Morro Bay National Estuary Program's

Implementation Effectiveness Program

For the Morro Bay Watershed

Sediment Monitoring Report

2014

Prepared for
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INTRODUCTION

The Central Coast Regional Water Quality Control Board adopted the Central Coast Basin Plan (Basin Plan) on March 14th, 1975. The Basin Plan included a broad array of water quality objectives, beneficial use designations, discharger implementation plans, and incorporated 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 Central Coast Regional Water Quality Control Board (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 estimates 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 TMDL identified five numeric targets for monitoring and plans to track the progress of voluntary and required implementation actions. The Morro Bay National Estuary Program (Estuary Program) was identified as the lead monitoring and reporting agency. 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.

This report details progress on monitoring for the numeric targets included in the TMDL and other indicators more recently adopted by the Estuary Program.

PROJECT BACKGROUND

The TMDL established four numeric targets for the streams in the Morro Bay watershed: pool volume, median gravel size diameter (D50), percent fines in substrate, and percent of course fines in substrate. The TMDL identified tidal prism volume as the primary numeric target for Morro Bay. The numeric targets are detailed in the TMDL table shown on the next page.

TABLE 1: MORRO BAY SEDIMENT TMDL NUMERIC TARGETS

Parameter	Numeric Target
Chorro and Los Osos Creeks and Tributaries Streambed Sediment	
Residual Pool Volume	v*= (a ratio) Mean values ≤ 0.21 (mean of at least 6 pools per sampling reach) Max values ≤ 0.45
Median Diameter (D50) of sediment Particles in Spawning Gravels	D50= Mean values ≥ 69 mm Minimum values ≥ 37 mm
Percent of Fine Fines (< 0.85 mm) in Spawning Gravels	Percent fine fines ≤ 21%
Percent of Course Fines (all fines < 6.0 mm) in Spawning Gravels	Percent course fine ≤ 30%
Morro Bay Estuary	
Tidal Prism Volume	4,200 acre-ft

The Estuary Program collected ambient creek turbidity data from sites throughout the Morro Bay watershed either monthly or bi-weekly from 2002 through 2014 as part of ongoing water quality monitoring. Outside of storm events, the ambient turbidity levels rarely exceeded the Central Coast Basin Plan levels of concern of 25 NTU for protection of aquatic life in cold water and 40 NTU in warm waters. Of 1,707 readings since 2002, 2.4% exceeded 25 NTU and 1.1% exceeded 40 NTU. The Estuary Program has not conducted monitoring of the other parameters due to the cost and expertise required.

Multiple studies have analyzed the accuracy of measuring turbidity as a surrogate for monitoring total suspended solids (TSS) or suspended sediment concentration (SSC). Turbidity monitoring is significantly faster and less expensive than monitoring SSC or TSS. However, although turbidity data has generally proven to be more accurate than other surrogate measures (such as discharge), there are limitations to its usefulness in quantifying suspended sediment load in surface waters (Ankcorn, 2003).

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 SSC data using updated United States Geological Survey (USGS) approved laboratory methods. Turbidity was measured in the laboratory on a subset of samples analyzed for SSC. The findings can be used to characterize instantaneous and storm event suspended sediment loads and potentially assess the effectiveness of best management practices (BMPs) implemented throughout the Morro Bay watershed. This project built on total suspended solids (TSS) data collected during the National Monitoring Program (NMP) paired watershed study during the 1990s and early 2000s.

While suspended sediment concentration is not required in the Morro Bay Sediment TMDL, many recently adopted TMDLs include this type of monitoring, and it is one of the most effective ways to quantify instantaneous sediment loading. Additionally, this expanded effort investigated the relationship between turbidity and suspended sediment concentration at each monitoring site. The relationships developed by this project may enable the monitoring of turbidity as a surrogate for SSC under certain conditions. Further, this dataset illustrates a more comprehensive assessment of ‘Wet Season’ turbidity levels in the Chorro Creek watershed.

While substantial data has been collected throughout this effort, this report will focus on the only series of storm events during the 2014 rain year that produced sufficient elevated stage to monitor for SSC. These storms occurred from February 26 to March 3, 2014, and approximately 2.6 inches of rain was recorded at the project’s rain gauge.

SUSPENDED SEDIMENT MONITORING EFFORT

Event SSC monitoring required the deployment of automated sampling equipment programmed to collect water samples on an even-timed interval during storm events. The Estuary Program utilized ISCO 6712 automated samplers housed in shelters at each monitoring site. Samples were drawn into ½-inch diameter polyvinyl tubing, sheltered by 1-inch electrical conduit and a 4-inch perforated PVC intake guard at the intake end. All samples were drawn from a fixed intake location near the low flow centroid of the channel. Due to budget and equipment constraints, equal width increment sampling and depth distributed sampling were not feasible. The representativeness of these fixed intake locations remains unverified.

Samplers were programmed manually by staff members and were not automatically activated by specified event conditions. Each sampler contained a set of 24 bottles that was manually retrieved and replaced at the conclusion of each sampling program. Sampling regimes varied by storm event and among field sites due to rapidly changing 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 Morro Bay Water Science Lab (MBWSL) located at Cuesta College. Due to the limitations associated with sample analysis by an outside laboratory, the Estuary Program established its own laboratory facility in 2007 through a cooperative agreement with Cuesta College. The school donated space in their newly-renovated physical sciences building to establish the Morro Bay Water Sciences Lab under the guidance of the Estuary Program. The MBWSL opened in January 2008 and is operated by the Estuary Program’s Monitoring Program.

The MBWSL conducts analysis for SSC 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 when monitoring for 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 et al., 2000). The results from the two methods can differ significantly when the sample is comprised of a significant fraction of sand-sized particles.

Samples were weighed upon arrival at the lab, labeled and then stored in a refrigerator until analysis. There is no specified hold time for SSC, however most samples were analyzed within 60 days of collection. Samples were vacuum filtered through tared glass fiber filters (47 mm, Whatman 934-AH) on a six position vacuum manifold and placed into a convection oven for drying. Samples with turbidity in excess of 500 NTU or with noticeable sand or sediment accumulation were partially filtered and then dehydrated in tared glass crucibles. When fully dried, sample filters and crucibles were removed from the oven and stored in dessicators until they were sufficiently cool for final weighing, yielding a sediment concentration value of mg/L for each sample.

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 MBWSL is a volunteer participant in the USGS Sediment Lab Quality Assurance (SLQA) program, which supplies single-blind quality assurance samples to participating laboratories twice a year. The MBWSL receives nine samples of an unknown concentration, conducts SSC analysis, and submits results electronically to the SLQA program. The program successfully participated in six years of biannual SLQA testing with the USGS. These quality assurance activities assess accuracy and precision of laboratory processes. See the report section titled "SSC Quality Assurance Measures" as well as Appendix A for 2013 to 2014 SLQA results.

The MBWSL conducts ongoing accuracy checks of equipment and procedures throughout the year. Balances are routinely checked with calibration weights and re-calibrated annually by a certified technician. The MBWSL operating procedures, protocols, and quality assurance measures are documented in detail as part of the Estuary Program's Quality Assurance Project Plan which is updated annually and undergoes review by the Environmental Protection Agency and Water Board. The MBWSL is a 'paperless' lab, and all incoming sample information and analytical results are recorded in an Access database. The database was designed specifically for operations at the MBWSL. The Access database is queried and printed out quarterly for off-site storage to prevent electronic data loss.

Accurate discharge data is critical in order to determine storm event suspended sediment loading estimates. In order to avoid ongoing labor-intensive discharge monitoring, stage-discharge relationships were developed for each site. Stage height (the height of the water surface) was correlated to the discharge (volume of water) to develop a rating curve. Discharge and stage data were collected over a wide range of conditions to develop the rating curve. Although discharge values had been periodically collected at the site on Chorro Creek at Canet Road (site code 310CAN) and San Luisito Creek (site code 310SLU) sites throughout the last twelve years, most of the monitoring had taken place at base-flow wadeable conditions. While this data was important for characterizing dry season conditions, there remained a need for data collected during storm events when streams were no longer wadeable. Collecting discharge measurements during non-wadeable flows required specialized equipment and training. These limitations prevented the Estuary Program or SLO County FC&WCD staff from collecting data during these events. To obtain this crucial high-stage data, the Estuary Program contracted with the Irrigation Training and Research Center (ITRC) at Cal Poly. Engineering staff at ITRC conducted high stage discharge monitoring throughout the project.

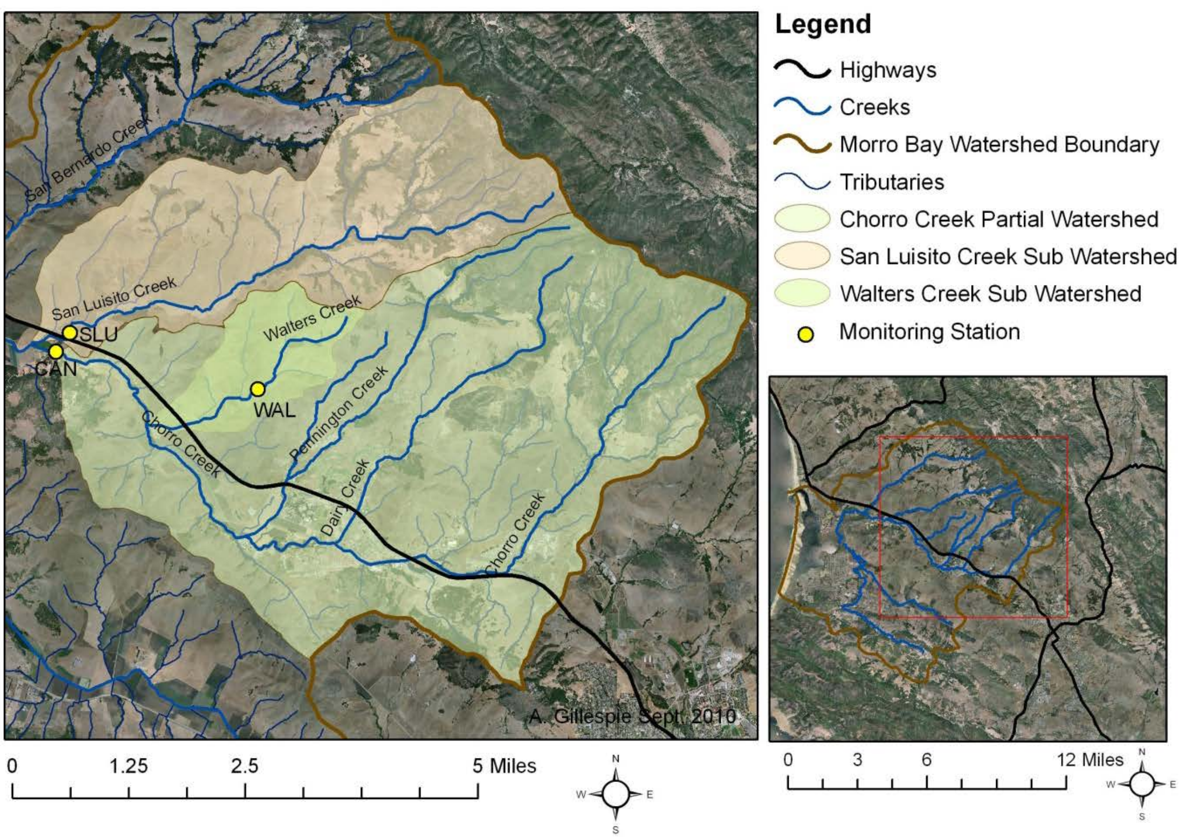
ITRC targeted flows greater than 50 cubic feet per second (cfs) at San Luisito Creek and flows greater than 200 cfs at Chorro Creek. Engineers utilized either a Marsh-McBirney Flo-Mate unit or a Sontek flow tracker mounted on the end of a specially designed stabilizing/measuring pole that was constructed for the project. The velocities at the San Luisito Creek site were especially high (greater than 10 feet/second at 180 cfs) and required that equipment be modified to provide stable readings and positioning under those conditions.

At each site, 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. Further, the hydrographs for these creeks were subject to rapid changes, mandating the need for fast measurement techniques. All measurements were completed by a two person field team. At the conclusion of the 2009 to 2010 water year, ITRC provided a final report that included a best-fit equation of flow rate versus upstream water depth for each site that incorporated the data that was collected throughout the previous three years.

SITE LOCATIONS

The Chorro Creek subwatershed drains runoff from approximately 43.4 square miles into Morro Bay and is estimated to contribute 86% of the total sediment load to Morro Bay (Tetra Tech, 1998). Three SSC monitoring sites in the Chorro Creek watershed were established that encompass a total watershed area of approximately 30 square miles. Monitoring sites are shown in Figure 1 below.

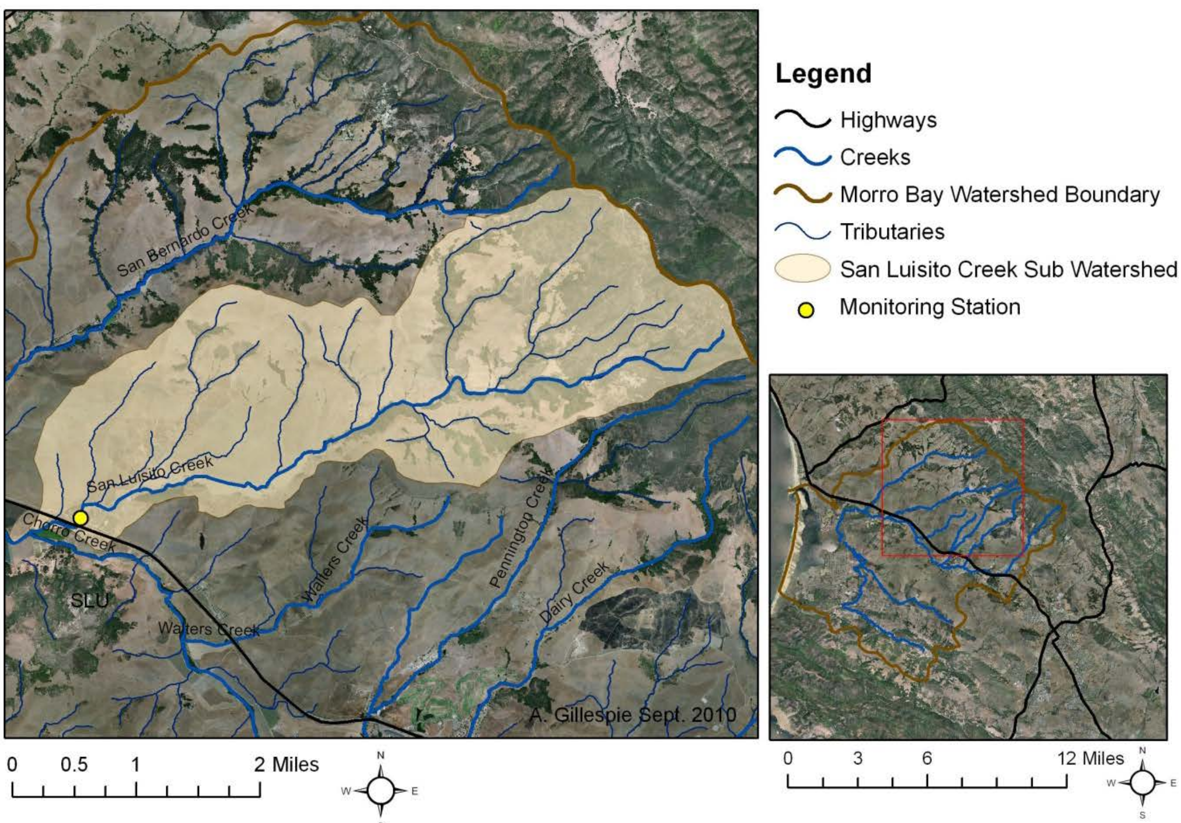
FIGURE 1: MORRO BAY SUSPENDED SEDIMENT STUDY AREA



SAN LUISITO CREEK AT ADOBE ROAD (310SLU)

The site located on San Luisito Creek at Adobe Road (site code 310SLU) includes drainage from approximately 8.28 square miles dominated by rangeland with light residential use (Tetra Tech, 1998). San Luisito Creek is a major tributary to Chorro Creek and joins at a confluence downstream of the Canet Road station. The Adobe Road bridge over San Luisito Creek was constructed in 1951, and the gauging station was established by SLO County Engineering Department in 1985 (Station 775). The site is an active San Luis Obispo County gauging station and is equipped with an H-500 XL data logger and potentiometer. In 2007, ALERT capability (radio with antenna) was added to the site, providing real-time data acquisition via the existing County ALERT network. In 2007, the Estuary Program installed an ISCO 6712 automated sampler and an Esterline KPSI pressure transducer to facilitate SSC monitoring. A rain gauge was installed at the nearby 310CAN station. Due to site conditions and close proximity to the Canet Road station, an additional rain gauge was not installed at 310SLU. The site was fully operational starting at the 2007-2008 water year.

