MORRO BAY NATIONAL ESTUARY PROGRAM

Sediment Monitoring Report
2019 Water Year

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

February 2021

CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

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 six sites assessed by this method, five 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 2019 SLQA effort are included in this report.

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. This report details progress on monitoring to assess sediment conditions in the Morro Bay watershed and estuary for 2019. 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 (EPA) 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. Tidal prism volume assessments are not conducted frequently, due to the high cost and because of the time needed between surveys to obtain meaningful results. The most recent tidal prism calculation was conducted in 1998 and the volume was estimated to be about 4,200 acre-ft. A topo bathymetric LiDAR survey was conducted in 2019 and updated tidal prism calculations are expected in 2021. The numeric targets for sediment are detailed in Table 1.

Table 1: Morro Bay Sediment TMDL numeric targets for Chorro and Los Osos creeks and tributaries.

Parameter	Numeric Target
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 2019 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 3,607 turbidity readings collected since 2002, 2.2% 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. 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 monitoring was not specified 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. Suspended sediment monitoring resumed for 2017 through 2019.

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).

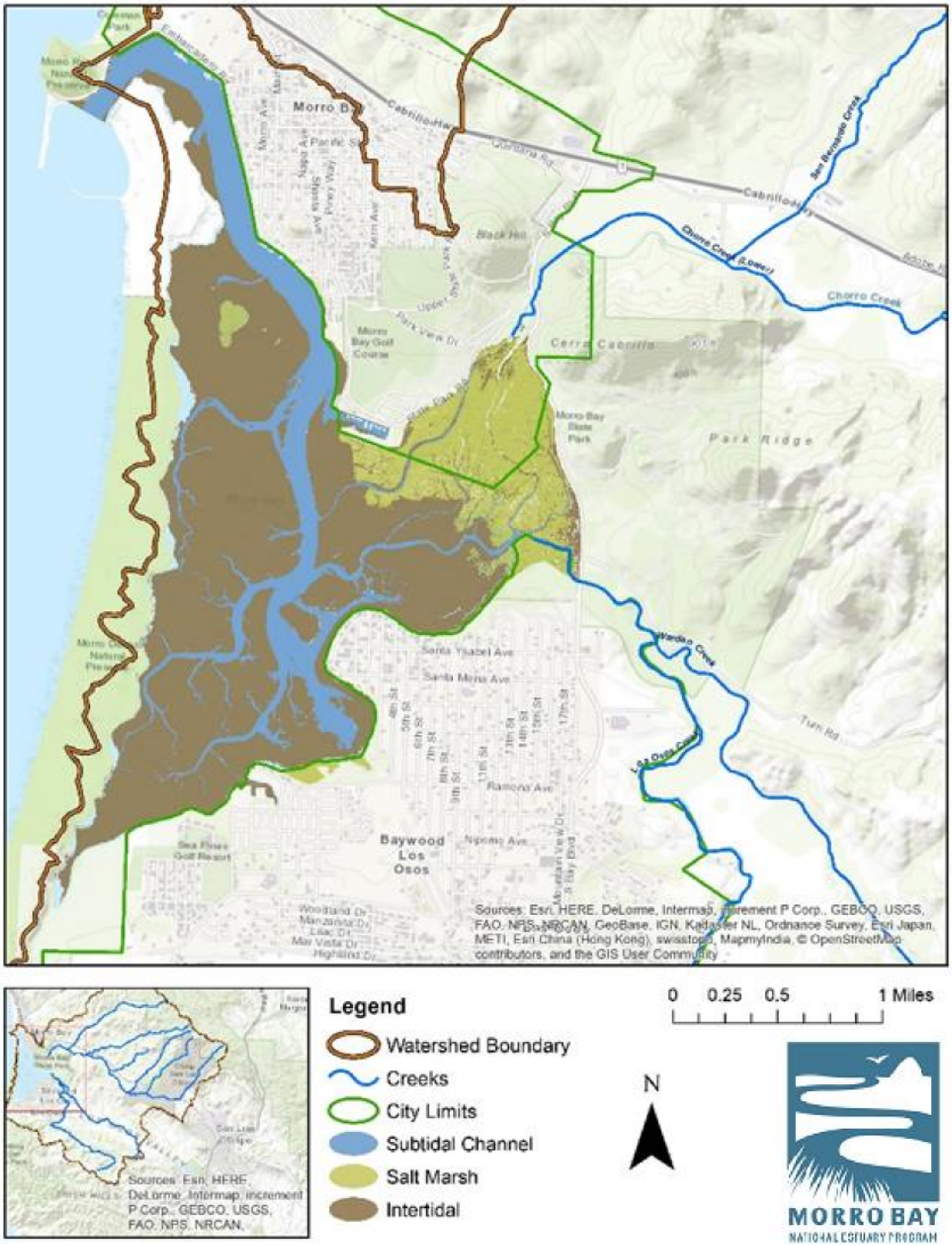


Figure 1: Map of Morro Bay estuary habitat types

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.

Zostera marina (eelgrass) is an important component of coastal habitat and provides diverse benefits to coastal marine and migratory species as well as substantial benefit in the form of ecosystem services. Eelgrass meadows are known to be highly sensitive to water clarity degradation. The Morro Bay estuary previously supported the third largest remaining eelgrass beds in Southern California (Bernstein, et. al. 2011). Historic monitoring of eelgrass extent indicates that intertidal eelgrass beds may have spanned up to 500 acres in Morro Bay during the 1970s. 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, 2019a). More recent eelgrass surveys from November 2019 indicated approximately 42 acres of eelgrass bay-wide. This improvement is likely the result of multiple factors, including eelgrass restoration efforts, changing water quality conditions, shifting bay elevations, etc.

In addition to providing critical marine habitat, Morro Bay is also a popular destination for outdoor recreation. 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 also an important center for commercial fishing and aquaculture operations. The 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 mean lower low water (MLLW).

In 2019, the 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 28, 2019 and was completed on June 16, 2019. According to pre and post-dredge surveys, no eelgrass was found within the project area or within the area of potential effect (APE). The nearest eelgrass to the APE was located approximately 90 meters (295 feet) from the northernmost portion of the main channel. Water quality monitoring was conducted before, during, and after construction at multiple sites within the project area. Parameters included light transmittance, dissolved oxygen, turbidity, pH, temperature, and salinity. All parameters at all stations were recorded within normal ranges for seawater throughout monitoring. (M&A, 2019).

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 to help meet TMDL goals.

The Coastal San Luis Resource Conservation District (CSLRCD) implemented the Chorro Flats Enhancement Project in 1997, a floodplain restoration project 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.

The CSLRCD has also implemented a broad array of agricultural best management practices (BMPs) 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 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 (CCRWQCB, 2003). Fencing installations have resulted in the protection of important stream corridors like those 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 National Monitoring Program (NMP) paired watershed study during the 1990s. Following the completion of the NMP in 2001, substantial in-stream restoration work was undertaken. Changes were also made to the grazing regime and ranch road management practices in the watershed.

The 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 California Polytechnic State University (Cal Poly), Camp San Luis Obispo Army Base (Camp SLO), and U.S. 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. Estimates show that this project will eliminate 1,225 tons per year of sediment erosion over ten years.

In 2019, the Chorro Creek Ecological Reserve restoration project was completed, which restored 1,000 linear feet of a side channel at the base of Hollister Peak. This project was 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, thereby lowering the total load to the estuary and reducing the amount of fine sediments that can degrade habitat quality for sensitive species. As part of this project approximately 24,000 cubic yards of sediment were removed, a large portion of which would have been flushed down Chorro Creek into the estuary over time. 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 CIRCULATION

The Estuary Program has collaborated with research partners to better understand the hydrodynamics of Morro Bay and how sediment transport is tied to eelgrass resilience.

In 2019, Dr. Ryan K. Walter of Cal Poly's Physics Department completed research on Morro Bay hydrodynamics and differences in sediment grain size. Through the collection of sediment samples at various estuary locations, Walter found substantial differences in sediment composition between the mouth of the bay and the back of the bay. At the mouth, currents are stronger and flushing occurs more regularly due to the incoming and outgoing tides. This creates prevalent wave-driven sediment transport, often moving larger grain sizes toward the mouth. At the back of the bay, by contrast, currents are much weaker, resulting in longer residence times for sediment. In addition, adjacent creeks bring silts and clays downstream from the watershed into the back of the bay. (Walter, 2019) This is illustrated in Figure 2, where the percentage of sand and gravel is nearly 100% at the mouth and decreases moving toward the back of the bay (Figure 2A). The percentage of silts and clays (Figures 2B, 2C) is much lower at the mouth and highest toward the back bay.

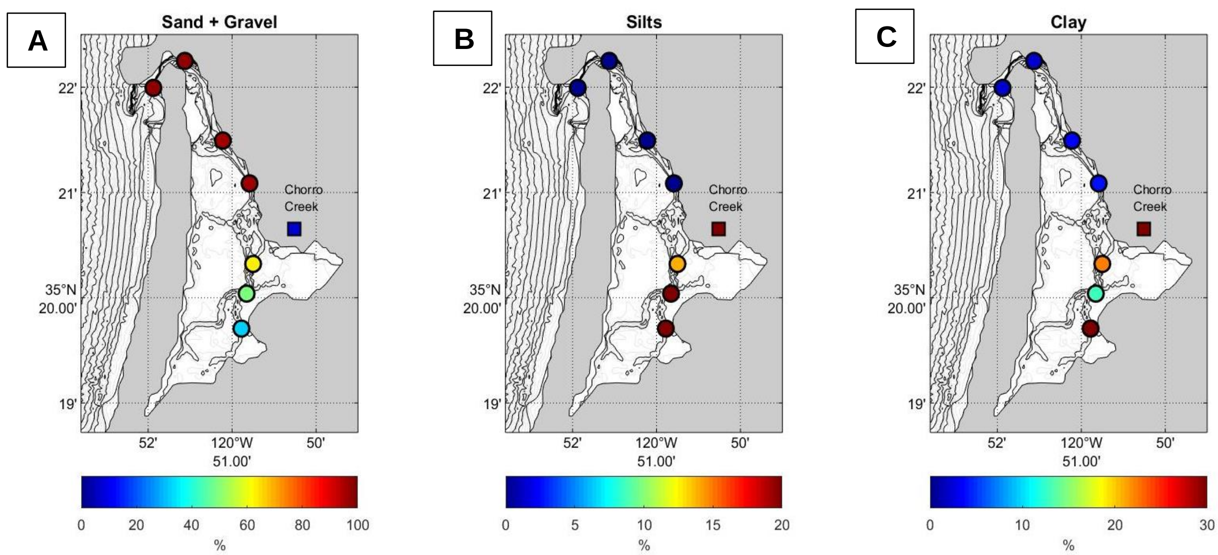


Figure 2: Sediment composition at varying locations in Morro Bay. (Walter, 2019)

Cal Poly and the Estuary Program partnered on a California Sea Grant project, under which researchers Mohsen Taherkhani and Dr. Sean Vitousek studied sediment transport in Morro Bay utilizing hydrodynamic modeling. Taherkhani and Vitousek created models of the bay with modeling software called Delft3D, and the models were calibrated and validated using field data. Water quality data to support the model was collected in the summer 2018 and winter 2019 at four unique mooring stations in the estuary. This data was used to calibrate modeling of water level, velocity, temperature, salinity and turbidity within the bay. The Delft3D models were generally found to represent hydrodynamic processes well, showing tidal advection as the dominant process for the given parameters (Taherkhani et al., 2019). The model helped predict how the Morro Bay estuary might respond to varying amounts of sea level rise (Figure 3). Factors like flushing time can drastically affect the sediment composition in the estuary and affect eelgrass resilience.

