Sediment Monitoring Report for 2017 and 2018 Water Years

Morro Bay National Estuary Program
601 Embarcadero
Morro Bay, CA 93442

March 16, 2020

CONTENTS

TABLE OF FIGURES

EXECUTIVE SUMMARY

The Morro Bay Estuary is impaired by accelerated sedimentation rates. Monitoring efforts underway by the Morro Bay National Estuary Program (Estuary Program) are intended to assess sedimentation in the watershed and the bay. To that end, the following monitoring data are detailed in this report.

- Suspended sediment concentration: An automated sampler on the Chorro Creek mainstem at Canet Road collects water during storm events for analysis of suspended sediment concentration.
- Suspended sediment load modeling: Suspended sediment concentration data collected over several years was statistically analyzed to create a predictive relationship between discharge and sediment concentration.
- Streambed Sediment Impairment Indicators: Utilizing a method under development by the Central Coast Water Quality Control Board and University of California researchers, watershed bioassessment data was assessed to determine the impacts of sedimentation on aquatic health. Of the five sites assessed by this method, four frequently have scores indicating some level of impairment.
- Sediment Quality Assurance Measures: The Estuary Program participates in the USGS Sediment Lab Quality Assurance (SLQA) effort each spring and fall. The results for the 2017 and 2018 efforts are included. The program's results of analysis of blind samples were on par with results from other labs participating in the effort.

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 a key monitoring and reporting partner. 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 to assess sediment conditions in the Morro Bay watershed and estuary for 2017 and 2018. This report will focus on sediment monitoring conducted on Chorro Creek at Canet Road.

The *Morro Bay Total Maximum Daily Load for Sediment* 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 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 coarse fines in substrate. The TMDL identified tidal prism volume as the primary numeric target for Morro Bay. The numeric targets are detailed in Table 1.

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's Monitoring Program has been conducting regular water quality monitoring throughout the estuary and watershed for over fifteen years. Program volunteers are trained by staff to conduct water quality monitoring in the bay and creeks. The Estuary Program has collected ambient creek turbidity data from sites throughout the Morro Bay watershed either monthly or bi-weekly from 2002 through 2018 as part of this 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 (beneficial use COLD) and 40 NTU in warm waters (beneficial use WARM). Of the 3,403 turbidity readings collected since 2002, 2.3% exceeded 25 NTU and 1.2% exceeded 40 NTU. The Estuary Program has not conducted monitoring of the TMDL targets in Table 1 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, there are limitations to its usefulness in quantifying suspended sediment load in surface waters (Ankcorn, 2003). These limitations prevent the use of turbidity as a predictor of the total sediment load in a given storm or water year and thus requires direct measurement of the suspended sediment concentration.

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. 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 previous total suspended solids (TSS) data collected during the National Monitoring Program (NMP) paired watershed study during the 1990s and early 2000s.

While SSC is not required in the Morro Bay Sediment TMDL, many more recently adopted TMDLs include this type of monitoring, and it is one of the most effective ways to quantify instantaneous sediment loading. With the exception of very low-flow or drought years, the Estuary Program has been able to sample storms spanning a decade to track Chorro Creek's sediment loading. Due to the drought in California, there were no storms large enough to warrant suspended sediment monitoring from 2014 through 2016. In these years, sediment loads in the creek can only be inferred by the predictive relationship generated from previous SSC monitoring efforts. It is assumed, however, that Chorro Creek did not contribute a significant amount of sediment to Morro Bay in this period. Monitoring was resumed for 2017 and 2018.

MORRO BAY WATERSHED

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 Army National Guard Base Camp San Luis Obispo. Chorro Creek receives drainage from 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 in the watershed occur in the Warden Creek drainage area.

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 1).

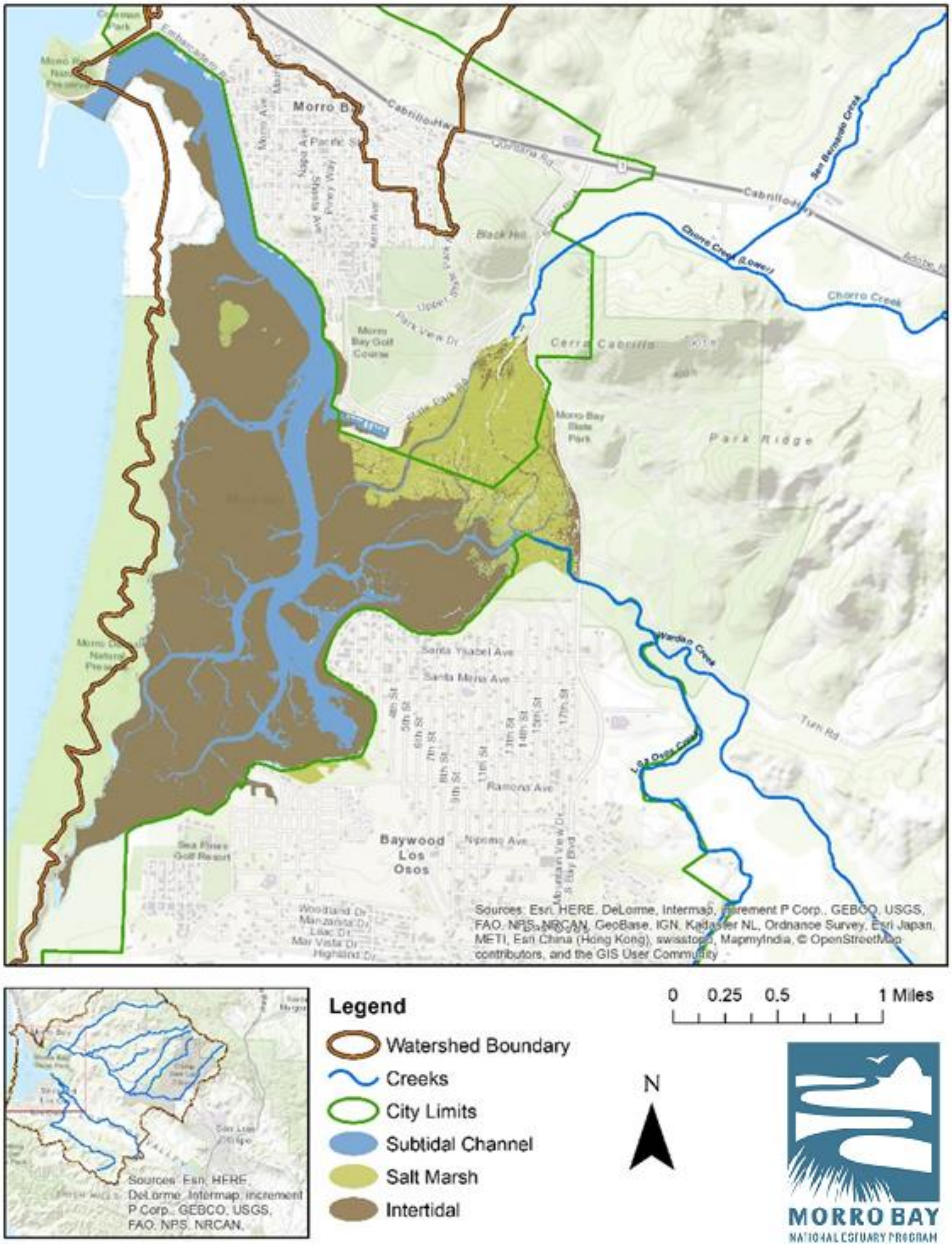


Figure 1: Map of Morro Bay estuary habitat types

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 previously supported the third largest remaining *Zostera marina* (eelgrass) beds remaining in Southern California (Bernstein, et. al. 2011). In 2010, the Estuary Program estimated that eelgrass covered 176 acres. A survey from December 2017 estimated that just over 13 acres of eelgrass remained in Morro Bay (MBNEP, 2019). 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 Water Board.

Morro Bay is designated as a Harbor of Safe Refuge and is the only safe harbor between Santa Barbara and Monterey. 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 (ACOE) to maintain a channel depth of approximately +40 feet MLLW. During May of 2014, 2015 and 2016, the Yaquina hopper dredge removed 173,600 cubic yards (CY), 138,200 CY, and 260,000 CY respectively. During these years, the Yaquina did not dredge the mid channel or back channels of Morro Bay Harbor.

In 2017, the ACOE issued two separate dredging contracts. ACOE contracted with the Portland District hopper dredge, Yaquina, to dredge portions of the Entrance Channel, Transition Area, and Main Channel. Dredging began on May 1 and was completed on May 28. No eelgrass was lost in this dredge event. ACOE also contracted Ahtna Design-Build, Inc. to conduct suction cutterhead pipeline dredging within portions of the Navy Channel, Morro Channel, and the Sand Trap. The pipeline dredging began in February and ended in July, pausing operations while the Yaquina dredged in May. The pipeline dredging resulted in a net loss of 22 m^2 of eelgrass around the Coast Guard T Pier. Due to the relatively small amount of eelgrass impacted, it was recommended that the ACOE defer mitigation or participate in other eelgrass recovery projects (M&A, 2017).

In 2018, another round of dredging was completed between May 1 and May 18 by the Portland District hopper dredge, Yaquina, under contract with ACOE. Dredging included portions of the Harbor Entrance Channel, Transition Area, and Main Channel up to Channel Marker 8. The ACOE concluded that there were no impacts to eelgrass and, thus, a post-dredge survey was not conducted (M&A, 2018).

SEDIMENT RETENTION AND EROSION PREVENTION PROJECTS

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 (CSLRCD) 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 CSLRCD 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. An unusual reoccurrence of high magnitude storm flows during the 1990s resulted in 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 the 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.

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 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 Estuary Program completed construction of the Morro Bay Watershed Road Erosion Prevention project from October 2014 through April 2016. This project treated approximately 11 miles of roads within Cal Poly, Camp SLO, and US Forest Service properties. Over fifty sites were treated with culverts, sediment settling basins, rolling dips, and other measures to reduce sediment delivery to nearby stream systems.

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. That land has been transformed into a functional floodplain as of 2019, and is prepared to better disperse and slow down flood waters and sediment in large storm events. 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 DATA SOURCES

A variety of data sources were utilized to measure 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.

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. Methods under development by the Water Board and UC Davis researchers use habitat survey scores as indicators of sedimentation impact. Within this report, the physical habitat data collected during spring 2017 and 2018 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 in partnership 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 to measure elevation change: marker horizons and surface elevation tables (SETs). The most recent SET survey with University of San Francisco was conducted in 2015 and shows that the higher elevations of the marsh are accreting sediment at low rates, around 1.2mm per year, while the lower elevation mudflats accrete sediment at slightly higher and more variable rates, ranging from 0.65 to 3.85mm per year over the 11-year period between 2004 and 2015. These rates are similar to the 2-3mm per year rate of sea level rise (Callaway, 2015)[1].

Between April 2013 and February 2019, USGS conducted similar SET monitoring in Morro Bay as part of a larger study of sedimentation rates on the west coast (Thorne et al., 2018) by USGS. The Morro Bay sites in this study are located near two other SET sites used in the University of San Francisco study (Figure 2). A USGS progress report from July 2019 shows that the cumulative change in all four sites is +5.39 mm over the 2013-2019 period. In the two low marsh sites, the accumulation rate is 1.15 mm/yr and in the high marsh sites it is 0.50 mm/yr.

It is important to note that these two studies overlap geographically, but the extent of the University of San Francisco's study is much larger, so terms of relative elevation such as 'high' or 'low' are not necessarily interchangeable when discussing the studies together.

[1] This 2015 report is available in Appendix A of the Estuary Program's 2016 Sediment Monitoring Report

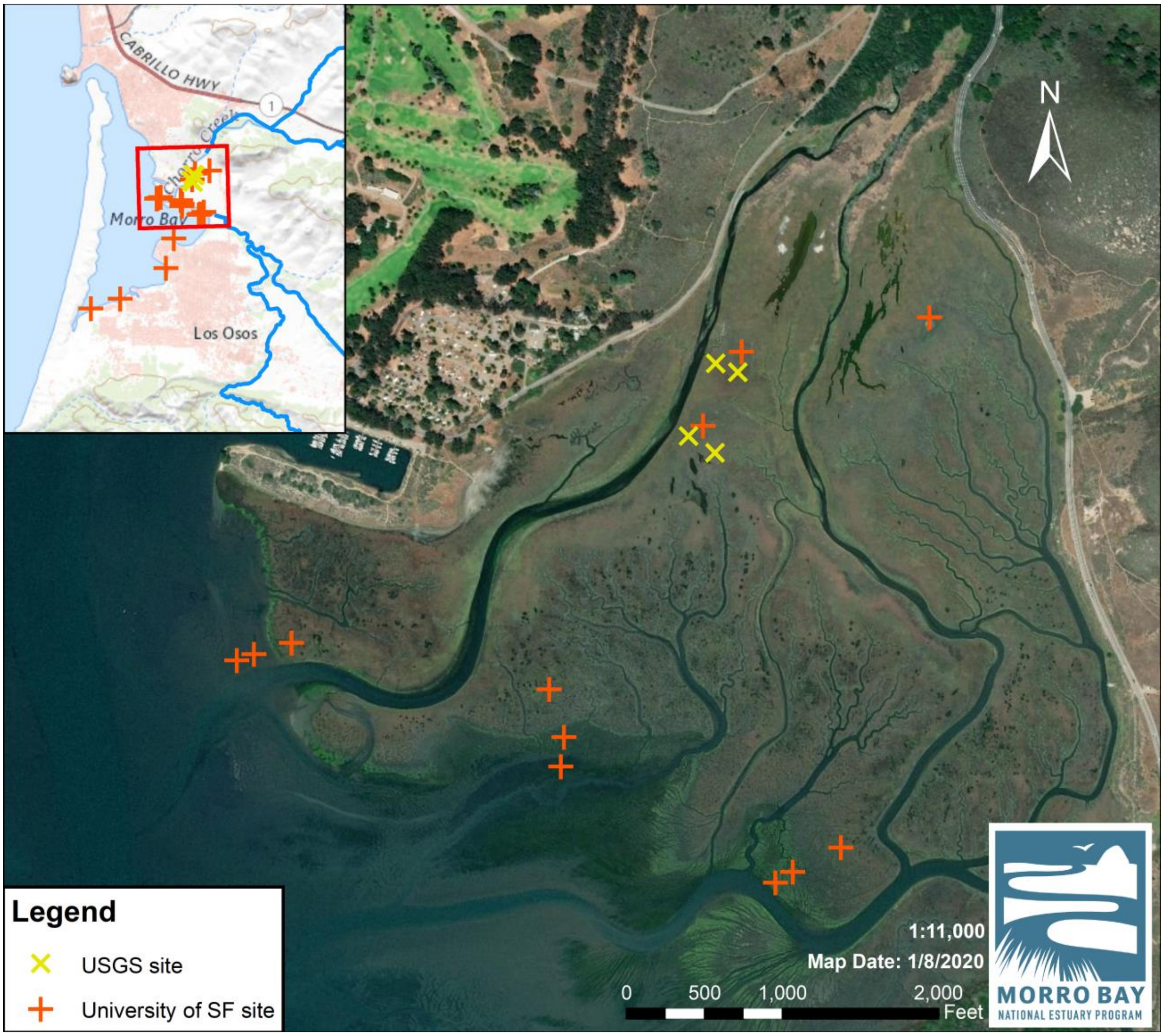


Figure 2: Plotted points of SET locations in the marsh area.

