Technical Report NOS OES 010

NATIONAL OCEAN SERVICE PARTNERSHIP: REAL-TIME ENVIRONMENTAL MONITORING IN UPPER SAN FRANCISCO BAY

FINAL REPORT

Silver Spring, Maryland
May 1996

DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

noaa National Oceanic And Atmospheric Administration

U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Office of Ocean and Earth Sciences
Marine Analysis and Interpretation Division
Coastal and Estuarine Oceanography Branch

Office of Ocean and Earth Science
National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

The Office of Ocean and Earth Sciences provides for the understanding of the coastal and ocean environment through the conduct of applied research and development in geophysics; the measurement, analyses, and product development of ocean and lake water levels; the collection, analyses, product development, and dissemination of coastal and global marine data; and the synthesis and interpretation with numerical and mechanistic modeling of global marine data sets. The Office cooperates with the U.S. Navy in conducting oceanographic activities for defense and mixed defense-civil sector purposes and applications.

It plans, develops and coordinates NOAA participation in Federally conducted oceanographic programs and activities, and facilitates cooperative programs, projects, and activities with the oceanographic research community. It monitors and analyzes oceanographic activities between NOAA and other organizations and agencies; identifies potential conflicts, overlaps, and opportunities for joint or cooperative efforts; and develops and maintains cooperative agreements, Memoranda of Understanding and other arrangements as appropriate to resolve issues and to ensure maximum benefits from programs of mutual interest. It develops and maintains inventories of oceanographic programs, projects, systems, and activities of other organizations and agencies to provide a basis for integrating current and future programs, systems and activities to ensure maximum efficiency, and effectiveness in meeting national goals and requirements. The Office conducts research and development; carries out theoretical studies, data analyses, and engineering development; and formulates and executes programs encompassing technological development and application to oceanography, geophysics, geodesy, and related fields.

For the Great Lakes, coastal estuaries, sea coast, and oceans, the Office plans, develops, and applies numerical and mechanistic models and produces predictions, forecasts, and analysis guidance materials of oceanographic and related marine meteorological phenomena; collects, analyzes, and disseminates tide and water-level observations and associated information; and computes water-level datums for hydrographic, marine boundary, and other special surveys. It evaluates and improves methods of data analysis; compares and integrates existing and new classes of data and products; provides and quality controls data sets and an array of output products; and assures science and technology transfer to and from the Office's programs and projects. The Office produces and disseminates operational marine environmental forecast and analysis guidance materials; manages and supports ocean climate studies; installs and operates real-time marine data collection systems; and formulates requirements for marine data sets and for data processing and communications systems; and designs and manages computer-based systems in support of these requirements.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
U.S. DEPARTMENT OF COMMERCE

NOAA Technical Report NOS OES 010

NATIONAL OCEAN SERVICE PARTNERSHIP: REAL-TIME ENVIRONMENTAL MONITORING IN UPPER SAN FRANCISCO BAY

FINAL REPORT

Kurt Hess, C. John Klein III, Karen Dennis, and Michael Vasey

May 1996

noaa National Oceanic And Atmospheric Administration

U.S. DEPARTMENT OF COMMERCE
Michael Kantor, Secretary

National Oceanic and Atmospheric Administration
D. James Baker, Under Secretary

National Ocean Service
W. Stanley Wilson
Assistant Administrator

Office of Ocean and Earth Sciences
David Evans, Acting Director

Marine Analysis and Interpretation Division
Frank W. Maloney, Acting Chief

Coastal and Estuarine Oceanography Branch
Bruce Parker, Chief

NOTICE

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

ACE	(U. S.) Army Corps of Engineers
ADCP	acoustic Doppler current profiler
ATT	American Telephone and Telegraph
CEOB	Coastal and Estuarine Oceanography Branch
CES	Coastal Environmental Systems (Inc.)
CMA	California Maritime Academy
CT	conductivity-temperature
CTD	conductivity-temperature-depth
DAS	Data Acquisition System
DCU	Data Collection Unit
DWR	(CA) Department of Water Resources
EC	electrical conductivity
EPA	(U. S.) Environmental Protection Agency
F	Fahrenheit
GMT	Greenwich Mean Time
kHz	kiloHertz
mb	millibar
MLLW	mean lower low water
nmi	nautical mile
NB-ADCP	narrow-band ADCP
NERRS	National Estuarine Research Reserve System
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
OES	(Office of) Ocean and Earth Sciences
OLLD	Ocean and Lake Levels Division
ORCA	(Office of) Ocean Resources Conservation and Assessment
psu	practical salinity unit
PVC	polyvinyl chloride
QA	quality assurance
QC	quality control
RDI	RD Instruments
SBE	Sea Bird Electronics
SFEI	San Francisco Estuary Institute
SFSU	San Francisco State University
USBR	U. S. Bureau of Reclamation
USGS	U. S. Geological Survey
VDRS	Voice Data Response System
µS/cm	micro-Siemans per centimeter

EXECUTIVE SUMMARY

In the spring of 1994, the National Ocean Service (NOS) began the Partnership Project, "Real-Time Environmental Monitoring in Upper San Francisco Bay", to gain more information about a critically stressed habitat, namely Suisun Bay CA, by analyzing the historical data and installing *in situ* monitoring instruments. Project activities began in April 1994 and continued until September 1995. The project focused on the potential for negative impacts of fresh water withdrawal from San Francisco Bay tributaries for agricultural and municipal uses which could lead to increased salinity in upper San Francisco Bay, especially in Suisun Bay and in the Sacramento-San Joaquin River Delta, thereby altering the habitat. At risk are the marsh and slough areas around the perimeter of Suisun Bay which provide nurseries for fish and cover for wildlife. In addition, NOAA's National Marine Fisheries Service has designated the Chinook salmon, which spawns in the Sacramento River and passes through Suisun Bay, an endangered species.

Participants in the NOS partnership included NOS's Office of Ocean and Earth Sciences (OES), NOS's Office of Ocean Resource Conservation and Assessment (ORCA), and San Francisco State University (SFSU). The project consisted of a data analysis and assessment component, a real-time monitoring component, and a data management and dissemination component. NOS/ORCA inventoried historical data, analyzed real-time conductivity and temperature data and used the results to assess existing resources, and compared data from the study period to its historical context. These analyses furthered the understanding of the impact of management alternatives for pollution abatement and helped develop future NOS monitoring plans. NOS/OES designed, installed, and maintained (from March to September 1995) a real-time monitoring system for salinity and currents in the Suisun Bay. This system was designed to help monitor the habitat for changes due to fresh water withdrawal, to provide timely data for local estuarine research and management, and to use the information for improving navigational safety and hazardous materials spill response. SFSU, the local lead agency for the San Francisco Bay components of the National Estuarine Research Reserve System (NERRS), provided coordination with local management agencies, planned a workshop on the partnership program, and coordinated local press releases.

