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
January 2011

A Project for:

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

Prepared by:

TIERRA DATA INCORPORATED

Tierra Data Inc.
10110 West Lilac Road
Escondido, CA 92026
P (760) 749-2247 F (760) 751-9707

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1.0 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, as well as determining 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 providing 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]).

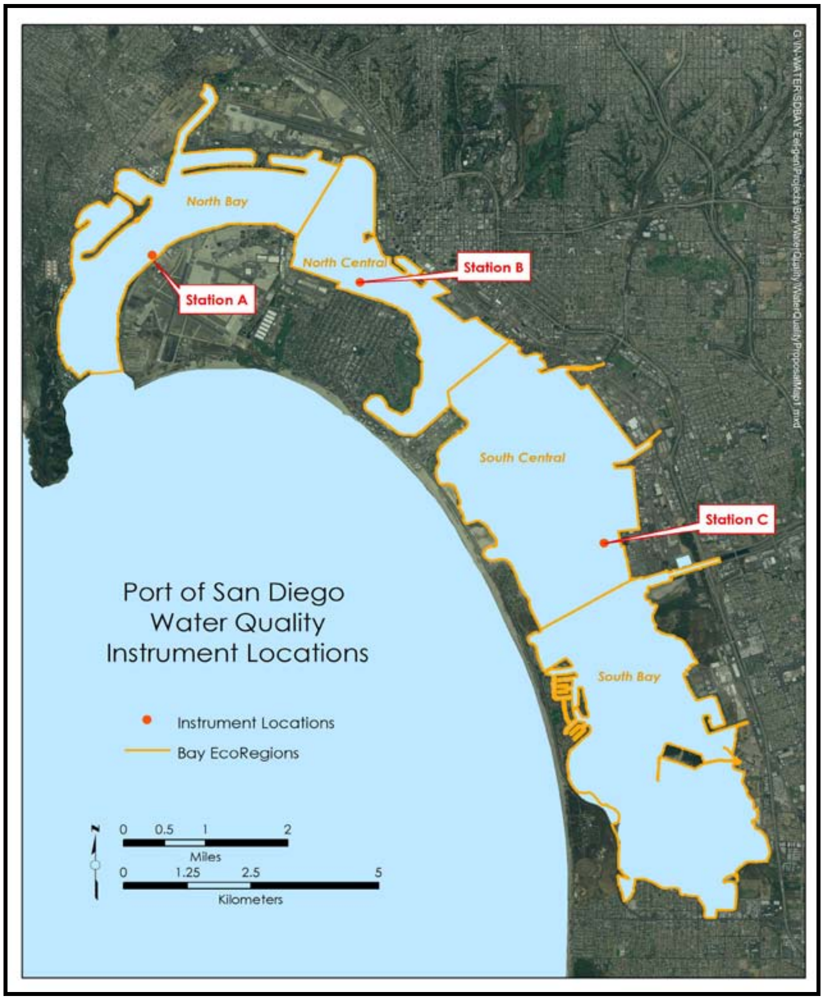
The biological productivity (health) of the Bay depends on adequate circulation and exchange of Bay and ocean waters which supports primary production generated by phytoplankton, submerged aquatic vegetation (eelgrass), and coastal marsh systems. The influence of temperature on chlorophyll “a” concentration 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 they can be 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 20, 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 steel 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.

2.0 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 ecoregions, 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 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 successive 14 day deployment periods 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, representative navigational aids (buoys) were identified for sonde placement. Unattended sondes were deployed at USCG 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 sondes batteries, probe wipers, and antifouling coatings are replaced.

Presently two biologists visit each of the three station locations bimonthly using a 20-foot (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 approximately one foot-per-second until it reaches the bay 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 utilized to examine physical water quality parameters throughout the entire water column. The vertical cast sonde also serves as a reference for data collected by unattended sondes.

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 is downloaded 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.

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

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.

3.0 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 from April 20, 2010 – December 15, 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 were attributed to primarily biological fouling, limitations of sampling probes, and calibration drift and were highlighted in red.

Significant data gaps resulting from the removal of sondes at all three stations occurred from November 2 through November 16 and again from November 29 through December 7. Sondes were removed to insure that no damage or loss of the units occurred during the USCG's servicing of the navigational buoys where data sondes were mounted. 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 in Appendix are flagged in red and normalized prior to calculations of monthly averages. 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 identical parameters among stations 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 relation to the stations proximity to the ocean and diurnally due to tidal effects. Diurnal variation was most prominent at Station A near the mouth of the Bay. The spatial variation in temperature data with regards to individual stations was most pronounced during the summer months when thermal warming has a greater effect on surface water layers. Monthly temperature averages displayed expected results based on the location of individual stations and their proximity to the open ocean throughout the monitoring period. Observations collected during the most recent quarter suggest the water mass within the bay is more homogenous and well mixed during the winter season (Figure 1). 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). Lower temperatures recorded within the bay versus those collected by the NOAA Mission Bay Offshore Buoy are likely due to the fact that the NOAA buoy records SST and the bay temperature data are obtained at -6 to -7 ft. MLLW depth. Temperatures followed expected seasonal trends, well documented for the Southern California Bight (SCB), with the highest temperatures occurring in the summer and early fall and shifting noticeably lower during the winter and early spring (Figure 1).

