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

Quarterly Report
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A Project for:

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

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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 using existing equipment provided by the Port of San Diego. San Diego Bay is comprised of several ecological regions (ecoregions) previously developed to describe the gradient of physical and ecological parameters occurring within San Diego Bay (Figure 1). Physical water characteristics, most notably tidal flushing, salinity and temperature, of San Diego Bay display spatial trends with respect to 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 other water quality characteristics such as dissolved oxygen (DO) and turbidity. Understanding patterns in dissolved oxygen (DO) and turbidity are further complicated by tidal change and the variation of complex hydrological interactions between ocean water and freshwater inputs from natural and anthropogenic sources. Continuous long term water quality data sets provide a valuable baseline for current and future physical and biological investigations within San Diego Bay.

1.1 Project Purpose

The project was intended to test a pilot deployment of instrumentation purchased by the Port of San Diego.

1.2 Equipment

Independent electronic water quality instruments, often called ‘sondes’ are typically deployed to measure physical water quality parameters. Sondes are electronic data loggers outfitted with various sampling probes designed to collect measurements of specific 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 to observe dynamic temporal changes. Data sets collected in either manner have limitations and drawbacks. Single event deployments provide information for specific times and locations. Continuous sonde deployment provides the ability to detect changes of physical water quality characteristics over time and space while reducing effort to collect daily measurements. Continuous sonde data collection at defined locations enables investigators to evaluate natural variation of selected physical 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. However, data inconsistencies attributed to instrument drift and data probe fouling from debris, invertebrates, and/or algae are problematic with increased durations of sonde deployment. The advantages of continuously deployed sondes include an expanded data set and capturing fluctuations during various tides, seasons, and unexpected events that are clearly beneficial from a regional perspective.

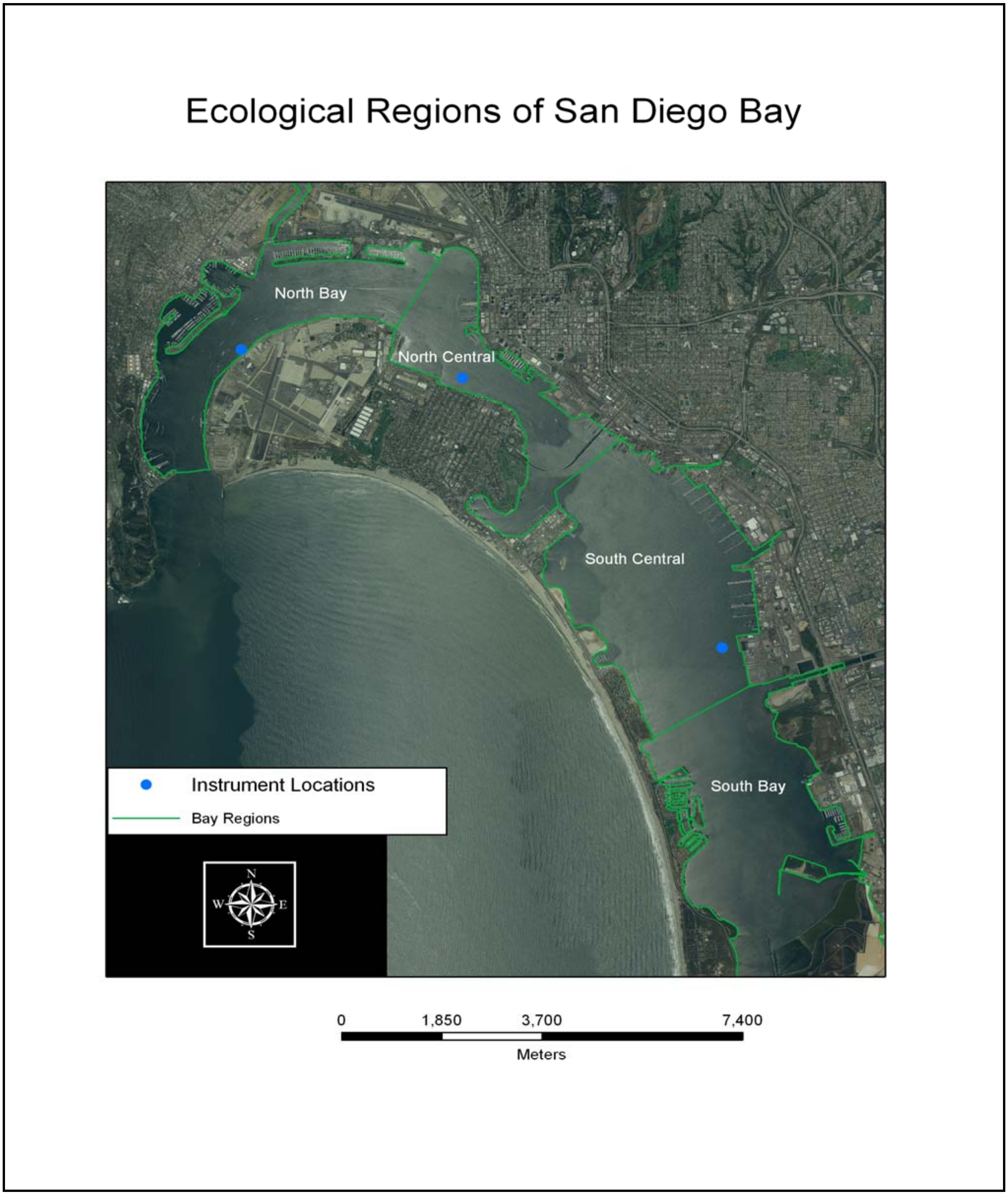


Figure 1. Ecoregions and instrument locations within San Diego Bay.