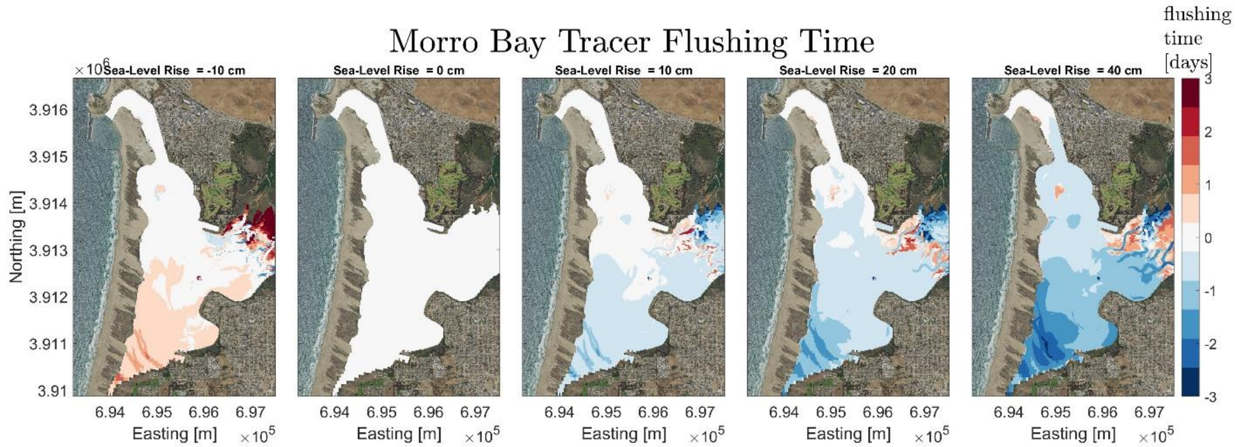


Figure 3: A model of Morro Bay flushing time in response to varying sea-level rise (Taherkhani et al., 2019).

BATHYMETRIC MAPPING

Bathymetry, a measurement of water depth at various places in a body of water, can provide valuable insight into how sediment is transported and circulated in the bay.

In May 2019, the National Oceanic and Atmospheric Administration Office of Coastal Management (NOAA) contracted with Quantum Spatial, Inc. (QSI) to collect topobathymetric Light Detection and Ranging (LiDAR) data in Morro Bay. Because of the limitations of LiDAR in deeper areas, QSI contracted Merkel & Associates (M&A) to conduct subtidal swath acoustic bathymetric surveys to support their LiDAR topographic data. In general, bathymetric sonar data was prioritized in deeper areas of the channel, and LiDAR collection was prioritized in shallower areas. LiDAR data for the NOAA Morro Bay project area was collected on May 22, 2019 at low tide, while sonar data was collected from June 17 to 19, 2019 at higher tides. The two survey efforts were conducted over a total area of 419.7 acres of the bay.

The final project combined near-infrared LiDAR coverage from QSI with swath acoustic bathymetric collected by M&A to create a comprehensive topographic-bathymetric digital elevation model (DEM) of Morro Bay. The DEM can support circulation and sediment transport modeling within the estuary. The survey results can be compared to previous bathymetric and topographic surveys from 1999 and 2009-10 to map temporal change, as well as address any data gaps from previously non-surveyed areas (Quantum, 2019).

Figure 4 shows the locations of erosion and accretion throughout the bay through relative elevation changes between the 2009-10 topobathy survey and the 2019 survey. The numbers in the legend refer to the elevation of the bay bottom relative to the average height of the lowest tide of the day, referred to as the mean lower low water (MLLW). Erosion is indicated in dark blue, and deposition is shown in green. Areas in white indicate little to no change between the two surveys. The relative elevation changes seen in Figure 4 show a higher percentage of erosion in areas surrounding the main channel, as well as some accretion along the shore and within the main channel.

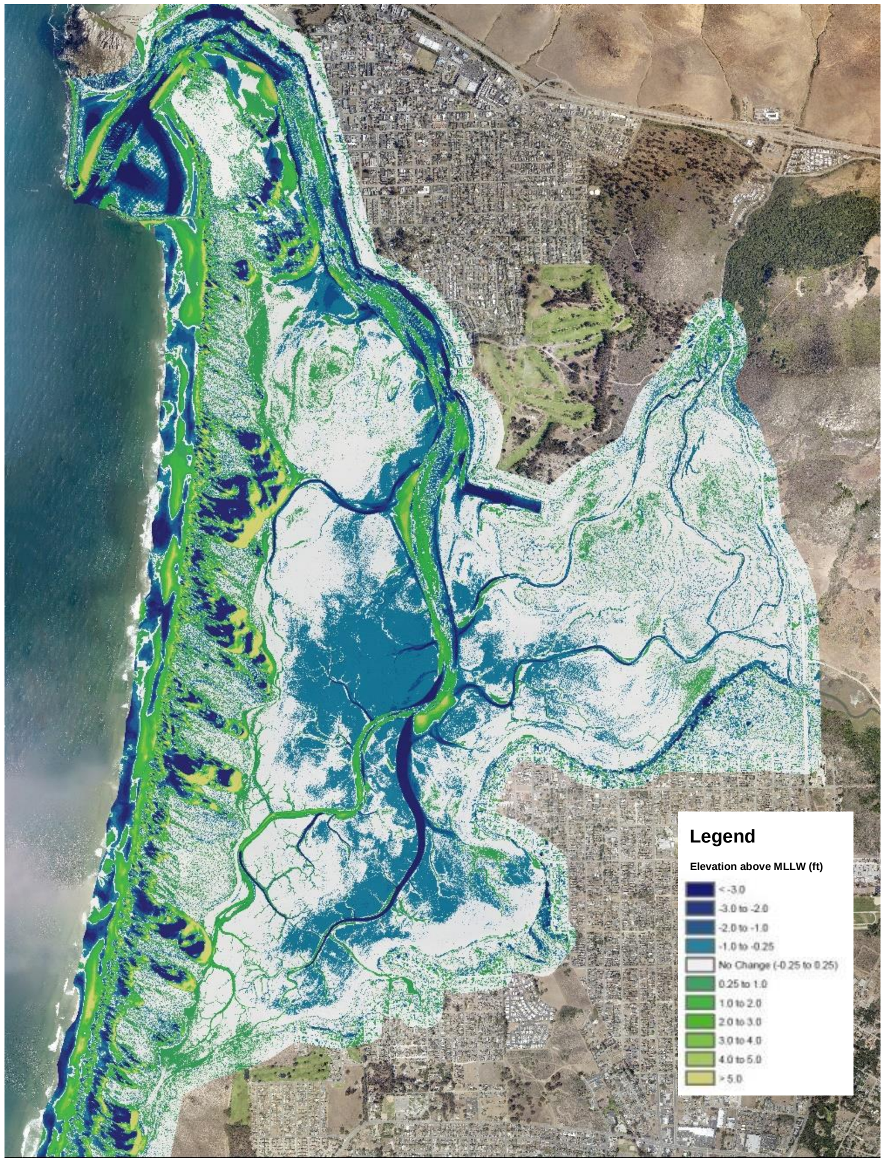


Figure 4: Relative elevation changes of Morro Bay depth between 2009-10 and 2019. Dark blue indicates erosion and green indicates deposition.

It should be noted that, as mentioned previously, the northern channel of Morro Bay was dredged by the Portland District hopper dredge Yaquina between May 28 and June 16, 2019. This dredging occurred less than a month prior to the completion of the topobathy survey, meaning that significant changes in bedform seen in the 2019 topobathy survey may likely be linked to prior dredging as opposed to natural sediment transport over such a short period of time (Quantum, 2019).

This topobathymetric data will be used as a basis for future tidal prism calculations to assess the volume of water present in the bay, as calculated from the difference of the ebb and flood volumes. Tidal prism calculations are expected in 2021.

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 surveys 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 the spring 2019 bioassessment survey 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 their larger study of sedimentation rates on the west coast. The Morro Bay sites in this study are located near two other SET sites used in the University of San Francisco study (Figure 5). A USGS progress report from July 2019 shows that the cumulative elevation 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

