Southern California Bight
2008 Regional Marine Monitoring Survey
(Bight'08)

Coastal Wetlands and Estuaries Eutrophication Assessment Workplan

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I. INTRODUCTION

Eutrophication is the increased production of organic matter resulting from aquatic algae and plants. Cultural eutrophication of estuaries and coastal waters is a global environmental issue, with demonstrated links between anthropogenic changes in watersheds, increased nutrient loading to coastal waters, harmful algal blooms, hypoxia, and impacts on aquatic food webs (Valiela et al. 1992). These ecological impacts of eutrophication of coastal areas can have far-reaching consequences, including fish-kills and lowered fishery production (Glasgow and Burkholder, 2000), loss or degradation of seagrass and kelp beds (Twilley 1985, Burkholder et al. 1992, McGlathery 2001), smothering of bivalves and other benthic organisms (Rabalais and Harper 1992), nuisance odors, and impacts on human and marine mammal health from increased frequency and extent of harmful algal blooms and poor water quality (Bates et al. 1991, Trainer et al. 2002). These modifications have significant economic and social costs. According to EPA, eutrophication is one of the top three leading causes of impairments of the nation's waters (US EPA 2001).

In California, the impacts of nutrient loading on estuaries and coastal waters have not been well monitored, with the notable exception of San Francisco Bay (Cloern 1982, Cloern et al. 1985, Cloern 1991, 1996, Cloern 1999). In southern California, only 3 of the regions 50+ estuaries were included in the NOAA's National Estuarine Eutrophication Assessment Report (Bricker 2007); all three have been impacted by eutrophication. Of those estuaries not included in the assessment, many tend to have restricted circulation and high nutrient inputs, thus increasing the likelihood that they suffer from eutrophication. Without management actions to reduce anthropogenic nutrient loads and other factors controlling eutrophication, eutrophication could expected to develop or worsen in the majority of systems, primarily due to projected population increases along the coastal areas.

California lacks consistent, statewide water quality standards to manage the effects of nutrient-overenrichment and eutrophication in its estuaries. The State Water Resources Control Board recently launched an effort to develop statewide nutrient numeric endpoints (NNEs) for estuaries, based on a conceptual framework and recommended actions to address data gaps (EPA 2007 and 2008). One fundamental data gaps was the need to better articulate regional differences in estuarine ecology with respect to biological response to nutrient loads. Data from southern California Bight estuaries would help to drive the selection of appropriate indicators, shed light on critical conditions for assessment with those indicators, and provide context for discussion of eutrophication thresholds.

The Southern California Bight Regional Monitoring Program is a partnership of more than 60 organizations collaborating to address management questions of regional importance in the Bight offshore, nearshore and estuarine habitats. The Bight surveys have also provided a forum for multi-party agreement about ways to analyze and interpret marine and estuarine monitoring data. "Core" components of Bight surveys include: 1) offshore water quality, 2) coastal ecology, focusing on sediment quality, and 3) shoreline microbiology. "Estuaries and Coastal Wetlands" is a new component of the Southern California Bight Regional Monitoring Program. The impetus for the formation of this group is from the Southern California Wetland Recovery Project (www.scwrp.org), a collaboration of 17 state and federal agencies committed to developing a regional plan for wetland recovery. This group is working towards the development of an Integrated Wetlands Regional Assessment Program (IWRAP), focused initially on estuaries. Because the Bight Regional Monitoring Program shares a similar geographic focus with the IWRAP and has a well-functioning administrative structure, it is cost-effective to link implementation of the IWRAP with ongoing Bight Regional surveys. The recommended design for the IWRAP includes a probability-based survey of estuarine condition with respect to several physical and biological indicators.

Among the top priority indicators for early implementation was eutrophication. For this reason and others, explained below, this is the focus of the first survey of the Bight Coastal Wetlands workgroup.

The purpose of this document is to provide a workplan for the Bight '08 Estuaries and Coastal Wetland Eutrophication Assessment. Detailed field methods, laboratory methods and quality assurance plans are available as companion documents on the SCCWRP website. A list of the participants in the Bight '08 Estuaries and Coastal Wetlands workgroup are presented in Table 1.

Table 1. List of Participants in the Bight '08 Coastal Wetlands and Estuaries Workgroup.

