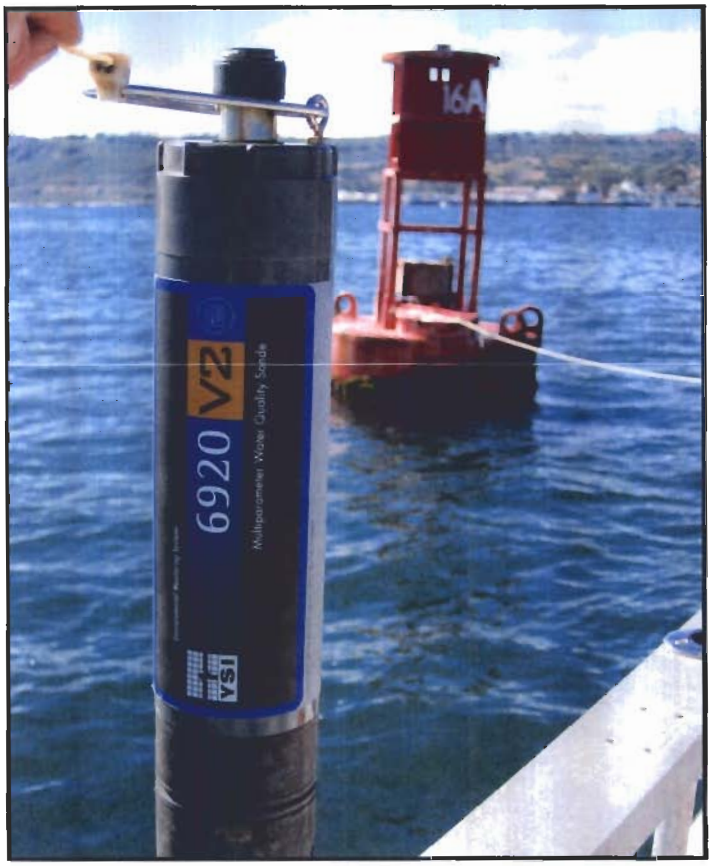
Characterizing the Spatial and Temporal Variation of Key Physical Water Quality Parameters in San Diego Bay: The Importance of Continuous Baseline Data when Evaluating Physical, Biological, and Chemical Processes.



Quarterly Report
October 2010

A Project for:

Environmental Projects to Benefit San Diego Bay
San Diego Unified Port District
Environmental Services Department

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1 Introduction

This project was launched to pursue the development of a long term physical water quality data set capable of establishing baseline conditions in San Diego Bay and determine the spatial and temporal variation of key physical water quality parameters in various portions of the Bay. This project is focused on identifying dominant components and characteristics of turbidity and provide consistent long-term data as a baseline for future physical, biological, and chemical scientific evaluations. Building upon existing data sets intermittently collected in the same locations by the Port of San Diego (Port) first piloted in 2000 and more recently in 2007/2008, this study concentrates on establishing a data set suitable for identifying correlations between turbidity generated from rainfall events, suspended particulate matter, and primary production. Annual and seasonal changes in water quality, hydrology, surface water runoff, and non point source pollution are difficult to evaluate; long term data sets enable managers and researchers to identify natural and anthropogenic events. This study archives and documents existing water quality conditions within three of the four ecological regions (ecoregions) in San Diego Bay. It compliments concurrent investigations in the South Bay by Tijuana National Wildlife Refuge (funded by the National Oceanographic Atmospheric Administration [NOAA]) and at the Scripps Pier (funded by the Scripps Institute of Oceanography [SIO]).

The biological productivity (health) of the Bay depends on adequate circulation and exchange of Bay and ocean waters which supports primary production generated by phytoplankton, submerged aquatic vegetation (eelgrass), and coastal marsh systems. The influence of temperature on chlorophyll a concentration is well correlated and positive growth of various bivalves have been found to be positively correlated to temperature, chlorophyll a concentration and particulate organic matter (Toro et al. 1999). Physical water characteristics, most notably salinity and temperature, create defined vertical and horizontal spatial distribution gradients in estuarine, bay, and ocean water masses that sculpt and partition biological processes. Continuous functioning primary production processes display temporal components that affect water clarity and thus turbidity throughout the Bay. Understanding and documenting temporal and spatial changes of these parameters is imperative to support investigations of upper trophic level species and establish the variation of the overall ecological system.

This effort is coordinated with the ongoing Regional Harbor Monitoring Plan and focuses on evaluating dominant components and characteristics of turbidity as they relate to potential effects to primary production. The acquisition of baseline physical water quality properties (turbidity, temperature, salinity, etc.) and chlorophyll "a" provides early detection of potential harmful algal blooms while providing managers and policy makers information beneficial to natural resource management, habitat restoration, and environmental education.

1.1 Equipment

Instruments, sometimes called 'sondes' are typically deployed to measure physical water quality parameters. Sondes are electronic data loggers outfitted with various probes depending on the desired data parameters. Sondes can be deployed intermittently to examine vertical stratification or document physical water quality characteristics from specific events; or deployed continuously for several days or months. Data sets collected in either manner have limitations and drawbacks. Single deployments provide only limited information for specific times and locations; however, errors associated with probe calibrations, drift, and fouling are reduced. Continuous deployment provides a greater ability to detect changes in physical water quality characteristics over time and space while reducing the time and effort to collect daily measurements; however, there is a greater possibility of fouling from debris, invertebrates, algae, and water movement. Continuous sonde data collection at defined locations enables investigators to evaluate natural variation of selected water quality characteristics over time and observe how specific events (rainfall, dredging, algal blooms) affect various parameters at their peak, at onset, and as they dissipate. The advantages of continuously deployed sondes include an expanded data set capturing fluctuations during various tides, seasons, and unexpected events that are clearly beneficial in a regional perspective.