The Partnership had two main accomplishments: (1) the analysis of historical salinity data which led to new ways of understanding and categorizing salinity variability, and (2) the design and implementation of a real-time monitoring system in Suisun and San Francisco Bays.

Based on analysis of the historical salinity data, the forcing mechanisms (freshwater inflow, tides, and winds) affect salinities in the Bay over several different time scales, including hours, days to weeks, months, seasons, and years. The importance of each of these forcing mechanisms varies, depending on the time scale being considered. In order to clarify the forcing mechanisms and time scales of variability in Suisun Bay, NOS scientists examined the changes in salinity at five stations over five different time scales, and analyzed the salinity data for both the dry season (July to September) and the wet season (February to April). These are the periods of highest and lowest salinity respectively. These data were then sorted by flow into the estuary (using daily flow values) in order to categorize the years into dry, normal, and wet. In order to categorize flows for a season, the flows for the three months in the season along with flow from the antecedent month (i.e. January for wet and June for dry) were used. The variability of salinity for each time scale for each station and each year type was analyzed.

The main accomplishments of the project are:

(1) completion of an analysis of historical salinity data which indicated that, with salt water intrusion into Suisun Bay during dry springtimes, the salinity in Suisun Bay is not only higher than normal but the salinity variability at all time scales is lower,

(2) identification of Grizzly Bay, which is representative of the shallow nursery areas of Suisun Bay and lies north of the heavily-monitored deep natural channel, as a location in need of more monitoring,

(3) deployment of two continuously-operating solar-powered, radio-linked salinity (conductivity) and temperature sensors in remote sites far from commercial power sources but in environmentally-sensitive locations,

(4) establishment of the components (sensors, communications, central data collection, data dissemination) of a real-time environmental monitoring system in Suisun and San Francisco Bay that is not constrained to dockside locations, and

(5) establishment of the foundation of a Physical Oceanographic Real-Time System (PORTS) for navigation and oil spill risk mitigation that includes currents near Benicia Bridge which assist ship maneuvering to avoid collisions and water density which assist ship loading to increase capacity.

This Partnership ended in October 1995. Since that time, there have been some changes to the system, and additional current meters and water level sensors have been installed. This document, however, describes the system as of the end of the Partnership.

1. INTRODUCTION

In the spring of 1994, scientists from the National Ocean Service's (NOS's) Office of Ocean and Earth Sciences (OES), the Office of Ocean Resources Conservation and Assessment (ORCA), and San Francisco State University (SFSU) began work on the project for "Real-Time Environmental Monitoring in Upper San Francisco Bay" (Hess et al., 1994). The project was designed to gain more information about Suisun Bay, CA, a critically stressed coastal marine habitat, by assessing the historical data and installing *in situ* monitoring instruments. This report documents the work accomplished by that project.

The project focused on the negative impacts of fresh water withdrawal from San Francisco Bay tributaries for agricultural and municipal uses which has increased salinity in upper San Francisco Bay, especially in Suisun Bay and in the Sacramento-San Joaquin River Delta, thereby altering the habitat. Areas at risk include the marsh and slough areas around the perimeter of Suisun Bay that provide nurseries for fish and cover for wildlife. The National Oceanic and Atmospheric Administration's (NOAA's) National Marine Fisheries Service has designated the Chinook salmon, which spawns in the Sacramento River and therefore passes through Suisun Bay twice during its lifetime, an endangered species. In addition, Carquinez Strait is at risk of hazardous substance spills because of tanker traffic to nearby oil storage plants. After careful consideration of all these factors, real-time monitoring of salinity and currents was identified as the solution best suitable for identifying times of high salinity intrusion, assessing the potential for habitat degradation, and improving navigational safety.

Overview of the Management Issues

Fresh water withdrawal from the Sacramento-San Joaquin system is a highly political and complex scientific issue. Five federal agencies - US Geological Survey (USGS), Environmental Protection Agency (EPA), US Bureau of Reclamation (USBR), Army Corps of Engineers (ACE), and US Fish and Wildlife - and three state agencies - Department of Water Resources (DWR), Water Pollution Control Board, and Department of Fish and Game - all have different (and sometimes competing) missions related to the hydrologic system. DWR maintains the State Water Project, a system of impoundments and canals that catch and divert freshwater runoff from the Sierra Nevada mountains and other sources during the high-runoff spring season (January to May) to supply municipalities and others that have permits to use water. USBR maintains a similar system, the Central Valley Project, designed originally to supply water for agricultural users. Numerous local farmers in the Delta withdraw water directly from the tributaries in unregulated and unmonitored quantities. Additional water is lost through percolation and evaporation. Because tidal currents are so large relative to the mean freshwater current, it is impossible to measure freshwater discharge into Suisun Bay directly; DWR therefore developed and operates a numerical hydrologic model to estimate total flow.

It has long been recognized that diversion of fresh water from San Francisco Bay is detrimental to estuarine habitat and wildlife (Rozengurt, 1983). In particular, the shallow areas of Suisun Bay are spawning and nursery grounds for the Delta smelt, a threatened species. Suisun marsh, the largest brackish water marsh on the West Coast, is the home for a variety of waterfowl, including ducks.

The fresh water/brackish water interface is an especially productive region, and the 2 psu isohaline was selected, somewhat arbitrarily, to identify it. The location of the 2 psu isohaline, as measured along the Bay from the Golden Gate, is called X2. Numerous environmental indicators have been statistically related to X2 (SFEP, 1993).

Several local agencies are engaged in environmental monitoring programs focused on the measurement of salinity in Suisun bay. DWR is presently monitoring conductivity and temperature (and several other parameters) continuously at three locations in Suisun Bay - Martinez, Mallard Island, and Antioch (Figure 1.1) - to determine X2. Their equipment includes flow-through analyzers mounted on docks or piers with intakes approximately 2 meters below the surface. Some locations have an additional conductivity sensor located near the bottom but some distance away from the near-surface sensor. The data are analyzed and sent by microwave radio to the state-operated California Data Exchange in Sacramento. The USBR maintains continuous monitoring stations at Port Chicago, Pittsburg, and Collinsville. Although there are additional monitoring sites located in the marsh and slough areas, in Suisun Bay the stations are all located along the main channel near the southern shore.