San Diego Regional Water Quality Control Board
San Diego County NPDES co-permittees (21 entities)
State Water Resources Control Board
Tijuana National Estuary Research Reserve
San Elijo Lagoon Conservancy
Santa Monica Bay Restoration Commission
City of Los Angeles
National Park Service/Resources Conservation District
CSU Channel Islands
California State Parks
City of Ventura
Ventura County Watershed Protection District
UCSB Reserve
Camp Pendelton Marine Corps Base
Orange County
Santa Ana River Watershed Management Authority
US Army Corps of Engineers
Santa Ana Regional Water Quality Control Board
Los Angeles Regional Water Quality Control Board
University of South Carolina
University of Southern California

II. STUDY DESIGN

A. Study Objectives

The overall objective of this study is to characterize the extent and magnitude of eutrophication in SCB estuaries. Within this objective, there are two major questions of interest:

Determine whether differences exist between estuarine classes (protected embayments, perennially tidal lagoons, seasonally tidal lagoons, nontidal lagoons, river mouth estuaries)

Determine how muting of the tidal forcing within an estuary impacts the biological response to nutrient loads.

The first question seeks to evaluate the differences among estuarine classes including: enclosed bays, perennially tidal lagoons, seasonally tidal lagoons, river mouth estuaries and nontidal lagoons. Estuaries within southern California are highly variable in how they respond to nutrient loading due to differences in tidal forcing, freshwater residence time, salinity regime, stratification, denitrification, etc. This combination of factors results in differences in the dominant aquatic primary producer communities (i.e. phytoplankton, macroalgae, submerged aquatic vegetation, etc.). This question seeks to characterize differences in estuarine biological response to nutrient loads and residence time by three major classes: seasonally tidal lagoons, perennially tidal lagoons, and protected embayments. Additional sites will be sampled in a special study in the San Diego area to assess eutrophication in nontidal lagoons and river mouths.

The second question will determine the impact of muting of tidal forcing within an estuary on biological response to nutrient loads. Muting of tidal forcing occurs when a portion of the estuarine area is impounded by levees, tide gates or weirs. This muting results in an increased residence time of water within the impounded area and is hypothesized to exacerbate eutrophication.

One important explanatory variable in this study are the total annual and seasonal terrestrial loads of nitrogen and phosphorus that are discharged into each estuary. Theoretically, biological response should vary as a function of the nutrient loads into the system. Total nitrogen and phosphorus loads into each estuary are being estimated as a component of the Bight '08 Offshore Water Quality study. The approach being used to develop annual loads will provide a coarse estimate. The eutrophication assessment will use these data, in an exploratory fashion, with the intent to establish whether a dose-response relationship exists over a gradient of disturbance captured by these estuaries.

Two special studies are also being conducted in conjunction with the eutrophication assessment. The first seeks to assess the presence of harmful algal bloom toxins in estuarine sediment and surface water. The second will use stable isotopes of nitrogen and oxygen to assess nitrogen sources and cycling within two of the 32 estuaries being sampled. The study plans for these components are detailed in Appendix B.

B. Conceptual Approach and Timeline for Assessment

The basic approach to the eutrophication assessment is a probability-based survey in which sites are randomly selected from a comprehensive list of estuaries. Because eutrophication is likely to be spatially variable within an estuary, sampling will occur in a targeted index area or "segment" within each selected estuary. If the estuary is large enough to have more than one segment, then the segment selected will be that most likely to exhibit symptoms of eutrophication. For small estuaries, the "segment" will be synonymous with the entire estuary. Thus reporting on eutrophication will be on a "percent of segments".

In each of these segments, the magnitude of eutrophication of Southern California estuaries will be assessed via a series of biological response indicators. These biological response indicators have a more direct linkage to estuarine beneficial use impairment than ambient nutrient concentrations. These biological response indicators include dissolved oxygen, macroalgal biomass and percent cover, surface water phytoplankton biomass (e.g. chlorophyll a), benthic algal biomass (sediment chlorophyll a), nuisance submerged aquatic vegetation (SAV) density and percent cover. The use of multiple indicators in a "weight of evidence" approach provides a more robust means to assess ecological condition and determine impairment. This approach is similar to the multimetric index approach, which defines an array of metrics or measures that individually provide limited information on biological status, but when integrated, functions as an overall indicator of biological condition (Gibson et al. 2000).