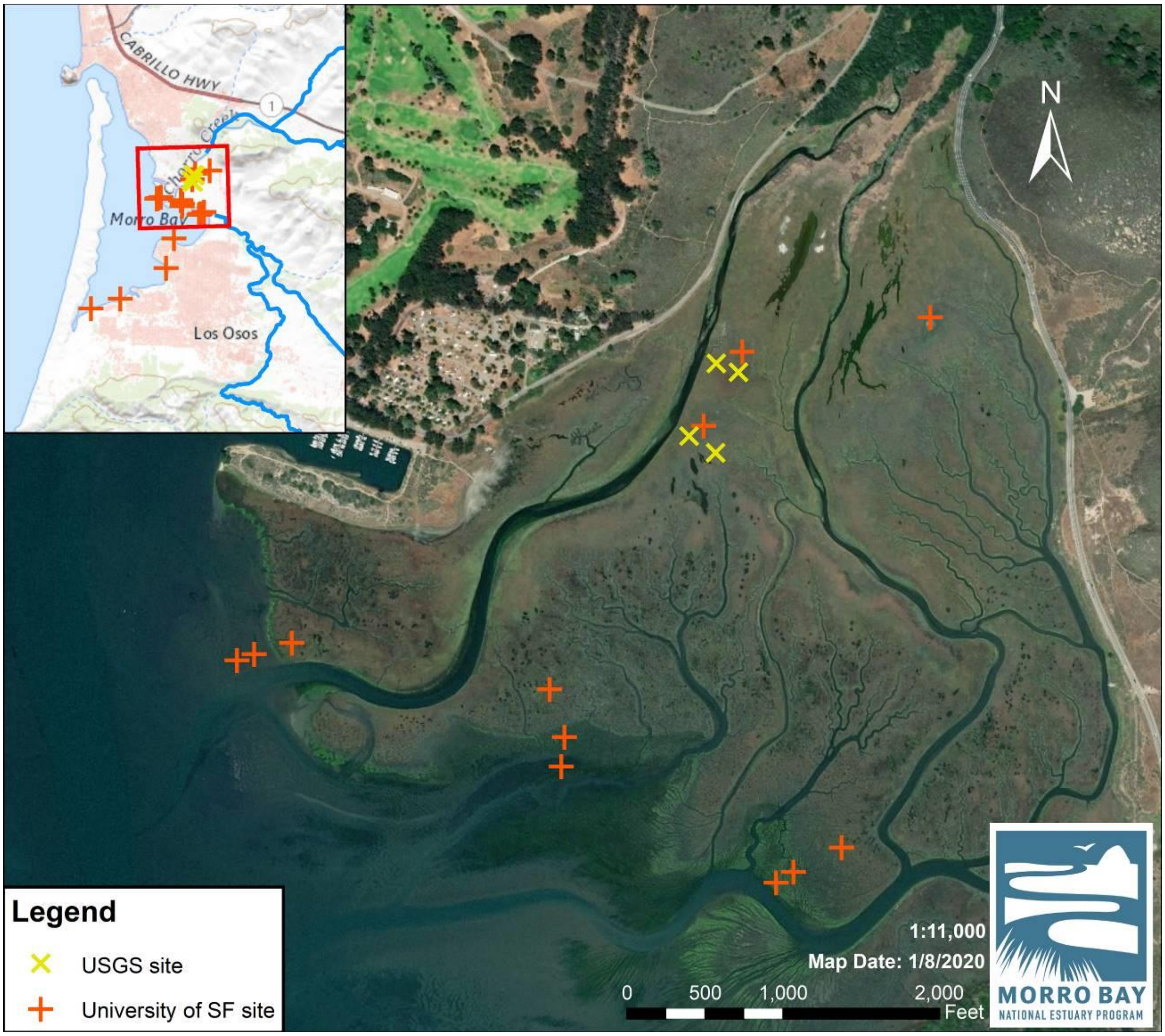


Figure 5: Plotted points of SET locations in the marsh area

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.

Figure 6 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.

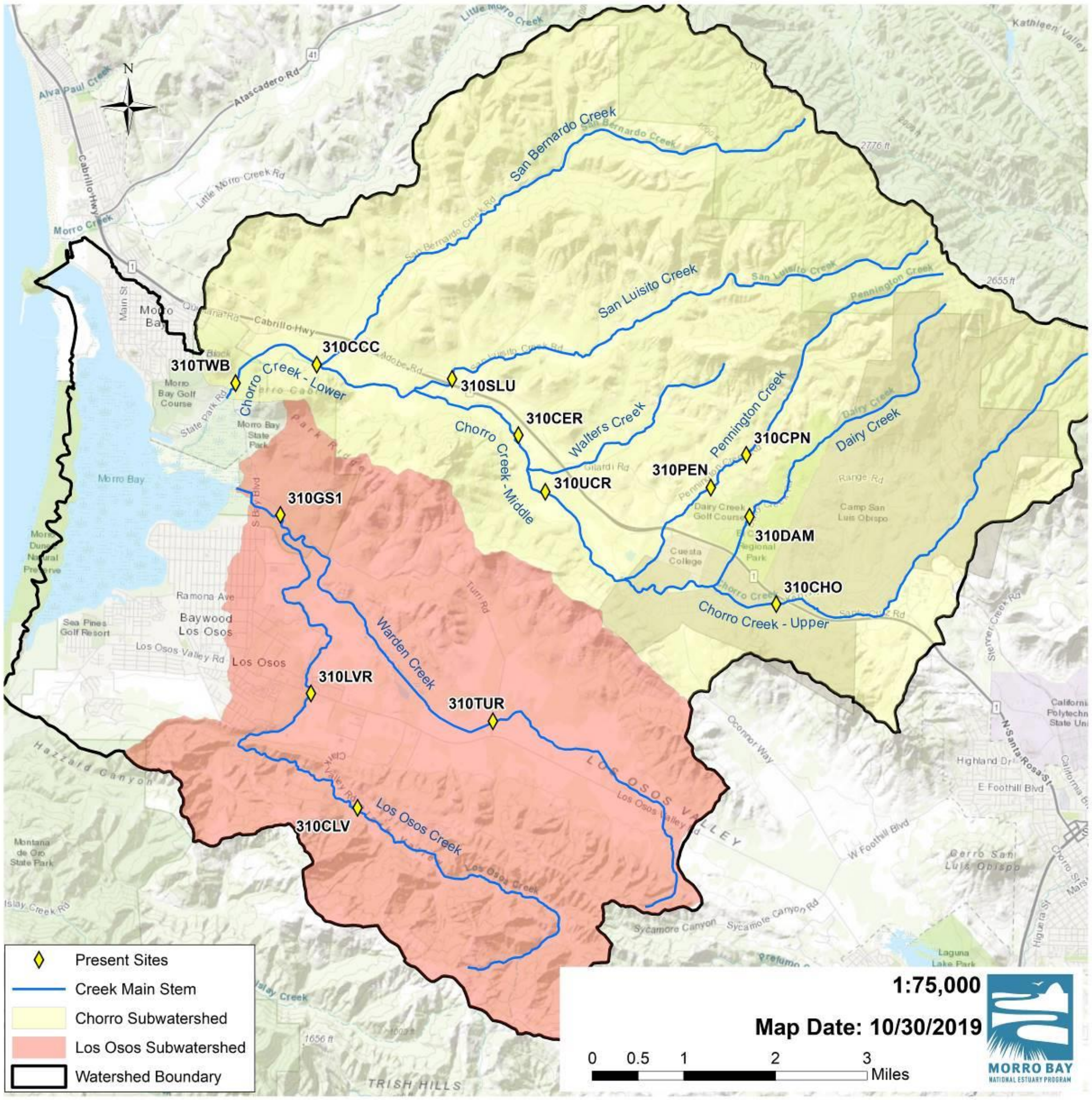


Figure 6: Map of the Estuary Program's ambient Volunteer Monitoring sites

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 2019 Creek Water Quality Memo.

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.

Automatic 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.

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 unknown concentrations 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 site includes flows from the Pennington Creek, Dairy Creek, and Walters Creek tributaries, shown in Figure 7. 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.

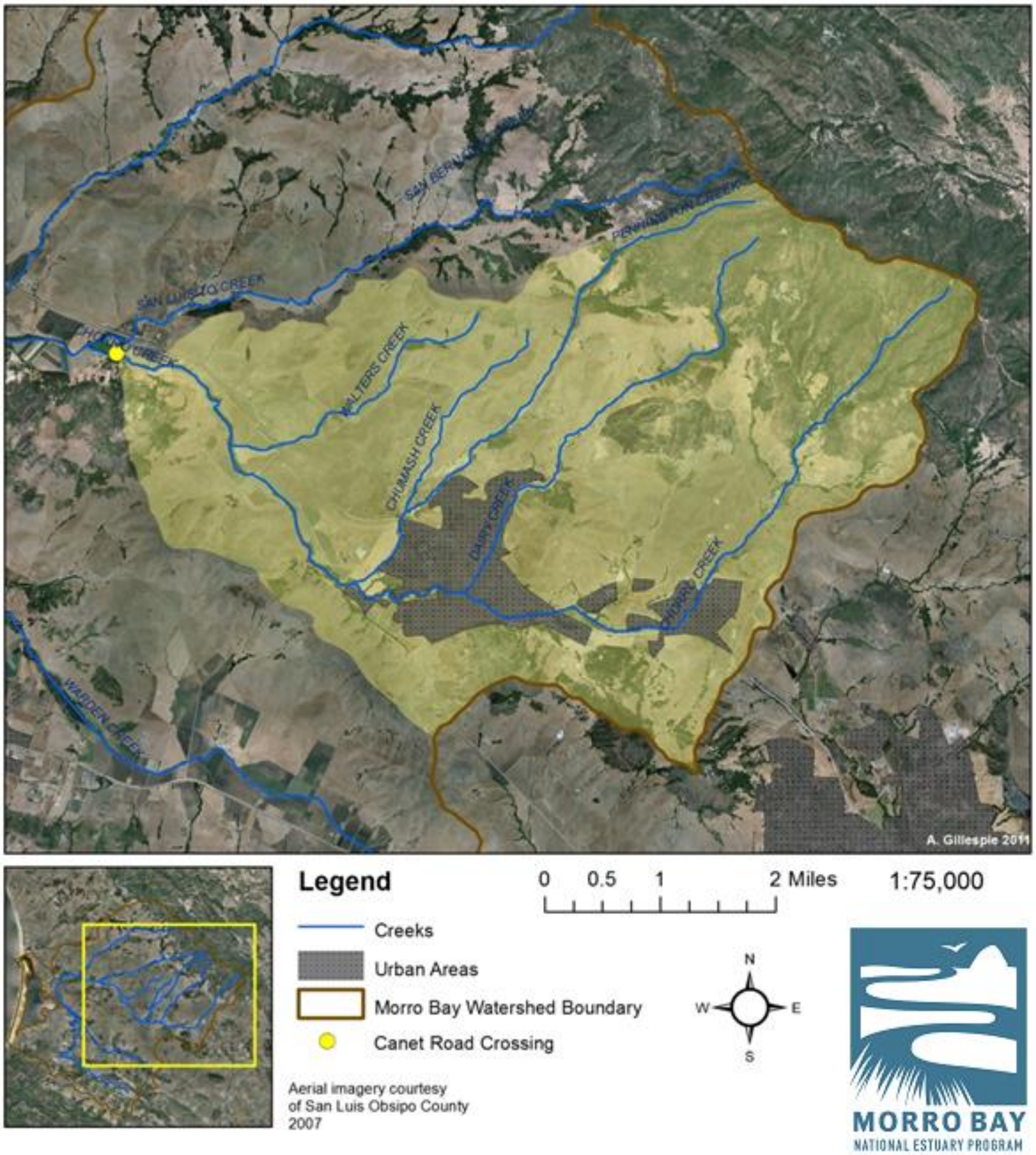


Figure 7: Map of watershed area that drains to Canet road sediment monitoring site

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 1,400 mg/L (Figure 8). The majority of measurements have been made at flows less than 400 cfs and SSC concentrations of 400 mg/L or less.

[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 8: Canet Road SSC dataset from WY 2009 - WY 2019.

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**	**2019**
Annual Discharge (AF)	8,970	14,290	24,850	2,480	26,860	7,830	15,581
Predicted Annual Sediment Load (Tons)	651	3,961	9,874	75	9,149	1,563	1,804
95% Confidence Interval (Tons)	566 – 743	3,605 – 4,338	6,762 – 20,973	61 – 90	8,450 – 9,878	1,403 – 1,733	1,707 – 1,905

Review of approximately 30 years of peak flow data (Figure 9) 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.