Equipment type and model of the sonde required for continuous physical water quality characterizations is predicated by the sampling design of the individual project, the parameters to be collected, and the environment of the water body being investigated. San Diego Bay is an semi-estuarine system primarily influenced by the influx of oceanic water at the entrance to San Diego Bay and to a lesser extent freshwater input from various creeks and storm water runoff. Equipment used to collect physical water quality parameters is affected by fouling from debris and settlement of various invertebrates and algae as well as waves, tidal action, and vessel movements. The initial proposal to design and implement this study proposed a purchase of six (6) new data sondes equipped with internal battery systems, expanded memory, and dual optical probes to investigate physical water quality characteristics and their relationship to 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.

2.0 Methods

YSI 6820 data sondes and associated equipment supplied by the Port of San Diego were obtained by Tierra Data Inc. (TDI) in October 2007 for evaluation and trouble shooting. The previous configuration of the equipment integrated YSI 6820 sondes with Ocean Sensor units, the Ocean Sensor units were designed to serve as both the power source and data storage location for data obtained from the YSI sondes. The Ocean Sensor units were cumbersome and problematic, prompting the reengineering of the data collection system and streamlining of the hardware. Subsequently, replaceable cost-effective battery storage devices were developed out of four-inch ABS (Acrylonitrile-Butadiene-Styrene) pipe and water proof connections. The YSI sondes were reprogrammed to store collected data internally, rather than on the Ocean Sensor units, further streamlining data acquisition and downloading. Initial field tests were conducted at TDI within a controlled environment. Data collected at each station included date, time (hh:mm:ss), temperature (°C), specific conductivity mS/cm, salinity (ppt), dissolved oxygen (mg/l), pH, and turbidity (ntu). Sondes were configured to continuously collect data at 10 minute intervals.

During initial implementation SCUBA divers, using coordinates supplied by the Port, located sampling Stations A and B and affixed mooring hardware to permanent pilings or mooring blocks associated with previously established Port water quality monitoring sites. Divers used stainless steel cable, shackles, and swivels to promote easy deployment and removal at mooring locations (Photo 1).

Four YSI sondes were originally obtained from the Port; three units performed adequately and one unit failed to calibrate within defined parameters. On March 27th 2008 sonde #547 was lost from Station B and subsequently, on April 21st 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 evident on the other mooring systems and the installation of zinc was required to offset corrosive effects.

Data collected by YSI sondes was 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 are cleaned and recalibrated after each data download and battery voltage is checked to ensure adequate power for the next sampling period.

Photo 1. YSI sonde with stainless rigging (weight is removed once the unit is affixed to the bottom).

3.0 Results

To date, Port data sondes have been reconfigured, installed, and are collecting continuous data at two stations (A and B) within San Diego Bay (See Figure 1). Initial examination of continuous data collected at the two monitoring stations beginning in December 2007 has provided interesting baseline data regarding various physical water quality parameters with respect to season, tidal change, and rainfall events. The design and development of battery housings, rigging, and instrument placement has been continuously adjusted to investigate the most effective configuration for long term data acquisition. The challenges of obtaining consistent data have been 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 to refining data collection reliability. Consistency and sustainability of data acquisition remains the focus of this monitoring effort.

3.1 Data Collection

Data collection in San Diego Bay began on December 28, 2007 at Station A, near pier Bravo located in the North Bay (off Coronado Island) and continued for a period of 14 days. The initial test period produced acceptable data for all six water quality parameters within expected values. Sampling was expanded to encompass Station A and Station B on January 9th 2008.

Data collected at Station A and Station B varied in relation to each other 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. The onset of spring increased fouling from invertebrate settlement and drift algae. This prompted amending servicing and data downloading of the sondes to a two-week interval beginning April 21st 2008. Continuous data have been collected at each station between December 2007 and January 2009. Errors in the data collected over the sampling period were primarily attributed to fouling and loss of units but have also included battery failure and calibration drift. Questionable data are highlighted in red in Appendix A of this report and were excluded from all analyses 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 developed.

Dissolved oxygen (DO) experienced the most frequent data anomalies, followed by turbidity. Dissolved oxygen levels 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. 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.