FIGURE 2: SAN LUISITO CREEK SUBWATERSHED MONITORING AREA



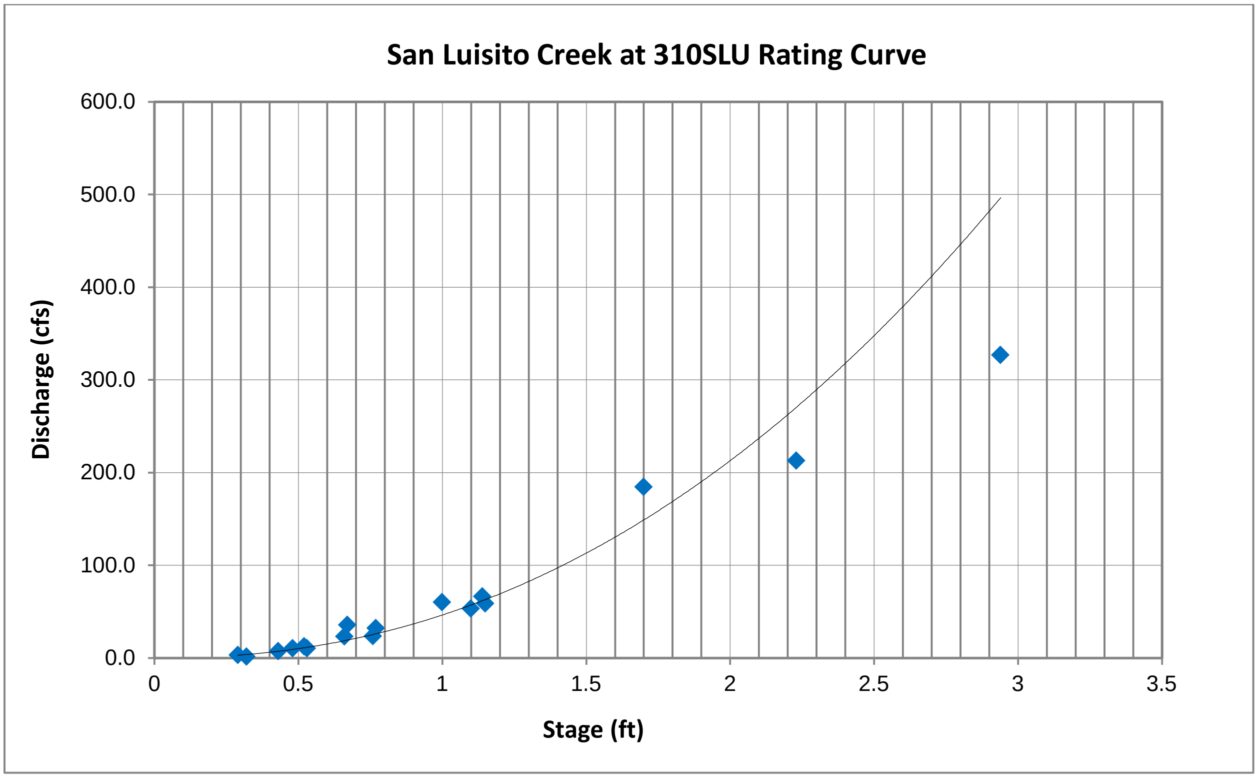
The design of the Adobe Road bridge crossing made the positioning of the sampler and sampling intake difficult. Sampling equipment was housed in a fiberglass shelter located on top of the bridge crossing. To instrument this configuration, the sampler intake line covered approximately 35 lateral feet with a 15 foot elevation gain. During low flows, San Luisito Creek flows through only one side of the double barrel bridge at a mean depth of about 0.02 feet. Positioning the intake along the center wall of the bridge would have prevented monitoring any events under approximately 7 cfs. Due to culvert sizing concerns and anadromous fish habitat regulations, construction of a flume or weir at the site was infeasible. After prolonged examination of all sampling intake options, a location was selected on the leading edge of one side of the concrete apron upstream of the crossing. This selection was made with acknowledgment of the risk of intake burial and the possibility of bedload sampling during major storm events. In order to reduce the amount of bedload being sampled in high flow events, another intake was installed directly on the culvert wall. This intake is approximately 0.45 feet from the channel bottom. Using the stage height – flow rate correlation (Figure 3), this stage height corresponds to flows of approximately 12.5 cfs.

Bedload is commonly defined as sediment that is transported by sliding, rolling or bouncing along the stream bed. Depending on the size of particles comprising the stream bed, the bedload may resist scour by stream velocities during higher frequency storm events (Edwards & Glysson, 1999).

The development of a rating curve was conducted by ITRC engineers from 2007 to 2010. High volume discharge measurements were conducted during storm events in December 2007, January 2008 and January 2010. The San Luisito Creek measurements were collected from atop the Adobe Road bridge over the creek. The creek flows through a 25 foot wide rectangular concrete channel under the bridge with a center wall. The 25 feet were divided into ten slices horizontally, and velocities were measured at relative 0.6 depths (rather than both 0.2 and 0.8) in each slice to be able to capture flows before they changed. At high flows, velocities were measured at relative 0.6 depths upstream of the center of each culvert. The velocity reading at the center of the culvert was assumed to be the average velocity in the culvert. All measurements were taken with either a SonTek Flow Tracker or a Marsh McBirney Flo-Mate (depending upon the flow condition and availability of devices).

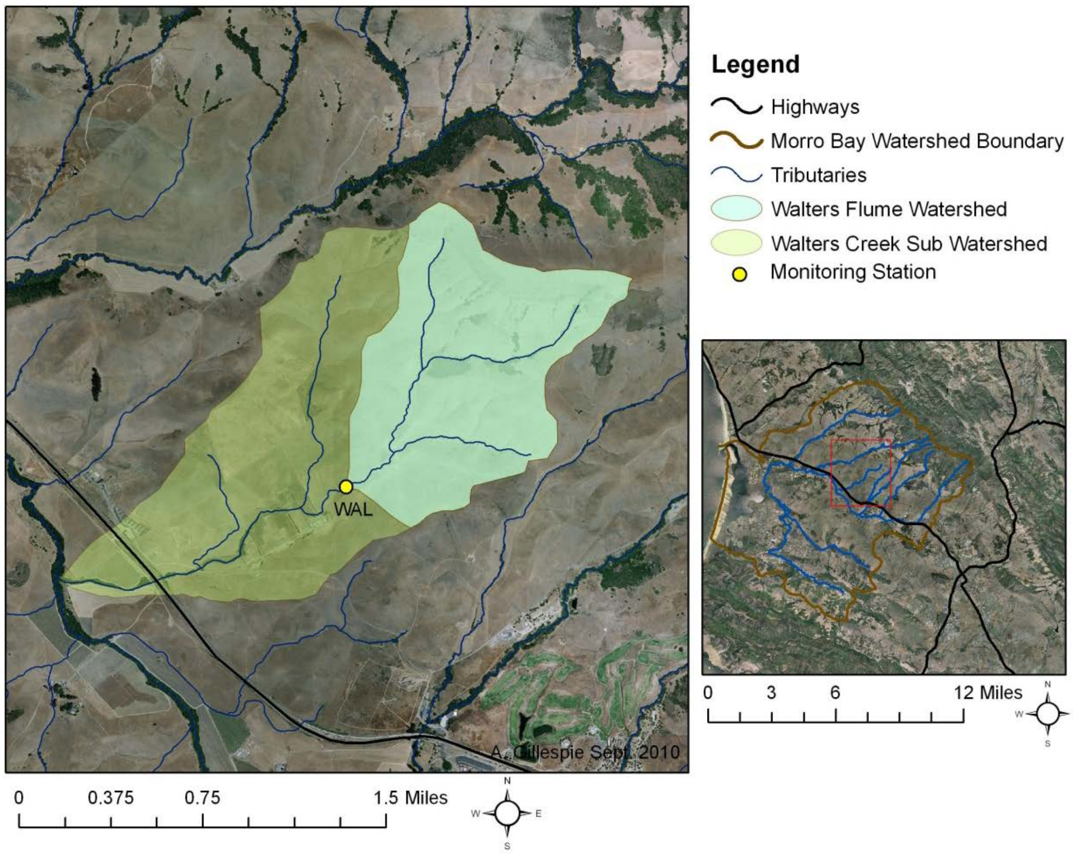
During a storm event at San Luisito Creek, the flow rate, in cfs, can be approximated by the equation Q (cfs) = $50Y^2$ where Y is the depth of water (in feet, measured via stage height readings) minus channel bottom elevation (0.12 ft) above the reference datum. This equation was used to estimate discharge volumes during the storm events detailed in this report. The stage discharge relationship for San Luisito Creek is shown below in Figure 3.

FIGURE 3: SAN LUISITO CREEK STAGE AND FLOW RATE CORRELATION



WALTERS CREEK (310WAL)

FIGURE 4: WALTERS CREEK STUDY AREA



The NMP study focused on monitoring effectiveness of BMPs at Chumash Creek during a pre-BMP period of 1993 to 1996 and post-BMP monitoring period of 1997 to 2001. In contrast to the BMP monitoring that took place at Chumash Creek during the NMP study, the Estuary Program's effectiveness monitoring spans a much longer time period before and after BMP installation. Recent Estuary Program suspended sediment monitoring examines the 1991 to 2001 NMP dataset as pre-BMP, and the 2008 to the present dataset as post-BMP. Thus, rather than monitoring the initial short-term effect of BMPs, the new dataset examines the longer-term net effect of BMPs at Walters Creek.

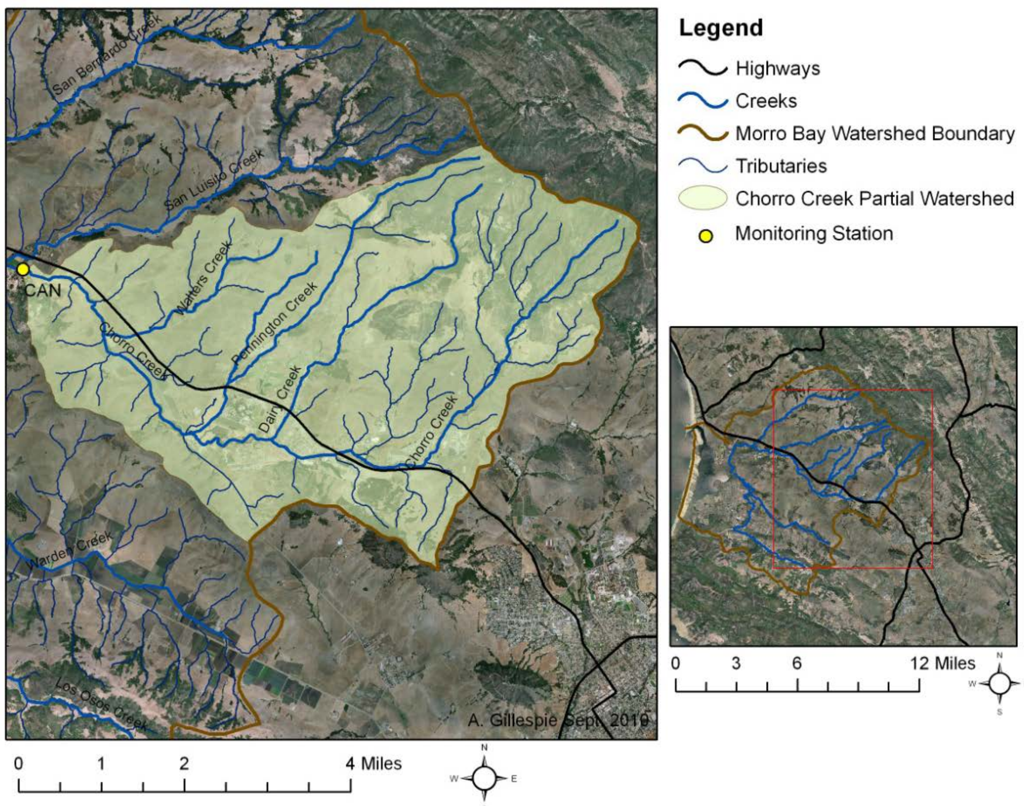
In order to generate consistent and comparable data, the Estuary Program implemented SSC monitoring at the same location as the NMP study. The existing structural components were repaired and re-instrumented for the new data collection effort. For consistency, the same sample intake was used for sample 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 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-BMP TSS data likely underestimated the true concentration of suspended sediment, but the site specific relationship between TSS and SSC data is unknown.

The Walters Creek monitoring station was re-equipped and operational for the 2008-2009 water year. However, the 2008-2009 water year did not generate any surface flows in Walters Creek. The 2009-2010 water year generated substantial surface flows during a few prolonged storm events. Analysis was conducted for two large storm events in January 2010. Following those events, the site has not been monitored due to lack of sustained flows.

CHORRO CREEK AT CANET ROAD (310CAN)

The Chorro Creek monitoring station at Canet road encompasses approximately 21.7 square miles of the 43 square mile watershed. The monitoring area includes the Pennington Creek, Dairy Creek, and Walters Creek tributaries, shown in Figure 5.

FIGURE 5: CHORRO CREEK, CANET ROAD SUB WATERSHED AREA



The intake location and equipment configuration complicated the sampling effort at this site. Consultation of historic hydrograph records prompted the decision to house sampling equipment at approximately 23.5 feet above the creek channel bed. Channel morphology is quite dynamic within this reach, with bottom elevations changing by up to three feet during storm events. After testing multiple configurations, the sampler intake was positioned at 6.2 feet on the staff gauge, approximately 1.5 feet above base flow stage height. To instrument this configuration, the sampler intake line covered approximately 85.0 lateral feet with a 17.0 foot elevation gain. Due to the raised elevation of the sampler intake, small storm events did not consistently submerge the intake to enable sampling.

The dynamic morphology of the channel bottom at this site were challenging to all parties involved in the project. Fluctuations in channel bottom elevation prohibited the creation of a highly reliable stage discharge relationship. However, it was determined that efforts to quantify high stage discharge volumes would still be a valuable component of the project.

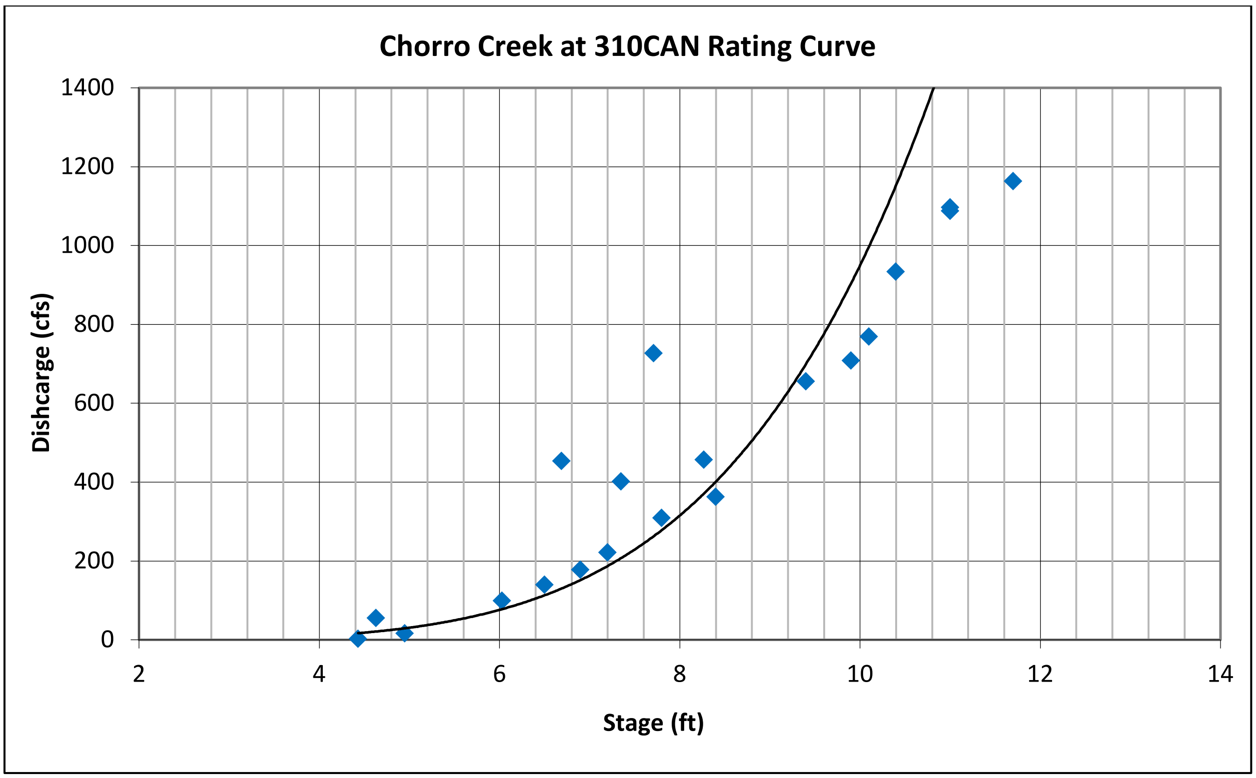
Discharge monitoring at 310CAN was conducted by ITRC engineers throughout the project. High volume discharge measurements were conducted during storm events in December 2007, January

2008 and January 2010. 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 ft^3/s can be approximated by: **Q (cfs) = 26$Y^{1.8}$** 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 Q was 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 (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. The stage discharge relationship for stage heights below 12.10 feet is shown in Figure 13.

FIGURE 6: ORIGINAL CHORRO CREEK STAGE DISCHARGE RELATIONSHIP



During the analysis of the data for this report, potential inaccuracies of the discharge calculations at low flows were identified. It was determined that this was caused by insufficient low flow data points on the rating curve and the inability of the curve to approach 0 cfs at low stage. Fifteen low flow discharge values from Estuary Program monitoring and the corresponding San Luis Obispo County Flood Control stage records were added to the curve. In the March 2010 ITRC Streamflow Measurement Summary Report, three discharge and stage values were not included in their rating curve. It is unknown why they were included in the curve above but excluded from the report. These three data points were also removed from the rating curve below.