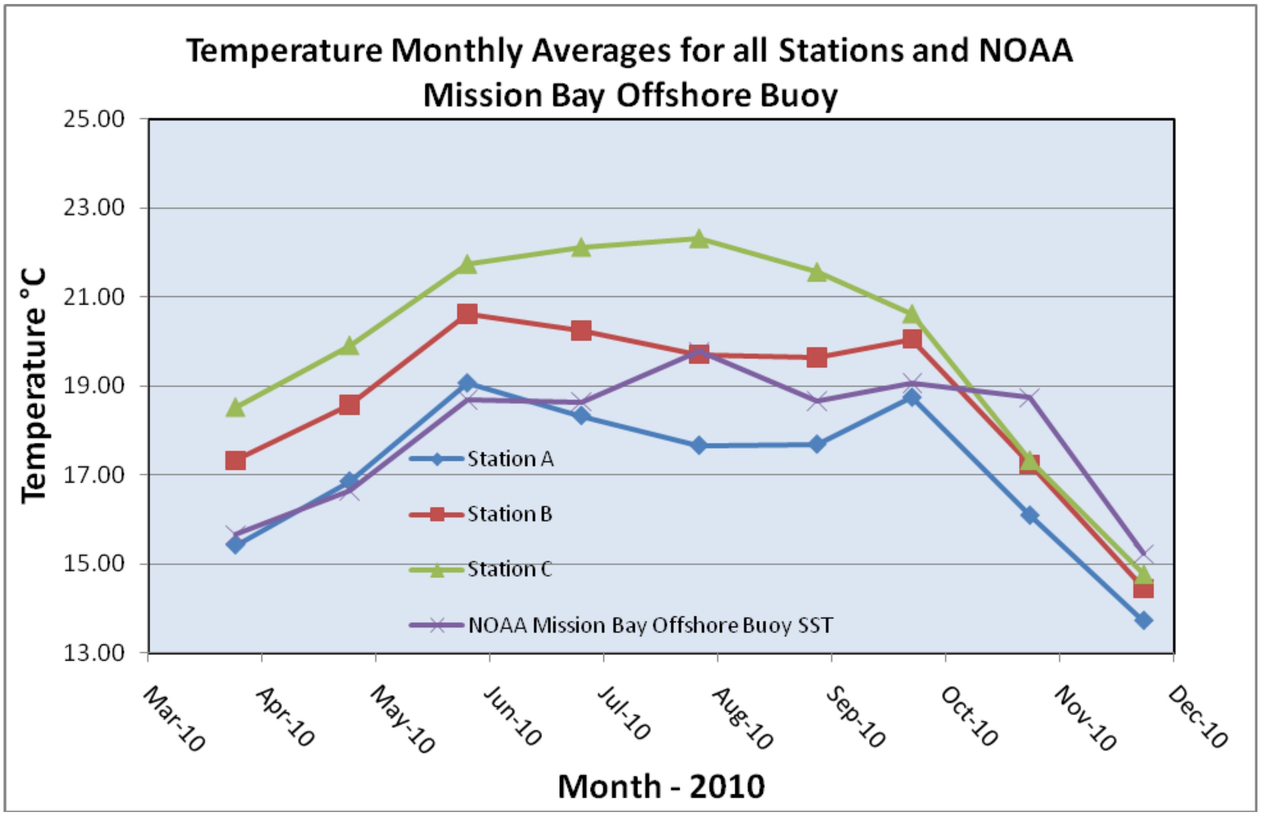


Figure 1. Temperature Monthly Averages for all Stations and the NOAA Mission Bay Offshore Buoy.

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.

Average monthly turbidity (NTU's) was relatively low (< 3 NTU's) at each station over the entire sampled time period (Figure 2), based on parameters established by the World Health Organization for drinking water (WHO 2010). Elevated turbidity data points were recorded intermittently and were determined to be attributed to large ship movements, localized disturbances, and biological fowling. The magnitude of tidal exchange (change between high and low tides) displayed a relational and consistent effect on turbidity measurements at all three stations with peak turbidity measurements occurring in conjunction with the greatest tidal exchanges typically associated with spring tides (Figure 3). The least variable and lowest turbidity measurements were most frequently recorded during peak flood tide times when clean, clear, ocean water dominated individual station locations.