3.2 Monthly Averages

Monthly averages of temperature, DO, and turbidity followed expected patterns (Figure 2). 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 of turbidity at Station A showed a similar seasonal pattern as DO. 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. Extreme diurnal temperature fluctuations of approximately 7.2 ° C were notable on several occasions and specifically on June 2, 2008 at Station A during the highest tidal ranges. Monthly averages gathered from continuous data collection provided important trend information with respect to all the data parameters while significant daily events, such as localized upwelling, remained apparent within the data stream. Elevated monthly turbidity averages in the early part of 2008, presented in Figure 2, 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.

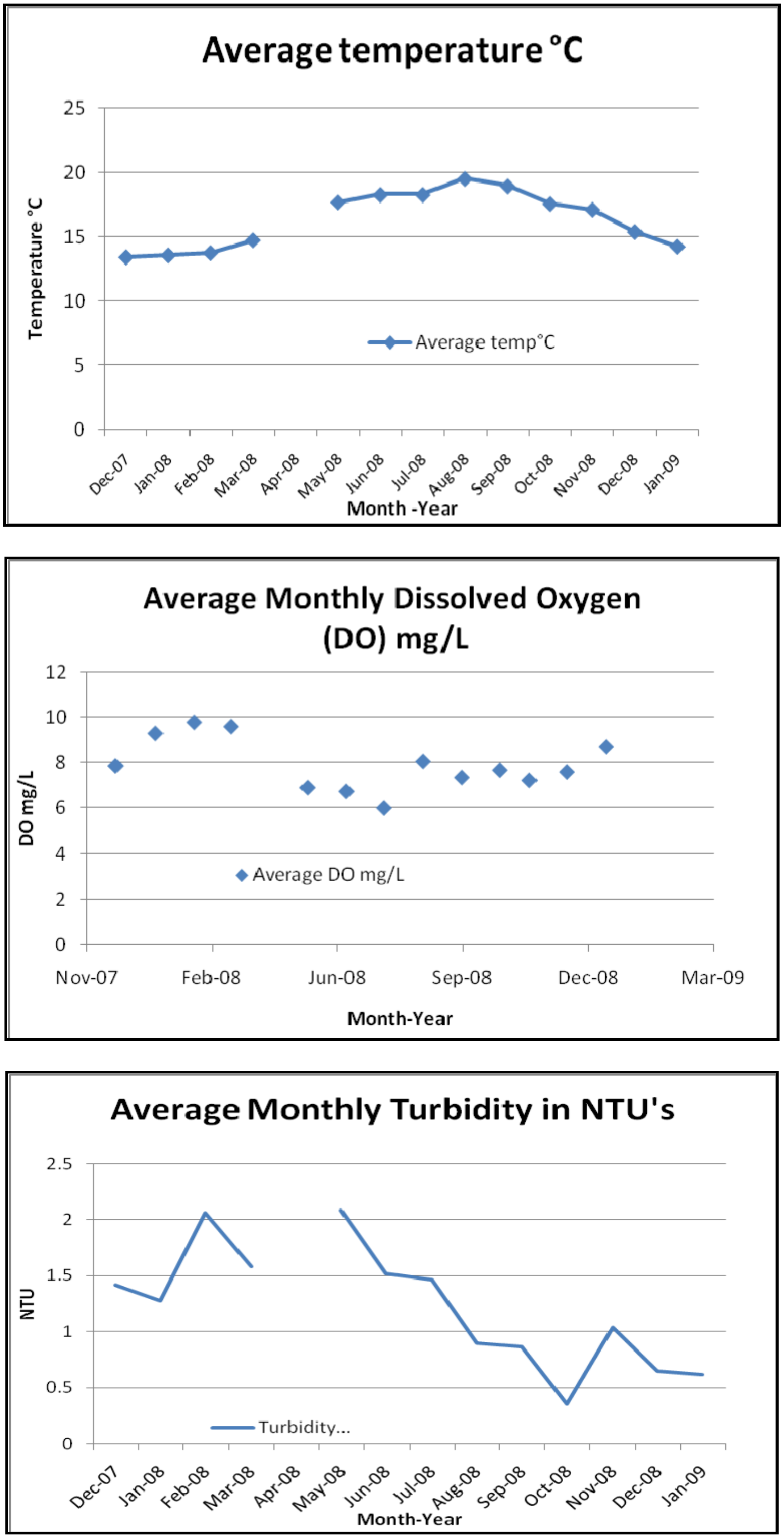


Figure 2. Station A. temperature, dissolved oxygen, and turbidity monthly averages.

Turbidity at Station A varied from 0 to 10 nephelometric turbidity units (NTUs) and tidal fluctuations were observed to have noticeable effect. Peak turbidity measurements consistently occurred during the largest tidal changes associated with spring tides and the lowest measurements occurred during peak flood tide times when clean, clear, ocean water dominated the station's location (Figures 3 and 5). Figures 3 and 5 illustrate that peak turbidity is correlated with the steepest slope of the tidal change (Figures 4 and 6). Tidal influences at Station B were less pronounced than those observed at Station A, likely because the sonde at Station B is deeper (z = 41ft. vs z = 26ft.), further from the open ocean, and located at a wider portion of the bay. Fouling of the turbidity sensors was intermittently evident at both Stations A and Station B; large amounts of kelp (*Macorcystis pyrifera*) and eelgrass (*Zostera marina*) were removed from the sonde at both stations on several occasions.

