on a stochastic model developed by Li and Shen (Li and Shen, 1975). The program requires user input for following information: flow velocity of the basin, sediment size (d_g), depth and length of the basin, and sediment concentration.

The settling depth of the basin was assumed to be the following relationship:

$$d_b = \frac{1}{2} d + H$$

Where:

d_b: settling depth

d: the average depth of the flow in the channel

H: the height of the settling basin beneath the invert of the channel

Velocity in the settling basin is calculated using the following equation:

$$V_b = \frac{Q}{A_{avg} + \Delta A}$$

Where:

Q: the flow rate at the settling basin

A_{avg}: the average flow area of the channel

ΔA: the flow area of the settling basin

As the height of the basin is changed, the velocity also changes. The width of the settling basin is set 2.5 m away from the toe on either side of the channel. Riprap will be used to maintain the integrity of the sideslopes. A typical basin layout is presented in Figure 6.

Sediment concentration plays a small role in the model. A conservative value of 1,000 ppm was used in modeling. The summary of trapping for a 10-year return period at Sites 1 and 3 are shown in Tables 8 and 9, respectively.

TABLE 8. SUMMARY OF SEDIMENT TRAPPING FOR SITE 1 – 10-YEAR EVENT

BASIN DEPTH (m)	BASIN FLOW VEL. (m/s)	SETTLING DEPTH (m)	BASIN LENGTH (m)	PERCENT TRAPPED (%)
3.048	3.47	6.07	774	65.8
2.743	3.51	5.76	774	66.4
2.438	3.57	5.46	774	66.8
2.134	3.63	5.15	774	67.3
1.829	3.69	4.85	774	67.8
1.524	3.78	4.54	774	68.3

TABLE 9. SUMMARY OF SEDIMENT TRAPPING FOR SITE 3 – 10-YEAR EVENT

BASIN DEPTH (m)	BASIN FLOW VEL. (m/s)	SETTLING DEPTH (m)	BASIN LENGTH (m)	PERCENT TRAPPED (%)
3.048	2.44	5.18	928	73.3
2.743	2.50	4.88	928	73.6
2.438	2.56	4.57	928	73.9
2.134	2.62	4.27	928	74.2
1.829	2.68	3.96	928	74.5
1.524	2.77	3.66	928	74.8

Table 10 shows the summary of trapping at Site 5 for a 10-year flood. Site 5 has a shorter basin length than that of Site 3; however, the velocity is considerably slower due to the wider channel of Ballona Creek in this location. The channel bottom width has increased from 50 m to 61 m, causing the movement of water to slow. The slow velocity helps the sediment basin to capture a higher percentage of sediment even though the length of the basin is shorter.

TABLE 10. SUMMARY OF SEDIMENT TRAPPING FOR SITE 5 – 10-YEAR EVENT				
BASIN DEPTH (m)	**BASIN FLOW VEL. (m/s)**	**SETTLING DEPTH (m)**	**BASIN LENGTH (m)**	**PERCENT TRAPPED (%)**
3.048	1.52	5.27	877	76.0
2.743	1.55	4.97	877	76.2
2.438	1.58	4.66	877	76.4
2.134	1.65	4.36	877	76.5
1.829	1.71	4.05	877	76.7
1.524	1.77	3.75	877	76.9

In a similar matter, the basins were then evaluated for different storm events. The following probability equation was used to calculate the annual average of any property (i.e., sediment or discharge) for given property under 1-, 2-, 5-, 10-, 25-, 50-, and 100-year storm events:

$$P = 0.5P_1 + 0.2P_2 + 0.2P_5 + 0.04P_{10} + 0.04P_{25} + 0.01P_{50} + 0.02P_{100}$$

The complete results from the settling program are presented in Appendix C.

