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# MORRO BAY SEDIMENT LOADING UPDATE

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COMPILED BY THE MORRO BAY NATIONAL ESTUARY PROGRAM  
DECEMBER, 2011

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## ACKNOWLEDGEMENTS

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The Morro Bay National Estuary Program would like to recognize and thank the following staff members, contributors, partners, and volunteers who contributed to this report:

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Annie Gillespie, Morro Bay National Estuary Program  
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Elizabeth Watson, United States Environmental Protection Agency  
John Callaway, University of San Francisco

*For their partnership and technical assistance in this effort:*

Debra Stakes, Physical Sciences, Cuesta College  
Kathy Jimison, Physical Sciences, Cuesta College

Sylas Cranor, San Luis Obispo County Flood Control and Water Conservation District  
Kim Hubbs, San Luis Obispo County Flood Control and Water Conservation District

Russ White, Department of Natural Resources, California Polytechnic State University  
Adrienne Greve, Department of City and Regional Planning, California Polytechnic State University  
Charles Burt, Irrigation Training and Research Center, California Polytechnic State University

Mark Barnett, Natural Resources Conservation Service

Ann Kitajima, Morro Bay National Estuary Program  
Anna Halligan, Morro Bay National Estuary Program

*And for their tireless, good-humored help in the field and the lab:*

Craig Jacobson  
Mike Weddige  
Kelly Church  
Alexander Remar  
Jacob Smith  
Dylan Theobald  
Erich Kast

## EXECUTIVE SUMMARY

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In 1998, Chorro Creek, Los Osos Creek and the Morro Bay estuary were determined to be impaired by accelerated sedimentation. Through Section 303(d) of the Clean Water Act, a Total Maximum Daily Load (TMDL) was developed by the Central Coast Regional Water Quality Control Board (Water Board) and was formally adopted in 2003. The Morro Bay National Estuary Program (Estuary Program) has been a lead partner in monitoring and implementation efforts to reduce erosion in the watershed and prevent excessive sedimentation of Morro Bay. The Morro Bay Sediment Loading Study, completed by Tetra Tech in 1998, has served as the framework for the TMDL and the resulting implementation and monitoring efforts of the Estuary Program. The Tetra Tech report estimated that the Morro Bay watershed delivers an average of approximately 70,000 tons per year of sediment into the Morro Bay estuary and that the Chorro Creek sub-watershed contributes 86 percent of the total sediment delivered to Morro Bay, approximately 60,689 tons. Since the approval of the TMDL, numerous monitoring efforts have better characterized sediment transport dynamics, accumulation rates, and impairment severities throughout the watershed and estuary. As the majority of the sediment load is attributed to storm event loads from the Chorro Creek subwatershed, implementation and monitoring efforts have been focused predominately in that subwatershed.

Ambient (dry weather or baseflow) water quality conditions throughout the Los Osos and Chorro subwatersheds indicate only rare exceedances of turbidity thresholds of concern. A large dataset spanning 2002-2011 strengthens the assertion that the majority of sediment transport, and elevated turbidity, occurs during storms and large runoff events, and that ambient water quality conditions do not reflect chronic impairment by sediment.

A suite of new criteria have recently been developed for determining physical sediment impairment of Central Coast streams. Five physical streambed indicators were compared against data collected from ten monitoring sites in the Morro Bay watershed in spring 2011. The data indicate only moderate impairment at eight sites and no impairment at two sites. The criteria for severe impairment was only met for a single indicator at one site.

In 2004, surface elevation tables (SETs) were installed throughout the Morro Bay salt marsh and mudflats to measure sediment accretion rates. Subsequent monitoring since 2004 indicates that accretion rates in the salt marsh ranged from 0.3 to 4.4 mm/year while accretion in the mudflats ranged from 2 to 18 mm/year. On a regional scale, the recent accretion rates are considered to be near the low end of the range and have not indicated large-scale rapid filling of mudflats or unusually rapid sediment deposition in Morro Bay wetlands.

In 2007, the Estuary Program incorporated additional storm event monitoring to quantify suspended sediment loads at three stations in the Chorro Creek watershed. Through the use of stage gauges and automated samplers, sediment loads were quantified for the Chorro Creek watershed over a three-year period. Hydrologic conditions during the three year period were highly variable from year to year, and a range of conditions was measured. Accordingly, annual sediment load estimates range from under 2,000 short tons during the 2008-09 water year (characterized by below average rainfall) to over 140,000 short tons during the 2010-11 water year (characterized by above average rainfall). Annual discharge volume and estimated sediment loads are shown in Table 1.

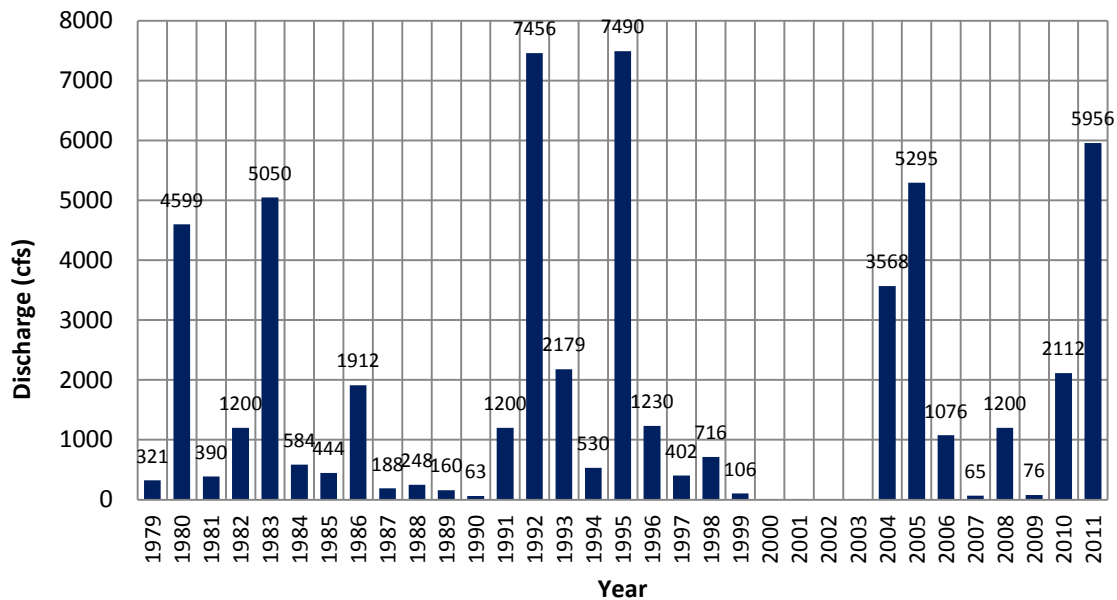
TABLE 1: CHORRO CREEK DISCHARGE VOLUME, SEDIMENT LOAD

Water Year	2008-2009	2009-2010	2010-2011†
Chorro Creek Annual Discharge (acre-feet/year)	20,220	29,796	38,357
Chorro Creek Sediment Load, Short Tons	146	8,604	136,043

†Partial water year, Oct.1, 2010 - Jun.8, 2011 with sediment load outlier excluded.

Examination of peak flow records from the Canet Road gauge on Chorro Creek indicates that significant resolution may be lost by averaging annual sediment loads across several years. Review of approximately 29 years of peak flow data (Figure 1) indicates tremendous inter-annual variability in peak flows at the gauging station, with a range of approximately 7,427 cubic feet/second (cfs). As models indicate that flow volume and suspended sediment concentration are strongly correlated, it can be inferred that sediment loading is similarly variable from year to year.

FIGURE 1: CHORRO CREEK, CANET ROAD, PEAK FLOW RECORDS†



†Data not available from 2000 through 2003 due to reconstruction of the crossing and gauge.

The relatively short time period and highly variable hydrologic record associated with the most recent sediment loading data (2007-2010) are important to consider in assessing progress towards achievement of the sediment TMDL. Suspended sediment loading data from Chorro Creek indicates tremendous variability in annual loads, owing largely to a high degree of variability in peak flows and the duration of elevated discharge from storm events.

While physical indicators of sedimentation do not currently indicate severe biological impairment across the watershed and estuary, further data collection is necessary to capture the potential for variability across a range of hydrologic conditions.

# INTRODUCTION

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## MORRO BAY WATERSHED

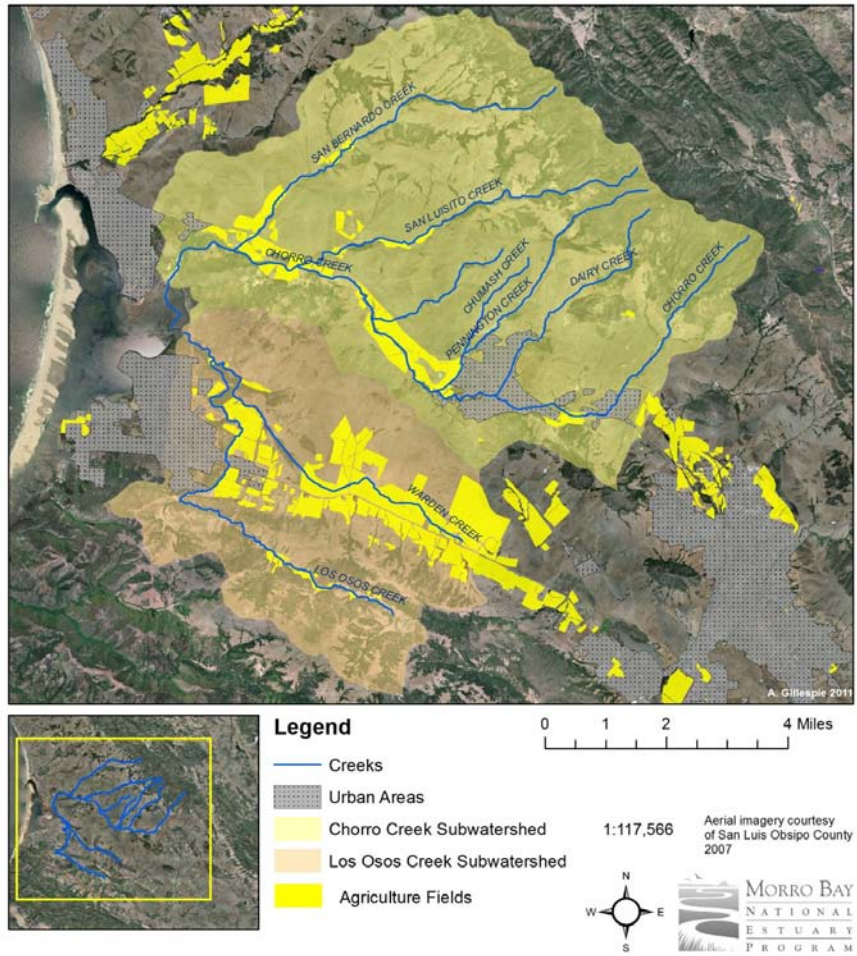
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The Morro Bay watershed is located in San Luis Obispo County on California's central coast and encompasses a drainage area of approximately 75 square miles. The inland watershed drains west to the Morro Bay estuary and Pacific Ocean via two primary creeks: Chorro Creek and Los Osos Creek.

The Chorro Creek subwatershed encompasses a drainage area of 43.4 square miles. Land use in the subwatershed is primarily agricultural, with much of the area used as rangeland for beef cattle operations. Notable urban areas include the City of Morro Bay, Cuesta College, the California Men's Colony prison complex, and military infrastructure at Camp San Luis Obispo. Chorro Creek receives drainage from numerous tributary drainages: Dairy Creek, Pennington Creek, Walters Creek, San Luisito Creek and San Bernardo Creek.

The Los Osos Creek subwatershed encompasses a drainage area of 23.1 square miles. Land use in the subwatershed is primarily agricultural and residential. In contrast to the Chorro Creek subwatershed, agriculture in the Los Osos subwatershed is characterized by plowed rotational fields generating a variety of forage and truck crops. Much of the intensive farming operations occur in the Warden Creek drainage area. Figure 2 demonstrates the distribution of urban areas and plowed agricultural fields within the two subwatershed areas.

FIGURE 2: MAP OF MORRO BAY WATERSHED

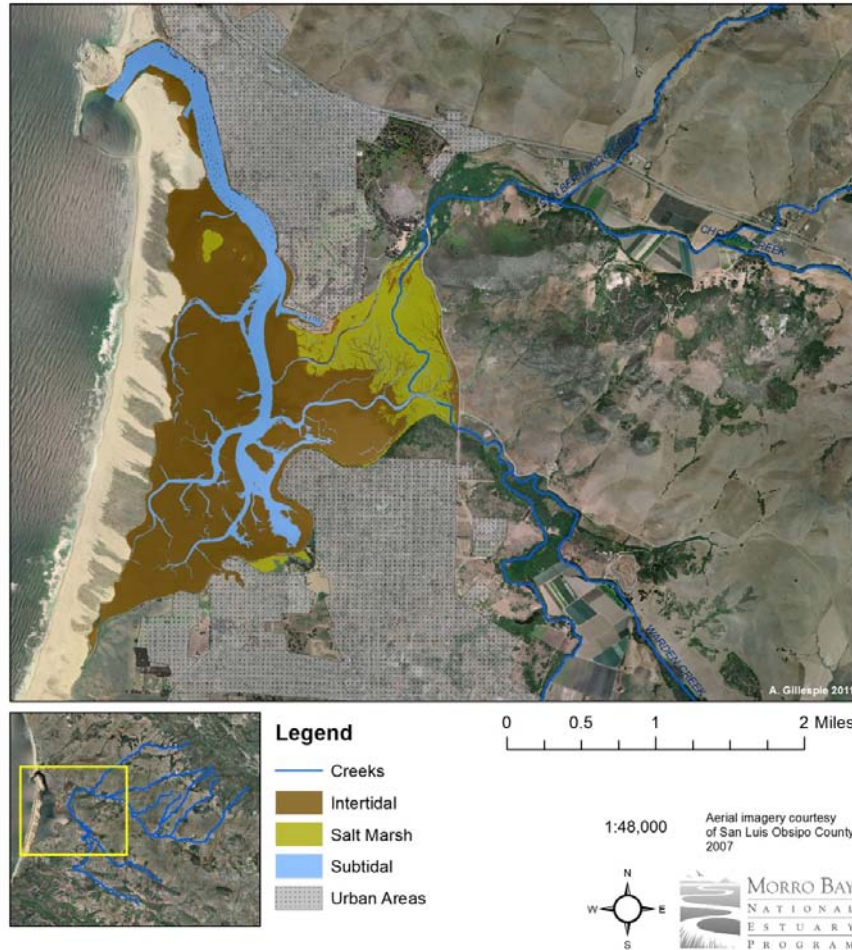




## MORRO BAY ESTUARY

The Morro Bay estuary is comprised of approximately 2,300 acres of shallow, semi-enclosed intertidal and sub-tidal habitat. The estuary is bordered to the west by a four-mile vegetated natural sandspit that separates Morro Bay from the Pacific Ocean (Figure 3).