To date, Port data sondes have been configured, installed, and are collecting continuous data at three stations (A, B, and C) within San Diego Bay (Map 1). Initial examination of continuous data collected at the monitoring stations began on April 20th, 2010 and continues uninterrupted to date. Polyvinyl chloride (PVC) sonde housings which were placed on United States Coast Guard (USCG) navigational buoys (with approval) have proven to be most effective at reducing biological fouling and facilitating consistent data acquisition. PVC housings were affixed to mooring chains with stainless house clamps and large zip ties. Housings were outfitted with large stainless steel bolts to retain the sondes and deter tampering.

Map 1. San Diego Bay ecoregions and associated instrument (sonde) locations.

2 Methods

In order to evaluate the temporal and spatial physical water quality conditions throughout San Diego Bay specifically designed unattended instrumentation was distributed in distinct ecroregions, and data collection equipment was frequently calibrated to ensure data quality. Four YSI 6920 V2 data sondes (Photo 1) and associated equipment were identified as the appropriate instrumentation and were subsequently purchased by the Port of San Diego from Merkel & Associates through Tierra Data Inc. (TDI) in December 2009. Upon acquisition the instruments (sondes) were shipped to YSI for full evaluation, software upgrade, and servicing. After inspection and return, three of the sondes were configured for unattended continuous sampling and one was set up to perform vertical casts, at each station location, prior to unattended sondes being removed, downloaded, and calibrated. Unattended sondes at each location were set to collect defined parameters at ten minute intervals over a fourteen day deployment period and outfitted with antifouling measures to enhance data consistency. Data parameters included date (dd:mm:yy), time (hh:mm:ss), battery voltage (v), temperature (°C), specific conductivity (mS/cm), salinity (ppt), pH, turbidity (ntu), and chlorophyll "a" (µg/l). The remaining sonde was utilized to perform bimonthly vertical casts at each station, configured with the same data probes and parameters as the unattended sondes, except the chlorophyll "a" probe was exchanged for a dissolved oxygen probe to examine potential oxygen minimum zones throughout the water column.

Photo 1. YSI 6920 V2 ready for deployment at Station C.

Using station locations established during previous investigations representing North, North Central and South Central ecoregions, adjacent navigational aids (buoys) were identified for sonde placement. Unattended sondes were deployed at navigational buoys 16A, 22A, and 34 in San Diego Bay. Divers removed individual sondes from protective PVC housing on relatively regular two-week intervals (Photo 2). During bimonthly data downloading and calibration individual sondes remain associated with their original deployment location to reduce variability related to instrument drift.

Sondes were initially deployed at all three station locations on April 20, 2010. Since deployment sondes have been regularly serviced every 14 to 15 days at which time each instrument is inspected and calibrated. During each visit both the data sonde and their associated housings are physically cleaned using brushes, and during every other visit the batteries, probe wipers, and antifouling coatings are replaced.

Presently two biologists visit each of the three station locations bimonthly using a 20 ft. Boston Whaler outfitted to facilitate diving operations and equipped to ensure safe conditions for both personnel and sensitive equipment manipulation. Upon arrival at each station the vessel is secured to the navigational buoy using a quick release line and the vertical cast sonde is deployed as close as possible to the station buoy. The vertical cast sonde is weighted with a five-pound weight, placed in the water at surface level and allowed to equilibrate for approximately one minute. The sonde is then lowered at one foot-per-second until it reaches the ocean bottom. Once the sonde reaches the bottom is it brought up about two feet to reduce interference from sediment disturbance, and allowed to collect data for one minute. The sonde is then raised at the same speed (one foot-per-second) until it reaches the surface. The vertical cast sonde collects data points once per second and is performed to examine physical water quality parameters throughout the entire water column. The vertical cast sonde serves as a reference for data collected by unattended sondes.

Photo 2. YSI 6920 V2 Sonde and PVC housing used to reduce fouling, prior to installation on buoy mooring chains.

After the vertical cast is performed divers enter the water to remove the individual station sonde and clean the housing. Once on board the vessel the sonde is inspected, cleaned, and data is downloaded using an YSI 650 MDS data logger. After data download the probes are cleaned and calibrated and the instrument is redeployed by divers. Each data file is labeled by month, day, and site (May5b) according to the deployment date and provides consistency and quality control during file maintenance. Vertical casts are similarly labeled adding a "c" on the end of the file name to denote a cast (May5bc). Individual files also contain date and time stamps as a quality control measure.

Sonde data is stored in the YSI 650 MDS data logger as a comma delimited (comma separated value) text file and downloaded directly to a TDI office personal computer (PC) after each sampling period, using an YSI hyper terminal. Individual data files remain on both the sonde and the data logger until sufficient quality assurance can be performed on the database files. Raw comma delimited text files from each station and cast are saved under a raw file directory, by station, prior to conversion to Microsoft Office Excel workbook files (xls). The converted files are stored under a separate directory labeled "originals" and are reviewed for outlying data points and manipulated for analysis. Finally files are assimilated by station into continuous (xls) data files for importation into an Access database. These files are labeled "working" and are organized by station, creating three distinct station files (A, B, and C). Data contained within the Access data base is normalized (see results for explanation) to remove outlying data points attributed primarily to fouling near the end of deployment intervals, and reduce variability that can mask daily or monthly trends or means. All data files are backed up and archived on the TDI server daily to reduce the risk of data loss.

