Central Coast Watershed Studies

CCoWS

Turbidity as a Surrogate Measure for Suspended Sediment Concentration in Elkhorn Slough, CA

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Executive Summary

This is a report to the Elkhorn Slough Foundation and Elkhorn Slough National Estuarine Research Reserve. An extensive dataset exists for turbidity measurements throughout the Elkhorn Slough watershed, but has not yet been calibrated to satisfy local sediment characteristics. This project marks the completion of the project to calibrate the legacy data for local suspended sediment concentrations, which was funded by the Elkhorn Slough National Estuarine Research Reserve with grant support from the David and Lucille Packard Foundation.

Estuaries and coastal lagoons are among the Earth's most biologically productive ecosystems. Accelerated sea level rise due to global climate change is likely to have an effect on the world's coastal environment. Elkhorn Slough is an estuary located on the Central California Coast and supports one of the largest coastal marshes in California. Recent marsh erosion in the Elkhorn Slough as triggered an interest in understanding the flux of potentially marsh-building sediment through the system. A multiyear record of slough water turbidity exists. This study attempts to convert the turbidity record to a record of suspended sediment concentration (SSC) through an analysis of paired turbidity and SSC samples. The study yielded no clear relationship between turbidity and SSC, with an R-squared value of 0.1267 for all samples. There are various sources of sediment within the slough watershed, each potentially requiring their own calibration curve, which added variation in the overall relationship. Future studies need to develop a sampling regime that accounts for spatial variability of Elkhorn Slough sediment characteristics.

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1 Introduction

Significant loss of wetland habitat had prompted major efforts for restoring extensive habitat areas (ESTWP 2006, CALFED 2000, Steere and Schaffer 2001). The sustainability of restored tidal marshes is dependent upon the balance between relative sea-level rise and sediment supply (Orr et al. 2003). Turbidity trend analysis in Elkhorn Slough, CA indicates an increase in turbidity over the record time period (Los Huertos, unpublished report). Suspended sediment fluxes to and from tidal wetlands are of increasing concern because of habitat restoration efforts and wetland sustainability due to sea level rise (Ganju et al. 2005). Therefore, restoration plans need to incorporate sediment budgets to maintain proper marsh elevation and protect vegetation. Resource managers and researchers at Elkhorn Slough need to know sediment fluxes within the slough to determine accretion rates and revise restoration options.

Maintenance of salt marsh habitat requires accumulation of sediment on the marsh plain from tidal inundation (Geyer et al. 2001). Long term average suspended sediment concentrations (SSC) are a key input variable into models of marsh plain accretion (Randerson 1979; Krone 1987; Allen 1990a, 1990b, 1995, 1997; French 1991, 1993; Callaway et al. 1996; Temmerman et al. 2003; Orr et al. 2003). Uncertainty regarding current, historic and episodic sediment dynamics in Elkhorn Slough limits the ability to solve the current marsh loss and channel scour problems (Malzone and Kvitek 1999). Spatial and temporal variability of suspended sediment concentrations can inform efforts to erosion and accretion monitoring and qualitatively assess sediment dynamics.

Estuaries and coastal lagoons are among the Earth's most biologically productive ecosystems. Out of all terrestrial ecosystems, wetlands provide the largest suite of ecosystem services on a per-acre basis (Costanza 1997). Yet, wetlands are among the most highly altered landscapes, with conservation lagging behind that of other terrestrial and marine systems (Kennesh 2002, Adam 2002, Van Dyke and Wasson 2005). Human modification to environmental systems during the past century has greatly accelerated salt marsh deterioration, resulting in a 50% loss of original salt marsh habitat throughout the U.S. (Kennesh 2001). In California specifically, estuaries are among the most threatened ecosystems and habitat degradation due to anthropogenic impacts result in a disproportionate number of rare, threatened, and endangered species (ESTWP 2006).