FIGURE 3: MAP OF MORRO BAY ESTUARY HABITAT TYPES AND URBAN AREAS



Habitats and beneficial uses within the estuary are protected through numerous regulatory frameworks. Morro Bay was established as California's first State Estuary in 1994 and was accepted into the National Estuary Program in 1995. Today, Morro Bay is one of the Environmental Protection Agency's 28 recognized National Estuaries. In 2007, the Morro Bay Estuary was incorporated into the California Department of Fish and Game's Marine Protected Areas. Through the Marine Protected Area designations, the intertidal and subtidal habitats within Morro Bay are protected as either a State Marine Recreational Management Area or a State Marine Reserve. All of these frameworks serve to protect important habitat for marine and migratory species.

The Morro Bay estuary currently supports the third largest remaining *Zostera marina* (eelgrass) beds remaining in Southern California (Bernstein, et. al. 2011). Eelgrass beds are an important component of coastal habitat and provide diverse benefits to coastal marine and migratory species as well as substantial benefit in the form of ecosystem services. Historic monitoring of eelgrass

extent indicates that intertidal eelgrass beds may have spanned up to 500 acres in Morro Bay during the 1970s. Eelgrass meadows are known to be highly sensitive to water clarity degradation.

Morro Bay is a popular destination for outdoor recreation and also an important center for commercial fishing and aquaculture operations. Recreational uses in the bay include kayaking, sailing, fishing, wildlife observing and waterfowl hunting. Many of these uses are noted and protected as designated "Beneficial Uses" within the Central Coast Regional Basin Plan administered by the Central Coast Regional Water Quality Control Board (Water Board).

Maintenance of the harbor as a port for fishing and recreational vessels requires frequent dredging operations. The harbor entrance is dredged annually by the Army Corps of Engineers to maintain a channel depth of approximately +40 feet MLLW. During 2008 and 2009, the Corps' Yaquina hopper dredge removed 140,798 cubic yards (CY) and 151,067 CY of material (respectively) from the entrance channel and main channel. Dredge spoils from this annual maintenance were deposited at a designated near shore placement site. In 2009, additional dredging of the mid-channel was made possible by an American Recovery and Reinvestment Act award. Dredging operations excavated a total 573,969 CY of material from the main navigation channel in two phases. The project was completed in September 8, 2010 (Kirk C. Brus, personal communication, June 29, 2011).

#### MORRO BAY SEDIMENT TOTAL MAXIMUM DAILY LOAD (TMDL)

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The Water Board adopted the Central Coast Basin Plan (Basin Plan) on March 14, 1975. The Basin Plan included a broad array of water quality objectives, beneficial use designations, discharger implementation plans, and statewide plans and policies. Section 303(d) of the Clean Water Act requires that States create a list of water bodies that do not meet water quality objectives and establish load and waste load allocations. Total Maximum Daily Load (TMDL) documents detail the impairment of the listed water bodies and are incorporated into the Basin Plan upon approval. In California, this action is the responsibility of the Regional Water Quality Control Boards.

In 1998, the Water Board identified Chorro Creek, Los Osos Creek and the Morro Bay Estuary as impaired by sediment and listed the water bodies under Clean Water Act Section 303(d). The TMDL identified accelerated sedimentation due to anthropogenic disturbance as the primary cause for listing. TMDL documentation cited the 1998 Tetra Tech report which estimated that the Chorro and Los Osos Creeks sub-watersheds deliver an average of approximately 70,000 tons per year of sediment into the Morro Bay estuary. The report indicated that the Chorro Creek watershed was estimated to contribute 86 percent of the total sediment delivered to Morro Bay, approximately 60,689 tons.

*The Morro Bay Total Maximum Daily Load for Sediment (including Chorro Creek, Los Osos Creek and the Morro Bay Estuary)* was formally adopted by the Environmental Protection Agency on December 3, 2003. The TMDL calls for a 50% reduction in the annual loading to Morro Bay. Sediment loads less than 34,885 tons per year would comply with the TMDL targets. This TMDL would be achieved by an average reduction of 607 tons/year over a 50 year time schedule, for compliance by 2052.

The TMDL identifies four physical monitoring targets for the streams in the Morro Bay watershed and calls for bathymetric surveys to determine changes in tidal prism volume of Morro Bay.

## SEDIMENT RETENTION AND EROSION PREVENTION PROJECTS

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Numerous projects have been undertaken throughout the Morro Bay watershed to prevent further sediment erosion and maximize sediment capture and retention within the watershed. The Estuary Program has worked with many local partners to implement projects towards the progress of the TMDL goals.

The Coastal San Luis Resource Conservation District (RCD) implemented a broad array of agricultural best management practices throughout the Morro Bay watershed from 2001 to 2008. Work completed as part of “Project Clearwater” included several projects that targeted erosion and sediment loading. Efforts included road drainage improvements, stream bank stabilization and stream crossing improvements. It is estimated that the work completed through Project Clearwater reduced sedimentation by approximately 9,041 tons (CSLRCD, 2010).

The RCD also implemented the Chorro Flats Enhancement Project in 1997, a floodplain restoration project intended to capture sediment from the Chorro Creek watershed. The project was designed to capture approximately 610,000 cubic yards of sediment over a 61 year timeframe. Unusual reoccurrence of large hydrologic events during the 1990’s resulted in unusually large sediment loads reaching the site. By 2001, it was estimated that only 412,000 cubic yards of potential storage area remained (CSLRCD, 2002). Since 2001 there has been limited work to quantify storage capacity or sediment trapping efficiency at the site. Recent LIDAR surface elevation data may provide the means to assess current topography and future storage potential of the site.

The Estuary Program has worked with public and private landowners to install thousands of feet of riparian fencing within rangeland area of the Chorro Creek watershed. The installation of fences in riparian areas can yield up to a 66% reduction in sediment load from stream banks and riparian areas (Morro Bay Sediment TMDL). Fencing installations have resulted in the protection of large corridors of Dairy Creek, Walters Creek, Pennington Creek and San Luisito Creek. Riparian fencing projects are ongoing throughout the watershed.

In addition to riparian fencing work, a suite of restoration efforts and BMPs have been installed throughout the Walters Creek watershed. The Walters watershed served as the ‘control’ site in the National Monitoring Program (NMP) paired watershed study during the 1990s. Following the completion of the NMP in 2001, substantial in-stream restoration work was undertaken. Changes were also made to the grazing regime and ranch road management practices in the watershed. The effects of this work are discussed later in this report.

BMP implementation and restoration projects to prevent erosion and increase floodplain sediment retention remain a high priority for the Estuary Program and its partners. Following a comprehensive assessment and prioritization, numerous road repair projects have taken place on public and private lands throughout the Chorro Creek watershed. In 2003 The Estuary Program partnered with the Trust for Public Lands and others to purchase property on Chorro Creek to restore floodplain areas. The Estuary Program continues to work with public and private landowners to identify properties that could be converted back to active floodplain.

## MORRO BAY SEDIMENT TMDL DATA SOURCES

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A variety of data sources are available for measuring the transport and effects of sediment in the Morro Bay watershed and estuary. Since the adoption of the TMDL in 2003 numerous monitoring efforts have been undertaken to quantify sediment transport and delivery to Morro Bay. The Estuary Program has taken a lead role in coordinating monitoring efforts.

The Estuary Program's Volunteer Monitoring Program has collected water quality data at numerous tributary creek sites throughout the watershed since 2002. These data are valuable in characterizing flow regimes and the ambient water quality condition. A subset of this data is included in this report to characterize ambient turbidity and discharge conditions throughout the watershed.

In 2007, the Estuary Program launched an expanded monitoring effort to generate detailed measurements of suspended sediment and turbidity in the Chorro Creek watershed at three sites over a three-year period. The expanded monitoring generated a new dataset of suspended sediment concentration (SSC) data using updated United States Geological Survey (USGS) approved laboratory methods. Turbidity was measured in the laboratory on a subset of samples that were also analyzed for SSC. This project built on total suspended solids (TSS) data collected during the NMP paired watershed study during the 1990s and early 2000s. Data from two sites (Chorro Creek at Canet Road and Walters Creek Flume) is summarized in this report. Data from the San Luisito Creek station was not analyzed for this report. The station continues to function in order to quantify loads from the San Luisito subwatershed. However, data analysis was prioritized to address BMP effectiveness at Walters Creek and cumulative loads from the Chorro Creek watershed. Data from the Chorro Creek Canet Road site was scaled up using a location specific equation, which negated the use of San Luisito Creek loading data for determining cumulative loads.

Since 2008, the Estuary Program has conducted Surface Water Ambient Monitoring Program (SWAMP) Bioassessment annually at a variety of creek monitoring sites throughout the watershed. The data collected during these surveys generates metrics for several physical and biological characteristics of the survey reach. In 2011, staff at the Water Board issued a draft table of indicators for determining sediment impairment. These indicators were developed as a means of assessing sediment impairment in the San Lorenzo river watershed. These criteria are being tested for applicability as a region-wide set of indicators. Several of the proposed indicators can be evaluated with data collected during bioassessment surveys. Within this report, the physical habitat data collected during spring 2011 surveys is compared with proposed sediment indicator criteria.

In addition to monitoring sediment transport rates and depositional trends in the watershed, the Estuary Program coordinates monitoring of sediment deposition in Morro Bay with staff from the University of San Francisco. In 2004, numerous sampling stations were established in the Morro Bay mudflats and salt marsh to measure sedimentation rates and establish baseline elevations. The stations are monitored through two approaches: marker horizons to measure rates of sediment accretion and Surface Elevation Tables (SETs) for measurement of changes in sediment elevation.

## ESTUARY PROGRAM AMBIENT WATER QUALITY DATA

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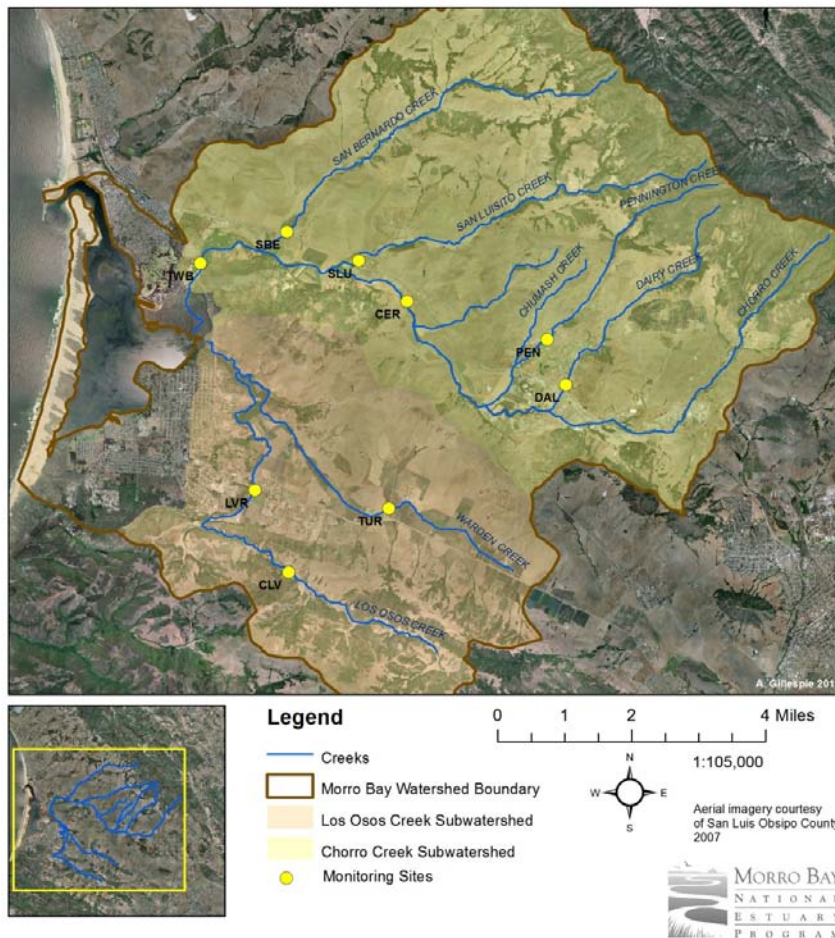
The Estuary Program collects monthly water quality data from up to 18 creek sites throughout the watershed. Data is collected by trained volunteers in compliance with the program's rigorous

Quality Assurance Project Plan. Due to safety issues and monitoring constraints, data is collected only during base flow conditions when streams are wadeable. Volunteers measure a variety of water quality parameters including nephelometric turbidity and instantaneous flow volume. While this data is important for understanding long term ambient trends across the watershed, it does not capture data during major winter storm events.

Water quality monitoring visits take place at each site once or twice monthly, depending on volunteer availability and site hydrology. Turbidity is measured in the field using a HACH 2100P field meter, which makes use of the nephelometric method of measurement. The meter has a range of 0 to 1,000 nephelometric turbidity units (NTU) and a resolution of 0.01 NTU. Instantaneous flow volumes are calculated by applying the velocity-area method to measurements collected by volunteers in the field. Depth and segment width measurements are obtained using a top-setting rod and standard measuring tape. Velocity measurements are obtained with a Marsh-McBirney Flo-Mate 2000 that reports 30-second fixed point average velocity measurements. Volunteers typically record six or more depth and velocity readings to generate volume estimates. The Flo-Mate 2000 meter has a range of measurement up to 20 feet per second.

Figure 4 demonstrates a subset of ambient water quality monitoring sites located throughout the watershed. The sites shown are either perennial or semi-perennial and have long running datasets.