Note that this map excludes USF sites that were also monitored in the southern extent of the bay (not shown), but includes all USGS SET sites in the bay.

ESTUARY PROGRAM AMBIENT WATER QUALITY DATA

The Estuary Program collects monthly water quality data from up to 13 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 twelve or more depth and velocity readings to generate volume estimates. The Flo-Mate 2000 meter has a range of measurement from 0.01 to 20 feet per second.

Figure 3 illustrates 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.

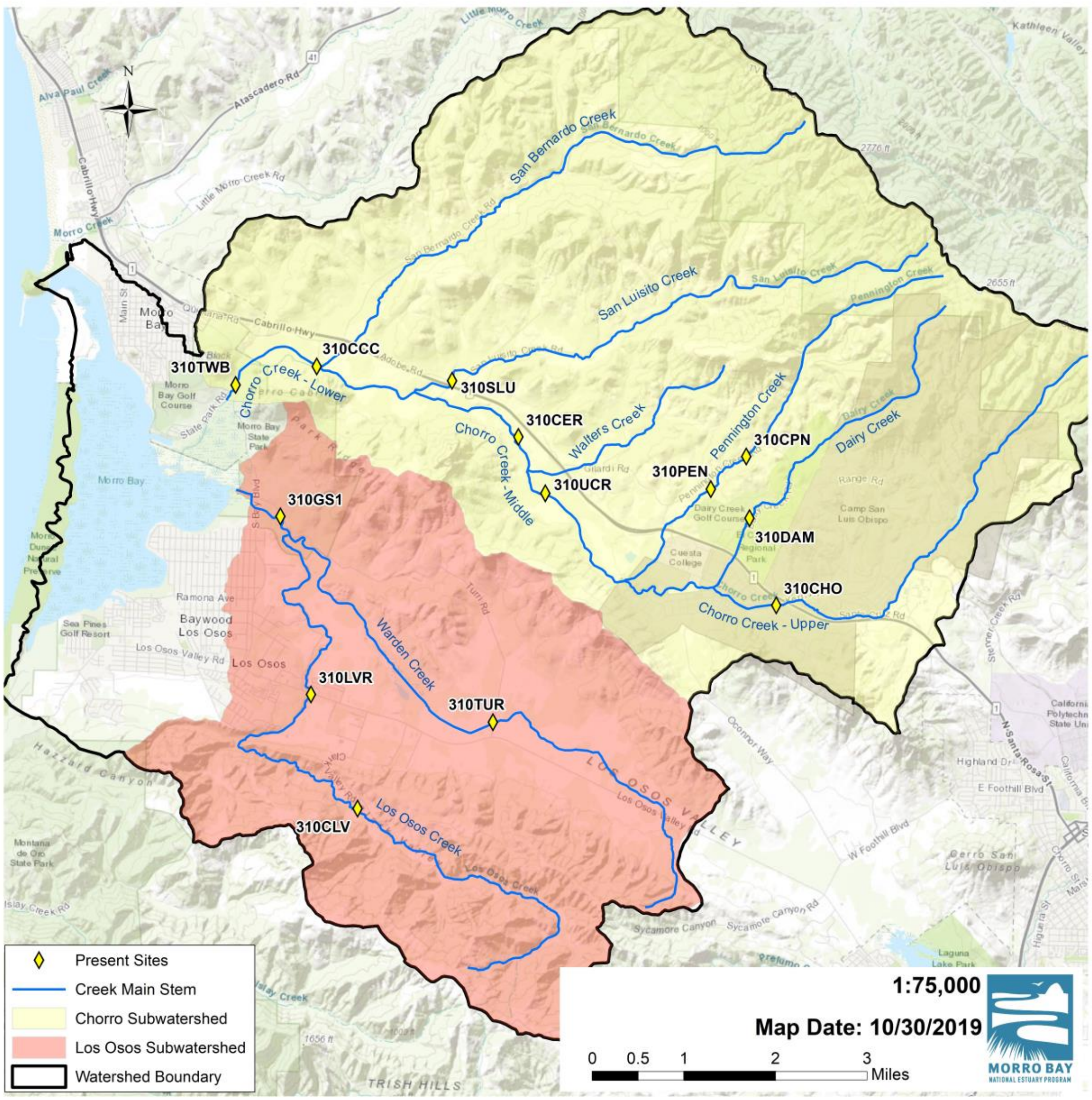


Figure 3: Map of Estuary Program Ambient Volunteer Monitoring Sites

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.

Additional information on ambient water quality data can be found in the program's 2017 and 2018 Creek Water Quality Memos.

ESTUARY PROGRAM SUSPENDED SEDIMENT LOADING DATA METHODS

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. 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. Samples were collected at 30-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 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. To extrapolate from SSC to creek sediment loads, the creek's discharge was multiplied by the sediment concentration. Doing this several times over the course of a storm provides a good estimate of the mass of solid sediment moved through the stream.

Turbidity data was collected in the laboratory using a HACH 2100AN turbidimeter per 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.

MONITORING SITE: CHORRO CREEK AT CANET ROAD

The Chorro Creek monitoring station at Canet Road was established by the Estuary Program in 2007. The site (referenced throughout the report as either site code CAN or Canet) includes a drainage area of approximately 21.8 square miles out of the 43 square mile watershed and was established as a gauging station by San Luis Obispo County in 1978. This monitoring includes flows from the Pennington Creek, Dairy Creek, and Walters Creek tributaries, shown in Figure 4. The area in the map highlighted in yellow is the area that drains to the Canet Road gauging station, which collects stage readings at fifteen-minute intervals on a continuous basis.

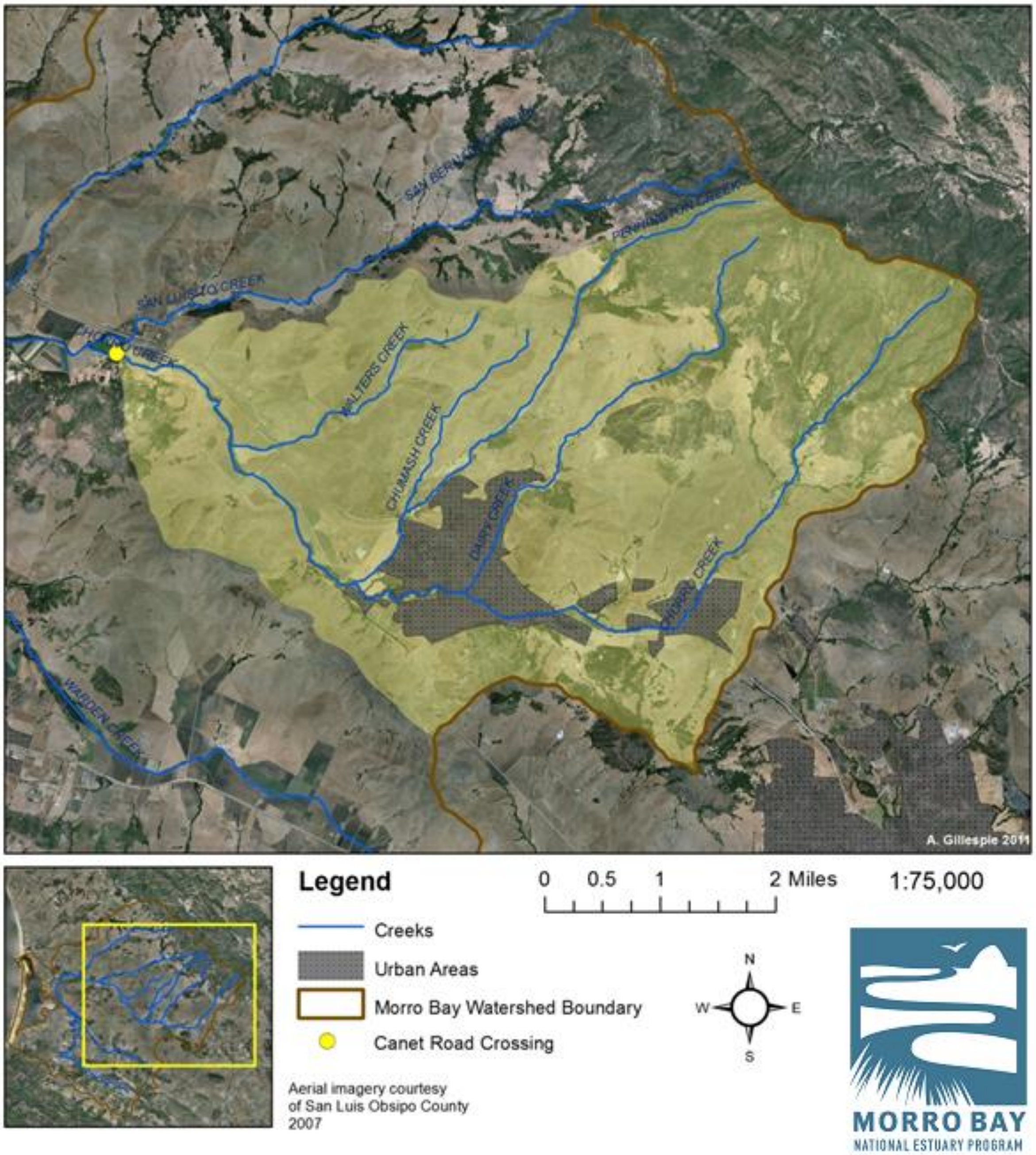


Figure 4: Map of watershed area that drains to Canet road sediment monitoring site

In 2010, Irrigation Training and Research Center (ITRC) engineers at Cal Poly developed a rating curve to better estimate peak flows at Canet. Analysis of field measurements determined that three unique equations were necessary to approximate flow rates at the site, depending on stage height.

The following equations were used to calculate discharge in this report[2]:

- For stage heights below 12.10 feet, discharge 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.
- For stage heights between 12.1 feet and 13.2 feet, the discharge is approximated by:
  Q (cfs) = 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.

SEDIMENT MONITORING RESULTS AT CANET

Since 2007, Canet has been the primary sediment monitoring site in the Chorro Creek watershed, and this report considers sediment trends at this site to be indicative of the behavior of the watershed overall. The data at Canet is distributed over a flow range of nearly 2,000 cubic feet per second (cfs) and SSC of 1,400mg/L (Figure 5). The majority of measurements have been made at flows less than 400 cfs and SSC concentrations of 400 mg/L or less. There is great sediment variability both within and between water years.

[2] Hydrographs generated by MBNEP for the Canet Road gage prior to 2011 used a different rating curve, so results from more recent reports are not comparable with pre-2011 results.