Elevated turbidity measurements attributed to large ship movements or localized disturbances generally are displayed as sharp elevated values that taper off with successive sampling points (ten minute intervals), eventually settling near the mean of the surrounding data records again. Increased turbidity levels attributed to rainfall events persist over longer time periods depending on the length of the rainfall event but individual rainfall events lasting less than a day appear to increase turbidity levels two fold for approximately one to three days depending on the amount rainfall experienced in adjacent bay side communities and watersheds. Overall turbidity at Station C was consistently higher than stations A and 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 and Figure 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.

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 seasonal decrease in readings beginning in the early fall through the end of the data collection period (December 15) (Figure 5).

Chlorophyll "a" data displayed interesting spatial and temporal trends relative to the time of day and tidal conditions. Stations displayed diurnal variations apparently inversely correlated with tidal height (Figure 6 and Figure 7). Two days were plotted to evaluate the consistency of the inverse relationship and displayed complementary results. Each of the three stations exhibited elevated hourly averages of chlorophyll during or immediately following the low tide in close agreement with findings reported in the previous monthly report (Figure 6 and Figure 7). Considering the distance between sampling stations and associated tidal heights relative to analyzed time periods the lag effect is apparent between stations but the relative trends among stations remained somewhat consistent over the entire 24-hour tidal cycle. Data collected on October 19, 2010 occurred during the first major rainfall event of the year with 1.43 inches of rain recorded during a 24-hour period

The relative depth (approximately two 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. The analysis of the vertical cast data has been previously focused on temperature and salinity to explain the temporal and spatial patterns in stratification. No specific analysis of the vertical cast data are presented in this report but will be further presented in future reports.

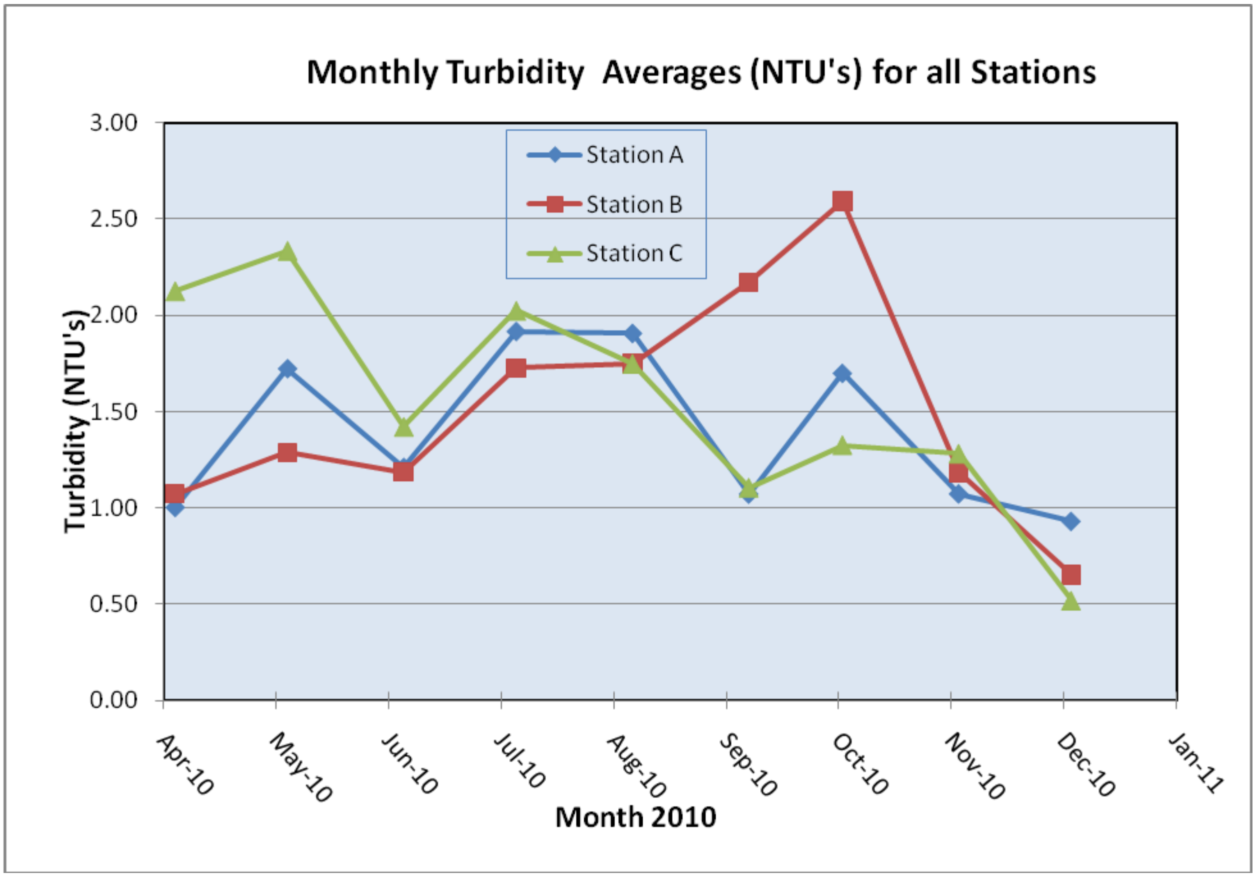


Figure 2. Monthly Turbidity Averages (NTU's) for all Stations April through September 2010.