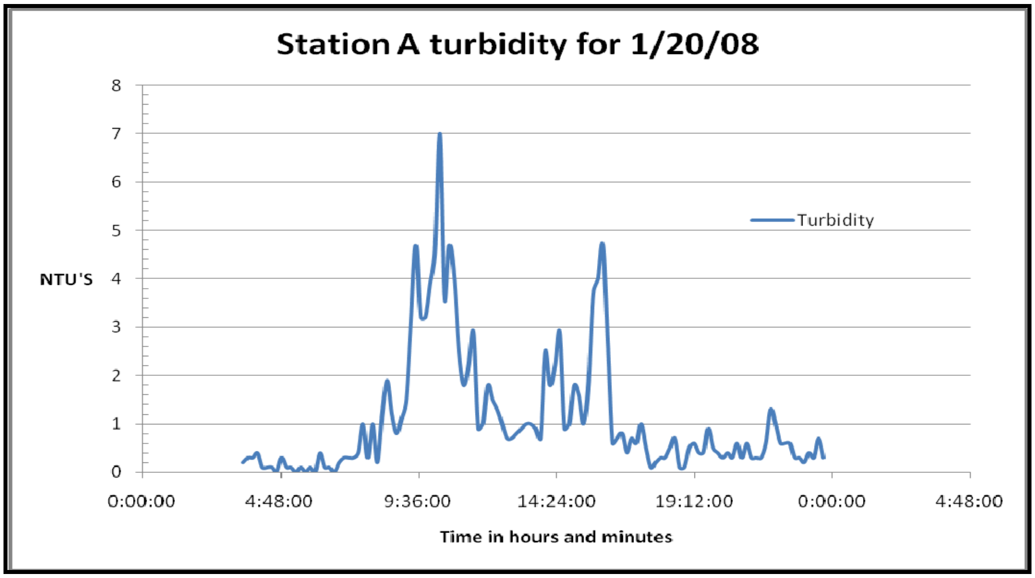


Figure 3. Station A turbidity for a 24 hour period during the maximum tidal change in January, 2008.

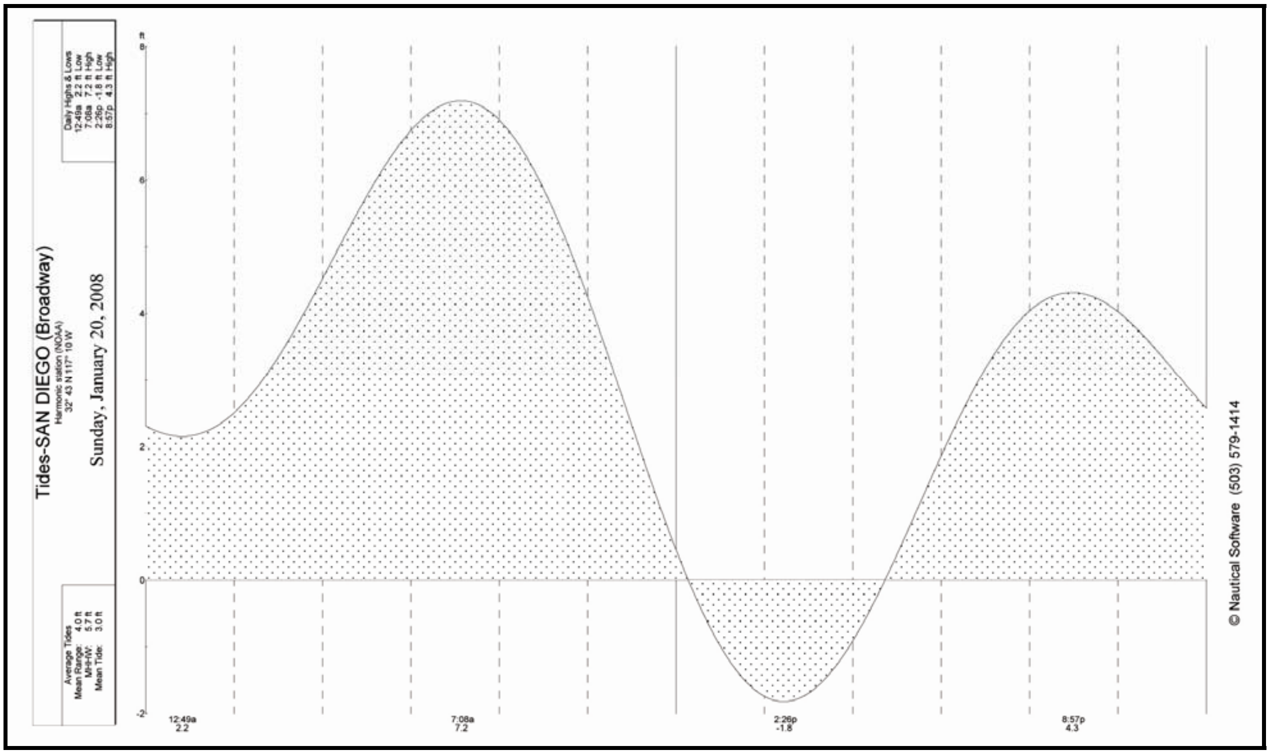


Figure 4. Tide graph for 1/20/08 showing areas of greatest change in tidal height.

