Sediment Load Reduction Quantification through Outfall Repair and Relocation for the Los Peñasquitos WMA

June 21, 2016

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EXECUTIVE SUMMARY

The Sediment Load Reduction Quantification through Outfall Repair and Relocation for the Los Peñasquitos WMA Study was performed by Tetra Tech Inc. at the request of the City of San Diego (City) to assess the current loading to the Los Peñasquitos Lagoon caused by the erosive scour associated with outfall discharge, as well as possible load reductions associated with various BMP practices. Sediment loading is a primary concern within the Lagoon, and outfall-based sediment scour is considered a major source of this loading. Quantifying these loads, and estimating the potential for their reduction, creates a clearer understanding of the nature of the problem and the possibilities for remediation.

The sediment loading analysis method utilizes the USDA Bank Stability and Toe Erosion Model (BSTEM) to estimate scour potential. This model is traditionally used to estimate bank instability within streams, but was found to be applicable to the case of outfalls discharging onto sloped surfaces for our study. The BSTEM simulation of 102 outfalls resulted in a total of 1,400 ft^3 (approximately 85 tons) per year of sediment related to erosive discharge in the Los Peñasquitos watershed. Three BMPs were investigated to estimate the amount of this loading that could potentially be eliminated. It was determined that the total sediment load from all modeled outfalls could be reduced by 50% through outfall relocation, 79% by installing energy dissipation structures, and 84% by regenerative stormwater conveyance (RSC) practices if applied at selected High Priority locations.

According to the Water Quality Improvement Plan (WQIP) for the Los Peñasquitos watershed, an average annual loading of 6,000 tons of sediment is generated each year. The resulting 85 tons per year from the BSTEM analysis for all modeled outfalls account for approximately 1.4% of the total load. Sensitivity analyses demonstrate that this can vary significantly, from a negligible amount to nearly 240 tons (4%), depending on input precipitation and soils information.

CONTENTS

*Note that values in the Appendix tables include additional significant digits. Values in the report were rounded.

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

The Los Peñasquitos WMA identified potential water quality concerns associated with existing canyon outfalls. The outfalls' structural integrity or configuration issues have the potential to cause or contribute to downstream water quality problems, including excessive erosion and sedimentation. In response, the City developed and implemented a prioritized assessment strategy for canyon outfall assets to identify areas where assets may need to be rehabilitated, replaced, or relocated to prevent structural damage, reduce or eliminate potential erosion issues, and improve water quality in downstream receiving waters. The purpose of this study is to identify potential sediment load reductions associated with outfall repair/relocation and prioritize the outfall rehabilitation sequencing. The results of this study will be used to validate and refine the sediment load reduction assumptions in the Los Peñasquitos WQIP.

Quantifying the sediment loading at outfalls requires a comprehensive understanding of current and historical outfall condition; past, present, and future upstream development; and stability of the channel. This report presents the results of a desktop analysis to estimate sediment loading and potential reduction through outfall rehabilitation for inclusion in the WQIP to validate and refine the sediment load reduction assumptions. This project builds upon the previous Fiscal Year 2013 outfall assessment study performed by the City: Inventory and Assessment of Storm Water Outfall Conditions in Select Canyons (Phase IV).

The sediment loading analysis method utilizes the USDA Bank Stability and Toe Erosion Model (BSTEM) to estimate scour potential. This model is traditionally used to estimate bank instability within streams, but was found to be applicable to the case of outfalls discharging onto sloped surfaces for our study. The BSTEM simulation of 102 outfalls resulted in a total of 1,400 ft^3 (approximately 85 tons) per year of sediment related to erosive outfall discharge in the Los Peñasquitos watershed. A total of 42 outfalls were deemed sufficiently problematic to be identified as high priority outfalls, warranting further investigation. The investigation included the simulation of three BMPs designed to limit or treat erosion. Outfall relocation entails extending stormwater conveyance infrastructure from a location near the top of a canyon to one near the valley floor. Energy dissipation involves placing materials below the outfall that reduce the energy of incoming storm flows. Regenerative stormwater conveyance (RSC) is a relatively new BMP intended to treat stormwater through a series of energy dissipation structures and small retention ponds. The simulations assumed that each BMP was applicable at each outfall. In reality, various environmental, permitting, and legal challenges would limit applicability. Therefore, further investigation is required to determine the ideal BMP at each location. Overall, if fully implemented at High Priority locations, the total sediment load from all modeled outfalls (102) could be reduced by 50% through relocation, 79% by energy dissipation, and 84% by RSC practices. RSC additionally treats catchment based sediment contributions (suspended solids), and could eliminate an additional 1,000 ft^3 (63 tons) of sediment from the watershed each year.

There exists a substantial amount of variability associated with the analysis. The range of variability, sensitivity to input parameters, and the potential relationships with the Los Peñasquitos Water Quality Improvement Plan (WQIP) are presented in the summary.

Additionally, a memo was prepared for the City in March, 2016, detailing the limitations of a proposed LiDAR-based analysis, as well as a summary of prior sediment loading studies within the Los Peñasquitos watershed. These are included as Appendix E and Appendix C, respectively.

2 BANK STABILITY AND TOE EROSION MODEL (BSTEM)

The BSTEM, designed by the USDA Agricultural Reasearch Service, National Sedimentation Laboratory, estimates stream bank erosion due to the scouring force of flowing water (Figure 2.1). The bank stability component, which predicts bank failure due to mass wasting, was not used. The toe-erosion portion of the BSTEM was used to calculate estimated sediment loads that may be caused by erosional processes. Within the model, bank erosion is calculated by balancing the resisting forces (mass and cohesive attraction between soil particles plus additional shear strength of the vegetation) against the tractive forces (shear stress of the flowing water which is a function of slope and water depth). The model was found to be applicable in the case of outfalls discharging on canyon slopes since the physical processes governing stream bank erosion are similar, and paramaters could be readily obtained for input.

2.1 ANALYSIS METHODS:

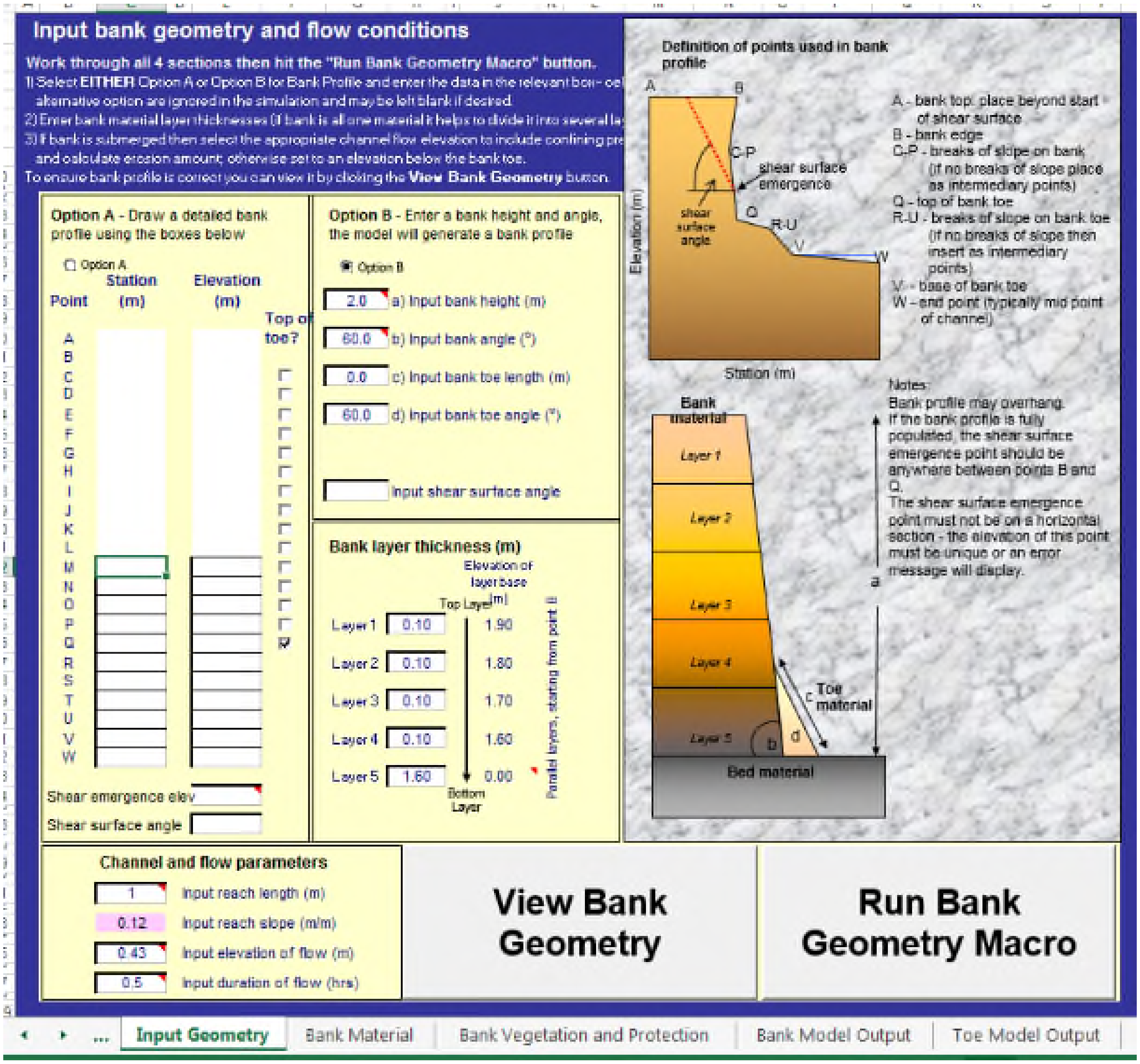
The input data to the BSTEM were developed from known parameters combined with assumptions of unknown conditions. Generating the assumptions required developing runoff quantity and event frequencies based on historic precipitation data, creating channel cross section profiles based on outfall size, and selecting soil erodibility levels based on the USDA Soil Survey Geographic Database (SSURGO). The details of the assumptions and how the input parameters were developed are described in this section. Aerial images and longitudinal profiles for each outfall are included in Appendix B.

