Characterizing the Spatial and Temporal Variation in Turbidity and Physical Water Quality Characteristics in San Diego Bay:

A Study to Determine a Cost-Efficient Strategy for Long-term Monitoring

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A Project for:

Environmental Projects to Benefit San Diego Bay
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1.0 Introduction

This project was designed and funded to establish a cost-effective strategy for characterizing the spatial and temporal variation of turbidity and physical water quality characteristics within San Diego Bay by examining the current equipment and methods previously utilized during the 2001 Port of San Diego water quality pilot study, and to determine whether the methods could be amended to obtain intended physical water quality measurements continuously and consistently. Physical water quality measurements provide the most fundamental and interpretable indicators of water quality and can be utilized to evaluate the biological productivity of the Bay. Enclosed bays with perennial tidal exchange like San Diego Bay are constantly changing and have complex patterns of water quality variability because they are mixing zones between the ocean and terrestrial sources of fresh water, sediments, nutrients, toxic contaminants, and other materials, carried by tides, stream flow or storm water runoff. Source water flow changes from season to season and year to year, so the water quality of San Diego Bay also changes similarly. Physical properties such as water transparency (turbidity), temperature, and density stratification change based on natural processes and human impacts. Understanding the temporal and spatial variability of these physical properties is crucial to the interpretation of chemical and biological elements used to measure water quality within coastal water bodies, and identify natural versus human induced contributions.

Federal and state laws have been enacted that establish the requirements for the control of water quality through adequate planning, implementation, management, and enforcement. The principal federal and state laws pertaining to the regulation of water quality are known respectively as, the 1972 Federal Water Pollution Control Act (also known as the Clean Water Act) and Division 7 of the 1969 California Water Code (also known as the Porter-Cologne Water Quality Control Act). The fundamental purpose of both laws is to protect the beneficial uses of water (CRWQB 1994). The objective of the Clean Water Act is to "*restore and maintain the chemical, physical and biological integrity of the Nation's waters*" to make all surface waters "*fishable*" and "*swimmable.*" In order to adequately evaluate water quality, all source and nonpoint source contributing factors must be considered, and continuous, long-term water quality data sets maintained to provide a valuable baseline for separating human versus natural background patterns and conditions in San Diego Bay.

San Diego Bay is comprised of several ecological regions (ecoregions) in which a gradient of dominant physical and ecological parameters occurs (Figure 1). Physical water characteristics, most notably turbidity, salinity, and temperature, display spatial trends with respect to these ecoregions and their associated water masses. Temperature and density gradients, both with depth and along a longitudinal cross-section of the Bay, drive tidal exchange of Bay and ocean water beginning in spring and continuing into fall (Largier 1997). Diurnal and seasonal spatial and temporal changes in temperature, and to a lesser extent salinity, are important factors when interpreting trends of water quality characteristics such as dissolved oxygen (DO) and turbidity. Understanding patterns in DO and turbidity are further complicated by tidal exchange and the variation of complex hydrological interactions between ocean water and freshwater inputs. Watershed features, such as geology, human development (agricultural uses or urban development), topography, vegetation, tidal exchange, wave action, and precipitation also influence water turbidity.

Turbidity is a measure of water clarity or murkiness. It is an optical property that expresses the degree to which light is scattered and absorbed by molecules and particles. Turbidity results from colored dissolved organic matter and suspended particulate matter in the water column. Suspended particulate matter may include clay and silt (*e.g.* suspended sediment), and detritus and organisms (algae and zooplankton).

The most obvious effect of increased turbidity is the reduction in light available for photosynthesis due to a decrease in light availability under water. Phytoplankton and free-floating macroalgae are better competitors for light than benthic plants including seagrasses (Duarte 1995), and will tend to out-compete them as light becomes limiting during progressive eutrophication. Turbidity also controls the phytoplankton biomass that can potentially develop (Cloern 1987, Monbet 1992) potentially affecting multiple trophic levels and Bay wide productivity.

The importance of collecting continuous physical water quality measurements within various portions of San Diego Bay is that it provides temporal and spatial baseline data that can be utilized to separate regional trends from naturally occurring events (rainfall, tidal exchange, and algal blooms), as well as unexpected episodes (floods, El Nino, etc.), or human induced impacts (sewage spills, dredging, etc.). The health of San Diego Bay is based in large part on its biological productivity. By measuring physical water quality parameters, correlations with biological productivity can be developed that will assist in evaluating cause and effect relationships and adaptively manage regional concerns.

Figure 1. Ecoregions and instrument (sonde) locations within San Diego Bay.

2.0 Methods

The initial proposal to design and implement this study recommended the purchase of six new multi-parameter water quality instruments (data sondes) equipped with internal battery systems, expanded memory, and dual optical probes to investigate physical water quality characteristics and their relationship to phytoplankton productivity (chlorophyll *a*). Subsequent revisions and budget limitations amended this project to utilize existing Port of San Diego (Port) data sondes and investigate the feasibility of continuous sonde deployment to gather baseline physical water quality data over the span of approximately two years and eliminate the chlorophyll *a* evaluation. Data sondes supplied by the Port of San Diego were deployed in the winter of 2007-2008 to collect continuous physical water quality measurements at two stations, representing two separate ecoregions, within San Diego Bay (see Figure 1). Data collected at each station included date, time (hh:mm:ss), temperature (°C), specific conductivity in milliSiemens per centimeter (mS/cm), salinity parts per thousand (ppt), dissolved Oxygen milligrams/liter (mg/l), pH, and turbidity nephelometric turbidity units (ntu). Sondes were configured to continuously collect data at 10-minute intervals. SCUBA divers affixed YSI 6820 data sondes to permanent pilings or mooring blocks approximately three to six feet off the Bay bottom at previously established Port water quality monitoring sites (Photo 1). Divers used stainless steel cables, shackles, and swivels to promote easy deployment and removal at mooring locations.

Four YSI 6820 sondes originally obtained from the Port were reconfigured to store data internally and outfitted with external batteries (Photo 2). Of the four sondes, three performed adequately and one sonde failed to calibrate within defined YSI parameters. Data collected by data sondes were downloaded bimonthly onto a laptop computer using ECO Watch software. Data files were saved in both ASCI and Excel file formats for storage, data manipulation, and graphics display. Individual files were integrated by station to form a continuous data record by station, and provided to the Port for web-based publishing. YSI sondes were cleaned and recalibrated after each data download and battery voltage was checked to ensure adequate power for the next sampling period.

Instrument rigging design, frequency of data download, and calibration were adjusted over time to investigate the most effective configuration for long term data acquisition. The challenges of obtaining consistent data were numerous, including loss of sondes, fouling, calibration errors, and battery failure. The installation of a third station within the south Bay near National City was originally planned for March-April 2008 to provide sampling locations within three different ecoregions of the Bay, but limitations of available sondes and the drift of data associated with individual probes focused the effort on refining data collection reliability rather than spatial distribution. Consistency and sustainability of continuous long term data acquisition remained the focus of this monitoring effort.

Continuous data records were recorded at Station A from 27 December 2007 through 19 May 2009 with the exception of the dates 27 March 2008 through 14 May 2008. Continuous data records were recorded at Station B from 09 January 2008 through 19 May 2009 with the exception of dates 28 February 2008 through 27 March 2008. On 27 March 2008, sonde #547 was missing from Station B and subsequently, on 21 April 2008, sonde #579 was lost from Station A. Failure of the brass crimps used to hold the stainless steel cables together was identified as the source of the problem. Deterioration from electrolysis was identified as the source of the problem and was evident on the other mooring systems. Replacement rigging hardware fitted with anode zinc's was installed at all stations to offset corrosive effects.