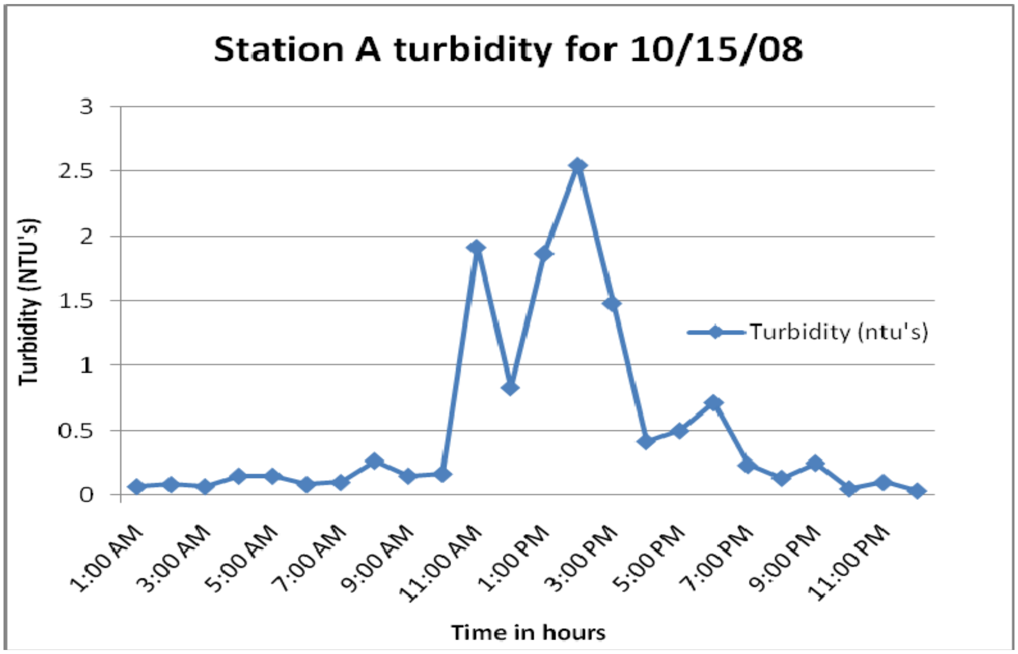


Figure 5. Station A turbidity for a 24 hour period during the maximum tidal change in October, 2008.