FIGURE 4: MAP OF ESTUARY PROGRAM AMBIENT VOLUNTEER MONITORING SITES

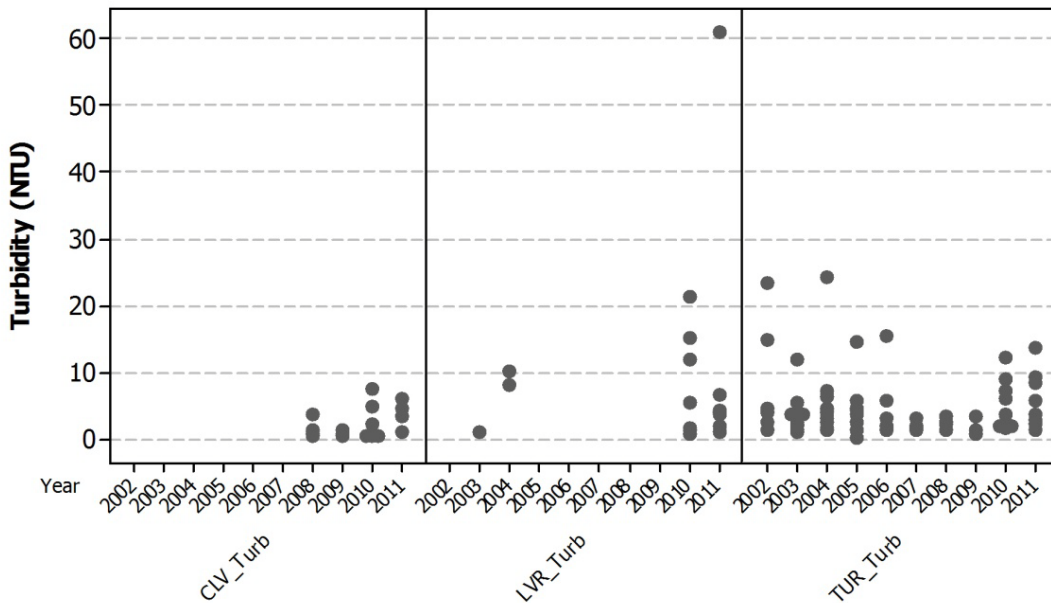




The Los Osos Creek subwatershed is believed to contribute only 14% of the sediment load to Morro Bay. Due to private property and hydrology limitations, the dataset for this watershed is limited. Estuary Program volunteers have monitored at three sites in the subwatershed (site codes CLV, LVR and TUR) for several years.

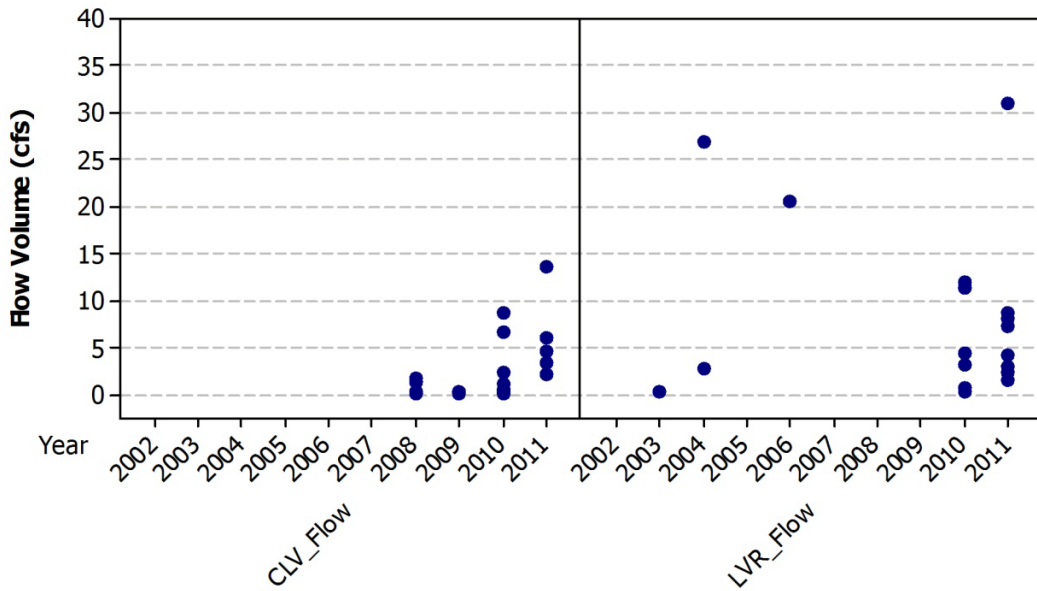
Nephelometric turbidity data for the three sites in the Los Osos subwatershed are summarized in the individual values plot shown in Figure 5 below. Generally, nephelometric turbidity remains below 10 NTU, with a few exceptions usually occurring during winter storms.

FIGURE 5: LOS OSOS AND WARDEN CREEK AMBIENT TURBIDITY DATA



Flow volume data has been collected periodically at two sites on Los Osos Creek. Both sites have semi-perennial flow regimes and dry up during the summer months most years. The LVR station is part of the San Luis Obispo County Flood Control and Water Conservation District's (the District) monitoring network. The site is equipped with a stage height recorder that logs data on a 15-minute interval. Individual values for flow measurements for sites CLV and LVR are shown in Figure 6.

FIGURE 6: FLOW VOLUME MEASUREMENTS, LOS OSOS CREEK



Currently, there is extremely limited discharge data available from Warden Creek. The TUR monitoring site on Warden Creek has been identified by the District as a high priority site for inclusion in the stage height monitoring network due to recurring flood issues downstream. The Estuary Program is conducting expanded monitoring at new sites on Warden Creek in support of the RCD’s Morro Bay Agricultural Water Quality Enhancement Program.

The Estuary Program conducts monitoring at several sites in the Chorro Creek watershed. The data shown here is from a subset of those monitoring sites. Additional information on ambient water quality data can be found in the program’s 2011 Data Summary Report.

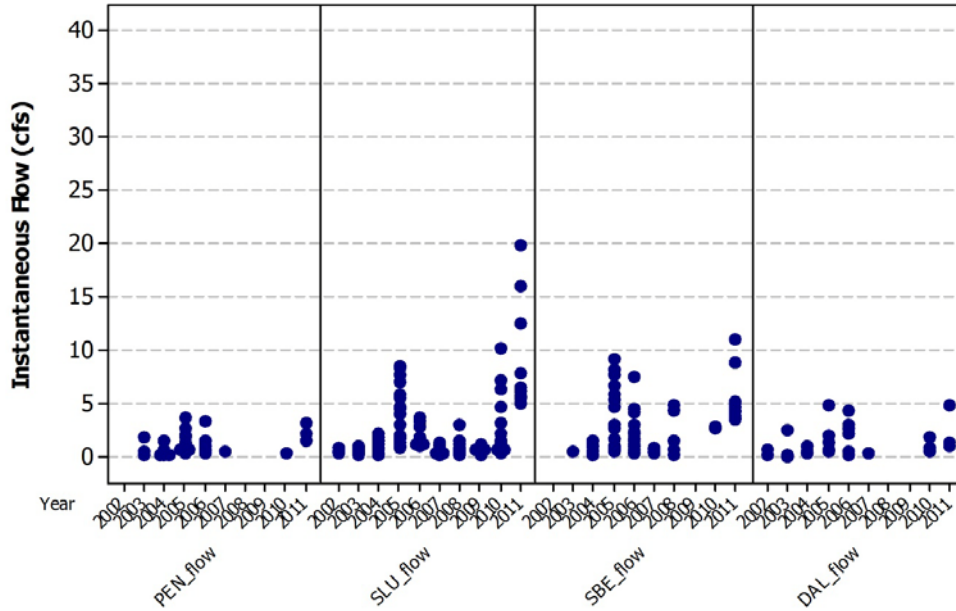
Nephelometric turbidity data from 2002 to 2011 is shown for sites in the Chorro Creek subwatershed in the individual values plot shown in Figure 7 below. Generally, nephelometric turbidity remains below 25 NTU with a few exceptions usually occurring during or following winter storms.





The data shown in Figure 9 summarize flow values collected from tributaries to Chorro Creek. Many of these tributaries are semi-perennial, which prevents data collection during the summer months of most years.

FIGURE 9: FLOW VOLUME MEASUREMENTS, CHORRO TRIBUTARIES



The approved TMDL document does not specify numeric targets for nephelometric turbidity in streams. The ambient monitoring data indicates that turbidity levels remain below thresholds of concern during most monitoring visits. The CCRWQCB Basin Plan has a turbidity water quality objective of > 25 NTU for cold water. It is important to note that this turbidity data is typically collected during monthly or twice-monthly “fair- weather” visits and is not targeted to collect data during storm events or elevated flow conditions.

### ESTUARY PROGRAM SUSPENDED SEDIMENT LOADING DATA

In 2007, the Estuary Program launched an expanded monitoring effort to generate high frequency measurements of SSC and turbidity in the Chorro Creek watershed at three monitoring sites. The expanded monitoring generated a new dataset of SSC data following updated USGS-approved laboratory methods. Turbidity was measured in the laboratory on a subset of samples analyzed for SSC.

Event SSC monitoring required the deployment of automated sampling equipment programmed to collect water samples on an evenly-timed interval during storm events. The Estuary Program utilized automated samplers with a 24-bottle configuration at each monitoring site. All samples were drawn from a fixed intake location. Intake locations varied by site due to unique site characteristics. Due to budget and equipment constraints, equal width increment sampling and depth distributed sampling were not feasible. Whether the fixed intake locations are truly representative of conditions across the stream width and depth has not been verified.

Samplers were programmed manually by staff members and sampling regimes varied by storm event and among field sites due to unique site conditions. In most cases, samples were collected at either 30 or 60-minute intervals. Samples were retrieved from the field and processed at the Estuary Program's lab facility which is located at Cuesta College.

Lab analysis for SSC is conducted according to ASTM method 3977 D. This method calls for the analysis of the entire sample rather than an aliquot of a specified volume as allowed for total suspended solids (TSS). USGS conducted extensive studies comparing the differences between TSS and SSC laboratory methods and found that the TSS methodology consistently under-sampled the sediment concentration in surface waters (Gray, Glysson, Conge, 2000). The results from the two methods can differ significantly when the sample is comprised of a significant fraction of sand-sized particles.

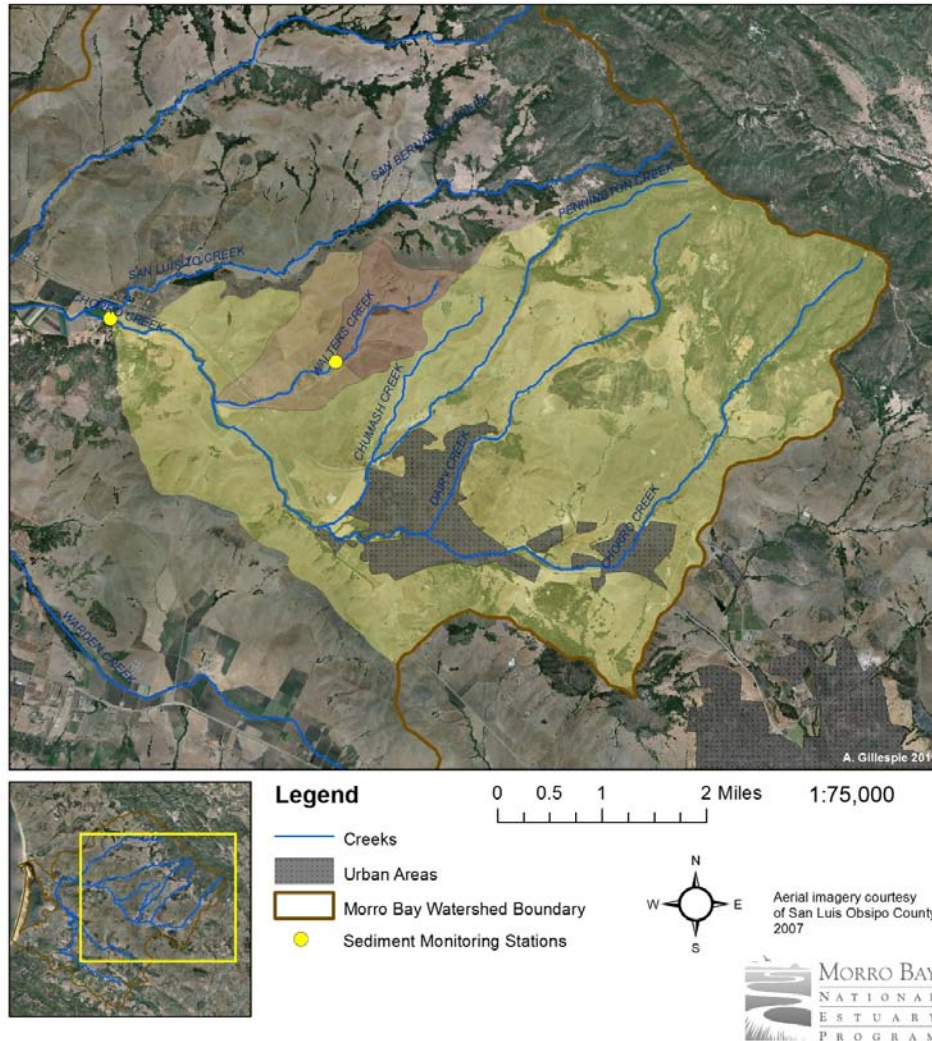
Turbidity data was collected in the laboratory using a HACH 2100AN turbidimeter compliant with USEPA Method 180.1. Samples were mixed, decanted to sample cells and returned to sample bottles following measurement. Measurements were taken with the multidetector ratio mode activated and with signal averaging to minimize noise.

The Estuary Program participates in the USGS Sediment Lab Quality Assurance (SLQA) program, which supplies single-blind quality assurance samples to participating laboratories twice a year. Staff analyzes nine samples of an unknown concentration and submits results electronically to the SLQA program. The Estuary Program has consistently achieved results within the 10% acceptable margin of error.

## WALTERS CREEK SUSPENDED SEDIMENT

The Walters Creek subwatershed encompasses drainage from approximately 1.90 square miles. The watershed is used as rangeland for beef cattle operations with a rotational grazing scheme. The flume monitoring station includes drainage from approximately 0.86 square miles of the subwatershed. The Walters Creek confluence with Chorro Creek is upstream of the Canet Road monitoring site. Figure 10 demonstrates drainage areas and monitoring station locations.

FIGURE 10: SUSPENDED SEDIMENT MONITORING STATIONS



The Walters flume site (WLF) was monitored extensively during the NMP study from 1993 to 2001. During the NMP, the Walters Creek watershed was used as a control watershed in the paired-watershed study. The NMP study focused on the effectiveness of BMPs implemented at Chumash Creek in comparison to the control site at Walters Creek during a pre-BMP period of 1993 to 1996 and post-BMP monitoring period of 1997 to 2001. Following the conclusion of the NMP, extensive restoration efforts took place throughout the Walters watershed between 2003 and 2005. The

Walters Creek flume station was re-instrumented for SSC and discharge monitoring during the 2008-09 water year. The monitoring work undertaken by the Estuary Program compares the pre-project and post-project condition of the Walters Creek watershed through the use of similar methods at the same monitoring location.