The eutrophication assessment sampling design for Bight 08 will be divided into three primary components: (1) continuous monitoring of water quality parameters, and (2) transects of primary producer biomass and percent cover, 3) measurement of freshwater nitrogen and phosphorus concentrations and water level (where stream gauges are not available to provide flow).

Continuous monitoring of water quality parameters will occur from December 2008-October 2009. Measurement of primary producer communities will occur every other month in all estuaries for a year beginning in December 2008 and ending in October 2009. This monitoring will provide information on when blooms occur in each class of estuary, how far they extend spatially, and how long they endure.

Measurement of freshwater nitrogen and phosphorus concentrations will be conducted every other month in the winter (coincident with primary producer monitoring and every month in the summer (coincident with some maintenance events for continuous monitoring). Where no existing gauging of stream flow exists, water level will also be measured by continuous water level sensors in selected systems. Wetted channel width and velocity will be measured across the channel cross section in order to develop a rating curve for the channel. These data would be used to supplement the modeling of terrestrial nutrient loads shared by the Bight '08 Offshore Water Quality Component. Efforts in this area will be increased during dry periods (summer) due to the difficulties in modeling dry weather flows. Wet weather data will be used to ground-truth wet weather modeling.

Monitoring for domoic acid will occur coincident with primary producer community monitoring in February, April, and June, the time period in which *Pseudo nitschia* is known to bloom (Appendix B for detailed explanation of special studies). Monitoring for microcystin will occur once a month from June through September, the peak period for cyanobacteria production.

Stable isotope studies for nitrogen source tracking will occur five times during the year in selected systems. Sampling will occur coincident with primary producer sampling. Time periods for sampling were chosen to cover a range of estuarine conditions so that changes in nitrogen sources and cycling throughout the year can be adequately characterized.

The segment sampled within each estuary will be the area in which eutrophic symptoms would be most likely to occur. The selection of the segment will be governed by the following guidelines: 1) proximity to major areas of fine-grain sediment deposition or nutrient loads; 2) maximum residence time of the estuarine water column; 3) deep subtidal areas of the estuary, and 4) field crew safety and access; and 5) adequacy for field sampling.

Table 2. Timeline of components of Eutrophication Assessment.

Month	Continuous Monitoring	Primary Producer Communities	Freshwater Loading	HABs Toxins	Stable Isotope Studies
Oct 08	Quality Assurance Check on Protocols and Algal Identification				
Nov 08					
Dec 08	X	X	X		
Jan 09	X				
Feb 09	X	X	X	X (domoic acid)	X
Mar 09	X				
Apr 09	X	X	X	X (domoic acid)	X
May 09	X				
Jun 09	X	X	X	X (domoic acid + microcystin)	X
Jul 09	X		X	X (microcystin)	
Aug 09	X	X	X	X (microcystin)	X
Sept 09	X		X	X (microcystin)	
Oct 09	X	X			

C. Target Population, Sample Frame Development, and Site Selection

Survey design takes into account the two subpopulations of interest to Bight '08 participants:

- Estuarine class
- Tidal regime (muted or fully tidal)

While these were not sampled as separate strata in the survey, some weighting took place to emphasize sampling of selected classes and tidal regime, as discussed below.

The sample frame was development by drawing up a comprehensive list of coastal drainages in southern California coastal watersheds and applying the SWRCB's definition of enclosed bay or estuary (see below). Estuarine class was attributed to each system, as defined in Appendix A. The system was also attributed by whether it is muted or fully tidal, as defined below. "Muted" refers to a tidal regime in which the fluctuation in an estuary's water level that is lower in amplitude than the fluctuation in a neighboring tidal body of water, due to levees or other artificial devices which inhibit the exchange of water between the site and the tidal body. Estuaries that had both types of habitat were entered twice in the list of estuaries. Small creek mouths and open embayments were excluded from the frame.

