The San Francisco Physical Oceanographic Real-Time System

EXECUTIVE SUMMARY

The San Francisco Physical Oceanographic Real-Time System (PORTS) is a decision support tool that improves the safety and efficiency of maritime commerce, coastal resource management and recreational uses of the San Francisco Bay. It integrates real-time environmental observations, forecasts and other geospatial information in user friendly, assessable formats. PORTS measures and disseminates observations and predictions of water levels, currents, salinity, and meteorological parameters. PORTS provides information that allows mariners, shippers and port operators to maximize port throughput while maintaining prescribed margins of safety for the increasingly large vessels visiting the ports of the San Francisco Bay and Delta. It is a ready source of reliable information for use by environmental managers, resource trustees, recreational users and general citizens.

The National Oceanographic and Atmospheric Administration/National Ocean Service (NOAA/NOS) funded PORTS during the Developmental Demonstration Phase. This phase lasted from October 1995 through October 1997. The Operational Demonstration phase followed and responsibility for the operation and maintenance of the system was passed to the Marine Exchange of the San Francisco Bay Area. Funding during this time was provided jointly by the California Department of Fish & Game, Office of Oil Spill Prevention and Response (85%) and the Department of Boating and Waterways (15%). This phase officially ended in 1999. Since that time the Marine Exchange has continued to operate and maintain the system with funding from a variety of legislative and other non-recurring sources.

The San Francisco Harbor Safety Committee (HSC) has recognized the role that PORTS has played in the improvement of navigational safety on San Francisco Bay. It has also been informed that the current funding for the system is inadequate, and without a new source of funding the system will be forced to close down. In the spring of 2002 the HSC responded by establishing a PORTS Funding Workgroup to explore and develop potential "recurring" sources of funding to keep PORTS operational.

The workgroup has identified both the primary and secondary users of PORTS, and that the benefits of the system are both direct and indirect. The users directly benefit by being able to operate with a greater degree of safety and an ability to take advantage of better information to maximize the utilization of their vessels and cargos. Additionally the general public and region benefit by the reduced risk of a marine casualty, and an increased ability to respond in the event a casualty does occur. It is only natural than that the cost of PORTS should also be shared between the public and the users.

This paper was put together to provide background information in support of the continuing funding of PORTS. The PORTS Funding Workgroup will be approaching the user groups to solicit support in any form with the expressed goal of finding recurring funding sources to continue to keep PORTS operational on San Francisco Bay.

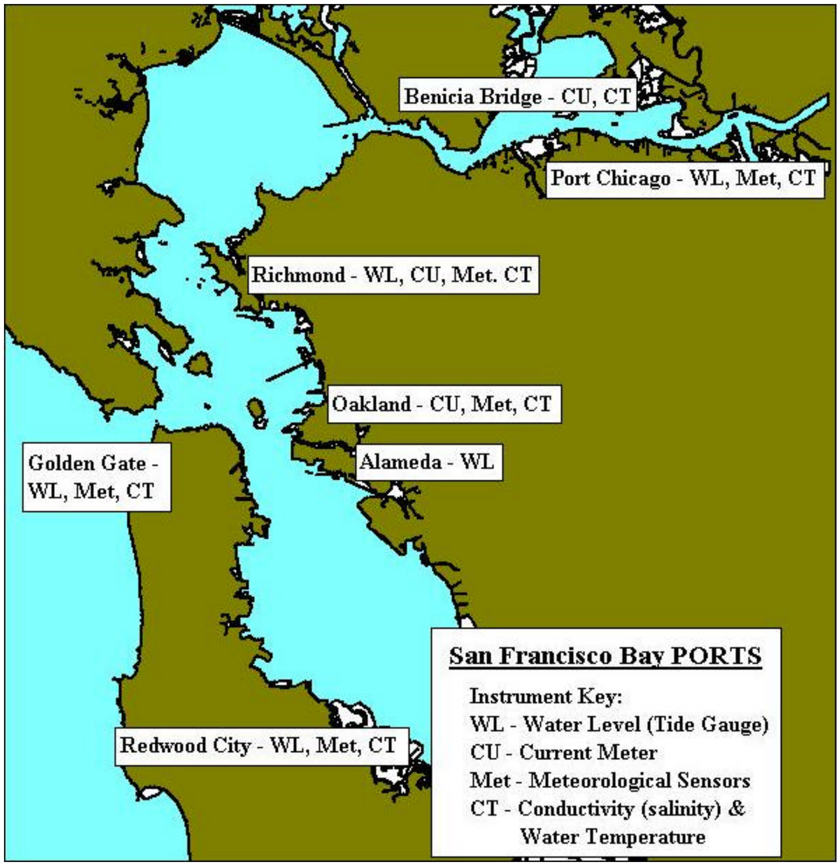

Figure 1 - PORTS Sensor Locations.