3 Results

3.1 Data

Data collected at each of the three stations fell mostly within expected ranges and varied in relation to each other due to differences in proximity to the open ocean, localized conditions, and tidal influences. Continuous data, collected at each station between April 20th, 2010 - September 22nd, 2010 presented in this report, displayed only intermittent outlying data points for measured parameters. Errors in collected data over the sampling period presented in this quarterly report was attributed to primarily biological fouling, limitations of sampling probes, and calibration drift. Data collected at Station A (Appendix A) displayed consistent results with respect to all recorded parameters with few exceptions and outlying data records occurred intermittently and more commonly at the end of deployment time periods. Potential erroneous data points observed for both turbidity and chlorophyll "a" measurements represented a relatively small portion of the data set. (Suspect data records are flagged in red for this report but will be corrected and assimilated into the larger database as normalizing strategies are tested and implemented.) Data collected at Station B and Station C (Appendix B and C respectively) displayed consistent results for most of the recorded parameters with obvious data errors flagged and adjusted using adjacent records for developing monthly averages. Data presented in this quarterly report should be utilized conservatively until the entire data base can be formally normalized through standardized database procedures currently being tested.

Temperature data (°C) varied between individual stations with diurnal variation most prominent at Station A. The frequency and degree of temporal and spatial variation in temperature data with regards to individual stations were described in depth in the April 2010 quarterly report, highlighting correlations between temperature and tidal change. Monthly temperature averages displayed expected results based on the location of individual stations and their proximity to the open ocean. Monthly averages for each station were plotted against each other and the NOAA Mission Bay Offshore Buoy Sea Surface Temperature (SST) values (Figure 1) (Scripps Institute of Oceanography 2010). The gradual warming trend apparent from April to June, that followed expected temporal patterns well documented for the Southern California Bight (SCB) shifted noticeably lower for the time period of July through September (Figure 1).

As expected, Salinity (ppt) and specific conductivity (mS/cm) displayed only minor variations among all sampled stations with salinity ranging between 31.5 and 34.5 (ppt). Calibration drift associated with the specific conductivity probes likely accounted for the slight variance in readings. Temporal and spatial variations with regards to salinity are more prevalent during the winter months when rainfall in conjunction with storm water runoff contributes to stratification and neap tides affect vertical mixing during specific time periods. Both processes have significant and complicated impacts to Bay water characteristics.

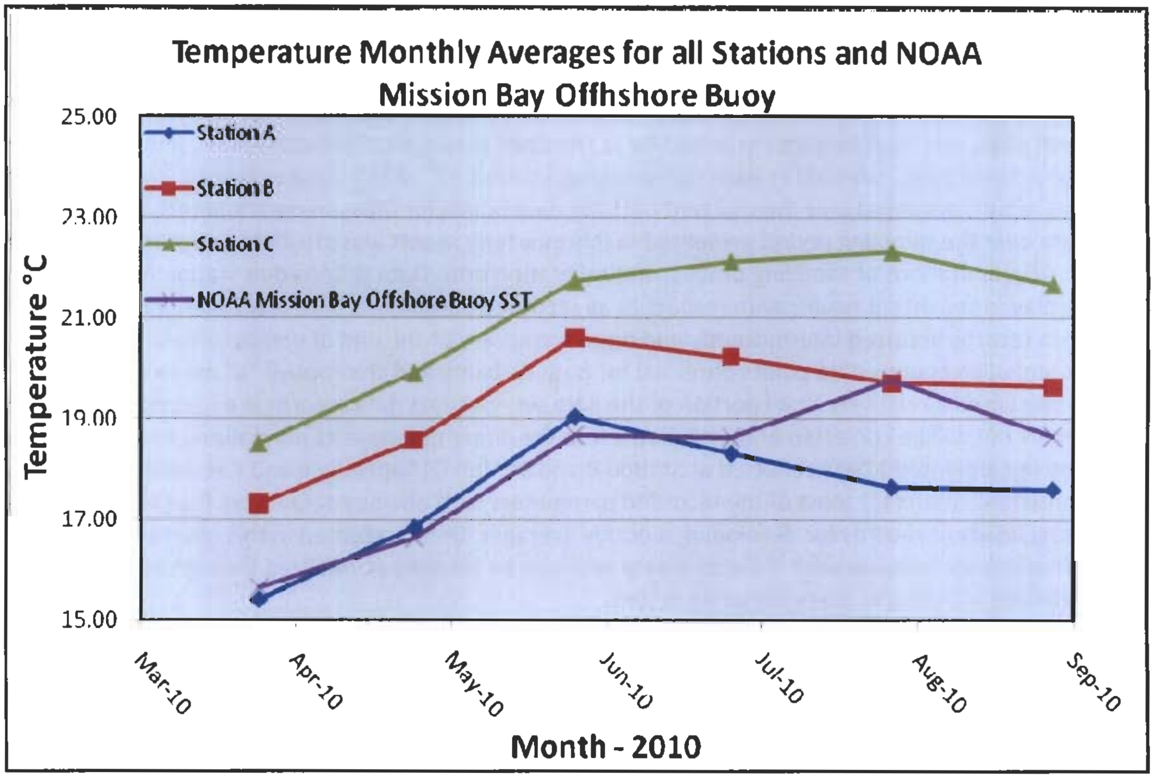

Figure 1. Temperature Monthly Averages for all Stations and the NOAA Mission Bay Offshore Buoy.

Turbidity at each of the three stations was markedly low (< 5 NTU's) for the sampled time period, based on parameters established by the World Health Organization for drinking water (WHO 2010). Elevated data records were recorded infrequently and were determined to be attributed to large ship movements, localized disturbances, and biological fowling. Tidal fluctuations were observed to have noticeable effect in various instances with peak turbidity measurements occurring during the largest tidal changes associated with spring tides and the lowest measurements recorded during peak flood tide times when clean, clear, ocean water dominated the station's location. Changes to turbidity were variable among stations. Station B, within the North Central bay, displayed the most consistent spikes in turbidity. Natural occurring turbidity events attributed to rainfall or large ship movements generally are displayed as sharp elevated values that taper off with successive sampling points (10 minute intervals), eventually settling near the mean of the surrounding data records again. Overall turbidity at Station C was consistently higher than stations A &B during the early portion of the data collection process, displaying the highest monthly averages through July 2010 (Figure 2).