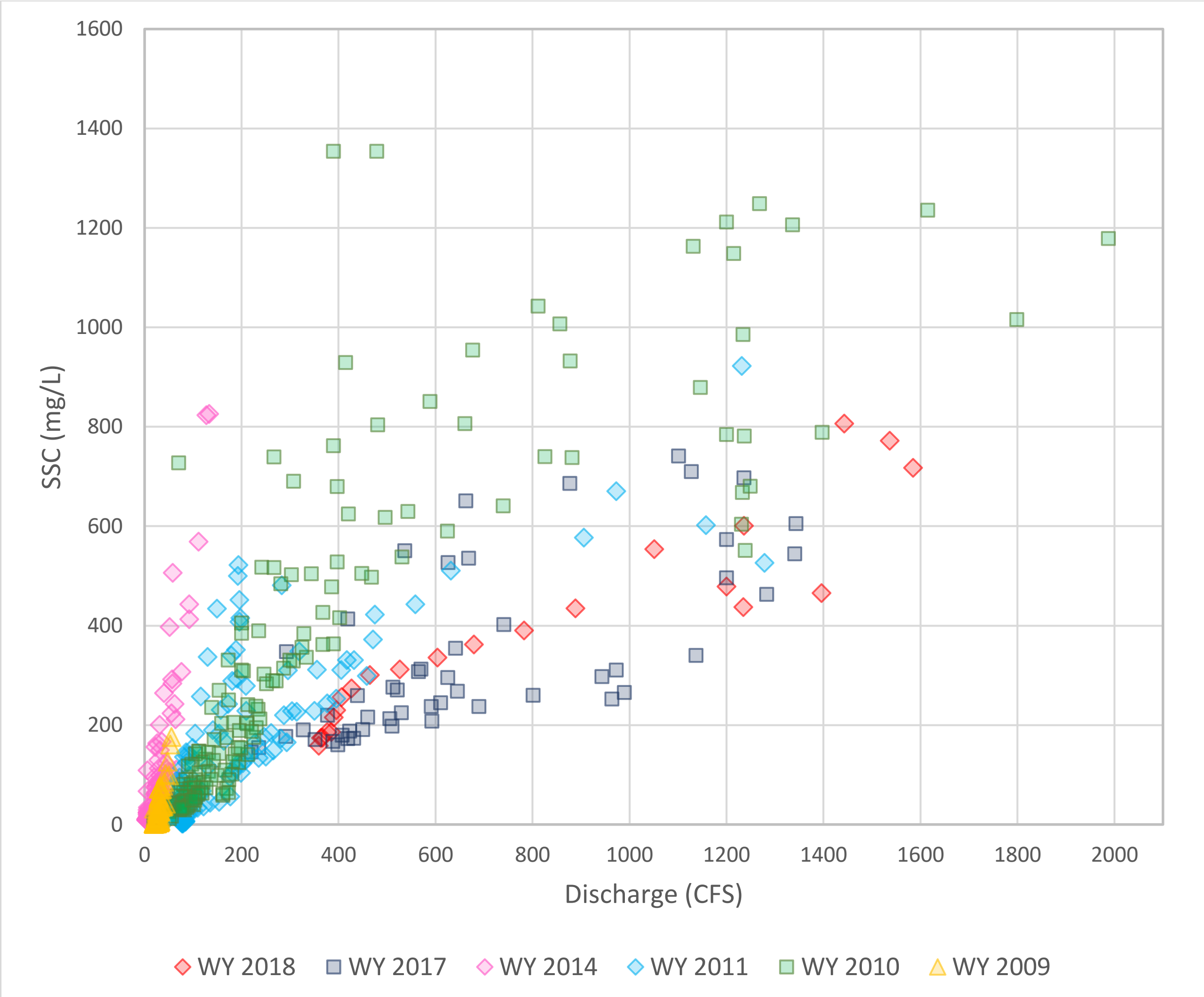


Figure 5: Canet road SSC dataset from WY 2009 to WY 2018

In Table 2, the annual sediment load predictions from the latest predictive model are summarized, along with the actual annual discharge in acre-feet (AF). These differ from the more detailed sediment loading analyses done in later sections, where a series of water samples containing storm flow sediments were analyzed in the lab and then scaled up to represent the entire creek during the monitoring period. This detailed analysis was the more accurate method for determining the creek's sediment load over short periods, but the method is not feasible for year-round monitoring because of how labor-intensive the process is. The predictive model helps bridge that gap.

Table 2: Chorro Creek discharge volume, sediment load estimated with predictive model

Water Year	**2009**	**2010**	**2011**	**2014**	**2017**	**2018**
Annual Discharge (AF)	8,970	14,290	24,850	2,480	26,860	7,830
Predicted Annual Sediment Load (Tons)	651	3,961	9,874	75	9,149	1,563
95% Confidence Interval (Tons)	566 – 743	3,605 – 4,338	6,762 – 20,973	61 – 90	8,450 – 9,878	1,403 – 1,733

Review of approximately 29 years of peak flow data (Figure 6) indicates large inter-annual variability in peak flows at the gauging station, with a range of approximately 7,427 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 in Chorro Creek. In Table 2, this variability is also captured by the results from the latest suspended sediment concentration (SSC) model for Canet. These results were obtained by re-applying the same sediment loading analyses as previous reports, but with a new SSC-discharge (SSC-Q) relationship based on a larger dataset. The upper and lower 95% confidence intervals of SSC-Q were also predicted by the model.

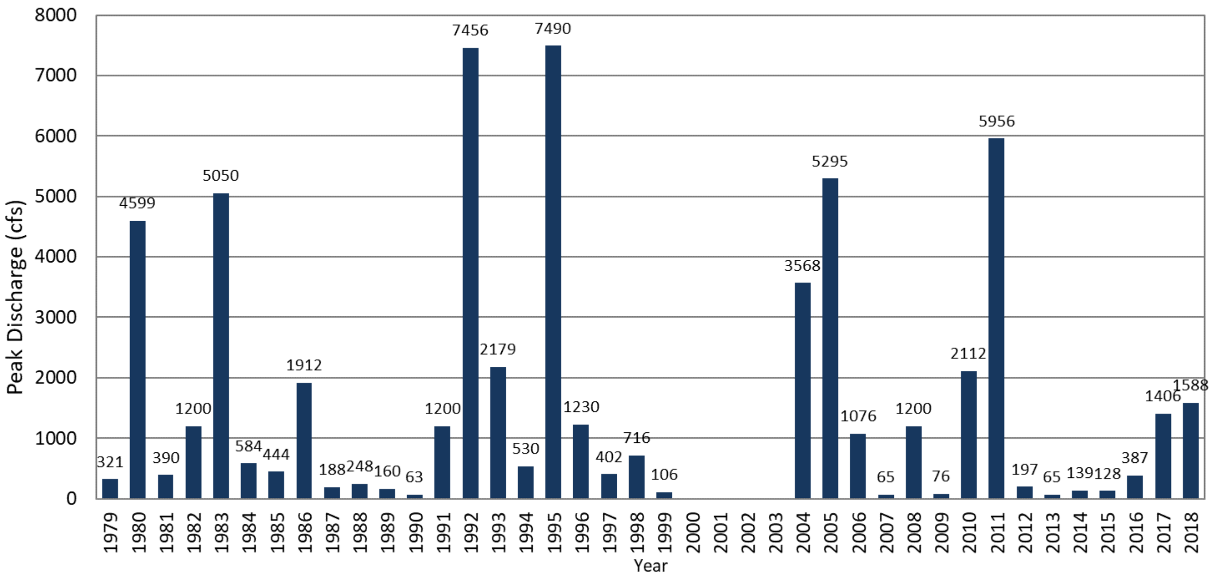


Figure 6: Chorro Creek, Canet Road peak flow records †

Figure 7 illustrates how peak flow magnitude and annual rain totals are not strongly correlated. For example, the wet water year of 2017 presents as a high peak on the annual rain total plot but corresponds with a relatively low peak flow. The rain events were spread out enough over time and did not lead to rapid concentrations of overland flow that typically contribute the largest inputs of sediment in a surface water system. Thus, rain year totals are unlikely to be a reliable indicator of the relative sediment contribution to Morro Bay in any given year. Additionally, previous analyses done by the Estuary Program show that annual rainfall is a poor predictor of suspended sediment loads (MBNEP, 2011).

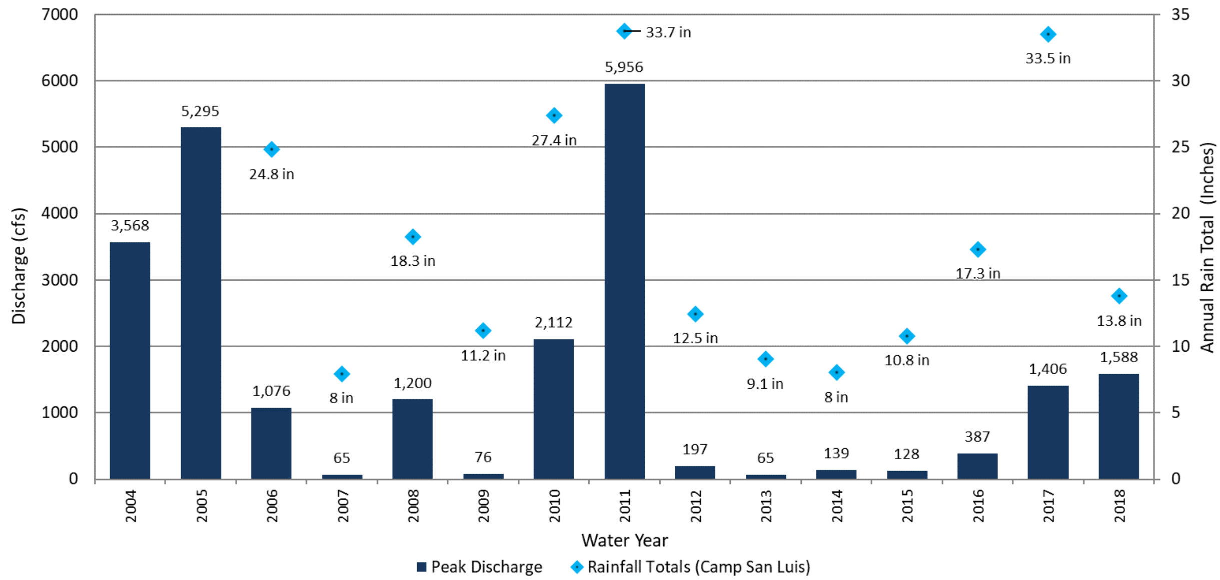


Figure 7: Chorro Creek, Canet road peak flows and annual rain totals from Camp San Luis rain gauge ††

†No data for 2000-2003
††Precipitation data not shown for 2004 and 2005 due to faulty equipment.

CHORRO CREEK SEDIMENT LOADING MODEL AND OVERVIEW

Multiple years of suspended sediment monitoring at Canet have provided a firm basis for the development of a predictive model that estimates SSC for a given discharge. A spline was fit to a plot of SSC as a dependent variable and discharge as the independent variable (Figure 8). Refer to Figure 5 to see these data differentiated by water year. The predictive model is built from data ranging from 2009 to 2017. The model is not year-specific and instead aggregates data from all years, assuming an average-year effect.

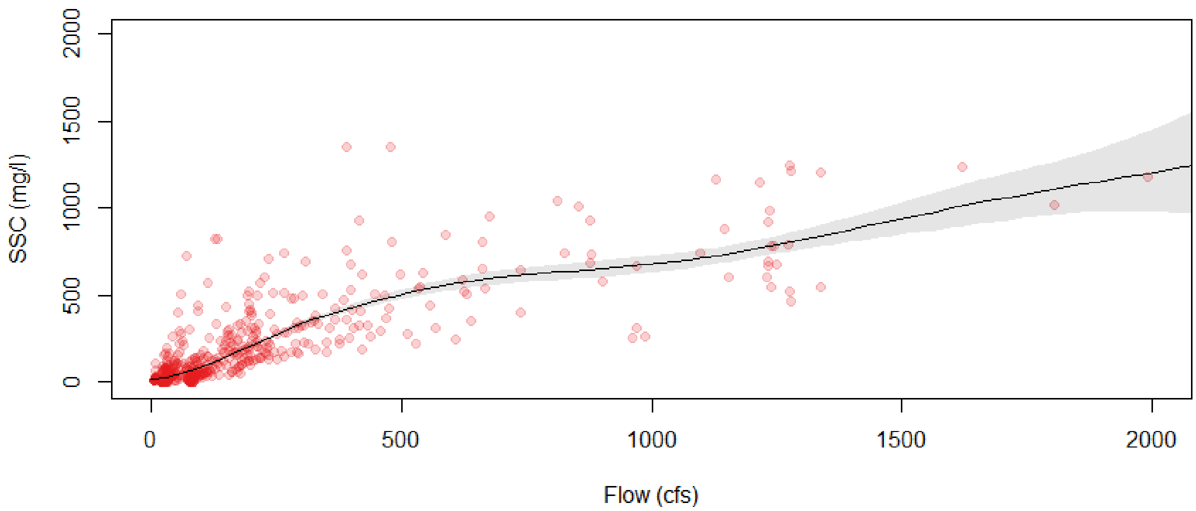


Figure 8: Spline-fit suspended sediment model at CAN.

The gray region bounds the 95% confidence interval. The entire range of SSC data is shown.

Most of the data fall below 400 cfs (Figure 9). This is explained by the improbability of stormflows over 400 cfs, as well as sampling bias; samplers are deployed when staff note a change in weather that will produce a storm flow, but the arrival of the peak flow is challenging to predict and the end-to-end storm flow is not always captured in the data. The lower-magnitude receding limb of the storm hydrograph is typically over-represented simply because it lasts much longer than the rising limb and peak flows.

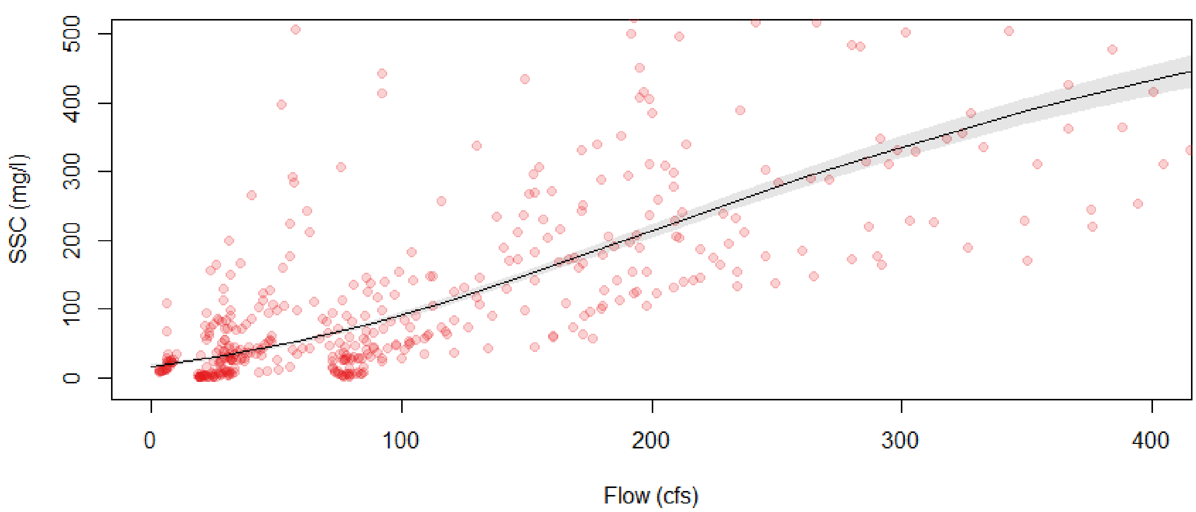


Figure 9: Spline-fit suspended sediment model at CAN, values below 400 CFS.