Accelerated sea level rise due to global climate change is likely to have an additional effect on the world's coastal environments (IPCC 2001, Kearney 1988, Patrick and DeLaune 1990). For salt marsh vegetation to remain productive, the marsh surface must accrete sufficient sediment to maintain elevation within an appropriate tidal range (Patrick and DeLaune 1990). Sea-level rise and decreasing sediment supply from the watershed (Wright and Schoellhamer 2004, Inman and Jenkins 1999) threaten future sustainability of established and restored wetlands in the Sacramento-San Joaquin Delta and Suisun Bay (Ganju 2004). In Elkhorn Slough, future sustainability of marsh habitat and proposed restoration plans are relatively undetermined due to the lack of sufficient suspended sediment flux analysis.

Rockwell et al. (2001) concluded that the Hudson River estuary supports Meade's (1969) observation that under normal flow conditions estuaries tend to import sediment from the seaward direction. Leonard and Reed (2002) found that incoming tide brings sediment onto the marsh system, which then deposits due to reduced flow velocities within marsh vegetation, favoring rapid settling and prevention of further resuspension. However, currents within Elkhorn Slough are ebb dominant, which significantly increase bottom stresses that resuspend and scour sediments (Monismith et al 2005), creating a sediment pulse that leaves the system during outgoing tides. If sediment loads are also decreasing over time, there may be less sediment available for restoration projects and sensitive areas may begin to erode (McKee et al. 2002). Williams (2001) further concluded that a coupling of a decrease in sediment supply, along with an increase in sea level, will result in an increase in shoreline erosion causing loss of fringing marsh in addition to conversion of mudflats into shallow subtidal habitats.

Collecting SSC data with the requirements needed to overcome large spatial and temporal variability of transport in estuarine environments (Ganju 2005) would be extremely inefficient and cost prohibitive (Pfannkuche 2003). Using turbidity as a surrogate for SSC measurements would be more cost-effective and less time consuming. Several studies have shown a very close relationship of SSC and nephelometric turbidity units in freshwater lakes and rivers (e.g. Stubblefield 2007; Bull 1997; Assellman 1999; Gippel 1995; Jansson 2000; Pfannkuche 2003), while US Geological Survey researchers (Buchanan and Schoellhamer 1995, McKee et al 2006, Ganju and Schoellhamer 2006) have pioneered the use of turbidity to measure total SSC of the water column using continuous optical backscatter sensors at buoys in San Francisco and have developed strong statistical relationships between the two (Buchanan and Lionberger 2006).

Optical backscatter sensors can be used to measure SSC and provide high resolution time series data (e.g. Stubblefield 2007, Ganju 2005, Schoellhamer 2001, and Gippel 1995). Networks of optical sensors can be utilized to capture spatial and temporal variability of SSC (Schoellhamer 2002). To record concentration values continuously, nephelometric turbidity measurements are frequently used because these units (NTU) often correlate well with the concentration of suspended solid material (Gippel 1995). However, it is noted that turbidity meters vary widely in optical design leading to instrument-specific turbidity measurements, which requires individual calibration of turbidity meters to take into account local and temporal conditions (Minella 2007).

For the past 13 years, optical sensors have been deployed at various sites in Elkhorn Slough, providing the potential for continuous and historical analysis of SSC flux. The SSC data collected, processed, and analyzed using consistent protocols are comparable in time and space (Gray et al 2000). In addition, 20 years of water quality monitoring (volunteer program) provide a monthly dataset spatially distributed at 24 sampling sites around the Slough, which can be used to historically analyze SSC once the relationship has been determined (Minella 2007, Schoellhamer 2001).

A major advantage of deploying optical sensors for turbidity analysis is that they can provide automated continuous time series of SSC (Schoellhamer, 2001); especially in environments with rapidly changing SSC such as tidally-affected water bodies (Christiansen and others 2000, Dyer and others 2000, Uncles et al 1994). However, these sensors are prone to fouling due to algae growth, fish, plankton and other biological interference (Schoellhamer 1993). When properly deployed, optical backscatter sensors, along with proper calibration, can be used to successfully monitor suspended sediment concentrations in the water column (Gippel 1995, Uncles 1999).