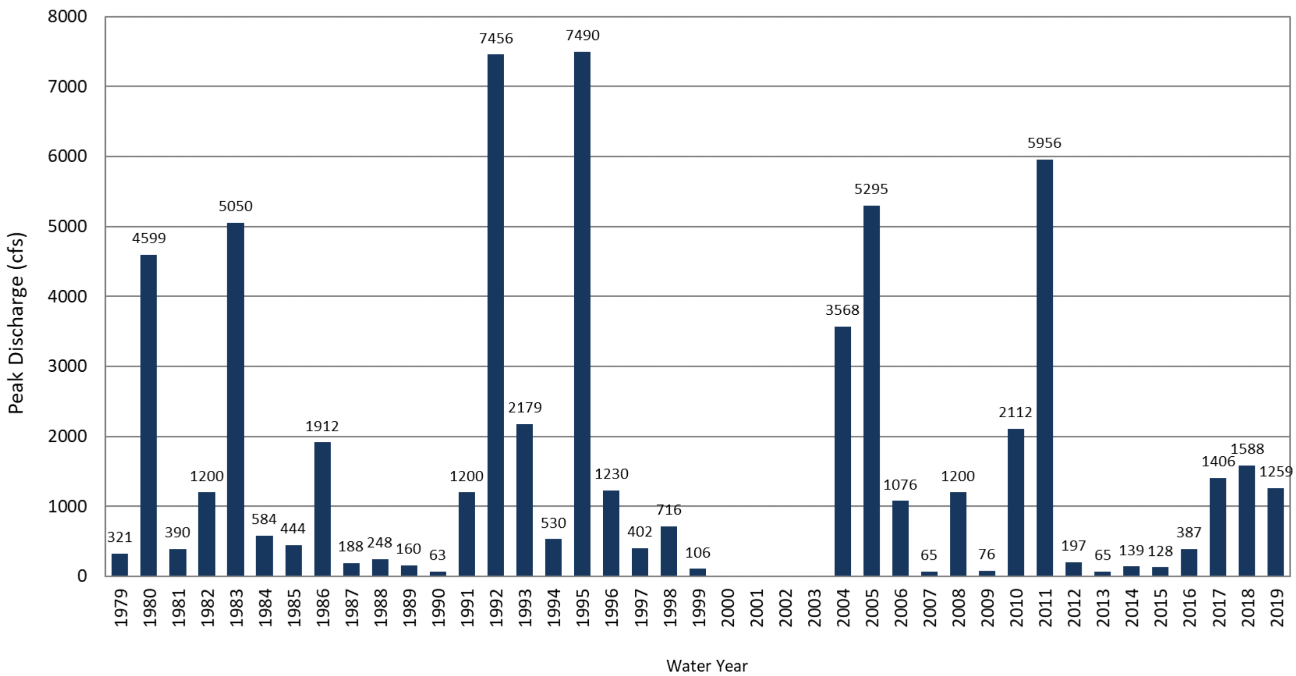


Figure 9: Chorro Creek, Canet Road peak flow records

Figure 10 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 by the Estuary Program show that annual rainfall is a poor predictor of suspended sediment loads (MBNEP, 2011).

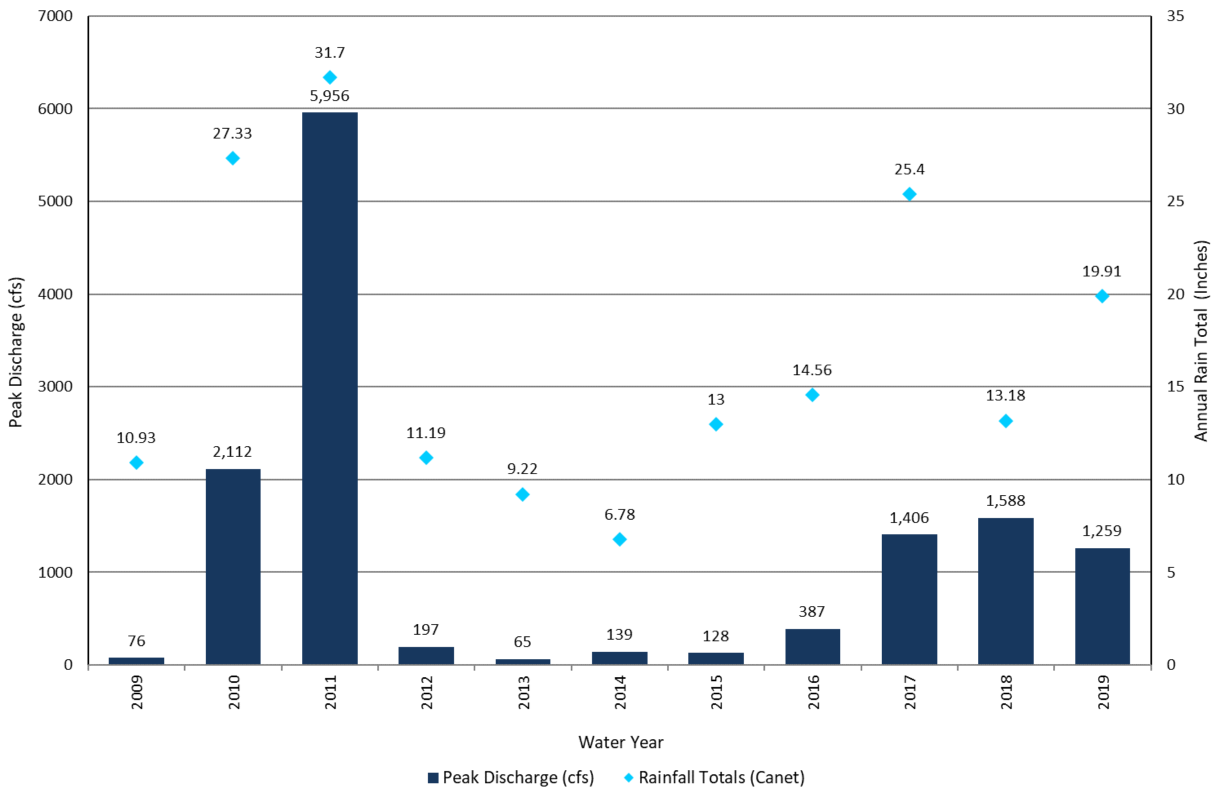


Figure 10: Chorro Creek, Canet road peak flows and annual rain totals from Camp San Luis rain gauge

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 11). Refer to Figure 8 to see these data differentiated by water year. The predictive model is built from data ranging from 2009 to 2019. The model is not year-specific and instead aggregates data from all years, assuming an average-year effect.

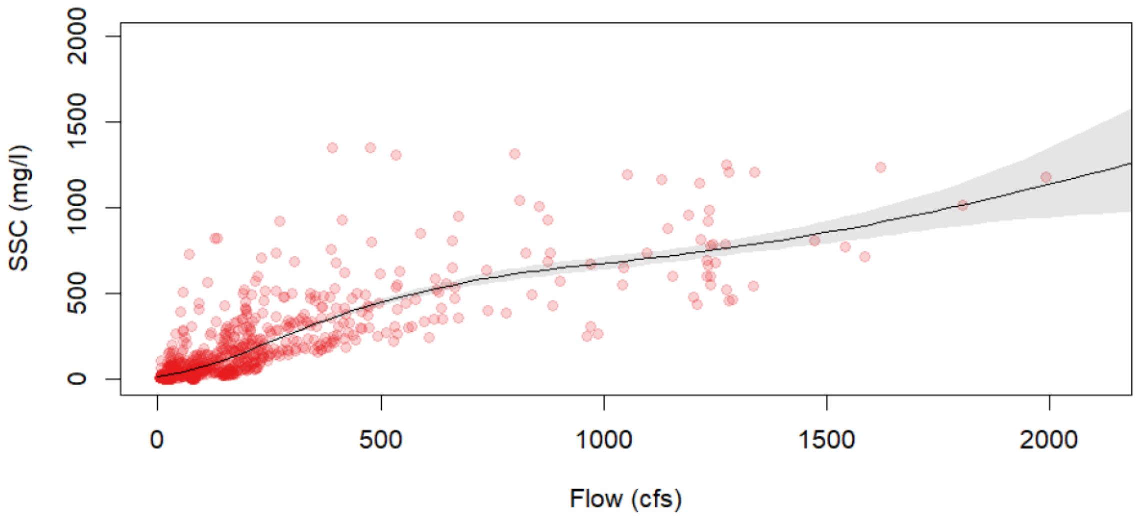


Figure 11: Spline-fit suspended sediment model at CAN during WY 2019. The entire range of SSC data is shown in red. The gray region bounds the 95% confidence interval.

Figure 11 shows the highest density of data occuring below 700 cfs. This graph is enlarged to show distribution in Figure 12. Most data fall below 700 cfs in part due to the improbability of stormflows greater than 700 cfs, and in part due to sampling bias; samplers are deployed when staff note a change in weather that will produce a storm flow. The specific arrival of peak flow is challenging to predict and thus 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.

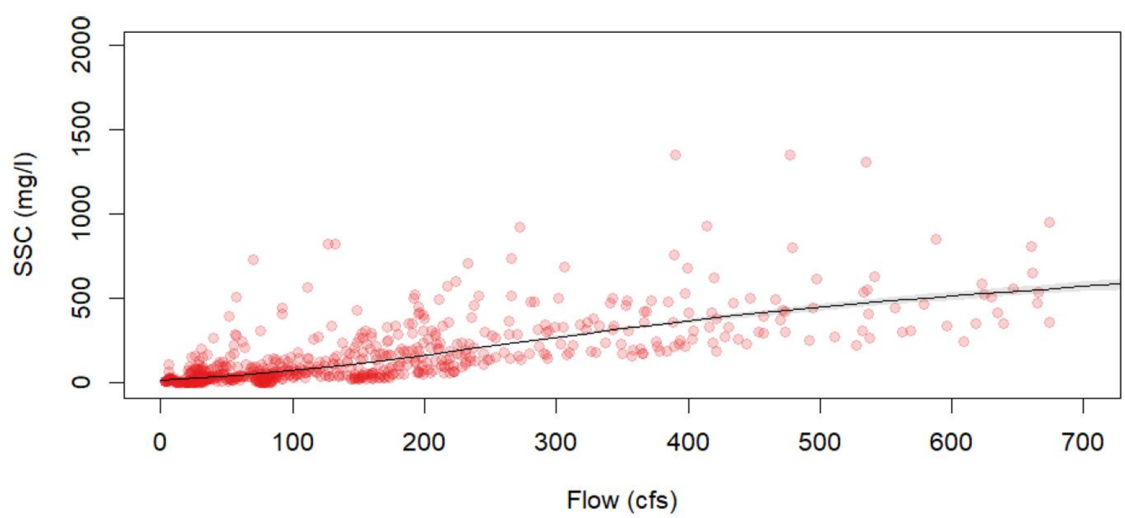


Figure 12: Spline-fit suspended sediment model at CAN during WY 2019, values below 700 CFS. This figure is an expanded view of the low range from Figure 8.