Turbidity measurements collected immediately following the servicing and deployment of sondes during two successive sampling periods, under similar tidal conditions, were averaged hourly to examine spatial comparisons between stations (Figure 3 & 4). Turbidity data examined over the 12 hour time periods presented in Figures 3 and 4 show low variability at Station C and higher variability at Station B and to a lesser extent Station A, compared favorably with trends observed in monthly averages presented in Figure 2. Reduced monthly turbidity averages at Station C, compared to previous months, occurred during a time period with few spring tides or any measurable rainfall and hovered near minimum detection levels for sampling hardware.

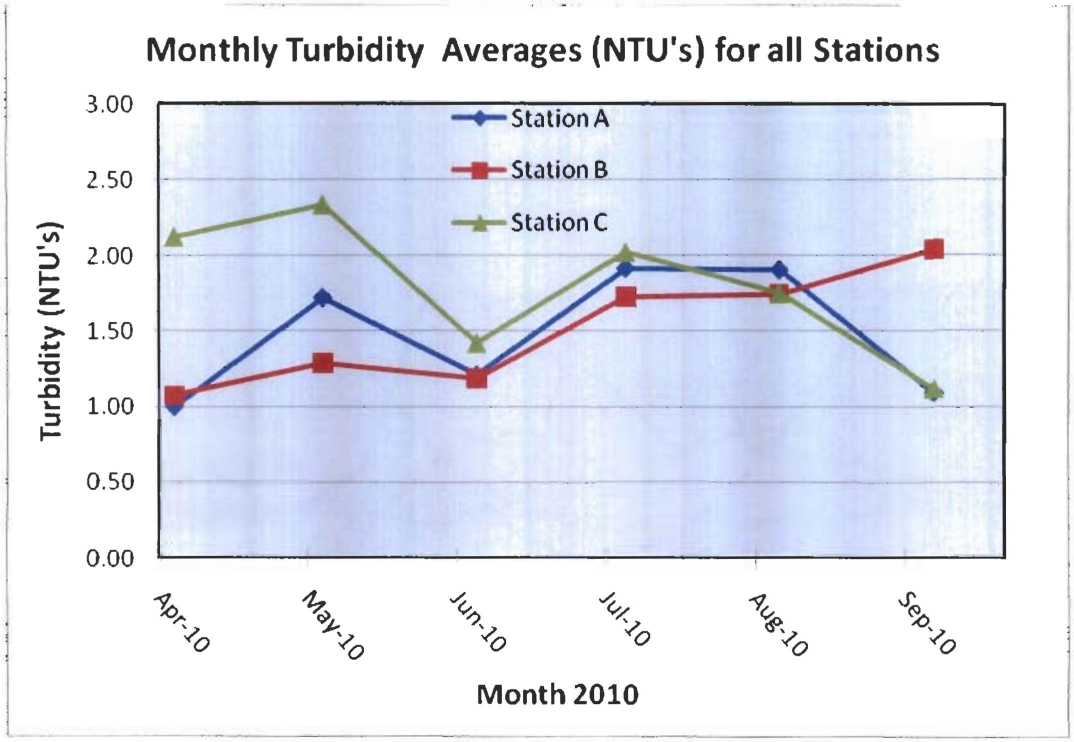

Figure 2. Monthly Turbidity Averages (NTU's) for all Stations April through September 2010.

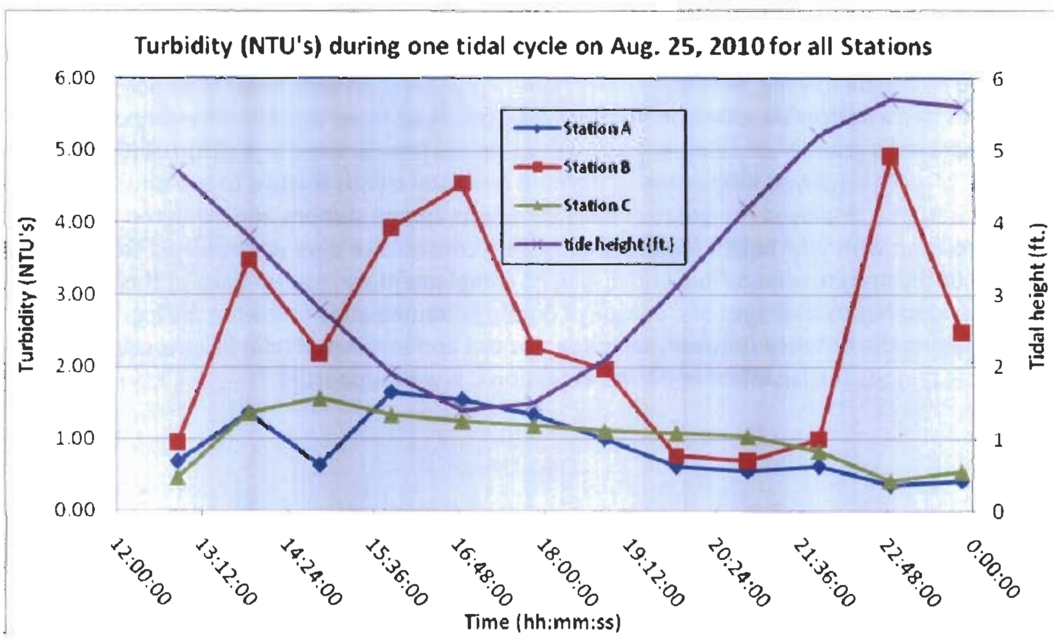

Figure 3. Hourly Turbidity Averages (NTU's) for all Stations on Aug. 25, 2010 during one 12 hour period.