INTRODUCTION

The precursor to PORTS was developed and installed in Tampa Bay, Florida in response to the fatal collision of a vessel with the Sunshine Skyway Bridge in 1980. Since then, the system has been refined and standardized. There are now seven PORTS nationwide; Tampa Bay, Houston/Galveston, Chesapeake Bay, New York/New Jersey, Narragansett Bay, Los Angeles/Long Beach and San Francisco Bay.

The San Francisco Bay PORTS was implemented in two phases. The Developmental Demonstration Phase began in October 1995 and continued for two years. During this period, the National Oceanic and Atmospheric Administration/National Ocean Service (NOAA/NOS) installed, operated and funded the system. NOS actively worked to develop partnerships with local government and maritime interests to define needs and involve users in the development of what would become "their" system. This resulted in the second, or Operational Demonstration Phase of the San Francisco PORTS, where operation and maintenance of the system was the responsibility of the San Francisco Marine Exchange and funding was provided jointly by the California Department of Fish and Game, Office of Spill Prevention and Response (85%) and the

California Department of Boating and Waterways (15%). The Operational Demonstration Phase ended in 1999. Subsequent legislation and agreements continue to fund the San Francisco PORTS and the San Francisco Marine Exchange continues to have responsibility for system operation and maintenance.

SYSTEM DESCRIPTION

SYSTEM ARCHITECTURE

The San Francisco Bay PORTS consists of an array of sensors located throughout the Bay, connected to a Data Acquisition System (DAS) by telephone and radio communication links. The sensors provide raw data for water level, profiles of current speed and direction, water temperature and conductivity, and meteorological parameters (wind speed & direction, air temperature and barometric pressure). The DAS collects raw data every six minutes and performs initial processing and quality control before distributing information to the PORTS hub. The PORTS hub is where data is disseminated to users via Internet and voice, and where data is also made available for the generation of derived data products such as time-series plots. The DAS is linked to the Continuous Operational Real-time Monitoring System (CORMS), where NOAA employees continually monitor system status and data quality, twenty-four hours per day, seven days per week. If error checking routines note bad or suspect data, CORMS operators can run diagnostic utilities and/or initiate a service call to the sensor as required. Whenever bad or suspect data is noted, CORMS operators will program the hub to cease disseminating the affected data and issue a notice that the data is temporarily unavailable. The CORMS allows NOAA to assume full liability for the data disseminated from PORTS.

PORTS DATA DISSEMINATION

Quality controlled data from all PORTS sensors is available from the PORTS hub in near real-time, and is updated every six minutes. Users access PORTS information online via the Internet, or by telephone through an automated voice processor system.

Internet users access PORTS through the Web site of the San Francisco Marine Exchange (**www.sfmx.org**), where clicking on the PORTS icon will take the user to the PORTS hub text screen. Displayed on one screen in text format are data from each of the sensors, as well as the time and date that the data was processed by the hub. The screen will automatically update itself every six minutes. The screen will note whenever CORMS personnel have made data unavailable due to bad data or sensor problems. Users may check on instrument status and availability by clicking through the "News and Info" screen to access the "CORMS Instrument Status" page. By choosing the "Products" icon from the PORTS hub text screen, users may access a variety of data products including time-series plots of actual data and predictions, archived PORTS data available in text form or as time-series plots, or the San Francisco PORTS Research Site, provided by the United States Geological Survey. At the San Francisco PORTS Research Site users can access a variety of products derived from PORTS data, including current profile plots, models of wind and current throughout the San Francisco Bay, and other products.