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 13). Adding up the area under the curve in Figure 13 yielded a graph of the predicted sediment accumulation throughout the year (Figure 14).

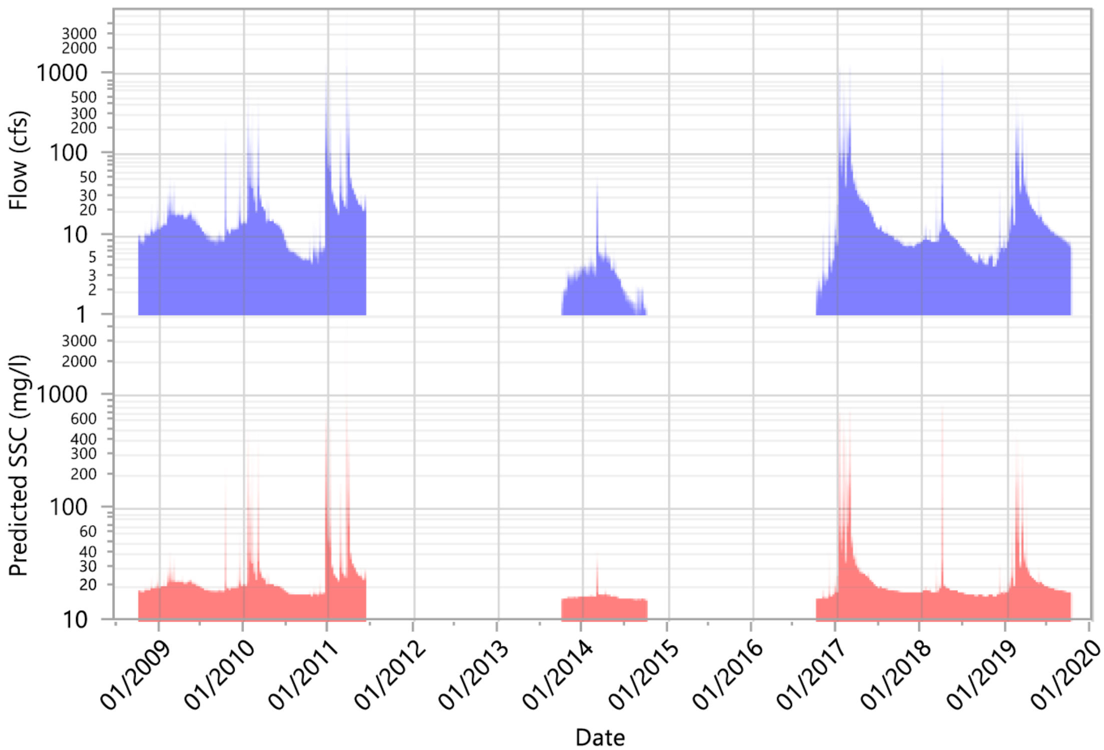


Figure 13: Hydrograph and corresponding predicted SSC values modeled for water years where SSC monitoring took place. Gaps in graph indicate no monitoring conducted.

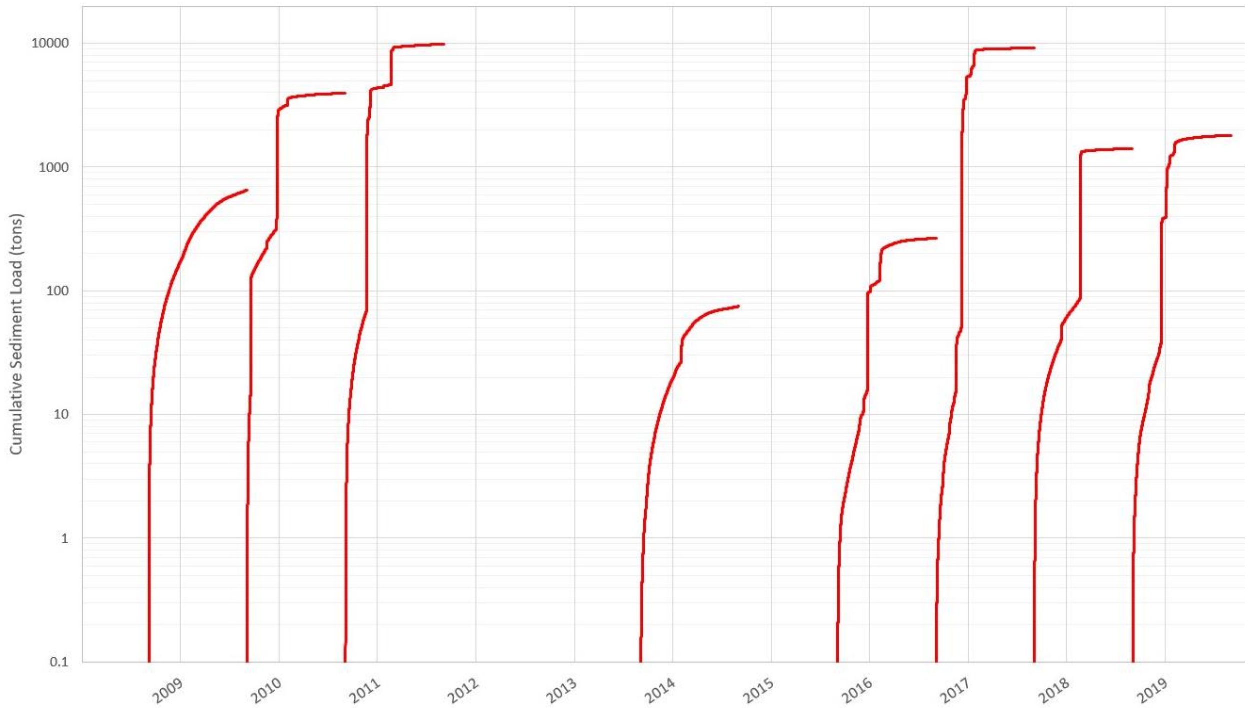


Figure 14: Model-predicted cumulative sediment load at Canet for years where suspended sediment samples were collected.

Gaps in the graphs exist because of low flow or drought years, which 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 YEAR 2019 RAINFALL AND DISCHARGE

Discharge was calculated with Estuary Program's rating curve equations using continuous stage data from the San Luis Obispo County stage recorder at Canet Road.

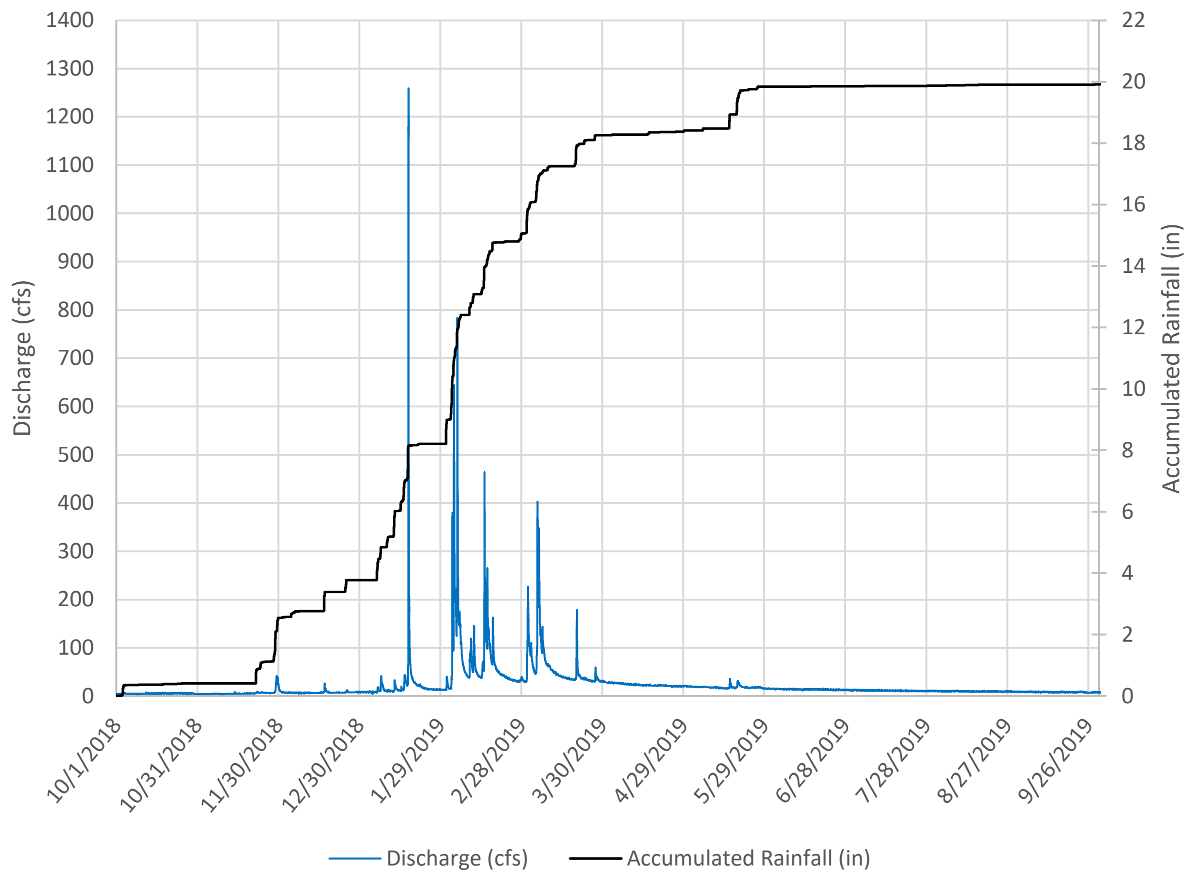


Figure 15: Hydrograph and precipitation accumulation at CAN for WY 2019.

According to the San Luis Obispo 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. Comparatively, WY 2019 was close to average, with 19.91 inches in cumulative rainfall. Table 3 summarizes the totals from Figure 15 and includes WY 2017 and 2018 for reference.

Table 3: Summary hydrology statistics for WY 2017, 2018 and 2019

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%
2019	1,259	15,581	19.91	99.6%

WATER YEAR 2019 SEDIMENT LOAD MONITORING

Three storm events were analyzed for SSC in WY 2019. Sampling efforts targeted rain events from January 10 to February 14, 2019. 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 2019 for Canet Road

Storm Event	Sampling Begin	Sampling End	Number of Samples Analyzed	Total Load (tons)	Total Discharge (AF)
15-18 Jan 2019	6:00 AM	3:30 AM	86	440	570
2-5 Feb 2019	1:30 AM	8:30 AM	106	244	954
14 Feb 2019	4:00 AM	3:30 PM	23	73	241

In total, there were 216 suspended sediment samples analyzed for WY 2019, all of which were sampled between January 10 and February 14, 2019. Distribution of this data is outlined in Figure 16.