3.0 Results

Continuous data collected at both Stations A and B are presented in Appendix A. They display both expected and unexpected results that provide valuable insight into contributing factors influencing water quality within San Diego Bay. Data collected at Station A and Station B varied in relation to each other primarily due to differences in depth, proximity to the open ocean, and localized tidal influences. Data sondes were originally removed and replaced approximately every thirty (30) days, at which time data were downloaded, batteries checked, and calibrations performed. Equipment limitations and increased fouling in the spring prompted amending servicing and data downloading frequency to a two-week interval beginning 21 April 2008. Continuous physical water quality data were collected between December 2007 and January 2009. Errors in the data collected over the sampling period were primarily attributed to data probe calibration drift, fouling, loss of units and battery failure. Data falling outside of expected ranges are highlighted in red in Appendix A of this report and were excluded from all analysis including range and monthly averages. Data from this monitoring effort should be utilized for comparison and in general context only until the end of the evaluation period, at which time a complete standardized data correction protocol can be implemented.

Initial examination of continuous data collected at the two monitoring stations beginning in December 2007 displayed notable trends in several physical water quality parameters with respect to season, tidal exchange, and rainfall.

Photo 2. Diver prepares to install YSI sonde at Station A.

Photo 2. YSI sonde with stainless rigging (weight is removed once the unit is affixed to the bottom).

3.1 Collected Data

Data collected at each station was reviewed monthly and evaluated for consistency based on expected ranges, in order to detect errors and examine the data sondes' reliability to record accurately. Expected ranges were based on a combination of historic data collected by the National Oceanographic and Atmospheric Administration (NOAA) at Scripps Pier (La Jolla, CA), Navy data sets collected by Dr. Ken Richter of Space and Naval Warfare (SPAWAR) during monitoring within the Turning Basin of San Diego Bay (1994-1998), and data reported from various estuary/bay systems throughout Southern California. The instruments' (data sondes') placement near the Bay bottom (1-2 m off the sand) required important consideration when evaluating the data records and their temporal fluctuations due to influences from tidal exchange.

Temperature ranged from 11.89°C to 22.77°C, at Station A with an average of 16.22°C ± 2.27 and ranged at Station B from 12.8°C to 23.3°C, with an average of 17.4°C ± 2.62. Temperature data displayed expected fluctuations with respect to tide, season, and proximity to the entrance of San Diego Bay. Temperature data was consistently recorded with few outlining data records noted and followed expected seasonal trends with respect to winter/spring lows and summer/fall highs. Temperature readings oscillated diurnally at Station A, up to 7°C, during some Spring tide periods that occurred in tandem with coastal upwelling events.

Salinity measurements are derived from specific conductivity and temperature and ranged from 28.37 ppt to 37.77 ppt, at Station A with an average of 33.87 ppt and median of 33.58. Salinity data recorded at Station B was inconsistent and fluctuated outside of expected ranges during several deployment periods due to inconsistencies in the calibration of the specific conductivity probe and the biological fouling of the data sonde. Significant portions of the Station B salinity data set contain reliable data records but overall were insufficient to present an annual average or examine defined temporal trends.

Turbidity data records varied noticeably during several deployment periods presumably from localized disturbances, data probe fouling, and influences from tidal exchange. Turbidity data records were carefully reviewed and all records greater than 10 ntu were highlighted in red (Appendix A) for special examination. Overall turbidity was relatively low. Divers exchanging instruments regularly noted differences in water clarity and suspended sediment during peak ebb and flood tides as well as times when large ships passed in close proximity to data sonde locations. Data records in conjunction with diver observations verified that increased turbidity events from ship movements were short in duration and relatively infrequent. Tidal range appears to have a significant effect on turbidity near the Bay bottom at both stations and displayed a direct correlation between peak tidal exchange and increased turbidity (Figures 2 and 3, 4 and 5, and 6). A correlation between tidal range and turbidity was observed at both Station A and Station B in February 2008 and was evident throughout the data set under similar tidal conditions over the study period (Figure 6). Apparent anomalies at Station A during the latter part of the month are well correlated with rain events occurring during the same time period (Figure 6). Considering the depth and width of the Bay near Station B in conjunction with the limited amount of rainfall recorded during specific events, it is likely that the fresh water introduced into the Bay is not mixed to a depth sufficient to affect salinity measurements. In fact, both Station A and Station B in February showed that salinity remained consistent at Station B, while Station A salinities followed the trend of rainfall events (Figure 9). Monthly averages ranged between 0.4 and 2.1 ntu, averaging only acceptable recorded data values between 0 and 11 ntu (Figure 7). Average turbidity over the entire sampling period was 1.33 ± 1.08 (ntu) for Station A and 1.58 ± 1.55 (ntu) at Station B.

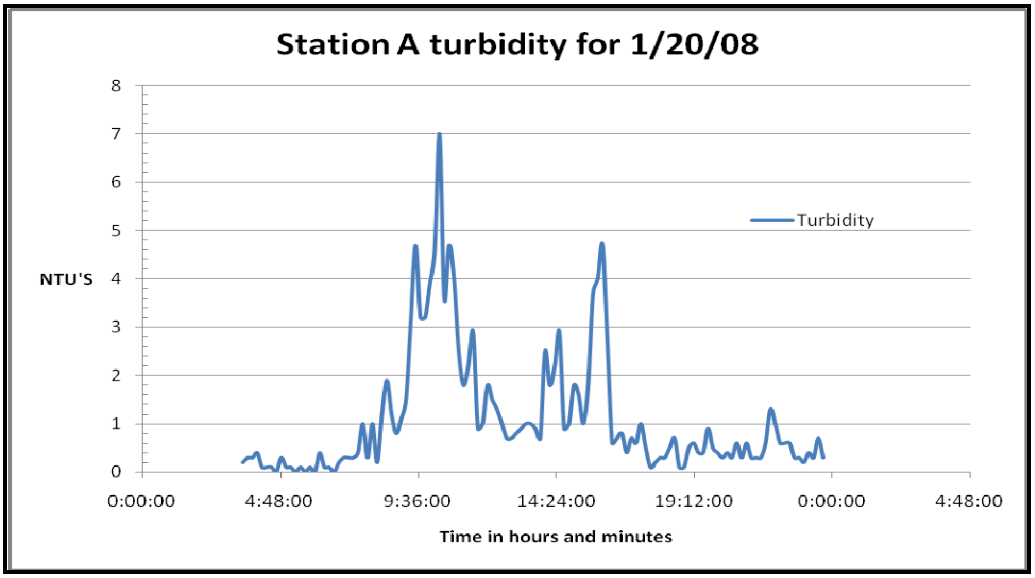


Figure 2. Station A turbidity for a 24 hour period during the maximum tidal change in January, 2008.