Estimating sediment flux in estuaries can be complicated due to large range of tidal and riverine forcing (Ganju et al 2006). Elkhorn Slough is subject to variable freshwater flow from the watershed (Inman and Jenkins 1999), in addition to semi-diurnal tides. The sustainability of restored tidal marshes is dependent upon the balance between relative sea-level rise and sediment supply (Orr et al 2003). Turbidity trend analysis in Elkhorn Slough indicates an increase in turbidity over the record time period (Los Huertos, unpublished report). A focused study on suspended sediment in the slough would be beneficial to evaluate these turbidity changes.

2 Study area – Elkhorn Slough Watershed

Elkhorn Slough is an estuary located on the Central California Coast, at the midpoint of Monterey Bay. It supports one of the largest coastal marshes in California, extending 11.4 kilometers inland (Byrd et al 2004). This provides a rich ecosystem for over 780 aquatic bird, marine invertebrate, marine mammal and fish species. In the Elkhorn Slough watershed, two dozen species are included in rare, threatened, or endangered categories (ESTWP, 2006). Even though, Elkhorn Slough is designated National Marine Sanctuary and National Estuarine Research Reserve it is subject to a number of potentially detrimental influences.

Intensified strawberry farming in the watershed greatly increased soil erosion rates (Caffrey et al., 2002), resulting in nutrient and sediment loading onto the marsh system. Extensive loss of wetlands due to changes in erosion associated with increased tidal action that has been observed since Moss Landing Harbor construction (Wong 1970), along with changes in tidal prism due to subsidence (Malzone and Kvitek 1994). Sediment cores from Monterey Canyon indicate land use practices associated with the early stages of modern development in the Salinas and Pajaro Valleys greatly increased soil erosion as deeper soil horizons were exhumed (Paull et al 2006). Byrd 2005 identified a process of plant succession that led to arroyo willow encroachment into pickleweed marsh due to the alluvial fan deposits.

Extensive coastal marsh at the Elkhorn Slough contains sensitive marsh plant Pickleweed (*Salicornia virginica*), which exists only in a tiny elevation zone ranging from 0.13 m to 0.42 m above mean high water (Selisker 1985). Suspended sediment fluxes to and from tidal wetlands are of increasing concern because of habitat restoration efforts and wetland sustainability due to sea level rise (Ganju et al 2005). Therefore, restoration plans need to incorporate sediment budgets to maintain proper marsh elevation and protect Pickleweed vegetation. Resource managers and researchers at Elkhorn Slough need to know sediment fluxes in and out of the slough to determine accretion rates and rework restoration options.

3 Goal

The objective of this study is to calibrate the historical turbidity dataset for local suspended sediment characteristics at Elkhorn Slough, CA.

4 Methods

Water Quality Data

National Estuarine Research Reserve (NERR) system collects consistent system-wide water quality and weather monitoring. Four monitoring sites (Azevedo Pond North, North Mash, South Marsh and Vierra Mouth) permanently occupied at Elkhorn Slough collect data every fifteen minutes since 1999. Instrument recovery, calibration checks to known standards and site maintenance occurs four weeks from deployment on a rotating schedule. Data collection provided by YSI 6600 data sonde measures various water quality parameters: temperature, conductivity, salinity, dissolved oxygen % saturation, dissolved oxygen concentration, depth, pH, and turbidity (also chlorophyll a, depending on site). Data undergo rigorous QA/QC analysis developed by NERR system to remove spurious points before online submission. Data is available to the public and can be found at the Central Data Management Office website.

Over the past 20 years, Elkhorn Slough implemented a volunteer water quality monitoring program. A total of 24 sites located throughout the watershed are visited monthly (Figure 1). Volunteers collect and retain nutrient and water quality data similar to that of the NERR monitoring system. Potential for long term time series analysis of ambient suspended sediment concentrations exist in the Elkhorn Slough watershed.