Specific concerns about fresh water withdrawal were addressed in a series of science-policy-management workshops beginning in August 1991 that were sponsored by EPA's San Francisco Estuary Project (SFEP) (San Francisco Estuary Project, 1993). The workshops resulted in the following recommendations: (1) salinity, as measured 1 meter above the bottom, be the index for developing standards; (2) X2 be the index for species abundance/survival; (3) X2 serve as an indicator of total freshwater inflow; and (4) a series of (at least) six near-surface and near-bottom salinity sensors be maintained along the main channel from Carquinez Bridge to Emmaton and the data be telemetered to a convenient location. Ultimately, these data could be used to assess impacts of fresh water diversion and distribution policies.

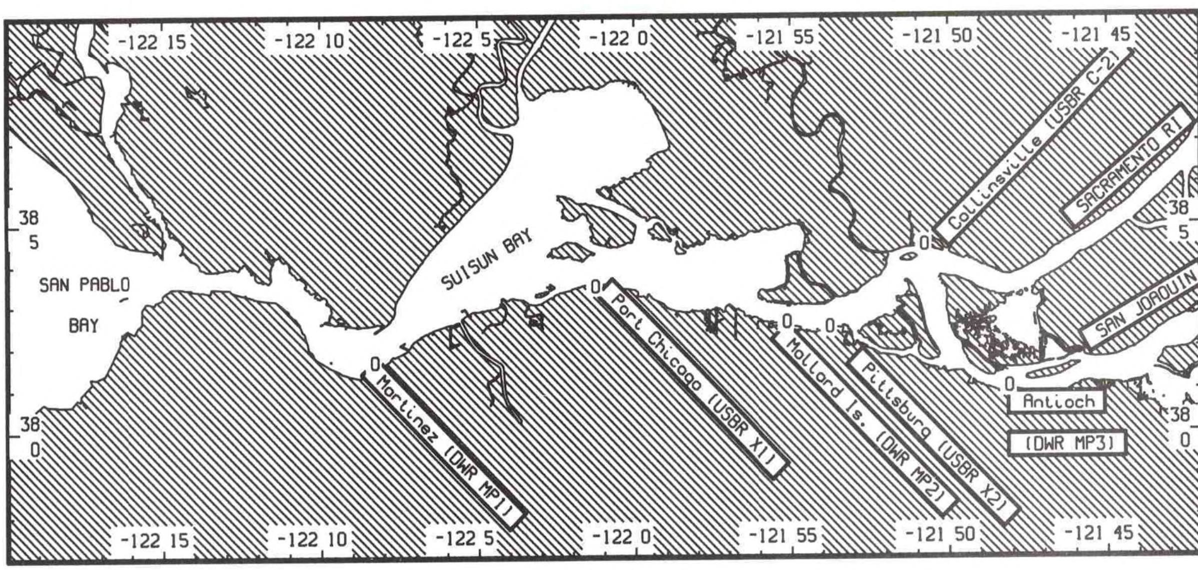

Figure 1.1. Locations (denoted by an "O") of the existing California Dept. of Water Resources (DWR) and U.S. Bureau of Reclamation (USBR) continuous monitoring stations around Suisun Bay.

Subsequent to the workshop's conclusion, DWR, USBR, and USGS have worked cooperatively to address some of the above needs. Several real-time salinity/conductivity monitoring stations have been installed on piers along the main channel, although funding limitations have prevented the creation of the extensive monitoring system that was recommended in the workshop.

In developing its strategy, the Partnership examined how best to augment the monitoring program that was already in place. The Partnership assessed first, the need for additional stations along the channel and second, the need for stations in other parts of the system. Data from DWR and USBR shows that the daily variation of X2 due to tidal currents is about 10 to 15 km (Figure 1.2). This distance approximately equals the spacing of the existing continuous monitoring stations, so the spacial sampling is probably sufficient.

However, since Suisun Bay and marsh comprise a complicated hydrologic region, it is not clear how salinities measured from piers located some distance from the navigation channel along the south shore can be related to the health of the entire ecosystem. Low springtime salinities would occur in a completely natural system, although the important timescales of salinity variability are not known. The relationship between salinity measured in the lower bay and the salinity in the marshes and sloughs is not well understood. Therefore, there are many research questions that must be addressed before better management practices can be formulated. Therefore, USGS has

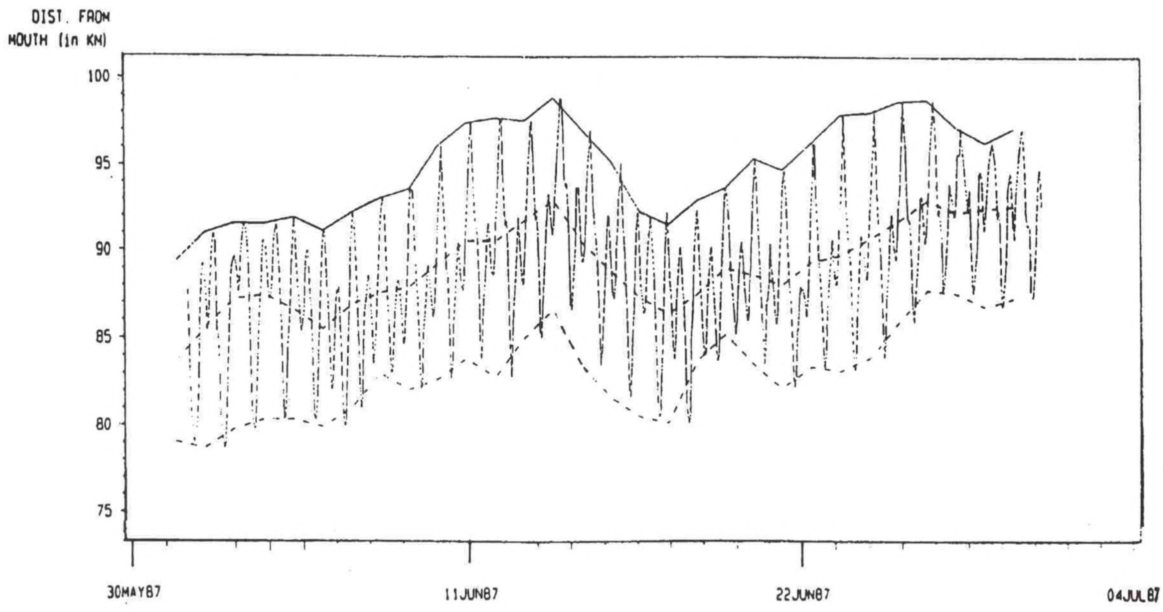

Figure 1.2. Hourly values of X2 for a representative time period. A value of 3000 µS/cm at the surface corresponds (approximately) to 2 psu at the bottom of the water column. X2 values were determined from hourly values of conductivity at existing monitoring stations. Daily variations, which are due primarily to tidal currents, are approximately 10 to 15 km, which is roughly the distance between existing monitoring stations. For reference, Pittsburg is located at 76 km, Collinsville is at 81 km, and Emmaton is at 94 km.

been investigating fine-scale patterns of circulation and salinity at a variety of points at short time intervals during the past several years. Their preliminary findings suggest that mixing patterns are much more complex then originally envisioned. The most glaring gap in knowledge concerns the secondary channels and the shallow embayments north of the main channel. Ironically, these settings are generally regarded as the most important rearing habitats for imperiled fish species, such as the Delta smelt. As a result of the first few meetings, it became evident that the significant gaps in baseline knowledge concerning the system precluded an intelligent monitoring design with specific management applications. The consensus by all parties was that the project could best assist the overall effort by beginning to fill the gaps in the existing monitoring system.