The Estuary Program examined Walters Creek data with the 1991 to 2001 NMP dataset as pre-Project and the 2008 to the present dataset as post-Project. The new dataset examines the net effect of BMPs and restoration work at Walters Creek.

In order to generate consistent and comparable data, the Estuary Program implemented SSC monitoring at the same location, using similar equipment and protocols as the NMP study. The existing structural components were repaired and re-instrumented for the new data collection effort. For consistency, the same sample intake was used for sample collection.

The primary difference between the NMP and Estuary Program dataset is the laboratory method of sample analysis. The NMP study utilized TSS analysis protocols for analyzing suspended sediment content and noted in the conclusions that error might be reduced by the use of method ASTM D 3977-97. The Estuary Program has utilized method ASTM D 3977-97 for all sample analysis throughout the recent three-year monitoring period. The discrepancy between these methods is more apparent in samples that contain larger particles. The TSS methodology has shown bias in under sampling the true sediment concentration in samples containing coarse or sand-sized particles. Pre-Project TSS data likely underestimated the true concentration of suspended sediment, but the site specific relationship between TSS and SSC data is unknown.

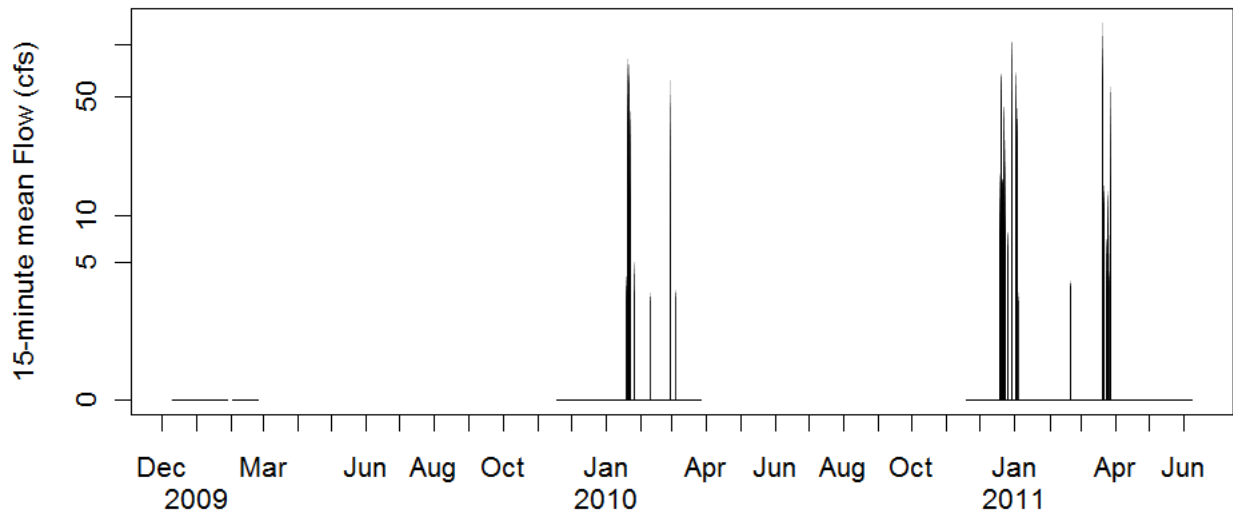
The flume discharge equation used during the NMP study was applied to the stage height data collected by the Level Troll to determine discharge volumes during measureable storm events. Stage height data records were collected on a 10 or 15-minute frequency. Flow values were not calculated or assigned to stage height measurements below the flume rating standard of 0.25 feet. SSC data collected at stage heights below 0.25 feet are not included in this analysis.

In order to compare pre- and post-Project data, both datasets were modeled to determine the relationship between flow volume and SSC. The expectation was that if the BMP implementation had generated the desired reductions in SSC, that the relationship between SSC and flow would be different under the two conditions with lower SSC across the range of flows during the post- Project condition.

Flow data for the post-Project period from December 9, 2008 to July 18, 2011 (57,436 complete flow records) were considered for the model. The 2009-2010 water year did not generate any measurable flows and was excluded from further analysis. Valid flow values were binned into 15-minute intervals, except when multiple readings occurred in an interval. In these cases, the mean was computed, resulting in 38,578 binned flow values.

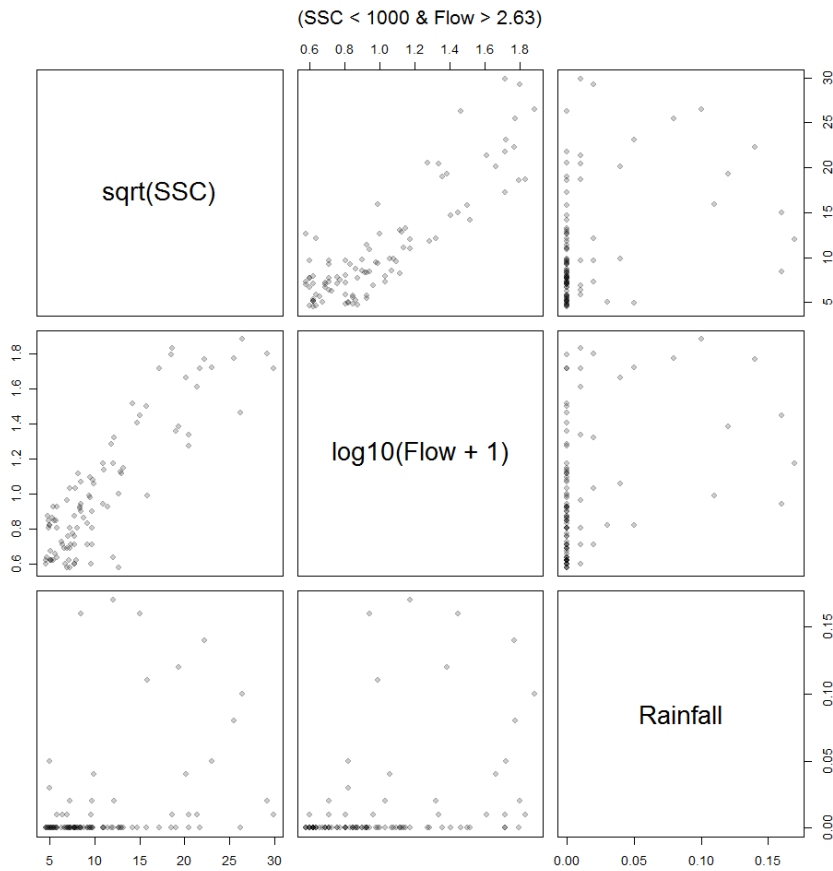
Figure 11 indicates the frequency and magnitude of measureable flow volumes at the Walters Creek flume. The flow regime at Walters Creek is characterized by long periods of shallow base flow and short duration elevated flows associated with storm events.

FIGURE 11: 15 MINUTE MEAN FLOWS AT WALTERS CREEK



The data was analyzed to identify a reasonable set of transformations for modeling the variables. Transformations were applied to stabilize the variance, achieve linearity (so linear models could be fit), induce normality in the residuals, and balance leverage across the data points so that outlying x-values wouldn't have undue influence on the regression coefficients. Transformations were applied to the SSC data ( $\text{SqrtSSC}$ ), and the flow volume data ( $\text{Log}_{10}(\text{Flow} + 1)$ ). Rainfall data from the Canet station at Chorro Creek was considered as a possible variable but was not included in the final models. The final model analysis considers only data when flow is greater than 2.63 cfs and  $\text{SSC} < 1000 \text{ mg/L}$ . Transformed values and relationships are shown in Figure 12, below.

FIGURE 12: DATA TRANSFORMATIONS APPLIED FOR NORMALIZATION OF WALTERS DATA



The final model adopted for predicting sediment loading and establishing the relationship between the variables included a higher order flow term and dropped the rainfall predictor variable, which was shown to be non-significant ( ). Residual diagnostics appeared to satisfy modeling requirements. The model adopted for determining sediment concentration based on flow volume achieves a very high R-sq (adj) = 79%, indicating that a substantial fraction of the variability in SSC can be explained by Flow alone. The higher range of the model has a wider confidence interval and prediction bands owing to a lack of data. Additional data collection efforts could reduce the width of these intervals.

Figures 13 and 14 display the fitted model with 95% confidence and prediction bands as well as the data used to generate the model. Note that all data is plotted for reference, but the model only includes Flows greater than 2.63 cfs.

FIGURE 13: WALTERS CREEK POST-PROJECT PREDICTIVE MODEL (FULL RANGE)

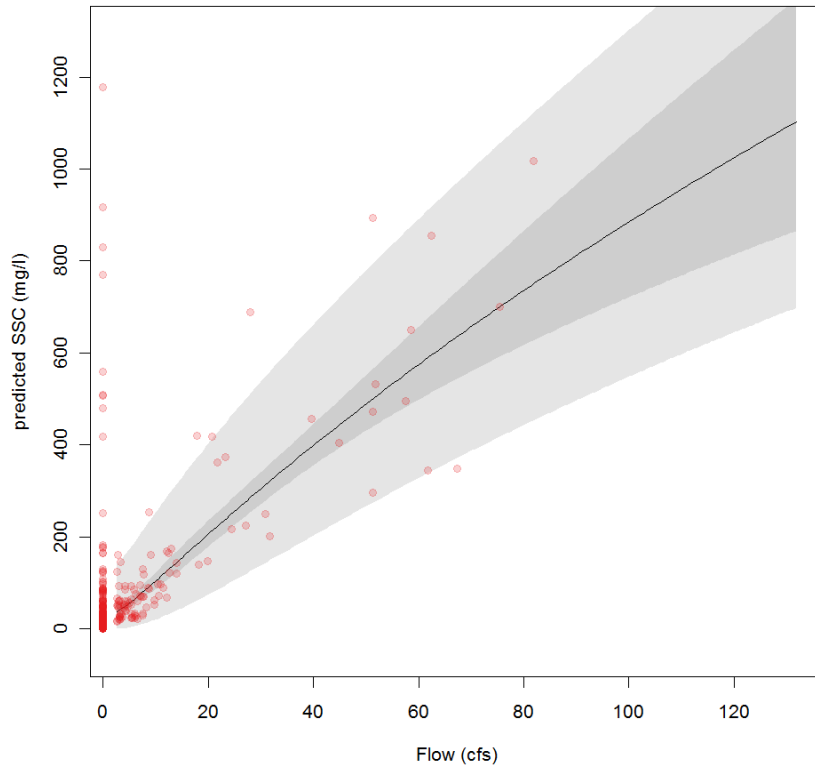
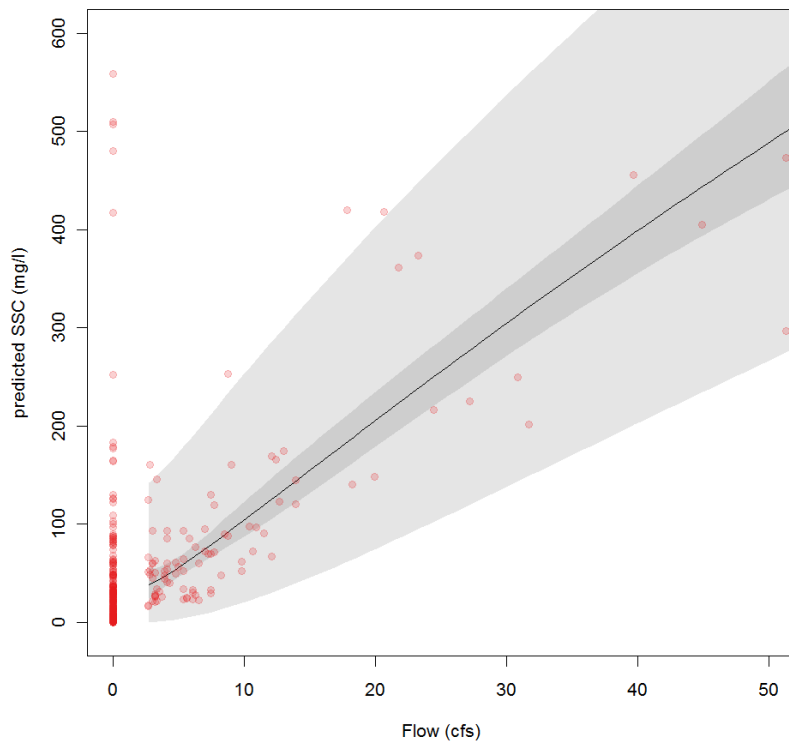


FIGURE 14: WALTERS CREEK POST-PROJECT PREDICTIVE MODEL (LOW RANGE)



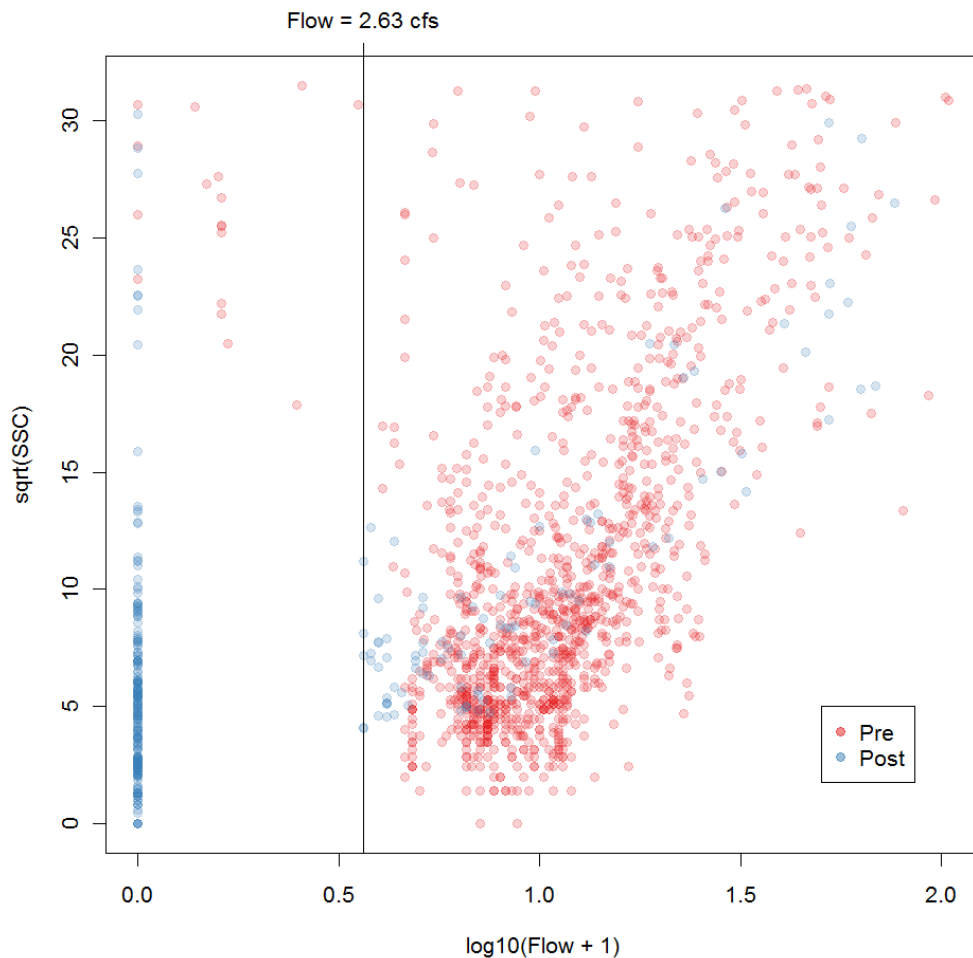
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## WALTERS CREEK PRE- AND POST-PROJECT COMPARISON

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The following graphic displays the pre-Project TSS and post-Project SSC data on the same plot. Due to the different time periods of pre- and post-Project analysis, there is a greater number of pre-Project (red) data points and also greater variability among the pre-Project data. Data shown to the left of the reference line at 2.63 cfs was not included in model analysis as it did not meet the minimum flow criteria.