The BSTEM input data includes:

- Soil grain size - Derived from the SSURGO soil maps in GIS (Table 2.1).
- Channel geometry - Bank profile is assumed to be a trapazoidal channel with 60 degree sides. Slope and downhill analysis distance (reach lengths) are derived from the 2014 LiDAR based topography (example shown in Figures 2.2 and 2.3). The reaches were created in GIS using a semi-automated process. Flow accumulation surfaces were used to determine flow paths, which follow downstream gradient. These were inspected at each outfall and manually edited to ensure that the primary channel was collected, and to extent/trim the line to include only the reach segment impacted by outfall discharge.
- Vegetation - No vegetative cover was applied. The notes on vegetation from the 2013 outfall inventory were limited to too short a distance below each outfall to be certain that it was an accurate representation of the entire analysis reach.
- Flow - *The San Diego County Hydrology Manual* was used for guidance in applying the Rational Method. Precipitation data from the manual were used to predict the typical magnitude, frequency, and duration of heavy rainfall events. A detailed explanation of the use of the Rational Method to determine discharge and the Manning’s equation to estimate flow depth are included in Appendix D.
- Catchment Area - Draft Outfall Catchment Areas were provided by the City. However, they did not correspond to all of the outfalls in the database. Where missing, catchment areas were digitized in GIS using a combination of outfall dimensions, existing storm drain conveyance network, topography, and aerial imagery (Figure 2.4).

Assumptions included:

- Uniform channel cross section and constant slope.
- Magnitude and frequency of scouring rainfall event.
- Homogenous soil grain size and translation of the SSURGO grain size to BSTEM grain sized based erodibility.
- No bankface vegetation.



Input bank geometry and flow conditions

Work through all 4 sections then hit the "Run Bank Geometry Macro" button.

1) Select **EITHER** Option A or Option B for Bank Profile and enter the data in the relevant box- ce
alternative option are ignored in the simulation and may be left blank if desired.

2) Enter bank material layer thicknesses (If bank is all one material it helps to divide it into several la

3) If bank is submerged then select the appropriate channel flow elevation to include confining pr
and calculate erosion amount; otherwise set to an elevation below the bank toe.

To ensure bank profile is correct you can view it by clicking the **View Bank Geometry** button.

Option A - Draw a detailed bank profile using the boxes below

☐ Option A

Point	Station (m)	Elevation (m)	Top of toe?
A			
B			
C			☐
D			☐
E			☐
F			☐
G			☐
H			☐
I			☐
J			☐
K			☐
L			☐
M			☐
N			☐
O			☐
P			☐
Q			☑
R			
S			
T			
U			
V			
W			

Shear emergence elev

Shear surface angle

Option B - Enter a bank height and angle, the model will generate a bank profile

● Option B

2.0 a) Input bank height (m)

60.0 b) Input bank angle (°)

0.0 c) Input bank toe length (m)

60.0 d) Input bank toe angle (°)

Input shear surface angle

Bank layer thickness (m)

		Elevation of layer base (m)
Layer 1	0.10	1.90
Layer 2	0.10	1.80
Layer 3	0.10	1.70
Layer 4	0.10	1.60
Layer 5	1.60	0.00

Top Layer

Bottom Layer

Parallel layers, starting from point B

Channel and flow parameters

1 Input reach length (m)

0.12 Input reach slope (m/m)

0.43 Input elevation of flow (m)

0.5 Input duration of flow (hrs)

Definition of points used in bank profile

A - bank top: place beyond start of shear surface
B - bank edge
C-P - breaks of slope on bank (if no breaks of slope place as intermediary points)
Q - top of bank toe
R-U - breaks of slope on bank toe (if no breaks of slope then insert as intermediary points)
V - base of bank toe
W - end point (typically mid point of channel)

Notes:
Bank profile may overhang.
If the bank profile is fully populated, the shear surface emergence point should be anywhere between points B and Q.
The shear surface emergence point must not be on a horizontal section - the elevation of this point must be unique or an error message will display.

Figure 2-1 Input geometry worksheet in BSTEM.

Table 2-1 Percent soil grain size distribution from the GIS SSURGO dataset.

Map Unit Symbol	Description	Sand	Silt	Clay
AtF	Altamont clay	24.7	29.1	46.3
AwD	Auld clay	22.1	27.9	50.0
CmE2	Cieneba rocky coarse sandy loam	68.5	19.0	12.5
DoE	Diablo-Olivenhain complex	30.4	32.1	37.5
FxE	Friant rocky fine sandy loam	66.5	19.6	14.0
GaF	Gaviota fine sandy loam	66.1	19.9	14.0
HrC2	Huerhuero loam	53.7	23.0	23.3
LeE	Las Flores loamy fine sand	67.3	5.8	27.0
LsE	Linne clay loam	35.6	36.4	28.0
LvF3	Loamy alluvial land-Huerhuero complex	53.7	23.0	23.3
OhE	Olivenhain cobbly loam	33.8	33.7	32.5
RdC	Redding gravelly loam	34.2	33.3	32.5
SbC	Salinas clay loam	34.9	34.4	30.7
SnG	San Miguel-Exchequer rocky silt loams	27.6	41.6	30.9
VbB	Visalia gravelly sandy loam	60.1	26.9	13.0

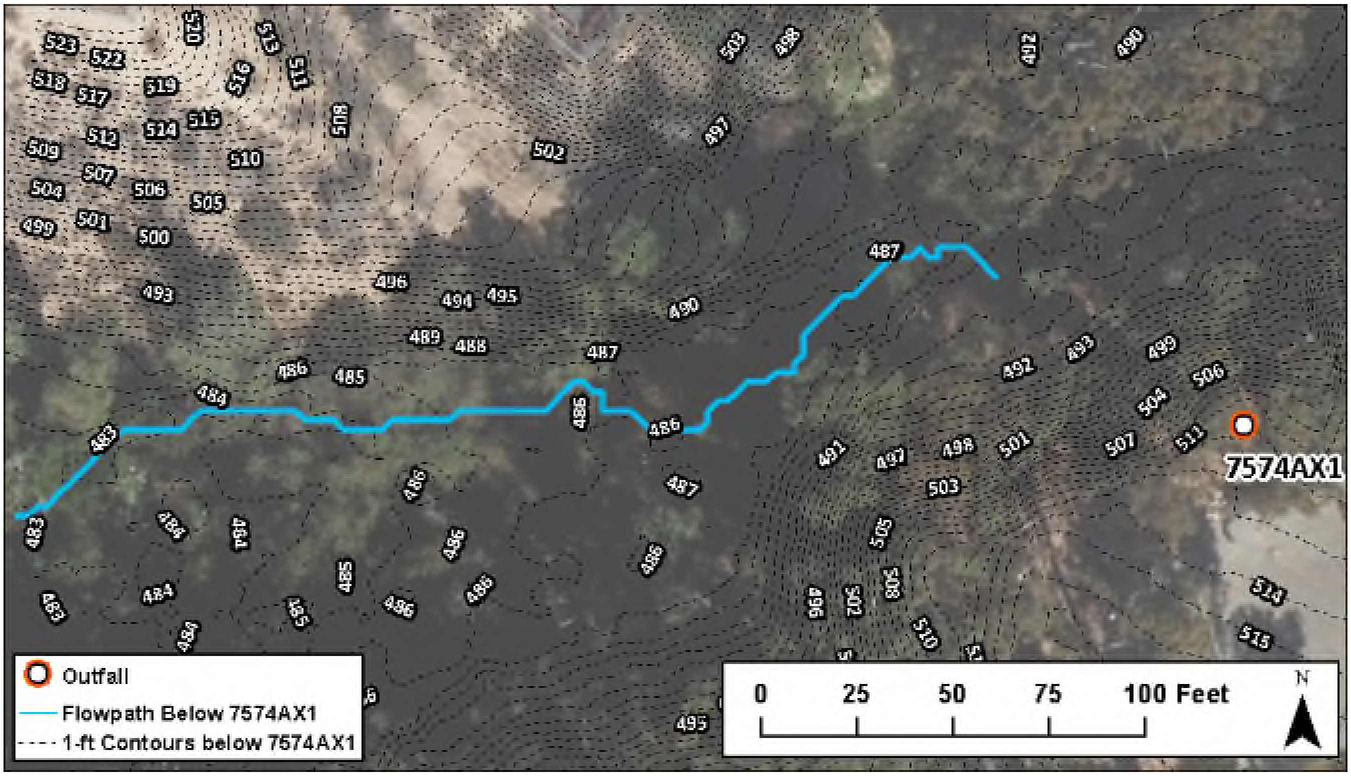
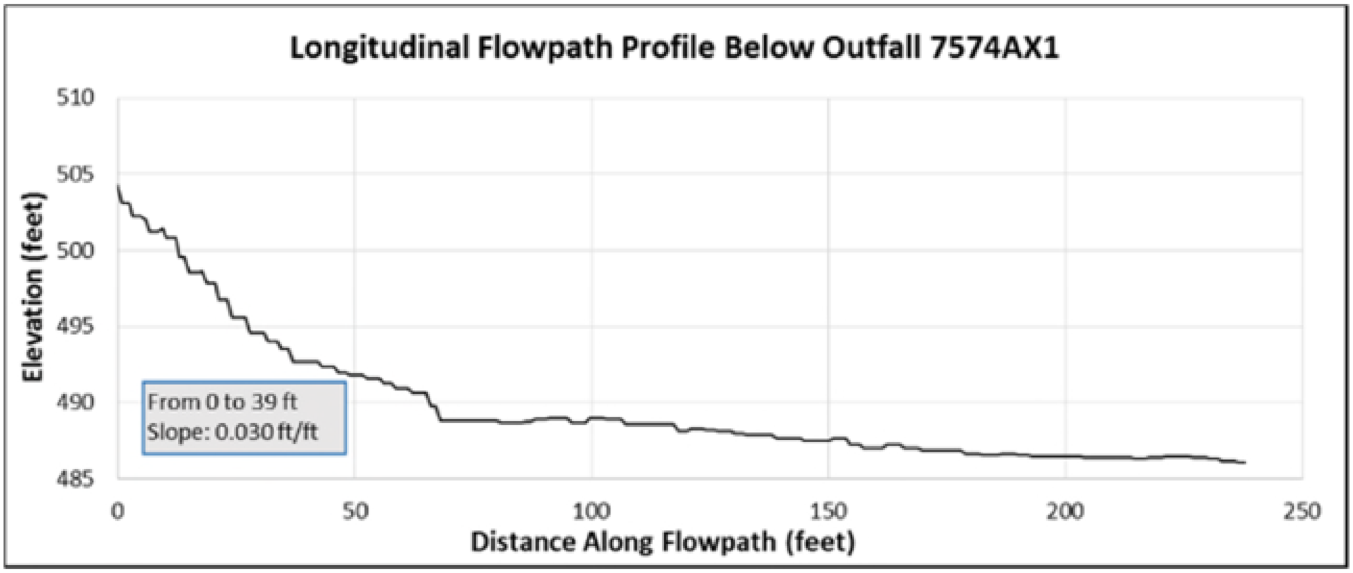