Accordingly, the following strategy evolved: (1) Analyze the present, course-grain monitoring system by reviewing data generated over the past 30 years and assess patterns of variability at different time scales, and (2) participate with USGS and others in building a fine-grain image of circulation and salinity patterns in the region that covers all major physiographic features and provides the foundation to correlate various salinity patterns in these different settings with the baseline monitoring system that is currently in place. This fine-grained analysis should then enable a consortium of responsible agencies to design a more accurate and meaningful long-term monitoring program designed to manage flows to promote ecosystem health.

The Partnership

To meet the above-identified needs, a Partnership was formed that included scientists with unique capabilities from NOS's Office of Ocean and Earth Sciences (OES), NOS's Office of Ocean Resource Conservation and Assessment (ORCA), and San Francisco State University (SFSU). Activities of each group are described below.

ORCA's Physical Environments Characterization Branch inventoried historical conductivity and temperature data, analyzed the data, and compared data from the study period to its historical context. These accomplishments advanced the understanding of the impact of management alternatives for pollution abatement and helped develop NOS monitoring plans.

OES's Coastal and Estuarine Oceanography Branch (CEOB) and Ocean Systems Development Group (OSDG) designed, installed, and maintained a real-time monitoring and data dissemination system for salinity and currents in the Suisun Bay from March to September 1995. This system was designed to help monitor the habitat for changes due to fresh water withdrawal, to provide timely data for local estuarine research and management, and to use the information for improving navigational safety and hazardous materials spill response.

SFSU provided coordination with local management agencies, planned a workshop on the Partnership program, and helped develop ideas for continued funding of the system. SFSU also assisted in the creation of a news column describing the system and, through its Romberg-Tiburon Laboratory, provided ship support. SFSU is the local lead agency for the San Francisco Bay components of the National Estuarine Research Reserve System (NERRS).

For these activities, OES received $172,000, ORCA received $24,000 (this amount was $10,000 less than requested), and SFSU received $36,000. NOS and SFSU staff who worked on the project are listed in Appendix A.

NOS and SFSU worked closely with several Bay Area groups, including the California Maritime Academy (CMA), which provided a location of the data dissemination computers; the USGS in Sacramento, which has research, monitoring, and modeling experience in Suisun Bay; and the California DWR, which has an established real-time conductivity monitoring program. In addition, the US Coast Guard provided ship time for installation of the current meter; the USBR, which maintains numerous continuous monitoring sites in the Delta, provided historical data; and the San Francisco Estuary Institute (SFEI) in Richmond has been a continuing supporter of the project. The names of the Bay area scientists who participated in, or were contacted about, the project are given in Appendix B.

Related NOS Activities in the Bay Area

At the outset of the Partnership, NOS had several ongoing activities in the Bay area that were relevant to the project. NOS maintains a coast-wide system of tide gauges (the National Water Level Observational Network) with sensors located at the Naval Weapons Station Concord (formerly Port Chicago) on Suisun Bay, Alameda near Oakland, and San Francisco at the Presidio near the Golden Gate. Data from these gauges were incorporated into the real-time monitoring system. NOS was also studying the feasibility of installing a physical oceanographic real-time system (PORTS) in the Bay to support the marine navigation community; because of a specific request from the local pilots, the current meter originally planned for the Carquinez Bridge was moved to the Benicia Bridge. NOS completed its last full circulation survey of the Bay in 1980, and completed a quality-assurance mini-project in April and May 1992. As a result of NOS's continuing assessment of the quality of its products, it was determined that the tidal current charts for San Francisco Bay were no longer reliable and they were subsequently withdrawn from distribution. Data collected in this project will be used to improve NOS tidal current predictions and CEOB has begun development of a digital tidal atlas to provide tide and current predictions with a desktop computer. Finally, OES's Ocean and Lake Levels Division has installed temporary tide gauges in the area to support US Army Corps of Engineers (USACE) dredging activities.

Organization of this Report

The remaining sections of this report cover the following topics. Section 2 describes the historical data analysis and the likely changes in habitat with increased fresh water withdrawal; a more complete analysis is given by Dennis and Klein (1995). Section 3 describes the real-time monitoring system, including development, installation, sensor locations, and a typical screen display of the data. Section 4 shows time-series plots of most of the types of data gathered by the monitoring system. Section 5 contains a discussion of the entire project, Section 6 summarizes the project, Section 7 acknowledges all those who participated, and Section 8 contains references.

NOS and SFSU staff who worked on the project are listed in Appendix A. The names of the Bay area scientists who participated in, or were contacted about, the project are given in Appendix B. Appendix C gives a brief overview of all the locations where real-time monitoring equipment are situated and briefly describes the system hardware at each place. Appendix D describes times of data loss and a few issues concerning data quality.

2. ANALYSIS OF HISTORICAL SALINITY DATA

The purpose of the ORCA component of the Partnership is to understand salinity variability in Suisun Bay, and thereby determine the best locations for additional monitoring stations. Using the available historic salinity record, we have investigated the salinity variability in two ways: 1) variability of salinity at each station, and 2) variability of the location of the 2 psu bottom isohaline. The location of the 2 psu bottom isohaline, measured in kilometers from the mouth of San Francisco Bay is called X2 and is significant because it correlates with several biological resources (San Francisco Estuary Project, 1993).

Time Scales of Variability

Analysis of the variability for both salinity and X2 was performed for each of the time scales shown below, each of the year-type groups (wet, normal, dry, and critically dry), and each of the stations, using the following methods:

Hours	The maximum minus the minimum hourly values for each day was averaged over each of the three month periods. For the USBR data prior to 1988, only the daily average, maximum, and minimum were retained. For these years, the hourly variability was calculated as the difference between these reported maximum and minimum values.
Days	The maximum difference in consecutive daily values each month was averaged over each of the three month periods.
Days to Weeks	The maximum minus the minimum of the daily averaged values for each month was averaged over each of the three month periods.
Months	The maximum minus the minimum of the monthly averaged values was calculated for each of the three month periods.
Seasons	The difference of the average of the yearly three month period average for each three month period (wet versus dry) was calculated.