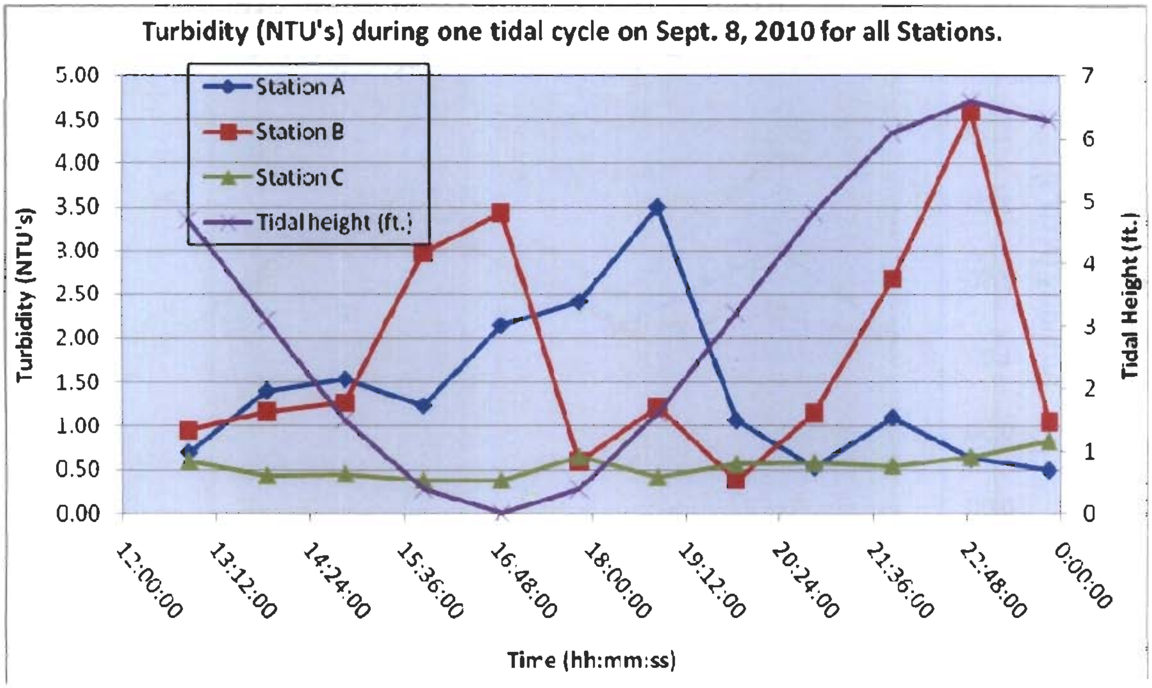

Figure 4. Hourly Turbidity Averages (NTU's) for all Stations on Sept. 8, 2010 during one 12 hour period.

Chlorophyll "a" data at each of the three stations ranged primarily between 0.2 and 10 µg/l for the sampled time period. Elevated data records were recorded infrequently and were determined to be attributed to biological fowling. Seasonal components in conjunction with lower than normal water temperatures had a noticeable effect on monthly averages at all three stations. Monthly chlorophyll averages displayed a gradual decrease in readings during the late summer and early fall (Figure 5). Chlorophyll "a" data displayed interesting spatial and temporal trends relative to the time of day and tidal conditions. Station A displayed the greatest daily variations among stations and exhibited a noticeable inverse correlation with tidal height (Figures 6 & 7). Two consecutive days were plotted to evaluate the consistency of the inverse relationship and displayed complementary results. Each of the three stations reported elevated hourly averages of chlorophyll during or immediately following the low tide (Figures 6 & 7). Considering the distance between sampling stations and associated tidal heights relative to analyzed time periods the lag effect apparent at Station C is well supported.

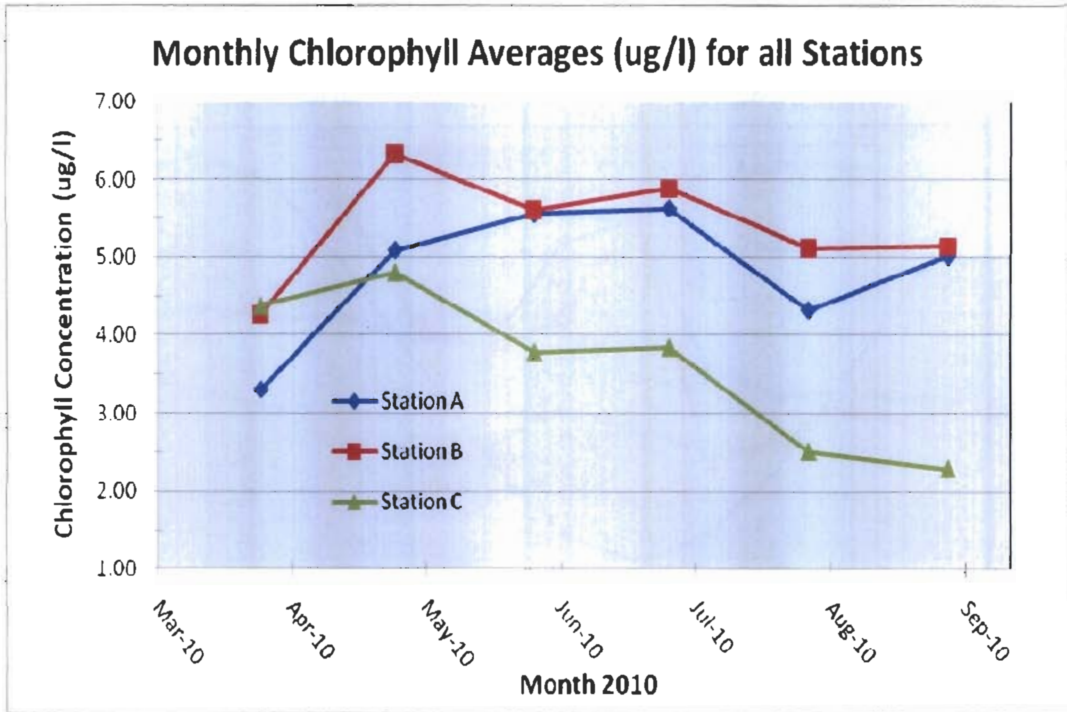

Figure 5. Monthly Chlorophyll Averages (ug/l) for all Stations April through September 2010.