Figure 2-2 Example flowpath and topography below outfall.



From 0 to 39 ft
Slope: 0.030 ft/ft

Figure 2-3 Example longitudinal profile below outfall.

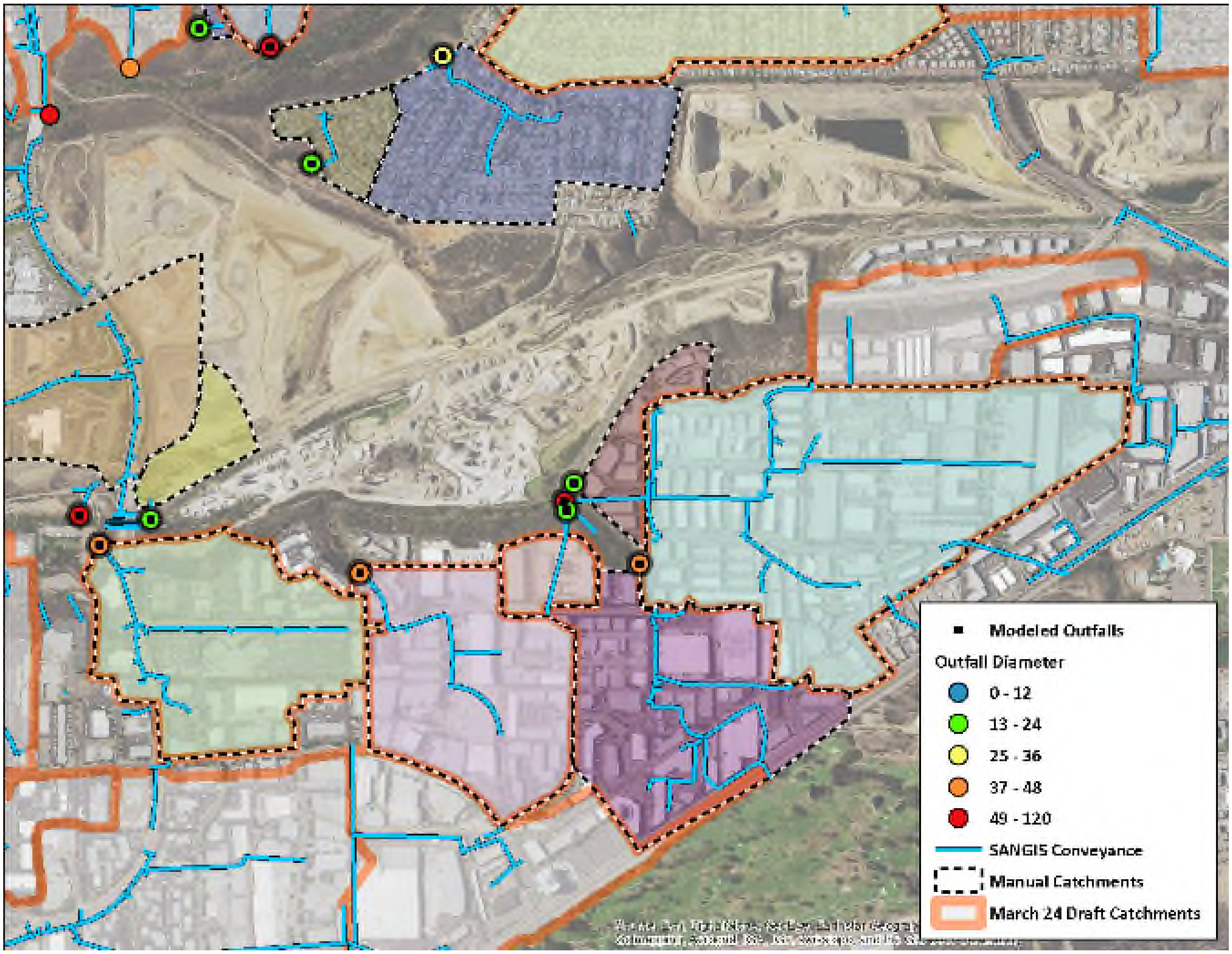


Figure 2-4 Outfall Catchment Areas digitized in GIS.

2.2 ANALYSIS OUTPUT

Data tables from the Phase IV outfall assessment were reviewed for fields that appeared to be the best indicator of severe erosion below an outfall. Two fields, “Erosion Score” and “Bank Erosion”, were selected. Of the 468 outfalls assessed during the previous study, 58 were selected for BSTEM analysis for having the maximum erosion score (5) or a bank erosion description of “active downcutting.” A review of the topography indicated that outfalls were located across a broad elevation range between the canyon valley floor and the top of the canyon walls. Thus, an additional 44 outfalls were selected based on their height above the canyon valley floor with higher outfalls assumed to have a greater potential for having an eroding hill slope below. These two groups of 58 and 44 outfalls, for a total of 102, were then analyzed using the BSTEM.

2.3 ANALYSIS RESULTS

The raw BSTEM output is in square meters of eroded channel cross section per runoff event. For each outfall, the eroded cross sectional area was multiplied by the assessment reach length to estimate a sediment volume per runoff event. The volume per runoff event was multiplied by the frequency of runoff events per year (six) to estimate an annual load.

Table 2.2 lists the BSTEM results for 10 sample outfalls. A total of 42 outfalls produced greater than 5 cubic feet of sediment per year and were selected as High Priority outfalls for a sediment load reduction analysis (Section 4). Key factors in the table that drive the potential energy available to cause erosion include catchment area, height of the outfall above the valley floor, reach slope, and the typical storm discharge. Appendix A (Table A.1) contains a table detailing all inputs, outputs, and result analysis. Nineteen of the outfalls are listed as “n/a” for the BSTEM results. These were excluded due to a mitigating factor discovered while setting up the analysis. Typical mitigating factors include a poorly defined flowpath within the topography and discharge flowing into constructed basins. Figures 2.4, 2.5, and 2.6 show the spatial distribution of outfall heights, discharges, and resulting loads, respectively.

Because of the highly variable nature of soil erosion and sediment transport, the results presented here need to be considered with caution. The variability in the analysis results, based on input assumptions, is discussed in Section 3.

Table 2-2 Key Outfalls Characteristics and BSTEM Output for 10 Sample Locations

Outfall	Height Above Valley or Confluence (ft)	Q (cfs)	Reach Slope (ft/ft)	Reach Length (ft)	Elevation of Flow (ft)	Avg Boundary Shear Stress (Pa)	Max Lateral Retreat (cm)	Volume Eroded (ft^3/yr)	Priority
2952	12	32	0.11	116	0.52	117	0.3	2.5	Low
3885	30	17	0.13	203	0.43	117	0.05	0.11	Low
3971	1	26	0.03	38	0.89	64	0.08	0.27	Low
4475	40	56	0.15	282	1.4	429	1.3	124	High
4756	15	13	0.075	179	0.72	117	0.24	4.5	Low
5429	100	28	0.51	109	0.56	600	1.0	13.9	High
5449	90	6.0	0.34	400	0.23	164	0.41	7.1	High
5475	65	2.6	0.24	272	0.26	132	0.36	3.2	Low
5481	80	6.1	0.30	150	0.30	188	0.50	3.4	Low
5483	100	6.8	0.35	287	0.33	249	0.65	9.9	High