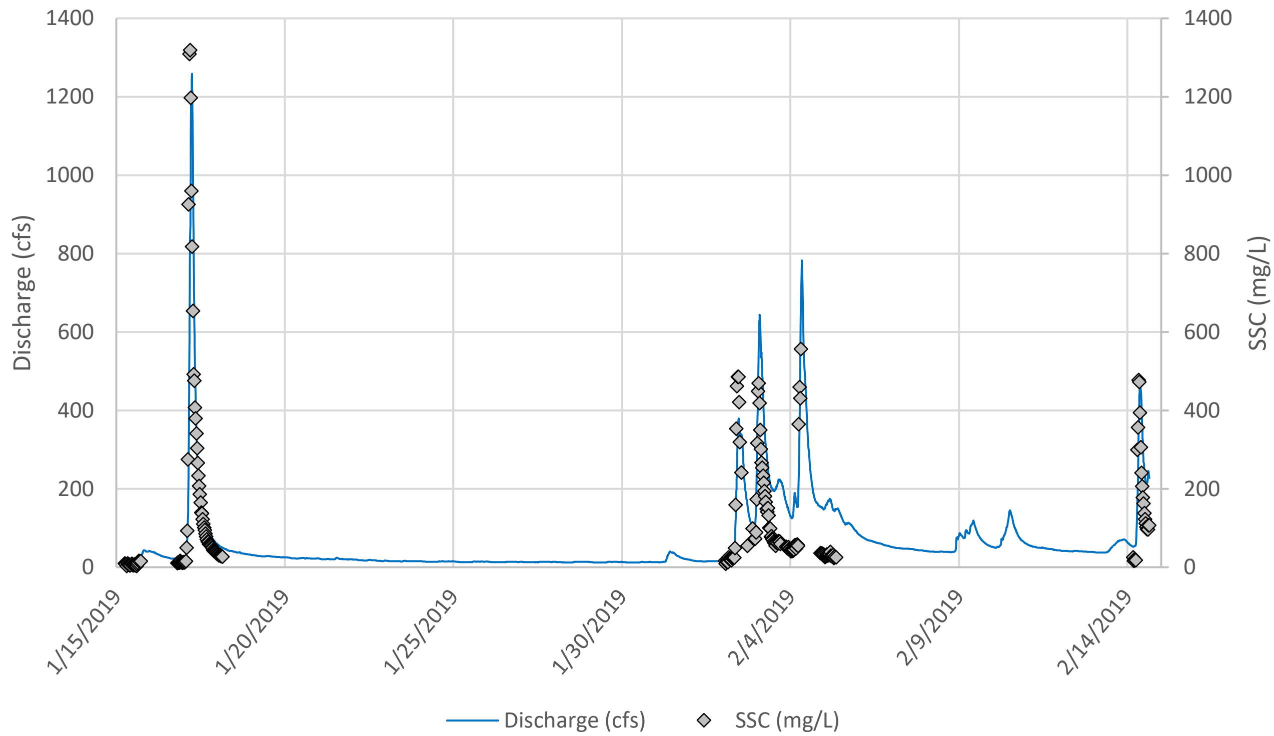


Figure 16: All processed WY 2019 sediment samples and the corresponding hydrograph for Canet Road.

Although suspended sediment transport is intrinsically linked to discharge, behavior of SSC during storm events is variable due to a number of factors. During WY 2019, the first storm (January 15-18) had a total sediment load much higher than the second (February 2-5), despite having a lower total discharge. This is due in part to different characteristics of the storm, such as duration, intensity, and amplitude. This may also be due to differences in soil conditions, where more fine surface soil particles are transported via runoff during the first storm.

The correspondence of SSC with discharge was variable between these storms. The wide distribution of SSC-Q relationships makes a single water year regression a poor predictor of sediment load (Figure 17).

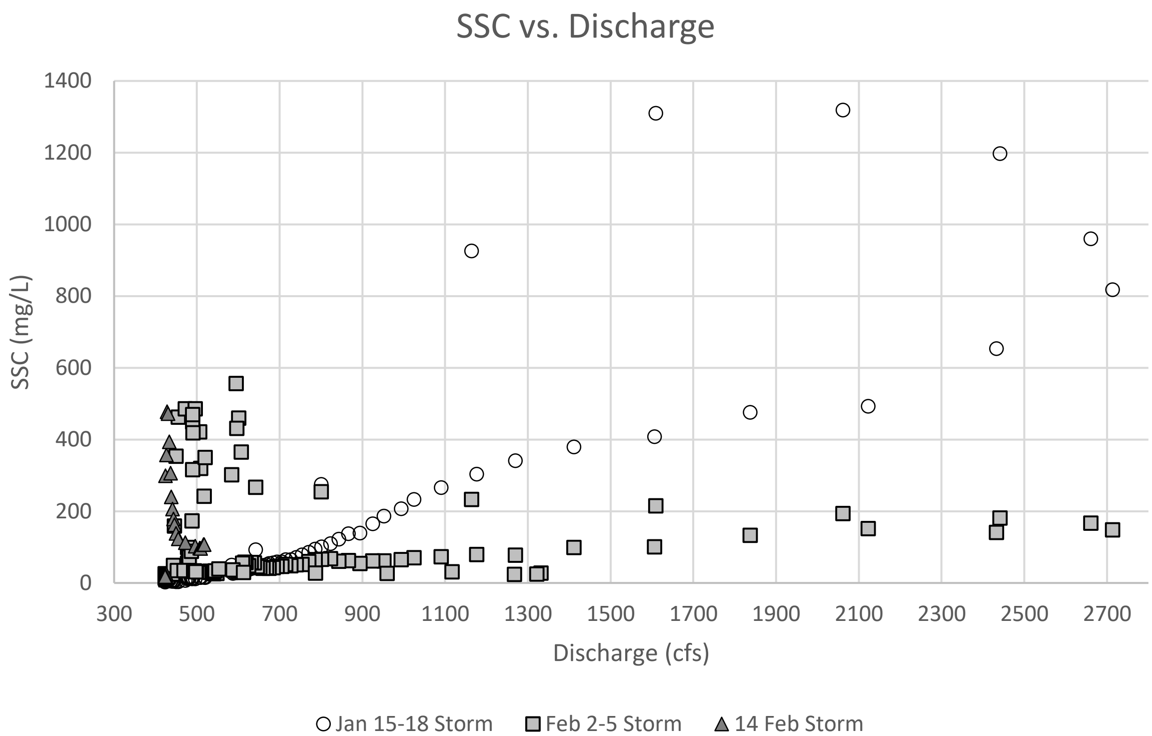


Figure 17: Plot of all WY 2019 SSC measurements and corresponding discharges at Canet Road.

The sediment samples taken during these storms can be compared to the calculated sediment load generated by the predictive model (Figure 18).

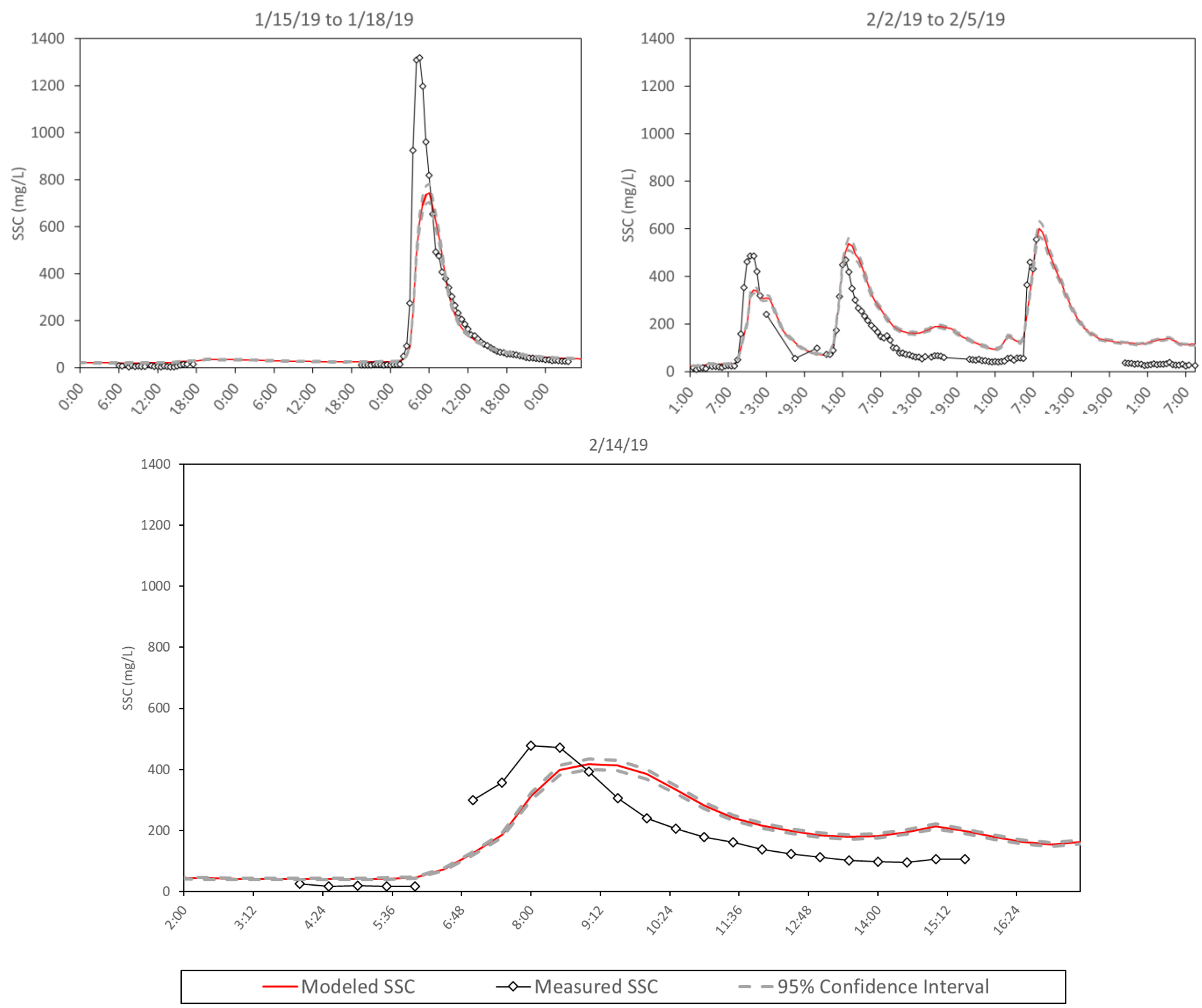


Figure 18: Comparison of measured SSC values with SSC values predicted by the model at Canet Road

The actual results and modeled results generally 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. This 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 2019 represents only one water year. The numeric totals for the predictive model's estimates are compared to the Estuary Program's measured values in Table 5.