Data used for analysis contains 7 years of 15min data and 20 years of monthly data for the necessary parameters.

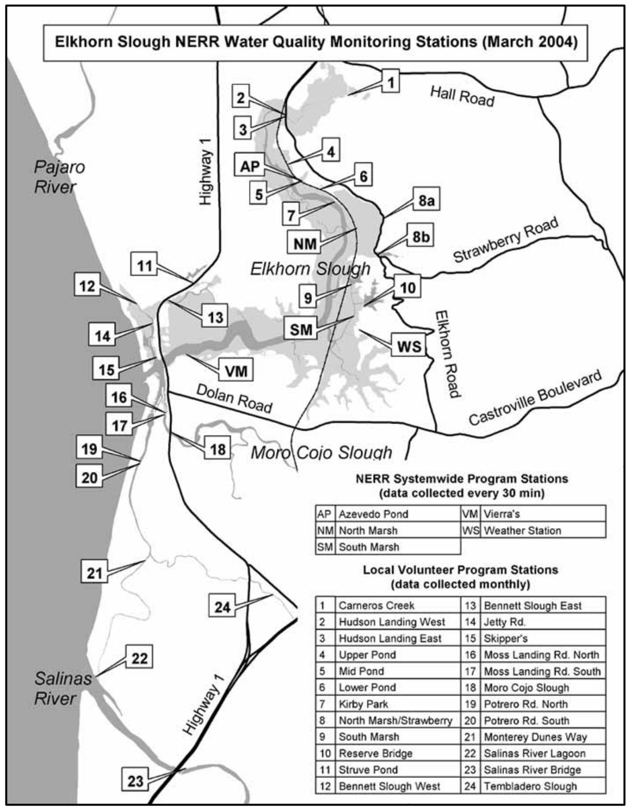


Figure 1: Map illustrating Elkhorn Slough NERR Water Quality Stations. Local volunteer stations indicated by numerical labels and NERR systemwide stations indicated by two-letter station code. Notice large spatial extent of monthly sampling stations.

The optical turbidity probe used on YSI 6600 for water quality monitoring reports in nephelometric turbidity units (NTU). Since optical properties of suspended sediment and solids vary with particle size and composition, water samples must be collected to calibrate the sensor for local sediment characteristics.

Water samples were collected using standard 1L bottles with a 1in diameter mouth. Samples collected at the 24 monthly volunteer sites were initially scooped from the undisturbed surface using a cutoff 1 gal jug. YSI 6600 instrument recorded discrete measurements of water quality parameters, after sensors reached equilibrium. Water collected and measured was then poured into sample bottles for laboratory analysis. Turbidity (NTU) from each sampling location was related to the corresponding actual suspended sediment concentration providing a calibration curve.

Laboratory analysis of water samples adhered to standard USGS protocols. SSC data are produced by measuring the dry weight of all the sediment from a known volume of a water-sediment mixture (Gray 2000). A pinch of sodium metahexaphosphate was used to deflocculate water sample and break apart any aggregates. Samples were filtered using Watt GF-F glass microfiber filter paper, dried for 1 hour at 100°C and cooled in a desiccator for 20 minutes. Analytical balance to 10^{-6} gram was used to account for small weight associated with very fine sediment in the samples. Mass per known volume of water yielded our suspended sediment concrentration (SSC).

Once a relationship between SSC data and corresponding turbidity measurement has been determined, historical analysis of turbidity data and sediment flux calculations can begin. Using the calibration curve, years of turbidity measurements (in NTUs) can have a local and relative meaning to suspended sediment concentrations.

Given that there is such a large dataset, graphic analysis will be of greatest use to visually interpret time series data. Following suspended sediment calculations, flux estimates can be made based on MBARI-LOBO flow data. Simple sediment flux calculations require use of basic multiplication of flow velocity during a given time period with averaged SSC from nearby water quality measurements. Tidal stage and direction (incoming, outgoing) will also be examined graphically during tidal cycles in combination with SSC to determine if tidal flow affects concentration values.