FIGURE 15: WALTERS CREEK PRE- AND POST-PROJECT SEDIMENT DATA



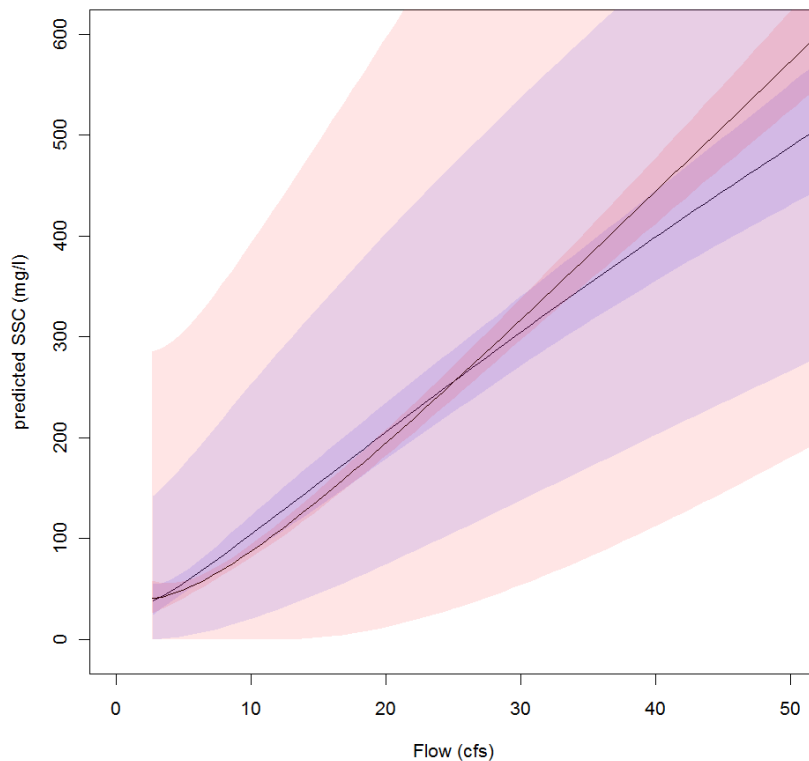
The pre-project data was incorporated into the final model that was used for determining the relationship for the post-Project data, assuming that the functional relationship between the two parameters would remain the same. However, the parameters in the pre-Project period were allowed to differ from the post-Project period. The residual behavior of the pre-Project data was checked using the functional form of the post-Project data and did not indicate a need for higher order terms in the model.



There was substantially more variability in the pre-Project TSS data as noted by the residual standard error (pre-project data = 5.33 mg/l, post-project data = 2.836 mg/l), and thus a lower adjusted R-sq = 41% for pre-Project data versus 79% with the post-Project data.

Figure 16 displays the pre- and post-Project model results. 95% confidence intervals are indicated by darker bands of red and blue, with lighter shades indicate corresponding prediction intervals for both conditions. The pre-Project data (red) has a very narrow confidence band due to the large sample size but a wide prediction band due to highly variable predicted SSC values. The post-Project data (blue) has a wider confidence band due to smaller sample size and narrower prediction band due to less variability within the post-Project dataset.

FIGURE 16: WALTERS CREEK PRE- AND POST-PROJECT SUSPENDED SEDIMENT MODELS



The 95% confidence interval bands essentially overlap for the pre- and post-Project datasets. A formal test to compare the model results (considering data for which flow is greater than 2.63 cfs) indicates there is only weak evidence for a difference between pre- and post-Project conditions ( ).

While there is not a significant difference between the pre- and post-Project conditions, there is some indication of a change in condition at different ranges of flow. At flows between approximately 5 to 25 cfs, the models indicate that SSC concentrations are higher in post-Project conditions. While this may indicate a change of conditions in the watershed, changes in lab methodology (greater recovery of suspended particles) may also be influencing this apparent trend. The appearance of reduced SSC in the post-Project condition at higher flows (greater 30 cfs) may become significant by narrowing of the 95% confidence interval through the addition of more data.

These empirical differences are not statistically significant but indicate that further data collection may improve the ability to detect a difference between pre- and post-Project conditions.

Post-Project data collection at Walters Creek will be continued through water year 2011-2012. Infrastructure improvements at the flume station to expand data collection capabilities should result in a higher percentage of useable data during measureable flow conditions. Additional data collection and analysis will improve the ability to detect differences between the pre- and post-Project condition at the site.

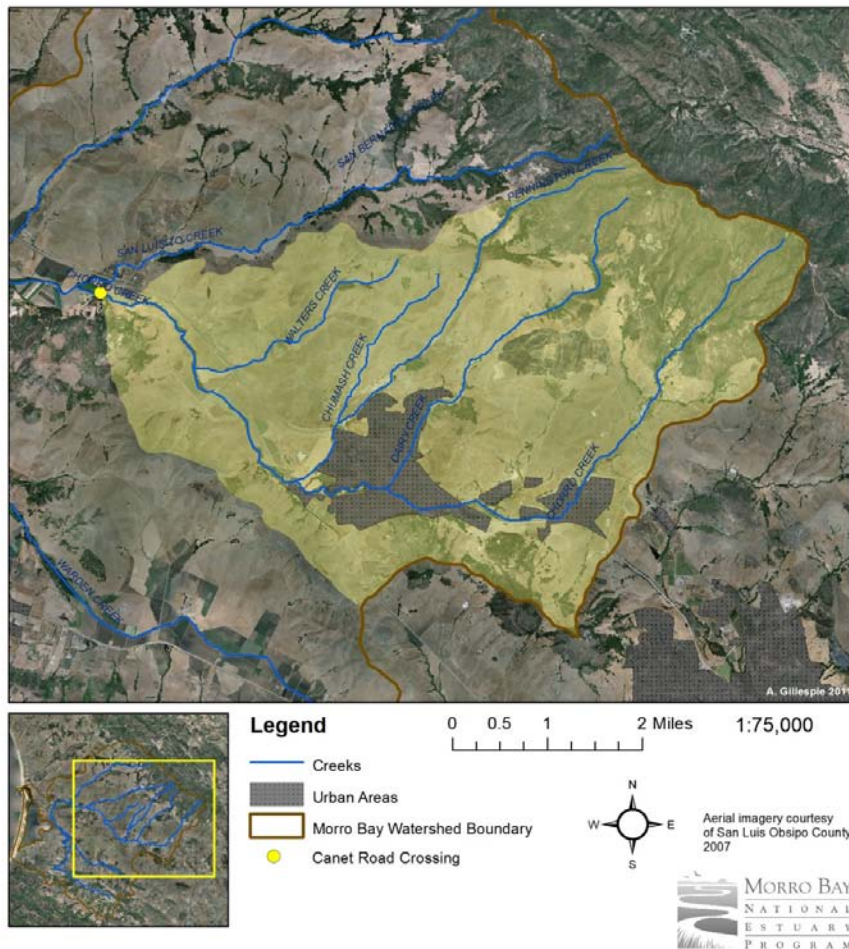
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## CHORRO CREEK , CANET ROAD, SUSPENDED SEDIMENT

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In 2007, the Estuary Program established a monitoring station to collect suspended sediment data from the Canet Road crossing on Chorro Creek. The site (referenced throughout the report as either site code CAN or Canet) includes drainage from approximately 21.8 square miles and was established as a gauging station by the District in 1978. The station has provided a continuous record of stage heights, with the exception of the years 2000 to 2003 when the crossing and gauge were damaged during high flows and subsequently rebuilt. The location is identified as Station 753 within the District's network and is instrumented with a stage height recorder and rain gauge. In 2006, ALERT capability (radio with antenna) was added to the site, providing real-time data acquisition via the existing County ALERT network.

FIGURE 17: MAP OF CHORRO CREEK, CANET ROAD SUBWATERSHED



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## CHORRO CREEK DISCHARGE VOLUME

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In order to avoid ongoing labor-intensive discharge monitoring, an updated stage-discharge relationship was developed for the site for the purposes of this monitoring project. Stage height (the height of the water surface, in feet) was correlated to the instantaneous discharge (volume of water, in cubic feet per second) to develop a rating curve.

New discharge data was collected over a range of flow conditions. Collecting discharge measurements during non-wadeable flows required specialized equipment and training. The Estuary Program contracted with the Irrigation Training and Research Center (ITRC) at Cal Poly to collect high stage discharge data and develop the rating curve for Chorro Creek at Canet Road. Engineering staff at ITRC conducted high stage discharge monitoring during large storm events in December 2007, January 2008 and January 2010.

ITRC engineers targeted data collection on flows greater than 200 cfs at Chorro Creek and utilized either a Marsh-McBirney Flo-Mate unit or a Sontek flow tracker mounted on the end of a specially designed stabilizing/measuring pole that was constructed for the project. Velocity readings were taken at the 0.6 depth of flow point. Due to high velocities and turbulence, two measurements (at the 0.2 and 0.8 depths) were not feasible. At the conclusion of water year 2009-2010, ITRC provided a final report that included a best-fit equation of flow rate versus upstream water depth for each site monitored (included in appendix).

Analysis of field measurements determined that two unique equations were necessary to approximate flow rates at the site during storm events. For stage heights below 12.10 feet, the flow rate in cfs can be approximated by:  $Q \text{ (cfs)} = 26Y^{1.8}$  where Y is the depth of water (in feet, recorded by the bubbler gauge) minus channel bottom elevation (3.75 ft) above the reference datum.

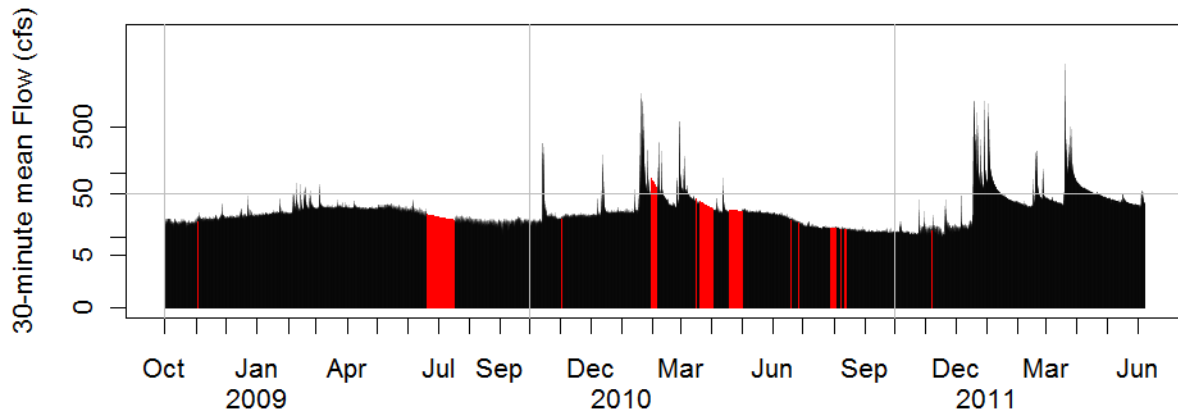
For recorded stage heights between 12.1 feet and 13.2 feet, the estimated flow rate is 1200 cfs. This is the case when the culverts are full, and the water is not overtopping the bridge.

When the water has overtopped the bridge at heights above 13.2 feet, the following equation is applied:  $Q \text{ (cfs)} = 1200 + 88 [(H - 13.2) + 0.326]^{2.1}$  where H is the staff gauge reference without adjustment for the channel bottom elevation. The extra water over the bridge was estimated using a complex weir equation. WinFlume software was used to create the equation.

Stage height measurements are recorded on a maximum 15-minute interval. The appropriate ITRC-generated discharge equation was applied to each individual stage height record. During high flow events or periods of rapid change, stage height measurements may be reported as frequently as every three minutes. Data was merged into 30-minute 'bins' to complete loading analysis. Total discharge for each 30-minute bin was calculated by averaging the instantaneous discharge values reported for each bin. In most cases, bins were characterized by a single stage measurement and corresponding discharge value.

There were a few instances of equipment failure in the stage height record during the period of analysis. These data gaps were interpolated through a statistical model. The flow record for the analysis period is shown in Figure 18, with interpolated data periods shown in red. This data period includes two complete water years: the 2008-2009 water year (October 1, 2008 - September 30, 2009), and the 2009-2010 water year (October 1, 2009-September 30, 2010). The 2010-2011 water year is shown as incomplete and spans October 1, 2010 through June 8, 2011.