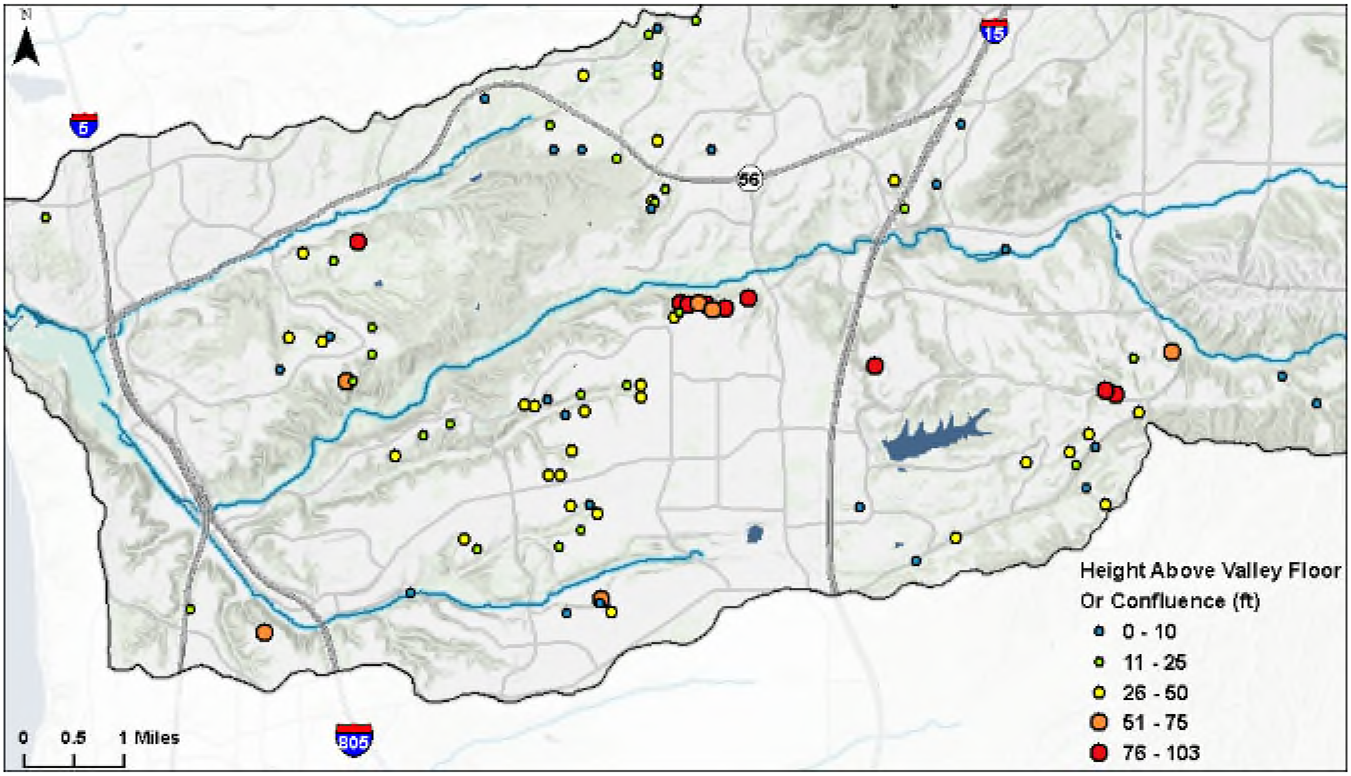


Figure 2-5 Height Above Valley Floor or Confluence for All Modeled Outfalls

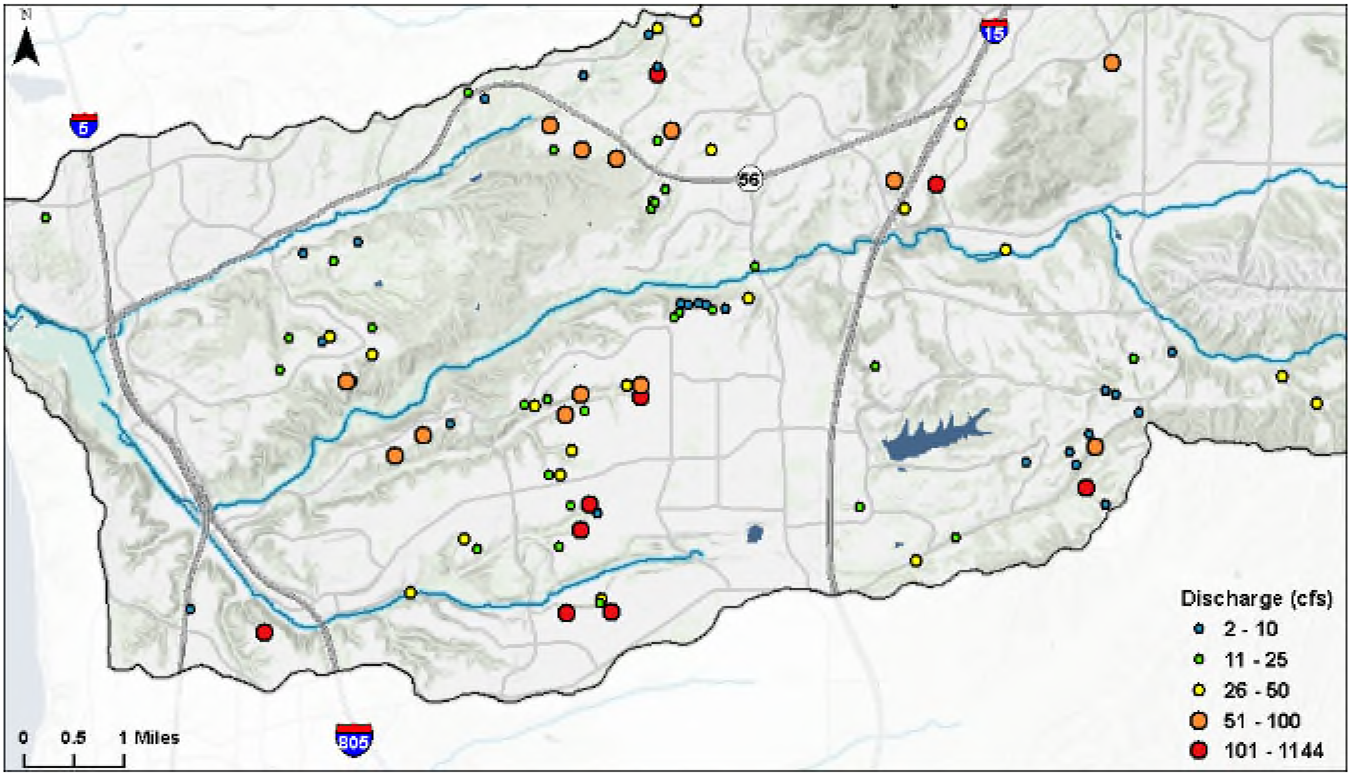


Figure 2-6 Peak Discharge for All Modeled Outfalls

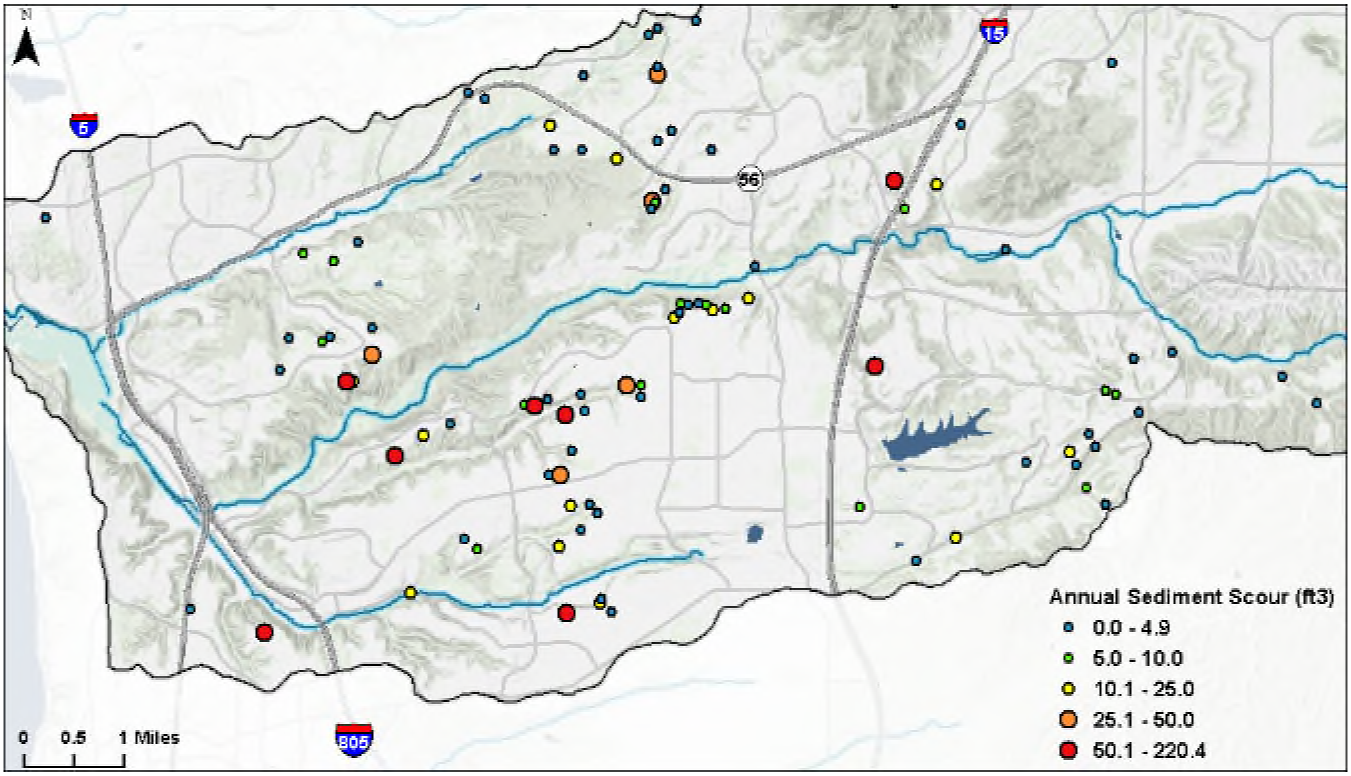


Figure 2-7 Annual Sediment Scour for All Modeled Outfalls

3 SENSITIVITY ANALYSES

The BSTEM model is sensitive to several key parameters. Reach length, slope, and catchment area greatly influence the resulting erosive force, but are driven by detailed GIS inputs. Inputs related to soil type and precipitation, while also highly sensitive, were based on less detailed information. Soil data was occasionally lacking near the outfall, and the precipitation events were greatly simplified. Thus, both soils and precipitation were evaluated for their influence on the erosion results.