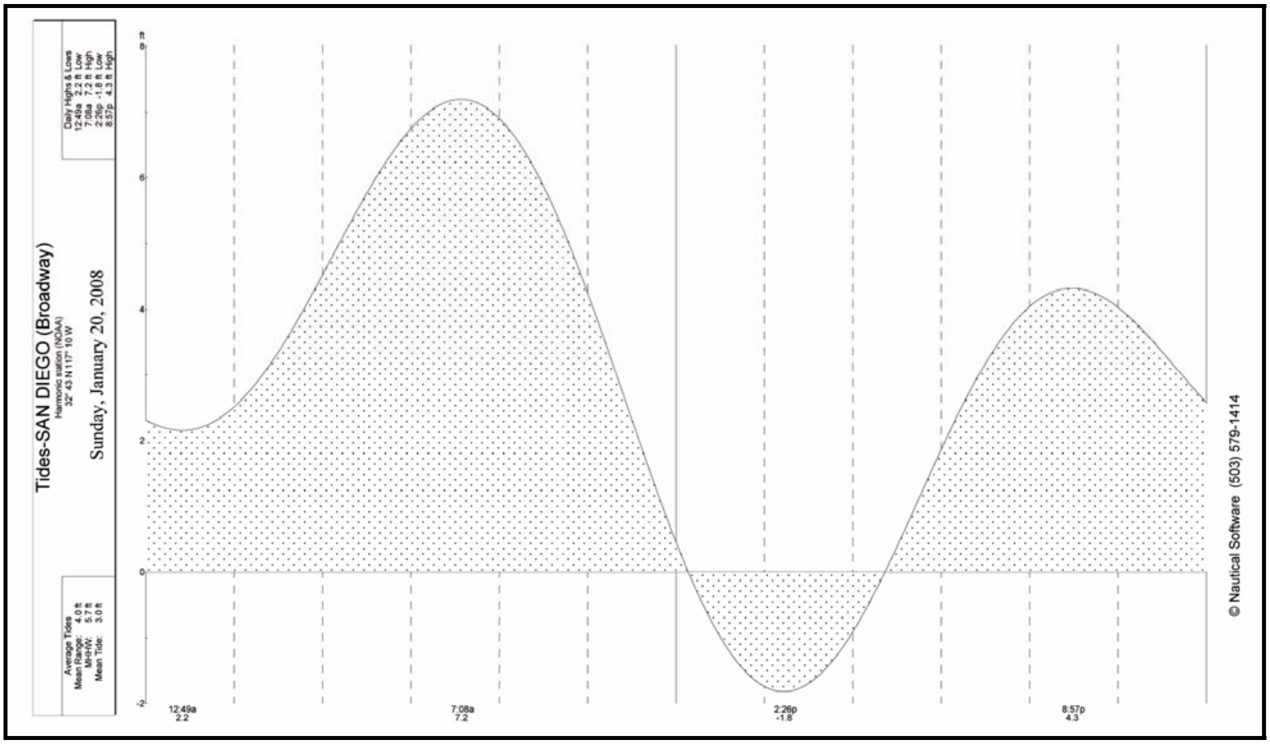


Figure 3. Tide graph for 1/20/08 showing areas of greatest change in tidal height.

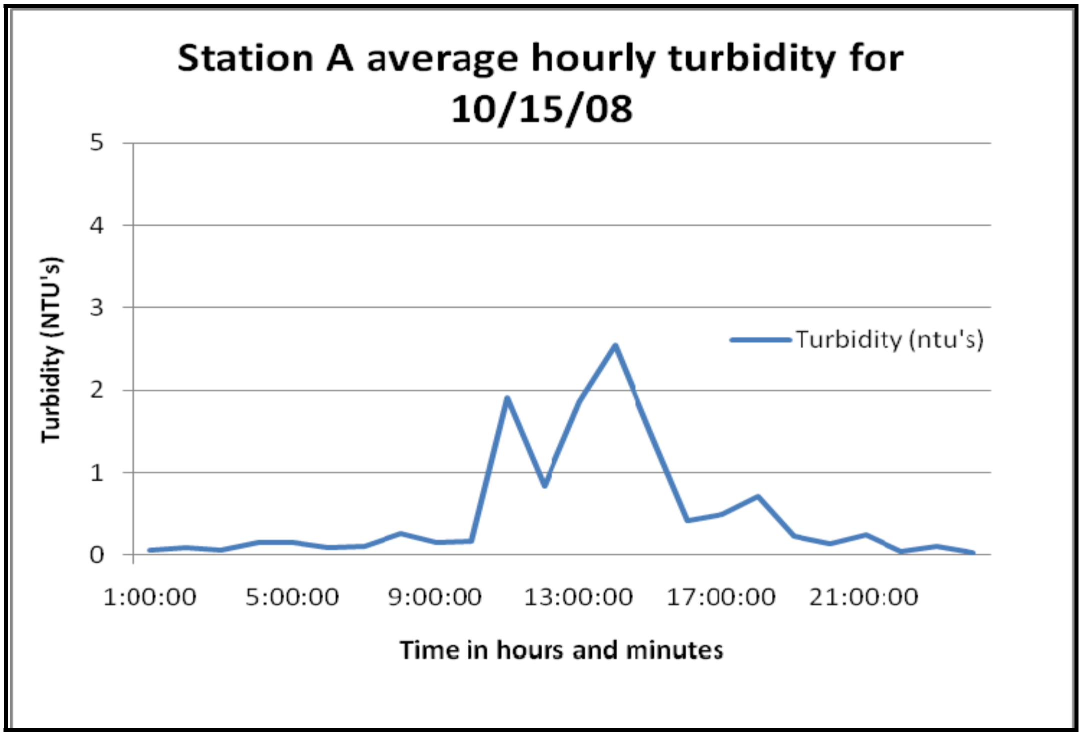


Figure 4. Station A average hourly turbidity for a 24 hour period during the maximum tidal change in October, 2008.

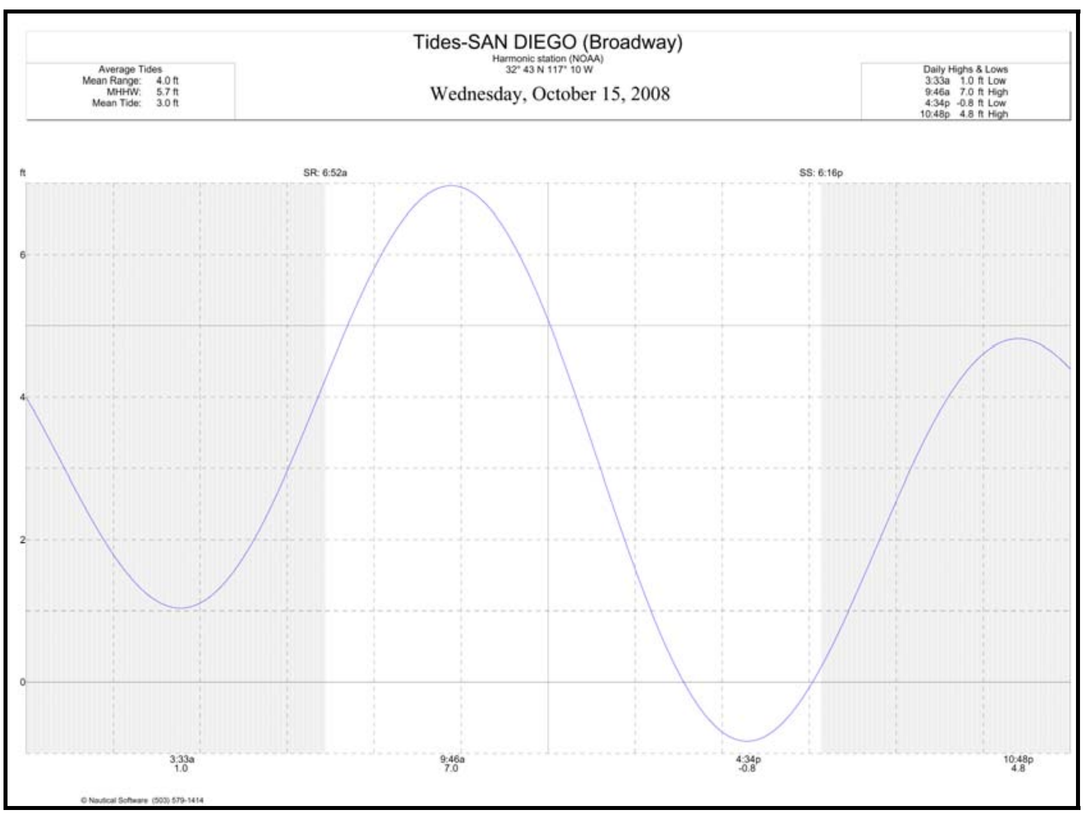
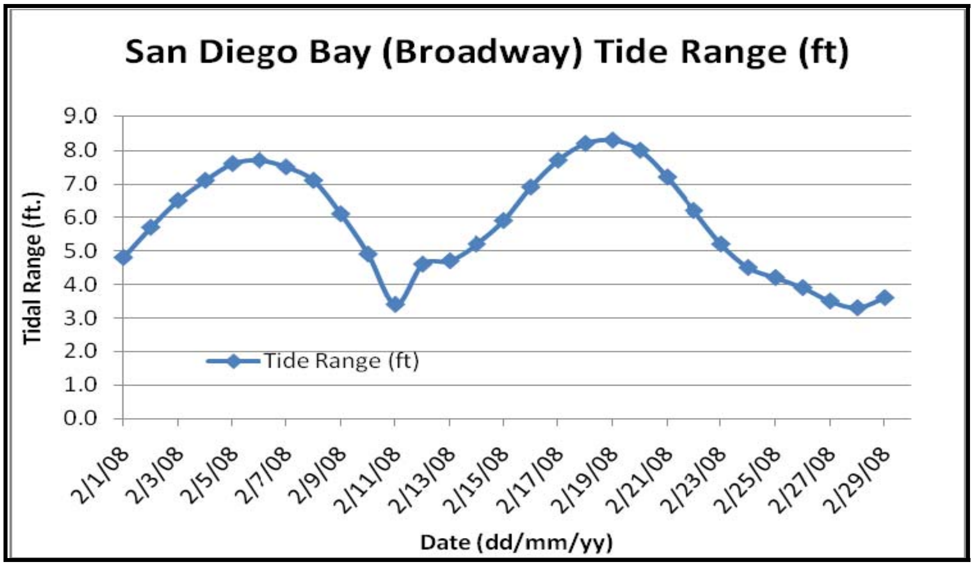
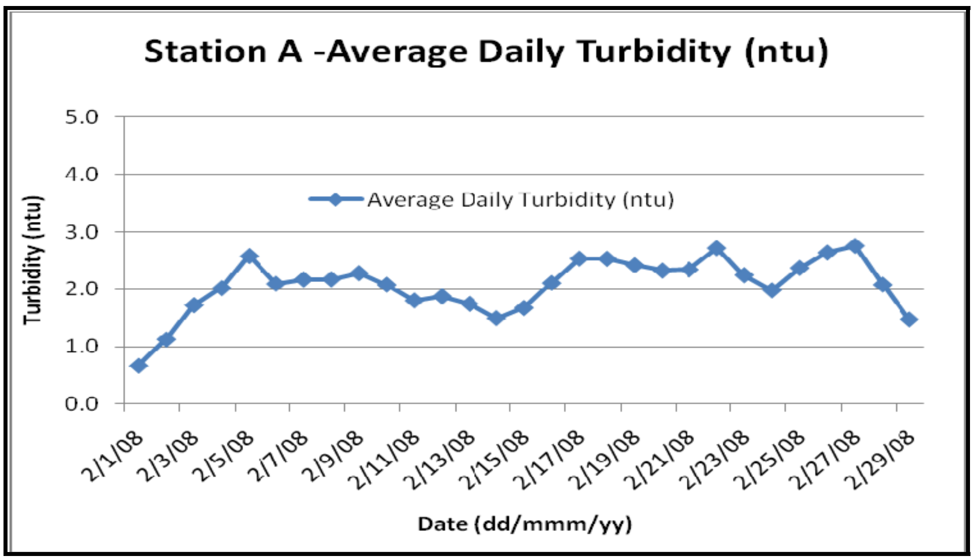