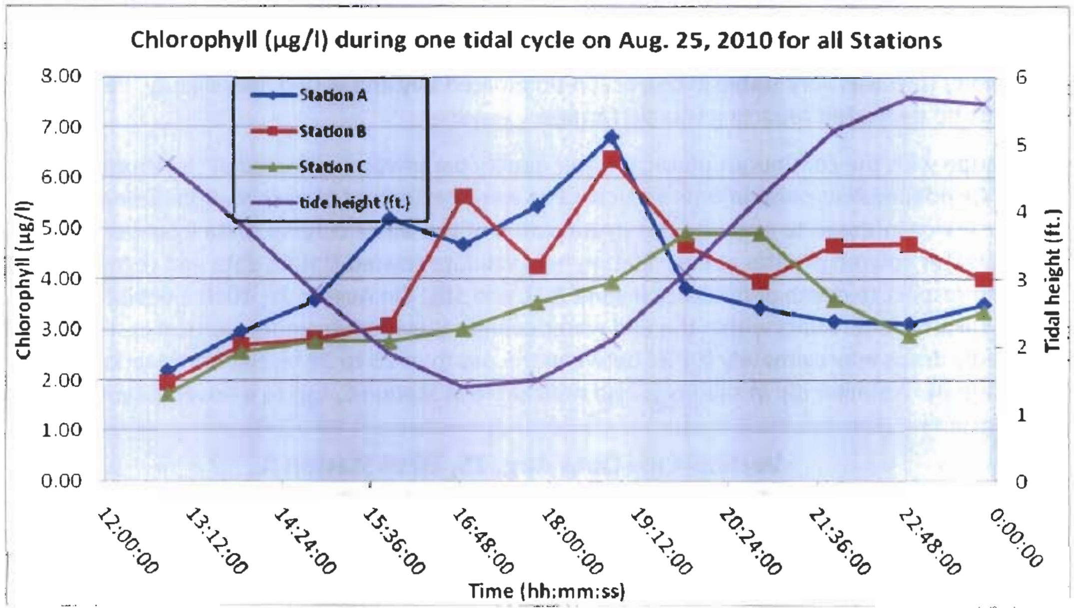

Figure 6. Hourly Chlorophyll Averages (µg/l) for all Stations on Aug. 25, 2010 during one 12 hour period.

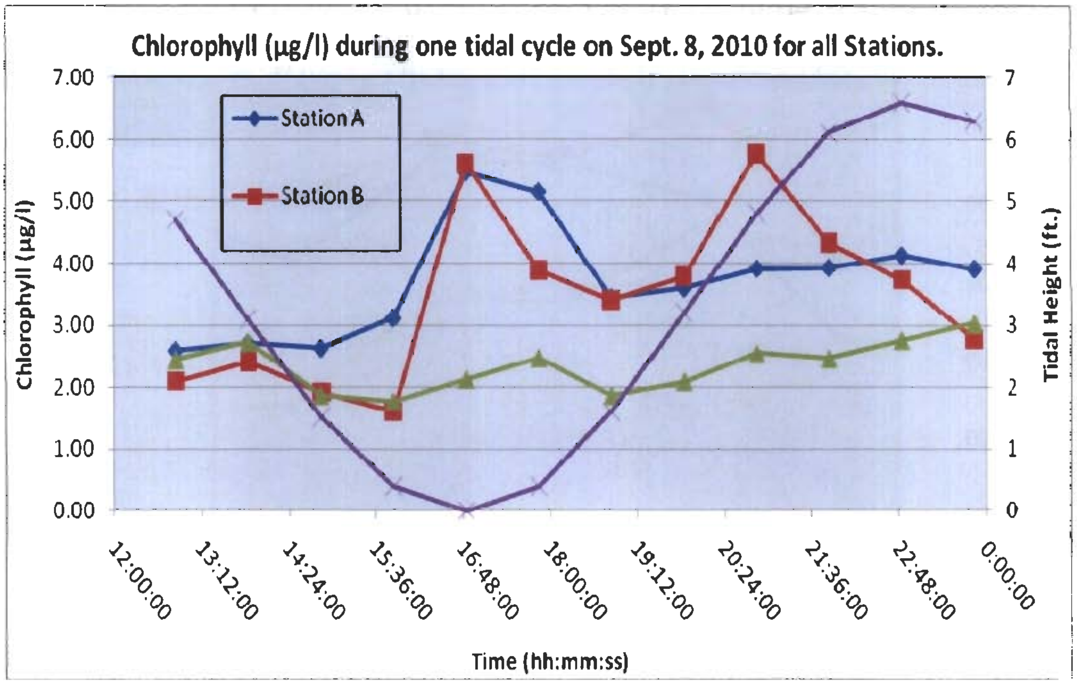

Figure 7. Hourly Chlorophyll Averages (µg/l) for all Stations on Aug. 25, 2010 during one 12 hour period.

Relative depth (approximately 2 meters) of collected data parameters remains unchanged during sampling intervals as sondes are affixed to floating navigational moorings that move vertically with the tide. Alkalinity (pH) was very stable in this ocean-dominated bay and varied only slightly, between 7.8 and 8.2 pH, thus no dedicated reporting was performed.