Salinity Variability Over Time

Salinity variability at different time scales in the bay is caused by several forcing mechanisms. Those which have the largest impact on the system are daily tides, spring/neap tides, and freshwater inflow. Wind also plays a role in forcing variability in the bay, but to a lesser extent. At the time scale of hours, the daily tidal cycle is the major forcing mechanism. At the time scales of days, months, and seasons the major forcing mechanism is freshwater inflow. Two forcing mechanisms impact the variability at the days-to-weeks scale: the spring/neap tidal cycle and freshwater inflow.

The average number of days between monthly salinity maximums and minimums (which determines days-to-weeks variability) is 15 to 18 during the February to April period, and 13 to 18 during the July to September period. This implies the influence of the spring/neap cycle, which is about 14 days long. The influence of freshwater inflow can be seen in the individual monthly values, which range from one to 30 days.

The most important change in salinity structure and variability in the Suisun Bay system is between normal and dry year types. This is because conditions over recent years have become increasingly dry. The most recent decade of data covers 1982 to 1992; the state of California has classified 7 of the 10 years as dry or critically dry. The drought conditions that have prevailed in recent years are also evident in both the high inflow season (February to April), where 7 of the 10 years are characterized dry, and in the low inflow season (July to September), where 5 of the 10 years are characterized dry. Therefore, the comparison of normal to dry years approaches a comparison of normal to present day conditions. Figure 2.1 shows the changes in both X2 and salinity structure and variability from normal to dry conditions.

The most significant change in salinity structure and variability from normal to dry conditions is the change in the X2 position during the February to April high-inflow season. The location of the X2 in normal years is at Port Chicago (km 64), while in dry years it is located near Collinsville (km 82). This shift of almost 20 km has a major impact on habitat availability.

The stationary features in the region around Port Chicago include significant shallow and marshy areas known to be important spawning and nursery habitat for many fish species. Analysis of data for Grizzly Bay, a large shallow embayment to the north of Port Chicago, shows that both salinity structure and variability are similar to Port Chicago, suggesting that when X2 is located at Port Chicago, conditions in Grizzly Bay are favorable for spawning and nursery areas.

In contrast, Collinsville is located at the confluence of the Sacramento and San Joaquin rivers, where the estuary is deep and narrow and there are not many shallow marshy areas. In addition, during the February to April high-inflow period, salinity variability at all time scales is also greater at Port Chicago in normal years than at Collinsville in dry years.

The change in the salinity structure and variability from normal to dry years can also be seen by comparing dry years during the February to April high-inflow season to normal years during the July to September low-inflow season (Figure 2.2). During dry conditions, the high-inflow salinity structure and variability are similar to that of low inflow during normal years. Therefore, the changes in recent years have caused the high-inflow period to be similar to normal conditions during the low-inflow period. This will have a significant impact on species spawning during high inflow.

Because much important habitat is located in the shallow embayments of Grizzly and Honker Bays, it was necessary to develop a relationship between them and the main stem of the estuary, where the majority of data are located. Biweekly data were available from 1975 to the present for Grizzly Bay. These data show that Grizzly Bay has a salinity structure similar to Port Chicago. The variability is also similar for normal and wet years. However, for dry years the monthly variability is higher, and the seasonal variability lower, than at Port Chicago.

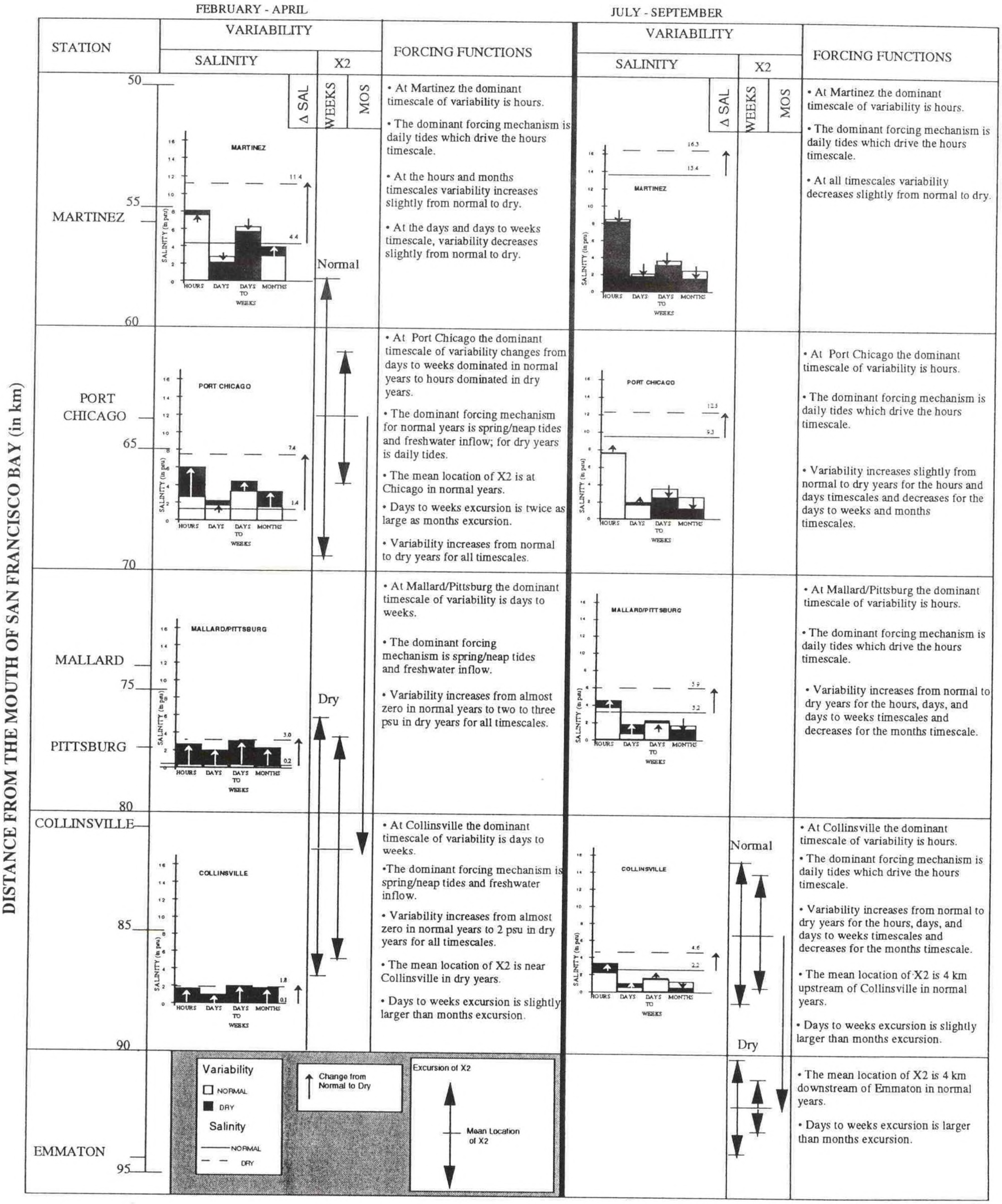

Figure 2.1. Changes in both X2 and salinity structure and variability from normal to dry conditions for the high inflow period (February to April) and the low inflow period (July to September).