Figure 5. Tide graph for 10/15/08 showing areas of greatest change in tidal height.





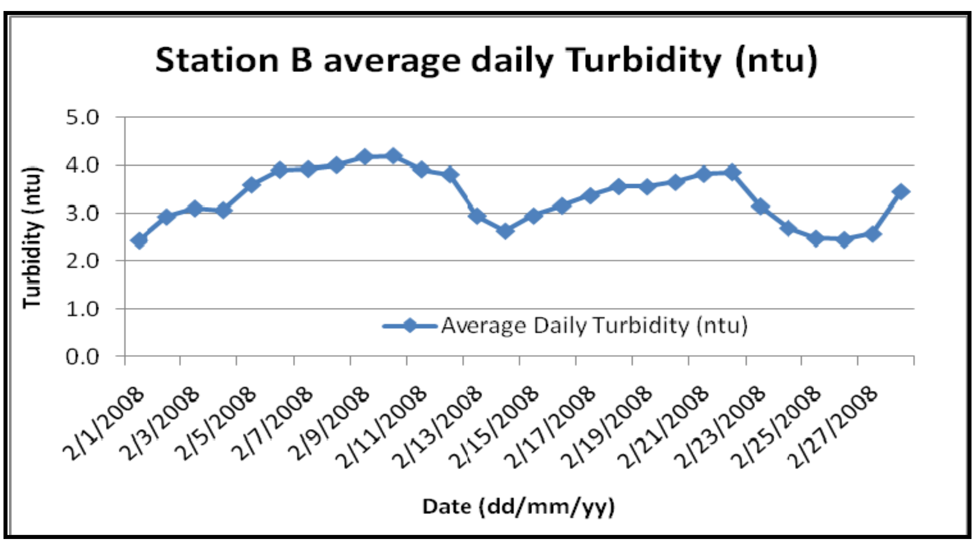


Figure 6. Average daily turbidity (ntu) for Station A and B compared to tidal range for the same time period.

Dissolved oxygen experienced the most frequent data anomalies. Dissolved oxygen data records below 5 mg/l and over 10 mg/l were marked in red as questionable, based on expected DO levels and patterns in recorded DO data observed at the time of sonde exchanges. Dissolved oxygen levels frequently drifted lower during the later portion of the sonde deployments consistent with clogging of the membrane utilized by the DO probe. Dissolved oxygen levels would be expected to be similar to those documented at other southern California bays, based on the hydrodynamics of the Bay and absence of previously documented eutrophication problems. The regular influx of freshwater and saltwater into an estuary, coupled with the shallowness, turbulence, and wind mixing, usually means there is an ample supply of oxygen in the water column (Nybakken 1997). Considering the proximity of Station A to the entrance of San Diego Bay and associated degree of water movement, DO levels would not be expected to be below 5 mg/ml. Dailey (1993) reported an average DO level for Los Angeles Harbor between 6.0 and 5.2 mg/l. Average monthly DO ranged between 6.0 and 10.0 mg/l (Figure 7).

The alkalinity (pH) varied slightly between 8.1 and 8.56, as expected. The alkalinity (pH) remained consistent with that typical of seawater. Oceanic water delivered from diurnal tides appears to be the dominant component to the Bays overall water mass, and limited annual freshwater input to San Diego Bay from seasonal rains and runoff has relatively little influence to pH at depth. Some data points fell well outside the expected range (<7) and were highlighted in red in Appendix A.

3.2 Monthly Averages

Monthly averages of temperature, dissolved oxygen, and turbidity followed expected patterns at Station A (Figure 7). Temperatures increased from spring to summer/fall and then decreased in late fall heading into winter months, while DO displayed an inverse relationship. Monthly averages were calculated from available data and must be viewed cautiously as several months contained only limited data sets and no standard error calculations were performed. The development of monthly averages underscores the importance of understanding individual years or seasons in a long term temporal context. Notable diurnal fluctuations were frequently recorded at both stations during spring tide events increasing the variability of monthly averages and complicating analysis of some seasonal relationships. However, monthly averages gathered from continuous data records provided important trend information with respect to all data parameters highlighting expected seasonal patterns and noticeable daily events.

Turbidity followed an expected trend with the greatest average monthly values observed in the winter, coinciding with measurable rainfall, and during the spring when primary production attributed to phytoplankton takes place (Figure 7). Elevated monthly turbidity averages in the early part of 2008, presented in Figure 7, are likely an artifact of monthly versus bimonthly sampling as increase fouling and calibration drift promoted elevated readings during the later portion of the initial sampling periods conducted in the early portion of 2008.

Trends in the monthly averages of dissolved oxygen, though apparent, are not well understood but follow the relationship with temperature rather closely. Warmer water holds less oxygen than colder water and the late summer and early fall months displayed reduced monthly averages with respect to DO levels. Conversely, primary production from phytoplankton and eelgrass (*Zostera marina*) would be expected to offset temperature factors and display elevated values. These discrepancies underscore the recommendation to utilize only optical DO probes rather than membrane probes while simultaneously measuring chlorophyll *a* to examine the contributions of primary production to the overall oxygen cycle within the Bay.