Convenient access to PORTS while on vessels underway can be had by using a cellular telephone to call the PORTS automated voice processor system at (866) 727-

6787. The automated voice processor system will answer the telephone and provide the user with a series of menu choices, which the user selects using the telephone's touch-tone keypad. All of the PORTS data is available via the automated voice processor system. As with the Internet server, all data disseminated by the automated voice processor system have been quality controlled by CORMS. Users are advised when CORMS operators make data unavailable.

PORTS SENSORS

Profiles of the speed and direction of currents are produced by Acoustic Doppler Current Profilers (ADCP). These instruments are placed on the bottom of the Bay and measure the currents above by sensing the Doppler shift of acoustic signals bounced off of particles in the water column. The ADCP measures the current at discrete depth intervals, or "bins", producing a profile of current speed and direction at numerous depths from the instrument on the bottom to the water's surface. Data are reported as speed in knots and direction in degrees relative to true north. Currents near the San Francisco PORTS ADCP sensors are fairly uniform throughout the water column. At any given moment, the speed and direction vary little from the water's surface to the bottom. For this reason, the PORTS hub text screen and infobot report a single speed and direction that is representative of the current throughout the water column. PORTS users may access the full current profile (speed and direction at discrete depths throughout the water column) on the Internet through the "Products" icon from the PORTS hub text screen.

PORTS water level data are measured with acoustic tide gauges. These highly accurate sensors report water levels in feet relative to the mean lower low water (MLLW) tidal datum. This is the same datum to which nautical charts and hydrographic surveys (NOAA and Army Corps of Engineers) are referenced. When used with the nautical chart, PORTS water level data provide the mariner with information on the actual depths of water at various locations at the present time, as well as an indication of the recent trend in actual water levels (trending deeper or shallower than predicted levels, and by how much).

Conductivity sensors measure the electrical resistance of the water. These sensors are paired with instruments to measure the water temperature. Mathematical relationships using conductivity and temperature data allow calculation of the salinity and the specific gravity of the water. Salinity data are reported in practical salinity units, a dimensionless unit. Specific gravity data is reported as the ratio of the weight of the water relative to pure fresh water at 4° C. Salinity values within San Francisco Bay can vary from near oceanic levels (up to 35) to fresh water (approximately 0). Changes in the salinity (and therefore density) of the water can significantly affect the draft of vessels as they transit from ocean to brackish or fresh water and vice-versa.

PORTS measures the wind speed and direction, air temperature and barometric pressure using a suite of standard meteorological sensors. Wind speed is reported in knots, direction in degrees relative to true north, and air temperature in degrees Fahrenheit. Atmospheric pressure is reported in millibars.

PORTS RELIABILITY

At the request of the PORTS Ad-Hoc Advisory Committee, an evaluation of the San Francisco PORTS was completed in March 1999. The evaluation (Lathrop, 1999) performed a thorough review of the reliability of PORTS and found that water level, water temperature and conductivity, and meteorological data were collected and disseminated by PORTS with very high reliability, while the performance of the ADCP's was less than satisfactory. Since oceanographic and meteorological conditions often do not change significantly in time scales on the order of 10 minutes, the evaluation assessed the reliability of PORTS considering only outages that lasted more than twelve minutes. Calculated in this manner, the reliability of the combined water level, meteorological and Richmond ADCP data was 98.9% during the study period. The reliability of the ADCP's was much lower however, with the Benicia ADCP at 75%, the Oakland ADCP at 48% and the Golden Gate ADCP at less than 1%. The evaluation concluded that low ADCP reliability was not inherent in the instruments themselves, rather resulted from the hostile operating environment. Consequently, ADCP mounting platforms and data cables are being re-engineered in an effort to increase ADCP reliability.

PORTS USES AND BENEFITS

REAL-TIME WATER LEVEL DATA

Vessel access to San Francisco Bay and the port facilities therein is constrained by bars, shoals and the limits of dredged channels. The depth of water over these constraints is such that the largest vessels may not be able to transit the Bay at maximum draft, and even smaller vessels might be limited in the timing of transits to within a certain period around the time of high water. The main ship channel through the San Francisco Bar has a project depth of 55 feet, and all vessels are limited to a maximum 50-foot draft. A shoal east of Alcatraz Island has maximum depths of approximately 49 feet. The Oakland Bar Channel, the Redwood City Entrance Channel, the Southhampton Shoal Channel and the Pinole Shoal Channel are all used by vessels of such size that they cannot perform the transit at full load/maximum draft.