This figure is an expanded view of the low range from Figure 8.

When the predictive model was applied to stage data recorded at Canet during water years where there was suspended sediment monitoring, a graph of SSC at half-hour intervals resulted (Figure

10). Adding up the area under the curve in Figure 10 yielded a graph of the predicted sediment accumulation throughout the year (Figure 11).

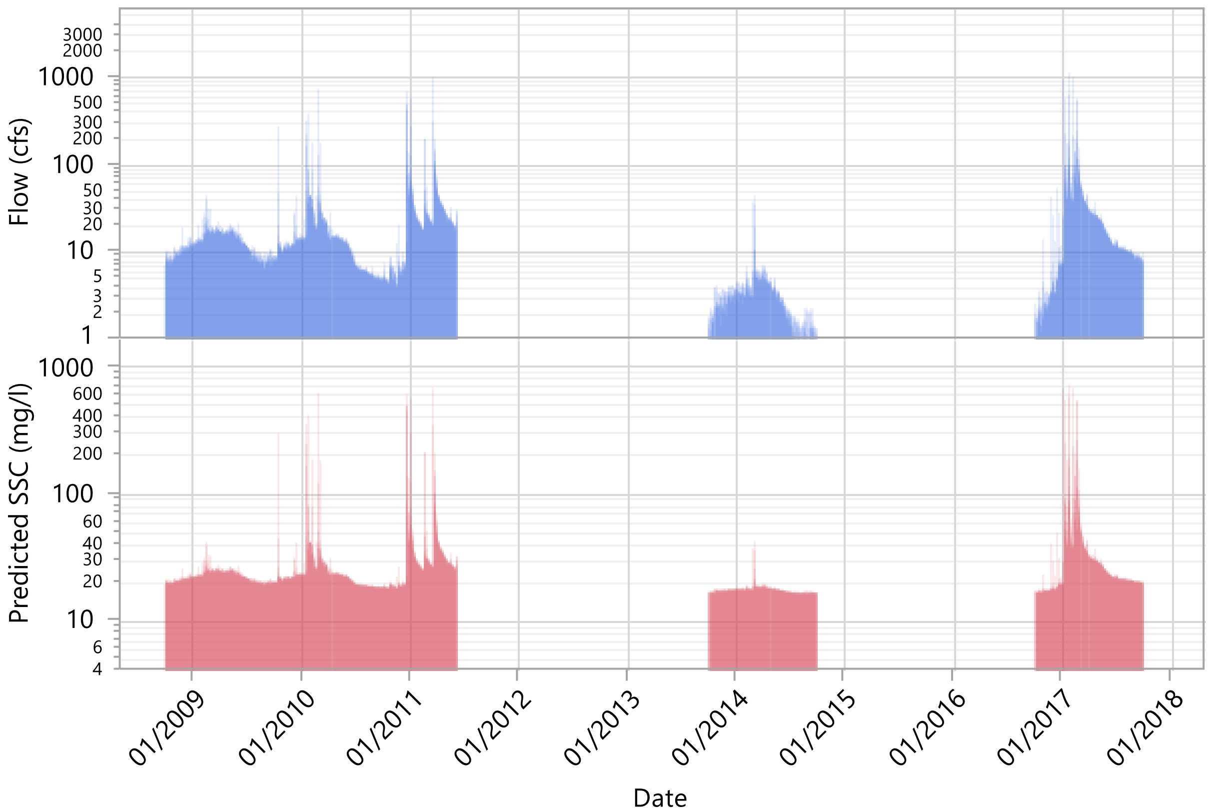


Figure 10: Hydrograph and corresponding predicted SSC values modeled for water years where SSC monitoring took place

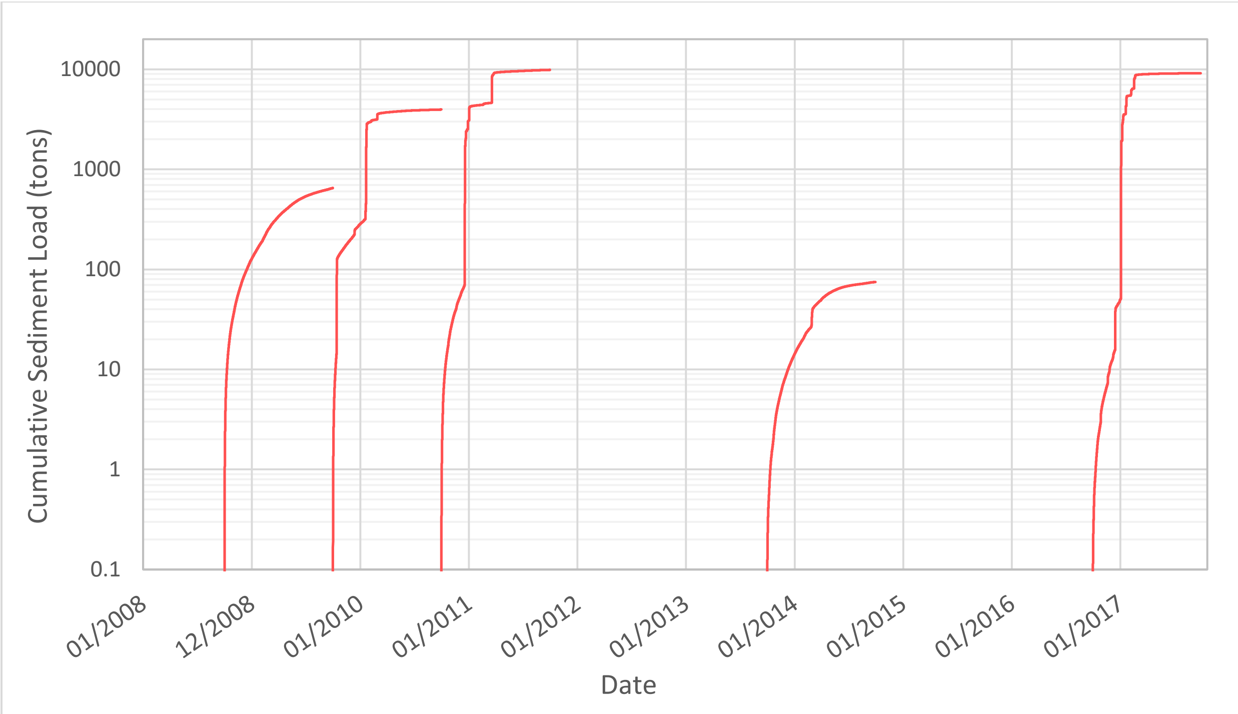


Figure 11: Model-predicted cumulative sediment load at Canet for years where suspended sediment samples were collected.

Water year 2018 is excluded because only one storm was partially captured in SSC monitoring.

There are gaps in the graphs because low flow or drought years did not warrant suspended sediment monitoring. In water years with dry conditions and few or relatively small storms, such as water year 2009, sediment load accumulates smoothly and steadily in the log-transformed graph. In water years with more significant storms, steep jumps in the graph can be seen in the winter months. Although storm events are brief when compared to the entire length of the water year, they have dramatic influence on the total amount of sediment moved through Chorro Creek.

The value of this predictive model is in the ability to estimate SSC values and, therefore, sediment loads for storms and baseflows that were not monitored directly or were under-represented in a given water year. For example, in WY 2017 there were no flows below 50 cfs sampled for SSC, but the model provides a statistically likely SSC for those low flows based on previous years of data, allowing for the ambient sediment load to be estimated.

WATER YEARS 2017 AND 2018 RAINFALL AND DISCHARGE

Discharge was calculated with Estuary Program's rating curve equations, using continuous stage data from the SLO County stage recorder at Canet Road. Water Years 2017 and 2018 differed significantly in the total amounts of rainfall and storm flows. The contrast of these water years can be seen by comparing Figures 12 and 13, the hydrographs and rain accumulations for these years. Although there was a series of large storms in WY 2017, an unusually late storm in WY 2018 exceeded all peak flows at Canet Road from WY 2017.

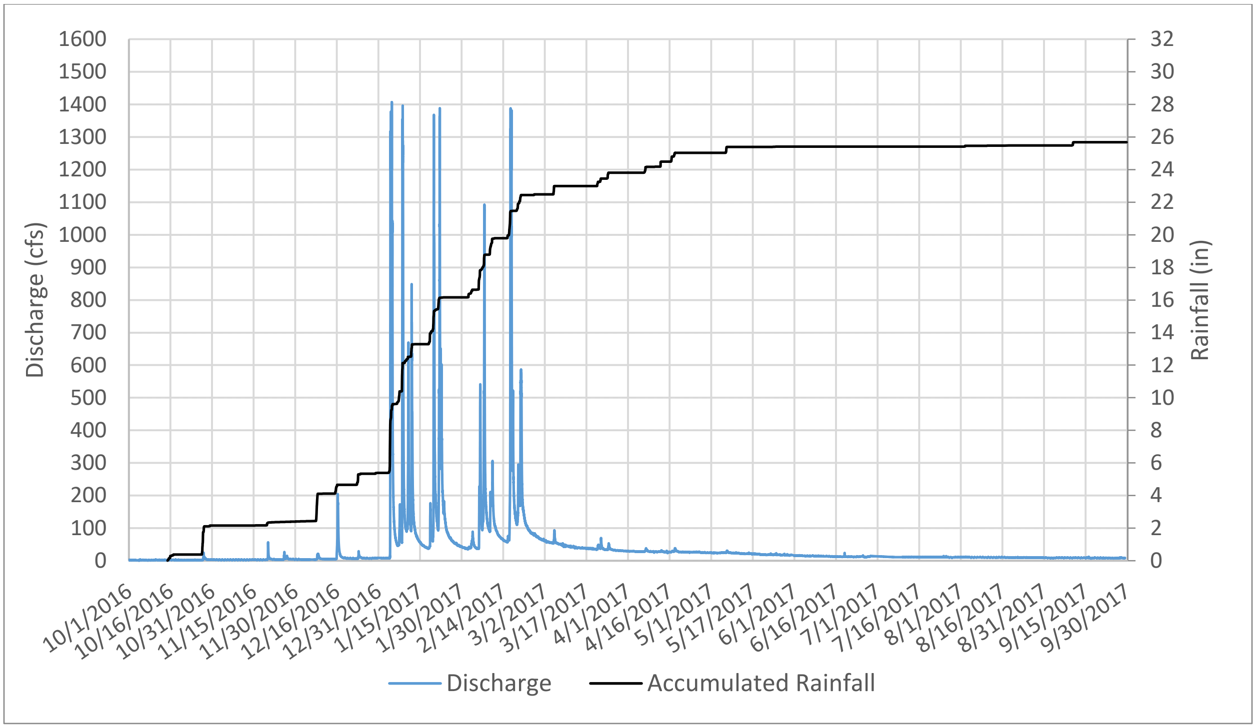


Figure 12: Hydrograph and precipitation accumulation at CAN for WY 2017

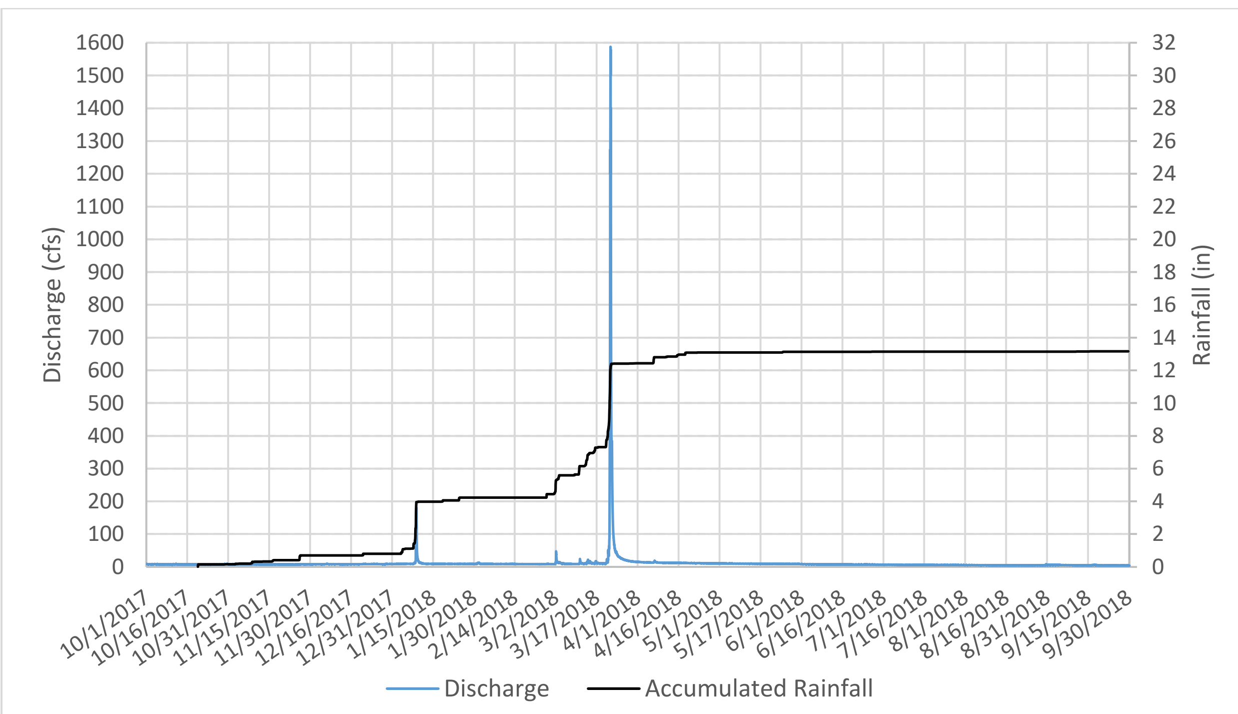


Figure 13: Hydrograph and precipitation accumulation at CAN for WY 2018

According to the SLO County Department of Public Works precipitation contours, Canet Road receives an average of 20 inches per year (Appendix B). The rain contours are a map of the county that shows what the expected average annual rainfall will be in any given area. Compared to this average, WY 2018 was drier than average, and WY 2017 was wetter than average. Table 3 summarizes the totals from Figures 12 and 13.