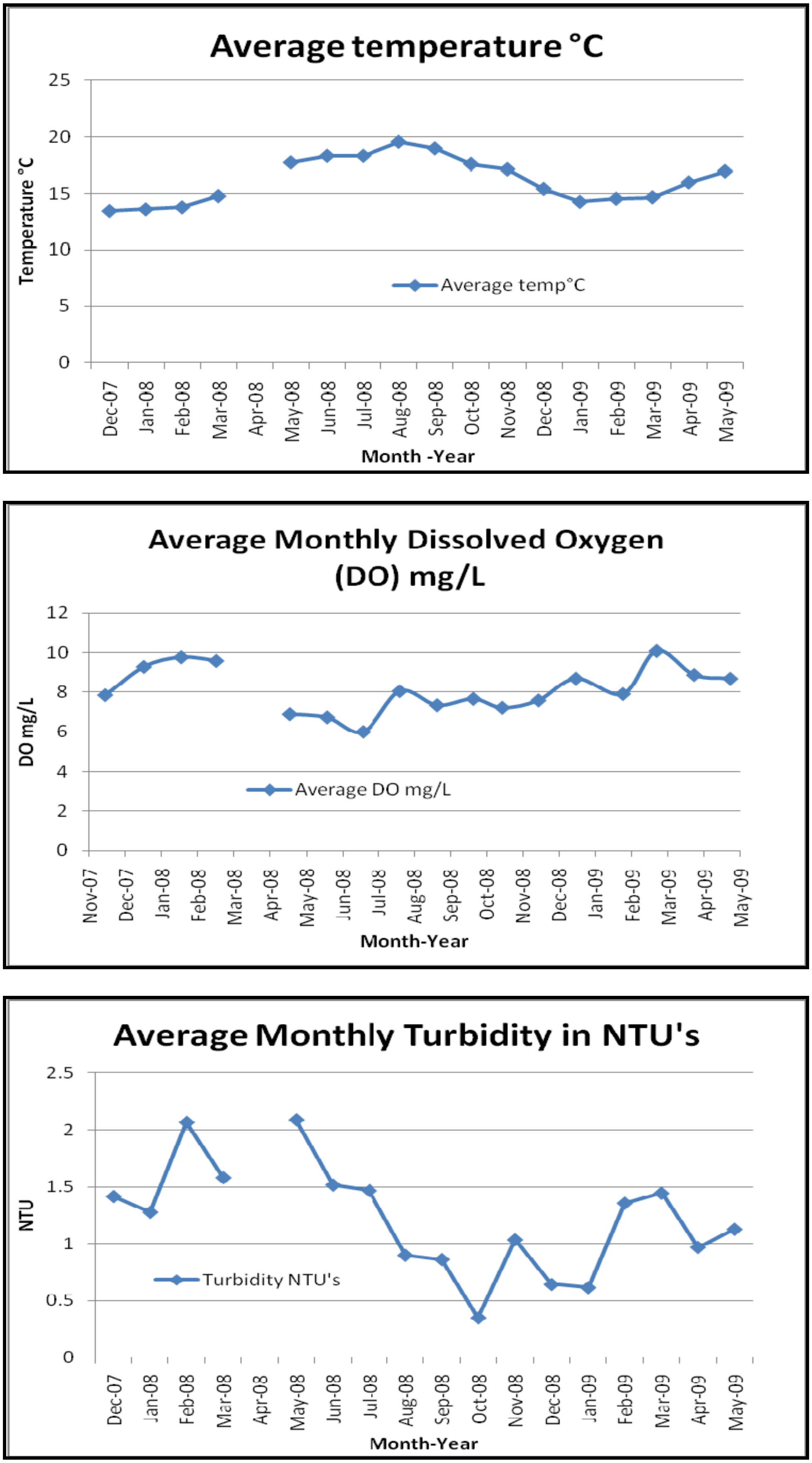


Figure 7. Station A. temperature, dissolved oxygen, and turbidity monthly averages.

3.3 Rainfall Correlations

Monthly rainfall amounts from San Diego Lindbergh Field were plotted from National Weather Service (NWS) data for January 2008 through May 2009 to examine the potential effects of rainfall on collected data parameters (Figure 8). Rainfall and associated freshwater inputs from streams and storm water runoff emptying into San Diego Bay have noticeable and documented effects to the water quality within the Bay. Freshwater is less dense than seawater and creates and surface lens that stratifies the water column. Mixing of the water column from wind, waves, and tidal exchange take a substantial amount of time depending on individual regions of the Bay and the degree of physical factors occurring at any one time.

Mixing and stratification are affected by several factors. Flushing rates change drastically moving away from the Bay entrance. The longest San Diego Bay water residence times are observed in the summer, apparently related to the density stratification of the Bay at that time (Chadwick 1997). The amplitude of the tidal cycle also affects flushing rate. During a strong tidal cycle, up to 40 percent of the mean volume of the Bay passes Ballast Point during the ebb flow, at least temporarily residing outside the Bay. During an average tidal cycle, the volume of water leaving the Bay is about 13 percent. While the residence time of water near the northern inlet is short except for side basins where commercial and marina activities are located (Largier 1995), it can take from ten to 100 days for water as a whole to be exchanged, depending on tidal amplitude. Residence times in south Bay may be months, ranging from 20 to 300 days (Chadwick 1997).

Considering resident times of the water within various portions of the Bay physical water quality parameters most notably turbidity and salinity maybe greatly modified for extended periods as evident in salinity data at Station A (Figure 9). Increased turbidity measurements were evident in both December 2008 and February 2009 associated with substantial rainfall events (Figure 10 and 11). However, it is important to note that both events are superimposed over spring tide occurrences, explaining the onset of elevated turbidity measurements prior to the rain and increases the daily turbidity averages are likely well above that strictly attributed to the rainfall event.

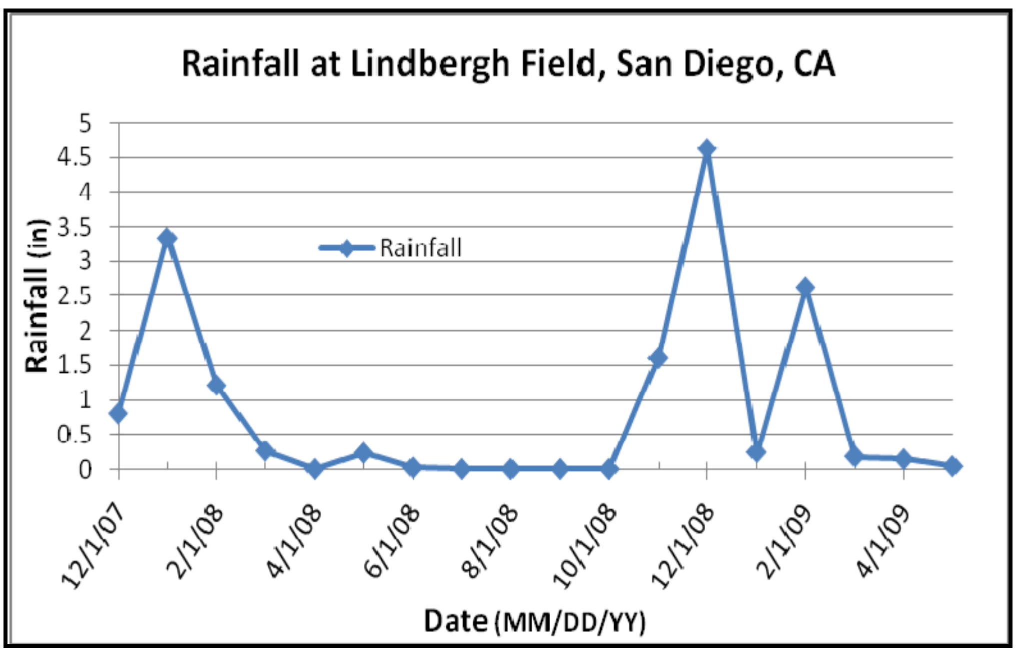
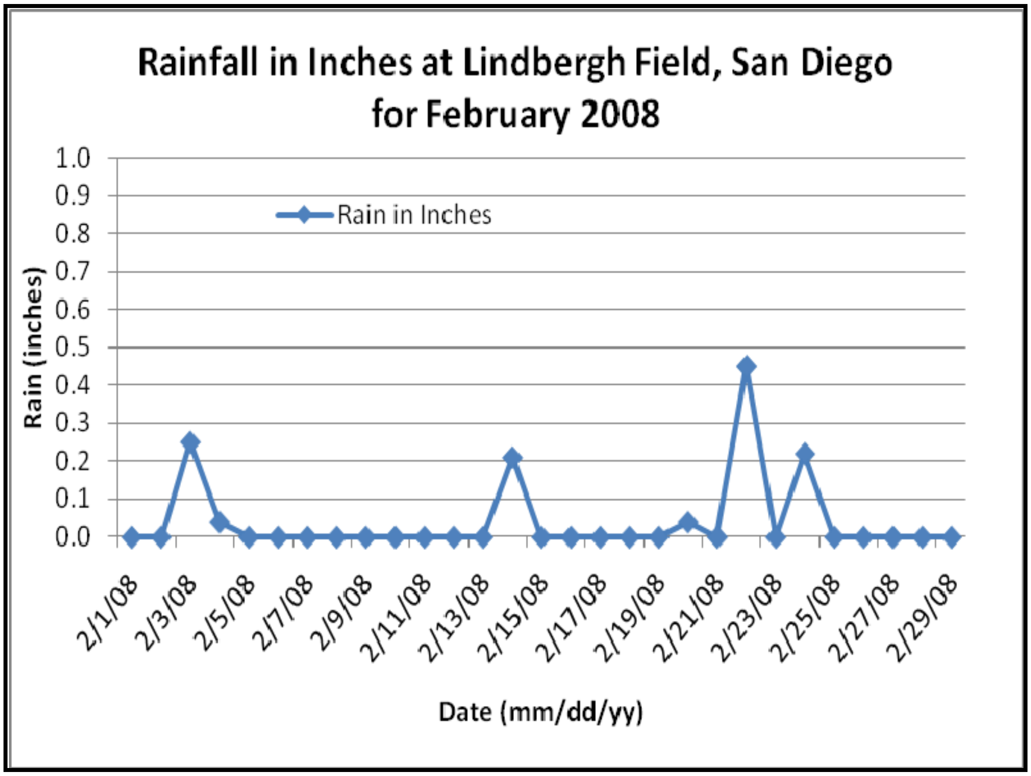