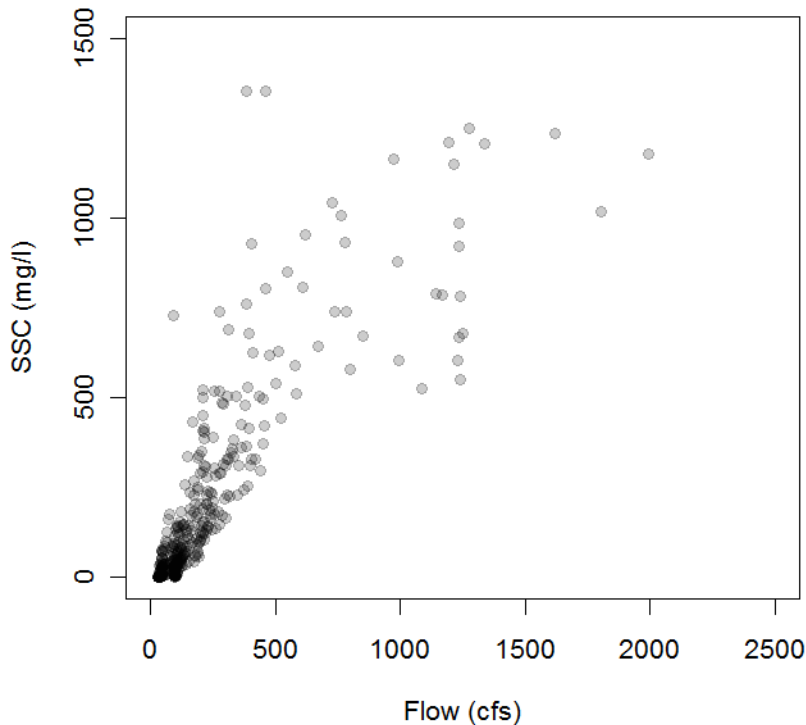
FIGURE 18: CHORRO CREEK, CANET ROAD, DISCHARGE RECORD WITH INTERPOLATION



#### CHORRO CREEK, CANET ROAD SEDIMENT TRANSPORT

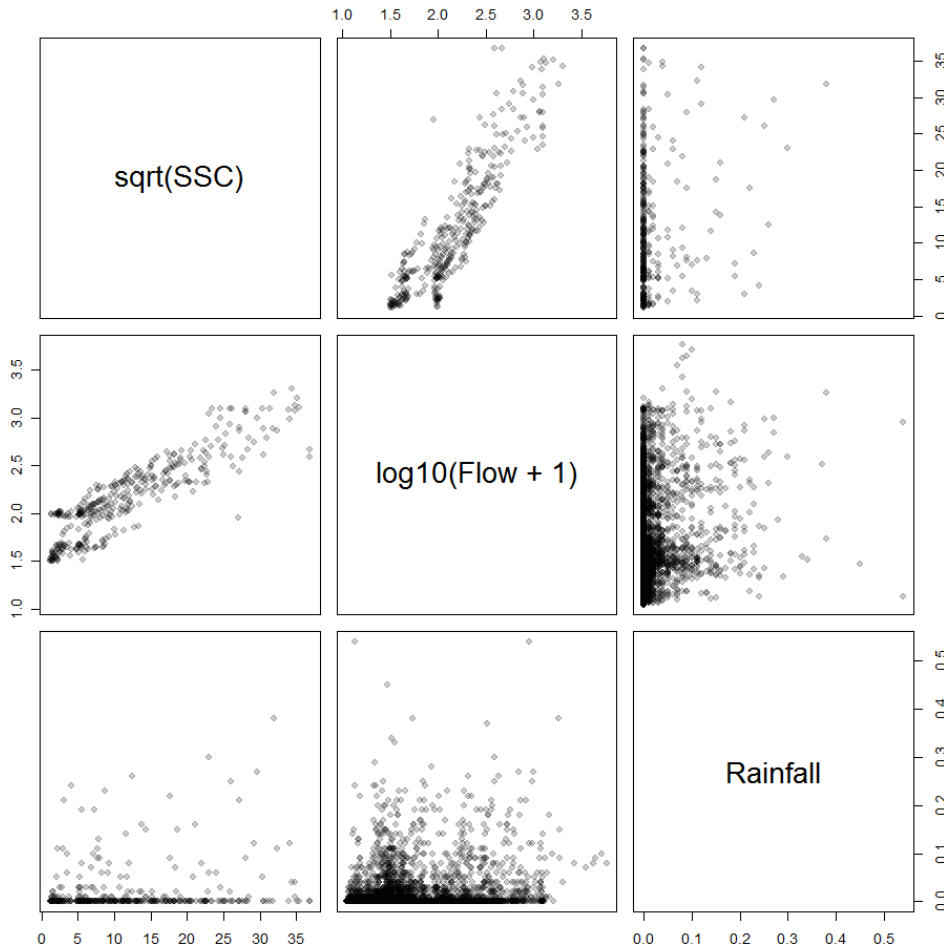
The three year data collection effort generated 523 individual records of SSC for the Canet station. Samples were collected on 30 or 60-minute intervals during storm events. The dynamic channel bed morphology of the Canet site resulted in burial of the sampler intake during a few major storm events. To ensure accuracy and rule out samples contaminated by bed-load materials, only samples with SSC less than 1,000 mg/L were included in the following analysis. Of the 523 records collected, 503 met the criteria for inclusion in the model. Figure 19, below, demonstrates the raw data from CAN incorporated into the model.

FIGURE 19: CANET ROAD SSC DATASET



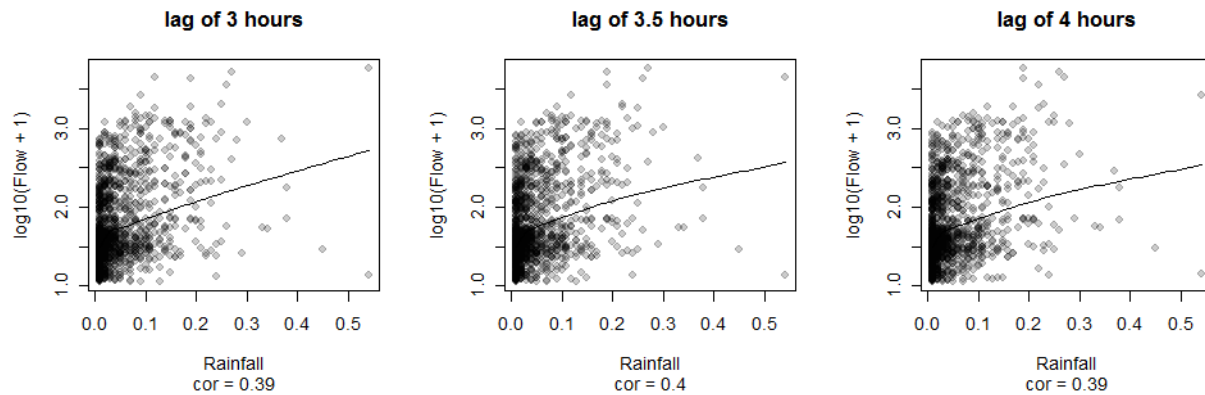
The data was analyzed to identify a reasonable set of transformations for modeling the variables. Transformations were applied to stabilize the variance, achieve linearity (so linear models could be fit), induce normality in the residuals, and balance leverage across the data points so that outlying x-values wouldn't have undue influence on the regression coefficients. It was determined that transformations similar to those used for the Walters Creek dataset adequately normalized the datasets for the Canet station.

FIGURE 20: DATA TRANSFORMATIONS APPLIED FOR NORMALIZATION OF CANET ROAD DATA



The relationship between flow and rainfall was examined for the possibility of inclusion in the model. Surprisingly, there is little apparent relationship between rainfall and stage height recorded at the Canet gauge. The relationship was tested in time intervals of 30 minutes, from 0 minutes of lag time up to 8.5 hours of lag time. Lagged data (Figure 21, with loess smooth curve) suggests that flow may be most highly correlated with rainfall recorded three and a half hours earlier, indicating that it likely takes about three and a half hours for rainfall to maximally impact flow volumes at the Canet station. Ultimately, rainfall was not found to be a useful predictor of suspended sediment and was not included in the final model for suspended sediment load at Canet.

FIGURE 21: CANET RAINFALL AND FLOW VOLUME CORRELATION



Initial modeling of the relationship between flow and SSC indicated that higher ordered flow terms were needed. A second-order model (similar to that applied to Walters Creek) was tested with the CAN data. The model indicated a tendency to underestimate SSC for flows in the 100 to 600 cfs range. Additionally, the residuals still showed some curvature indicating that higher ordered terms were needed.

Sequentially including higher ordered terms suggested the use of a 5<sup>th</sup> order model. A 6<sup>th</sup> order term was not found to be statistically significant ( ). While unconventional, the intent to use this as a predictive model suggests that the higher order model may be appropriate. Consideration was given to the concern that a 5<sup>th</sup> order model would ‘over-fit’ the data. However, graphs of model predictions reveal that this is likely not a concern. This model achieves an adjusted R-sq = 81%.

Figure 22 demonstrates the model for SSC at Canet. The model captures the range of flows from base flow (~17 cfs) up to approximately 1,200 cfs. The bridge crossing becomes impassable at flows above approximately 1,200 cfs.

FIGURE 22: SUSPENDED SEDIMENT MODEL, CHORRO CREEK AT CANET ROAD

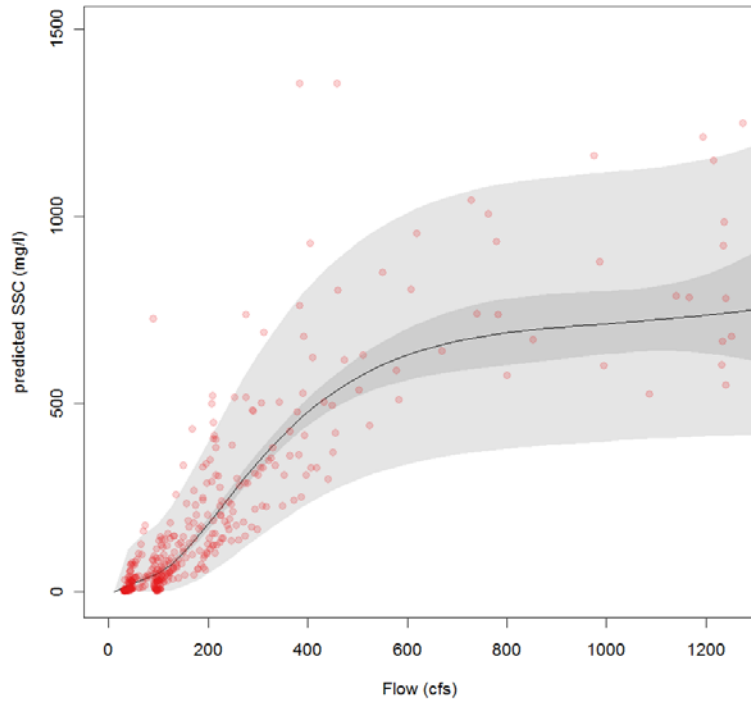
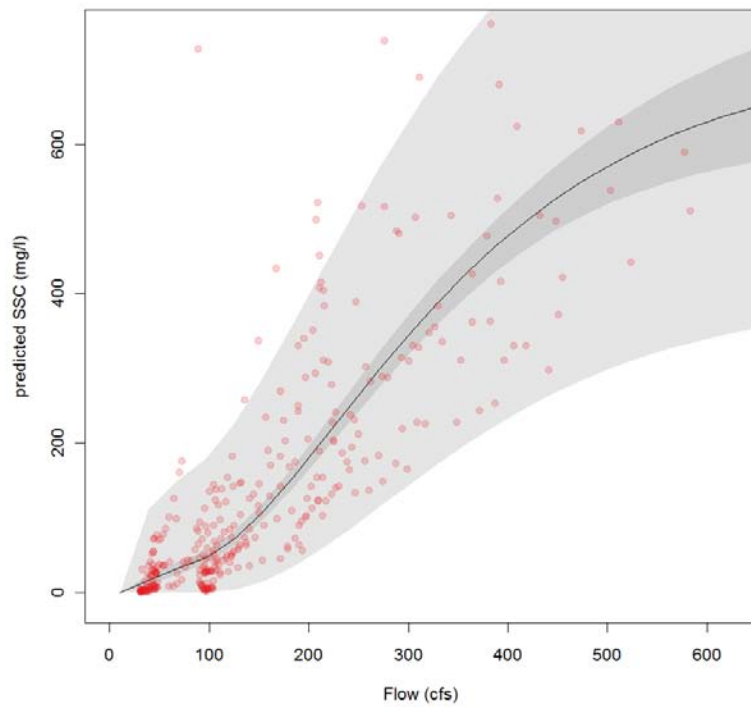


Figure 23 demonstrates the performance and correlation of the model at flows ranging from 0 to 600 cfs.

FIGURE 23: SUSPENDED SEDIMENT MODEL, CHORRO CREEK AT CANET ROAD, LOW RANGE





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## CHORRO CREEK SEDIMENT LOAD

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The suspended sediment data collected at Canet constitutes a relatively large, new dataset for analysis of sediment loading from the Chorro Creek watershed. The collection of storm event SSC data from a large area of the watershed reduces the degree of extrapolation required to estimate annual sediment loads from the entirety of the watershed. Improvements in stream gauging infrastructure and data collection, as well as recent efforts to develop a stage discharge rating curve at the Canet site in 2003 have generated a large, robust dataset for determining instantaneous and annual flow volumes.

In order to estimate sediment loading from the entirety of the Chorro Creek watershed to Morro Bay over the study period, the following steps were completed.

- Acquired all recorded stage heights from the District for Chorro Creek at Canet Road.
- Applied an updated stage-discharge equation to all recorded stage heights to average data into 30-minute bins.
- Scaled average instantaneous flow rates to determine net discharge for each 30-minute bin.
- Interpolated discharge values for bins where stage height data was not available.
- Used Tetra Tech equation (below) to scale up discharge values from Canet site to encompass the entire Chorro Creek watershed.
- Applied the predictive model for SSC at Canet to discharge values for the entire Chorro Creek watershed.
- Scaled sediment load in 30-minute bins to determine annual loading in short tons.

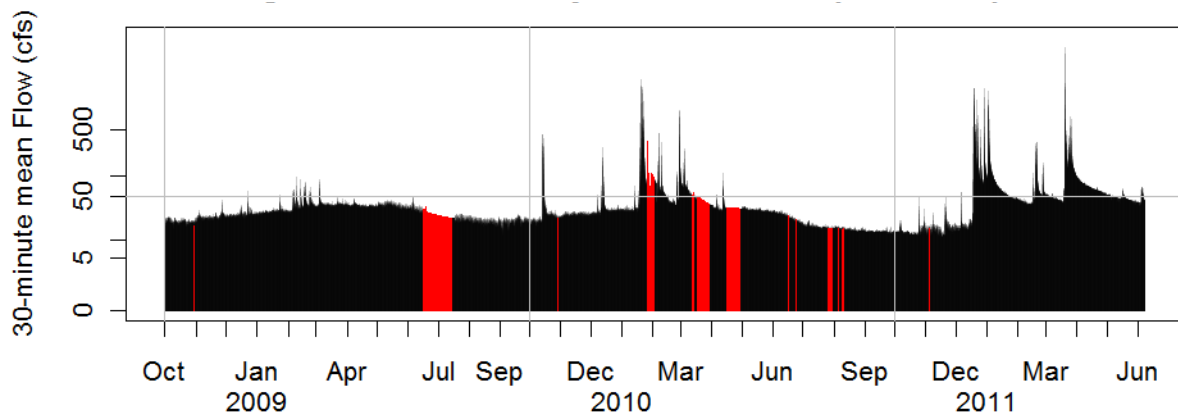
This process allows for estimation of the net discharge and suspended sediment load from the Chorro Creek watershed for the 2008-2009, 2009-2010 and partial 2010-2011 water years. The 2010-2011 dataset spans October 1, 2010 through June 8, 2011 and encompasses the major winter flow periods.