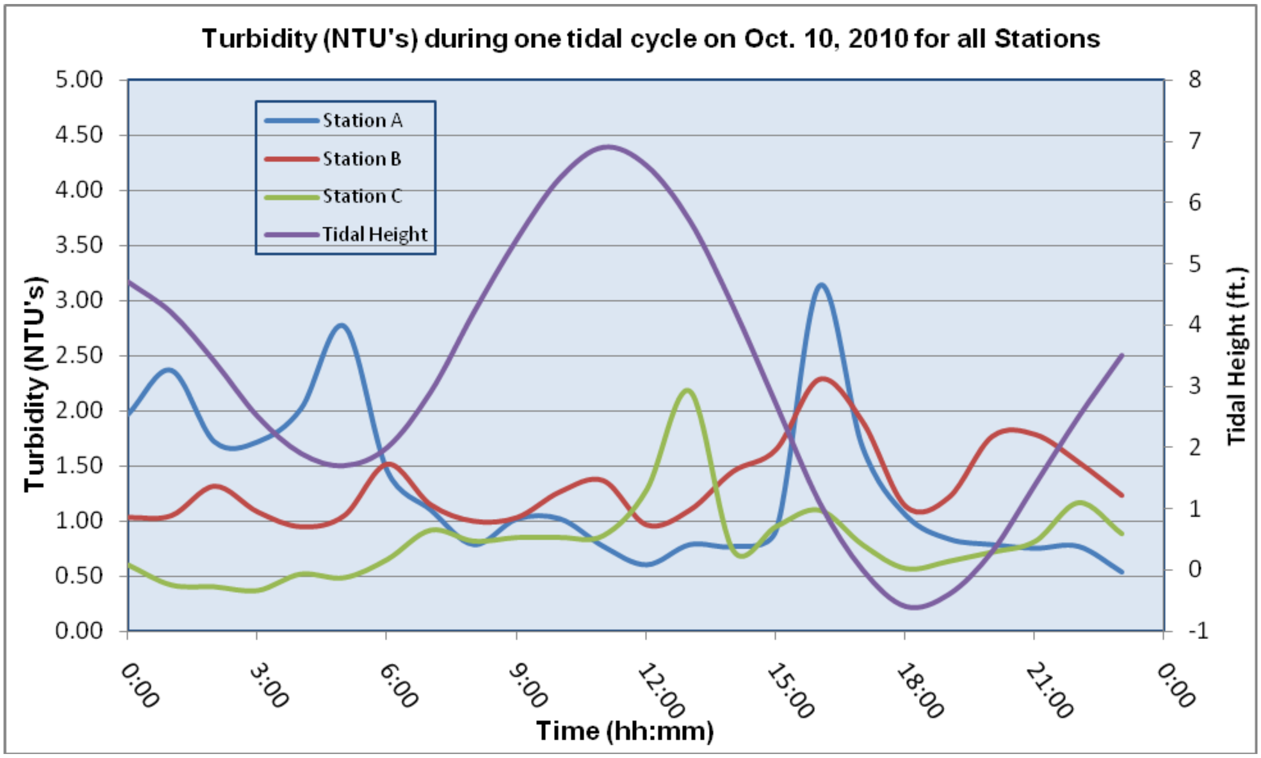


Figure 3. Hourly Turbidity Averages (NTU's) for all Stations on Oct 10, 2010 during a 24 hour period.