Figure 8. Rainfall in inches at Lindbergh Field, San Diego, California over the entire sampling period. Data obtained from National Weather Service (NWS) archives.



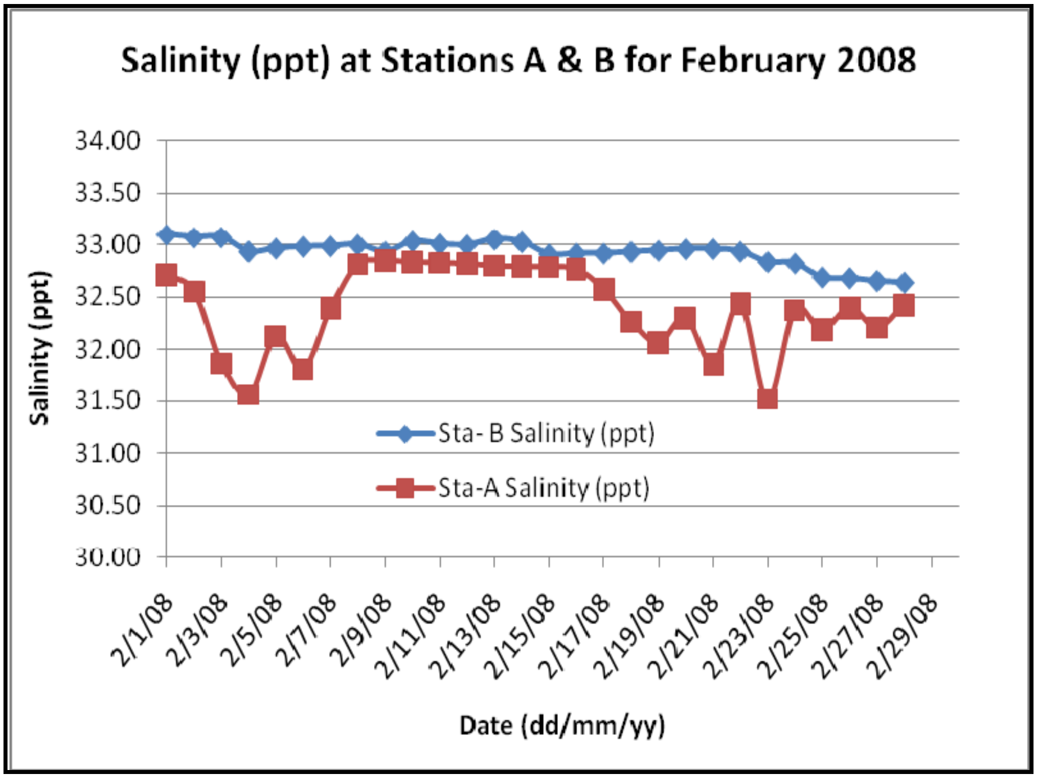
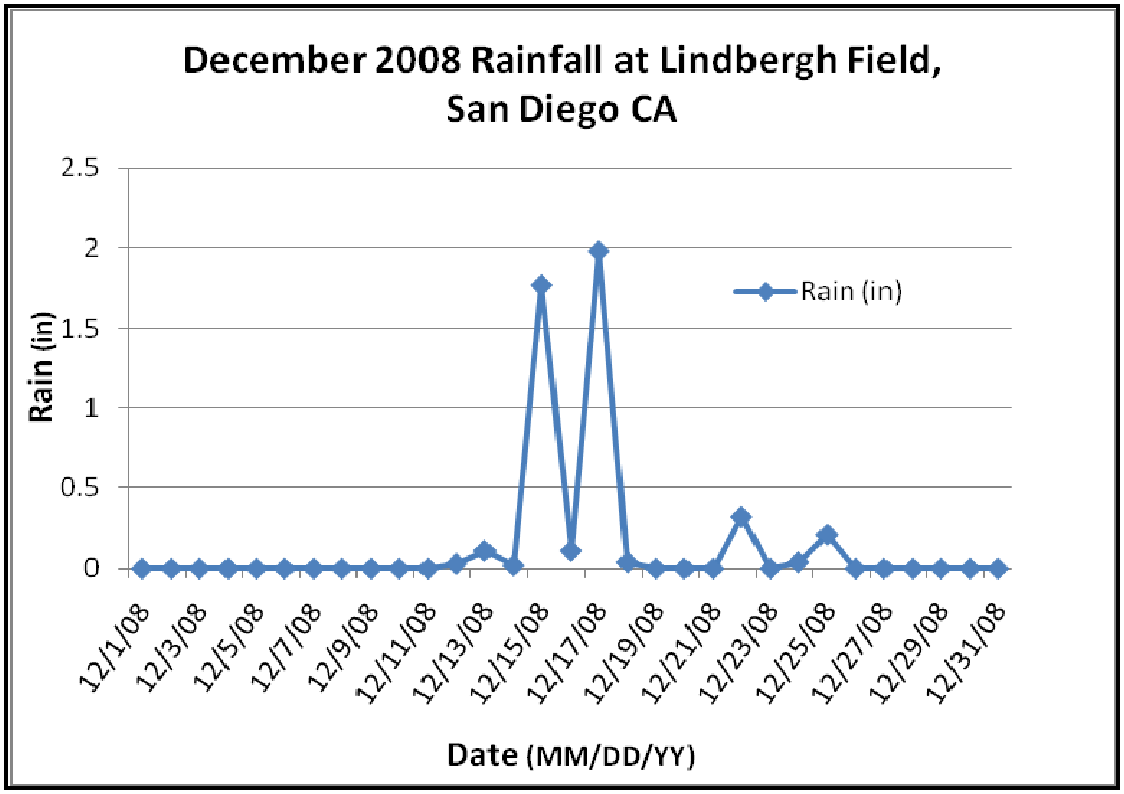


Figure 9. Rainfall in inches at Lindbergh Field, San Diego, California for February 2008 compared to average daily salinity (ppt) for Stations A and B rainfall (in) during the same time period.