3.1 SENSITIVITY TO SOIL TYPE

The soil type input into the model was based on SSURGO fractions for sand, silt, and clay. However, many outfalls exist in areas lacking this information. Where information was available, the grain size fractions correlated to BSTEMs “resistant silt” category, and therefore, these outfalls were assumed to fall within the same category. However, since limited data establishes uncertainty for these outfalls, the soil type was changed to the next most erodible class in the model (“resistant silt” to “moderate silt”). Several outfalls, originally classified as having “resistant silt” also had higher clay fractions (greater than 20%), and were also modeled with “moderate silt”. 30 outfalls fell into these categories, and once run in BSTEM, resulted in a significant increase in scoured load, averaging a 510% change (Table 3.1).

Table 3-1 BSTEM eroded sediment volume increase when soil type is adjusted

Outfall	Volume Eroded (ft^3/yr)		Increase
	Resistent Silt	Moderate Silt	
3971	0.3	3.9	1381%
4756	4.5	33.5	642%
5429	13.9	92.3	565%
5449	7.1	35.3	396%
5481	3.4	15.3	348%
5511	20.6	120.5	485%
5527	4.7	32.8	605%
5900	29.4	115.2	292%
6166	86.9	410.0	372%
6510	1.5	10.7	623%
8453	22.6	138.1	512%
8511	6.2	26.7	334%
44662	1.4	5.1	264%
44710	14.2	67.4	376%
44790	26.2	87.5	234%
45054	34.8	180.0	418%
45163	73.5	257.0	250%
45547	77.0	346.4	350%
45785	9.7	35.2	261%
48193	20.4	109.2	435%
48197	1.5	12.8	730%
48381	3.8	14.3	277%
49017	71.5	327.9	359%
50298	11.8	80.6	585%
50589	2.5	13.1	418%
52677	6.8	25.5	272%
54957	86.3	321.9	273%
55012	2.5	18.6	656%
55027	1.9	45.3	2229%
55036	25.9	121.7	370%

Taken into consideration with the remaining, unmodified outfalls, the estimated annual load climbs from 1,400 ft^3/year (85 tons) to4,000 ft^3/year (240 tons), resulting in a 180% increase.

3.2 SENSITIVITY TO PRECIPITATION

Precipitation events, combined with catchment area and outfall dimensions, are used to develop flow-based inputs to the BSTEM model, which is a primary driver in calculating the scouring force. Based on calculations presented in Appendix D, six identical, representative storm events were used. While these simplified storm events are a reasonable estimation of the events likely to cause flows of erosive force, real-time information provides a higher resolution look at scour patterns.

Load Simulation Program in C++, (LSPC) models were developed as part of the Los Peñasquitos WQIP. These models contain continuous time-series data related to precipitation events. These events are tied to Hydrologic Response Units (HRUs), which associate various hydrologic parameters with land use and land type. Of particular to interest to our analysis are the impervious components of the HRUs. Pervious surfaces do not tend to transport water as quickly as impervious surfaces, and as such were not examined in this analysis.

The impervious area within each outfall catchment was combined with the impervious HRU timeseries information to develop hourly discharge rates. These were calculated for 9 outfalls, selected based upon a representative distribution of catchment areas and reach slope (each grouped into Low, Medium, and High), ensuring that the basic types of outfall characteristics would be simulated.

The modeled precipitation events differed greatly in character. The Rational Method produced six events of equal discharge (peak) and duration (half-hour), while the LSPC timeseries discharges vary over the course of 391 hours, corresponding to 8 events in water year 2003. Figure 3.1 presents the continuous hourly discharge for Outfall 4475, and compares the peaks to the Rational Method events.

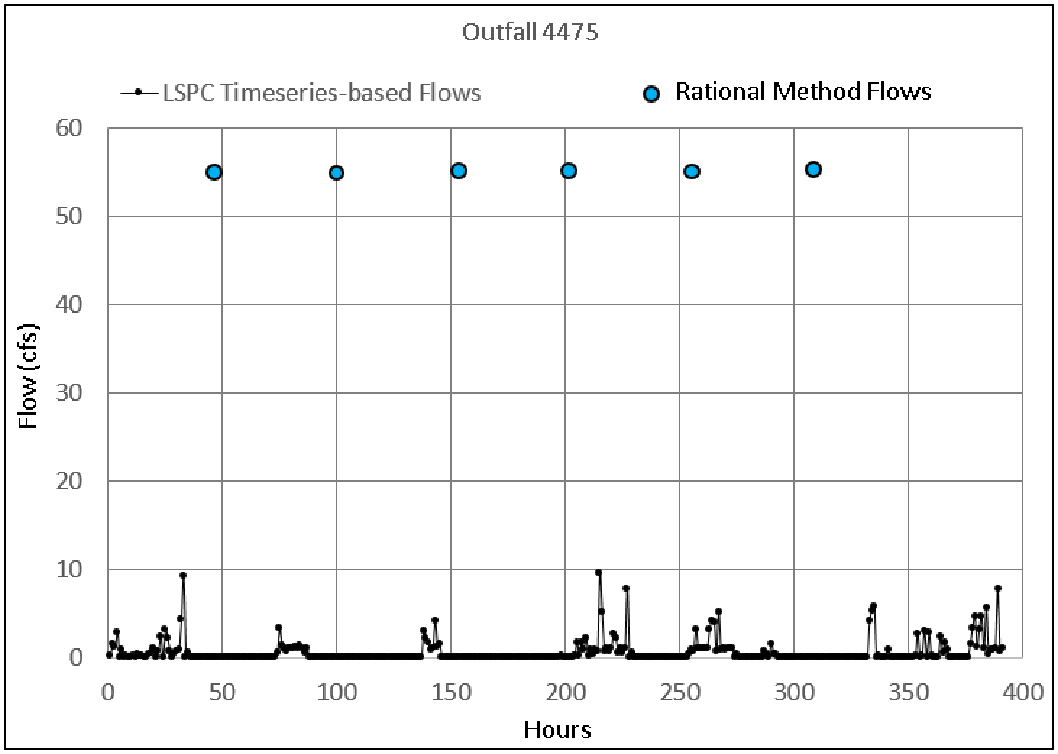


Figure 3-1 Comparison between flows generated by LSPC and the Rational Method

While the characteristics of the storm events vary considerably, the total volume of water that is simulated in each case is similar, as see in Table 3.2. The volume generated through LSPC, while typically higher than the Rational Method, is not exceptionally different.

Table 3-2 Runoff comparison between LSPC and Rational Method for an outfall sample set

	LSPC Timeseries		Rational Method	
Outfall	Max Flow (cfs)	Volume in 2003 (ft^3)	Max Flow (cfs)	Annual Volume (ft^3)
3885	2.7	226,000	17.2	185,000
3971	3.8	218,000	25.7	278,000
4475	9.6	800,000	56.3	608,000
5429	4.0	336,000	28.2	304,000
5449	0.35	28,800	6.0	64,800
5951	11.1	925,000	57.6	622,000
6646	1.3	104,000	51.1	553,000
6707	0.84	69,700	6.6	71,000
44662	8.2	680,000	53.9	582,000

The LSPC timeseries values were simulated on an hourly basis within the BSTEM model. When summarized annually, many of the outfalls no longer produce scour, while the rest produce significantly less (Table 3.3). This suggests that, although precipitation was modeled over a much longer period through LSPC, the difference in peak discharge events is the driving factor in producing sediment scour. It should be noted that wet years typically tend to generate significantly more sediment than do the long term average rainfall years. Therefore, although the 2003 water year may have represented the average sediment load, it likely underestimated the long-term load.

Table 3-3 BSTEM eroded volume comparison between LSPC and Rational Method input flows

Outfall	Reach Slope	Acres Impervious	Slope Rank	Impervious Rank	Per Year Volume Eroded (ft^3) Representative Storms (6)	Per Year Volume Eroded (ft^3) LSPC Simulated Storms (2003)
6646	0.02	2.4	Low	Low	3.5	0.0
3971	0.03	7.3	Low	Med	0.27	0.0
5951	0.03	21.1	Low	High	3.3	0.0
6707	0.15	1.6	Med	Low	24.9	0.63
3885	0.13	5.2	Med	Med	0.11	0.38
4475	0.15	18.8	Med	High	124	9.2
5449	0.34	0.7	High	Low	7.1	0.0
5429	0.51	8.2	High	Med	13.9	6.8
44662	0.37	15.5	High	High	1.4	0.24

4 SEDIMENT LOAD REDUCTION

Various BMP designs are available which can help address erosion associated with outfalls. Outfall relocation, energy dissipation, and regenerative stormwater conveyance (RSC) were selected as applicable BMPs to reduce sediment load. The first two address scouring action associated with the force of water flowing from the outfall. Relocation moves the outfall downslope to a receiving topography that is less susceptible to erosion. Reduced slope gradients near the base of the valley walls help reduce the energy in the flow thus reducing the potential for scour. Energy dissipation reduces the scouring potential through physical barriers at the current outfall location. RSC provides energy dissipation which reduces scouring and also helps treat sediment associated with stormwater runoff within an outfall catchment area located upstream. The three BMP's are considered equally applicable to all High Priority outfalls (42). In reality, each outfall should be investigated individually to determine constraints relating to environmental conditions, permitting issues, and legal challenges.