Several estuaries were excluded because of planned or ongoing restoration work. 25 estuaries will be monitored, with a total of 30 sites (Table 3). Table 4 gives a list of sites selected for the eutrophication assessment, their class and tidal regime. To select sites for the Bight 08 eutrophication assessment, priority was assigned to protected embayments, seasonally tidal lagoons, and perennially tidal lagoons. Estuaries were selected in order to approximate equal weighting for each class for protected embayments, seasonally tidal and perennially tidal lagoons in the Northern portion of the SCB region (Newport Bay and north). Interest and participation allowed for an intensification of effort in the San Diego Region (Dana Point/San Juan Creek and south); thus all estuaries were selected in the San Diego Region to complete a census of perennially tidal and seasonally tidal coastal lagoons, and enclosed embayments.

Table 3. Summary of sites and estuaries to monitored by estuarine class.

Estuarine Class	Number of Estuaries Monitored	Number of Sites Monitored
Enclosed Bay	3	5
Perennial Tidal Lagoon	9	12
Seasonally Tidal Lagoon	9	9
Nontidal Lagoon	2	2
River Mouth Estuary	2	2
Total	25	30

River mouth estuaries and nontidal lagoons were given less priority but will be included in the survey as special studies on a case-by-case basis. This was the case for the Santa Clara River estuary and San Diego River estuary (river mouth estuaries), San Mateo Lagoon (nontidal lagoon). Buena Vista Lagoon, Loma Alta Slough and Famosa Slough were assessed in 2007-2008 with a compatible set of protocols because monitoring related to ongoing TMDL work, and thus these data will be utilized in the Bight '08 study.

Some estuaries were excluded from the sample frame because of ongoing or planned restoration work that would have occurred during the assessment window. These included:

- Malibu Lagoon (restoration to begin June 2009)
- Upper Newport Bay (restoration ongoing)
- San Luis Rey Estuary (restoration ongoing)
- Sweetwater Marsh at Paradise Creek (restoration to begin fall 2008)

Table 4. List of sites proposed for inclusion in the eutrophication assessment. Under tidal regime, "N/A" or not applicable refers to seasonally tidal or nontidal lagoons, which are naturally muted for part of all of the year.

Estuary	Field Lead	Estuarine Class	Tidal Regime
Tijuana River estuary	Jeff Crooks, TJ NERR	Perennially Tidal Lagoon	Full
San Diego Bay- fully tidal		Protected Embayment	Full
San Diego Bay- muted tidal		Protected Embayment	Muted
Famosa Slough*		Perennially Tidal Lagoon	Muted
San Diego River		River Mouth Estuary	Full
Mission Bay		Protected Embayment	Full
Los Penasquitos Lagoon		Seasonally Tidal Lagoon	N/A
Batiquitos Lagoon	Jeff Crooks, TJ NERR	Perennially Tidal Lagoon	N/A
Agua Hedionda		Perennially Tidal Lagoon	N/A
San Elijo Lagoon	Doug Gibson, San Elijo Lagoon Conservancy	Seasonally Tidal Lagoon	N/A
Buena Vista Lagoon*	Karen McLaughlin, SCCWRP	Nontidal Lagoon	N/A
Loma Alta Slough*		Seasonally Tidal Lagoon	N/A
Santa Margarita Estuary		Seasonally Tidal Lagoon	N/A
San Juan Creek		Seasonally Tidal Lagoon	N/A
San Mateo Creek		Nontidal Lagoon	N/A
Santa Ana River wetlands		Perennially Tidal Lagoon	Muted
Bolsa Chica – fully tidal		Perennially Tidal Lagoon	Full
Bolsa Chica – muted tidal		Perennially Tidal Lagoon	Muted
Seal Beach – fully tidal		Protected Embayment	Full
Seal Beach – muted tidal		Protected Embayment	Muted
Ballona Wetlands	Sean Bergquist, SMBRC and Gerald McGowan, City of Los Angeles (Ballona Lagoon only)	Perennially Tidal Lagoon	Muted
Ballona Lagoon		Perennially Tidal Lagoon	Muted
Topanga Lagoon	Rosi Dagit, Resource Conservation District	Seasonally Tidal Lagoon	N/A
Zuma Lagoon	Sean Anderson, CSU Channel Islands	Seasonally Tidal Lagoon	N/A
Mugu Lagoon- fully tidal		Perennially Tidal Lagoon	Full
Mugu Lagoon – muted tidal		Perennially Tidal Lagoon	Muted
Santa Clara River Estuary	Sean Anderson, CSU Channel Islands and David Thomas, Ventura County Watershed Protection District (Santa Clara River estuary only)	River Mouth Estuary	N/A
Devereaux Slough	Lisa Stratton, UCSB CCBER	Seasonally Tidal Lagoon	N/A
Goleta Slough		Seasonally Tidal Lagoon	N/A
UCSB Campus Lagoon		Perennially Tidal Lagoon	Muted