FIGURE 7: AMENDED CHORRO CREEK RATING CURVE

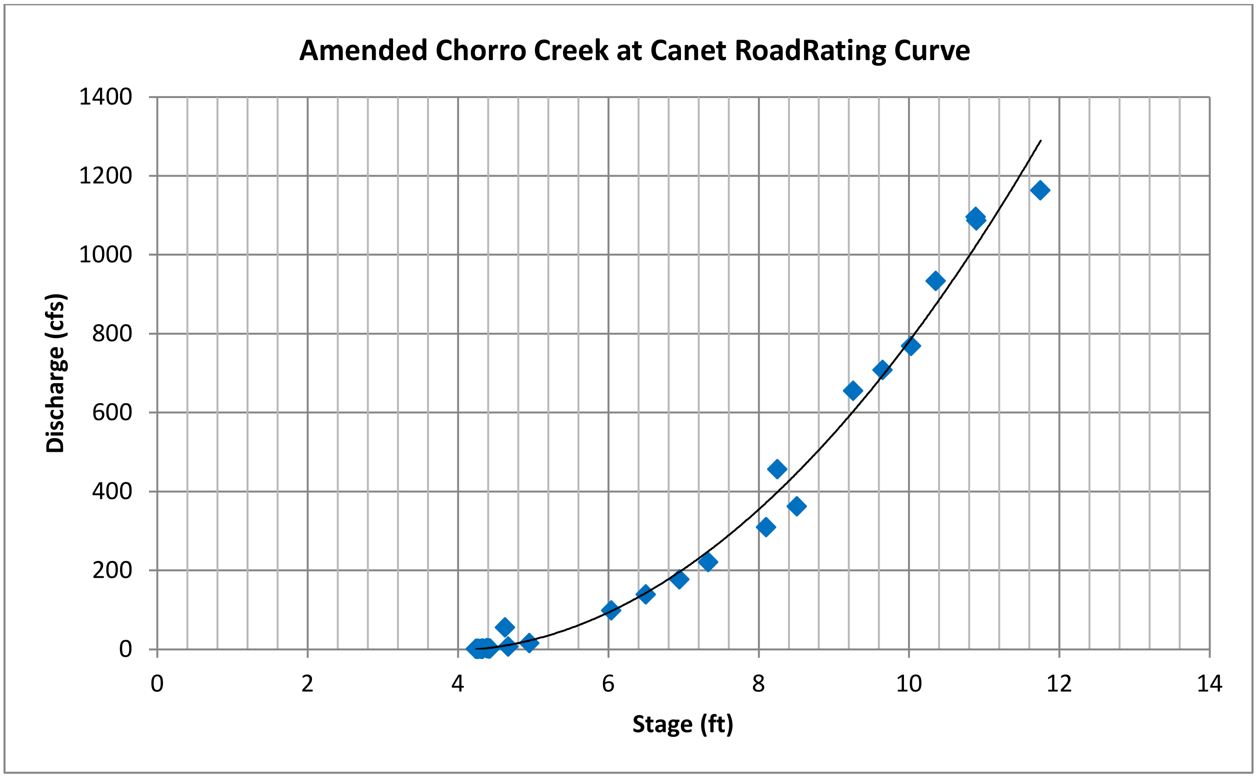


Figure 7 shows the amended rating curve with the removal of three data points and the addition of 15 low flow discharge values. Discharge for stage heights below 12.10 feet can be approximated by: **Q (cfs) = $20.907Y^2 - 5.8341Y$** where Y is the depth of water (in feet, recorded by the bubbler gauge) minus channel bottom elevation (3.75 ft) above the reference datum. This equation was used in the sediment load analysis of this report.

2014 WATER YEAR HYDROGRAPH

During the 2014 water year, a total of 6.8 inches of rain (as of July 25, 2014) was measured at the Canet Road rain gauge. Average annual precipitation for this gauge is approximately 21 inches. Due to extreme drought conditions, only one series of storm events produced sufficient elevated stage to monitor for SSC. This series of storms occurred from February 26th to March 3rd of 2014 and approximately 2.6 inches of rain was recorded at the Canet Road rain gauge.

310CAN and 310SLU were monitored for SSC. There was insufficient flow at 310WAL to deploy the sediment samplers.

FIGURE 8: 2014 WATER YEAR HYDROGRAPH-SAN LUISITO CREEK (310SLU)

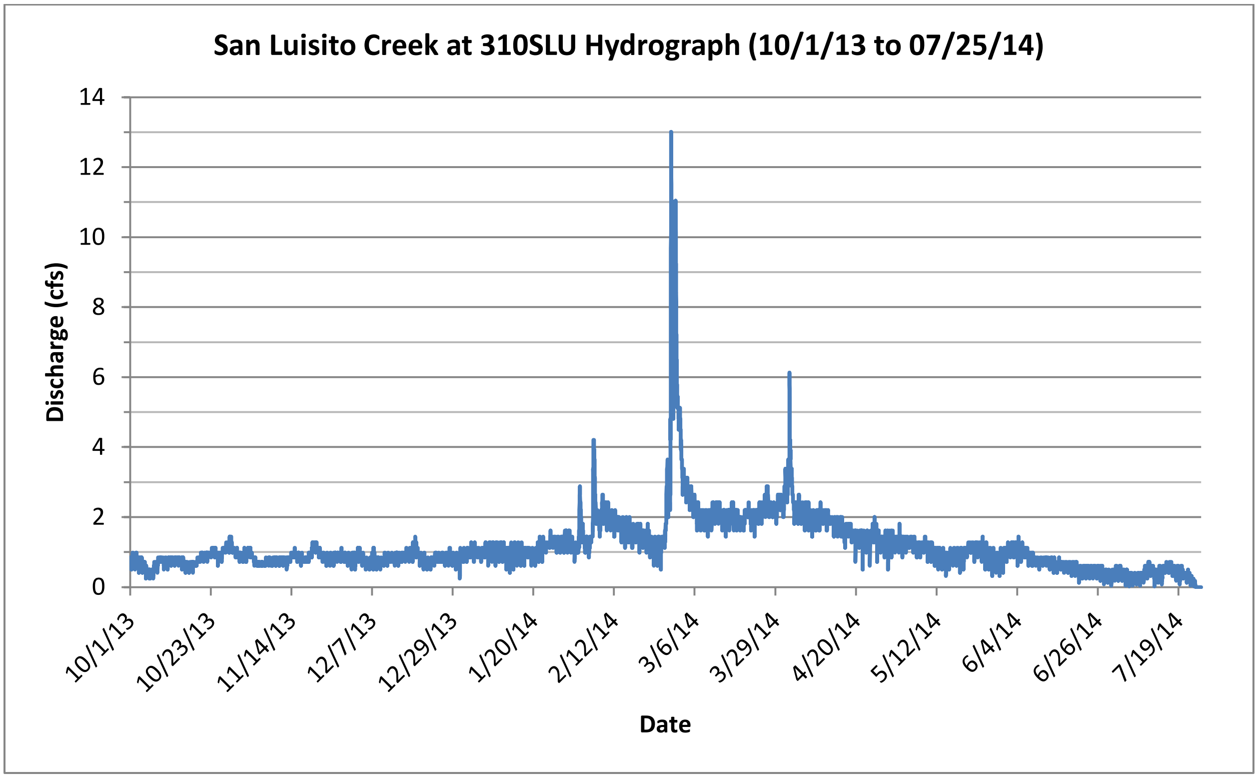


Figure 8 shows discharge (cfs) from October 1 , 2013 to July 25, 2014. Discharge values were calculated using stage heights from San Luis Obispo County Flood Control stage recorder and the rating curve outlined in Figure 3.

FIGURE 9: 2014 WATER YEAR HYDROGRAPH-CHORRO CREEK (310CAN)

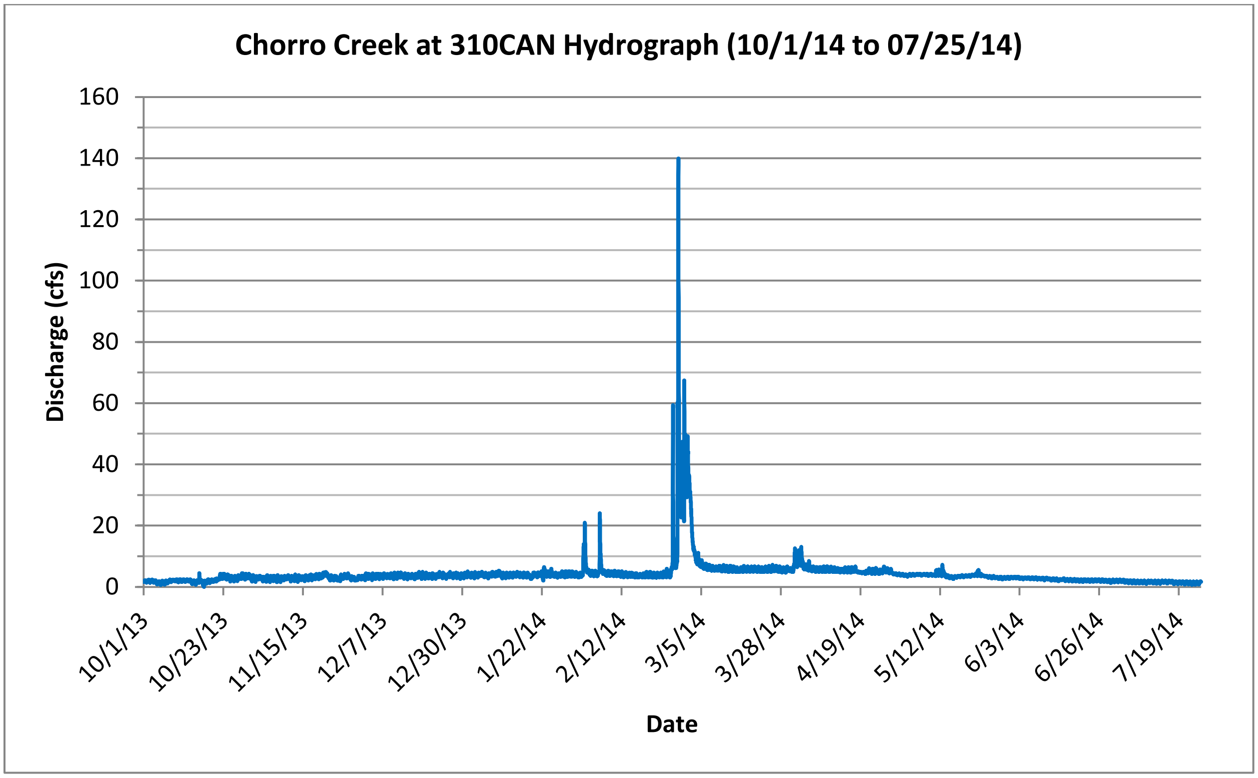


Figure 9 shows discharge (cfs) from October 1, 2013 to July 25, 2014. Discharge values were calculated using stage heights from San Luis Obispo County Flood Control stage recorder and the rating curve outlined in Figure 7.

FIGURE 10: EVENT HYDROGRAPH AND RAINFALL RATE

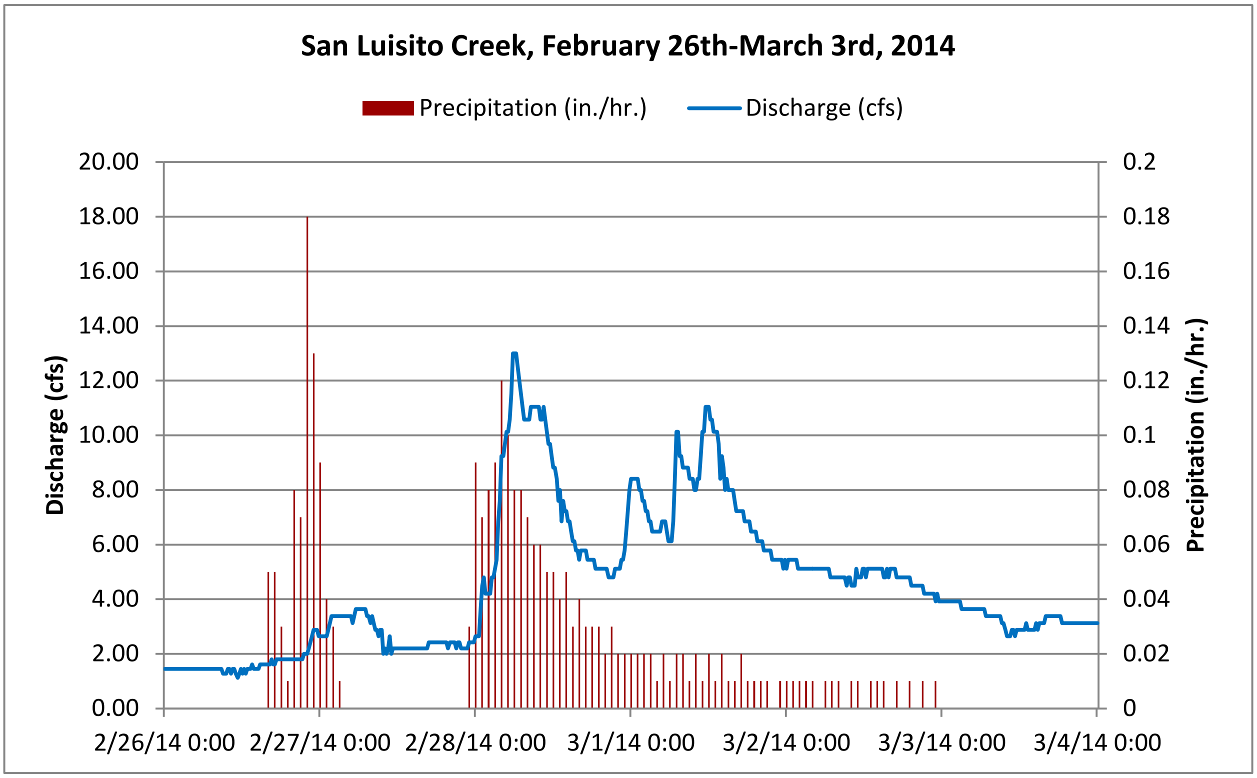


Figure 10 illustrates the rainfall measured at the Canet Road rain gauge over one-hour intervals and the discharge (cfs) of San Luisito Creek during the storm event. Approximately 2.6 inches of rain was measured at the Canet Road rain gauge from February 26th to March 3rd, 2014.

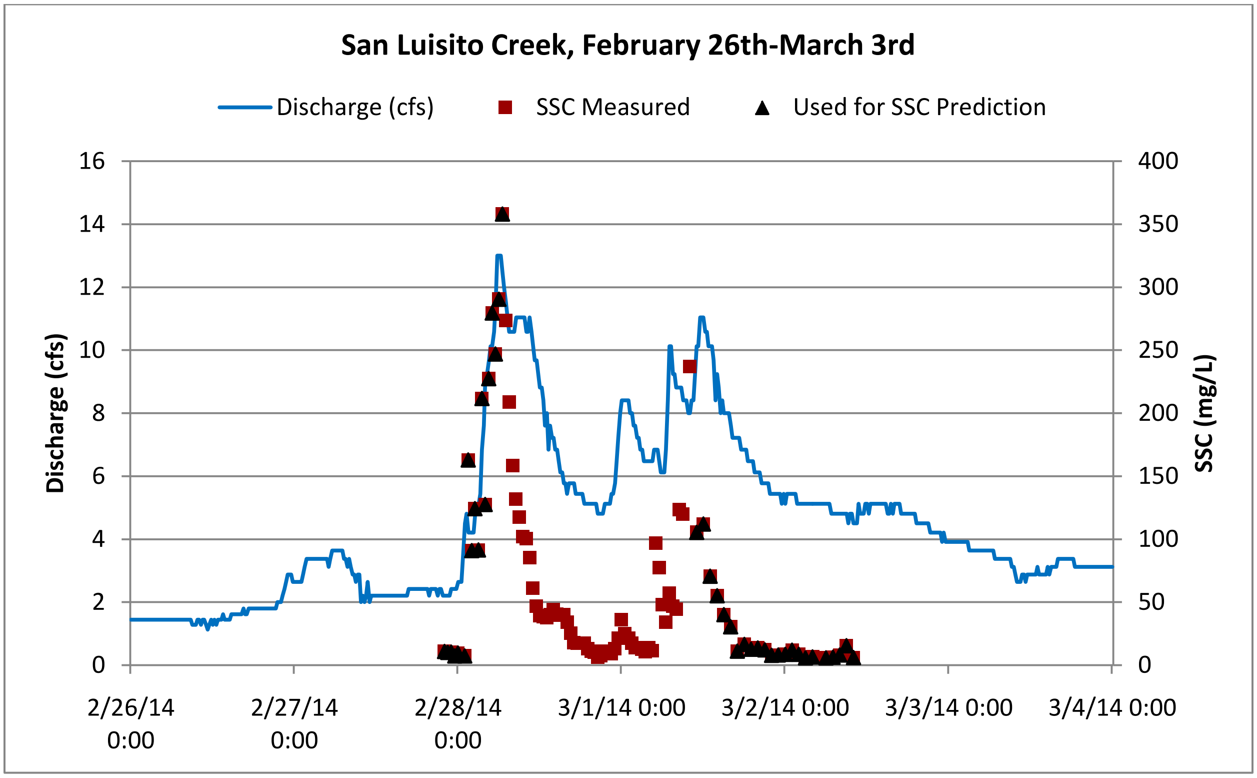
SAN LUISITO CREEK SEDIMENT SAMPLER DEPLOYMENT

Samples from the beginning of the storm on February 26 were not collected due to an error in the programming; however, there was no significant runoff during that time due to antecedent soil moisture conditions. The sampler was run from February 27 to March 1. All deployments were programmed for 30-minute intervals except for the last set which was programmed for one-hour intervals. SSC samples were collected for the majority of the storm event's hydrograph.