Before PORTS, mariners relied upon tide tables to calculate the stage of the tide and the available depth over such constraints, and adjusted vessels' draft and cargo load accordingly. The tide tables are highly accurate and reliable for calculating the stage of the tide due to gravitational forcing by celestial objects, however that is only one of the factors that influence water levels in San Francisco Bay. Meteorological conditions, fluvial inputs and water diversion all have significant effects on water levels. Depending on the factor influencing the water level, the observed deviation between actual water levels and those predicted in the tide tables may vary significantly within the Bay, and might even change sign! For instance, meteorological conditions over the North Pacific may reduce the sea surface elevation off of the California coast. Freshwater inputs in the Delta may raise water levels there. A mariner sailing through the Golden Gate and up the Bay to Sacramento might find water levels at the Golden Gate a foot lower than predicted by the tide tables. When passing Port Chicago the water levels may be a foot higher than predicted by the tide tables.

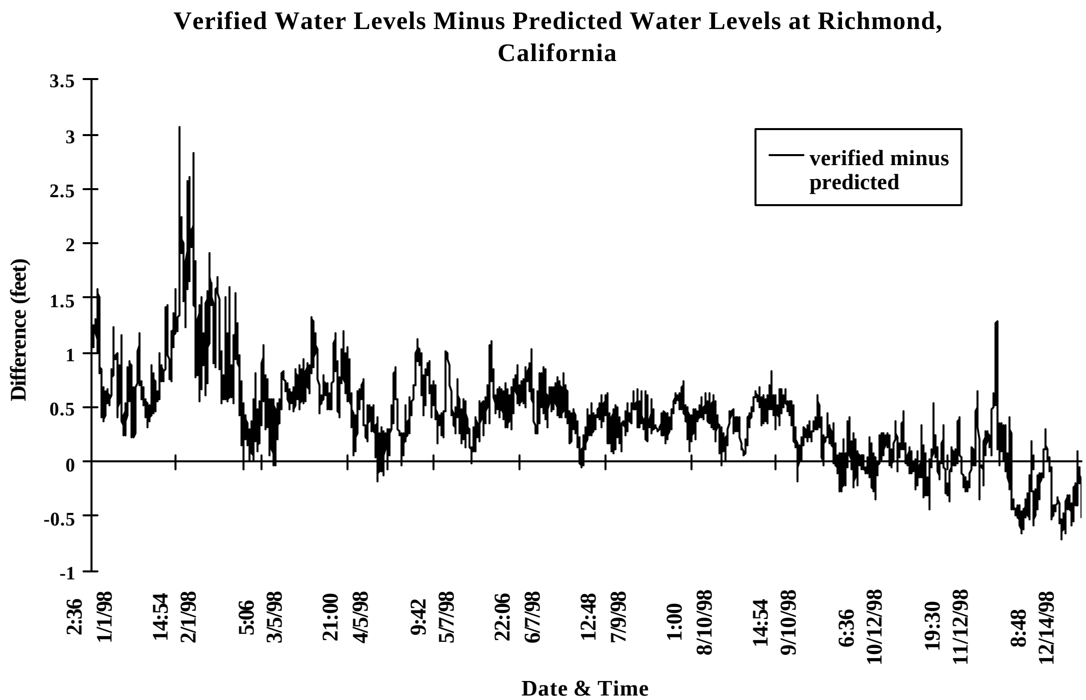

Figure 2 - The difference in water levels measured by PORTS and predicted by tide tables at Richmond, California in 1998.

The difference between actual water levels measured by PORTS and water levels predicted by the tide tables illustrates the significance of using PORTS data versus predicted tides when planning and executing vessel movements. Figure 2 shows this difference at Richmond for all of 1998. In one instance, actual verified water levels exceeded predicted water levels by more than 3 feet in February 1998. Even more significantly, actual water levels were less than predicted water levels by more than 0.7 feet in December of that year.

Significant deviations between actual water levels and predicted water levels occur a great percentage of the time. Using the same 1998 Richmond water level data as portrayed in figure 2, figure 3 shows the frequency of deviations according to the magnitude of the difference. Significant negative differences, where actual water levels were less than predicted levels by more than one-quarter foot, occurred during more than 6% of 1998. Significant positive differences, with actual water levels more than one - quarter foot greater than predicted levels occurred more than 66% of the year. Positive differences of more than three quarters of a foot occurred more than 15% of the year.