D. Indicators of Eutrophication

Four types of indicators are used in this survey: 1) dissolved oxygen and related water quality parameters, 2) primary producer community indicators, 3) harmful algal bloom toxins, and 4) nitrogen and phosphorus concentrations and water level or flow (in selected systems) at the mass loading station. In addition, a suite of stable isotopes will be used as indicators in selected systems. These indicators are summarized in Table 5 and explained in detail below.

Table 5. List of indicators measured in the Coastal Wetlands Eutrophication Assessment.

Type	Analyte	Location
Continuous monitoring	Dissolved oxygen pH Salinity Turbidity Chlorophyll a fluorescence Temperature	Bottom Waters, Index area
Macroalgae	% Solids (wet weight, dry weight) Biomass Taxonomic composition Percent cover	Transects within designated "segment"
Brackish water submerged aquatic vegetation	Percent solids (wet weight, dry weight) Biomass Genus Percent cover	Transects within designated "segment"
Phytoplankton	Chlorophyll a concentration	Water column at macroalgal transects
Benthic microalgae	Sediment chlorophyll a concentration	Surface sediments (0-1 cm) at macroalgal transects
Sediment quality	Percent solids Sediment TN Sediment TP Sediment TOC Grain size	Benthic microalgal transects
Mass loading station nutrient concentrations	Surface Water Total nitrogen Surface Water Total phosphorus	Mass loading station
Mass loading station discharge	Water level Channel cross section	Mass loading station
[1]Harmful algal bloom toxin	Water column domoic acid	Benthic microalgal transects in perennially tidal estuaries
	Sediment domoic acid	Coastal Ecology sites
	Microcystin	Benthic microalgal transects in seasonally tidal or nontidal estuaries
[2]Stable isotope analyses	Nitrogen-15 and Oxygen-18 of dissolved nitrate Oxygen-18 of water Nitrogen-15 and Carbon-13 of macroalgae and SAV biomass	Along salinity gradients in selected systems

[1] Sampled as a part of a special study. See Appendix B for details.

Bottom Water Dissolved Oxygen

Oxygen is necessary to sustain the life of all fishes and benthic invertebrates. When the supply of oxygen from the surface waters is cut off (via stratification), or the consumption of oxygen exceeds the resupply (via decomposition of excessive amounts of organic matter), oxygen concentrations can decline below the limit for survival and reproduction of benthic (bottom-dwelling) or pelagic (water column dwelling) organisms (Stanley and Nixon 1992, Borsuk et al. 2001, Diaz 2001). Changes in the survival and reproduction of benthic and pelagic organisms can result in a cascade of effects including loss of habitat and biological diversity, development of foul odors and taste, and altered food webs (Sutula et al. 2007).

Primary Producer Communities: Macroalgae Biomass and Percent Cover

Increased eutrophication often results in a shift in primary producer communities (Hernandez et al. 1997, Valiela et al. 1997). One change is the proliferation of macroalgae. These algae are typically filamentous (sheet-like) forms (e.g., Ulva, Cladophora, Chaetomorpha) that can accumulate in extensive thick mats over the seagrass or sediment surface. Although macroalgae are a natural component of these systems, their proliferation due to nutrient enrichment reduces habitat quality in four ways: 1) increased respiration at night and large oxygen demand from decomposing organic matter, 2) shading and out-competing submerged aquatic vegetation, and 3) impacts on the density of benthic infauna, which are a principle food source for birds and fish, and 4) increases in poor aesthetics or odor. Among the literature on impacts of eutrophication on West Coast estuaries, the proliferation of macroalgae, particularly in shallow subtidal and intertidal environments, is one of the most commonly cited (Fong et al. 1998, Kamer et al. 2001, Kennison et al. 2003).