Figure 6 Typical Sediment Basin Layout

10. Results and Recommendations

The results of the sediment settling analysis are summarized in Tables 11, 12, and 13. The trapping rates of each option were adjusted to reflect the basin volume adjustments discussed below. After the average annual sediment was calculated, a maintenance analysis was conducted. The amount of years to maintenance was calculated for each basin depth and presented in Tables 11, 12, and 13.

In the Dredge Material Management Plan F4 (DMMP)(USACE, 2000b), a sediment concentration relationship with the flow was proposed. The relationship was used in the coastal modeling and produced reasonable results. The same sediment relationship was used to produce sediment volume of each event in the creek to keep the basin analysis consistent with coastal modeling.

The settling analysis was revised to consider the available basin's volume. Excess sediment amount will be assumed to bypass the basin when the incoming sediment amount is greater than the available volume of the basin. This conservative approach also implies the consideration of sediment re-suspension in the long sediment basin. In cases where the sediment volume is greater than the available (90 percent) basin volume, as in 100-year and 50-year events, a discount ratio will be applied to the trapping rate to obtain the effective trapping rate. The results are presented in Appendix C.

Based on field observation of the study reach, the amount of submersible trash and debris that flow below the surface of the water was minimal. It was determined that submersible trash and debris will contribute about 10 percent of the total basin volume. The design of the basin will account for this 10 percent of volume and only use 90 percent of the volume when estimating the frequency of maintenance.

Flood-Control Impacts

Although Site 1 is outside of the tidal prism, this alternative will cause some flood-control impact to the creek. This is because the existing creek bottom is concrete-lined with a smoother surface or higher flow capacity. Once the basin is built under the invert, the flow will experience higher friction. A hydraulic analysis shows that the maximum 100-year water surface could be 0.64 m higher under the basin condition at Site 1.

It appears that the channel can only provide 100-year protection, much less then the Capital Flood Protection desired by Los Angeles County. Because the channel is under-capacity, the County would likely consider the water-surface impact significant. Since significant impacts to flood control are a potential fatal flaw, this option is eliminated from further analysis.

For the third (combined sediment basin and jetty) alternative, the potential flood control impact was also evaluated. Under the preferred Jetty Alternative 3B, the middle jetty would be reconstructed to turn to the south to direct the sediment away from the navigation channel. The reconstruction of the middle jetty, however, starts from a point outside of the south jetty, which causes no narrowing to the creek width. As the creek hydraulic analysis starts at the beginning of the south jetty (Sta. 0+00), it appears that the reconstruction of the middle jetty would not significantly impact the hydraulics of the creek upstream.

Recommendations

Site 3 provides less volume capacity than Site 5 for sediment capture. Site 5 with a 3.05-m (10-foot) depth is the preferred sediment basin alternative because it does not impact flood control functions, and provides more sediment volume capacity and longer periods between maintenance events than Site 3.

The preferred alternative at Site 5 is in the tidal influence zone. Although chloride is a problem in sediment disposal into a Class III landfill, other contaminants, such as TRPH, can also cause the same disposal issue. The increase in the disposal costs will affect the benefit/cost ratio of this alternative.

TABLE 11. SUMMARY OF SEDIMENT SETTLING – SITE 1											
Depth of Basin (m)	**Volume of Basin (m^3)**	**90% Volume of Basin (m^3)**	**1 Year Event % Trapped**	**2 Year Event % Trapped**	**5 Year Event % Trapped**	**10 Year Event % Trapped**	**25 Year Event % Trapped**	**50 Year Event % Trapped**	**100 Year Event % Trapped**	**Annual Sediment Trapped (m^3)**	**Maintenance Period (yr.)**
3.05	31400	28200	77.0%	71.6%	54.6%	42.2%	13.3%	11.4%	7.1%	12300	2.3
2.74	29500	26600	77.2%	72.0%	51.6%	40.1%	12.7%	10.8%	6.7%	12100	2.2
2.44	27400	24600	77.3%	72.4%	48.2%	37.4%	11.8%	10.1%	6.3%	11700	2.1
2.13	25000	22500	77.4%	67.0%	44.2%	34.4%	10.9%	9.3%	5.7%	11000	2.0
1.83	22300	20000	77.6%	60.1%	39.7%	30.8%	9.7%	8.3%	5.2%	10200	2.0
1.52	19300	17300	77.7%	52.3%	34.5%	26.9%	8.5%	7.3%	4.5%	9300	1.9