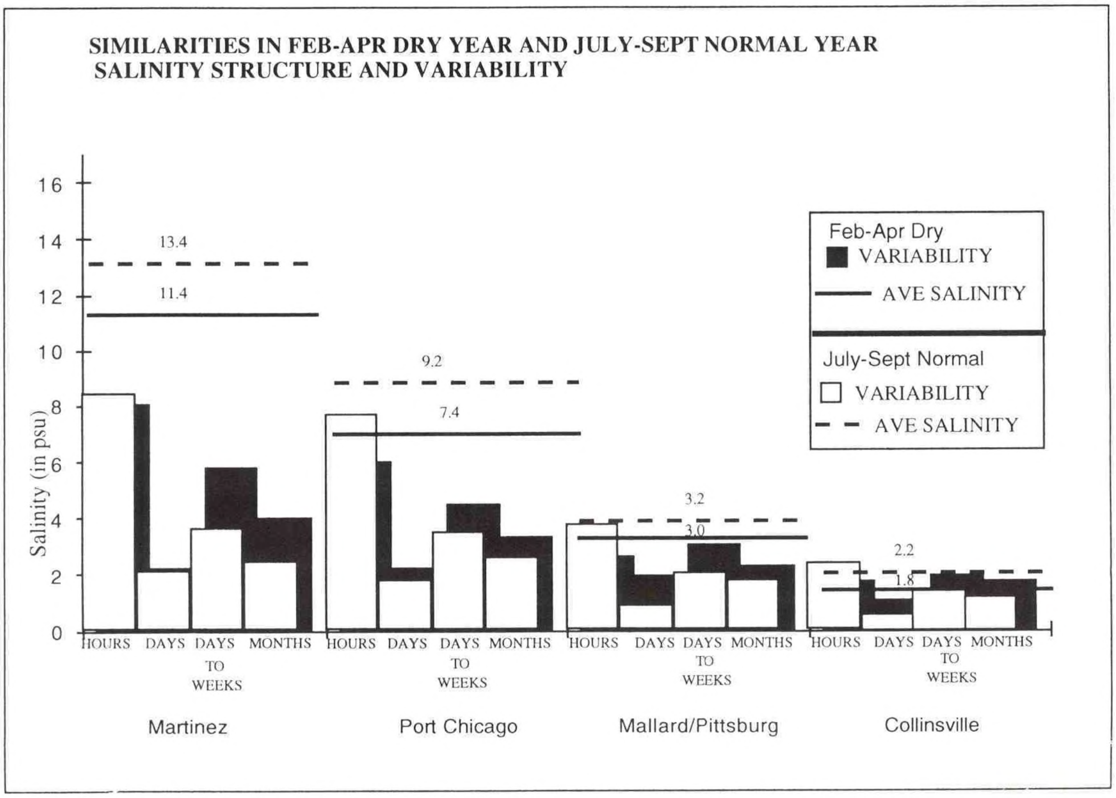

Figure 2.2. The change in the salinity structure and variability from normal to dry years can also be seen by comparing dry years during the February to April high-inflow season to normal years during the July to September low-inflow season.

The increase in monthly variability in Grizzly Bay is probably due to a larger impact of freshwater inflow on salinity variability during dry years, possibly due to use of the tide gate on Montezuma Slough to pump freshwater through the marsh. The decrease in seasonal variability is caused by slightly depressed salinities during the low-inflow period in Grizzly Bay, as compared to Port Chicago. In Honker Bay, the salinities are between the values at Port Chicago and Mallard/Pittsburg for dry years and are similar to the values at Mallard/Pittsburg for normal and wet years, while the monthly and seasonal variability is similar to that of Mallard/Pittsburg. This analysis illustrates the importance of collecting continuous data in Grizzly and Honker bays, to facilitate comparison of the hours, days, and days-to-weeks time scales of variability with that of the main stem.

Significant information can also be obtained by examining changes in the location of X2 from normal to wet years. During the high-inflow period, X2 only moves one kilometer downstream between normal to wet years, even though a much larger quantity of freshwater enters the bay. This is because a logarithmic relationship exists between freshwater inflow and the location of X2 in the vicinity of Port Chicago, which is the location of X2 during normal and wet years. Freshwater inflows in excess of a certain threshold value in this area tend to compress longitudinal salinity gradients without significantly moving the position of X2. This is important information for regulating the system since, after a certain point, the addition of more freshwater will have little impact on the position of X2.

3. REAL-TIME MONITORING

The real-time monitoring system was designed and installed substantially as described in the Partnership plan and it has worked admirably over the last several months of FY95. Design of the system was accomplished by a team lead by CEOB with critical support from OES's Ocean Systems Development Group (OSDG) and Ocean and Lake Levels Division. The system as installed comprises a major portion of the still-developing San Francisco Physical Oceanographic Real-Time System (PORTS).

Physical Oceanographic Real-Time Systems (PORTS)

The real-time environmental monitoring system installed in Suisun Bay was patterned after, and based on the experience of, the PORTS installations in Tampa Bay and in the New York/New Jersey Harbor. However, the San Francisco Bay system is the first to incorporate remote, solar-powered salinity stations and the first to be designed primarily for environmental monitoring rather than navigational safety.

Tampa Bay PORTS was installed in 1990 as a component of the Tampa Bay Oceanography Project (NOS, 1990; Frey, 1991). It consists of two current meters, five meteorological station, and four water level stations. The central computer data collection computer, originally located at the USCG base, St. Petersburg, is now housed at the University of South Florida campus at St. Petersburg (Bethem, 1991; Appell et al., 1994). Statistics on the use of the voice-data response system are given in Bethem (1995). The New York/New Jersey system was installed in 1994 (Wilmot et al., 1994) and consists of a current meter, four water level stations, and a meteorological, salinity, and water temperature station. Subsequent to the installation of the San Francisco system, an additional system has been deployed in Galveston Bay.