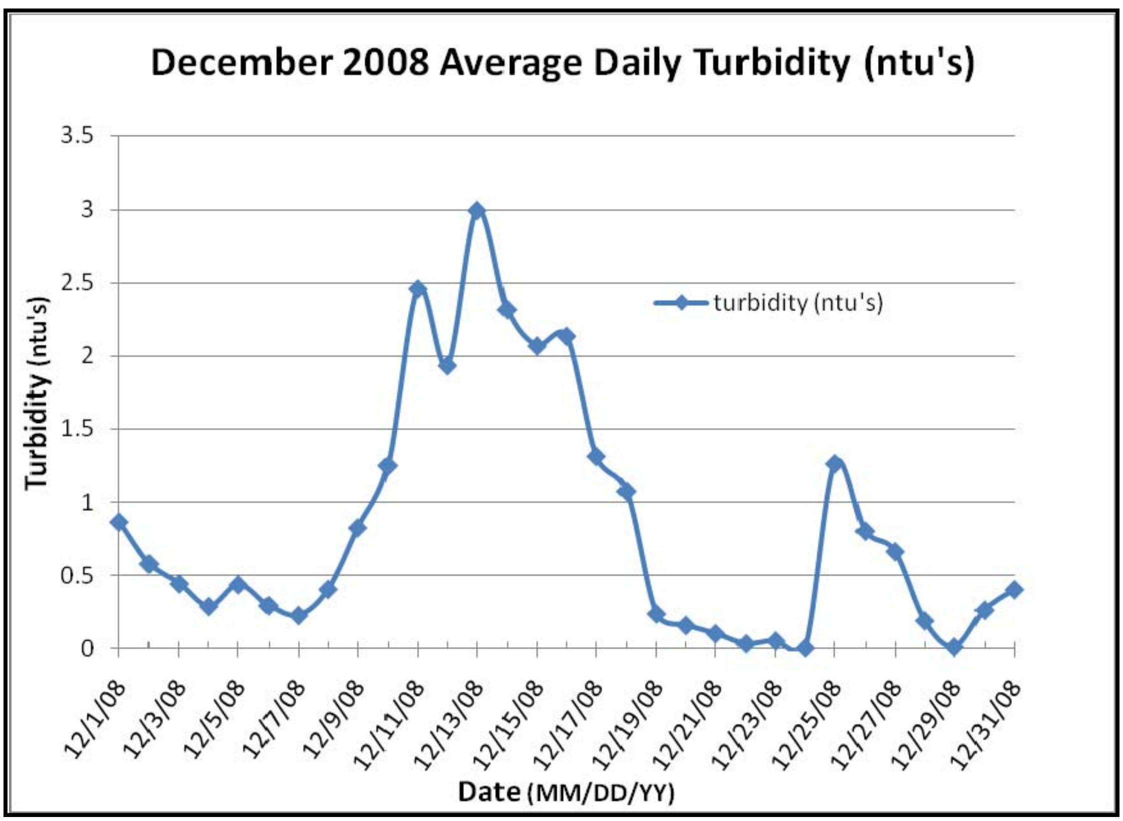
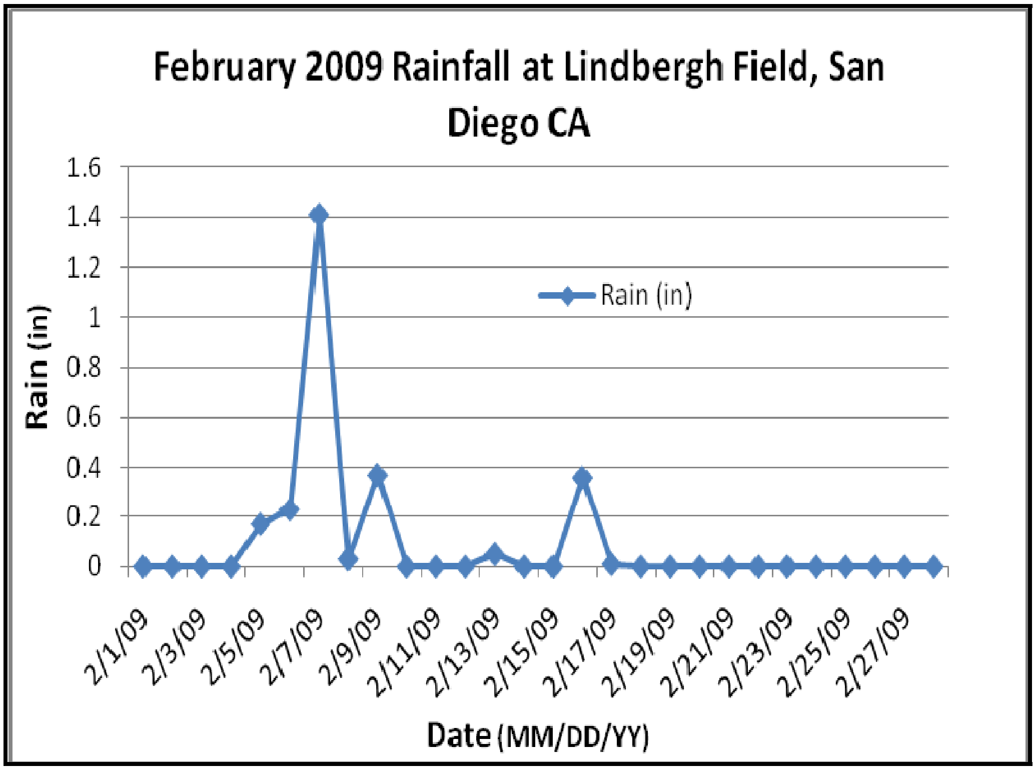


Figure 10. Rainfall in inches at Lindbergh Field, San Diego, California for December 2008 compared to average daily turbidity (ntu) for Station A during the same time period.



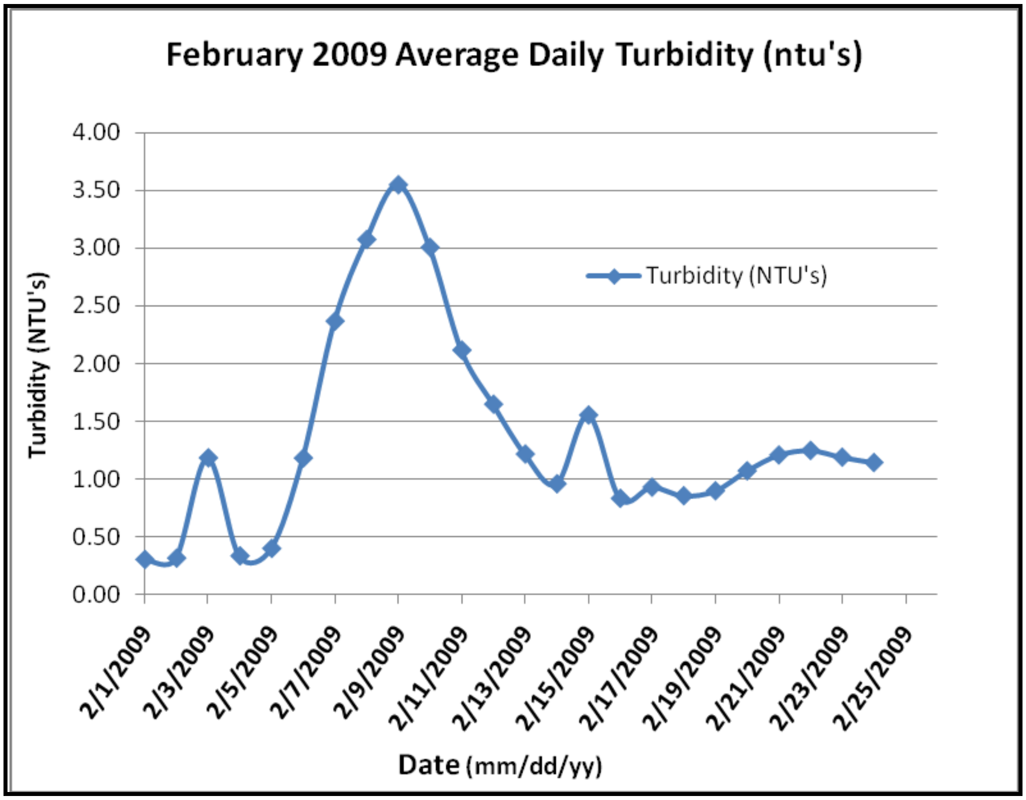


Figure 11. Rainfall in inches at Lindbergh Field, San Diego, California for February 2009 compared to average daily turbidity (ntu) for Station A during the same time period.