SAN LUISITO CREEK SSC AND DISCHARGE REGRESSION

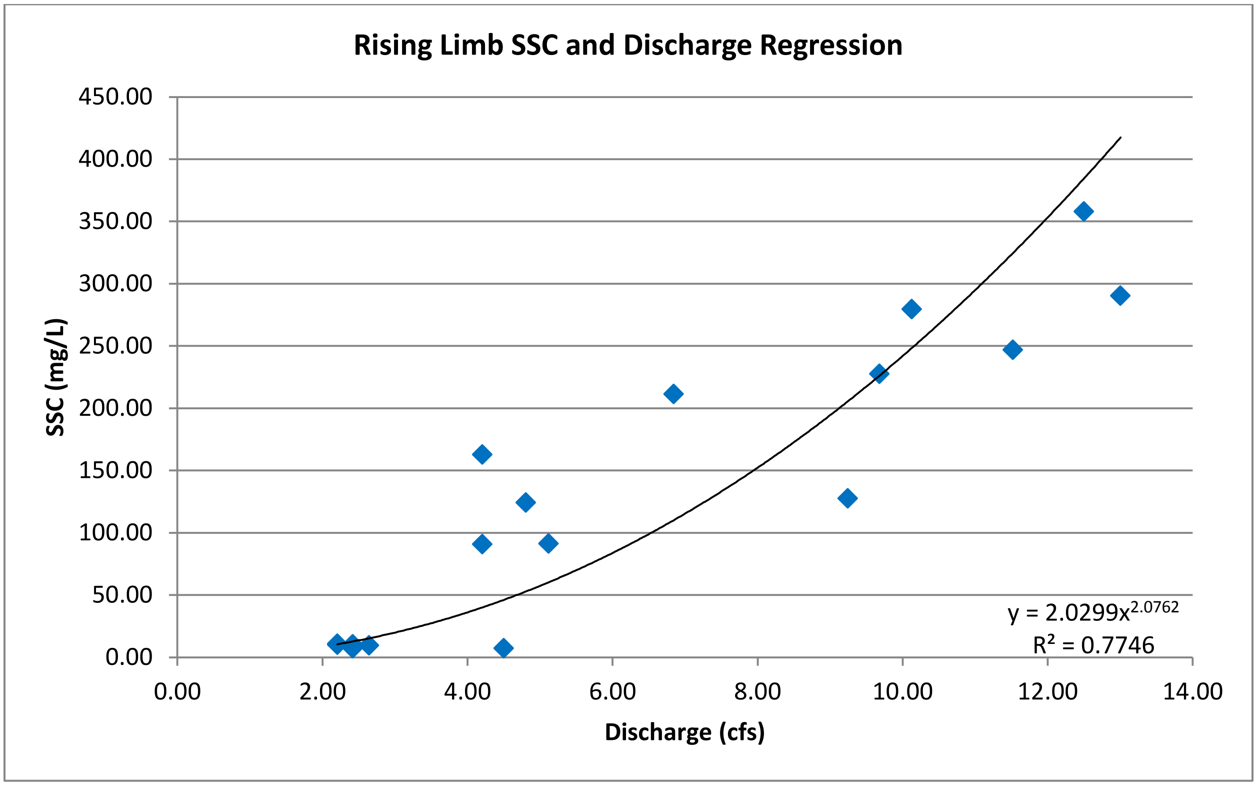
In previous reports, a single regression-derived equation was used to predict SSC values during unmonitored time periods. For the 2014 data, a strong correlation between discharge and all measured SSC values could not be produced. It was noted that during the storm event, runoff from nearby Adobe Road was discharging into San Luisito Creek near the sediment intake. This may have influenced the SSC samples collected. As a result, two regession equations were created using measured SSC values from two different portions of the storms event's hydrograph, the rising limb and the falling limb. These equations were used to calculate predicted SSC values for time periods that were not monitored.

FIGURE 11: COLLECTED SSC SAMPLES USED FOR SSC PREDICTION



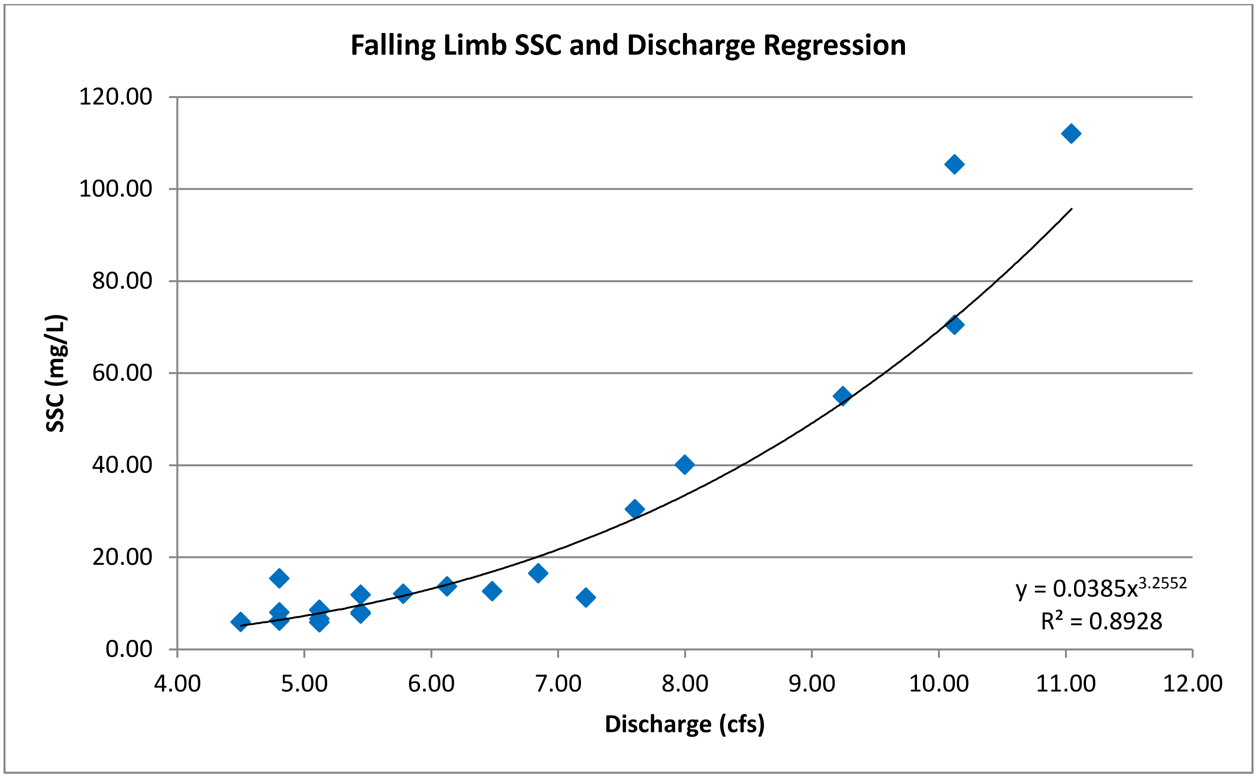
The SSC samples designated by ▲ were used in two measured SSC and discharge regression analyses. The measured SSC values from the rising limb of the hydrograph were used to predict SSC values from 16:00 on February 26 to 10:00 on February 27. Measured SSC values from the falling limb of the hydrograph were used to predict SSC values from 10:30 on March 2 to 00:00 on March 3.

FIGURE 12: RISING LIMB SSC AND DISCHARGE REGRESSION



The SSC and discharge correlation (shown in Figure 12) was used to generate estimated SSC values during the time period that was not monitored from 16:00 on February 26 to 22:00 on February 27. The measured SSC values were from the rising limb of the hydrograph. See Figure 11. The equation: $\mathbf{SSCpredicted = 2.0299X^{2.0762}}$ where X is discharge, was used to calculate predicted SSC values for the time period referenced above.

FIGURE 13: FALLING LIMB SSC AND DISCHARGE REGRESSION



The SSC and discharge correlation (shown in Figure 13) was utilized to generate estimated SSC values during the time period that was not monitored from 10:30 on March 2 to 00:00 on March 3. The measured SSC values were from the falling limb of the hydrograph. See Figure 11. The equation: $\mathbf{SSCpredicted} = \mathbf{0.0385X^{3.2552}}$ where X is discharge, was used to calculate predicted SSC values.

FIGURE 14: EVENT HYDROGRAPH AND SSC VALUES

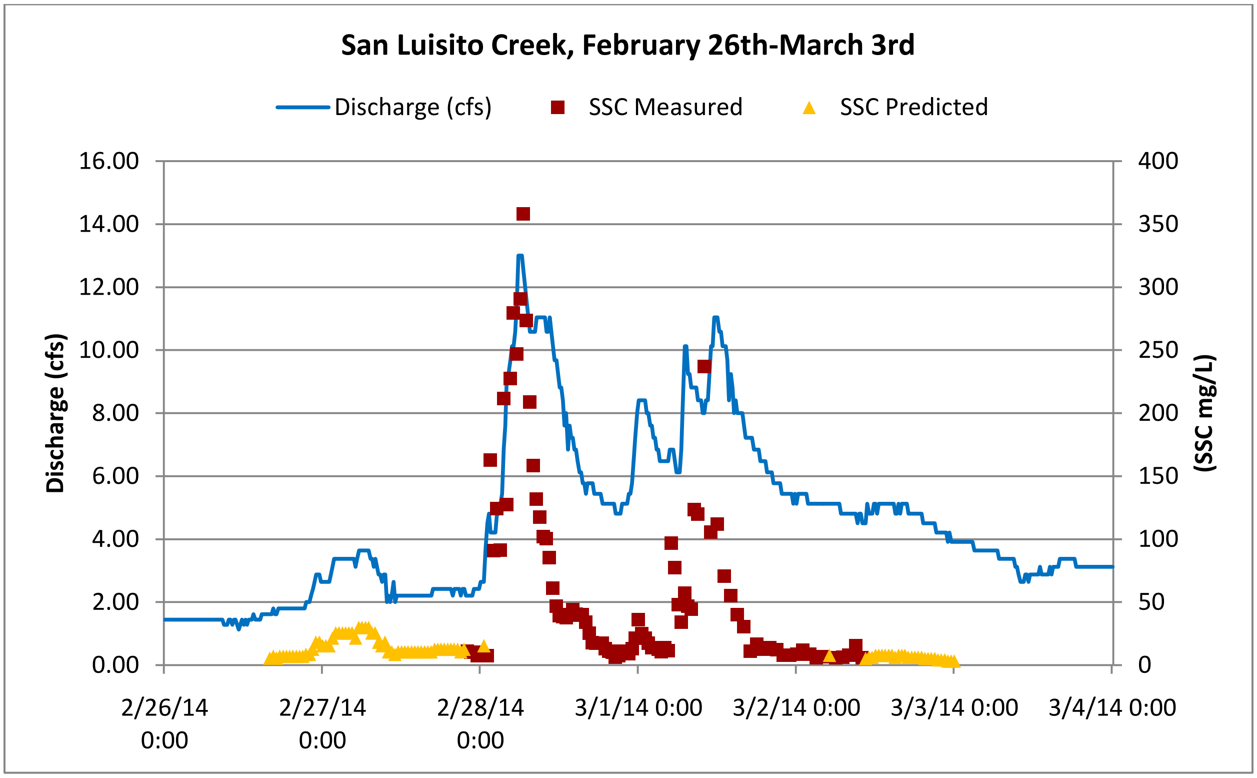


TABLE 2: EVENT DATA SUMMARY FOR SAN LUISITO CREEK

Data for 30-minute and one-hour intervals were compiled and summed to generate daily discharge and suspended sediment load estimates. For each time interval, the stage height measurement was used to calculate the discharge at the beginning of the interval. The SSC value at the beginning of the interval was applied to the discharge volume to generate a value for suspended sediment load for that interval.

Date	SSC Samples Analyzed	SSC Samples Estimated	Precipitation (in.)	Discharge (ac-ft)	Sediment Load (Short tons)
Feb. 26th, 2014	0	16	0.68	1.31	0.01
Feb. 27th, 2014	4	44	0.2	5.29	0.13
Feb. 28th, 2014	47	1	1.27	14.64	2.17
March 1st, 2014	33	0	0.33	15.10	1.14
March 2nd, 2014	10	29	0.16	9.72	0.10
Totals	**94**	**90**	**2.6**	**46.05**	**3.55**

FIGURE 15: SEDIMENT LOADING RATE AND HYDROGRAPH

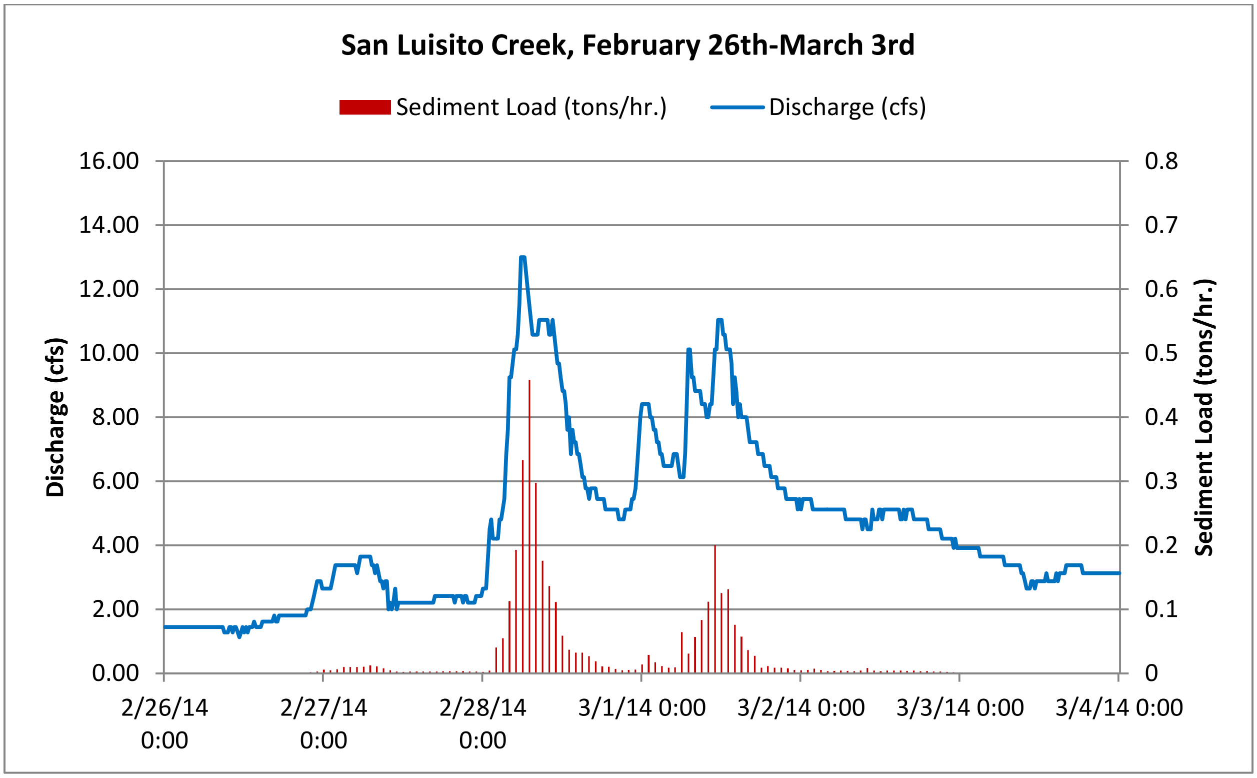


Figure 15 illustrates the sediment loading rate and discharge during the monitoring period.

CHORRO CREEK SSC MONITORING (FEBRUARY 26TH-MARCH 2ND)

FIGURE 16: EVENT HYDROGRAPH AND RAINFALL RATE

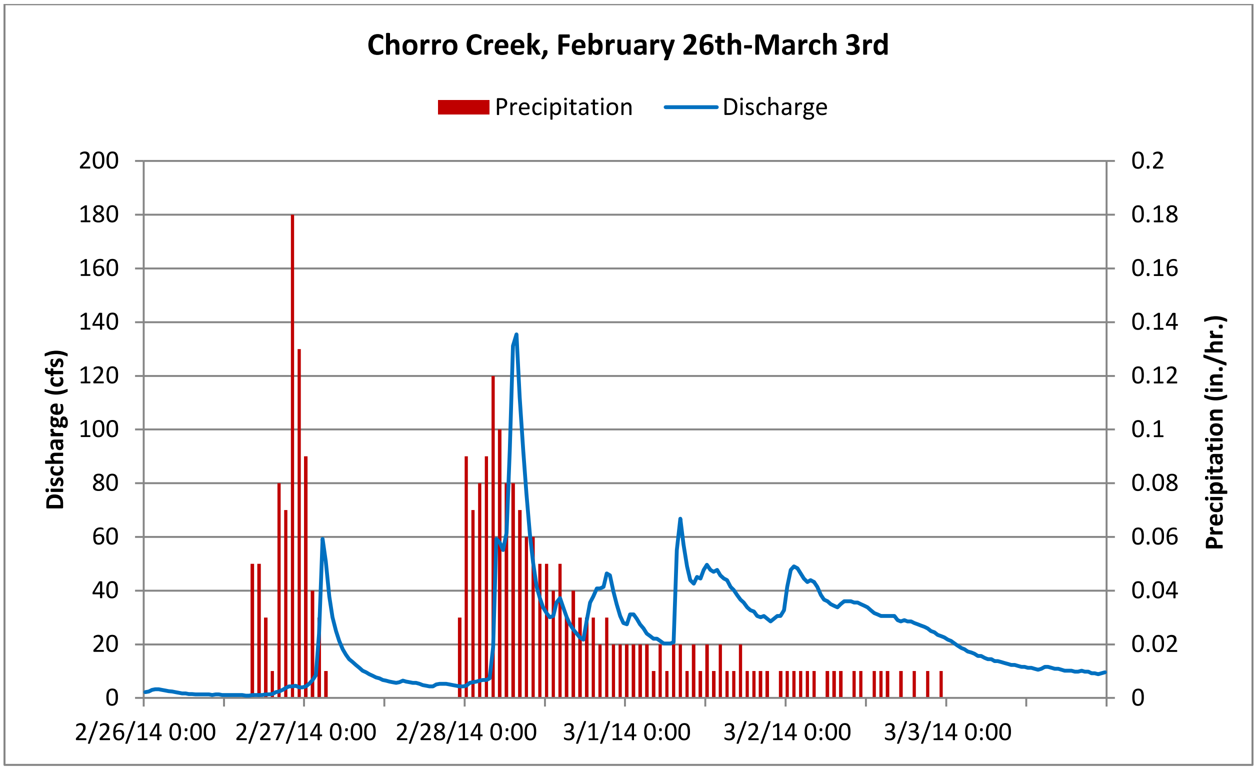


Figure 16 illustrates the rainfall measured at the Canet Road rain gauge over one-hour intervals and the discharge (cfs) of Chorro Creek during the storm event. Approximately 2.6 inches of rain was measured at the Canet Road rain gauge from February 27th to March 3rd of 2014.