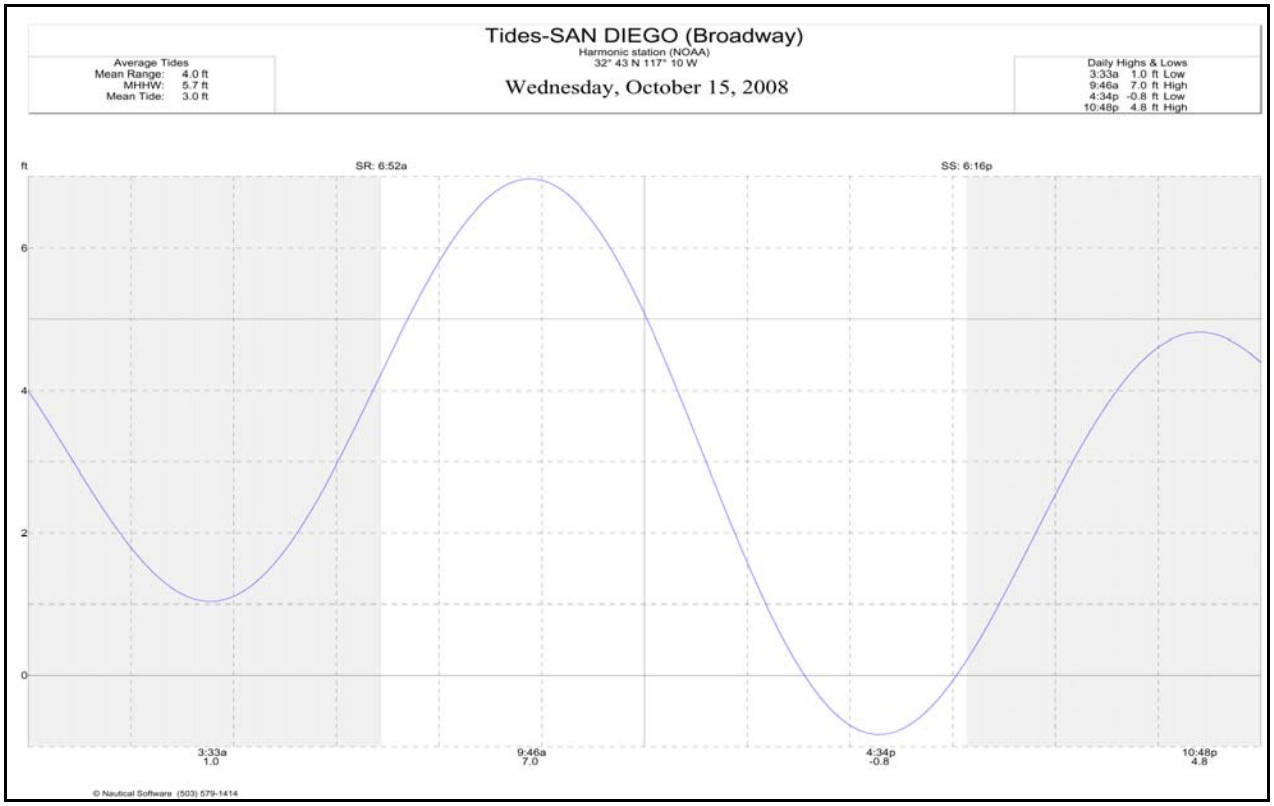


Figure 4. Tide graph for 10/15/08 showing areas of greatest change in tidal height.

3.3 Rainfall Correlations

Monthly rainfall amounts from San Diego Lindbergh Field were plotted from National Weather Service (NWS) data for January 2008 through January 2009 to examine the potential effects of rainfall on collected data parameters (Figure 7).

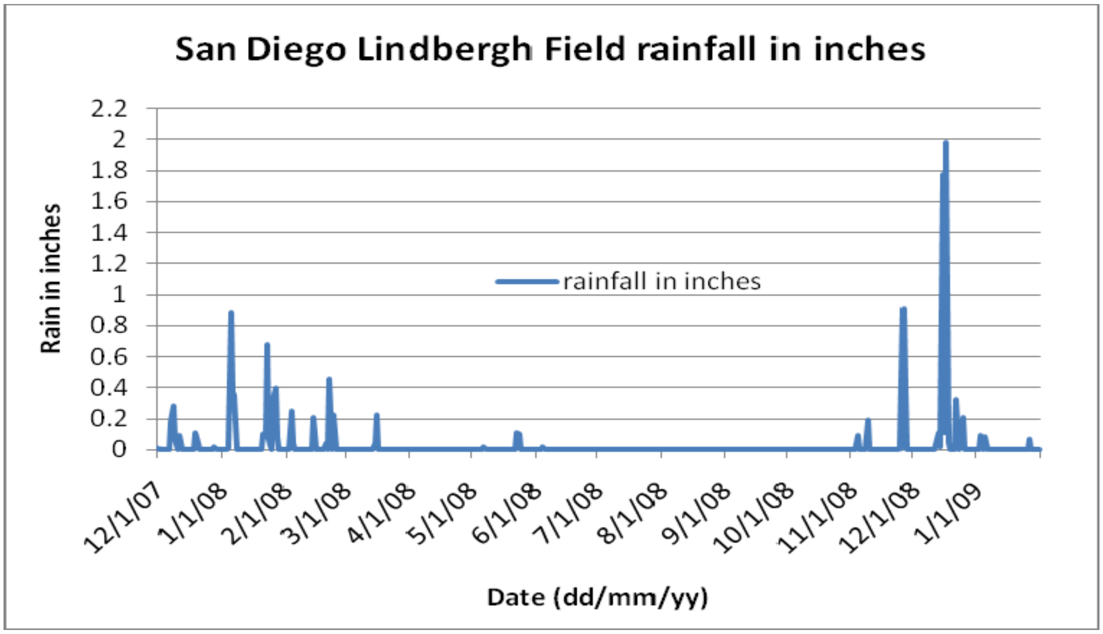


Figure 7. Rainfall in inches at Lindbergh Field, San Diego, California. Data obtained from National Weather Service (NWS) archives.

A correlation between tidal range, turbidity, and February rainfall events was observed at both Station A and Station B. The greatest tidal ranges and peak turbidity measurements followed similar trends over the same time period, and apparent anomalies at Station A during the latter part of the month were well correlated with rain events (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 probable that the fresh water introduced into the bay was not mixed to a depth sufficient to affect turbidity 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 8). Stratification of fresh water from rainfall events had varying influence on specific instrument locations and water quality characteristics as is evident in Figure 9.

Mixing and stratification are affected by several factors. Flushing rates change drastically moving away from the bay entrance. 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% 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%. This bay water mixes with ocean water. During the next flood tide, this mix gets pulled back into the Bay. 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).