TABLE 12. SUMMARY OF SEDIMENT SETTLING – SITE 3											
Depth of Basin (m)	**Volume of Basin (m^3)**	**90% Volume of Basin (m^3)**	**1 Year Event % Trapped**	**2 Year Event % Trapped**	**5 Year Event % Trapped**	**10 Year Event % Trapped**	**25 Year Event % Trapped**	**50 Year Event % Trapped**	**100 Year Event % Trapped**	**Annual Sediment Trapped (m^3)**	**Maintenance Period (yr.)**
3.05	69700	62800	79.3%	76.1%	74.6%	73.3%	32.8%	27.9%	17.3%	16500	3.8
2.74	64300	57900	79.4%	76.4%	74.8%	73.6%	30.4%	25.8%	16.0%	16300	3.6
2.44	58500	52700	79.5%	76.6%	75.0%	73.8%	27.8%	23.6%	14.7%	16100	3.3
2.13	52400	47200	79.5%	76.7%	75.3%	74.2%	25.0%	21.3%	13.2%	15800	3.0
1.83	46000	41400	79.6%	77.0%	75.6%	70.0%	22.0%	18.8%	11.7%	15500	2.7
1.52	39200	35300	79.7%	77.2%	74.6%	59.9%	18.9%	16.0%	10.0%	15000	2.3

TABLE 13. SUMMARY OF SEDIMENT SETTLING – SITE 5											
Depth of Basin (m)	**Volume of Basin (m^3)**	**90% Volume of Basin (m^3)**	**1 Year Event % Trapped**	**2 Year Event % Trapped**	**5 Year Event % Trapped**	**10 Year Event % Trapped**	**25 Year Event % Trapped**	**50 Year Event % Trapped**	**100 Year Event % Trapped**	**Annual Sediment Trapped (m^3)**	**Maintenance Period (yr.)**
3.05	123100	110800	80.2%	78.2%	76.8%	76.0%	60.3%	51.6%	32.2%	19500	5.7
2.74	112300	101000	80.2%	78.3%	76.9%	76.2%	55.3%	47.2%	29.4%	19000	5.3
2.44	101100	91000	80.3%	78.3%	77.0%	76.4%	49.9%	42.6%	26.6%	18500	4.9
2.13	89600	80600	80.3%	78.4%	77.2%	76.5%	44.3%	37.9%	23.6%	18000	4.5
1.83	77800	70000	80.4%	78.5%	77.4%	76.7%	38.6%	33.0%	20.6%	17500	4.0
1.52	65600	59100	80.5%	78.6%	77.6%	76.9%	32.6%	27.9%	17.4%	16900	3.5

References

Li and Shen, "Solid Particle Settlement in Open-Channel Flow", ASCE J. Hydraulic Engineering, V101, HY7, July 1975.

USACE, Los Angels District, *Marina del Rey and Ballona Creek Feasibility Study, Sediment Control Management Plan, F3 Report*, 2000a.

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USACE, Los Angels District, *Marina del Rey and Ballona Creek Feasibility Study, Dredged Material Management Plan Alternatives Analysis (F4) Report, April 2000b.*

USGS, Bulletin #17B of the Hydrology Subcommittee, *Guidelines for Determining Flood Flow Frequency (Revised),* March 1982.