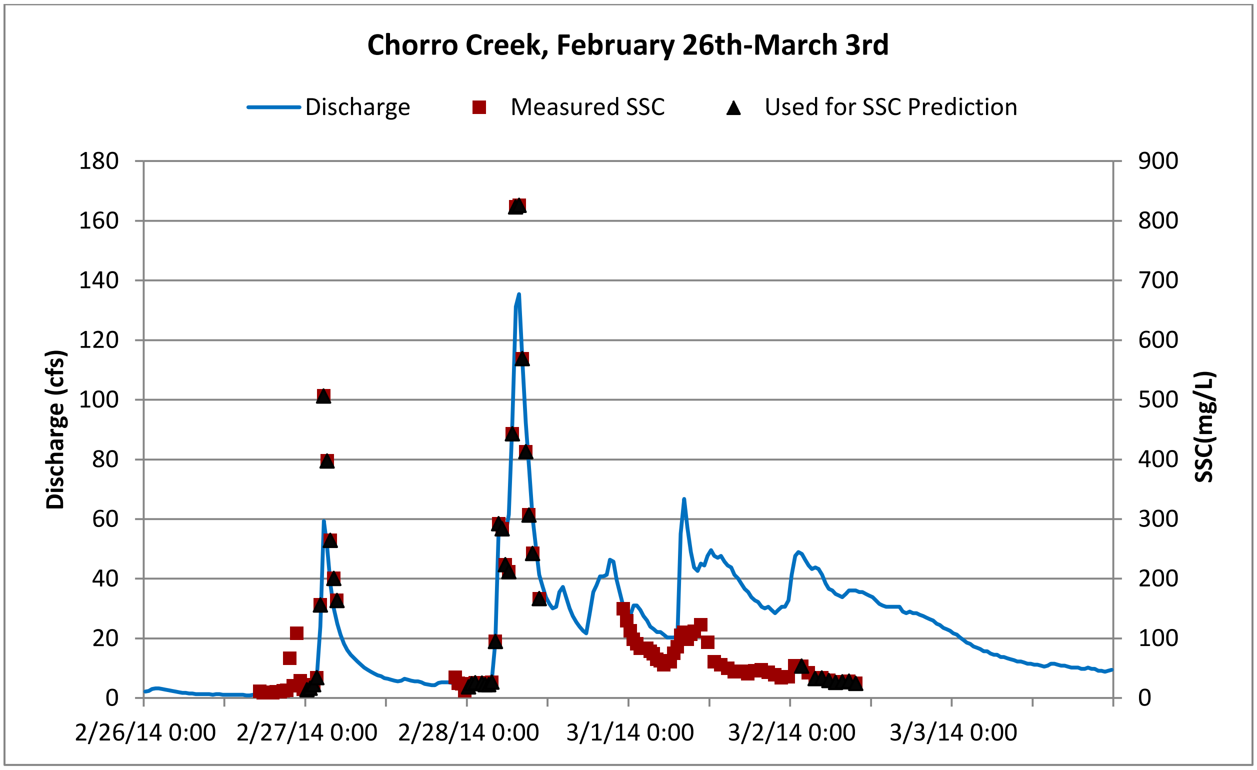
CHORRO CREEK SEDIMENT SAMPLER DEPLOYMENT SCHEDULE

The sampler was initial programmed to start at 17:00 on February 26th, and then on February 27 at 12:00, February 28 at 20:30, and March 1 at 10:30. All deployments were programmed at 30-minute intervals except the final deployment which was programmed at one-hour intervals.

CHORRO CREEK SSC AND DISCHARGE REGRESSION

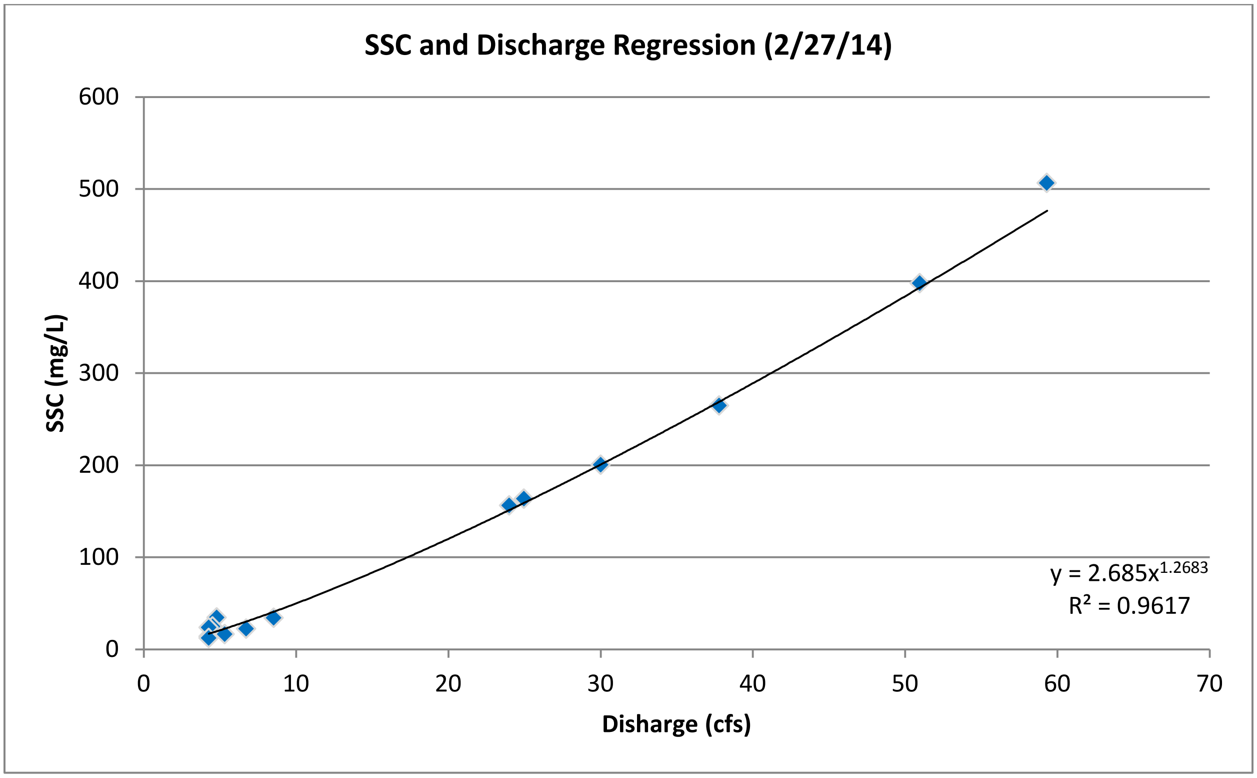
Again, a single regression-derived equation to predict SSC values for unmonitored time periods was not used. A strong correlation between measured SSC values and discharge could not be established. Instead, three separate equations were used.

FIGURE 17: MEASURED SSC SAMPLES USED FOR SSC PREDICTION



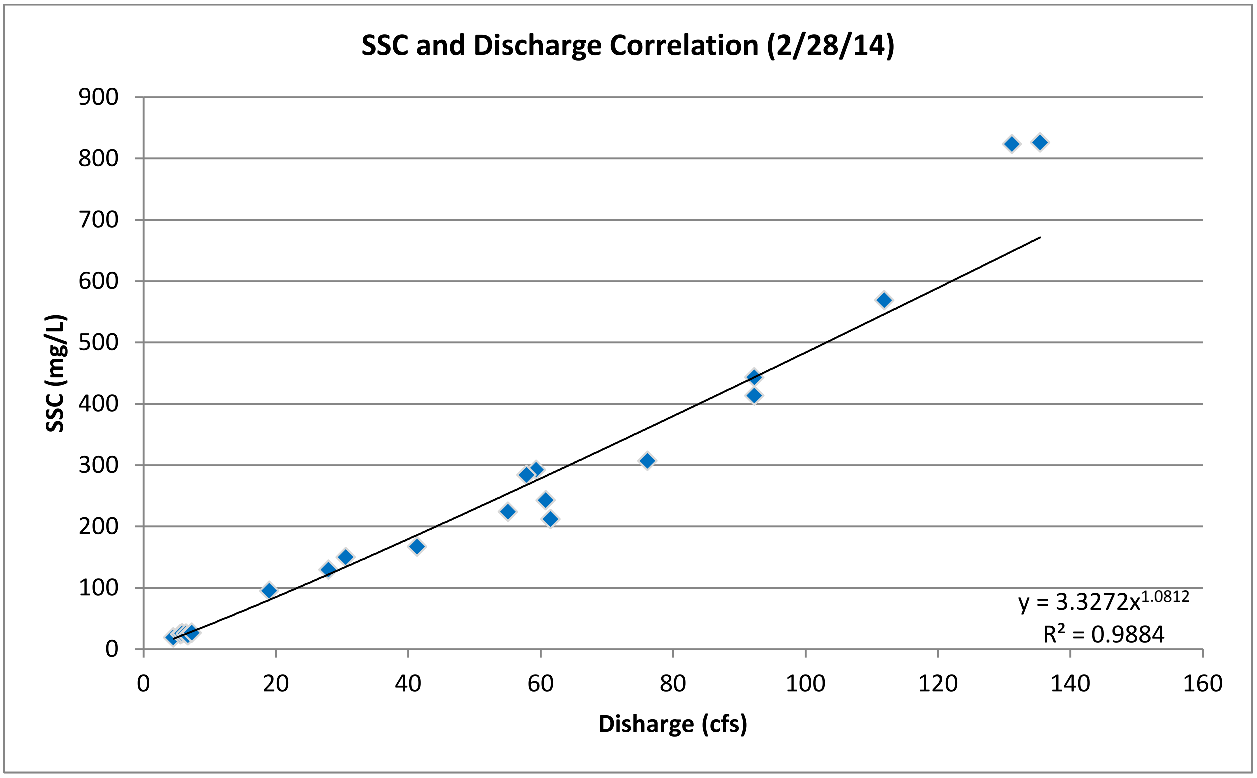
The SSC samples designated by ▲ were used in the three measured SSC and discharge regression analyse. The measured SSC values from the first portion of the hydrograph were used to predict SSC values from 5:00 to 21:30 PM on February 27. The measured SSC values from the center portion of the hydrograph were used to predict SSC values from 11:00 to 22:30 on February 28. The measured SSC values from the last portion of the hydrograph were used to predict SSC values from 10:00 on March 2 to 00:00 on March 3.

FIGURE 18: MEASURED SSC AND DISCHARGE REGRESSION (2/27/14)



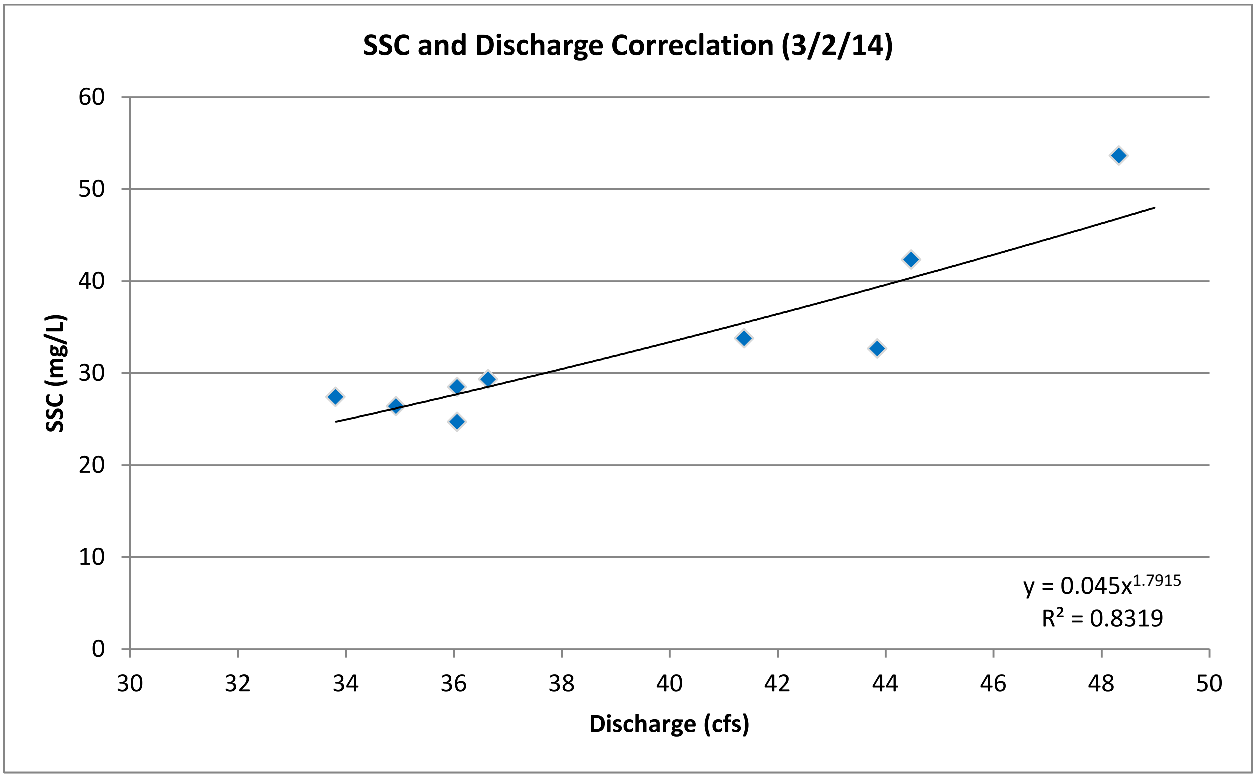
The SSC and discharge correlation (shown in Figure 18) was used to generate estimated SSC values during the time period that was not monitored from 5:00 to 21:30 on February 27. The measured SSC values are from the first portion of the hydrograph. See Figure 17. The equation: $\mathbf{SSCpredicted} = \mathbf{2.685X^{1.2683}}$ where X is discharge, was used to calculate predicted SSC values for the time period above.

FIGURE 19: MEASURED SSC AND DISCHARGE REGRESSION (2/28/14)



The SSC and discharge correlation shown in Figure 19 was used to generate estimated SSC values during the time period that was not monitored from 11:00 to 22:30 on February 28. The measured SSC values are from the center portion of the hydrograph. See Figure 17. The equation: $\mathbf{SSCpredicted = 3.3272X^{1.0812}}$ where X is discharge, was used to calculate predicted SSC values for the time period above.

FIGURE 20: MEASURED SSC AND DISCHARGE REGRESSION (3/2/14)



The SSC and discharge correlation shown in Figure 20 was used to generate estimated SSC values during the time period that was not monitored from 10:00 on March 2 to 00:00 on March 3. The measured SSC values are from the last portion of the hydrograph. See Figure 17. The equation: $\mathbf{SSCpredicted} = \mathbf{0.045X^{1.7915}}$ where X is discharge, was used to calculate predicted SSC values for the time period above.

FIGURE 21: EVENT HYDROGRAPH AND SSC VALUES

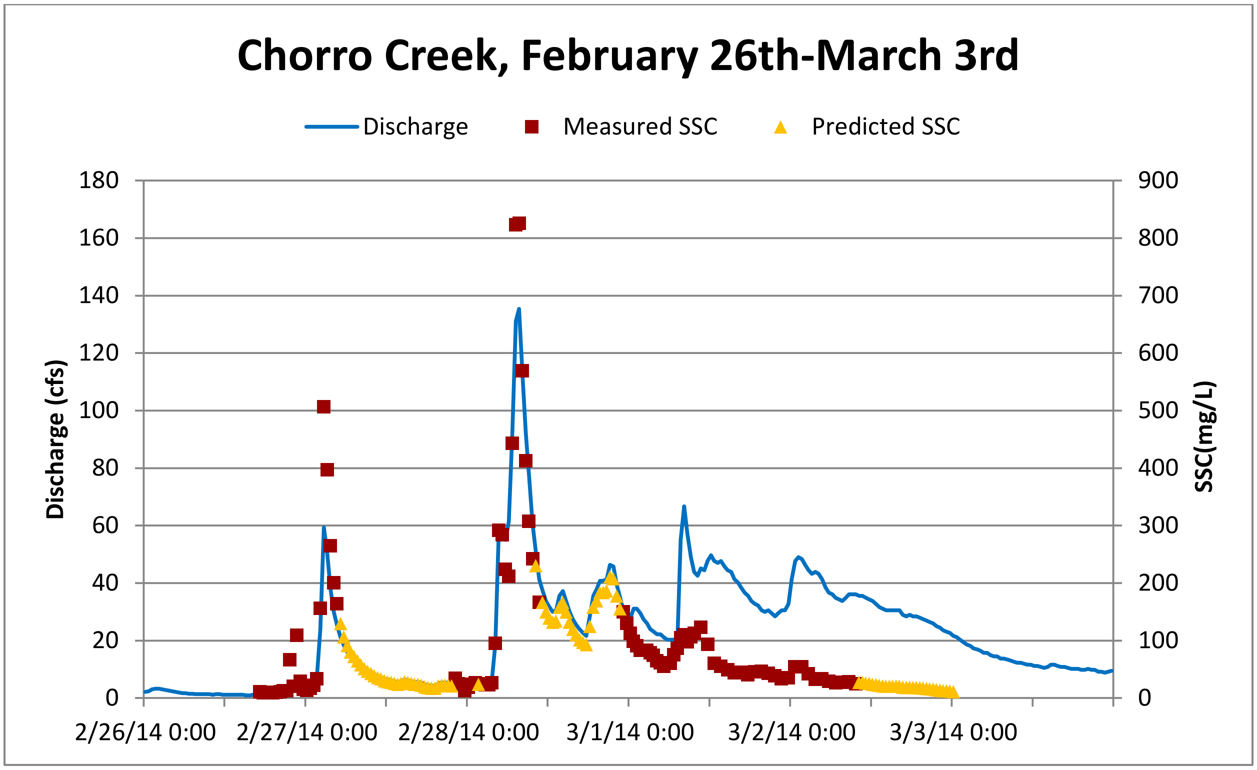


TABLE 3: EVENT DATA SUMMARY FOR CHORRO CREEK

	SSC Samples Analyzed	SSC Samples Estimated	Precipitation (in.)	Discharge (ac-ft)	Sediment Load (tons)
Feb. 26th, 2014	14	0	0.68	4.0	0.1
Feb. 27th, 2014	14	34	0.2	22.6	5.0
Feb. 28th, 2014	22	26	1.27	81.7	34.1
March 1st, 2014	33	0	0.33	70.6	7.0
March 2nd, 2014	10	29	0.16	66.9	2.7
Totals	**93**	**89**	**2.6**	**245.9**	**48.8**