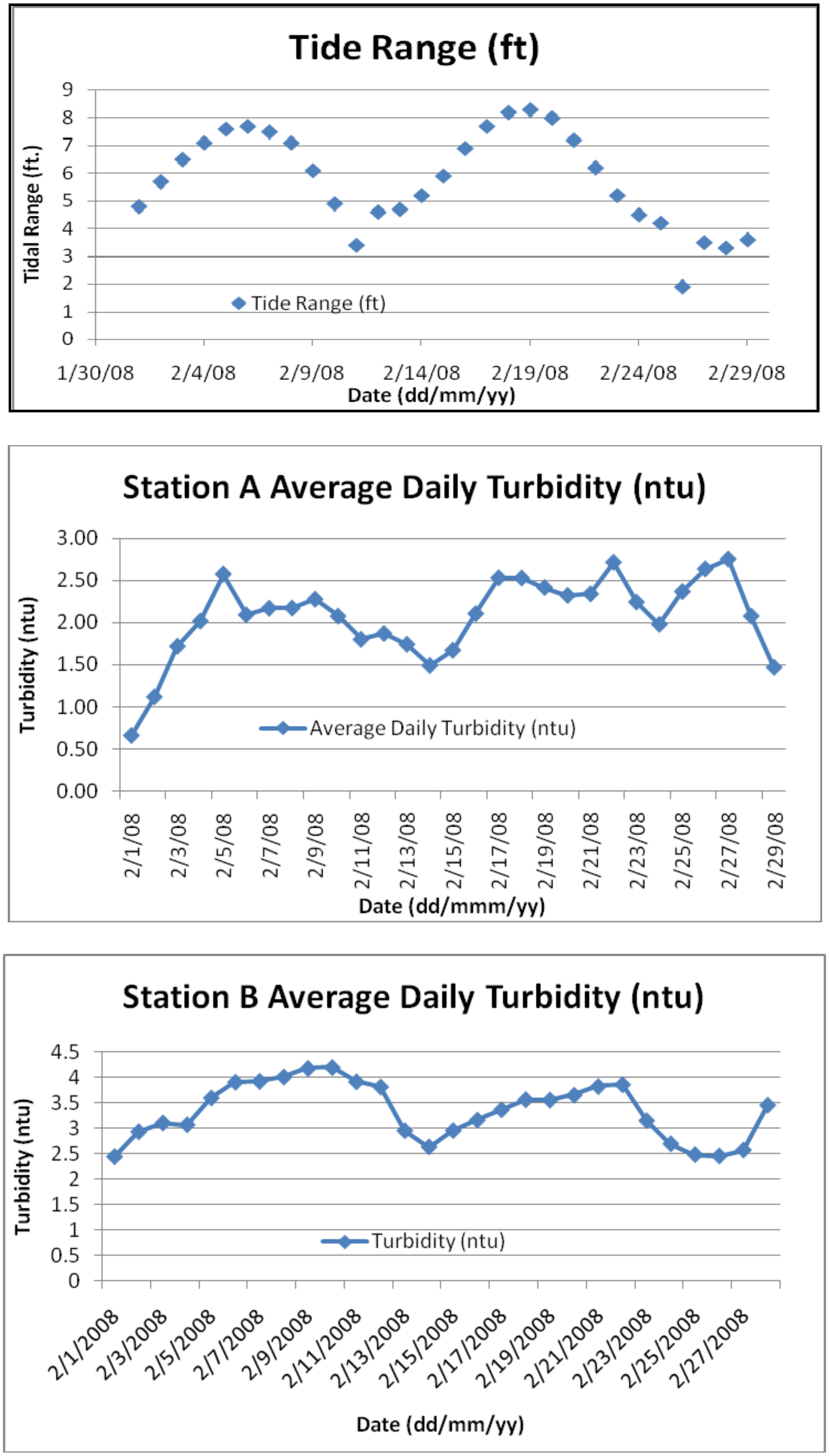
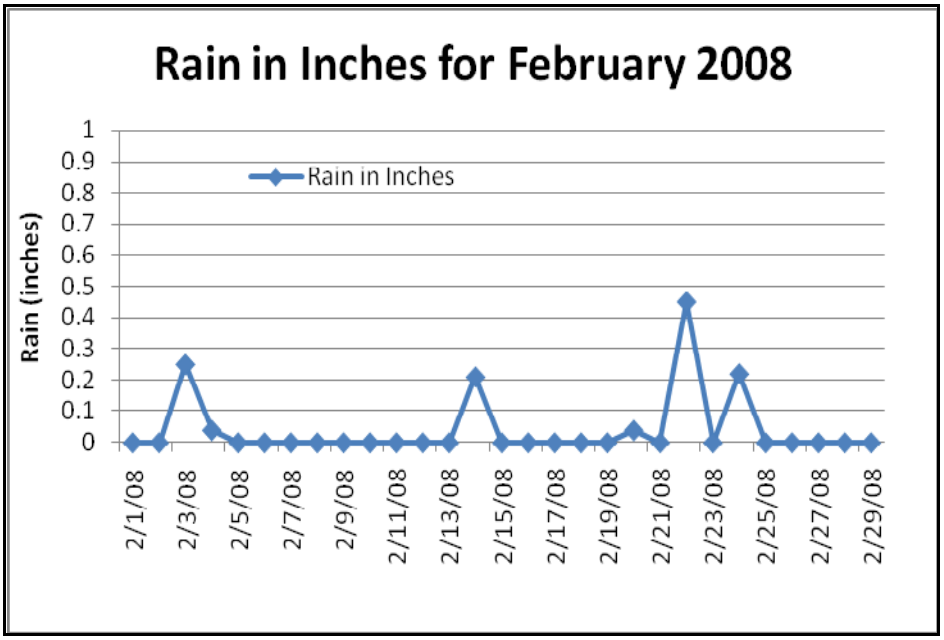


Figure 8. Average daily turbidity (ntu) for Station A and B compared to tidal range for the same time period.