The preceding data clearly illustrate that significant differences between actual water levels and predicted water levels based on tide tables occur the majority of the time. It is obvious that tide table predictions alone are not adequate for the mariner planning and performing deep draft vessel transits, especially when vessels are loaded with the maximum cargo consistent with minimum safe underkeel clearances. Real-time water level observations and a simple model with skill at forecasting water levels several hours into the future are absolutely necessary.

PORTS fulfills this need by providing real-time water levels at strategic locations throughout the Bay, coupled with predictions based upon tide tables. Actual water levels reported by PORTS include effects from all of the factors that influence water levels in San Francisco Bay; meteorological phenomena, fluvial inputs and water diversion. These factors, while impossible to forecast their effects well into the future, change relatively slowly. It is therefore reasonable and prudent to postulate that the difference between actual and predicted water levels at the present time will persist for at least several hours into the future. This affords the mariner the opportunity to plan a movement before getting underway, with knowledge of the actual depths that will be encountered along the way. The PORTS user can access this information easily from the Internet. From the

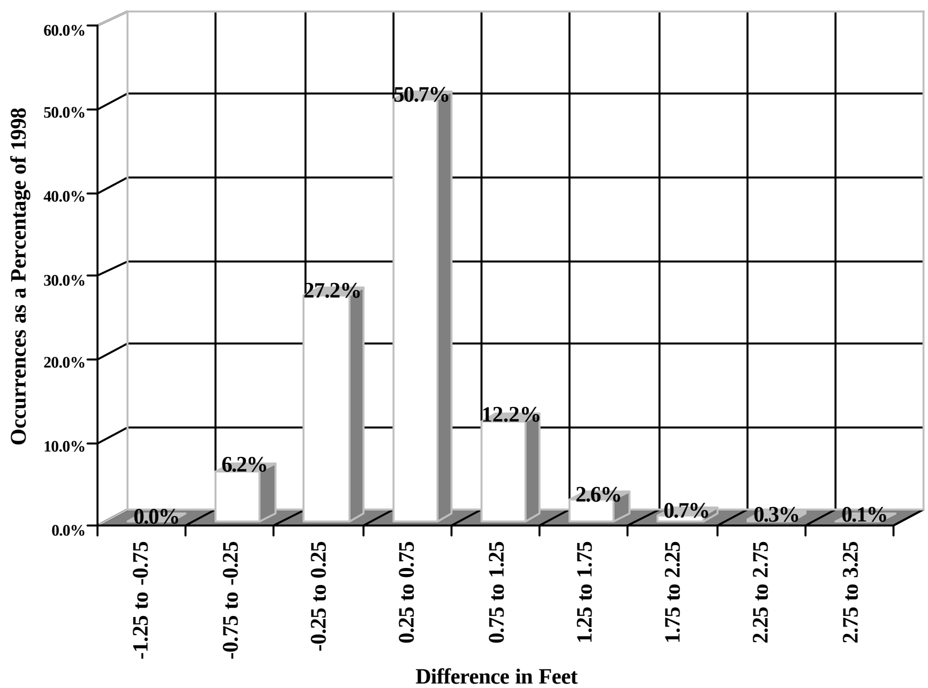

Figure 3 - Frequency distribution of differences between water levels measured by PORTS and predicted water levels at Richmond, California in 1998.

PORTS hub text screen, select "Products", then select "PICS - PORTS Image Component System". Products available from PICS include time-series plots of actual and predicted water level, with the predicted water level trendline projected several hours into the future. Figure 4 is a PICS time-series plot for water levels at Richmond. Note that the axis of the time series is 24 hours long and displays the previous 18 hours of actual water level data, as well as the previous 18 hours and future 6 hours of predicted water levels. Numeric values for the actual and predicted values are also provided.