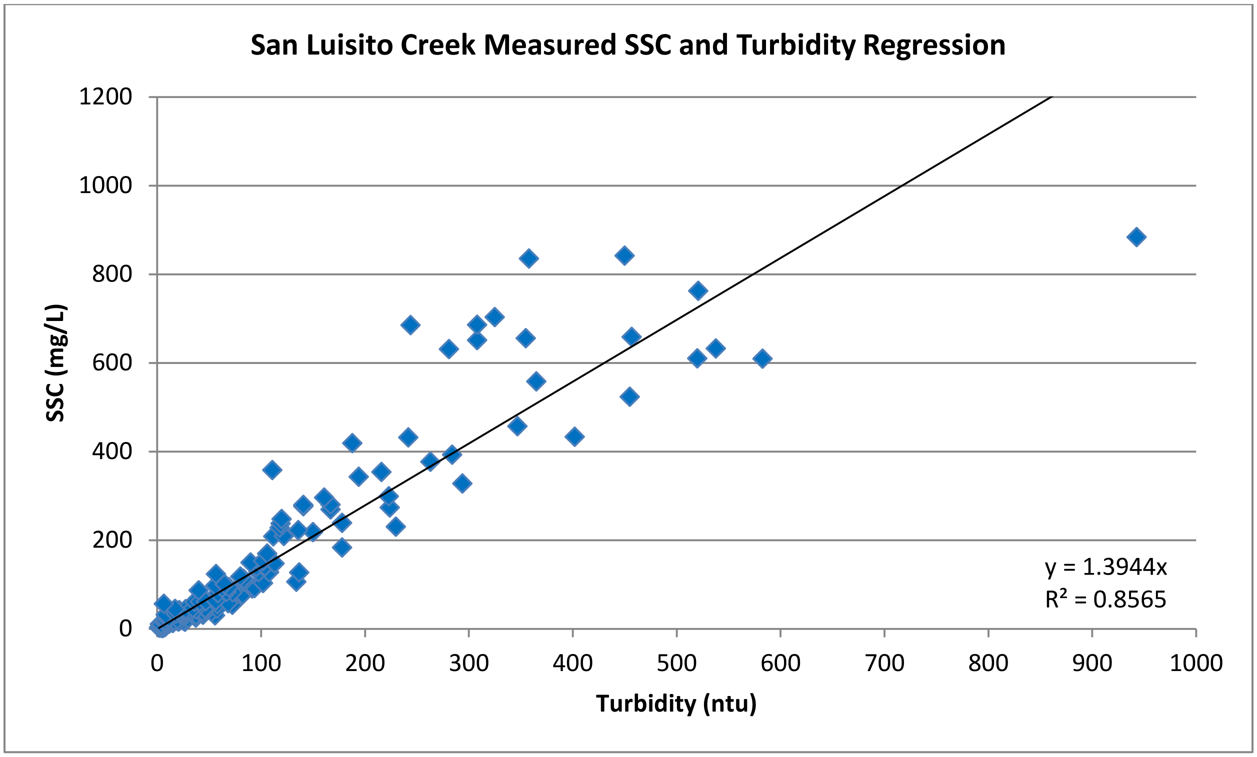
Data for 30-minute and one-hour intervals were compiled and summed to generate daily discharge and suspended sediment load estimates. For each time interval, the stage height measurement was used to calculate the discharge at the beginning of the interval. The SSC value at the beginning of the interval was applied to the discharge volume to generate a value for suspended sediment load for that interval.

USING TURBIDITY TO PREDICT SSC

One of the long term goals of the Estuary Program is to use turbidity to predict SSC. In order to do so a strong SSC and turbidity relationship must be developed.

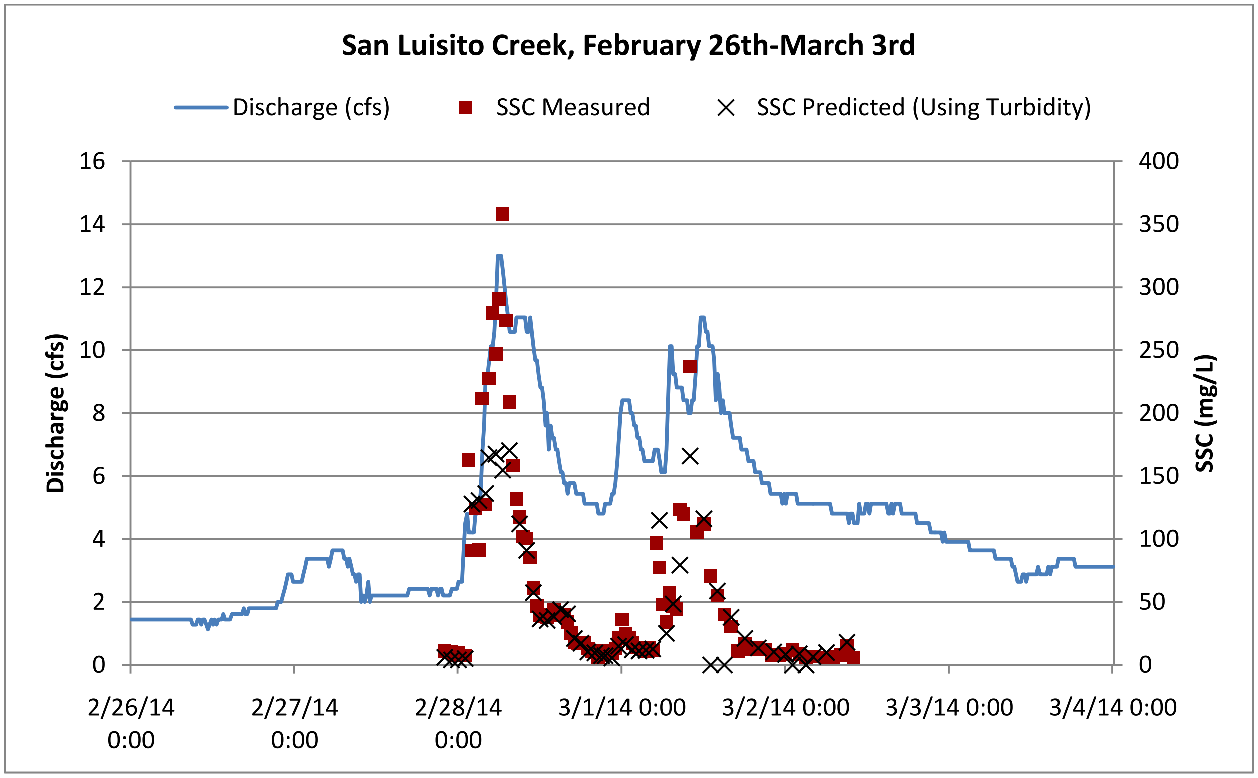
The graph below includes all SSC values below 1,000 mg/L and their corresponding turbidity values that the Estuary Program has measured since 2007 for San Luisito Creek.

FIGURE 22: SAN LUISITO CREEK TURBIDITY AND MEASURED SSC REGRESSION



The **equation** $\boldsymbol{SSCpredicted} = \mathbf{1.3944}(\boldsymbol{turbidity})$ was used to predict SSC values from 22:00 on February 27 to 10:00 on March 2.

FIGURE 23: SAN LUISITO CREEK MEASURED SSC AND PREDICTED SSC USING TURBIDITY



The graph above illustrates measured SSC values and predicted SSC values using the equation: $\boldsymbol{SSCpredicted = 1.3944(turbidity)}$. Turbidity was measured on every other SSC collected. Forty-seven SSC samples were measured for turbidity.

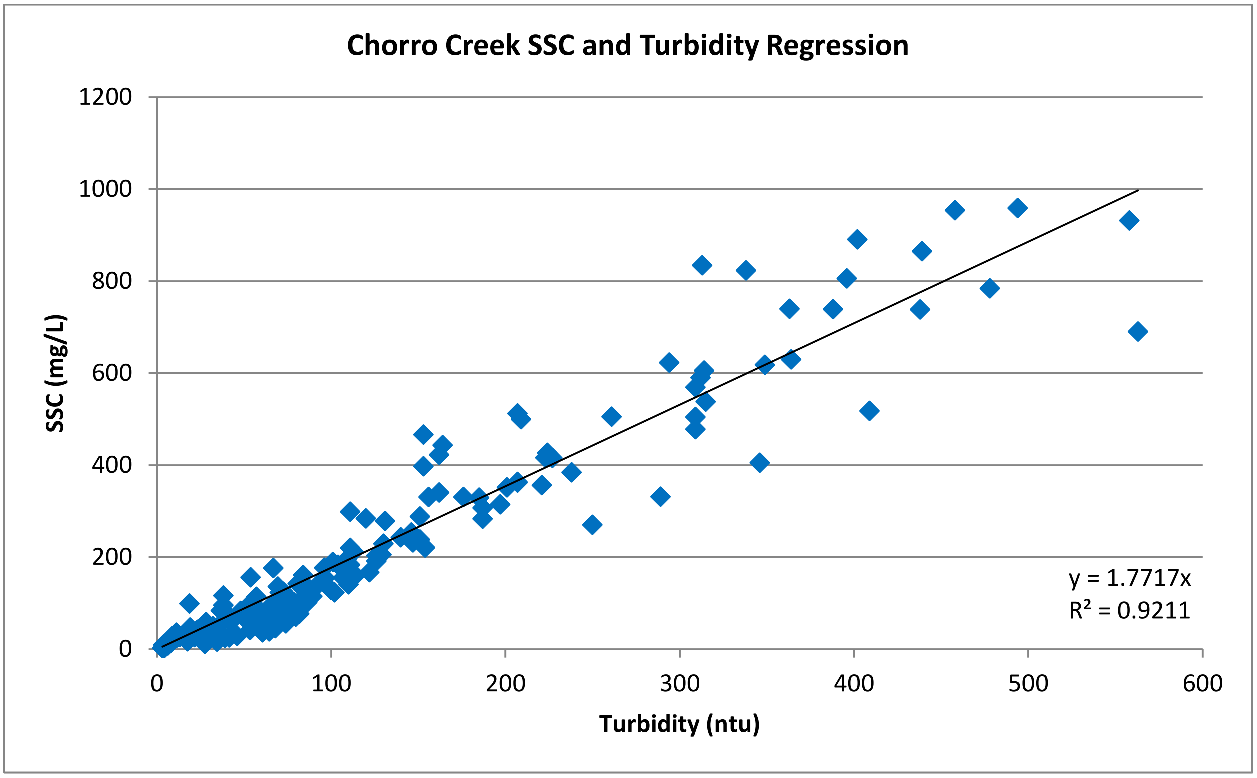
In the chart below, the sediment load is from time periods where the sediment load was derived from measured SSC values. Predicted SSC values from unmonitored time periods were not included. Because turbidity values were measured using every other SSC sample collected, the intervals were one and two hours. These values were then used to compute a sediment load using the same method previously stated in this report.

TABLE 4: SAN LUISITO CREEK MEASURED AND PREDICTED SEDIMENT LOAD

Date	Sediment Load Using Measured SSC (short tons)	Sediment Load Using Turbidity (short tons)
February 27th, 2014	0.01	0.00
February 28th, 2014	2.17	1.61
March 1st, 2014	1.14	1.11
March 2nd, 2014	0.05	0.06
Totals	**3.37**	**2.77**

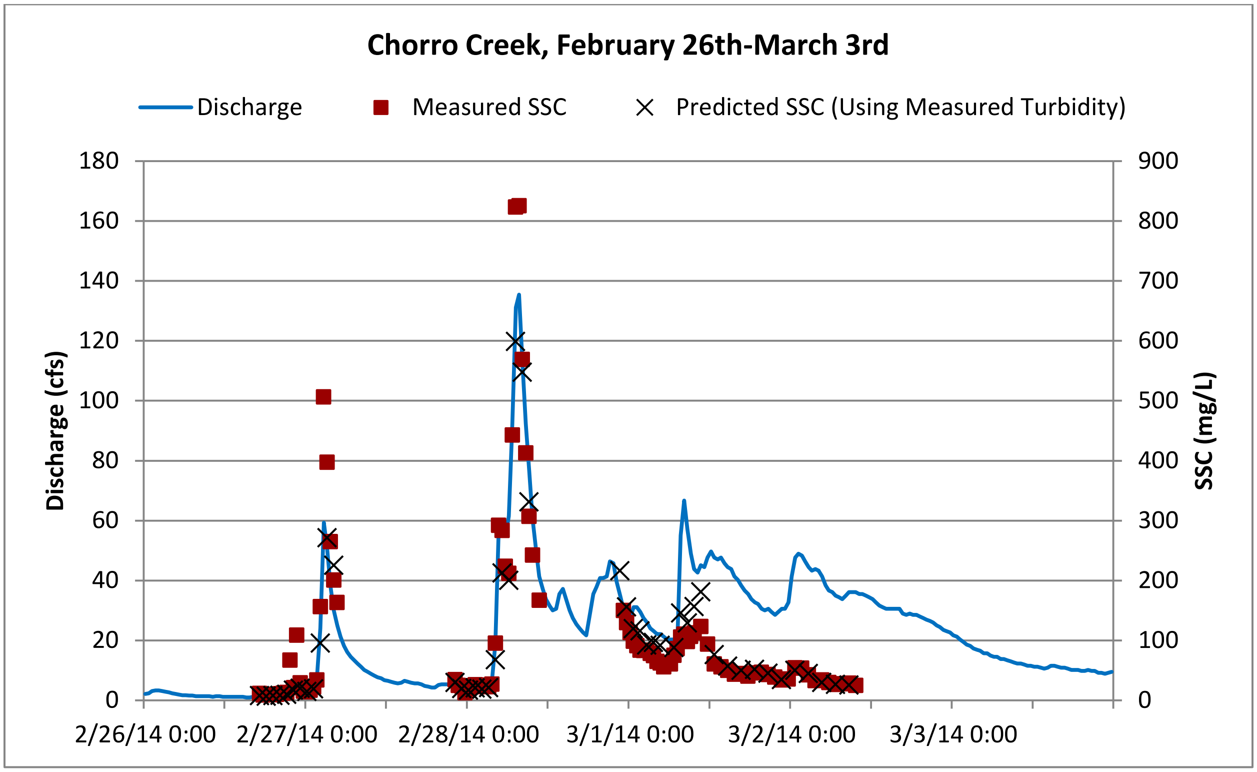
The graph below includes all SSC values below 1,000 mg/L and their corresponding turbidity values that the Estuary Program has measured since 2007 for Chorro Creek.

FIGURE 24: CHORRO CREEK TURBIDITY AND MEASURED SSC REGRESSION



The equation $SSCpredicted = 1.7717(turbidity)$ was used to predict SSC values from 5:00 PM on February 26 to 4:30 on February 27, 22:00 on February 27 to 10:30 on February 28, and 23:00 on February 28 to 9:30 AM on March 2.

FIGURE 25: CHORRO CREEK MEASURED SSC AND PREDICTED SSC USING TURBIDITY



The graph above illustrates measured SSC values and predicted SSC values using the equation: $\boldsymbol{SSCpredicted = 1.7717(turbidity)}$. Turbidity was measured on every other SSC collected. Forty-seven SSC samples were measured for turbidity.

TABLE 5: CHORRO CREEK MEASURED AND PREDICTED SEDIMENT LOAD

In the chart below, the sediment load was derived from measured SSC values. Predicted SSC values from unmonitored time periods were not included. Because turbidity values were measured using every other SSC sample collected, the intervals were one and two hours. These values were then used to compute a sediment load using the same method previously stated in this report.

Date	Sediment Load Using Measured SSC (short tons)	Sediment Load Using Turbidity (short tons)
February 27th, 2014	0.06	0.04
February 27th, 2014	3.63	2.55
February 28th, 2014	26.61	22.32
March 1st, 2014	6.98	8.10
March 2nd, 2014	1.68	1.63
Totals	**38.96**	**34.64**

PREDICTED SEDIMENT LOAD USING TURBIDITY ANALYSIS

According to Tables 4 and 5, both models used to predict sediment load produced values that were smaller than the measured values. This coincides with Figures 23 and 25 where both models tended to underestimate elevated SSC values.

Although the two models had varying degrees of error, they performed quite well, especially since the calculations used only 47 turbidity samples. Due to the fact that only half of the SSC samples were measured for turbidity, some samples with elevated SSC values were not measured for inclusion in the calculations. In the future, all SSC samples will be measured for turbidity.

The two models were inaccurate in varying amounts. The percent relative error for the results produced by the San Luisito Creek model was 17.8% while the percent relative error for the results produced by the Chorro Creek model was 11.1%. The error was lower for the Chorro Creek data because there was a stronger relationship between SSC and turbidity at Chorro Creek (r-squared = 0.9211) than there was at San Luisito Creek (r-squared = 0.8565).

In order to strengthen the model, more SSC and turbidity values must be added to the model, and statistical methods other than simple regression must be adapted. Despite some error in the current model, these preliminary results were promising.