In conjunction with the continuous physical water quality parameters collected at the three fixed stations (A, B, and C) independent point in time vertical casts were performed at each station during the regular two week service intervals to evaluate the stratification of the water column. Data from vertical casts displaying water column profiles at each station help validate related station data and reveal expected results with respect to depth and salinity (Figure 8, 9, and 10). On August 25, 2010 a deviation from predicted salinity data results within the mid water column is evident from the vertical cast data. Salinity unexpectedly drops approximately 0.1 ‰ between the depth of 20 to 30 feet at both Stations A and B (Figure 8 and 9). A similar dip in salinity is also noticeable at Station C, but to a lesser extent (Figure 10).

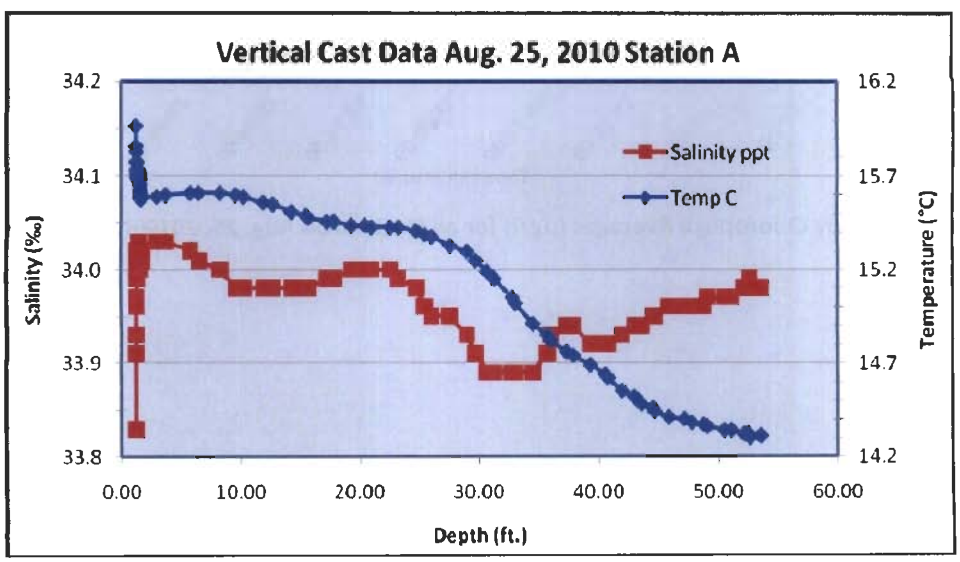

Figure 8. Vertical profile of temperature and salinity at Station A on August 25, 2010.

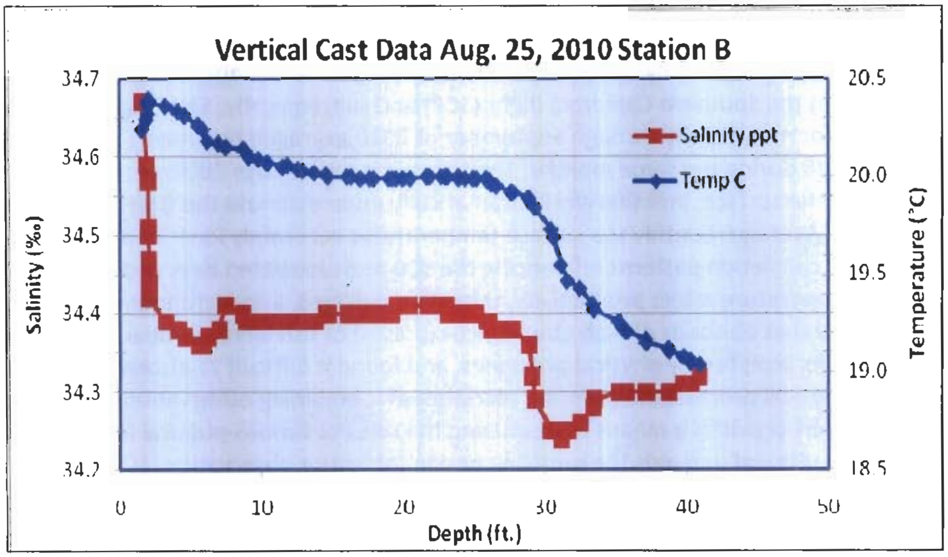

Figure 9. Vertical profile of temperature and salinity at Station B on August 25, 2010.

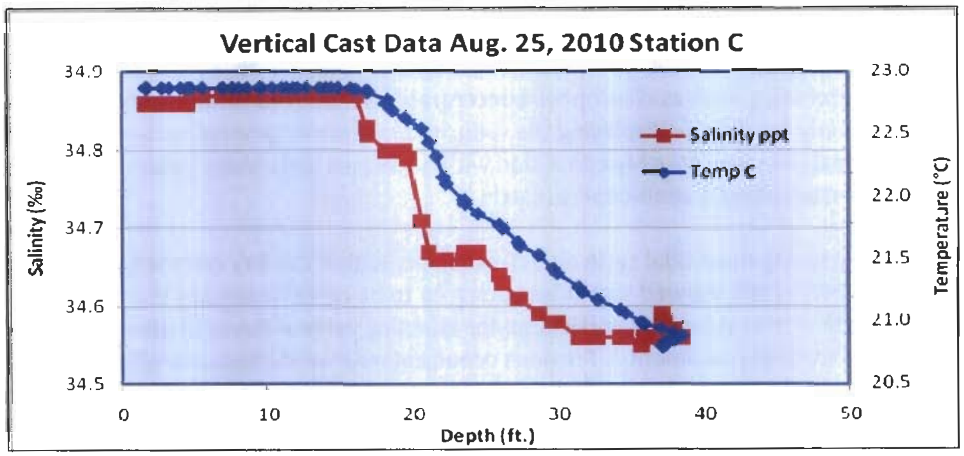

Figure 10. Vertical profile of temperature and salinity at Station C on August 25, 2010.