The Canet discharge record was ‘scaled up’ to represent the entire Chorro Creek watershed through the use of an equation generated by Tetra Tech for the *1998 Morro Bay Estuary Sediment Study*. The report notes that flow measurements from Canet can be scaled up to represent the entirety of the watershed (to the Chorro mouth) through an equation derived from HEC-1 models and regression analysis:

$$\text{AvgQ}_{\text{Chorro Mouth}} = 0.8845 \times (\text{AvgQ}_{\text{Canet Road}})^{1.094}$$

The regression equation was applied to the entire record of flow data to generate discharge totals from the entire Chorro Creek watershed (Figure 24). Interpolated values from when gauge data was not available are shown in red.

FIGURE 24: CHORRO CREEK DISCHARGE RECORD WITH INTERPOLATION



Data analysis indicated a significant outlier event that took place on March 20, 2011 from 3:00 a.m. to 3:30 a.m. The discharge in this bin was characterized by a peak flow estimate of 5,956 cfs, which exceeds most estimated criteria for a ten-year flood frequency event.

Due to a high degree of uncertainty in the prediction interval for flows of this magnitude, one 30-minute bin was excluded from the net sediment load analysis. (The model indicates that more than 87,000 short tons of sediment were transported during this outlier 30-minute bin.) However, this storm event took place over a period of approximately 36 hours, and the data from all bins before and after the outlier bin were included in the load estimate.

The 1998 Tetra Tech modeling effort indicated that the vast majority of the sediment load from the Chorro Creek watershed could be accounted for by assessing data from periods where flows equaled or exceeded 50 cfs. This criterion was applied to the data collected over the recent three-year period to assess sediment loading during low flow conditions versus elevated flow conditions.

In the 2008-09 water year, only 6% of the sediment load was transported during conditions where flows were greater than 50 cfs. Due to drought conditions during this year, flows exceeded 50 cfs during only a few short periods. In contrast, during the 2010-2011 water year, 99.7% of the sediment load was transported during flow conditions greater than 50 cfs. There were prolonged periods of flow volumes greater than 50 cfs during the 2010-2011 water year, as indicated in Figure 24.

Table 2 indicates the Chorro Creek annual discharge volume and the cumulative Chorro Creek sediment load for three water years. The load estimates between the three water years ranges from 146 short tons to 136,043 short tons. These differences are attributed to dramatically different winter hydrologic responses and interannual variability in total discharge. The wide variation in peak flows for Chorro Creek during each water year (ranging from 76 to 5,956 cfs during this period) serves as an indicator of how variable sediment loads can be from year to year.

The immense variability in sediment loading from Chorro Creek is not well captured by determining the “average annual load” based on several years of hydrologic data.

TABLE 2: CHORRO CREEK ANNUAL DISCHARGE AND SEDIMENT LOAD

<b>Water Year</b>	<b>2008-2009</b>	<b>2009-2010</b>	<b>2010-2011†</b>
Total Discharge	20,220 AF	29,795 AF	38,357 AF
Sediment Load <i>(complete data)</i>	146 <i>(0 to 1,460)</i>	8,604 <i>(2,492 to 21,629)</i>	223,688 <i>(5,450 to 994,756)</i>
2010-2011 Single Outlier removed <i>(3/20/2011 03:30)</i>			136,043 <i>(5,415 to 594,876)</i>
Load for 30-min intervals for which Flow > 50	9 <i>(0 to 39)</i>	8,451 <i>(2,492 to 20,256)</i>	223,342 <i>(54,496 to 992,865)</i>
Only using 30-min intervals for which Flow > 50 with outlier removed			135,698 <i>(54,148 to 592,986)</i>

†2010-2011 partial water year, from October 2010 to June 2011.

## STREAMBED SEDIMENT IMPAIRMENT INDICATORS

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The Water Board awarded a grant to researchers to investigate the aquatic health of the San Lorenzo River watershed and impacts due to sediment loading. Over a three-year period, researchers from the Sierra Nevada Aquatic Research Laboratory (SNARL) (associated with the University of California) and UC Santa Cruz conducted research to develop numeric targets for sediment impairment and biological thresholds in riverine systems in the Central Coast region. Although these criteria were not specifically developed for the Morro Bay watershed, they are being evaluated for assessments throughout the Central Coast region. However, the indicators were tested throughout the Central Coast and are considered regionally applicable.

An extensive number of indices were tested across a gradient of test sites. The final outcome included 16 indicators of sediment impairment on aquatic habitat. The indicators cover both the physical characteristics (sediment) and the biological community.

A significant data collection effort is required to determine the status of all 16 Sediment and Biological indicators for a study reach. However, the current SWAMP Bioassessment Protocol metrics can be used to generate five of the nine (in bold) Sediment Indicators, and six of the seven Biological Indicators. Due to limited data analysis detail available at the time of writing, this report includes comparison to only the indicators in bold in the list below. There are three threshold criteria for comparison of each of these indicators, shown below in Table 3.

### Sediment Indicators:

1. **Percent of Fines (F) on transects**
2. **Percent Sand (S) on transects**
3. **Percent of Fines (F) + Percent of Sands (S) on transects**
4. **Percent of Fines, Sands and Gravels <8mm on transects**
5. **D50 Median particle size**
6. Percent patch-scale grid Fines and Sands
7. Log Relative Bed Stability
8. Percent Fines (Steelhead)
9. Percent Cover of Fines and Sands (BMI Limits)

### Biological Indicators

1. Total Richness
2. EPT Richness
3. %EPT
4. Biotic Index
5. Percent Tolerant
6. Sensitive Number
7. Crayfish Number and Size

TABLE 3: SEDIMENT AND BIOLOGICAL INDICATOR CRITERIA

	<b>Recommended Numeric Targets To Support Beneficial Uses</b>	<b>Recommended Numeric Targets to Support Preliminary 303(d) Listing (lower priority)</b>	<b>Recommended Numeric Targets To Support 303(d) Listing (high priority)</b>
<b>Sediment Indicators</b>		<b>75/25</b>	<b>90/10</b>
Percent Fines on transects	<8.5%	8.5 to 15.2%	>15.2%
Percent Sands on transects	<27.5%	27.5 to 35.3%	>35.3%
Percent Fines + Sands on transects	<35.5%	35.5 to 42.0%	>42.0%
Percent Fines, Sands, Gravel <8mm on transects	<40.0%	40.0 to 50.2%	>50.2%
D50 median particle size	>15 mm	7.7 to 15 mm	<7.7 mm

The Estuary Program has conducted SWAMP Bioassessment on an annual basis since 2007. Sites are selected for monitoring based on program data needs and hydrologic conditions. Thus, many sites are monitored on a rotating basis, and data is not available across all sites each year.

While data collection efforts have been conducted using a consistent protocol since 2007, templates for managing the data electronically were not available to the Estuary Program until 2011. Due to the time intensive process of formatting templates, entering data, and completing quality assurance, only the most recent 2011 dataset is available electronically. The 2011 data are compared to the numeric targets in Table 4, the site locations are shown in Figure 26. The Estuary Program intends to enter previously collected data into the database templates as resources allow.

FIGURE 25: MORRO BAY BIOASSESSMENT SITES 2011

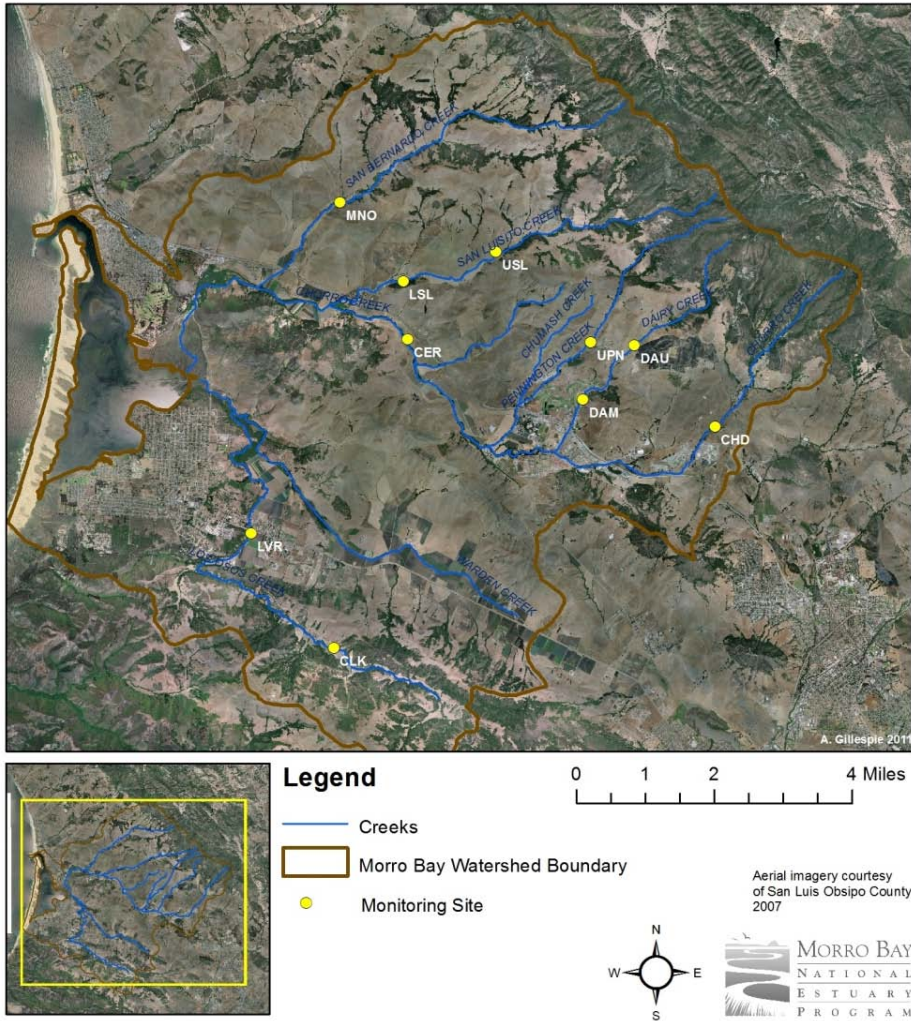


TABLE 4: MORRO BAY SEDIMENT IMPAIRMENT INDICATOR METRICS

Waterbody	Site Code	Percent Fines	Percent Sands	Percent <8	FS Sum Percentage	D50 Median particle size
Chorro Creek, on the Ecological Reserve	CER	4.8	34.3	41.0	39.0	13.0
Chorro Creek, below Chorro Dam	CHD	1.0	28.6	29.5	29.5	40.0
Dairy Creek, upper	DAU	15.2	14.3	32.4	29.5	23.0
Dairy Creek, middle	DAM	3.8	26.7	30.5	30.5	9.0
Pennington Creek, upper	UPN	2.9	16.2	19.0	19.0	157.0
San Luisito Creek, upper	USL	2.9	21.0	28.6	23.8	16.0
San Luisito Creek, lower	LSL	8.6	21.0	32.4	29.5	13.0
San Bernardo Creek	MNO	9.6	17.3	32.7	26.9	14.0
Los Osos	CLK	1.0	32.4	33.3	33.3	9.0
Los Osos	LVR	8.6	25.7	40.0	34.3	11.0

Of the five sediment indicators tested across ten monitoring sites, only one indicator at one site (at Dairy Creek Upper) indicated a high priority for 303(d) listing (Table 4). At several sites only one or two indicators met the lower priority criteria for 303(d) listing. Two sites, UPN at Pennington Creek and USL at San Luisito Creek, met the beneficial use criteria for all five indicators assessed.

This preliminary analysis indicates that physical characteristics are variable across sites in the Morro Bay watershed, and that some sites may indicate greater levels of impairment than others. It is important to consider that these results tables do not include the full suite of sixteen metrics that were found to be indicative of sediment impairment, and that the values represent only the most recent year of data (2011).

These indicator criteria are still being assessed for incorporation in the TMDL establishment and assessment process in the Central Coast region. It is noteworthy that these criteria are numerically different than the D50 and percent sands/percent fines criteria listed in the approved Morro Bay Sediment TMDL.



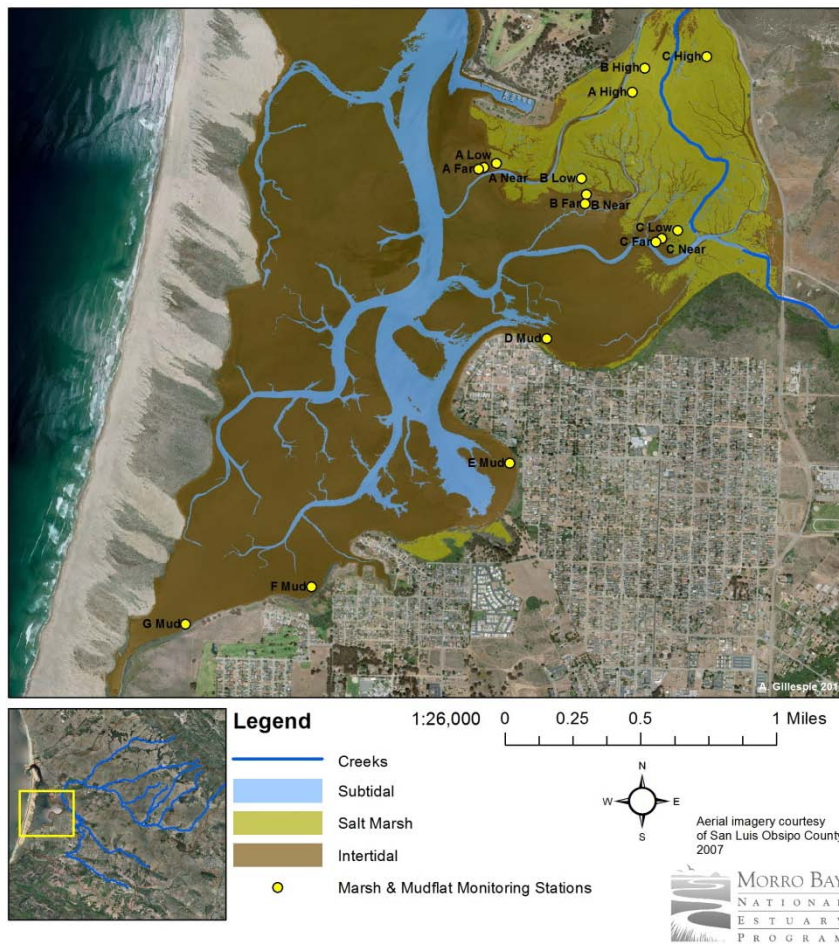
## MORRO BAY SURFACE ELEVATION TABLES AND MARKER HORIZONS

In addition to measurements of sediment transport and effects within the Morro Bay watershed, numerous sediment accretion sampling stations have been established in the salt marsh and mudflats. Surface Elevation Tables (SETs) and marker horizons were established in 2004 to measure sedimentation rates and establish a baseline for long term measurements.