4.1 OUTFALL RELOCATION

Since most of the High Priority outfalls are located at the top of the canyon, their discharges flow down the canyon walls, causing scour. The outfall relocation method extends each outfall pipe from the top of the canyon down to the valley floor. Rather than flowing over the steeply sloped and exposed earth, the discharge will continue down the pipe, eliminating sediment erosion by dissipating the erosive force along a lower gradient channel.

To simulate the effect of outfall relocation on sediment scour, the High Priority locations were moved in GIS to the nearest location on the valley floor (Figure 4.1). BSTEM input data were then regenerated for these new locations, resulting in new reach lengths and reach slopes. BSTEM was run again for these locations, yielding new eroded volumes.

Figure 4-1 Existing outfalls (yellow) physically moved to valley floor (red).

The resulting eroded volumes in the locations on the valley floor differed considerably, but generally led to reduced volumes. Of the 42 high priority outfalls analyzed, 13 showed an *increase* in sediment erosion. This is typically due to the topography on the valley floor being more conducive to erosion, whether related to higher slopes or longer reach lengths. The remaining 29 sites showed reduced sediment erosion. If implemented, relocating these outfalls could eliminate approximately 51% of the scoured sediment load in the Los Peñasquitos watershed. Table 4.1 lists the key BSTEM input parameters that changed due to relocation, and the associated modeled loads. Figure 4.1 shows the spatial distribution of High Priority outfalls and resulting scour differences. Appendix A (Table A.2) contains a table detailing all inputs, outputs, and result analysis.

Table 4-1 Key BSTEM Input and Output Differences for 10 Sample Locations/Relocations

	BSTEM Existing Condition				**BSTEM Outfall Relocation**			
Outfall	**Reach Slope (ft/ft)**	**Reach Length (ft)**	**Elevation of Flow (ft)**	**Per Year Volume Eroded (ft^3)**	**Reach Slope (ft/ft)**	**Reach Length (ft)**	**Elevation of Flow (ft)**	**Per Year Volume Eroded (ft^3)**
4475	0.15	282	1.44	124.1	0.10	43	1.64	18.9
5429	0.51	109	0.56	13.9	0.01	91	1.80	11.6
5449	0.34	400	0.23	7.1	0.01	404	0.52	7.2
5483	0.35	287	0.33	9.9	0.01	294	0.82	10.1
5495	0.30	247	0.36	7.8	0.01	82	1.18	2.6
5511	0.12	531	0.59	20.6	0.01	410	1.38	15.9
5569	0.18	285	0.52	16.0	0.02	339	1.02	19.1
5899	0.17	189	0.72	6.0	0.02	329	1.31	10.4
5900	0.16	144	0.98	29.4	0.02	319	1.84	64.9
5932	0.35	279	0.33	9.6	0.11	66	0.46	2.3

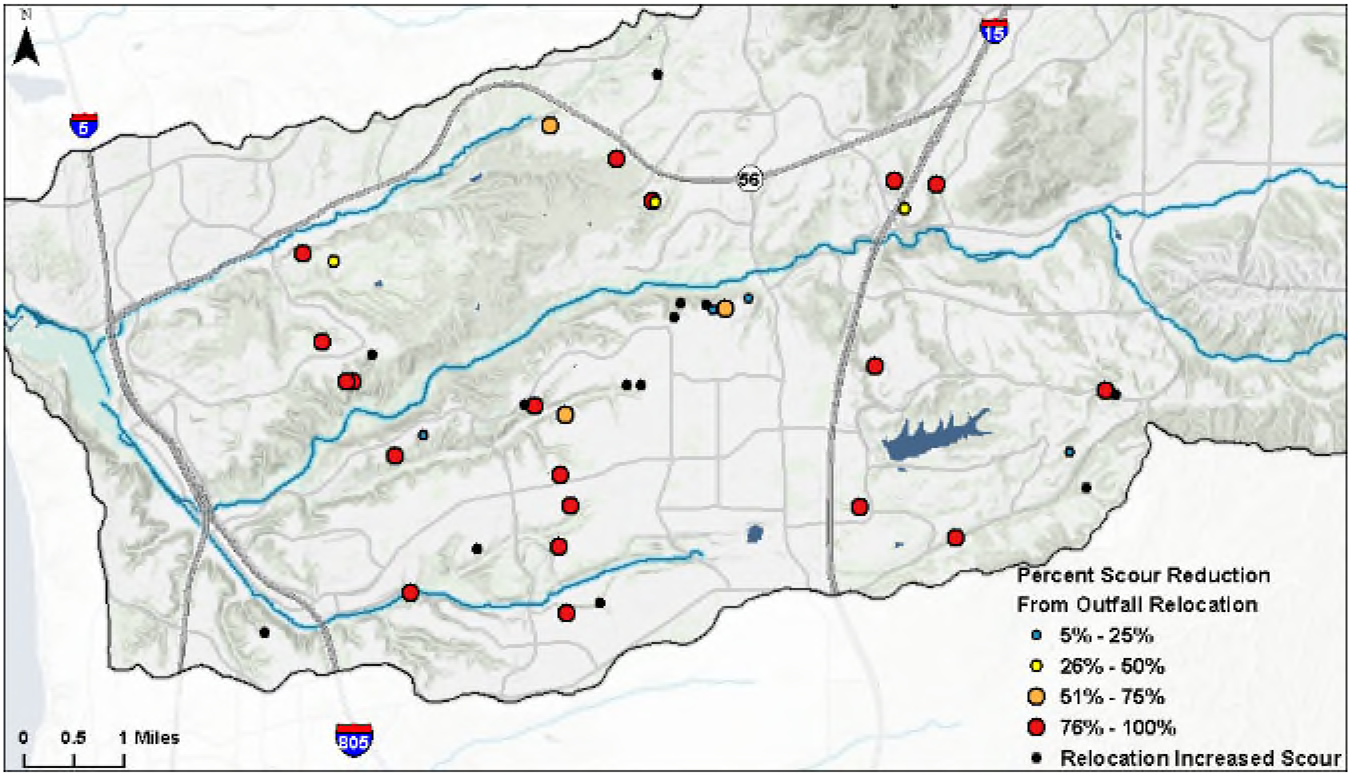


Figure 4-2 Percent Reduction in Scoured Volumes at High Priority Outfalls.

4.2 ENERGY DISSIPATION

In order to mitigate erosion downstream of the outfall, the energy of the discharge can be dissipated. Energy dissipaters (e.g. riprap) are devices designed to protect and prevent downstream areas from erosion by reducing the velocity of flow.

To classify flow conditions, the Froude number was calculated for each outlet based on the relationship between flow velocity and flow depth:

$$Fr = \frac{v}{\sqrt{gy}}$$

Based on the calculated Froude number, the flows are identified as subcritical, critical, or supercritical. Subcritical flow has a Froude number less than one (Fr < 1) and is characterized by its deep and low flow velocity. Critical flow takes place when the Froude number equals to one (Fr = 1) as the velocity of low flow is equal to the velocity of surface waves. Supercritical flow has a Froude number greater than one (Fr > 1), which are shallow and fast flows.

Because many of these High Priority outfalls are located on steep slopes with smooth concrete pipes, flow leaves the outfalls in a high velocity state of super-critical flow. Many of the hill slopes are very steep, in the order 0.1 ft/ft to 0.7 ft/ft, and as such the super-critical flow state may be maintained for a considerable length down the channel below the outfall. A cursory analysis was done to simulate dissipating the flow energy by changing the flow state from super to sub-critical. This provided a reduced potential for erosion. The analysis included an additional set of BSTEM scenarios with channel modifications designed to dissipate energy, to armor the channel bed and banks, and with increased flow depths due to the increased bed and bank friction. The modifications entailed simulating rip-rapped bed and banks in the BSTEM by changing the bank material from resistant silt to cobbles or boulders.   Because the results could be controlled by adjusting the boulder diameter, a complete table for all the outfalls is not provided. The general results are that boulders in the 12 to 24 inch range were typically required to reduce the erosion to zero without the boulders being moved themselves. A proper hydraulic engineering study needs to be completed to determine the actual size and extent of riprap needed to armor any one flowpath below an outfall.

A total of 35 of the 42 High Priority outfalls indicated the potential for super-critical flows (Appendix A, Table A.4 and Figure 4.2). Assuming that energy dissipation practices convert super-critical flows to sub-critical, and that the design eliminates erosion potential, the application of these BMPs at High Priority locations could eliminate approximately 79% of the total scoured sediment load associated with all modeled outfalls in the Los Peñasquitos watershed.