Table 5: Sediment model estimate and measured sediment for WY 2019 storms at Canet Road

Storm Event	Measured Sediment Total (tons)	Modeled Sediment Total (tons)	Model Over-Prediction
15-18 Jan 2019	440	333	-24%
2-5 Feb 2019	244	330	+35%
14 Feb 2019	73	85	+16%

RECAP: 2019 SEDIMENT MONITORING AND CONCLUSIONS

Although storm events are brief when compared to the entire length of the water year, they have dramatic influence on the amount of sediment transported through creeks. Rainfall and discharge can affect suspended sediment load, but alone are not strong enough predictors to quantify total load. This can be seen when comparing WY 2010 to WY 2019 (Figure 8, Table 2), where annual discharge was relatively similar, but sediment loads were quite different. Numerous factors are potentially responsible, including characteristics of the individual storm such as duration and intensity, soil conditions, and others.

Because neither rainfall nor discharge are directly related to suspended sediment load, a predictive model relating SSC to discharge has been under development by the Estuary Program to extend the use of SSC monitoring data. Using the model, annual sediment loads ranged from 184 tons to 9,874 tons between WY 2009 and WY 2019 at Canet (refer to Table 2). For WY 2019, the model predicted an average ± 25% of the measured value of individual storms, with predictions made during smaller storm events more accurate than those made during larger storm events. The annual WY 2019 sediment load was predicted to be 1,804 tons for the contributing areas upstream of Canet Road, although this value only accounts for about 51% of the total Chorro subwatershed area. By comparison, a model created by Tetra Tech in 1998 estimated 60,689 tons of sediment transport for the entire Chorro subwatershed (Tetra Tech, 1998).

SSC QUALITY ASSURANCE RESULTS

The Estuary Program participates in the USGS Sediment Laboratory Quality Assurance (SLQA) program to ensure SSC 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 with nine different 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. Results from USGS also provide a median percent difference value of all of the participating labs as compared to the known sediment concentrations.

The percent difference for Estuary Program 2019 results compared to the known concentration was higher than in past years. The bulk of the error came from the samples with very low to low sediment concentrations. The percent error for the samples with higher sediment concentrations was much lower. Much of the error was due to the sand split, which is not a standard practice for actual field samples run by the Estuary Program. The current equipment used by the Estuary Program to collect the sand split is not ideal and should be updated for future studies if extensive sand splits are going to be conducted. Thus, while the results from the spring SLQA effort were higher than ideal, the source of the error does not directly impact the Estuary Program's sample processing as we do not utilize a sand split.

Further SLQA result details are available in Appendix A.

Table 6: 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 2019	44	1	48.01%	Median
	67	2	19.82%	
	100	3	24.12%	-2.95%
	156	4	4.98%	
	278	5	7.89%	
	444	6	-1.23%	
	1,111	7	1.11%	
	2,444	8	-0.31%	
	4,889	9	0.00%	
	All	Average	**11.60%**	
Fall 2018	56	1	38.86%	Median
	78	2	41.84%	
	111	3	3.50%	-3.05%
	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), which is 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 likely relevant 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 sediment indicators, and six 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 7.

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 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, 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.

Six representative bioassessment monitoring sites were selected to be included in this analysis. This is a representative subset of the larger number of bioassessment sites that are monitored each year. Five of the representative monitoring sites are located in the Chorro subwatershed. Those sites include Pennington Creek (site code 310UPN), San Bernardo Creek (310MNO), San Luisito Creek (310LSL), Lower Chorro Creek (310TWB), and Middle Chorro Creek (310CER). One site from the Los Osos subwatershed, along upper Los Osos Creek (310CLK) is also included. These monitoring locations can be seen in more detail in Figure 19. Scores from representative sites are outlined from 2008 to 2019 in Table 8, and averaged scores from 2008 to 2019 are detailed in Table 9.

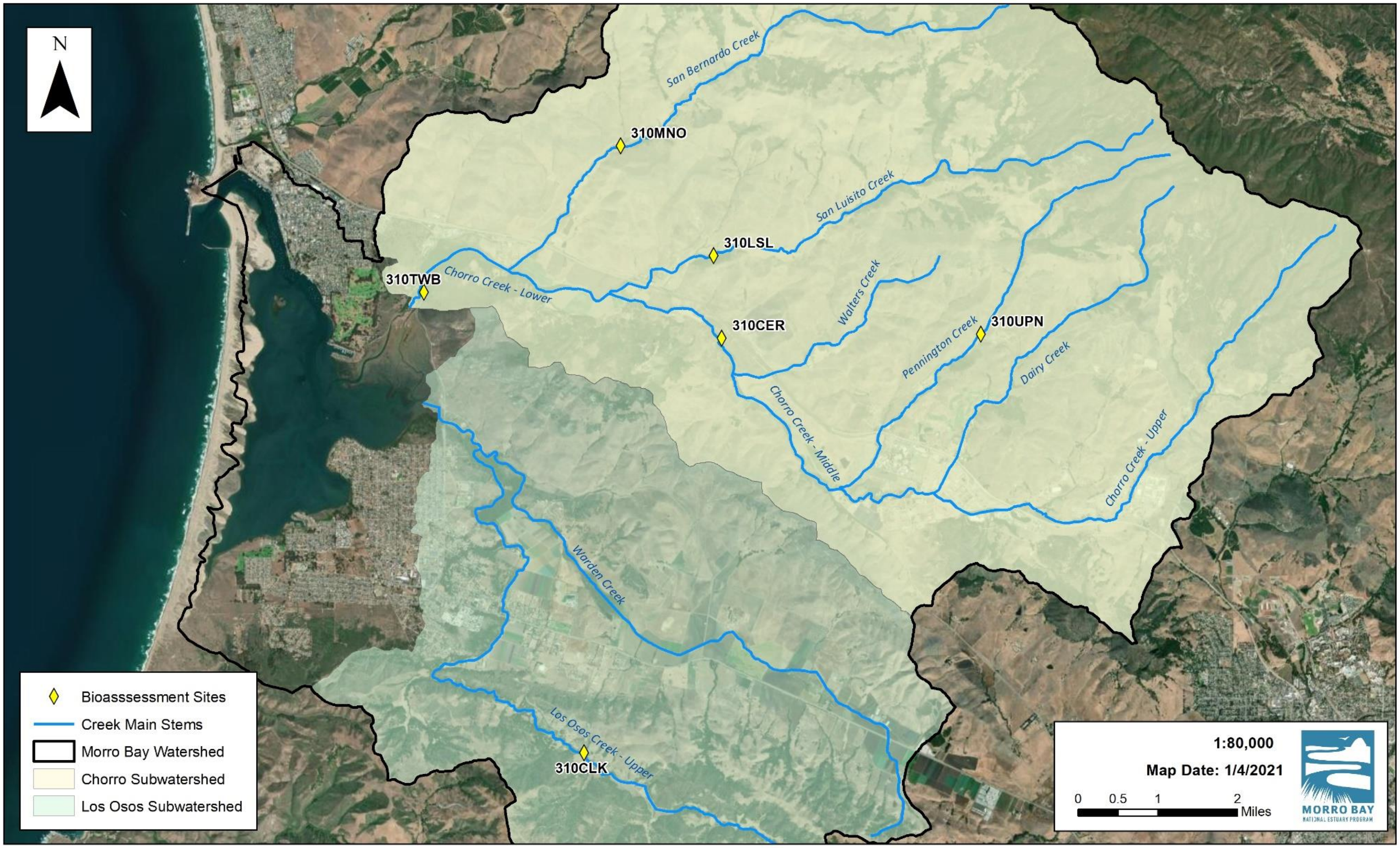


Figure 19: Six representative bioassessment sites for 2019, with five sites in the Chorro subwatershed, and one site in the Los Osos subwatershed.

Table 8: Sediment and biological indicators for a selection of Morro Bay watershed sites from 2008 to 2019.