Table 3: Summary hydrology statistics for WY 2017 and 2018

Water Year	Peak Flow (cfs)	Total Annual Discharge (AF)	Total Annual Rainfall (in)	Percent of 20 inch Average Rainfall
2017	1,405	26,865	25.68	128%
2018	1,587	7,829	13.16	66%

WATER YEAR 2017 SEDIMENT LOAD MONITORING

Four sediment sampling deployments were analyzed for SSC in WY 2017. Sampling efforts targeted storms expected to generate flows above 50 cfs. SSC was measured and sediment loads for each sampling period were calculated (Table 4). These loads are not the totals for the entire storm event, but for the flow within the time the sediment samples were collected.

Table 4: Suspended sediment sampling summary for WY 2017 for Canet Road

Storm Event	Sampling Begin	Sampling End	Number of Samples Analyzed	Total Load (tons)	Total Discharge (AF)
11 Jan 2017	12:30 AM	8:00 AM	14	132	278
20 Jan 2017	8:30 AM	6:00 PM	13	400	687
22-23 Jan 2017	7:00 AM	12:30 AM	33	438	962

In total, there were 60 suspended sediment samples analyzed for WY 2017, all from January 2017 (Figure 14).

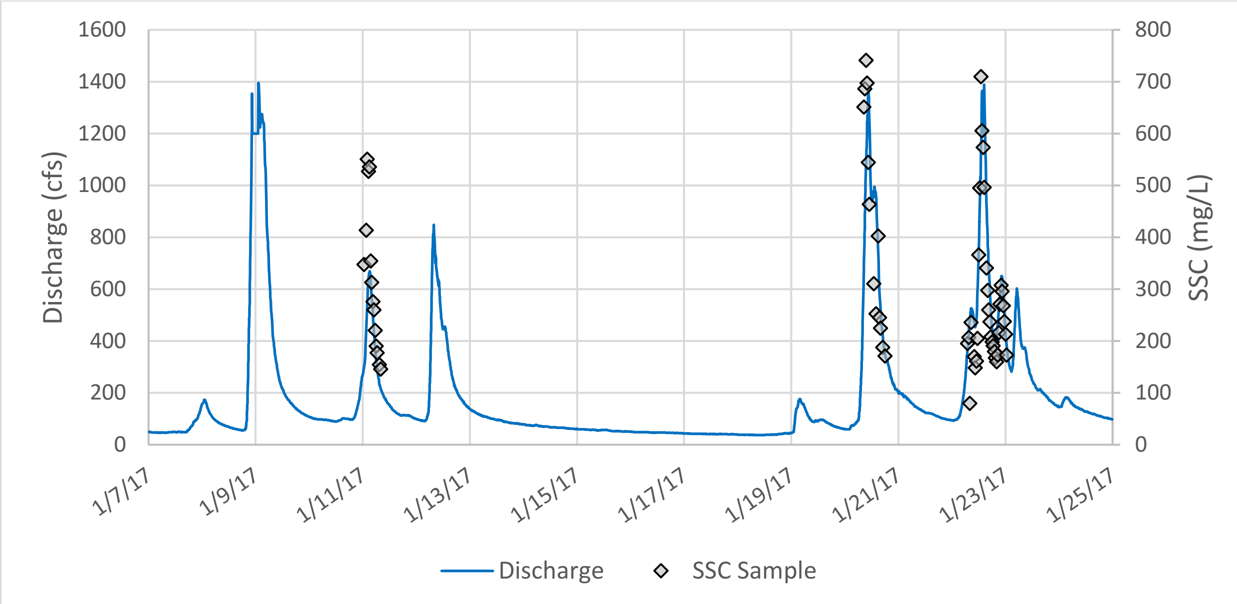


Figure 14: All processed WY 2017 sediment samples and the corresponding hydrograph for Canet Road

The correspondence of SSC with discharge was variable between these storms. The wide distribution of SSC-Q relationships made a single water year regression a poor predictor of sediment load (Figure 15).

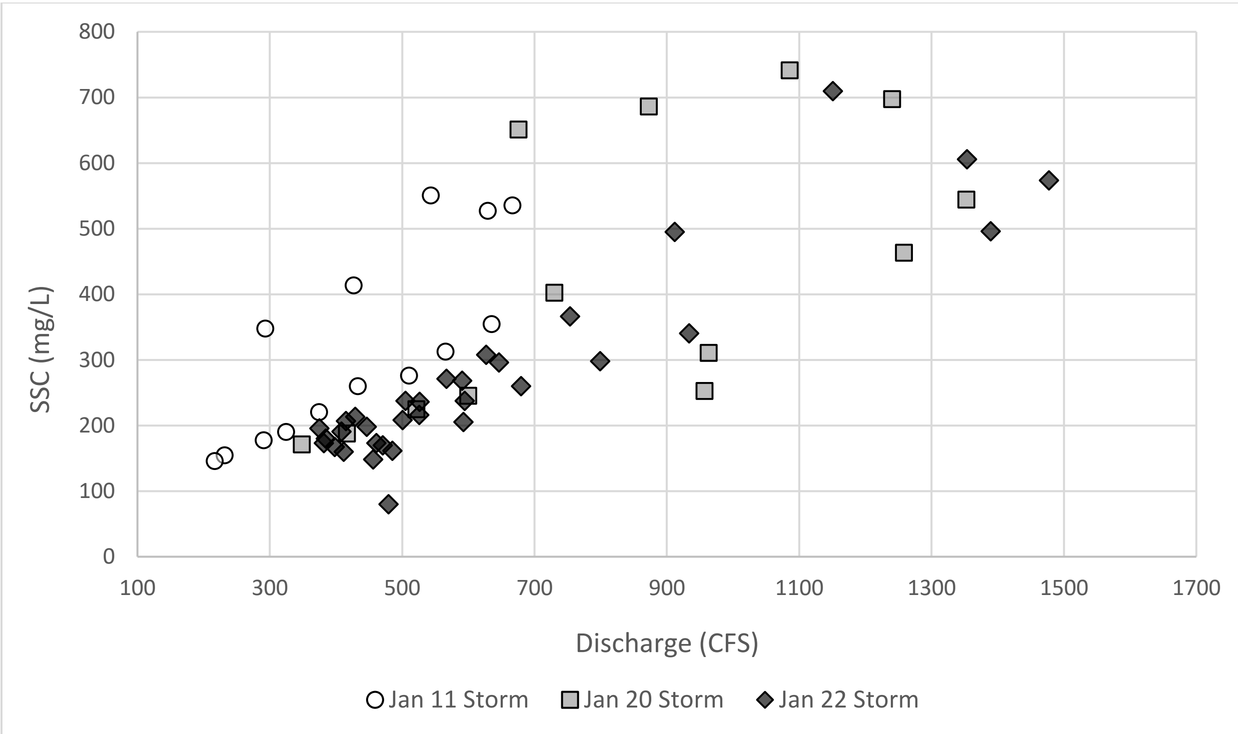


Figure 15: Plot of all WY 2017 SSC measurements and corresponding discharges at Canet Road

The sediment samples taken during these storms can be compared to the calculated sediment load generated by the predictive model (Figure 16).

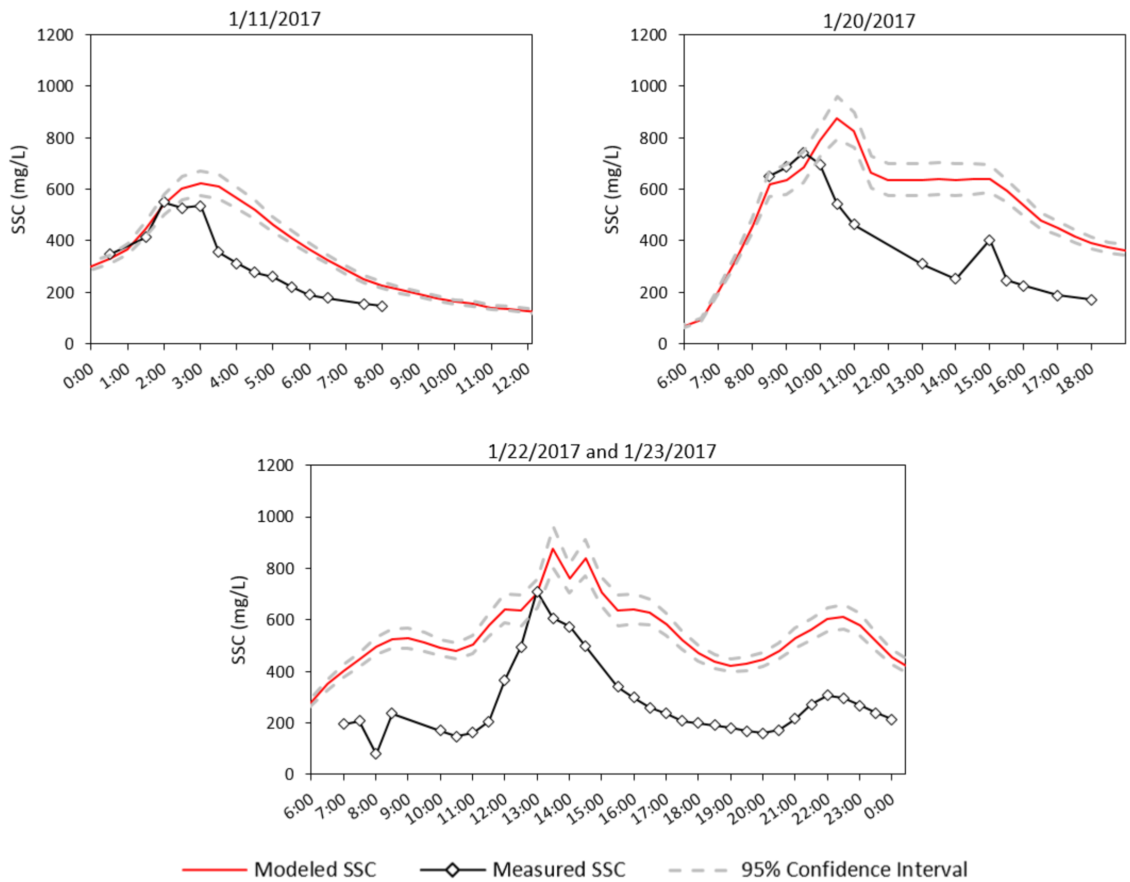


Figure 16: Comparison of measured SSC values with SSC values predicted by the model at Canet Road

The actual results and modeled results resembled each other in the shape and slopes of their graphs, but the totals were quite different. The model is not capable of predicting effects such as sediment hysteresis, which may explain fluctuations in sediment load that do not correlate with discharge. Sediment hysteresis is the nonlinear relationship between discharge and SSC that results when different sediment fluxes occur at the same discharge. It can be caused by a delay or advancement of sediments into the water column at a rate that is different than the simultaneous increase or decrease in streamflow. Sediment hysteresis is strongly affected by the soil water content of the catchment area for the sampling site, which also varies significantly from year to year in Mediterranean climates (Seeger et al., 2004). Furthermore, the predictive model is based on several years of data, whereas the measured data from 2017 represents only one water year. This could be interpreted to mean that these January storms in 2017 had a lower-than-average suspended sediment load and that the sediment supply was less than in other years that have been studied by the Estuary Program. The numerical totals for the predictive model's estimates are compared to the Estuary Program's measured values in Table 5.

Table 5: Sediment model estimate comparison for WY 2017 storms at Canet Road

Storm Event	Measured Sediment Total (tons)	Modeled Sediment Total (tons)	Model Over-Prediction
11 Jan 2017	132	181	+37%
20 Jan 2017	400	618	+55%
22-23 Jan 2017	438	786	+79%

WATER YEAR 2018 SEDIMENT LOAD MONITORING

Sediment results were not compared to model predictions as in WY 2017 because only a partial storm event was captured, missing the rising limb of the flow. Compounded with the fact that the magnitude of the discharge was on the high end of the model's range, such a comparison would not be very meaningful.