5 Results

Linear regression of turbidity versus suspended sediment concentration yielded an R-squared value of 0.1267 for all data collected during this study (Figure 2). Analysis of additional water quality parameters to be used as a surrogate for suspended sediment concentration yielded no distinct pattern (Figure 4).

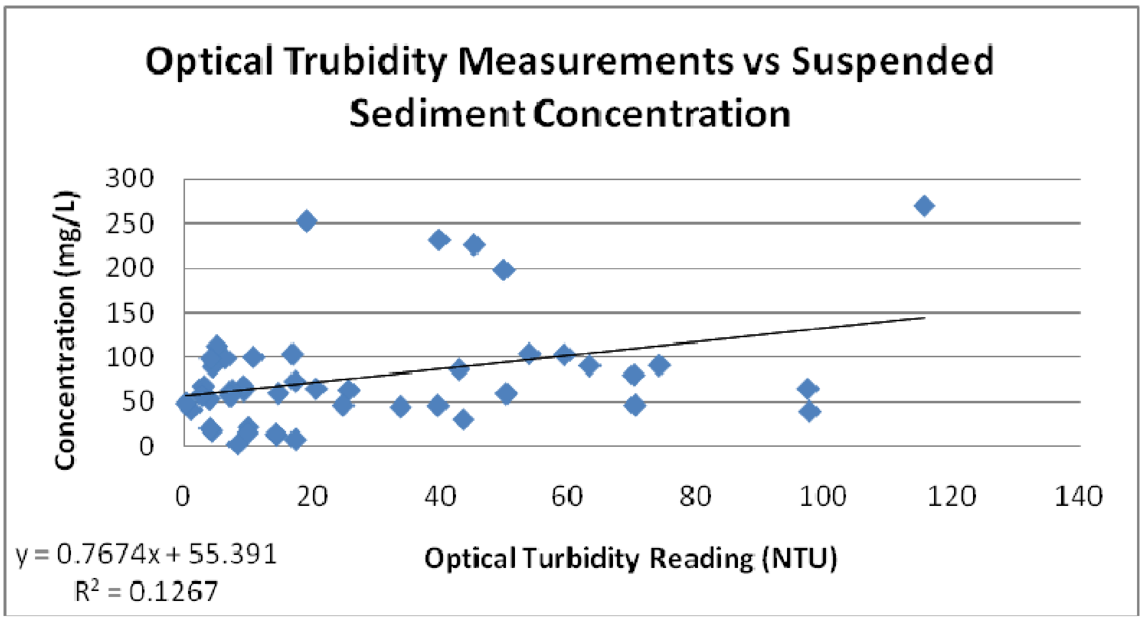
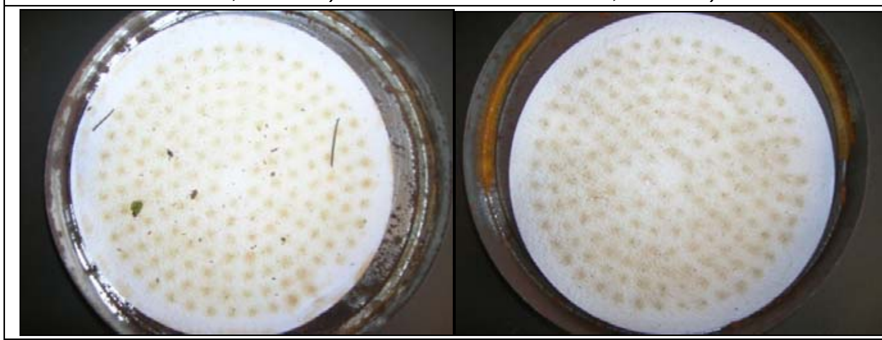


Figure 2: Plot illustrating optical turbidity measurements and corresponding suspended sediment concentrations in Elkhorn Slough, CA. Sampling locations correspond with monthly volunteer sites, with multiple samples taken at sites with turbidity values that fill gaps in turbidity range. Data plotted here are found in Table 1 below.