		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	0.0	24.8	64	20	50.4	4.7	9.4	10
310MNO	2010	1.0	23.3	30.1	24.3	14.0	1.0	24.3	42	14	61.8	4.7	7.1	5
310MNO	2012	2.9	9.8	14.7	12.8	37.0	2.9	12.8	69	22	42.8	4.8	8.7	10
310MNO	2013	2.9	7.8	18.6	10.8	31.0	2.9	10.8	66	18	19.0	5.7	9.1	14
310MNO	2014	5.0	24.0	35.0	29.0	24.0	5.0	29.0	46	3	3.4	7.3	17.4	3
310MNO	2015	6.7	9.5	24.8	16.2	17.0	6.7	16.2	57	5	4.3	6.9	14.0	4
310MNO	2016	13.5	11.0	36.5	12.4	12.5	13.5	12.4	70	16	23.6	5.91	14.3	9
310MNO	2017	6.7	20.0	34.3	26.7	23.0	6.7	26.7	37	12	52.7	4.9	10.8	4
310MNO	2018	7.6	17.1	30.5	24.8	27.0	7.6	24.8	52	19	21.2	5.7	15.4	9
310MNO	2019	9.5	26.7	46.7	36.2	9.0	9.5	36.2	52	17	32.2	5.4	5.8	6
310LSL	2008	5.7	19.1	33.3	24.8	12.0	5.7	24.8	55	14	25.2	4.5	12.7	9
310LSL	2010	11.8	10.9	33.7	22.8	13.0	11.8	22.8	48	18	50.7	4.6	6.3	9
310LSL	2012	2.9	23.3	32.1	26.2	14.0	2.9	26.2	61	22	18.3	4.5	9.8	16
310LSL	2013	10.5	9.5	25.7	20.0	17.0	10.5	20.0	39	4	0.9	5.2	15.4	2
310LSL	2014	16.2	11.4	34.3	27.6	20.0	16.2	27.6	44	8	4.3	5.5	9.1	6
310LSL	2015	14.4	11.5	37.5	26.0	11.0	14.4	26.0	54	14	17.8	5.3	9.3	6
310LSL	2016	23.8	9.5	40.0	33.3	9.0	23.8	33.3	44	15	36.0	4.54	8.9	9
310LSL	2017	9.8	12.7	27.5	22.5	20.5	9.8	22.5	37	12	28.8	5.0	13.5	6
310LSL	2018	1.9	30.5	32.4	32.4	14.0	1.9	32.4	55	22	51.4	4.2	7.3	12
310LSL	2019	15.5	17.5	47.6	33.0	9.0	15.5	33.0	52	19	39.7	4.9	7.7	10
310UPN	2008	1.9	12.4	20.0	14.3	25.0	1.9	14.3	62	17	18.4	5.0	9.7	14
310UPN	2011	2.9	15.2	19.1	18.1	120.0	2.9	18.1	59	25	64.4	4.3	5.1	13
310UPN	2012	1.0	16.5	17.5	17.5	63.5	1.0	17.5	56	21	48.5	4.0	8.9	15
310UPN	2013	2.9	7.7	14.4	10.6	100.5	2.9	10.6	70	24	32.6	4.5	5.7	17
310UPN	2014	1.9	3.8	9.5	5.7	87.0	1.9	5.7	73	20	17.6	4.9	6.9	15
310UPN	2015	5.8	4.8	16.3	10.6	55.5	5.8	10.6	53	10	16.1	5.4	9.4	5
310UPN	2016	2.9	9.0	24.8	2.9	24.0	2.9	2.9	42	3	2.9	7.2	21.4	3
310UPN	2017	1.0	15.2	23.8	16.2	21.0	1.0	16.2	50	15	58.4	4.7	6.0	8
310UPN	2018	1.9	24.8	29.5	26.7	30.0	1.9	26.7	57	21	45.0	4.0	3.5	16
310UPN	2019	2.9	6.7	16.2	9.5	34.0	2.9	9.5	60	16	26.4	5.0	6.7	11
310TWB	2008	18.8	7.9	31.7	26.7	13.0	18.8	26.7	55	14	27.3	5.4	14.6	7
310TWB	2012	8.0	29.0	44.0	37.0	9.5	8.0	37.0	46	8	6.8	6.7	21.7	3
310TWB	2013	9.7	18.5	44.7	28.2	9.0	9.7	28.2	52	9	3.7	6.4	21.2	4
310TWB	2014	24.8	11.4	53.3	36.2	6.0	24.8	36.2	41	4	6.9	6.5	24.4	2
310TWB	2015	12.5	41.0	59.0	41.0	5.0	0.0	41.0	31	0	0.0	7.6	29.0	0
310TWB	2016	12.4	24.8	51.4	37.1	12.5	13.5	37.1	31	9	34.1	5.5	19.4	4
310TWB	2017	12.5	21.2	34.6	33.7	16.0	12.5	33.7	31	9	34.1	5.5	19.4	4
310TWB	2018	14.3	35.2	63.8	49.5	3.0	14.3	49.5	46	11	14.6	6.3	17.4	5
310TWB	2019	16.3	35.6	63.5	51.9	1.0	16.3	51.9	43	10	22.8	6.6	18.6	1
310CER	2008	15.2	15.2	30.5	30.5	24.0	15.2	30.5	48	6	14.6	6.2	14.6	1
310CER	2011	3.8	34.3	41.0	38.1	13.0	3.8	38.1	50	14	48.1	5.5	12.0	4
310CER	2012	15.3	11.2	26.5	26.5	20.0	15.3	26.5	42	12	35.6	5.5	16.7	2
310CER	2013	13.8	22.3	45.7	36.2	15.5	13.8	36.2	26	5	6.3	5.6	19.2	0
310CER	2014	26.7	15.2	47.6	41.9	9.0	26.7	41.9	34	6	3.2	6.6	20.6	1
310CER	2015	25.0	12.5	39.4	37.5	14.0	25.0	37.5	53	9	11.9	6.2	19.1	2
310CER	2016	33.3	17.1	54.3	50.5	1.0	33.3	50.5	47	5	12.9	6.11	14.9	1
310CER	2017	4.0	26.7	38.6	30.7	13.0	4.0	30.7	39	9	34.1	5.6	10.3	4
310CER	2018	20.0	15.2	39.0	35.2	15.0	20.0	35.2	39	9	31.6	5.8	18.0	2
310CER	2019	10.5	23.8	38.1	34.3	12.0	10.5	34.3	36	6	36.6	5.7	11.1	0
310CLK	2008	8.6	16.2	35.2	24.8	13.0	8.6	24.8	46	13	17.94	5.15	15.22	8
310CLK	2010	11.4	13.3	25.7	24.8	16.0	11.4	24.8	27	13	31.71	4.93	0	7
310CLK	2012	3.8	22.9	32.4	26.7	16.5	3.8	26.7	51	14	63.48	3.7	15.69	8
310CLK	2017	3.9	10.7	19.4	14.6	35.0	3.9	14.6	51	8	5.0	6.4	15.7	5
310CLK	2018	3.8	18.1	31.4	21.9	14.0	3.8	21.9	59	10	21.6	6.2	17.0	6
310CLK	2019	4.8	18.1	25.7	22.9	29.0	4.8	22.9	40	11	23.4	4.9	10.0	4

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 9: Averages for sediment and biological indicators for a selection of sites from 2008 to 2019.

	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
310MNO	5.6	17.4	29.8	21.8	21.5	5.6	21.8	55.5	14.6	31.1	5.6	11.2	7.4
310LSL	11.3	15.6	34.4	26.9	14.0	11.3	26.9	48.9	14.8	27.3	4.8	10.0	8.5
310UPN	2.5	11.6	19.1	13.2	56.1	2.5	13.2	58.2	17.2	33.0	4.9	8.3	11.7
310TWB	14.4	24.9	49.6	37.9	8.3	13.1	37.9	41.8	8.2	16.7	6.3	20.6	3.3
310CER	16.8	19.4	40.1	36.1	13.7	16.8	36.1	41.4	8.1	23.5	5.9	15.6	1.7
310CLK	6.0	16.5	28.3	22.6	20.6	6.0	22.6	45.7	11.5	27.2	5.2	12.3	6.3

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)

SEDIMENT IMPAIRMENT ANALYSIS

With the averaged data from 2008 through 2019, 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. 310CLK has historically met nearly all targets, but shown a decrease in EPT Richness and Sensitive Number since 2012. 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, 2019. *Final Post-Dredge Eelgrass Survey Report in Support of the Morro Bay 2019 Maintenance Dredging Project*. M&A #17-022-02.

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, 2019a. *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, 2019b. *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)

Quantum Spatial, 2019. *Topobathymetric LiDAR with Sonar Integration Technical Data Report.* Prepared for NOAA Office of Coastal Management. Morro Bay, CA. September 3, 2019.

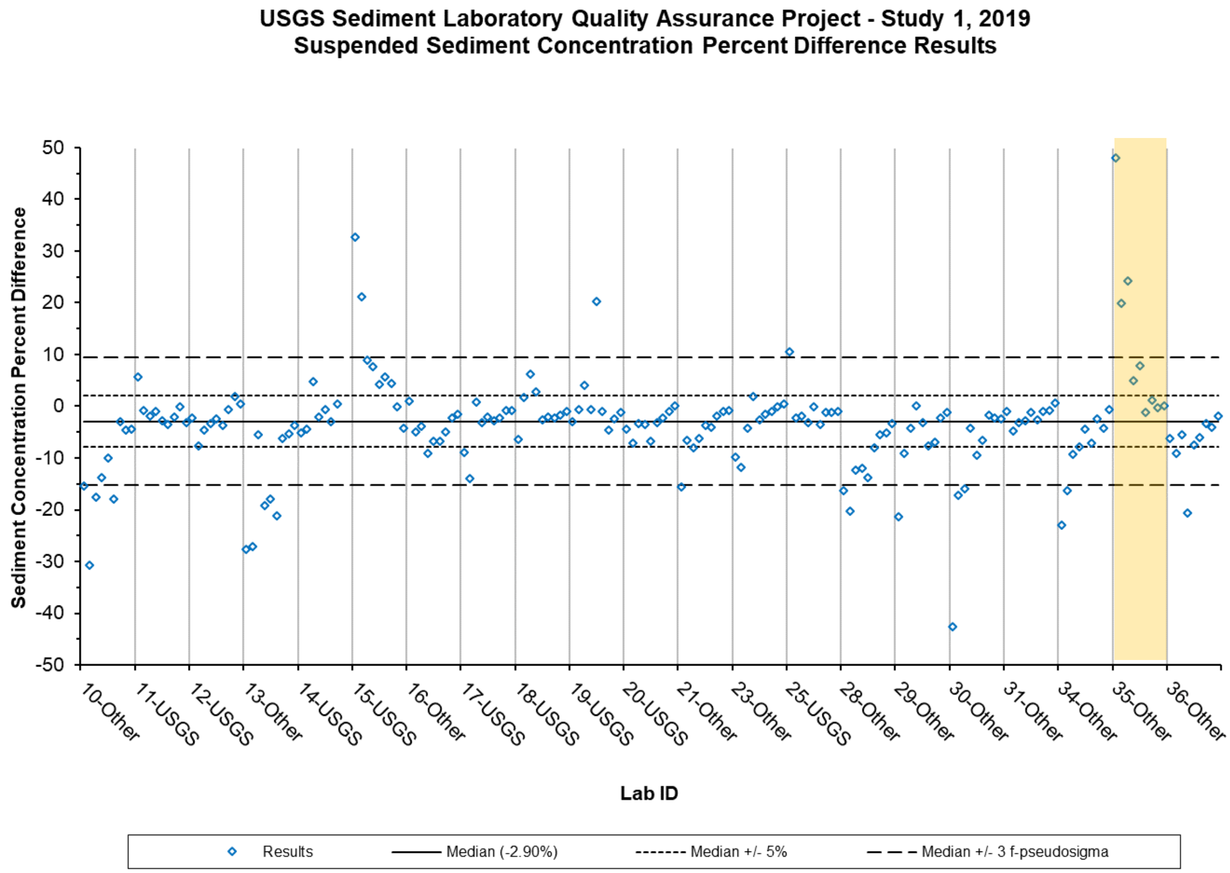
Seeger, M. & Errea, M.P. & Beguería, Santiago & Arnáez, J. & Martı, C. & García-Ruiz, José M., 2004. *Catchment soil moisture and rainfall characteristics as determinant factor for discharge/suspended sediment hysteretic loops in a small headwater catchment in the Spanish Pyrenees*. Journal of Hydrology.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

Taherkhani, M., Vitousek, S., Walter, R.K., O'Leary, J.K., and Kitajima, A., 2019. *The role of sediment dynamics on eelgrass resilience in Morro Bay.* Sea Grant Partner Meeting: Understanding the Past and Predicting the Future in a California Estuary. San Luis Obispo, CA. December 6, 2019.

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

Walter, R.K., 2019. *Hydrodynamics, water quality, sediment, and drone mapping in Morro Bay, CA.* Sea Grant Partner Meeting: Understanding the Past and Predicting the Future in a California Estuary. San Luis Obispo, CA. December 6, 2019.

APPENDIX A: USGS SLQA RESULTS



APPENDIX B: SLO COUNTY PRECIPITATION CONTOURS