SSC QUALITY ASSURANCE MEASURES

As part of efforts to ensure the quality of SSC data, the Estuary Program participates in the Sediment Lab Quality Assurance (SLQA) Project with the USGS Branch of Quality Systems. The USGS lab creates single-blind samples for SSC analysis by labs across the country. USGS provides triplicate samples from three ranges of sediment concentrations, one of which needs to be analyzed using a sand/fine split procedure. The individual labs analyze the samples and send the results to the USGS, which then compiles a summary report with results from all participating labs. This biannual quality control check provides an opportunity to verify that lab protocols, techniques, supplies and equipment are not introducing errors into the sample analysis process. The results from the fall 2013 and the spring 2014 rounds of SLQA testing are provided in Appendix A.

USGS presents the results as a sediment concentration percent difference, which is a measure of the difference between the known concentration of sediment in the prepared sample compared to the amount of sediment recovered by the individual lab. The results are usually negative percentages because typically sample is lost in the measurement process, rather than contamination being added to the sample. The results also provide a median percent difference value of all of the results as compared to the known sediment concentrations.

TABLE 6: RESULTS FOR SLQA PROGRAM, FALL 2013 AND SPRING 2014

SLQA Effort	SSC Target of QA Sample (mg/L)	Sample Replicate #	SSC Percent Difference for Estuary Program Analysis Compared to Known Concentration (%)	Average SSC Percent Difference for Estuary Program Analysis (%)	Median SSC Percent Difference for Results from All Labs (%)
Fall 2013	100	1	-4.83	-5.94	-4.21
		2	-6.46		
		3	-6.54		
	1,000	1	-1.89	-2.04	-1.57
		2	-2.16		
		3	-2.10		
	4,000	1	-0.68	-0.67	2.53
		2	-0.60		
		3	-0.72		
Spring 2014	50	1	-6.28	-5.85	-3.41
		2	-1.93		
		3	-9.34		
	750	1	-0.98	-1.01	-0.96
		2	-0.95		
		3	-1.11		
	4,000	1	-0.09	0.05	2.83
		2	0.21		
		3	-0.27		

No numeric targets are in place for assessing program accuracy. As demonstrated by the values in the above table, Estuary Program results were on par with the results from other labs across the country that participated in the SLQA Program.

STREAMBED SEDIMENT IMPAIRMENT INDICATORS

The relationship between aquatic health in a watershed and impacts due to sediment loading is of great interest in the regulation of sediment. Over a three-year period, researchers from the Sierra Nevada Aquatic Research Laboratory (SNARL) (associated with the University of California) 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. Initial analysis shows that the indicators are applicable in the Central Coast region.

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. The current SWAMP Bioassessment Protocol (SWAMP, 2007) metrics can be used to generate seven of the nine (in bold) sediment indicators, and six of the seven biological indicators (in bold). Since Estuary Program monitoring is conducted per the SWAMP protocol, only the indicators in bold in the list below are available for analysis. There are three threshold criteria for comparison of each of these indicators, shown in Table 7.

<u>Sediment Indicators:</u>

1. **Percent of Fines (F) on transects**
2. **Percent of 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 of Fines (Steelhead)**
9. **Percent Cover of Fines and Sands (BMI Limits)**

<u>Biological Indicators</u>

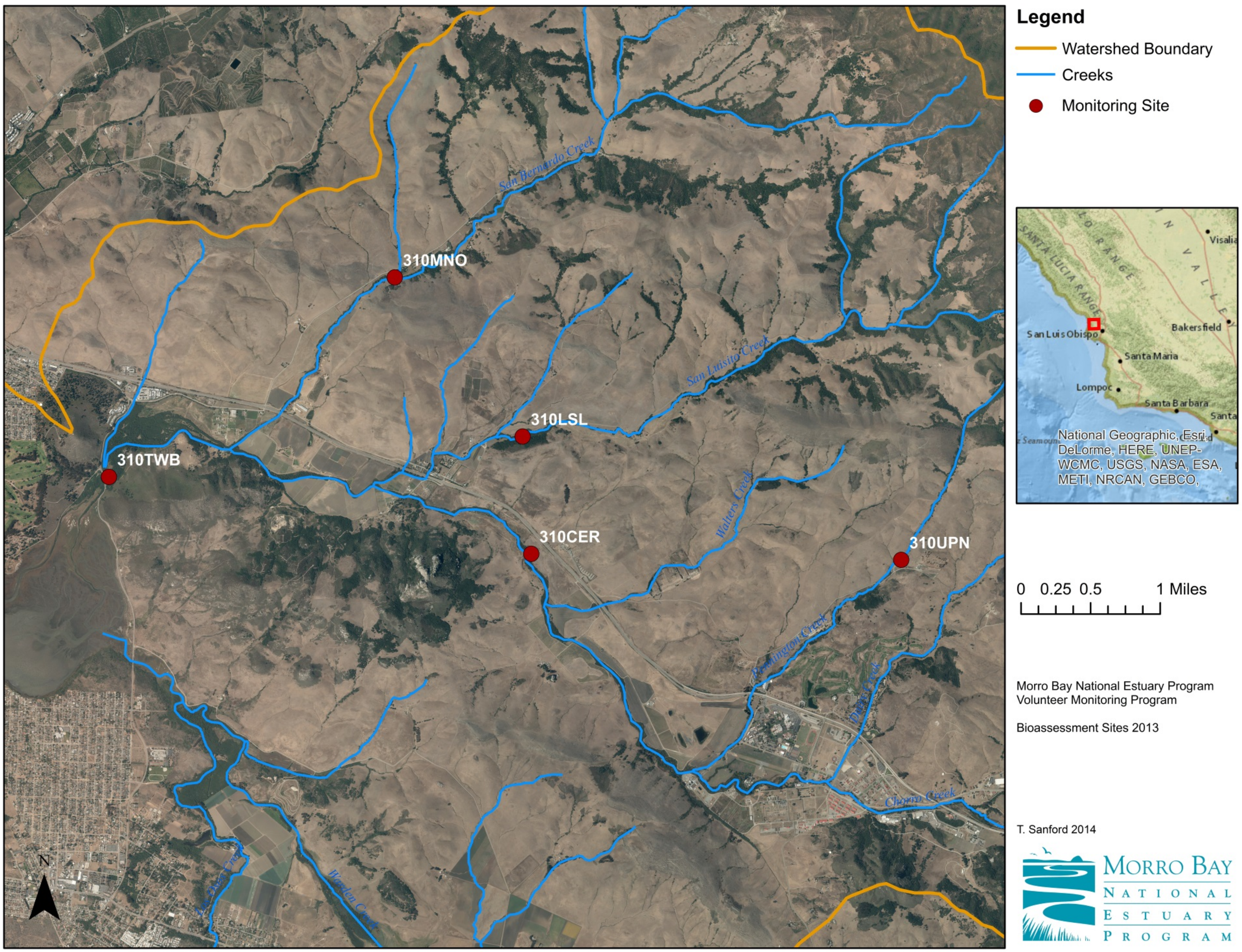
1. **Total Richness**
2. **EPT Richness**
3. **%EPT**
4. **Biotic Index**
5. **Percent Tolerant**
6. **Sensitive Number**
7. Crayfish Number and Size

TABLE 7: SEDIMENT AND BIOLOGICAL INDICATOR CRITERIA

	Recommended Numeric Targets To Support Beneficial Uses	Recommended Numeric Targets to Support Preliminary 303(d) Listing (lower priority)	Recommended Numeric Targets To Support 303(d) Listing (high priority)
Sediment Indicators		**75/25**	**90/10**
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
Percent Fines (steelhead)	<6%	6 to 10%	>10%
Percent cover of FS (BMI limits)	<30%	30 to 40%	>40%
Biological Indicators		**75/25**	**90/10**
Total Richness	>50.0	<50.0	<44.2
EPT Richness	>16.5	<16.5	<11.6
Biotic Index	<5.48	>5.48	>5.92
Percent Tolerant	<26.3%	>26.3%	>37.7
Sensitive Number	>9.5	<9.5	<5.8

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.

Five bioassessment monitoring sites were selected to be included in this analysis. These monitoring sites are located on Pennington Creek (310UPN), San Bernardo Creek (310MNO), San Luisito Creek (310LSL), Lower Chorro Creek (310TWB), and Middle Chorro Creek, (310CER). See Figure 26 for a map of the monitoring locations. The scores from 2008, 2010, 2012, and 2013 were averaged for all sites except 310TWB, which was not monitored in 2010.


Legend
Watershed Boundary
Creeks
Monitoring Site
310MNO
310LSL
310TWB
310CER
310UPN
San Bernardo Creek
San Luisito Creek
Walters Creek
Chorro Creek
Warden Creek
San Luis Obispo
Bakersfield
Santa Maria
Lompoc
Santa Barbara
Visalia
National Geographic, Esri, DeLorme, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO,
0 0.25 0.5 1 Miles
N
Morro Bay National Estuary Program
Volunteer Monitoring Program
Bioassessment Sites 2013
T. Sanford 2014
MORRO BAY NATIONAL ESTUARY PROGRAM

		Sediment Indicators							Biological Indicators					
Site Code	Survey Date	Percent Fines	Percent Sands	Percent <8	FS Sum Percentage	D50 Median particle size	Percent Fines (steelhead)	Percent cover of FS (BMI limits)	Total Richness	EPT Richness	Percent EPT	Biotic Index	Percent Tolerant	Sensitive Number
310UPN	2008	1.9	12.38	20	14.29	25	1.9	14.29	62	17	18.37	4.95	9.68	14.0
310UPN	2011	2.86	15.24	19.05	18.1	120	2.86	18.1	59	25	64.42	4.26	0.37	13.0
310UPN	2012	0.97	16.5	17.48	17.48	63.5	0.97	17.48	56	21	48.45	4.02	8.93	15.0
310UPN	2013	2.88	7.69	14.42	10.58	100.5	2.88	10.58	70	24	32.63	4.49	5.71	17.00
310MNO	2008	0.00	24.76	26.67	24.76	20	0.00	24.76	64	20	50.4	4.7	9.38	10.0
310MNO	2010	0.97	23.30	30.10	24.27	14	0.97	24.27	42	14	61.82	4.7	7.14	5.0
310MNO	2012	2.94	9.80	14.71	12.75	37	2.94	12.75	69	22	42.81	4.76	8.7	10.0
310MNO	2013	2.94	7.84	18.63	10.78	31	2.94	10.78	66	18	18.95	5.65	9.09	14.0
310LSL	2008	5.71	19.05	33.33	24.76	12	5.71	24.76	55	14	25.22	4.48	12.73	9.0
310LSL	2010	11.80	10.89	33.66	22.77	13	11.80	22.77	48	18	50.69	4.58	6.25	9.0
310LSL	2012	2.91	23.30	32.05	26.21	14	2.91	26.21	61	22	18.27	4.48	9.84	16.0
310LSL	2013	10.48	9.52	25.71	20.00	17	10.48	20.00	39	4	0.94	5.17	15.38	2.0
310TWB	2008	18.81	7.92	31.68	26.73	13	18.81	26.73	55	14	27.31	5.38	14.55	7.0
310TWB	2010													
310TWB	2012	8.00	29.00	44.00	37.00	9.5	8.00	37.00	46	8	6.77	6.65	21.74	3.0
310TWB	2013	9.71	18.45	44.66	28.16	9	9.71	28.16	52	9	3.7	6.44	21.15	4.0
310CER	2008	15.24	15.24	30.48	30.48	24	15.24	30.48	48	6	14.62	6.22	14.58	1.0
310CER	2011	3.81	34.29	40.95	38.10	13	3.81	38.10	50	14	48.05	5.48	12	4.0
310CER	2012	15.31	11.22	26.53	26.53	20	15.31	26.53	42	12	35.6	5.48	16.67	2.0
310CER	2013	13.83	22.34	45.74	36.17	15.5	13.83	36.17	26	5	6.32	5.64	19.23	0.0

		Sediment Indicators							Biological Indicators					
Site Code	Survey Date	Percent Fines	Percent Sands	Percent <8	FS Sum Percentage	D50 Median particle size	Percent Fines (steelhead)	Percent cover of FS (BMI limits)	Total Richness	EPT Richness	Percent EPT	Biotic Index	Percent Tolerant	Sensitive Number
310UPN		2.2	13.0	17.7	15.1	77.3	2.2	15.1	61.8	21.8	41.0	4.4	6.2	14.8
310MNO		1.7	16.4	22.5	18.1	25.5	1.7	18.1	60.3	18.5	43.5	5.0	8.6	9.8
310LSL		7.7	15.7	31.2	23.4	14.0	7.7	23.4	50.8	14.5	23.8	4.7	11.1	9.0
310TWB		12.2	18.5	40.1	30.6	10.5	12.2	30.6	51.0	10.3	12.6	6.2	19.1	4.7
310CER		12.0	20.8	35.9	32.8	18.1	12.0	32.8	41.5	9.3	26.1	5.7	15.6	1.8

Green: Recommended numeric targets to support beneficial uses
Yellow: Recommended numeric targets to support preliminary 303d Listing (low priority)
Red: Recommended numeric targets to support 303d listing (high priority)

STREAMBED SEDIMENT IMPAIRMENT INDICATORS ANALYSIS

310MNO and 310UPN met all of the sediment numeric targets that support beneficial use. Two sediment indicators met the lower priority criteria for 303(d) listing at 310LSL. 310TWB and 310CER had one indicator meet the high priority criteria for 303 (d) listing. All sites but 310UPN and 310MNO met at least one biological indicator that supports 303(d) listing.

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 do not include the full suite of sixteen metrics that comprise the analytical approach.

These indicator criteria are still being assessed for incorporation in the TMDL establishment and assessment process in the Central Coast region. These criteria differ greatly from the D50 and percent sands/percent fines criteria listed in the approved sediment TMDL for Morro Bay. Further guidance is needed from the Water Board for future assessments of the status of the Morro Bay Sediment TMDL.