System Design and Installation

The system includes six remote salinity-temperature data collection units, attached in pairs to three data transmission units; one current meter; three water level gauges; one meteorological sensor system; a remote data relay site; and a central data computer with a Voice Data Response System located at CMA. A schematic overview of the entire system is shown in Figure C.1.

The remote salinity data collection and transmission system was designed by OSDG. Two vendors were contacted concerning the remote data collection and transmission hardware. After considerable evaluation and discussion over the summer of 1994, the system produced by Coastal Environmental Systems (CES) of Seattle WA, was selected. After discussions with ORCA based on their meeting with representatives of the Contra Costa Water District, DWR, USGS, and USBR, it was decided to deploy CTs at remote sites in Grizzly Bay and Honker Bay (see Figure 3.1) because those locations have suitable mounting platforms (existing pilings), are far from existing monitoring stations, and are near an environmentally-sensitive area (the Suisun marsh). At the same time, it was decided to locate the remote data receiving station, which would collect data radioed from the Grizzly and Honker Bay sites, at the Benicia-Martinez Bridge toll plaza. For QA reasons, it was decided to install two CT's at each site.

The specifications for the DAS and VDRS are virtually identical to those developed by CEOB for the Tampa Bay system. There was extensive work to contract for installation of dedicated phone lines to relay information from the remote sites to the base station at CMA, and for public access to the data. The region surrounding Suisun Bay consists of four telephone area codes, so it was determined that would be cheaper to install dedicated lines than to have the DAS make periodic toll calls. Phone lines were installed by Pacific Bell and ATT during the week of December 11, 1994, at CMA and Golden Gate. The installations at Alameda and Port Chicago were completed the following week.

The VDRS, current meter, and three CT stations were installed, and the three water level gauges were accessed by phone line, during January 23 to February 5, 1995. A problem with the power supply to the bridge-mounted data collection unit caused data losses until the problem was corrected during the next maintenance trip in late February. Since that time the system has functioned remarkably well.

Sensor System Configuration and Location

The field installation (Figures 3.1 and 3.2) addresses the strategies of measuring salt flux through Carquinez Strait and salinity variability in the lateral (north-south) direction. Data are collected at 6-minute intervals.

Salinity Stations Three sets of real-time Conductivity-Temperature (CT) sensors were installed, one each at Benicia-Martinez Bridge, Grizzly Bay, and Honker Bay. At Benicia Bridge there is a near-surface CT (approximately 2 m below MLLW) and near-bottom CTD (1 m above the bottom) just south of highway bridge pier # 7 at 122° 7.47′ W, 38° 2.55′ N in about 24 m of water. In Grizzly Bay, there is a CT and a CTD, each located within 65 m of the dolphin at 122° 2.33′ W, 38° 7.05′ N at 1 m above the bottom in about 1.6 m of water. In Honker Bay, there are two CTs, each located about 65 m from the dolphin at 121° 57.50′ W, 38° 4.46′ N at 1 m above bottom in about 2.4 m of water.

Current Meter Station A real-time acoustic Doppler current profiler (ADCP) was installed in about 19 m (at MLLW) of water in Carquinez Strait south of Benicia at 122° 7.52′ W, 38° 2.48′ N, or approximately 210 m (0.12 nmi) due west of pier # 8 of Benicia-Martinez Bridge.

Water Level Stations Real-time water level data are collected from NOS's existing gauges at Port Chicago (122° 2.3′ W, 38° 3.4′ N), Alameda (122° 17.9′ W, 37° 46.3′ N), and Golden Gate (122° 27.9′W, 37° 48.4′N).

Meteorological Station Meteorological sensors were installed at NOS's Port Chicago tide gauge site.

Suisun Data Receiving Station NOS has installed a radio transmitter/receiver at the toll plaza at the north end of the Benicia-Martinez Bridge. The receiver is in line-of-sight to all CT stations and is connected by telephone to CMA.

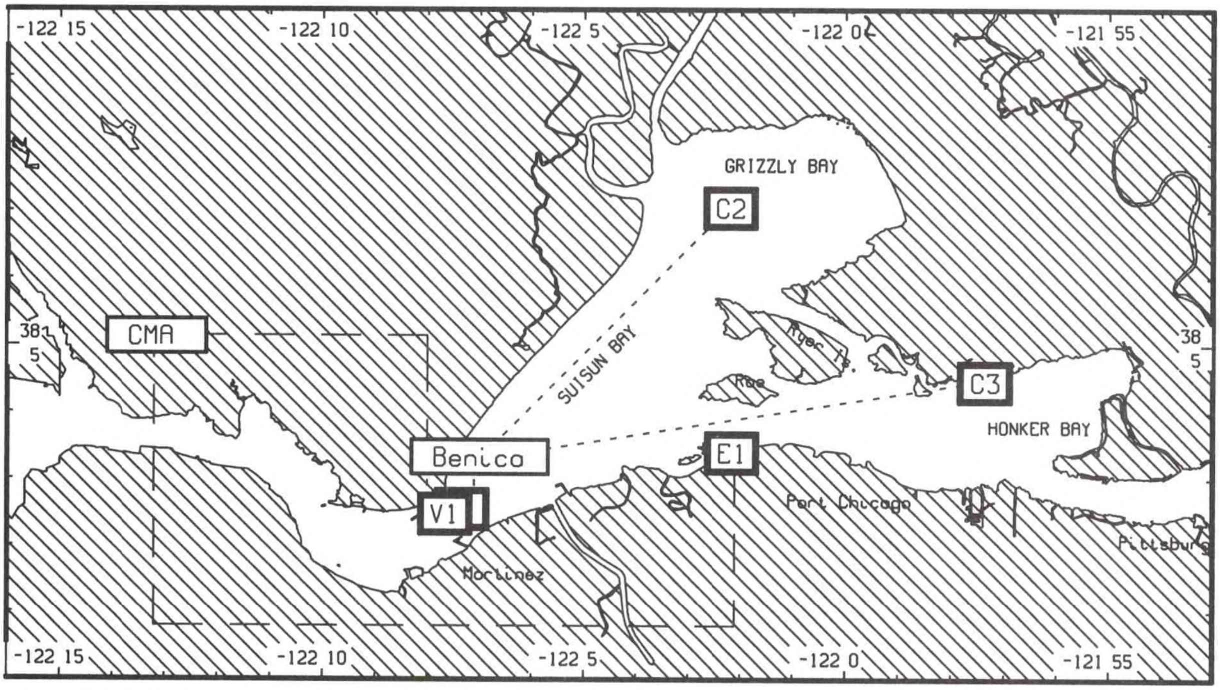

Figure 3.1. Suisun Bay showing location of CT sensors C1 (Benicia Bridge), C2 Grizzly Bay), and C3 (Honker Bay), current meter V1 (Benicia Bridge), and water level/met sensor E1 (Port Chicago). Data from V1, C1, C2, and C3 are transmitted via radio (short dashes) to the Suisun data receiving station at Benicia, where they are sent via dedicated phone line (long dashes) to the central computer at CMA. Water level and meteorological data from E1 are sent via dedicated phone line to CMA.