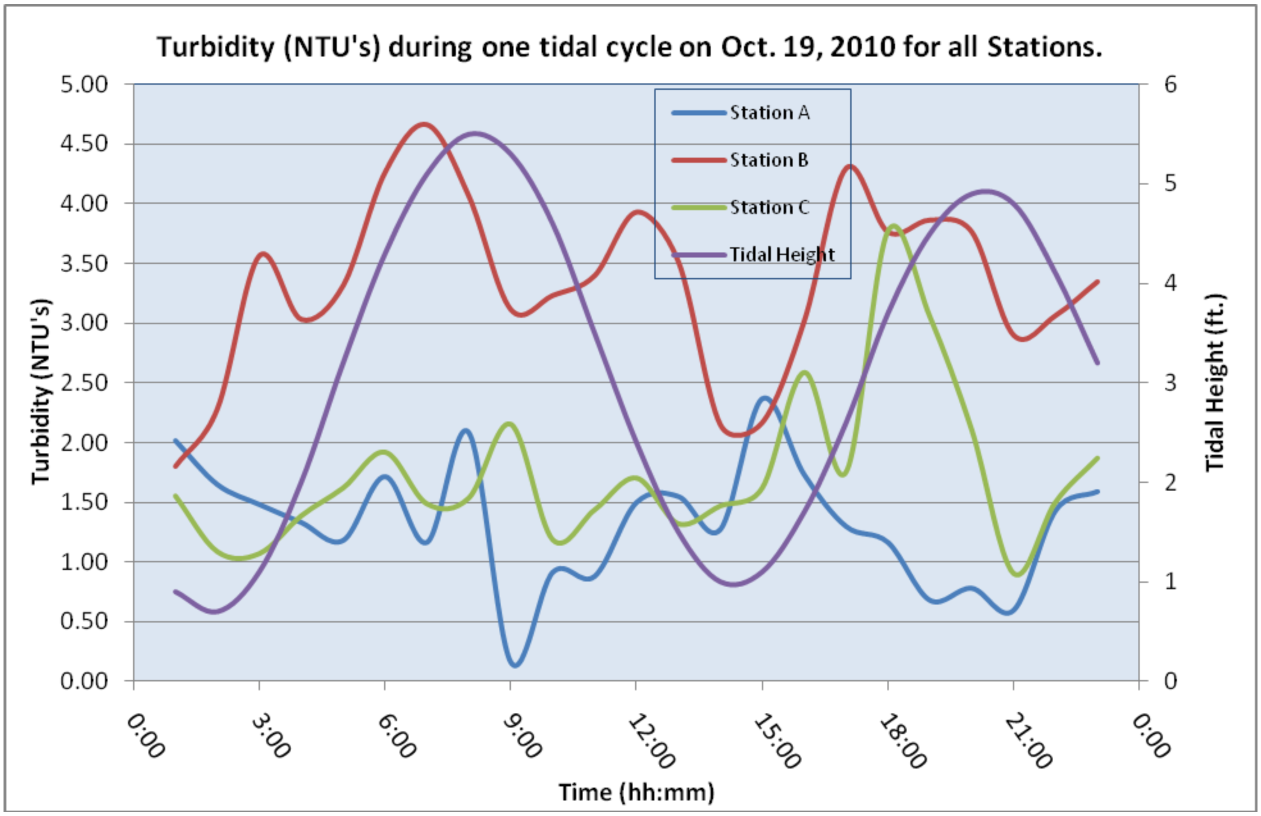


Figure 4. Hourly Turbidity Averages (NTU's) for all Stations on Oct. 19, 2010 during a 24 hour period.