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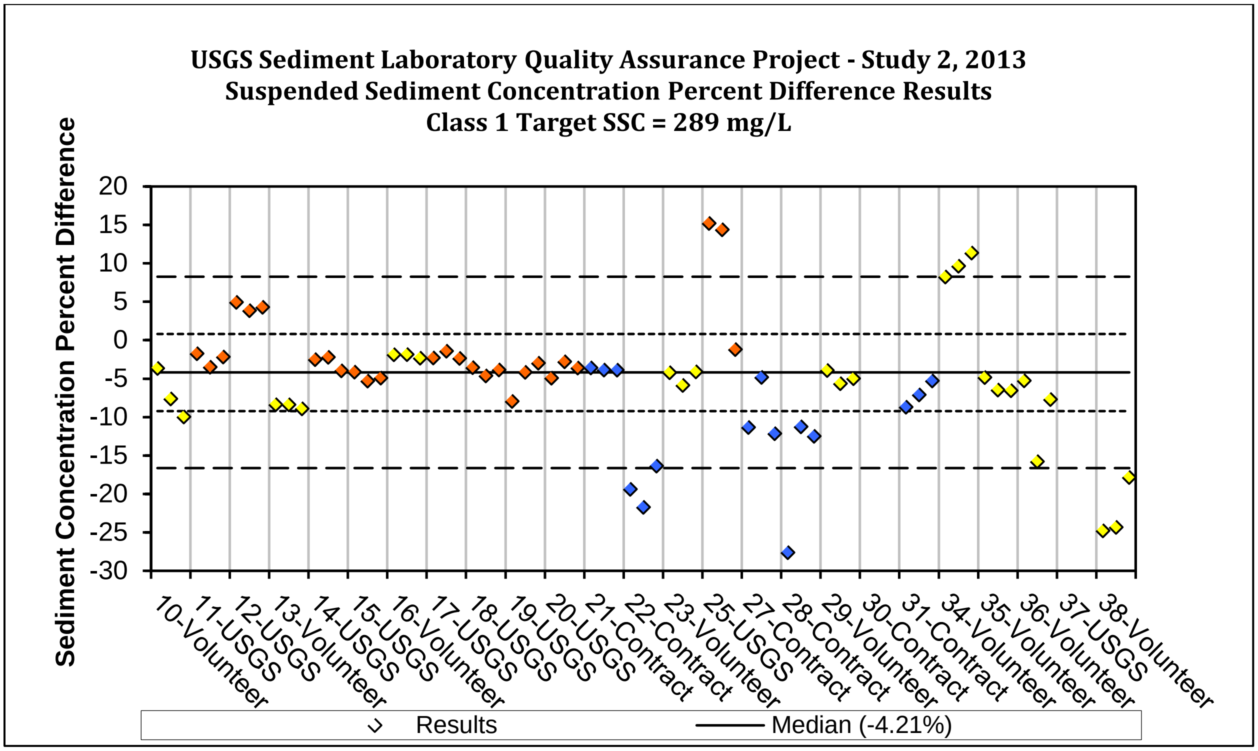
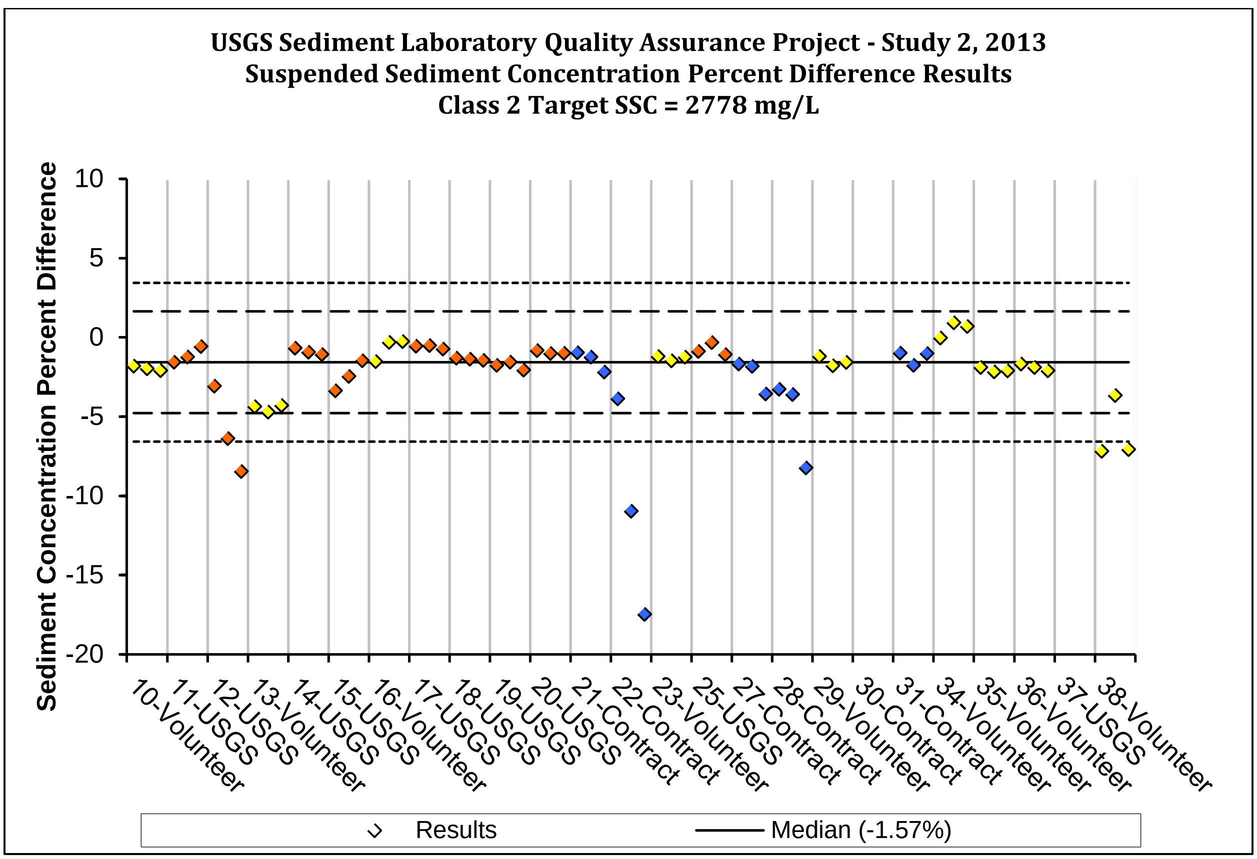
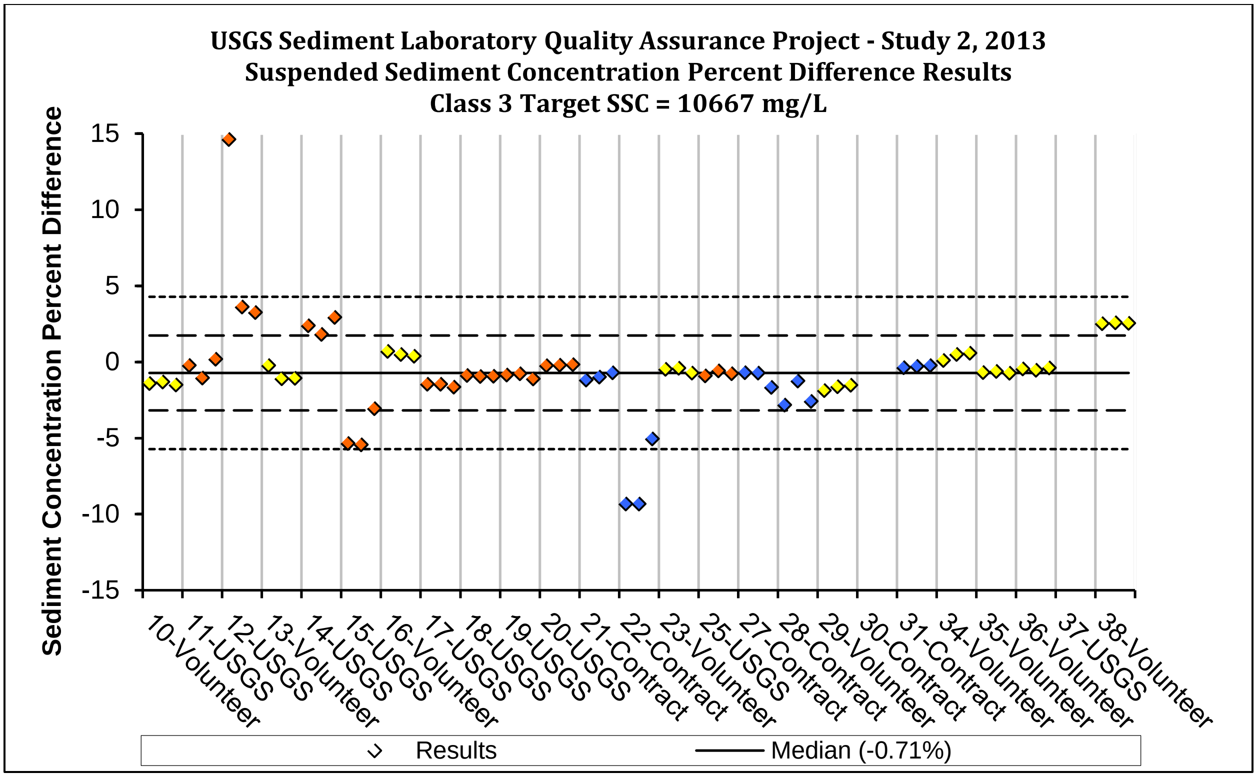
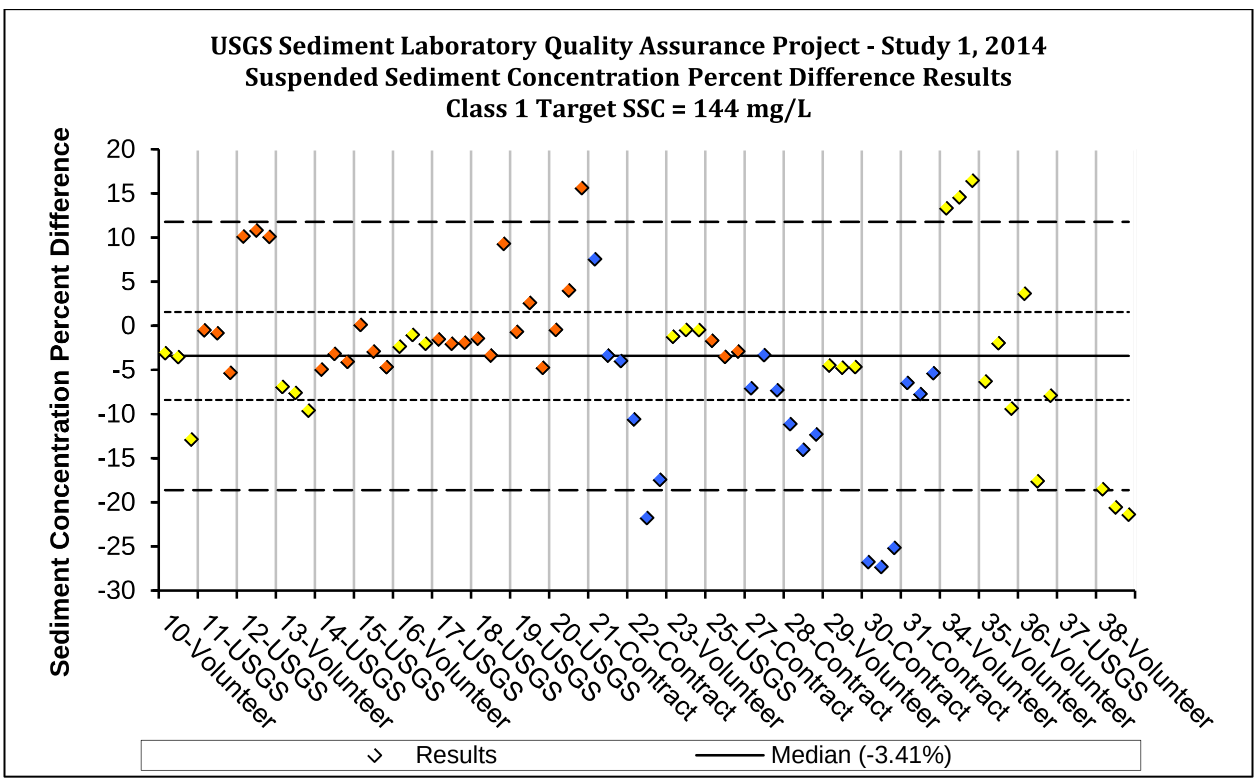
APPENDEX A: USGS SLQA RESULTS

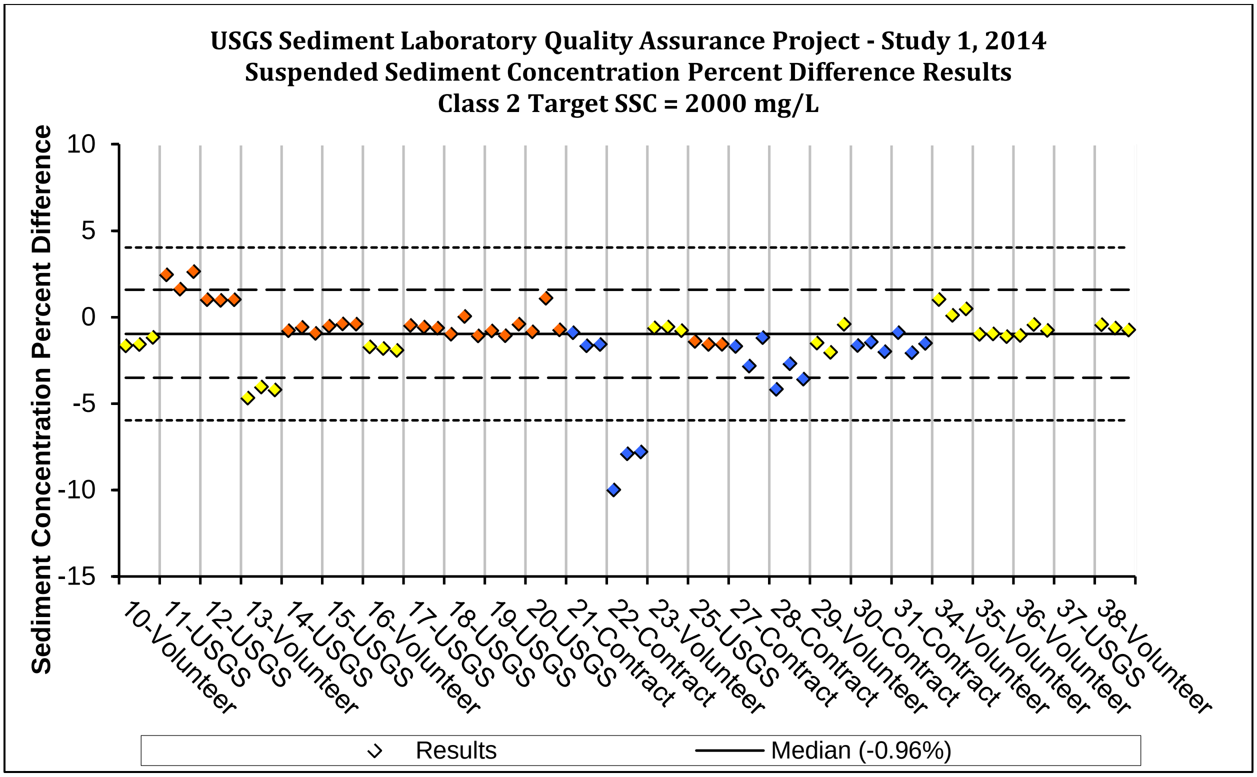
Note: MBNEP's results are labeled as "35-Volunteer."

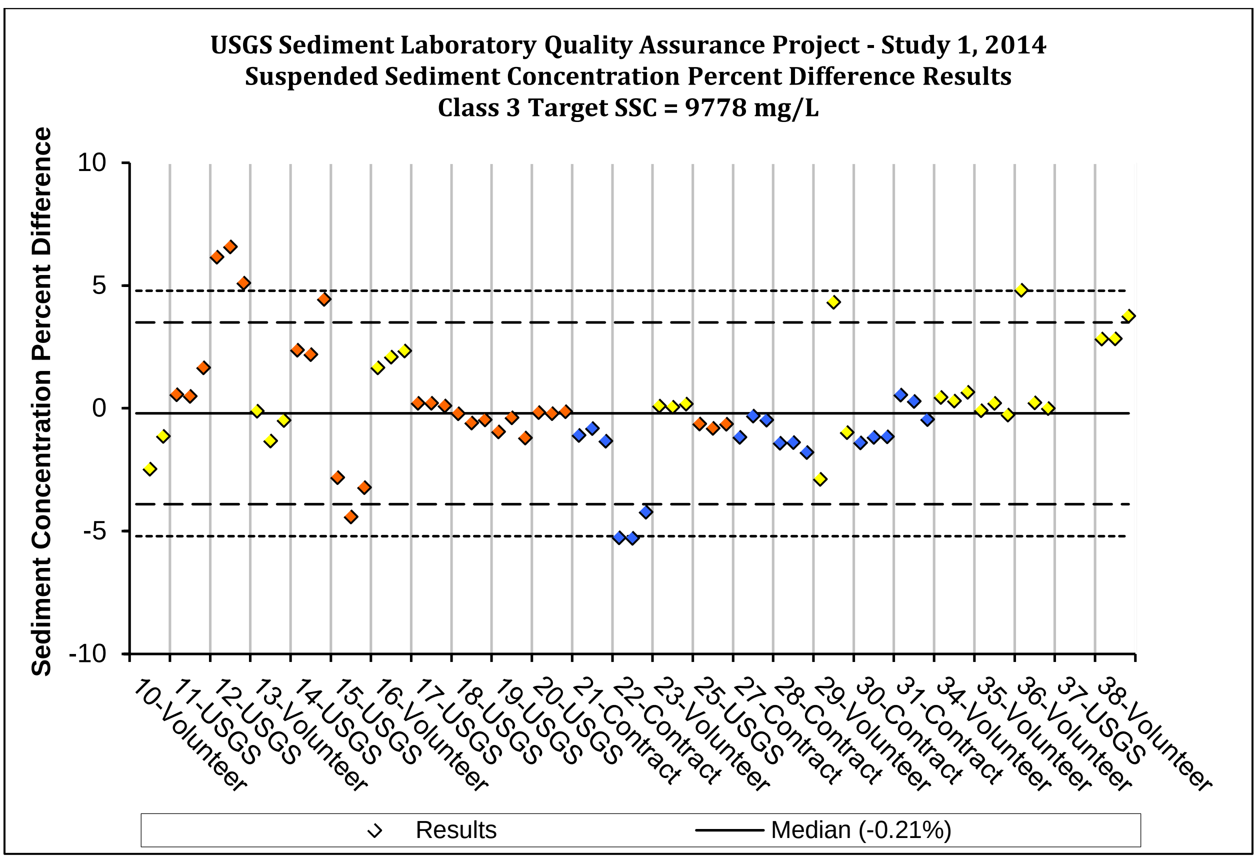





USGS Sediment Laboratory Quality Assurance Project - Study 2, 2013
Suspended Sediment Concentration Percent Difference Results
Class 3 Target SSC = 10667 mg/L
Sediment Concentration Percent Difference
15
10
5
0
-5
-10
-15
10-Volunteer
11-USGS
12-USGS
13-Volunteer
14-USGS
15-USGS
16-Volunteer
17-USGS
18-USGS
19-USGS
20-USGS
21-Contract
22-Contract
23-Volunteer
25-USGS
27-Contract
28-Contract
29-Volunteer
30-Contract
31-Contract
34-Volunteer
35-Volunteer
36-Volunteer
37-USGS
38-Volunteer
Results
Median (-0.71%)


USGS Sediment Laboratory Quality Assurance Project - Study 1, 2014
Suspended Sediment Concentration Percent Difference Results
Class 1 Target SSC = 144 mg/L
Sediment Concentration Percent Difference
20
15
10
5
0
-5
-10
-15
-20
-25
-30
10-Volunteer
11-USGS
12-USGS
13-Volunteer
14-USGS
15-USGS
16-Volunteer
17-USGS
18-USGS
19-USGS
20-USGS
21-Contract
22-Contract
23-Volunteer
25-USGS
27-Contract
28-Contract
29-Volunteer
30-Contract
31-Contract
34-Volunteer
35-Volunteer
36-Volunteer
37-USGS
38-Volunteer
Results
Median (-3.41%)


USGS Sediment Laboratory Quality Assurance Project - Study 1, 2014
Suspended Sediment Concentration Percent Difference Results
Class 2 Target SSC = 2000 mg/L
Sediment Concentration Percent Difference
10
5
0
-5
-10
-15
10-Volunteer
11-USGS
12-USGS
13-Volunteer
14-USGS
15-USGS
16-Volunteer
17-USGS
18-USGS
19-USGS
20-USGS
21-Contract
22-Contract
23-Volunteer
25-USGS
27-Contract
28-Contract
29-Volunteer
30-Contract
31-Contract
34-Volunteer
35-Volunteer
36-Volunteer
37-USGS
38-Volunteer
Results
Median (-0.96%)


USGS Sediment Laboratory Quality Assurance Project - Study 1, 2014
Suspended Sediment Concentration Percent Difference Results
Class 3 Target SSC = 9778 mg/L
Sediment Concentration Percent Difference
10
5
0
-5
-10
10-Volunteer
11-USGS
12-USGS
13-Volunteer
14-USGS
15-USGS
16-Volunteer
17-USGS
18-USGS
19-USGS
20-USGS
21-Contract
22-Contract
23-Volunteer
25-USGS
27-Contract
28-Contract
29-Volunteer
30-Contract
31-Contract
34-Volunteer
35-Volunteer
36-Volunteer
37-USGS
38-Volunteer
Results
Median (-0.21%)