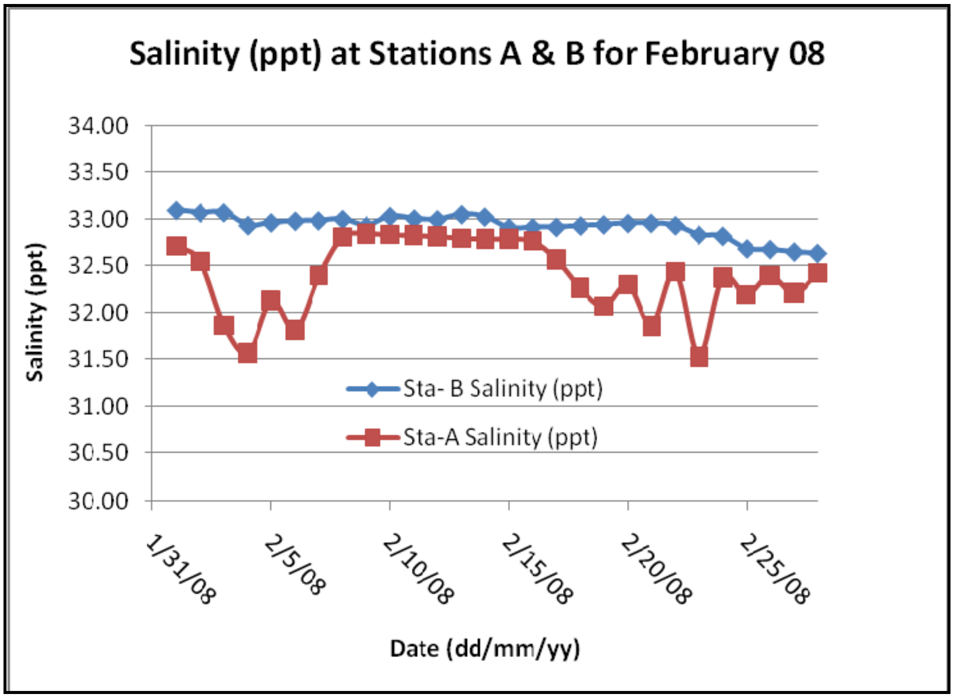


Figure 9. Average daily salinity (ppt) for Station A and B compared to rainfall (in) during the same time period.

4.0 Discussion

Results from the monitoring sites gathering water quality data varied in quality and consistency over the entire sampling period. Problems associated with fouling and calibration were identified and future data sets should become more reliable. The initial phase of this project was to examine the current equipment and methods previously utilized during the 2001 pilot study, and to determine whether the methods could be amended to obtain intended water quality measurements consistently.

The sondes currently in use, YSI 6820s, are older models configured with only one optical port fitted with a turbidity probe. The DO probes currently in use are membrane models that are easily fouled and require frequent calibration. Upgrading existing YSI equipment to the new YSI 6600's, with dual optical probes, would provide consistent higher quality, reduce the work load, and long term data consistency.

The expansion of a more consistent data set would significantly improve the ability to examine patterns and relationships between various physical 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 the relationship between chlorophyll *a* and turbidity. Dr Ken Richter, Space and Naval Warfare Systems Command (SPAWAR), collected physical water quality measurements including DO, chlorophyll *a,* and transmittivity from vertical sonde casts at multiple locations during the mid 1990s, providing additional baseline information. Future investigations intend to replicate Dr. Richter's previous vertical cast samplings as well as collect water samples for calibration and comparison.

The variability of DO measurements is a concern, and measurements appear to decrease gradually with increased deployment duration. Consultations with YSI technical staff in reference to DO inconsistencies centered on the fact that the current DO probe is a membrane type versus the newer, recommended, optical type probe. Temperature, salinity, pH, and conductivity data appeared to have few inconsistencies outside of the initial two-month testing period.

5.0 Conclusion

Problems associated with fouling of optical probes is 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. The most frequent calibration errors were associated with DO and attributed to the membrane filter currently in use. Integrating new sondes with dual optical probes would allow for sondes to be outfitted with an optical DO and turbidity probe. Old sondes could be utilized to collect chlorophyll *a* data or used to perform vertical casts at each station during sonde servicing. 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.

Further considerations regarding standardizing instrument depth for all sampling locations may be prudent in order to augment 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 the station.

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PHOTO FOR WEBSITE INTEGRATION:

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