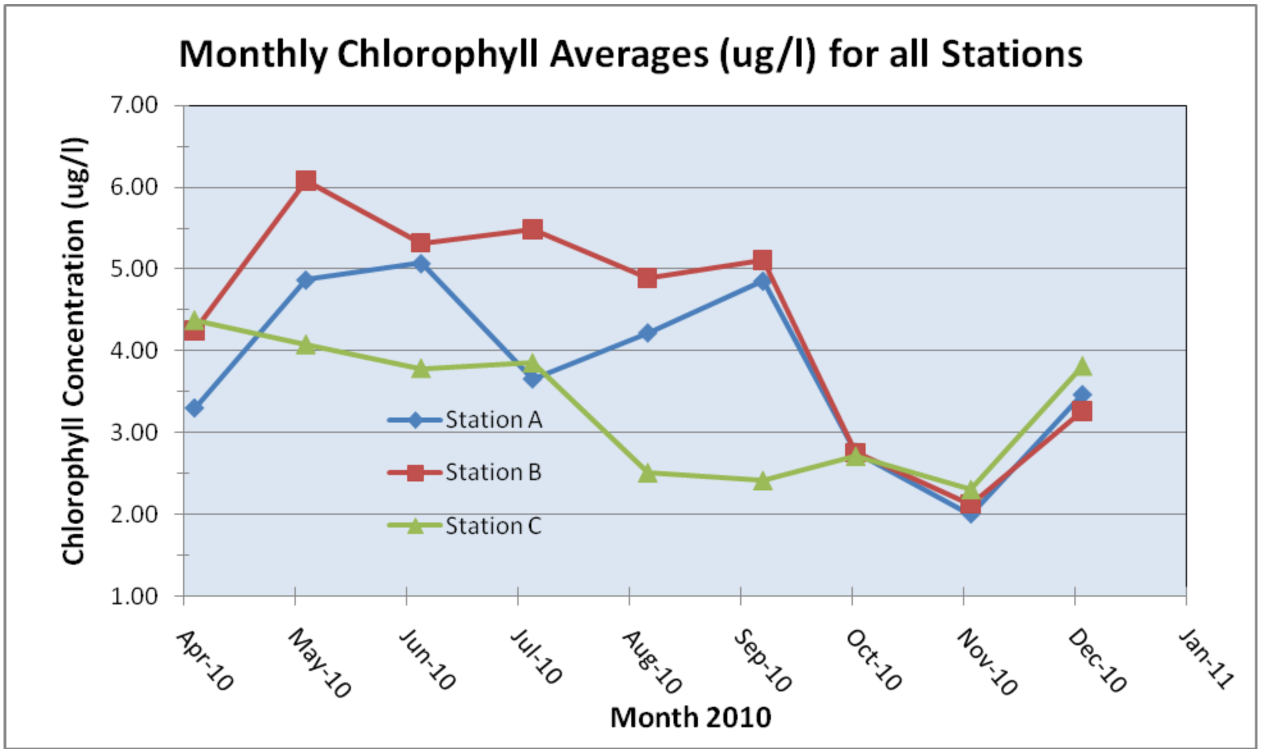


Figure 5. Monthly Chlorophyll Averages (ug/l) for all Stations April through December 2010.

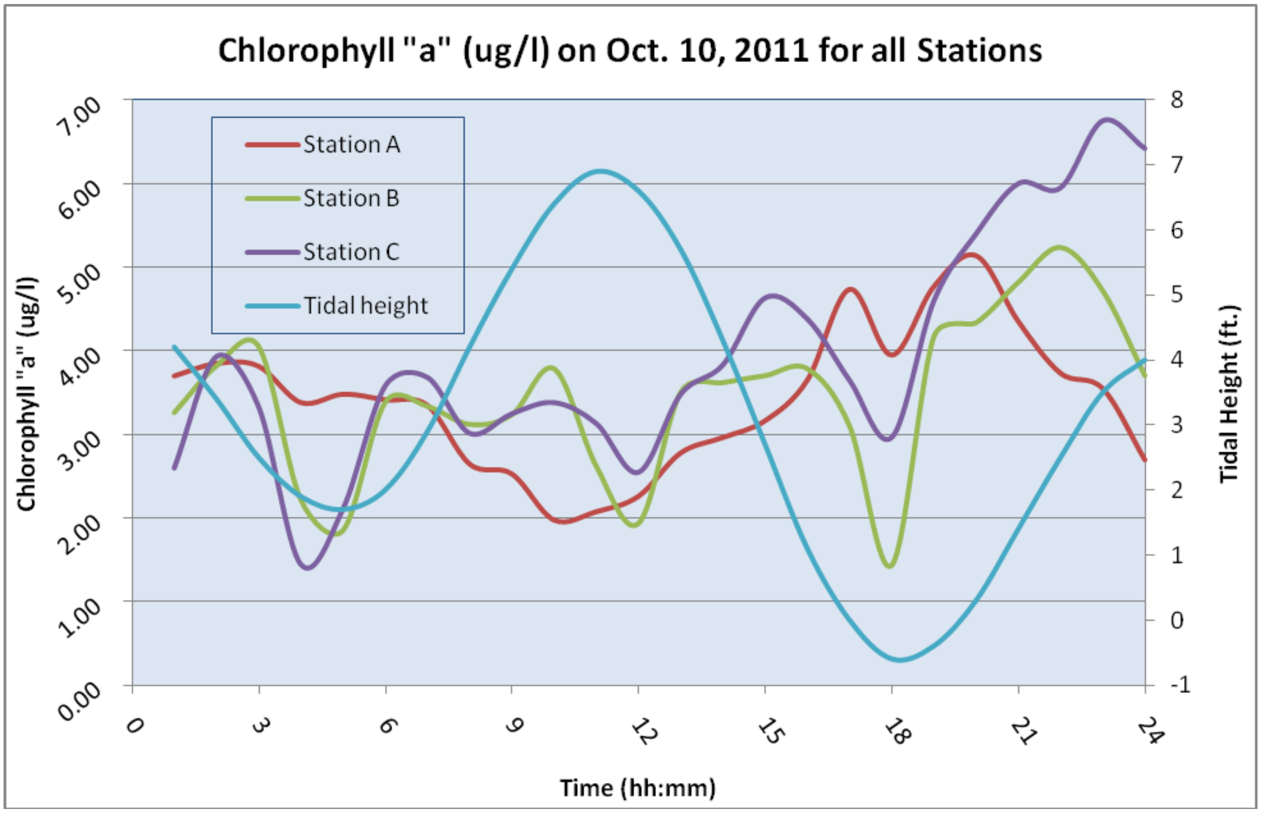


Figure 6. Hourly Chlorophyll Averages (µg/l) for all Stations on Oct. 10, 2010 during a 24 hour period.