4 Discussion

San Diego Bay is a shallow, tidally influenced, estuarine bay system dominated by the influx of oceanic water at the Bay's entrance. The properties of the water masses contained within the various ecoregions of the San Diego Bay are relatively homogeneous compared to other bays and consist of primarily seawater with consistent salinity, pH and dissolved oxygen. The importance of Bay-ocean temperature differences in Bay-ocean exchange flows explains differences in water masses within the bay ecoregions as described by Largier (1995) and Chadwick et al (1996). Equipment (data sondes) used to collect physical water quality parameters is affected by various biological and physical factors including fouling from debris, settlement of various invertebrates and algae, waves, tidal action, and vessel movements. Outside of freshwater input, typically constrained to winter months, mixing and stratification associated with the tidal exchange of oceanic waters and winds are the primary drivers affecting the spatial and temporal variability of physical water quality properties in the Bay. The south bay is far more isolated in terms of water circulation during summer, and typically displays time lags for observations made nearer to the bay entrance. During an average tidal cycle, the volume of water leaving the Bay is about 13%, and residence times in south Bay may be months (Chadwick 1997).

During the second quarter (July – September) of this study unseasonably cold sea surface temperatures (SST) dominated the Southern California Bight (SCB) and subsequently, San Diego Bay. Average monthly temperatures for months July through September of 2010 averaged between 1 and 2 °C less than data collected in 2008 during the same months. Temperatures recorded in 2008 were obtained from the Bay bottom versus the surface; and therefore, dramatically underestimate the true difference in sea surface temperatures. Average monthly sea surface temperatures accurately identify the dominant oceanographic circulation patterns influencing the SCB and associated bays and estuaries. Major shifts in sea surface temperature affect productivity, migration patterns, and recruitment. For instance Brown et al (2004) reported that episodes of high abundances (pulses) of fish larvae in tidal inlets are temporal and spatially variable, sculpted by physical processes, and found it difficult to discern large-scale recruitment events from physical processes influencing recruitment. Combining observations with numerical models of larval transport provides a means of examining the roles of various physical and biological processes influencing recruitment and aids the sampling design for future observations (Colby 1988; Werner et al. 1997).

While temperature is the most notable parameter for describing the dominant water masses within the SCB , physical properties like salinity and turbidity contribute greatly to indentifying processes more directly affecting the Bay and its physical and biological condition at a point in time. Salinity changes are difficult to evaluate outside of the rainy season but lower water temperatures reduce evaporation, which in turn affects salinity concentrations, especially within the south bay. Similarly, turbidity values fluctuate rather dramatically at times but monthly averages smooth that variability and afford comparisons to related characteristics, such as chlorophyll concentrations. Reduced turbidity at Station C during the late summer and early fall may be displaying the reduced presence of phytoplankton. While average monthly chlorophyll measurements roughly correlated with decreases in turbidity values, a direct relationship cannot be inferred without additional research.

The role of the spring-neap tidal cycle on SST variability within the Bay reported in the initial study conducted in 2007-2008 showed that tides appeared to be more important than winds as a source of energy for vertical mixing (and by implication for affecting vertical fluxes of plant nutrients into the euphotic zone from Bay sediments). Previous ocean chlorophyll studies quantified the seasonal to interannual variability of near-surface chlorophyll concentrations, showing that a spring biomass increase (bloom) is typically followed by a summer decrease and then a broad fall peak (Thomas et al. 2003). Thomas et al. (2003) also reported that low chlorophyll concentrations recorded during the winter and early spring of 1997–1998 may be related in some way to the anomalously cold SSTs that occurred.

Previous studies investigating water residence times in various portions of the Bay reported drastic changes moving away from the Bay entrance and that the longest residence water times are observed in the summer, apparently related to the density stratification of the Bay during that time (Chadwick 1997). Current data series recorded from the monitoring stations during this investigation highlight the tidal component affect and its influence on other physical water quality parameters. Differences in surface water turbidity can be manifested by a variety of conditions and activities both natural and anthropogenic. Identifying and partitioning the various contributors to surface water turbidity including implications attributed to seasonal increases in primary production (phytoplankton growth), rainfall, and storm water runoff will become increasingly applicable moving into the winter season.

During the subsequent phases of this project bimonthly photosynthetic active radiation (PAR) readings will be collected in conjunction with currently collected data parameters to analyze how surface turbidity limits light at depth and access what portions of the light spectrum are being absorbed. Working with Dr. Ken Richter, of the Space and Naval Warfare Systems Command (SPAWAR), data will be examined to identify relationships between chlorophyll "a" and turbidity on both a temporal and spatial scale. In conjunction with exploring the relationships between turbidity, chlorophyll "a", and PAR measurements additional data collected from SIO and NOAA will be integrated to evaluate regional contributions and associations.

All collected data will continue to be entered into a master database, updated and submitted quarterly with reports. In the next quarterly report a defined data management protocol will be presented to document the assimilation of erroneous data records into the overall database and discuss incorporation into monthly averages.

5 Conclusion

The continued data collection phase of this project progressed without incident and data sondes are in place and collecting data consistent with the proposed methods. Acquired data series continue to reveal and support important temporal and spatial relationships related to input from offshore waters, tidal flux, and localized hydrology within the Bay. Biological fouling of probes has remained in check and has been significantly reduced compared to previous efforts. A continued investigation of the relationship between turbidity and chlorophyll "a" is still being examined and will continue to integrate literature review, subject area input, and investigative analysis in conjunction with SPAWAR. Further analysis of season trends related to rainfall will be examined as conditions permit, and the integration of other complementary data series will be analyzed and referenced in future reports.

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