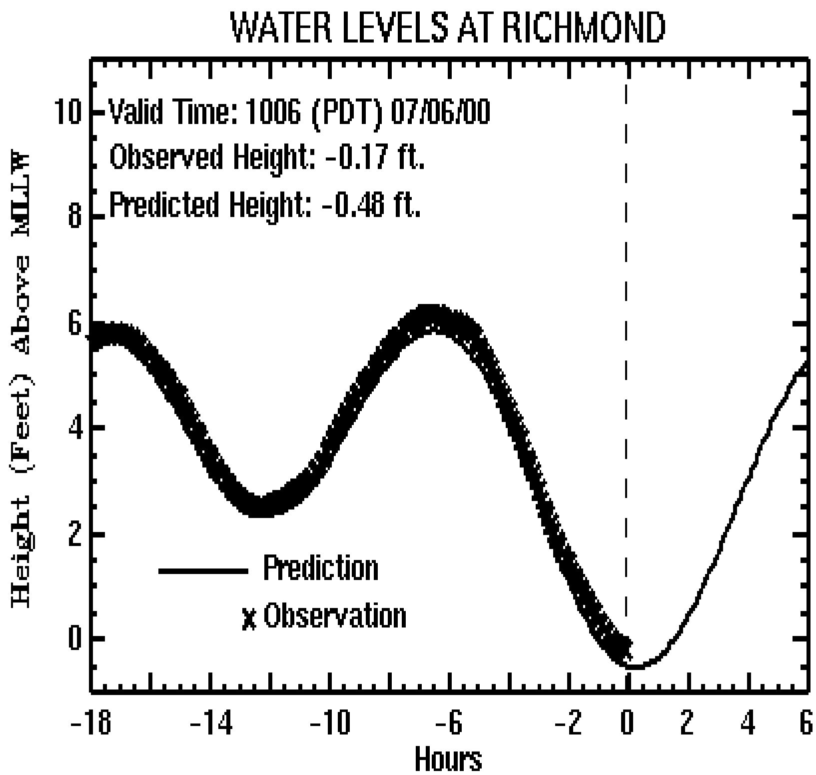

Figure 4 - PICS time-series plot of actual water levels at Richmond, California with predicted water level trendline projected 6 hours into the future.

REAL-TIME SALINITY AND SPECIFIC GRAVITY DATA

In addition to water level data, a second PORTS data set allows mariners to safely and confidently operate with minimum underkeel clearances. By measuring water temperature and conductivity, PORTS calculates the salinity and specific gravity of Bay waters. Ocean waters off of San Francisco may typically have a salinity of 35 and a specific gravity of 1.027. Upon entering San Francisco Bay, the mariner will sail in the brackish mid-Bay waters where salinity may drop to levels in the teens, with corresponding decreases in specific gravity of the water. Figure 5 portrays typical specific gravity values at Richmond. The time-series plot shows three days of summer and three days of winter data measured by PORTS. Notice that summer values fall in between winter values and the typical mid-latitude oceanic value of 1.027. The winter value of approximately 1.012 is 1.5% less than the oceanic value. This implies that a vessel's draft will ***increase*** by approximately 1.5% when transiting from the ocean to Richmond under these conditions. The effect is even greater at ports with a greater freshwater influence. At times of maximum freshwater flow, waters at Benicia may be nearly fresh, with specific gravities less than 1.005. To a mariner arriving from the ocean, this represents an increase in draft of over 2%, or 0.7 feet on a vessel with an initial 35-foot draft. The only way to assess the effect on vessel drafts of ever changing specific gravities in Bay waters is by monitoring specific gravity values in real-time. PORTS provides the mariner with the tools to conveniently perform such monitoring.