The SSC results of the storm monitored on March 22, 2018 were extrapolated to the entire stream discharge during the monitoring event, as shown in Figure 17. Discharge subsamples (green) are the instantaneous discharge values that were used to calculate the mass of sediment and extrapolated to the half hour interval until the next sample was collected. The peak flow rate was 1,587 CFS, and the maximum sediment concentration was 806.3 mg/L during this sampling event. Each point plotted on the sediment load series represents the total mass of sediment estimated for a half-hour block of time.

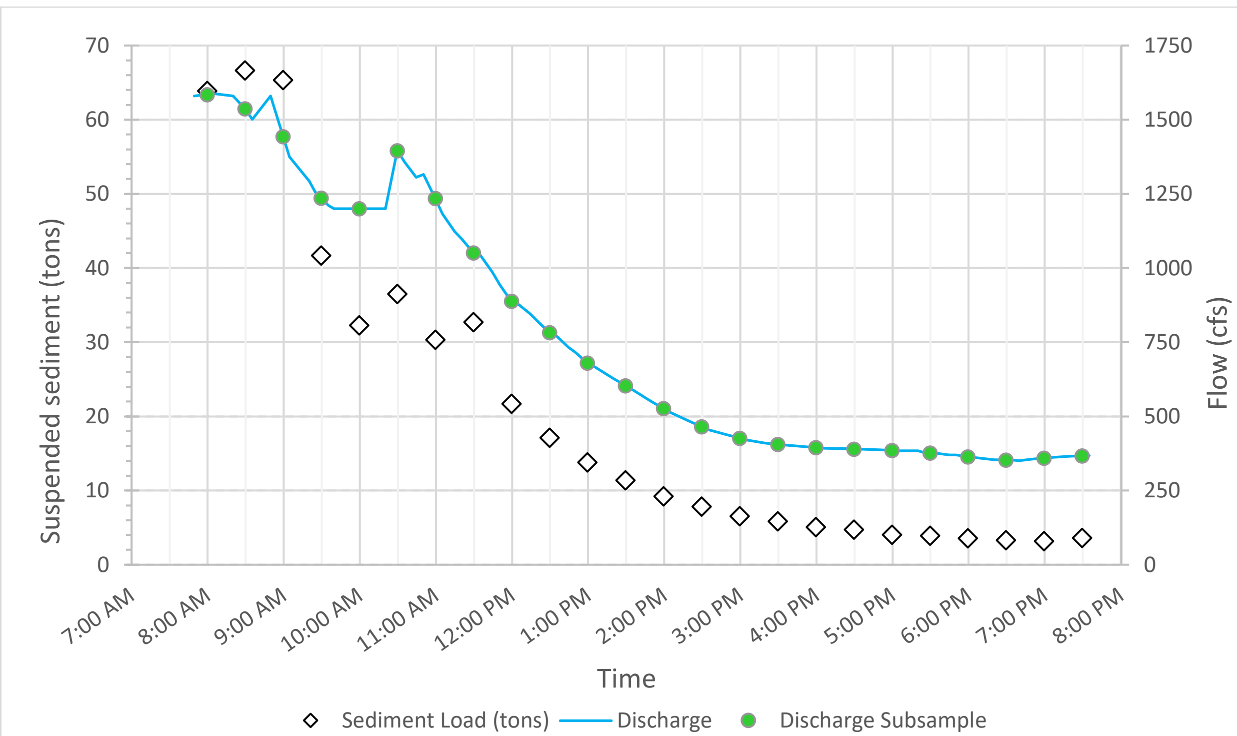


Figure 17: Sediment loading graph during March 22, 2018 storm at Canet Road

Note that the sampling rates of the ISCO sediment sampler and the water level gauge are not identical, so water level was interpolated to match the intervals of the ISCO sampler. Interpolation was necessary due to the irregularity of sampling by the water level gauge during storms, which varies in response to how rapidly the stage rises or falls. The ISCO sampler does not operate in this manner and is instead restricted to regular half-hour intervals. This is illustrated by the green dots along the hydrograph in Figure 17, which align exactly with sediment sampling events on the sediment loading curve. The sum total suspended sediment load of the above storm event is estimated to be 494 tons, or 448 thousand kilograms. The relationship between SSC and discharge for this storm is shown in Figure 18.

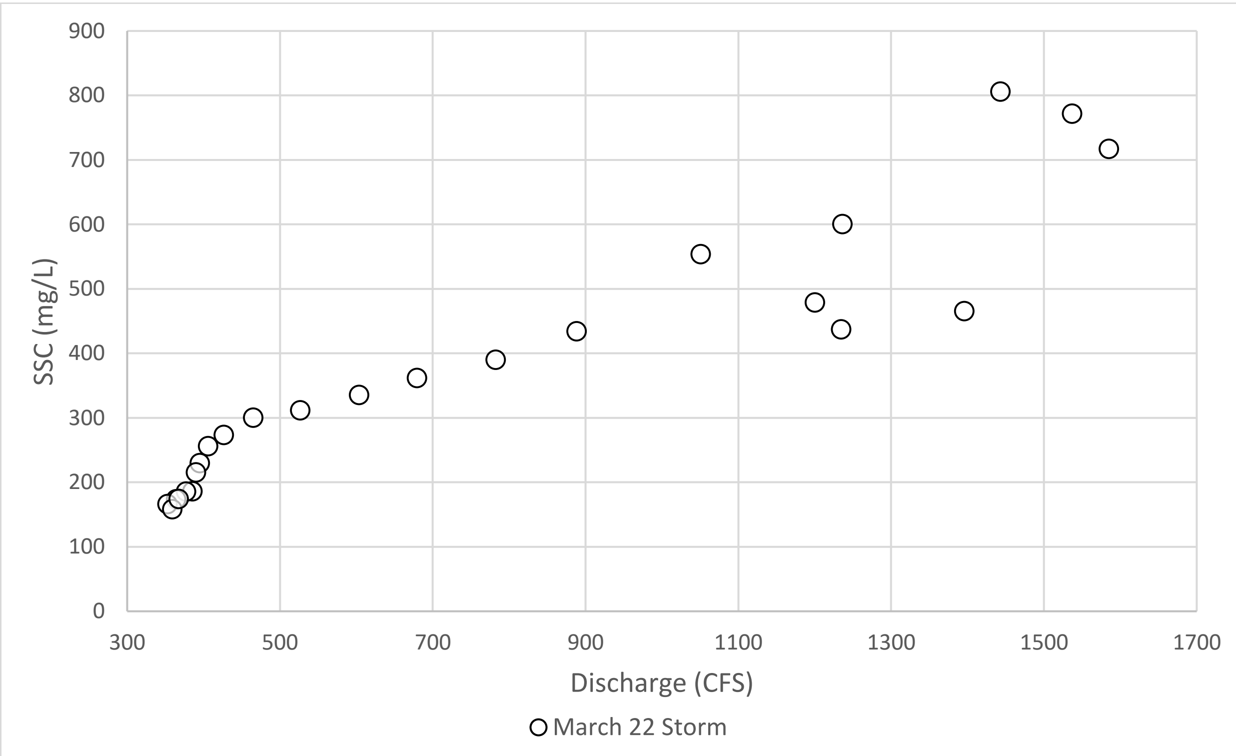


Figure 18: Plot of SSC-Q for WY 2018 storm at Canet Road

The flow generated by this storm was the largest since WY 2011. Its magnitude exceeded that of any storm observed at this gauge in the much wetter 2017 water year and was over eight times larger in volume than the next largest storm of the 2018 water year. See Figures 12 and 13 to compare. Given that the samples were collected on the falling limb of the storm flow, it is likely that the actual sediment load total was significantly larger than the 494 tons reported in Table 6.

Table 6: Suspended sediment sampling summary for WY 2018

Storm Event	**Sampling Begin**	**Sampling End**	**Number of Samples Analyzed**	**Cumulative Sediment Load (tons)**	**Cumulative Discharge (AF)**
22 Mar 2018	8:00 AM	7:30 PM	24	494	762

RECAP: 2017 AND 2018 SEDIMENT MONITORING AND CONCLUSIONS

The Estuary Program has continued to find that there is not a strong predictive relationship between rainfall and discharge or rainfall and sediment load. Instead, a predictive model relating SSC to discharge has been under development to extend the use of SSC monitoring data. Using the model, annual sediment loads between WY 2009 and WY 2018 range from 184 tons to 9,874 tons at Canet (refer to Table 2). In individual storms from WY 2017, the model regularly over-predicted storm loads by 37% or more. Despite over-predicting during these storms, the annual WY 2017 sediment load was predicted to be 9,149 tons for the contributing areas upstream of Canet Road, which accounts for only about 51% of the total Chorro watershed area. For comparison, the Tetra Tech modeling I 1998 estimated 60,689 tons of sediment transport, although this value accounts for the entire Chorro subwatershed.

Although storm events are brief when compared to the entire length of the water year, they have dramatic influence on the total amount of sediment moving through Chorro Creek. In order to mediate the effects of such large storms, the watershed's mobile sediment supply needs to be addressed from the headwaters to the mouth of the creek. The Estuary Program has participated in multiple projects that implement sediment reduction designs. The Road Erosion Prevention project, completed in 2016, was designed to reduce sediment loads in the steep headwaters of the Chorro Creek watershed and was calculated to reduce 1,225 tons/year of sediment over 10 years. The Chorro Creek Ecological Reserve restoration project was recently completed, restoring 1,000 linear feet of a side channel that can be filled by the large peak flows that tend to move the greatest amounts of sediment. This project is designed to utilize the historical floodplain to allow high-energy creek flows to spread out and drop sediment in areas outside of the main channel, lowering the total load to the estuary, and reducing the amount of fine sediments that can degrade habitat quality for sensitive species.

SSC QUALITY ASSURANCE RESULTS

The Estuary Program participates in the USGS Sediment Laboratory Quality Assurance (SLQA) program to ensure lab methods are consistently achieving a standard level of accuracy and precision. The USGS lab creates single-blind samples for SSC analysis by labs across the country. USGS provides nine samples from three ranges of sediment concentrations, each 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.

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 introduced to the sample. The results also provide a median percent difference value of all of the participating labs as compared to the known sediment concentrations. As shown in Table 7, the Estuary Program has been within +/- 10% of the true value of the sediment sample concentrations and performed similarly to other participating labs.

Further SLQA result details are available in Appendix A.

s

Table 7: Estuary Program lab SLQA results from the study period, compared with median values

SLQA Effort	SSC Target of QA Sample (mg/L)	Sample Replicate #	SSC Percent Difference for MBNEP Analysis Compared to Known Concentration (%)	Median for All SLQA Lab Participants (%)
Spring 2017	44	1	7.73%	Median -2.78%
	67	2	-5.58%	
	89	3	5.35%	
	111	4	-4.23%	
	222	5	-2.18%	
	311	6	-0.86%	
	644	7	-2.86%	
	1,111	8	-1.76%	
	4,000	9	-1.19%	
	All	**Average**	**-0.62%**	
Fall 2017	56	1	-8.85%	Median -3.22%
	78	2	NA	
	100	3	-4.76%	
	133	4	-5.67%	
	222	5	-3.92%	
	322	6	-2.75%	
	667	7	-2.88%	
	1,333	8	-1.83%	
	4,111	9	-0.97%	
	All	**Average**	**-3.95%**	
Spring 2018	49	1	5.84%	Median -1.64%
	62	2	NA	
	120	3	5.92%	
	178	4	5.29%	
	262	5	-0.55%	
	409	6	-1.71%	
	947	7	-0.82%	
	1,796	8	-0.60%	
	4,049	9	-0.32%	
	All	**Average**	**1.63%**	
Fall 2018	56	1	38.86%	Median -2.43%
	78	2	41.84%	
	111	3	3.50%	
	167	4	-1.17%	
	222	5	-1.39%	
	333	6	-1.25%	
	1,111	7	-0.38%	
	2,222	8	-1.40%	
	4,444	9	0.27%	
	All	**Average**	**8.77%**	

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 (in bold) of the nine sediment indicators, and six (in bold) of the seven biological indicators. Since Estuary Program monitoring is conducted per the SWAMP protocol, only the indicators in bold in the list below are collected and can be included in the analysis. There are three threshold criteria for comparison of each of these indicators, shown in Table 8.

Sediment Indicators:

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)**

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 8: 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, with the help of trained volunteers, has conducted bioassessment per the SWAMP protocol 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 19 for a map of the monitoring locations. The selective scores between 2008 and 2018 were averaged for all sites in Table 10. This is a representative subset of the larger number of bioassessment sites that are monitored in each year.