	April 15th, 2008		March 4th, 2008	
Location	**Turbidity (NTU)**	**SSC (mg/L)**	**Turbidity (NTU)**	**SSC (mg/L)**
Avezedo Pond Central (1)	97.5	64.1	4.4	16.9
Avezedo Pond Central (2)	97.8	39.1	NA	NA
Avezedo Pond North	4.2	98.2	7.3	56.5
Avezedo Pond South	54.0	103.6	74.3	90.7
Bennet Slough East	25.8	62.5	17.0	103.1
Carneros Creek	10.0	14.8	8.4	2.2
Hudsons Landing East	15.0	NA	14.4	13.7
Hudsons Landing West	5.5	NA	10.1	21.0
Jetty Rd	1.2	41.0	9.3	67.1
Kirby Park (1)	19.2	252.2	7.5	62.4
Kirby Park (2)	5.2	112.1	NA	NA
Kirby Park (3)	39.9	231.1	NA	NA
Monterey Dunes Way	NA	NA	50.4	58.8
Moro Cojo Slough	4.0	52.8	45.4	225.6
Moss Landing Rd North	3.1	67.1	6.5	98.5
Moss Landing Rd South	2.8	57.0	50.0	197.3
Potrero Rd North	24.9	46.0	43.0	86.0
Potrero Rd South	33.9	44.0	39.7	45.5
Salinas River Bridge	17.45	7.5	59.5	102.6
Skipper's Landing	0.4	48.1	10.9	99.8
Strawberry Rd	17.4	72.4	9.4	62.0
Struve Pond	115.7	269.4	20.7	64.1
Tembladero Slough - Molera Rd	70.5	46.0	70.3	79.8
Tembladero Slough - Preston Rd	43.7	29.9	63.4	90.2
Rookery Pond	NA	NA	4.1	19.8
Reserve South Marsh	NA	NA	4.5	88.9
Cattail Swale	NA	NA	14.5	12.2
Bennett Slough West	14.8	59.2	NA	NA

Table 1: Turbidity and suspended sediment concentration data collected by sampling date. Numbers in location names refer to duplicates. Data plotted in Figure 2 above.

Azevedo Pond South, Turbidity=74.3NTU *Struve Pond, Turbidity=20.7NTU*



Salinas River, Turbidity=59.5NTU *Carneros Creek, Turbidity=8.4NTU*

Figure 3: Digital photos of selected sampling sites illustrating the variability of visual sediment concentrations and actual turbidity measurements. Site location is given as well as corresponding turbidity measurement.