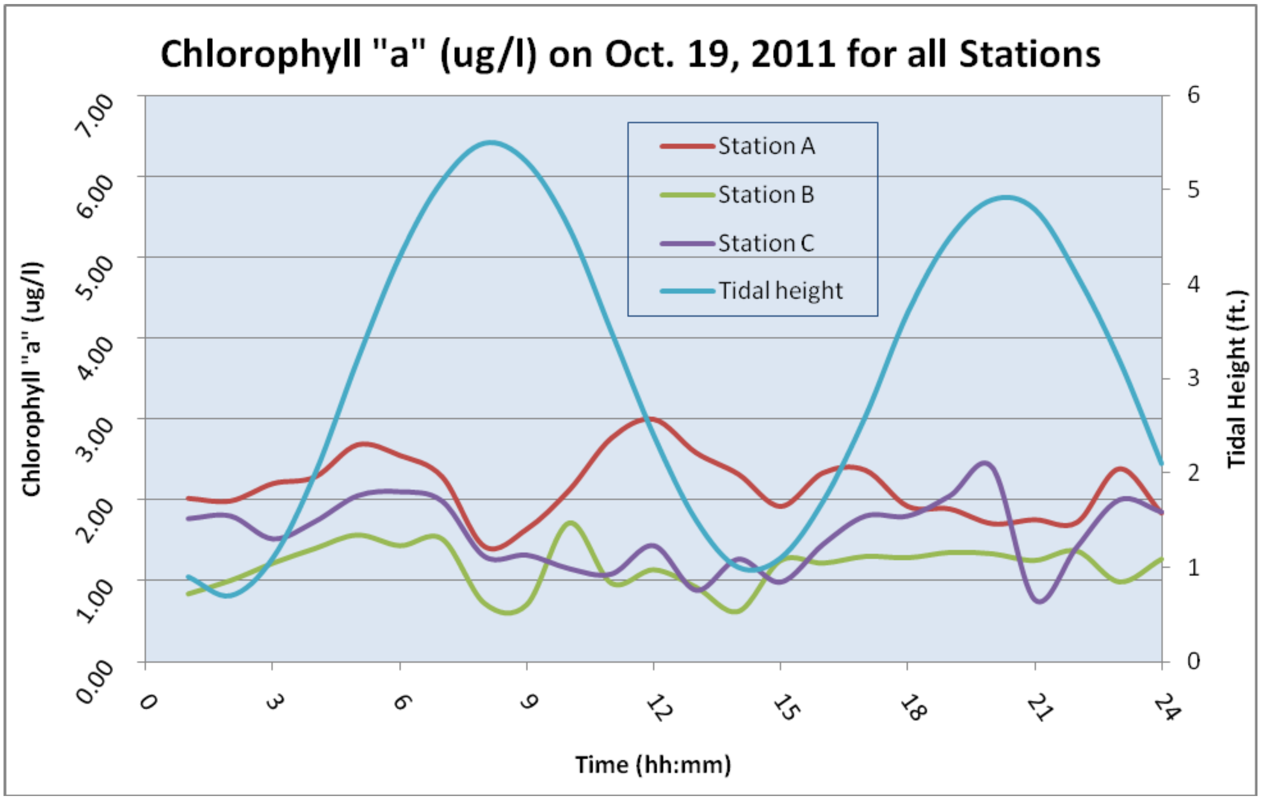


Figure 7. Hourly Chlorophyll Averages (µg/l) for all Stations on Oct. 19, 2010 during a 24 hour period.

Monthly rainfall data shows noticeable changes in precipitation during the late fall and early winter (Figure 8). Associated increases in monthly turbidity averages were apparent but a complete examination of the relationship was not performed due to the incomplete nature of the December data. Seasonal patterns with respect to rainfall and surface water runoff will be examined more in-depth during the following quarterly report.