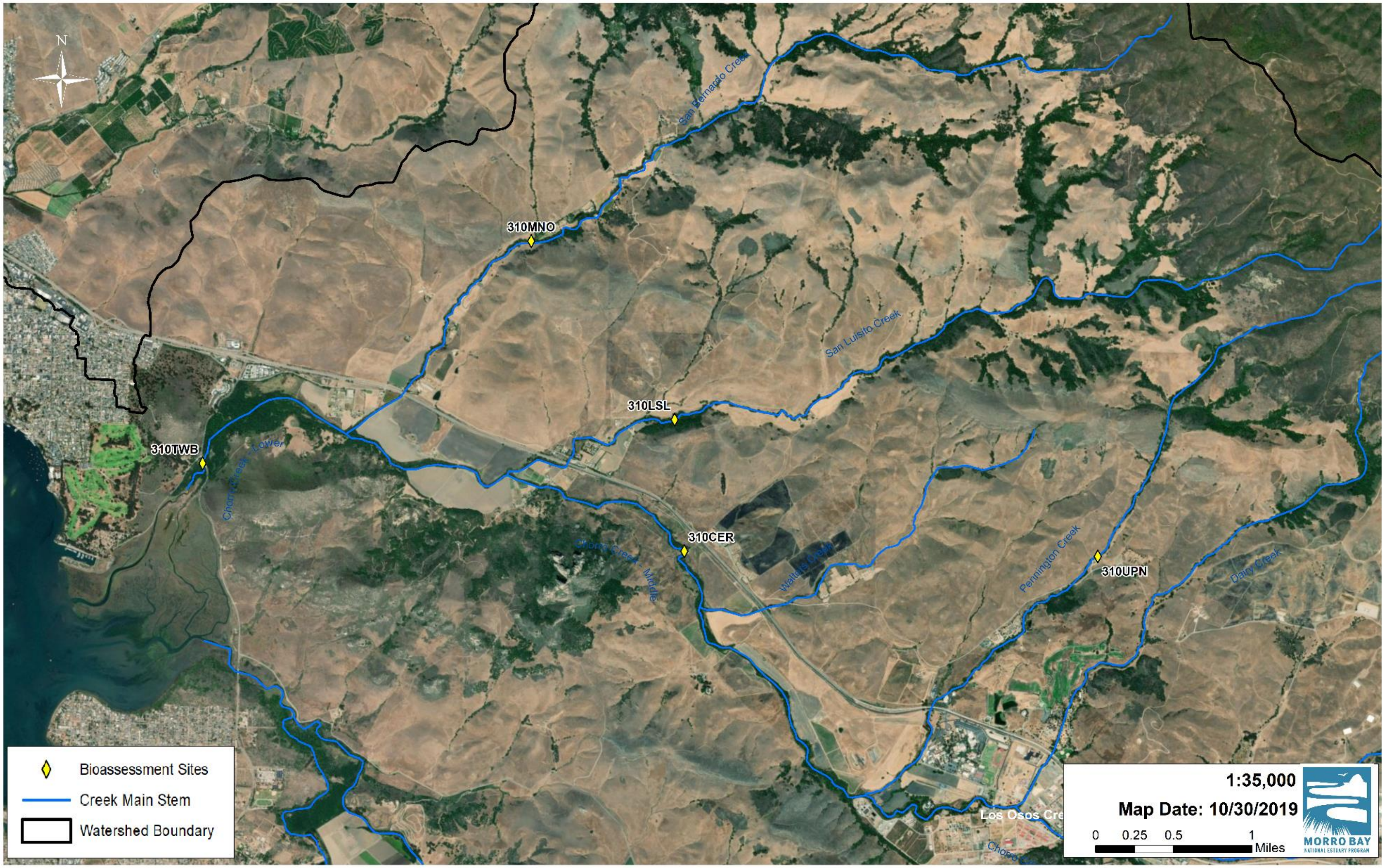


Figure 19: Representative bioassessment sites in 2017 and 2018

Table 9: Sediment and biological indicators 2008 to 2018 for a selection of Morro Bay watershed sites

		Sediment Indicators							Biological Indicators					
Site Code	Survey Date	Percent Fines	Percent Sands	Percent <8mm	FS Sum Percent	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
310MNO	2008	0.0	24.8	26.7	24.8	20.0	0	25	64.0	20.0	50.4	4.70	9.4	10.0
310MNO	2010	1.0	23.3	30.1	24.3	14.0	1	24	42.0	14.0	61.8	4.70	7.1	5.0
310MNO	2012	2.9	9.8	14.7	12.8	37.0	3	13	69.0	22.0	42.8	4.76	8.7	10.0
310MNO	2013	2.9	7.8	18.6	10.8	31.0	3	11	66.0	18.0	19.0	5.65	9.1	14.0
310MNO	2014	5.0	24.0	35.0	29.0	24.0	5	29	46.0	3.0	3.4	7.29	17.4	3.0
310MNO	2015	6.7	9.5	24.8	16.2	17.0	7	16	57.0	5.0	4.3	6.93	14.0	4.0
310MNO	2016	13.5	11.0	36.5	12.4	12.5	13	13	70.0	16.0	23.6	5.91	14.3	9.0
310MNO	2017	6.7	20.0	34.3	26.7	23.0	6.7	26.7	37.0	12.0	52.7	4.9	10.8	4.0
310MNO	2018	7.6	17.1	30.5	24.8	27.0	7.6	24.8	52.0	21.0	21.2	5.7	15.4	9.0
310LSL	2008	5.7	19.1	33.3	24.8	12.0	6	25	55.0	14.0	25.2	4.48	12.7	9.0
310LSL	2010	11.8	10.9	33.7	22.8	13.0	12	23	48.0	18.0	50.7	4.58	6.3	9.0
310LSL	2012	2.9	23.3	32.1	26.2	14.0	3	26	61.0	22.0	18.3	4.48	9.8	16.0
310LSL	2013	10.5	9.5	25.7	20.0	17.0	10	20	39.0	4.0	0.9	5.17	15.4	2.0
310LSL	2014	16.2	11.4	34.3	27.6	20.0	16	28	44.0	8.0	4.3	5.45	9.1	6.0
310LSL	2015	14.4	11.5	37.5	26.0	11.0	14	26	54.0	14.0	17.8	5.28	9.3	6.0
310LSL	2016	23.8	9.5	40.0	33.3	9.0	24	24	44.0	15.0	36.0	4.54	8.9	9.0
310LSL	2017	9.8	12.7	27.5	22.5	20.5	9.8	22.5	37.0	12.0	28.8	5.0	13.5	6.0
310LSL	2018	1.9	30.5	32.4	32.4	14.0	1.9	32.4	55.0	22.0	51.4	4.2	7.3	12.0
310UPN	2008	1.9	12.4	20.0	14.3	25.0	2	14	62.0	17.0	18.4	4.95	9.7	14.0
310UPN	2011	2.9	15.2	19.1	18.1	120.0	3	18	59.0	25.0	64.4	4.26	5.1	13.0
310UPN	2012	1.0	16.5	17.5	17.5	63.5	1	17	56.0	21.0	48.5	4.02	8.9	15.0
310UPN	2013	2.9	7.7	14.4	10.6	100.5	3	11	70.0	24.0	32.6	4.49	5.7	17.0
310UPN	2014	1.9	3.8	9.5	5.7	87.0	2	6	73.0	20.0	17.6	4.92	6.9	15.0
310UPN	2015	5.8	4.8	16.3	10.6	55.5	6	11	53.0	10.0	16.1	5.38	9.4	5.0
310UPN	2016	2.9	9.0	24.8	2.9	24.0	3	3	73.0	14.0	15.9	5.68	11.0	10.0
310UPN	2017	1.0	15.2	23.8	16.2	21.0	1.0	16.2	50.0	15.0	58.4	4.7	6.0	8.0
310UPN	2018	1.9	24.8	29.5	26.7	30.0	1.9	26.7	57.0	19.0	45.0	4.0	3.5	16.0
310TWB	2008	18.8	7.9	31.7	26.7	13.0	19	27	55.0	14.0	27.3	5.38	14.6	7.0
310TWB	2012	8.0	29.0	44.0	37.0	9.5	8	37	46.0	8.0	6.8	6.65	21.7	3.0
310TWB	2013	9.7	18.5	44.7	28.2	9.0	10	28	52.0	9.0	3.7	6.44	21.2	4.0
310TWB	2014	24.8	11.4	53.3	36.2	6.0	25	36	41.0	4.0	6.9	6.52	24.4	2.0
310TWB	2015	0.0	41.0	59.0	41.0	5.0	0	41	31.0	0.0	0.0	7.61	29.0	0.0
310TWB	2016	12.4	24.8	51.4	37.1	12.5	13	13	42.0	3.0	2.9	7.2	21.4	3.0
310TWB	2017	12.5	21.2	34.6	33.7	16.0	12.5	33.7	31.0	9.0	34.1	5.5	19.4	4.0
310TWB	2018	14.3	35.2	63.8	49.5	3.0	14.3	49.5	46.0	11.0	14.6	6.3	17.4	5.0
310CER	2008	15.2	15.2	30.5	30.5	24.0	15	30	48.0	6.0	14.6	6.22	14.6	1.0
310CER	2011	3.8	34.3	41.0	38.1	13.0	4	38	50.0	14.0	48.1	5.48	12.0	4.0
310CER	2012	15.3	11.2	26.5	26.5	20.0	15	27	42.0	12.0	35.6	5.48	16.7	2.0
310CER	2013	13.8	22.3	45.7	36.2	15.5	14	36	26.0	5.0	6.3	5.64	19.2	0.0
310CER	2014	26.7	15.2	47.6	41.9	9.0	27	42	34.0	6.0	3.2	6.64	20.6	1.0
310CER	2015	25.0	12.5	39.4	37.5	14.0	25	38	53.0	9.0	11.9	6.16	19.1	2.0
310CER	2016	33.3	17.1	54.3	50.5	1.0	33	33	47.0	5.0	12.9	6.11	14.9	1.0
310CER	2017	4.0	26.7	38.6	30.7	13.0	4.0	30.7	39.0	9.0	34.1	5.6	10.3	4.0
310CER	2018	20.0	15.2	39.0	35.2	15.0	20.0	35.2	39.0	9.0	31.6	5.8	18.0	2.0

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

Table 10: Averages for sediment and biological indicators from 2008 to 2018 for a selection of sites

	Sediment Indicators							Biological Indicators					
Site Code	Percent Fines	Percent Sands	Percent <8mm	FS Sum Percent	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	2.4	12.2	19.4	13.6	58.5	2.4	13.6	61.4	18.3	35.2	4.7	7.4	12.6
310MNO	5.1	16.4	27.9	20.2	22.8	5.1	20.3	55.9	14.6	31.0	5.6	11.8	7.6
310LSL	10.8	15.4	32.9	26.2	14.5	10.8	25.1	48.6	14.3	25.9	4.8	10.3	8.3
310TWB	12.6	23.6	47.8	36.2	9.3	12.7	33.2	43.0	7.3	12.0	6.4	21.1	3.5
310CER	17.5	18.9	40.3	36.3	13.8	17.5	34.4	42.0	8.3	22.0	5.9	16.1	1.9

Recommended numeric targets to support beneficial uses
Recommended numeric targets to support preliminary 303(d) listing (low priority)
Recommended numeric targets to support 303(d) listing (high priority)

SEDIMENT IMPAIRMENT ANALYSIS

With the averaged data from 2008 through 2018, 310UPN met all sediment numeric targets that support beneficial use. In 2016 310MNO supported beneficial uses across the board as well, but has since declined in EPT Richness, Biotic Index, and Sensitive Number (MBNEP, 2017). At 310LSL three biological indicators met the lower priority listing criteria, and Percent Fines rose to the high priority criteria for 303(d) listing. 310TWB and 310CER both had a majority of their indicators meet the lower priority criteria and several other indicators met the criteria for the high priority 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 note 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 303(d) listing process and TMDL 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.

REFERENCES CITED

Ankcorn, P., 2003. *Clarifying Turbidity- The Potential and Limitations of Turbidity as a Surrogate for Water Quality Monitoring*. Proceedings of the 2003 Georgia Water Resources Conference, held April 23-24, 2003.

ASTM, 1999. *Standard Test Method for Determining Sediment Concentration in Water Samples: American Society of Testing and Materials*, D 3977-97, Vol. 11.02, pp. 389-394.

Bernstein, B., Merkel, K., Chesney, B., Sutula, M., 2011. *Recommendations for a Southern California Regional Eelgrass Monitoring Program*. Technical Report 632. Prepared for the National Marine Fisheries Service. Southern California Coastal Water Research Project. Costa Mesa, CA.

Callaway, J., 2015. *Sediment Accumulation Rates in Morro Bay Estuary: Final Report 2015 Field Sampling*. San Francisco, CA: University of San Francisco.

Central Coast Regional Water Quality Control Board, 2003. *Morro Bay Total Maximum Daily Load for Sediment (including Chorro Creek, Los Osos Creek and the Morro Bay Estuary)*. (https://www.waterboards.ca.gov/centralcoast/board_decisions/adopted_orders/2002/2002_0051_mb_sed_tmdl_final_proj_rpt.pdf)

Coastal San Luis Resource Conservation District, 2002. *Chorro Flats Enhancement Project Final Report to the California State Coastal Conservancy*. (http://www.coastalrcd.org/images/cms/files/Chorro%20Flats%20final%20report%20smaller.pdf)

Coastal San Luis Resource Conservation District, 2010. *Morro Bay Project Clearwater Final Report*.

Gray, John R., Glysson, G. Douglas, Turcios, Lisa M., Schwarz, Gregory E., 2000. *Comparability of Suspended Sediment Concentration and Total Suspended Solids Data*, U.S. Geological Survey Water-Resources Investigations Report 00-4191, 14 p. (http://water.usgs.gov/osw/pubs/WRIR00-4191.pdf).

Merkel & Associates, 2017. *Pre-Dredge Eelgrass Survey Report in Support of the Morro Bay 2017 Maintenance Dredging Project*. M&A #17-022-01.