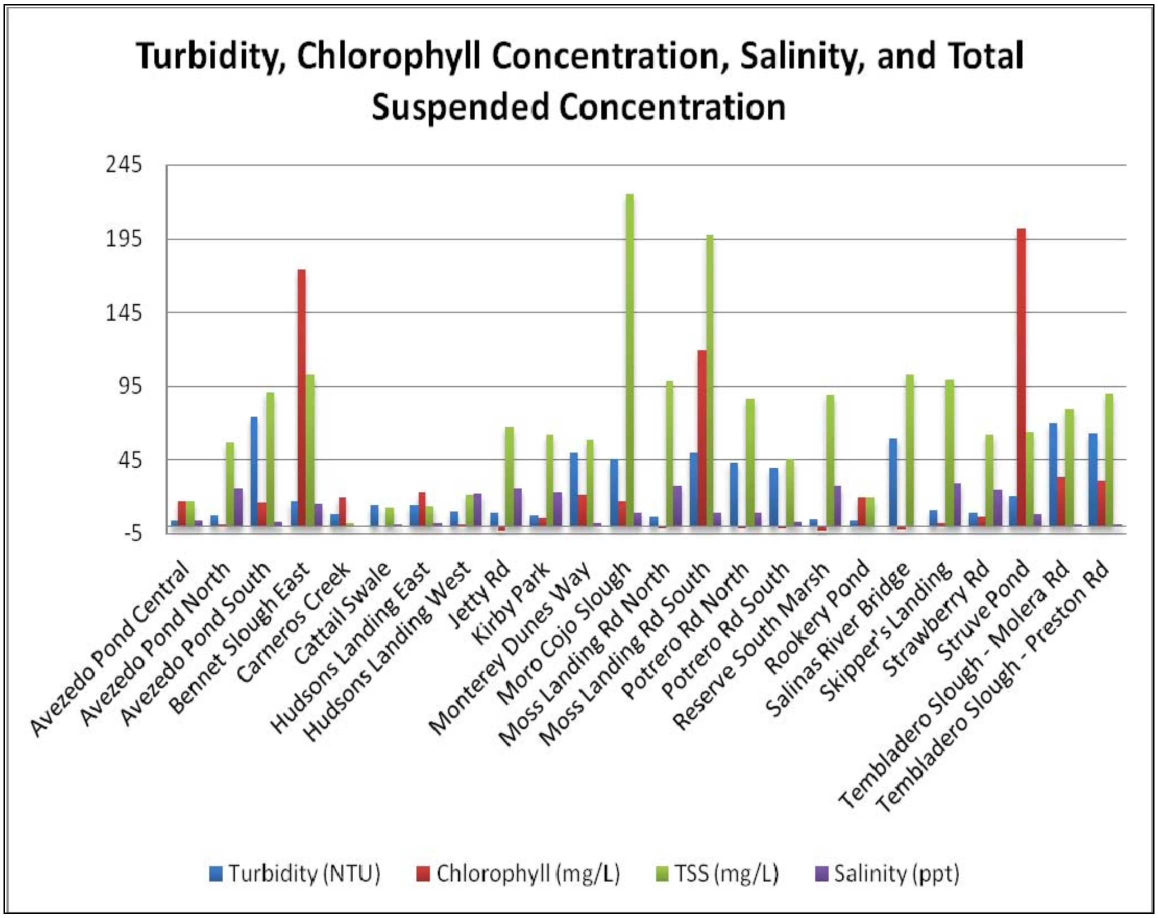


Figure 4: Bar plot illustrating potential surrogate measurements of Chlorophyll, Total Suspended Solids (TSS), and Salinity for turbidity for each sampling site. Notice lack of correlation between potential surrogates and turbidity values.

6 Discussion

Initial assessment of the calibration curve indicated an extremely noisy signal, lacking any linear relationship with an R-squared value of 0.0012. Data were clustered at low turbidity, but ranged considerably with SSC measurements, and had a few "spikes" of turbidity in the upper range. The second sampling gained more mid-turbidity values, hoping to fill the spread of low and high values. Figure 2 illustrates the noise associated with sampling at such large spatial scales, despite our efforts to gain an even spread of turbidity values.

Figure 3 illustrates the difficulty in determining a calibration curve at large spatial scales. One would think that since the first filter contains a large amount of fine sediment and large corresponding turbidity measurement, the other photos would be scaled to this reference. However, Struve Pond had very little (if any) sediment, but yielded a mid-turbidity value. In addition, Salinas River and Carneros Creek filters appear to contain relatively similar sediment concentrations, but yielded considerably different turbidity values.

There are additional surrogates that can be used for turbidity measurements, including salinity and chlorophyll. Figure 4 illustrates other surrogates tried for substitution of suspended sediment concentration that can be applied to Elkhorn Slough. The lack of trend for each measured surrogate at the sampling sites indicates that a statistical relationship would be difficult.

Determination of a turbidity calibration curve can be quite difficult, even with site specific locations. In Elkhorn Slough, the current spatial scale of sampling did not yield a relationship. There are various sources of sediment within the slough watershed, each requiring their own calibration curve, which added considerable variation in the overall relationship. However this would be improbable, unrealistic and expensive. Site calibration determination would be the best recommendation for future studies; given enough time and funding to gather enough samples with ranging turbidity values.

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