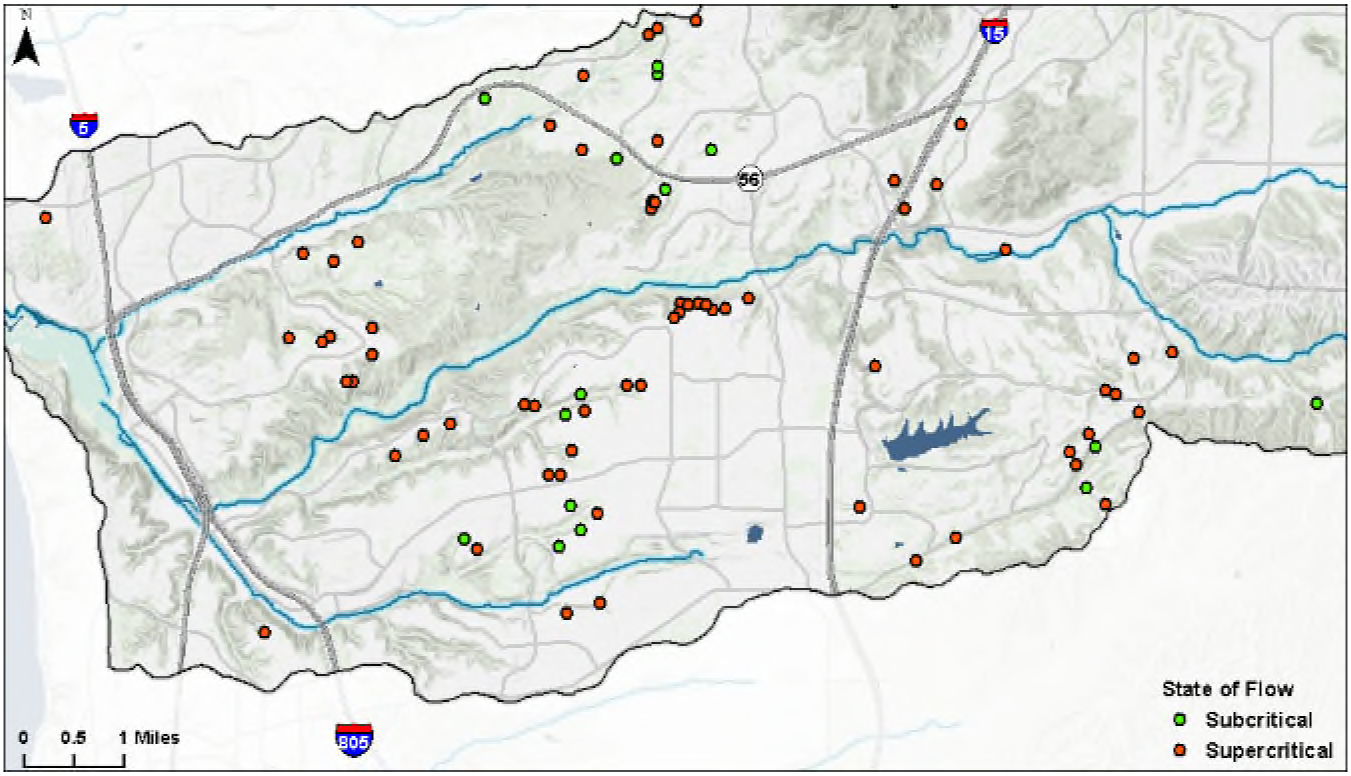


Figure 4-3 High Priority Outfalls exhibiting supercritical flows.

4.3 REGENERATIVE STORMWATER CONVEYANCE

Regenerative Stormwater Conveyance (RSC) has the ability to treat, infiltrate, and convey stormwater in a single system. These systems consists of shallow aquatic pools, native vegetation, riffle weir grade controls, and underlying sand and woodchip beds designed to capture, treat, and convey storm flow (WVDEQ). Considering the slopes of canyons, RSC stormwater practices are uniquely suited to be applied in these challenging areas.

Appropriate estimates of the effectiveness of RSC requires a characterization of the catchment source loads. Event Mean Concentration (EMC) values for Total Suspended Solids (TSS) were averaged based on values from the BMP Design Manual (Table 4.2) and the relative area of land uses within each catchment (generalized from San Diego Current Land Use (SANDAG)).

Table 4-2 TSS EMC Values

Land Use	TSS EMC, mg/L
Single Family Residential	123
Commercial	128
Industrial	125
Education (Municipal)	132
Transportation	78
Multi-family Residential	40
Roof Runoff	14
Low Traffic Areas	50
Open Space	216

The volume of water that is discharged from the individual outfalls was determined by the BSTEM model flows and the half hour duration of a storm event. Taking these volumes and the average EMC's, the mass of TSS for each outlet was calculated. Since BSTEM scoured sediment loads are volumetric, the mass was converted back to volume for comparison. The soil for this area was identified to be mostly sandy silty sediment. Based on the NAVFAC 70.1 document, the weight for this material ranges from 90-155 lb/ft^3. The median value of 122.5 was used for conversion purposes.

RSC generally reduces effluent sediment loads by 90% (WVDEQ). Since RSC practices treat both catchment sourced loads as well as scour, it is estimated that implementation at each of the 42 High Priority outfalls could eliminate approximately 2,170 ft^3 of sediment (135 tons) on an annual basis (1,170 ft^3 from scour (84% of total scoured load), and 1,000 ft^3 from catchment sources). Table 4.3 highlights the key calculations and conversions associated with several sample locations, while Figure 4.3 displays the spatial distribution of all individual practices.

Table 4-3 Key Calculations and Load Reduction associated with RSC for 10 Sample Locations

Site ID	TSS (mg/L)	Volume of Water (ft^3)	Sediment Mass (lb)	Volume of Sediment (ft^3)	Annual Volume of Sediment (ft^3/yr)	Catchment & Scour based Volume (ft^3)	RSC Load Reduction (ft^3)
4475	125	101,000	792	6.5	38.8	162.9	146.6
5429	127	50,700	402	3.3	19.7	33.5	30.2
5449	137	10,800	92.5	0.8	4.5	11.6	10.5
5483	113	12,200	86.3	0.7	4.2	14.1	12.7
5495	113	14,700	104	0.8	5.1	12.9	11.6
5511	111	19,800	138	1.1	6.7	27.3	24.6
5569	122	19,100	146	1.2	7.2	23.2	20.9
5899	105	115,700	760	6.2	37.2	43.2	38.9
5900	120	50,700	378	3.1	18.5	47.9	43.1
5932	113	16,400	115	0.9	5.6	15.2	13.7

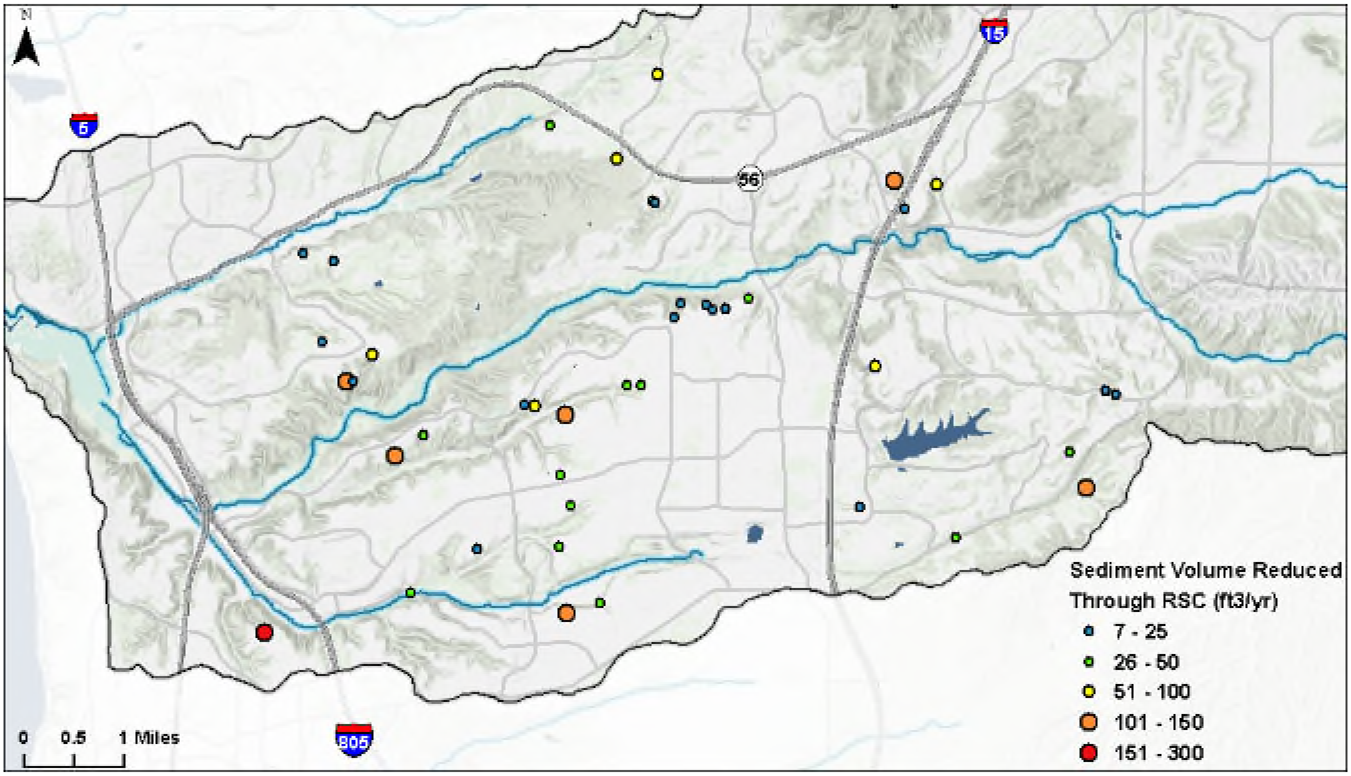


Figure 4-4 RSC associated Sediment Volume Reductions at High Priority Outfalls.

4.4 LOAD REDUCTION ENHANCEMENTS

The energy dissipation and RSC BMPs have been greatly simplified to provide an estimation of benefits. There exists potential to refine and enhance these estimations in the future.