4.0 Discussion

The purpose of this project was to examine the current equipment and methods previously utilized during the 2001 Port of San Diego water quality pilot study, and to determine whether the methods could be amended to obtain intended physical water quality measurements continuously and consistently. To maintain long term compatibility, future physical water quality monitoring efforts should attempt to obtain continuous data using the same parameters, time interval, and locations initially established in 2001 and duplicated in this effort.

Results from this monitoring effort varied in quality and consistency over the entire sampling period, yet provided a clear cost effective strategy for future evaluations. Problems associated with fouling and calibrations were identified and future data sets will become more consistent and reliable by incorporating these findings.

Upgrading existing YSI equipment to new YSI 6600s, with dual optical probes, was determined to be the most cost effective strategy to gather reliable high quality data, reduce service intervals, and provide long-term data consistency. The existing Port instruments (sondes) used during this study, YSI 6820s, were older models that were designed with only one optical port fitted with a turbidity probe. The DO probes utilized throughout the study were membrane-type probes that become easily fouled and subsequently required frequent calibration.

Data collected during the study provided valuable continuous baseline data over nearly 18 months (Appendix A) that displayed expected and unexpected daily and seasonal trends in turbidity, as well as spatial patterns that can be related to tidal influence and rainfall. The placement of the sondes at two stations near the Bay bottom, intended to evaluate potential issues with eutrophication and low levels of DO, was determined to be unnecessary based on the consistency of DO levels well above the oxygen minimum, 5 g/l. Future sonde placements are recommended to be within two meters of the surface to more completely examine turbidity components and reduce the influence of tidal exchange on the measured parameters.

Overall temperature, salinity, pH, and conductivity data appeared to have few inconsistencies outside of the initial two-month testing period and displayed more homogeneous water characteristics than anticipated. The continuous physical water quality data set obtained during this effort provided valuable temporal and spatial baseline information in terms of changes in turbidity at depth with respect to tidal exchange and rainfall. The health of San Diego Bay is based in large part to its biological productivity measured at multiple trophic levels. This study provided fundamental information on many of the components that shape primary productivity, which is the foundation of biological productivity.

The collection of an expanded data set incorporating the South Bay would significantly improve the ability to examine patterns and relationships between various physical water quality parameters and evaluate regional patterns both within and outside the Bay. The addition of chlorophyll *a* probes or redundant sondes would allow for examination of complex relationships between turbidity and primary production as well as more clearly evaluate effects from storm water runoff and rainfall.

Integration of this work with that of others locally and regionally will allow for better interpretation of natural versus human-caused effects. Examples are the salt pond monitoring conducted in South Bay by the Tijuana River National Estuarine Research Reserve (Jeff Crooks, pers. comm.) and the work of the Southern California Waters Research Program.

5.0 Conclusion

Characterizing the spatial and temporal variation in turbidity and physical water quality characteristics in San Diego Bay requires a focused coordinated effort using state of the art equipment in order to maintain data consistency. Problems associated with fouling of probes are difficult to remedy; however, new technology recently developed by YSI and other instrument manufacturers utilizing zinc and copper anodes in conjunction with wipers are a viable solution. Regular, two-week sonde data downloading and calibration provides the most cost effective sampling interval to reduce measurement drift. Integrating new sondes with dual optical probes would allow for sondes to be outfitted with an optical turbidity probe and DO or chlorophyll *a* probe. Existing Port instruments (sondes) could be utilized in the future as redundant data sources for individual parameters, or used to perform vertical casts at each station during sonde servicing, but would require major servicing and probe replacement. The feasibility of collecting continuous, consistent, long term physical water quality data is obtainable at or near the current monthly cost of this project if new, updated sonde units are purchased. Problems associated with moorings and batteries have been solved and future deployment of additional sondes is dependent on availability of equipment and funding.

Considering the consistency of DO measurements at depth in conjunction with the variation of turbidity with respect to tidal exchange and rainfall, a standardized instrument depth for all sampling locations is prudent to facilitate comparisons between stations and investigate relationships between chlorophyll *a* and turbidity as well as other properties. Additionally, a handheld data logger would streamline data acquisition, increase calibration efficiency, and enable sondes to collect real time data on station.

Data collected during this evaluation displayed spatial variability for several measured parameters which supported previous hydrographic studies (Chadwick 1997), documenting San Diego Bay as a partitioned estuary with complex circulation and stratification components. Contemplating the continued characterization of the spatial and temporal variation of turbidity and physical water quality characteristics in San Diego Bay, it is our recommendation that this effort focus on the relationship between turbidity and chlorophyll *a* and correlations with biological productivity. Examining turbidity and chlorophyll *a* can help pose cause and effect questions and support adaptive management for San Diego Bay.

6.0 References

Australian and New Zealand Environment Conservation Council/Agriculture and Resource Management Council of Australia and New Zealand (ANZECC/ ARMCANZ). 2000. Australian Guidelines for Water Quality Monitoring and Reporting, ANZECC/ARMCANZ, Canberra.

Chadwick, D.B. 1997. Tidal Exchange at the Bay-Ocean Boundary. Ph.D. diss., University of California, San Diego.

Cloern, J.E. 1987. Turbidity as a control on phytoplankton biomass and productivity in estuaries. *Continental Shelf Research* 7(11/12), 1367-1381.

Dailey M.D., Anderson J.W., Reish D.J. and D.S. Gorsline. 1993. The Southern California Bight: background and setting. In M.D. Dailey, D.J. Reish, and J.W. Anderson, eds. Ecology of the Southern California Bight. Berkeley: University of California Press. pp 746.

Duarte, C.M. 1995. Submerged aquatic vegetation in relation to different nutrient regimes. *Ophelia* 41, 87-112.

Largier J.L., Hollibaugh J.T. and S.V. Smith. 1997. Seasonally hyper saline estuaries in Mediterranean climate regions. Estuar Coast Shelf Sci 45:789–797.

Largier, J.L. 1995. San Diego Bay Circulation: A Study of Water in San Diego Bay for the Purpose of Assessing, Monitoring and Managing the Transport and Potential Accumulation of Pollutants and Sediment in San Diego Bay. Prepared for the California State Water Resources Control Board and the California Regional Water Quality Control Board, San Diego Region (Interagency Agreement #1-188-190-0).

Landres, P.B., Morgan, P. and F.J. Swanson. 1999. Overview of the Use of Natural Variability Concepts in Managing Ecological Systems. Ecological Applications, 9 (4): 1179-1188.

Monbet, Y. 1992. Control of phytoplankton biomass in estuaries: A comparative analysis of microtidal and macrotidal estuaries. *Estuaries* 15(4), 563-571.

Nybakken, James W. 1997. Marine Biology: An Ecological Approach, Fourth Edition. Addison-Wesley Educational Publishers Inc., Reading, MA.

San Diego Bay Advisory Committee for Ecological Assessment (SDBAC). 2005. Senate Bill 68 Report, December 2005. Natural Resources prepared by Elizabeth M. Kellogg, Tierra Data Inc., Escondido, CA.

San Diego Unified Port District (SDUPD). 2000. Bay-Wide Water Quality Monitoring Program, Field Sampling and Data Management Plan, December 2000. San Diego, CA.

South Carolina Department of Health and Environmental Control. 2001a. Environmental Investigations Standard Operating Procedures and Quality Assurance Manual. Office of Environmental Quality Control, Columbia, SC

U.S. Department of the Navy Southwest Division (USDON SWDIV) and San Diego Unified Port District (SDUPD). 2000. San Diego Bay Integrated Natural Resources Management Plan September 2000. San Diego, CA. Prepared by Tierra Data Inc., Escondido, CA.

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Appendix A: Water Quality Data

Water Quality Data was submitted in electronic format (MS EXCEL).

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