Appendix A Hydrologic Data

Table 1. Channel Summary of Ballona Creek (imperial unit)

Station (ft)	Invert Elev (ft)	Top of Bank Elev (ft)	Bank Height (ft)	Channel Slope	Bottom Width BW (ft)	Bottom Material	Side slope Material	Capital Flood* Q (cfs)	Description
0+00	-17.00	8.00	25.00	N/A	260	soil	riprap	69,700	Ocean @ begin of south jetty
10+22	-11.29	9.00	20.29	0.0016	260	soil	riprap	69,700	Begin BW transition
12+25	-10.97	9.20	20.17	0.0016	200	soil	riprap	69,700	End BW transition
13+01	-10.85	10.40	21.25	GB	200	soil	riprap	69,700	Grade Break
15+62	-10.65	N/A	N/A	0007493	200	soil	riprap	69,700	Pacific Ave Br. W=34' with 3 piers
88+50	-5.20	N/A	N/A	0007493	200	soil	riprap	69,700	Culver Blvd. Br. W=64' with 3 piers
93+27	-4.84	N/A	N/A	0007493	200	soil	riprap	69,700	Lincoln Blvd. Br. W=110' with 3 piers
109+00	-3.66	19.50	23.16	.0007493	200	soil	grouted riprap	69,700	Begin BW transition
118+14	-2.97	20.72	23.69	.0007493	178	soil	grouted riprap	69,700	d/s confluence of Centinella Creek
122+35	-2.65	21.04	23.69	.0007493	168	soil	grouted riprap	67,400	u/s confluence of Centinella Creek
123+71	-2.55	N/A	N/A	.0007493	165	soil	grouted riprap	67,400	Abn railroad br. W=17.5' w/ 3 piers
127+35 approx.	-2.28	N/A	N/A	.0007493	156	soil	grouted riprap	67,400	Hwy 90 Br.
159+00	0.09	21.39	21.30	GB	80	concrete	grouted riprap	67,400	End BW transition.
159+44	0.18	N/A	N/A	0.002011	80	concrete	grouted riprap	67,400	Centinella Blvd. Br. W=44' with 2 piers
175+83	3.47	N/A	N/A	0.002011	80	concrete	grouted riprap	67,400	Inglewood Blvd. Br. W=60' with 2 piers
188+20	5.96	33.32	27.36	0.002011	80	concrete	grouted riprap	67,400	Confluence of Sepulveda Ch.
203+20 approx.	8.97	N/A	N/A	0.002011	80	concrete	grouted riprap	57,500	Hwy 405 Br.
213+40	11.02	37.73	26.71	0.002011	80	concrete	grouted riprap	57,500	Gaging station & Sawtelle Blvd. Br. W=50' with 7 piers
223+20	13.00	38.58	25.58	GB	80	concrete	grouted riprap	57,500	d/s of drop
224+20	15.00	40.60	25.60	GB	80	concrete	grouted riprap	57,500	u/s of drop
225+10	18.33	N/A	N/A	0.002622	80	concrete	grouted riprap	57,500	Sepulveda Blvd. Br. W=71' with 7 piers
277+50	29.00	53.00	24.00	0.002622	80	concrete	grouted riprap	57,500	

* The *Capital Flood Flow*, recommended by LACDPW for a major regional flood-control design, uses a 50-year rainfall record, which In some cases can generate more than a 500-year runoff.

Table 3. Design Flood Flows in Lower Ballona Creek (imperial unit)

	County Results (F38C-R)	Lower Ballona Creek Reach (cfs)		
		Benedict Ch. to Sepulveda Ch. (F38C-R)	Sepulveda Ch. to Centinella Ck.	Centinella Ck. to Ocean
LACDPW Capital Flood Flow	57,500	57,500	67,400	69,700
Pro-rate factor	1	1	1.172	1.212
Return Period: 1 year	3630	3520	4130	4270
2 year	11300	11300	13250	13700
5 year	16700	16600	19460	20120
10 year	20500	20400	23910	24730
50 year	29600	29000	34000	35150
100 year	33700	32900	38570	39880
200 year	38100	36900	43250	44730
500 year	44300	42500	49820	51520

Appendix B – HEC-RAS Summary

Appendix C – Results of Settling Analysis