Primary Producer Communities: Brackish Water Submerged Aquatic Vegetation (SAV) Biomass and Percent Cover

Nuisance SAV can grow to levels that can impair beneficial uses in an estuary, particularly in non-tidal and seasonally tidal lagoons. Such species are mostly brackish (e.g. *Ruppia maritima*) and can increase in abundance under nutrient enrichment to dominate other seagrass communities (Johnson et al. 2003, Sutula et al. 2004). As biomass from nuisance SAV decays it will ultimately result in low DO conditions in bottom waters in the same way as macroalgal blooms (Sutula et al. 2004). As salinity regimes change seasonally, die-offs of nuisance SAV can cause a catastrophic hypoxic event.

Primary Producer Communities: Water Column Phytoplankton and Benthic Microalgal Mats (Surface Water and Sediment Chlorophyll a)

Chlorophyll a is a measure used to indicate the amount of microscopic algae, called phytoplankton, growing in a water body. High concentrations are indicative of nutrient loading (similar to macroalgal growth). Impairment issues related to phytoplankton blooms are similar to macroalgal blooms. In some estuaries, nutrients cause dense phytoplankton blooms for months at a time, reducing water clarity and blocking sunlight to submerged aquatic vegetation. Decaying phytoplankton from the blooms consumes oxygen that was once available to estuarine fauna. In other estuaries, these or other symptoms may occur, but less frequently, for shorter periods of time, or over smaller spatial areas. In still other estuaries, the assimilative capacity (or ability to absorb nutrients) may be greatly reduced, though no other symptoms are apparent. These eutrophic symptoms are indicative of degraded water quality conditions that can adversely affect the use of estuarine resources, including commercial and recreational fishing, boating, swimming, and tourism. Eutrophic symptoms may also cause risks to human health, including serious illness and death that result from the consumption of shellfish contaminated with algal toxins, from direct exposure to waterborne or airborne toxins, or from contact with enteric bacteria that flourish under eutrophic conditions. Water column chlorophyll *a* can be measured by fluorescence from a discrete water column sample, or inferred from fluorescence measured continuously with a data sonde. Sediment chlorophyll *a* is measured via extraction and analysis by a fluorometer.

Harmful Algal Blooms (HABs) Toxins

Domoic Acid. Domoic acid is a toxin produced by the marine algae *Psuedo nitschia*. Domoic acid poisoning can cause memory loss, brain damage and fatalities. Surface water particulate domoic acid samples will be collected in the field and frozen until analysis. Rapid analysis of domoic acid concentrations will be made using a new Enzyme Linked Immunosorbent Assay (ELISA) method (Garthwaite et al., 2001). The analysis (developed and now offered commercially by Mercury Science, Inc.) is based on a competitive binding assay and is highly specific for domoic acid. Sediment domoic acid will be analyzed by digestion, extraction and analysis by LC-MS.

Microcystin. Microcystin is a toxin produced by freshwater cyanobacteria. Surface water particulate microcystin samples will be collected in the field and frozen until analysis. Rapid analysis of domoic acid concentrations will be made using Enzyme Linked Immunosorbent Assay (ELISA) method.

Total Nitrogen/ Total Phosphorus Concentrations and Loads

Management of watershed nutrient loading is one of the primary means of mitigating the effects of eutrophication in estuaries. Determination of the specific nutrient loading rates that result in eutrophication is complicated by site-specific attributes that serve to modulate the biological response to nutrient enrichment. Data on nutrient loads will be used to investigate the dose/response relationship between nutrient inputs and biological response within each class of estuary. Since these loads are being modeled in the Bight Offshore Water Quality study, the emphasis in this study is provide additional data that to support modeling of nutrient loads to each site. Specifically, this includes: 1) measurement of total nitrogen and phosphorus concentrations at the major source of freshwater input to the site, and 2) where stream gauging does not exist, estimate channel discharge via measurement of continuous water level and periodic measurements of channel cross section and velocity to develop a rating curve. This monitoring will occur at the site's designated "mass loading station," an area in a stream or river that is sufficiently upstream of tidal influence.

E. Collateral Data

Additional data will be required in order to fully understand the data collected for the Eutrophication Assessment. For example, anomalously low salinity features observed during continuous monitoring could be explained by storm events, higher than normal primary producer community biomass during the winter could be explained by anomalously high temperatures, etc. Thus, collateral data will be obtained from local sources during this assessment (Table 5). Estuarine bathymetry and river discharge will be used to estimate residence time. For each estuary a local metrological station will be identified and daily data will be collected for each assessment period.