Morro Bay National Estuary Program, 2011. *Morro Bay Sediment Loading Update*. (https://www.mbnep.org/wp-content/uploads/2014/12/2011_Sediment_Report.pdf)

Morro Bay National Estuary Program, 2017. *Sediment Monitoring Report 2016*. (https://www.mbnep.org/wp-content/uploads/2018/01/2016-Sediment-Report-and-appendices.pdf)

Morro Bay National Estuary Program, 2019. *Morro Bay Eelgrass Report 2018*. (https://www.mbnep.org/wp-content/uploads/2019/04/2018-Eelgrass-Report.pdf)

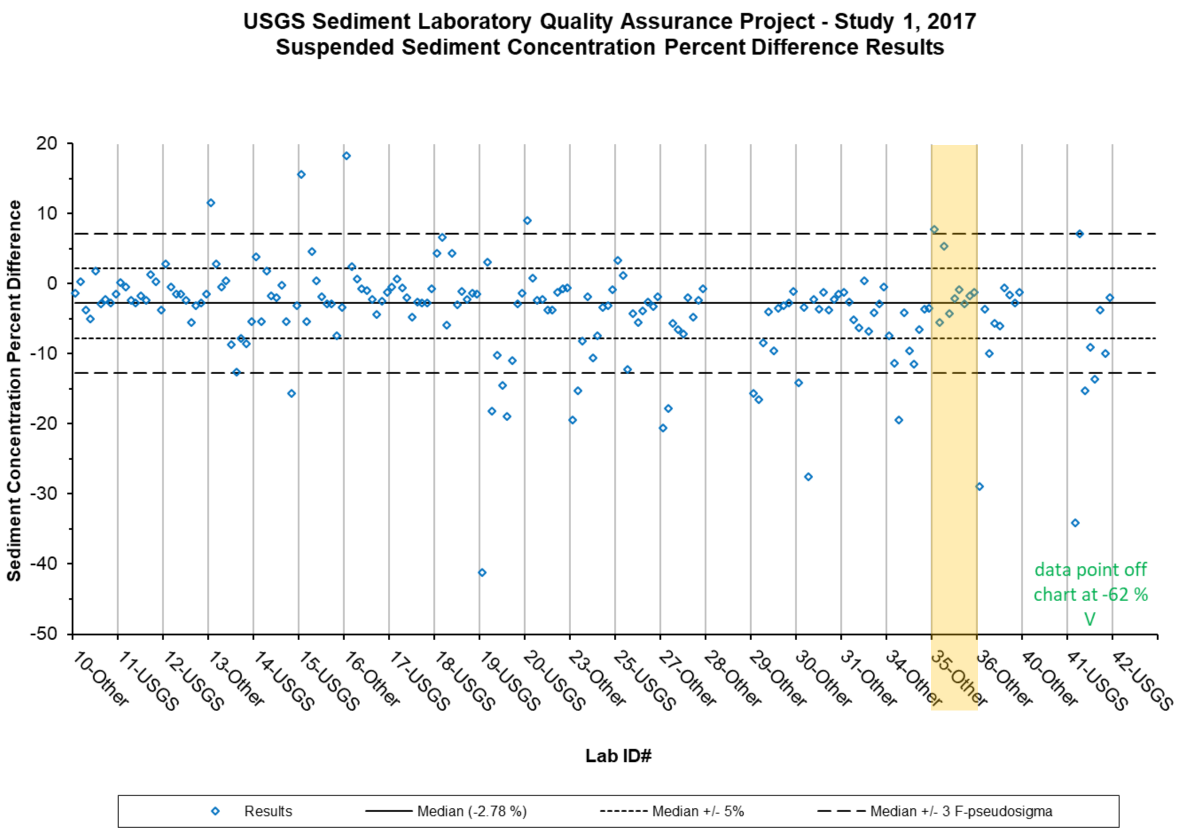
Morro Bay National Estuary Program, 2018. *Morro Bay Watershed Creek Health for Water Year 2017*. (https://www.mbnep.org/wp-content/uploads/2018/11/Morro-Bay-Watershed-Creek-Health-WY2017.pdf)

Morro Bay National Estuary Program, 2019. *Morro Bay Watershed Creek Health for Water Year 2018*.
(https://www.mbnep.org/wp-content/uploads/2019/07/Morro-Bay-Watershed-Creek-Health-WY2018_final.pdf)

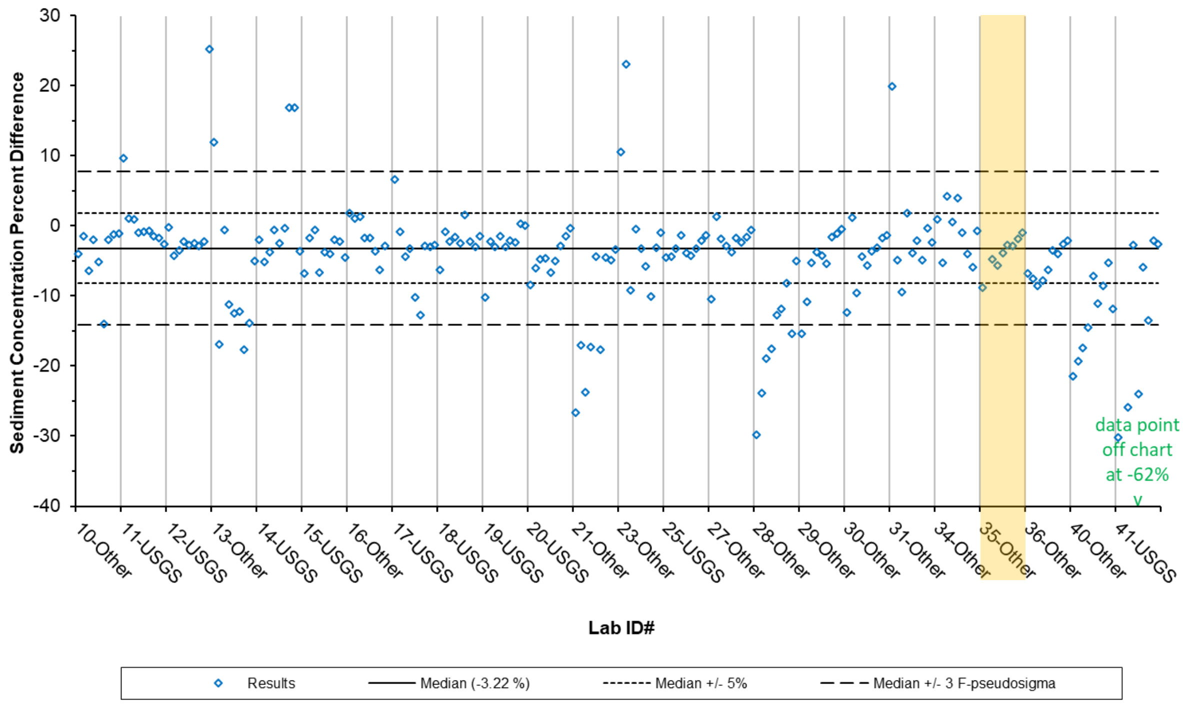
Seeger, M. & Errea, M.P. & Beguería, Santiago & Arnáez, J. & Martı, C. & García-Ruiz, José M., 2004. *Catchment soil moisture and rainfall characteristics as determinant factor for discharge/suspended sediment hysteretic loops in a small headwater catchment in the Spanish Pyrenees*. Journal of Hydrology. 288. 299-311. 10.1016/j.jhydrol.2003.10.012.

Tetra Tech, Inc, 1998. *Morro Bay Estuary Program Sediment Loading Study*.

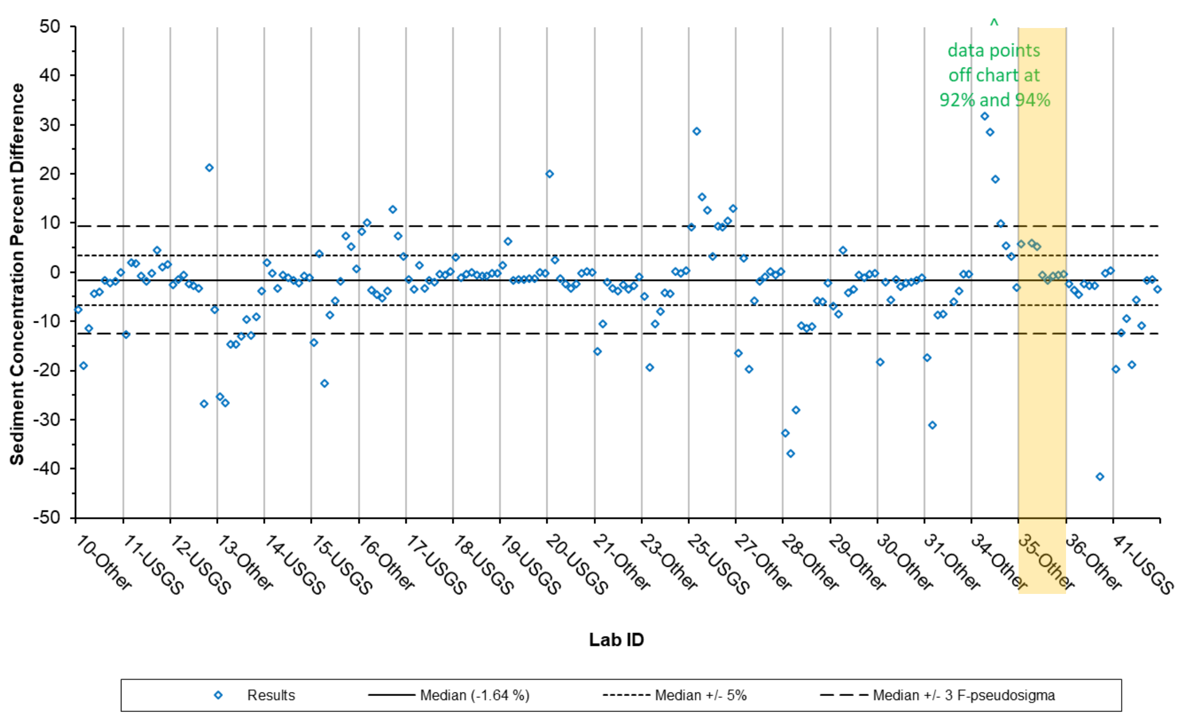
APPENDIX A: USGS SLQA RESULTS

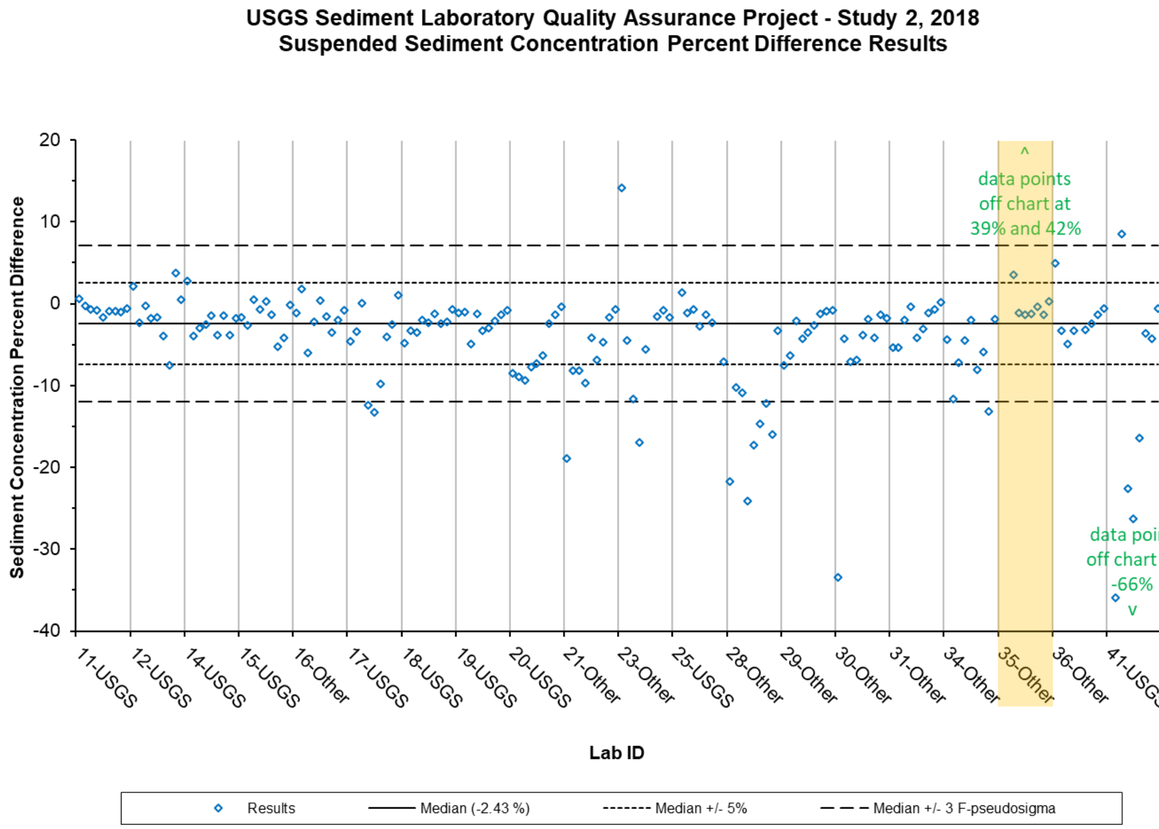


USGS Sediment Laboratory Quality Assurance Project - Study 2, 2017
Suspended Sediment Concentration Percent Difference Results



USGS Sediment Laboratory Quality Assurance Project - Study 1, 2018
Suspended Sediment Concentration Percent Difference Results




USGS Sediment Laboratory Quality Assurance Project - Study 2, 2018
Suspended Sediment Concentration Percent Difference Results
Sediment Concentration Percent Difference
20
10
0
-10
-20
-30
-40
data points
off chart at
39% and 42%
data point
off chart at
-66%
11-USGS
12-USGS
14-USGS
15-USGS
16-Other
17-USGS
18-USGS
19-USGS
20-USGS
21-Other
23-Other
25-USGS
28-Other
29-Other
30-Other
31-Other
34-Other
35-Other
36-Other
41-USGS
Lab ID
Results
Median (-2.43 %)
Median +/- 5%
Median +/- 3 F-pseudosigma

APPENDIX B: SLO COUNTY PRECIPITATION CONTOURS