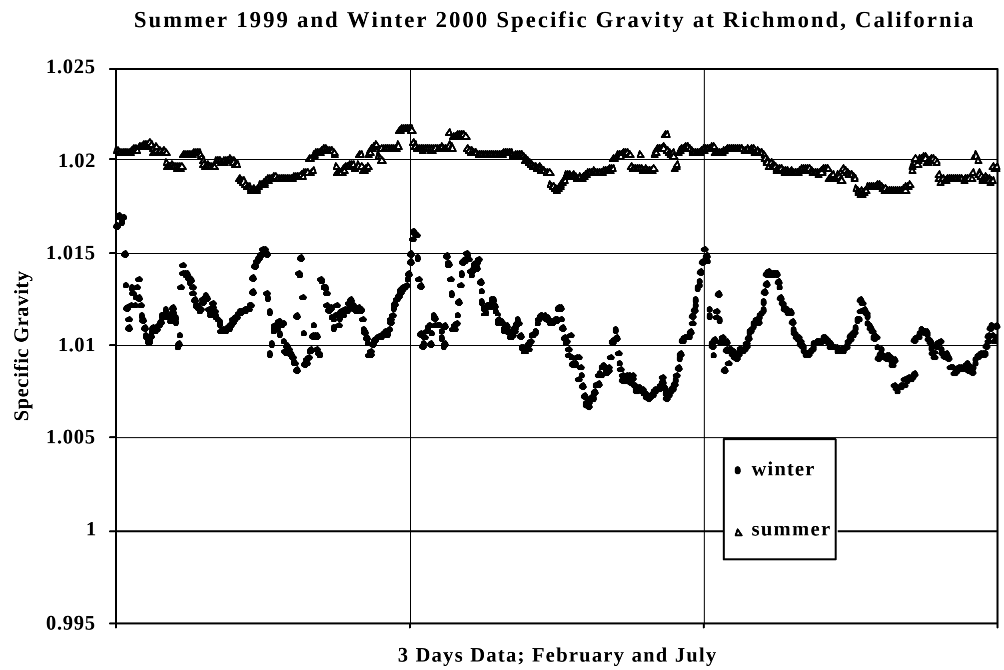

Figure 5 - Examples of specific gravity at Richmond, California for 3 typical days in winter and summer.

REAL-TIME CURRENT DATA

Acoustic Doppler Current Profilers (ADCP's) are located at 4 sites in the Bay where real-time current speed and direction data are of maximum benefit to the mariner. At the Oakland ADCP, measured currents set nearly perpendicular to the Oakland Bar Channel. Mariners entering the Bar Channel must line up on the channel centerline very shortly after passing under the Bay Bridge. The Oakland ADCP provides needed current information in this critical area.

Even more critical to mariners is the ADCP at Benicia. The Carquinez Strait is bracketed by San Pablo and Suisun Bays. These are large, shallow bodies of water, with currents that are heavily influenced by wind shear. Freshwater inputs also influence both the magnitude and timing of currents in the Carquinez Strait. At times of heavy runoff, flood currents may be severely reduced or even eliminated, with corresponding increases in the intensity and duration of the ebb current. Obviously, tidal current predictions are of little value to mariners transiting the strait or using one of the many terminals in the area. A tanker that is required to dock port side to one of the Martinez terminals has limited maneuvering room in the area west of the Benicia Bridge. Real-time current speed and direction information is critical to planning the timing of, and executing such a maneuver.

Similarly, the Richmond ADCP is situated where it provides information for vessels operating at critical areas; vessels approaching or leaving the Chevron terminal, and vessels making the 160° turn between the Southhampton Shoal Channel and the Richmond Harbor Entrance Channel. Figure 6 is an example of a time-series plot of current speed and direction from the Richmond ADCP. Similar time-series plots are available on the Internet for each of the PORTS ADCP's by accessing the "Products" page of the PORTS hub.

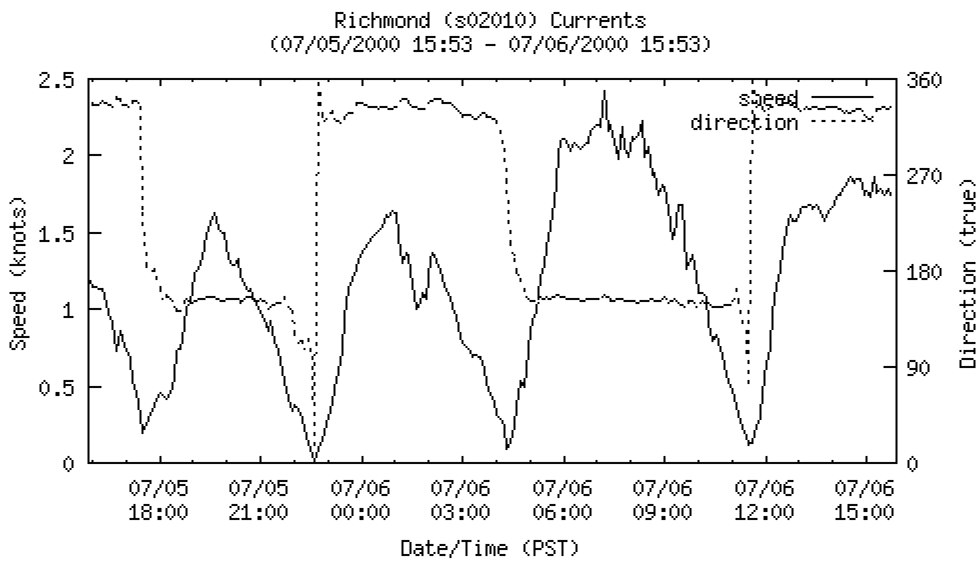

Figure 6 - Time-series plot of current speed and direction from the Richmond, California ADCP.