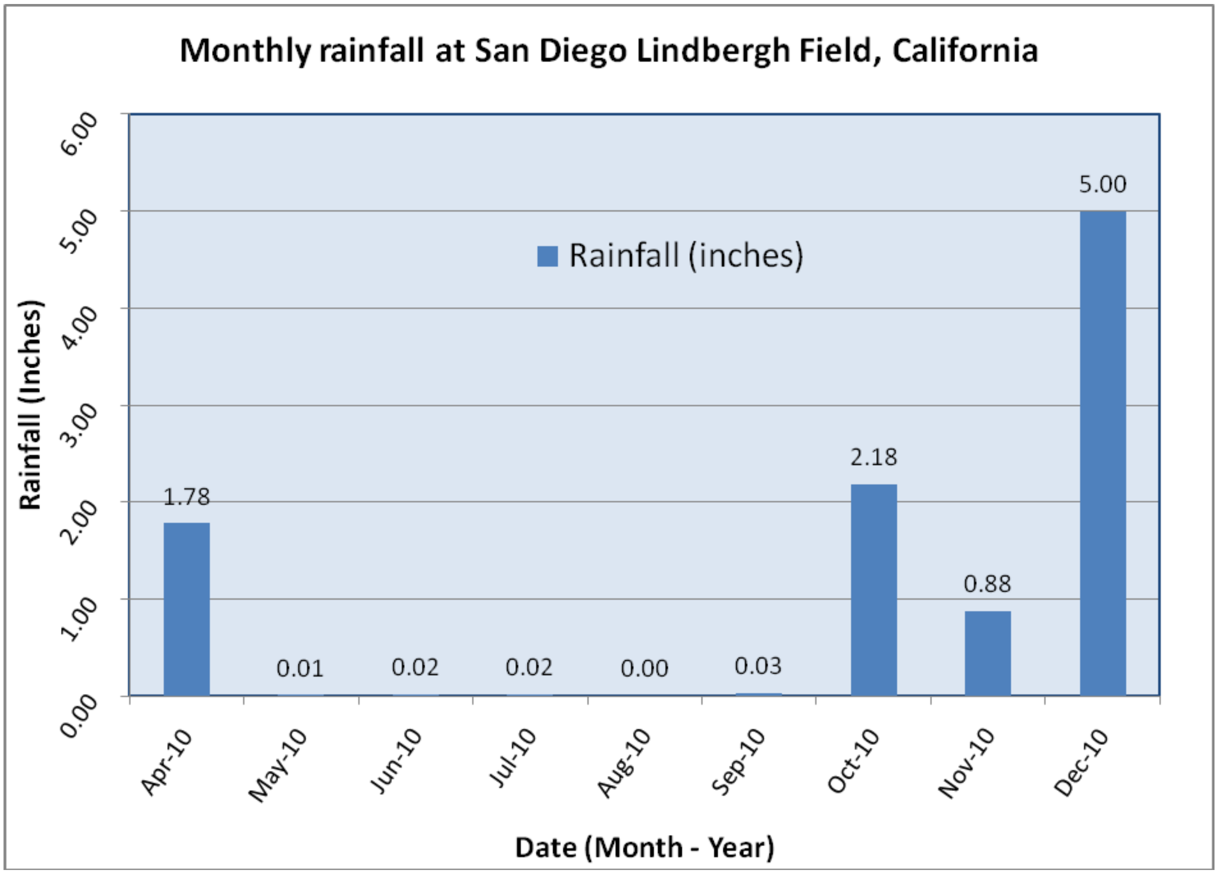


Figure 8. Monthly rainfall totals for San Diego Lindbergh Field (Source: NOAA National Weather Service).

4.0 Discussion

The properties of the water masses contained within the various ecoregions of the San Diego Bay are relatively homogeneous during the late fall and early winter as evident by reported monthly averages of temperature, turbidity, and chlorophyll data (see Results). Considering San Diego Bay is a shallow, tidally influenced, estuarine bay system dominated by the influx of oceanic water at the Bay's entrance Bay-ocean exchange flow is the primary factor influencing in water masses within the bay ecoregions as described by Largier (1995) and Chadwick *et al*. (1996). The onset of seasonal precipitation is the second greatest factor affecting physical water properties within the Bay and appears most influential with regards to turbidity. 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 winter months the water masses at all three stations were more closely related than during any other time of the year. Specifically temperature and chlorophyll tracked closely over the last three months.

During the third quarter (October – December) of this study cold SSTs continued to dominate the Southern California Bight (SCB) and subsequently, San Diego Bay. Reduced differences in average monthly sea surface temperatures display the reduced stratification of the bay in the absence of solar warming and highlight the contribution of tidal exchange in mixing nearshore water throughout the Bay. Major shifts in sea surface temperature affect productivity, migration patterns, and recruitment. Roughly half of the biosphere's net primary production (NPP) comes from photosynthesis by oceanic phytoplankton forming a vital link in the cycling of carbon between living and inorganic stocks (Behrenfeld *et al*. 2001). San Diego Bay relies on primary production from phytoplankton as well as carbon in the form of CO_2 is fixed into organic material by these ubiquitous, microscopic plants and organic carbon is transferred into bay ecosystems by sinking and grazing. The distribution of phytoplankton biomass and NPP is defined by the availability of light and nutrients (nitrogen, phosphate, iron). These growth-limiting factors are in turn regulated by physical processes of circulation, mixed-layer dynamics, upwelling, and the solar cycle. This link between the physical environment and biological functions occurs through changes in temperature and stratification, which influence the availability of nutrients for phytoplankton growth. The observed reduction in chlorophyll "a" during the winter months provides insight on how seasonal or yearly water mass changes can alter productivity.

Turbidity values fluctuate rather dramatically at times but monthly averages during this reporting period displayed low variability with the exception of influences from significant rainfall events (October 2010) smooth that variability and afford comparisons to related characteristics, such as chlorophyll concentrations. Further analysis of collected data intends to quantify the seasonal 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 similar to those reported in nearshore ocean water by 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.

5.0 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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