Six surface elevation sampling stations were established in the salt marsh along three transects (A, B & C) in January of 2004. Additional sampling stations were constructed in the intertidal mudflats at elevations below each of the marsh sampling stations. Four additional mudflat stations were established around the shoreline of the bay in October of 2004. Stations are illustrated in Figure 26.

Measurements were conducted on a variable frequency by staff at the Department of Environmental Science from the University of San Francisco. This section summarizes results from surveys conducted in 2004, 2007, and 2010. Additional detail on this data collection effort is located in the appendix.

FIGURE 26: MAP OF ALL MORRO BAY SETS & HORIZON MARKERS, SALT MARSH AND MUDFLATS





The marker horizon data indicates that sediment has been accumulating at a relatively constant rate at all marsh stations, with the exception of station B Low. While data have not been collected annually, it does not appear that there have been any large-scale annual “pulses” of sediment input to the marsh sites since 2004. Accretion rates for salt marsh stations are summarized in Table 5. Accretion rates dropped at B Low in 2010 due to localized erosion of sediment, whereas the SET data from other markers indicated a slight increase in elevation. These differences are probably attributable to local, small scale variation in sediment dynamics.

FIGURE 27: MAP OF MARSH MARKER HORIZONS AND SETS

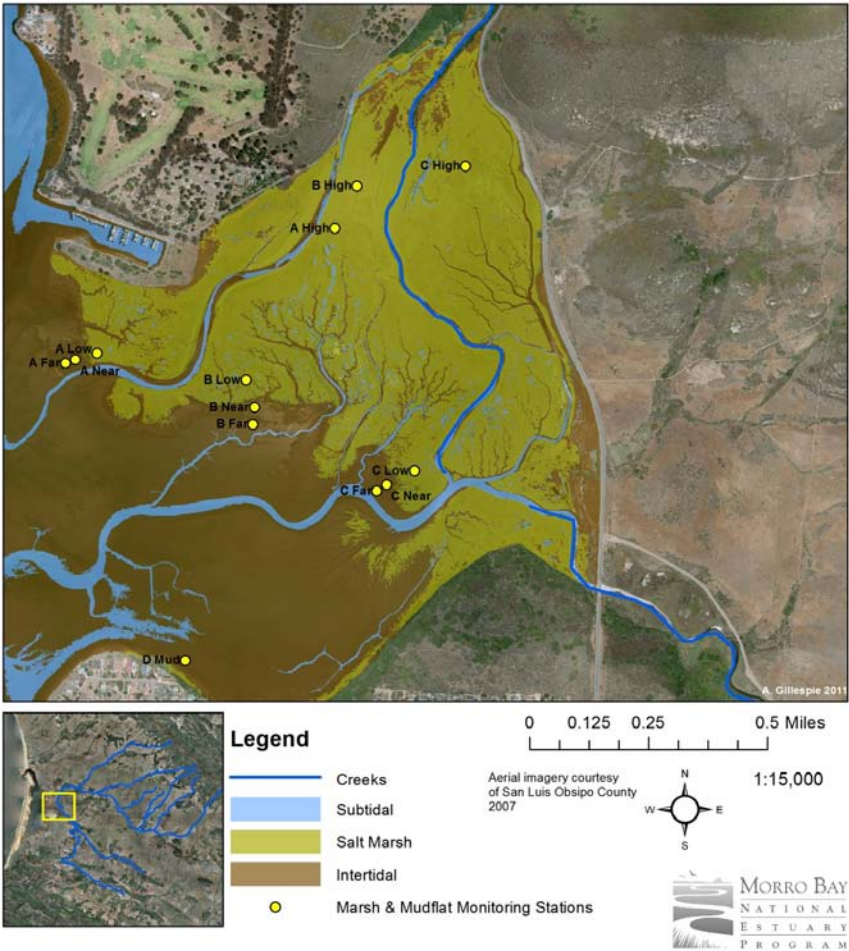
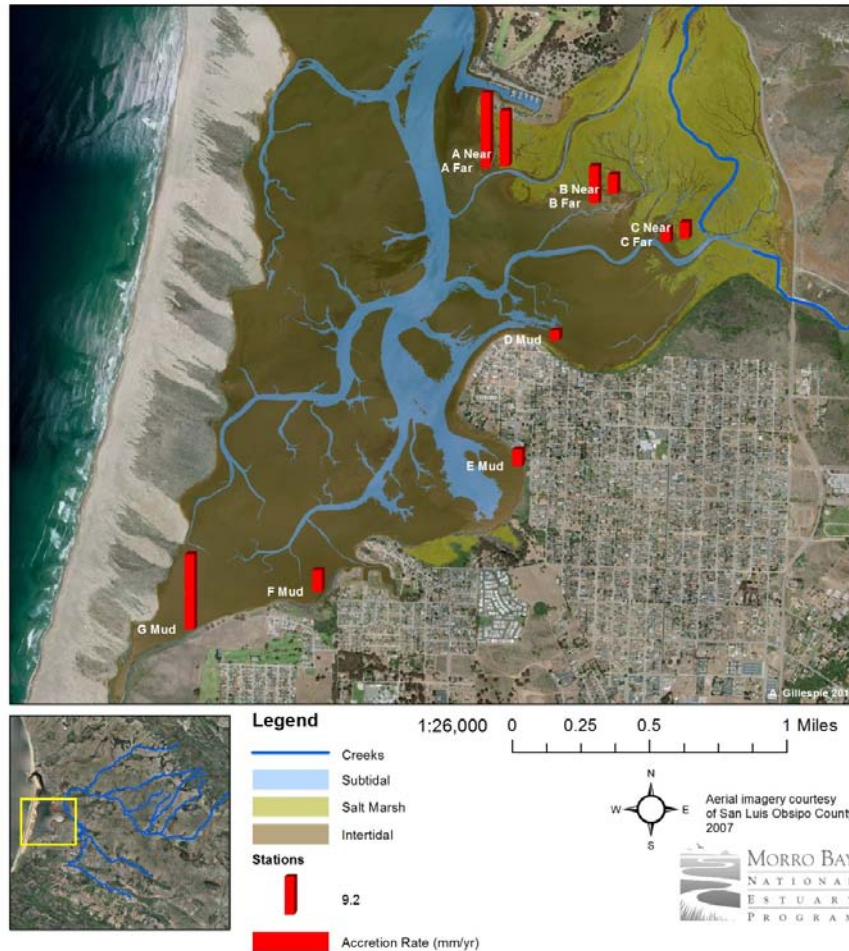


TABLE 5: SALT MARSH SET ACCRETION RATES

	<b>2007 Accumulation Rate (mm/year)</b>	<b>2010 Accumulation Rate (mm/year)</b>	<b>Average Annual Rate of Elevation Change (mm/year)</b>
A Low	5.1	4.7	2.0
B Low	4.0	1.5	1.5
C Low	6.2	5.5	4.4
A High	1.5	1.2	0.3
B High	2.2	1.6	1.4
C High	1.9	1.8	0.9

Mudflat marker horizons were used to measure the accretion rate at ten locations. Accretion rates for mudflat stations are shown in Figure 28. Based on measurements of sediment depth relative to the fabric plots, Stations A Far and G showed the highest rates of sediment accumulation, with both stations accumulating over 80 mm of sediment since October 2005. Stations A Near and B Far accumulated over 50 mm of sediment, while all other stations accumulated 30 mm or less. In some cases, these average values are based on a smaller sampling size due to damaged plots.

FIGURE 28: MAP OF MUDFLAT MARKER HORIZON ACCRETION RATES



Annual accretion rates based on these cumulative accumulation values ranged from 2 to 18 mm/yr, with the same trend evident across stations: the highest rates were at G and A Far, with both A Near and B Far also having relatively high rates. For these four stations, annual rates varied from 9 to 18 mm/yr. While these accretion rates are much greater than those measured in the salt marsh, they are not unusually high given the highly dynamic nature of mudflat ecosystems. In addition, the rates measured at the other locations are all in the range of 2 to 5 mm/yr, just slightly exceeding current rates of global sea-level rise and giving no indication of large-scale rapid filling of mudflats in the areas where these sampling stations are located.

### REGIONAL COMPARISON OF SURFACE ELEVATION TABLE DATA

An investigation conducted by the EPA compared Morro Bay data on sediment accumulation and marsh elevation with data available from Elkhorn Slough, San Francisco Bay, the Sacramento Delta, and South Slough (Coos Bay, Southern Oregon). Data was generally collected using comparative methods (the SET methodology).

At Morro Bay, salt marsh elevation appeared to track sediment deposition, with the difference between deposition and elevation gain presumably due to consolidation and decomposition of deposited sediment. Marsh elevation trajectories were positive, apart from the first sampling

period, and a positive, although modest, relationship between deposition and elevation gain was found to be present ( $r^2=0.15$ ). Average marsh elevation gain ranged from 1 to 4 mm/year, with larger elevation gains at sites with greater deposition rates. At Elkhorn Slough, elevation gains averaged from 0.6 to 1.8 mm/year for a total of 4.5 years; however, there was great variability in elevation from year to year. For most sampling intervals, Elkhorn Slough marshes lost elevation, and furthermore there was a significant negative relationship found between accretion and marsh elevation. At Greco Island in South San Francisco Bay, a positive trend in marsh elevation has been measured, with average elevation gains of 1.5 to 3.5 mm/year for five years. In the Sacramento Delta, wetland elevation change ranged from -25 mm/yr to +15 mm/year. Overall, there was little relationship between accretion and elevation change measured at the deltaic SETS. At eight South Slough SETS, aside from one site near the estuary mouth, marsh elevation was on a positive trajectory, with elevation gains averaging 3 to 8 mm/year from 1994 through 2011. Marsh elevation gain is greater near the head of the estuary, suggesting that proximity to the fluvial sediment source drives increased deposition and elevation gains.

This data from a range of West Coast environments suggests that coastal marshes are on a range of trajectories. With respect to sediment deposition rates, the rates measured at Morro Bay appear to be on the low end of the regional range. With respect to marsh elevation change, Morro Bay appears to be in the middle of the regional range. Overall, the data collected since 2004 do not support the hypothesis that unusually rapid sediment deposition is occurring in Morro Bay wetlands.

SET elevation monitoring in the mudflats and salt marsh will be continued through collaboration with USF faculty and staff. Monitoring recurrence is expected to vary depending on winter flow conditions and availability of funds to support continued data collection.

## CONCLUSIONS

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A variety of monitoring techniques have been employed to characterize sediment loading from the Morro Bay watershed and deposition into Morro Bay. Current monitoring efforts track ambient water quality, loads suspended during storm events, as well as sediment deposition rates and characteristics at both watershed and estuarine sites. However, the variability of timeframe, intensity, and spatial coverage between different monitoring techniques presents a challenge in determining progress towards achievement of the TMDL.

The National Monitoring Program and the Volunteer Monitoring Program have collectively built a robust long-term ambient water quality dataset for sites throughout the Morro Bay watershed. The wealth of data collected supports that established idea that 'dry-weather' water quality conditions do not show impairment for suspended sediment since in nearly every case, dry-weather data does not exceed levels of concern for turbidity. The dataset supports the idea that the bulk of sediment transport and impairment occurs during storm conditions, although spatially diverse monitoring of those conditions is limited. Expansion of water quality monitoring efforts during storm events could help better characterize the origination of suspended sediments and the relative severity of water quality impairments at a more temporally and spatially refined scale.

The recent three-year effort to monitor suspended sediment loading during storm events has illustrated the extreme variability in annual loads from the Chorro Creek watershed. The dataset has generated a refined model for sediment load prediction for Chorro Creek and better characterized the nature of sediment transport across a range of hydrologic conditions. The range of conditions seen over the study period highlights the challenge in accurately quantifying an 'average' annual sediment load, given the highly variable winter hydrology. The future predictive power of the model can be strengthened by additional data collection during under-represented high flow conditions. Data collection efforts during these conditions will continue as resources allow.

The suspended sediment monitoring effort has also taken initial steps at quantifying reductions in the sediment transport rate from the Walters subwatershed, generating the first pre- and post-project comparison dataset for this area. Physical and logistical limitations of this site have presented substantial challenges to the data collection effort at this location. In comparison to the storm events that took place during the National Monitoring Program effort, the storms that have occurred during the post-project period have been relatively benign. Further, drought conditions precluded data collection for almost a third of the post-project assessment period. The short timeframe of post-project monitoring has not generated conclusive results, and monitoring will be continued through the 2011-2012 water year.

The MBNEP's Monitoring Program will continue to collect physical substrate data during spring bioassessment surveys. This effort targets a rotating selection of creek sites on an annual basis and provides a spatially diverse assessment of substrate conditions across Los Osos Creek and Chorro Creek and their tributaries. Analysis of additional physical and biotic data to regional criteria will be completed as guidance resources become available.

Monitoring of Surface Elevation Tables (SETs) and marsh marker horizons will continue in the estuary and mudflats at a reduced frequency. As the initial data indicate low to moderate accretion rates, future monitoring is expected to be less frequent. The data collected to date does not support

the claim that the mudflats are currently subject to rapid and severe deposition, as they might have been during the 1990s. The SETs are intended to serve as a longer-term monitoring strategy for detecting change in mudflat and marsh elevations and reducing the recurrence of monitoring is not likely to affect data power or quality.

The Estuary Program remains committed to the protection and restoration of the Morro Bay watershed and Estuary. Program staff and partners are continuing to identify projects that will reduce erosion and transport of sediment to Morro Bay.

## LITERATURE CITED

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## APPENDICES:

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University of San Francisco Surface Elevation Table Monitoring Report

Environmental Protection Agency Surface Elevation Table Comparison Summary

Irrigation Training and Research Center Discharge Report

Chorro Creek Sediment Modeling

Walters Creek Sediment Modeling