Estuaries that experience more frequent tidal flushing and thus, have shorter water residence times may also be less susceptible to eutrophication. Tidal flushing provides a mechanism by which nutrients and/or primary producer communities can be effectively removed from the system before large blooms can occur. This study will utilize established algorithms that quantify freshwater residence time from measurements of flow and estuarine volume.

Table 6. Collateral Data.

Collateral Data	Source
River/stream discharge	USGS and County gauges
Estuarine bathymetry	Local stakeholders
Precipitation history	Local meteorological station
Daily mean air temperature	Local meteorological station
Daily mean wind speed	Local meteorological station
Daily mean solar irradiance	San Joaquin Marsh UCI
Tidal height	WX tides

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APPENDIX A: DEFINITIONS

The definition of estuary used to identify the target population follows that of the State Water Resources Control Board:

> ***ENCLOSED BAYS*** *are indentations along the coast that enclose an area of oceanic water within distinct headlands or harbor works. Enclosed bays include all bays where the narrowest distance between the headlands or outermost harbor works is less than 75 percent of the greatest dimension of the enclosed portion of the bay.*
>
> ***ESTUARIES*** *are waters, including coastal lagoons, located at the mouths of streams that serve as areas of mixing for fresh and ocean waters. Coastal lagoons and mouths of streams that are temporarily separated from the ocean by sandbars shall be considered estuaries. Estuarine waters shall be considered to extend from a bay or the open ocean to a point upstream where there is no significant mixing of fresh water and seawater.*

Estuarine classes designated in the eutrophication assessment are defined as follows (EPA 2007):

> **Protected Embayment**- This estuary type is typically semi-enclosed by land, dominated by subtidal or deepwater habitat. The inlet mouth is not restricted and is continuously open to tidal exchange. This class includes ports and marinas as a subclass with a high degree of anthropogenic use.
>
> **Perennially Tidal Lagoon**- These estuaries are dominated by shallow subtidal and intertidal habitat and have a long residence time due to the restricted width of the mouth. The inlet is continuously open to tidal influence year round, either by natural forces or anthropogenic management.
>
> **Seasonally Tidal Lagoon**- These estuaries are dominated by shallow subtidal and intertidal habitat, with a long residence time due to a seasonally restricted width of mouth or mouth closure. They support fresh to brackish submerged aquatic vegetation and emergent marsh for part of the year when the mouth is closed.
>
> **Nontidal Lagoon**- These estuaries are dominated by shallow subtidal and intertidal habitat, with a long residence time due lack of surface water connection with coastal ocean. The salinity regimes of these lagoons can be fresh to brackish due to limited input of ocean water during spring tides, storm surges or advective exchange through a sand berm.
>
> **River Mouth Estuary**- This class of estuaries is the terminus of high flow, perennial river systems as they enter the coast. The estuarine portion is the mixing zone at the mouth of the river. These systems are characterized by 1) ebb-dominated flows, 2) estuarine mixing zone found within the channel during dry season, and 3) continuous disturbance of flats discourages growth of emergent vegetation during average flow years.

APPENDIX B: DESCRIPTION OF SPECIAL STUDIES

Tracking Nitrogen Sources and Cycling Using Stable Isotope Ratios:

New and emerging tools may enhance ability to track the sources and cycling of nutrients. Use of these tools enables a greater understanding of how to manage watersheds to reduce excessive nutrient inputs and impacts to beneficial uses. This special study will utilize a suite of stable isotope and conventional measurements to understand the sources and cycling of nitrogen along a salinity mixing line in two estuarine systems. Transects from the freshwater end-member to the ocean end-member will be laid out in each selected system. All constituents will be measured at six locations along the transects. Three of these locations will coincide with the macroalgae transects.

The oxygen isotopic composition of water, together with salinity will be used to determine mixing of freshwater with ocean water in each estuary. Fresh, riverine water has low oxygen isotope ratios compared to ocean water. The use of oxygen isotopes and salinity will be used to generate mixing models of each estuarine system. These models will form the basis for the interpretation of nitrate and biomass stable isotope analysis.