Energy dissipation was assumed to drop loads to 0 with sufficient design. However, this may not be realistic, and there may be storm events during which these BMPs do not treat the entire flow. Threshold values could be determined, above which the BMP no longer effectively treats the discharge. The quantity of flow above the threshold could then be input into BSTEM, and the resulting scoured load considered untreated.

RSC effectiveness was determined by literature values. However, this BMP could be simulated within SUSTAIN using relevant and applicable design parameters. This would calculate an effectiveness at treating incoming sediment load, and also output a new downstream flow value, which could then be rerun in BSTEM, and an associated scoured load generated.

5 RANKING

Outfalls were ranked to provide a better understanding of the individual locations where BMP practices could be most effective. These rankings were based upon the BSTEM reduction estimates, as well as the condition of outfalls according to the Phase IV assessment. The ranking scheme consisted of attributing values of 1 where BMP practices were most effective, and a value of 0 where not. The initial prioritization provided the first cut, followed by the three reduction scenarios, and finally the condition assessment. This ensures that outfalls with the largest associated load reductions and need for repair/replacement are highly ranked. The spreadsheet-based conditional logic is as follows:

- If outfall is High Priority (>= 5 ft^3/yr of scour), score equals 1, otherwise score equals 0 (and is dropped from remaining steps)
- If outfall is within the top 50% in terms of volume reduced via relocation (where positive reduction occurs), score equals 1, otherwise score equals 0
- If outfall experiences supercritical flows, and is within the top 50% of associated volumes reduced via energy dissipation, score equals 1, otherwise score equals 0
- If outfall is within the top 50% in terms of volume reduced via RSC, score equals 1, otherwise score equals 0.
- If outfall scored highly (4 or 5) for either Repair *or* Replacement according to the field assessment, score equals 1, otherwise score equals 0

This results in a ranking between 0 and 5 for all 102 modeled outfalls. Table 5.1 presents a summary of 10 sample locations,Table 5.2 presents the distribution of outfalls amongst the ranking categories, and Figure 5.1 presents the spatial distribution of all ranked outfalls. Appendix A (Table A.4) contains the full table for all outfalls.

Table 5-1 Summary of ranking scores for 10 Sample Locations

Outfall	Eroded Volume (ft^3/yr)	Priority	Relocation Reduction (ft^3)	Flow State	Dissipation Reduction (ft^3)	RSC Reduction (ft^3)	Repair Score	Replace Score	Priority Score	Relocation Score	Dissipation Score	RSC Score	Repair/Replace Score	Ranking
2952	2.5	Low	N/A	Super	2.5	20.1	1	2	0	0	0	0	0	0
3885	0.11	Low	N/A	Super	0.11	9.5	2	3	0	0	0	0	0	0
3971	0.27	Low	N/A	Sub	N/A	14.8	1	2	0	0	0	0	0	0
4475	124	High	105	Super	124	146.6	3	4	1	1	1	1	1	5
4756	4.5	Low	N/A	Super	4.5	10.9	2	3	0	0	0	0	0	0
5429	13.9	High	2.2	Super	13.9	30.2	1	2	1	0	0	0	0	1
5449	7.1	High	-0.07	Super	7.1	10.5	3	4	1	0	0	0	1	2
5475	3.2	Low	N/A	Super	3.2	4.4	2	3	0	0	0	0	0	0
5481	3.4	Low	N/A	Super	3.4	6.7	1	1	0	0	0	0	0	0
5483	9.9	High	-0.24	Super	9.9	12.7	1	2	1	0	0	0	0	1

Table 5-2 Distribution of outfalls in rank classes

Rank	Number of Outfalls
0	60
1	11
2	11
3	12
4	5
5	3

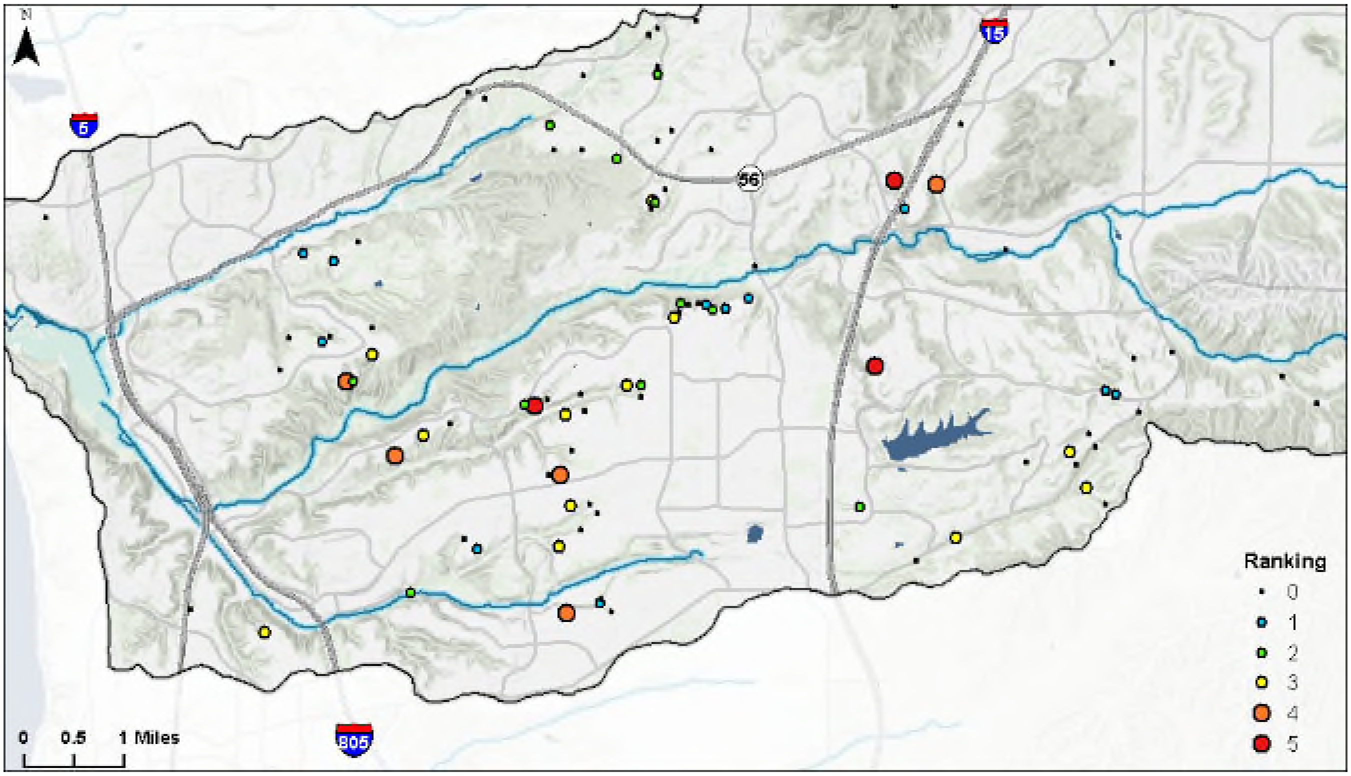


Figure 5-1 Ranking Scores for all Modeled Outfalls

6 SUMMARY AND CONCLUSION

Based upon the 102 outfalls assessed in this study, it is estimated that a total of 1,400 ft^3 (approximately 85 tons) of sediment is displaced annually due to scour. These values necessarily underestimate the total volumes, as a total of 468 outfalls and outfall-associated structures were identified during the Phase IV outfall assessment. However, it should be noted that the non-modeled outfalls were located near valley floors and were not qualified as erosion problems. Thus, they were not likely major contributors to sediment loading in the watershed.

If BMP practices aimed at reducing erosion are installed for the 42 High Priority outfalls within the watershed, significant reductions of total scoured sediment load could be expected (Table 6.1).

Table 6-1 Summary of Annual Sediment Load and Potential for Reduction.

Category	High Priority Outfalls (42)		All Modeled Outfalls (102)	
	ft^3 / year	tons/year	ft^3 / year	tons/year
Total Scoured Sediment	1,300	80	1,400	85
Relocation Reduction	700	43	700	43
Percent of Total Scour	*54%*		*50%*	
Dissipation Reduction	1,100	68	1,100	68
Percent of Total Scour	*85%*		*79%*	
RSC Scour Reduction	1,170	72	1,170	72
Percent of Total Scour	*90%*		*84%*	
RSC Catchment Reduction	1,000	63	1,000	63

According to the model results developed for the WQIP, the Los Peñasquitos watershed receives an average annual loading of 6,000 tons of sediment per year. The results of the BSTEM analysis suggest that 85 tons per year are associated with scoured sediment from all modeled outfalls (102), or approximately 1.4 % of the total load. The sensitivity analyses suggest that this can vary significantly, from a negligible amount based upon LSPC timeseries developed loads, to nearly 240 tons (4%) based on soil parameter modifications. It should be noted that the estimation of reduction percentages would remain relatively constant across this range, from 50% to 84% of the total scoured sediment load.

While erosion processes are well understood, part of this understanding includes the highly variable nature of erosion itself and the difficulties in accurately modeling or even empirically measuring erosion and sediment loads. Therefore the results of this analysis should be considered as a screening tool for predicting which outfalls are likely the dominant producers of sediment. The Phase IV outfall assessment provided cursory descriptions of the outfalls and the channels immediately downstream. These descriptions were useful in forming an analysis plan to determine which outfalls are most likely impacted by erosion and may be the large sediment producers. The BSTEM analysis has helped refine the list of outfalls to a group of outfalls of interest and provide a relative impact. This group should be inspected in greater detail in the field to verify the channel conditions further downslope from the outfalls to help determine if the BSTEM results are reasonable.

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