Another function served by the PORTS Acoustic Doppler Current Profilers does not involve navigation, however it is of vital importance to mariners and vessel owners. In the case of potential or actual oil and hazardous material spills, the NOAA Hazardous Materials Response Division (HAZMAT) works closely with the Coast Guard, the Environmental Protection Agency, the State and local governments involved, and the responsible parties, in an effort to minimize hazards and ecological and economic damage. One of the services performed by HAZMAT is to model the trajectories of spilled materials in order to advise authorities where best to employ assets for containment and cleanup. HAZMAT trajectory models employ site specific data related to the topography, bathymetry, hydrography and hydrology of the modeled body of water. The trajectory model for San Francisco Bay incorporates historic current data from PORTS ADCP's and is thus vastly improved relative to the same model without actual current data. The enhanced San Francisco Bay trajectory model demonstrated its worth in October 1996 after about 2,000 barrels of intermediate fuel oil were released from the **M/V Cape Mohican** into a dry dock. About 200 barrels of the oil overflowed the dry dock and entered the Bay. HAZMAT responded to the scene and provided trajectory analyses. While the trajectory model ran, it was constrained by real-time PORTS ADCP and meteorological data, further improving the accuracy of the results.

REAL-TIME METEOROLOGICAL DATA

Consideration of wind speed and direction are necessary aspects of pilotage, no matter the size or type of vessel. In San Francisco Bay, the proximity of cool oceanic air outside the Golden Gate to warm inland air and thermal lows, separated by hills and mountains makes for a very dynamic wind environment. Forecast winds give a picture of the general airflow over the region. They do not give adequate information for the job of piloting large vessels with considerable sail area through narrow channels. PORTS provides real time wind data at a variety of crucial navigation areas. The dynamic wind environment of San Francisco Bay and the need for accurate wind data is best illustrated by the following example. A PORTS meteorological package was in operation at Alameda, but it did not adequately characterize the winds experienced by vessels maneuvering a few miles away at the Oakland Outer Harbor. The need for real-time wind data at this critical spot prompted the Port of Oakland to request a PORTS meteorological package where it best served the vessels calling on that port.

THE FUTURE OF SAN FRANCISCO PORTS

Using PORTS, mariners in San Francisco Bay presently enjoy the ability to accurately predict the actual depth of water that will be encountered on a vessel transit within the Bay. They can precisely calculate changes to the vessel's draft that will occur as she maneuvers up or down estuary. They may use this information to maximize the amount of cargo they can safely load. The knowledge may dictate the time of arrival or departure. It could be used to determine if it is safe to delay sailing or arrival past the time of high water, and by how long. Before sailing, the master and pilot can check actual conditions that may affect sailing decisions. Once underway, a cellular telephone allows them to easily monitor critical parameters. Recreational boaters, fishers and windsurfers can also benefit from a more thorough knowledge of local wind, current, water level and salinity parameters to have a safe and enjoyable experience on the water.

New sensors are under development. Instruments to measure visibility can be a part of the future PORTS, as well as sensors to measure the air draft under bridges. Palm sized computers, equipped with radio modems and capable of sophisticated graphical displays will allow pilots to bring PORTS graphic data products to the bridge. New system architectures are being developed, integrating multiple data streams. Displays incorporating PORTS, Vessel Traffic Service and Automated Information Systems (AIS) are running today. PORTS will grow to provide the level of service and sophistication required by the mariners of San Francisco Bay.

REFERENCE

Lathrop, Douglass S., Evaluation of the Operational Demonstration Phase of PORTS, a final report to the PORTS Ad-Hoc Advisory Committee. March 4, 1999. Copies available from the San Francisco Marine Exchange.