Recent research into the stable nitrogen and oxygen isotopic composition of nitrate has shown that different substrates (*e.g.* soil nitrogen, atmospheric nitrogen, chemical fertilizers, manure, and sewage) have unique isotopic signatures (Kendall 1998). Furthermore, biological cycling imparts a unique isotopic signature on dissolved nitrate (Kendall 1998; Sebilo *et al.* 2006). By measuring the nitrogen and oxygen isotopic composition of dissolved nitrate, we can develop models that trace the mixing of sources of nitrate if no significant biological alteration has occurred. If the source signature has been altered through either denitrification (loss of nitrogen) and/or nitrification (source of nitrogen), these processes will over-write the source signature and the isotopic measurements can help us determine sources and sinks of nitrate within a system. The expected nitrate isotopic composition will be generated from the mixing lines established using the water oxygen isotope ratios and salinity measurements. The measured values at each station will be compared to the expected values to determine the extent of biological cycling at each location and/or whether an additional nitrate source has entered the system.

Use of carbon and nitrogen stable isotope ratios in primary producer biomass has long been established as an important tool for understanding important nutrient sources in estuarine environments (Kendall 1998, Wang et al. 1998). Algae and SAV are integrators of nutrient source signatures and by measuring the nitrogen and carbon isotopic composition of bulk biomass, we may be able to discern sources of nitrogen that are most easily utilized by algal and SAV communities (Kendall *et al.* 2001). The measured values will be compared to dissolved nitrate isotope ratios to see if the expected nitrate source signatures are confirmed in the nitrogen isotope ratios of biomass samples or whether the algae are accessing a different nitrogen source (e.g. ammonia, urea, etc.).

Harmful Algal Bloom Toxins in Estuarine Surface Waters and Sediments

Toxic blooms of a variety of algal species (harmful algal blooms (HABs)) have been documented throughout the world's coastal oceans, ultimately impacting shellfish, finfish, marine mammals and birds over large areas. Several species within the genus of Pseudo-nitzschia, a group of marine diatoms, produce the neurotoxin domoic acid (DA), and have been identified as common members of algal assemblages along the coast of California.

Most Pseudo-nitzschia research has focused on the upper water column in near-shore environments. However, recent evidence suggests that live cells containing toxin rapidly sink to the ocean floor (> 800 m) and can even survive entrainment into underlying sediments. In addition, data also suggest that estuarine sediments can also contain significant amounts of DA. These cells may potentially act as seed populations for future blooms or as a source of DA poisoning in filter and deposit feeding benthic communities. As such, there may be long lasting effects associated with DA that persist well after the demise of a toxic Pseudo-nitzschia bloom. Recent studies of the vertical flux of DA and Pseudo-nitzschia in bimonthly sediment trap samples collected from 2002 to 2007 at 550-m depth in the center of Santa Barbara Basin (SBB) as well as in underlying and coastal sediments show concentrations as high as 35.6 ppm in dried sediment trap material, with high DA concentrations coinciding with known coastal shellfish toxin events or with simultaneous measurements of high DA concentrations in overlying surface waters (Benitez-Nelson, unpublished data). It is hypothesized that substantial DA likely reaches shallower sediments as well, thus having serious implications for benthic community health and the possible release of DA back into overlying waters during bottom-water disturbances. Most monitoring of DA concentration has focused on offshore environments; very little effort has been focused on west coast estuaries.

Monitoring of sediment domoic acid concentrations and Psuedo-nitschia abundances has the potential to extend our understanding of trends in HAB occurrence over the past century. It allows us to use these data in conjunction with climate data to understand the role that natural variability and climate change has on HABs, and track the evolution of HABs in relation to changing anthropogenic inputs over the past century.

The purpose of this special study is to determine the concentration of DA in sediments from a variety of 10 different habitats within the Bight offshore, embayments and estuarine habitats, collected through the Bight '08 and Bight '03 Coastal Ecology studies. HAB toxins will also be monitored in estuarine surface waters at locations coincident with primary producer transects. The study will attempt to address three questions: 1) what are the concentrations of DA in surface sediments in the southern California Bight and how do they vary by habitat type? 2) is DA detectable in sediment cores from various locations in the Bight and, if so, how that these data be used to understand historical trends in DA concentration? And 3) are either DA or microcystin (a freshwater HAB toxin produced from cyanobacteria) present in estuarine surface waters?