The current meter at Benicia Bridge and the water level sensors are the first phase of a Physical Oceanographic Real-Time System (PORTS). The second phase of the deployment began in late 1995 and included additional sensors to measure currents at Golden Gate, Port of Oakland, and Port of Richmond.

The Information Dissemination System

In addition to the suite of sensors and telemetry systems, an information dissemination system (IDS) is a critical component of the real-time monitoring system. The IDS performs all tasks associated with the delivery of PORTS products for the general user. All incoming and outgoing real-time data and information pass through this system, which is located at CMA. The accompanying description of the IDS is based on a description of the Tampa PORTS by Bethem (1995).

There are three major components to the IDS. The first component is the Data Acquisition System (DAS) and its associated PC/486 microcomputer and Unix-based software. The DAS performs acquisition, processing, quality control, error handling, and archival of data, as well as the communications and system management functions for the PORTS. The real time concept

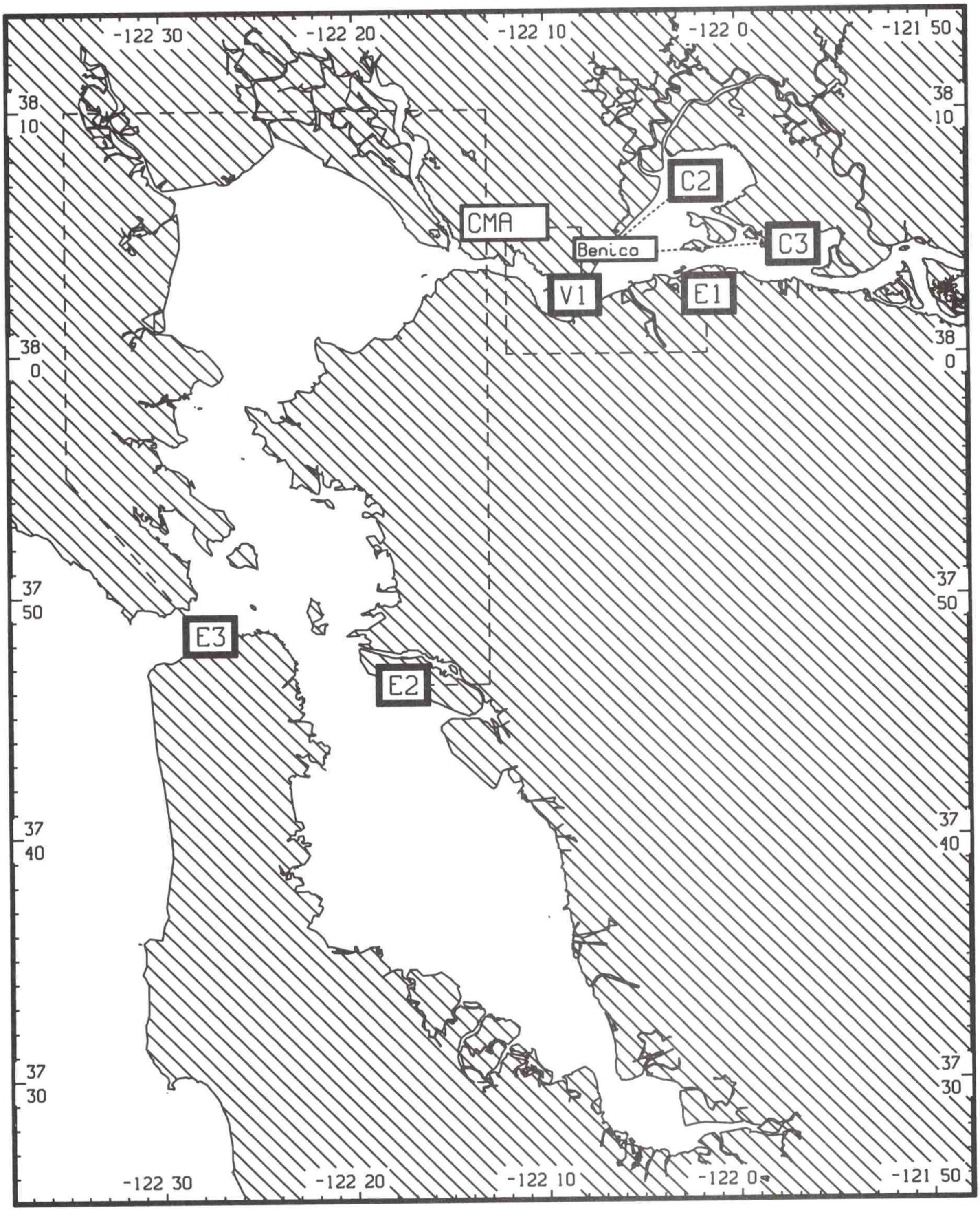

Figure 3.2. San Francisco Bay showing location of water level monitoring stations. Data from V1 (which includes C1), C2, and C3 are transmitted via radio (dotted line) to the Suisun data receiving station at the Benicia Bridge toll plaza, where they are sent via dedicated phone line (dashed line) to the central computer at CMA. Water level and meteorological data from E1, E2 (Alameda), and E3 (Golden Gate) are sent via dedicated phone line to CMA.

dictates that each remote measurement site transmit data over telephone lines as soon after acquisition as possible. All sensor systems are configured to report to the DAS over phone lines at 6-minute intervals and have been timed to provide an average measurement centered on the hour and at succeeding 6 minute intervals (each sensor system is controlled and operated by its own internal clock). Since timing is critical, the collection of data by the DAS is carefully orchestrated to provide reliable and consistent information. The DAS sorts the information and creates a message that can then be displayed.

The second component is the Voice Host, a PC/486 microcomputer running DOS that is connected to the DAS microcomputer. This communication connection is through a serial cable and a terminal emulator software package executing on the host PC. This configuration makes the host operate as a dumb terminal and its only purpose is to receive and pass on a specially-formatted screen from the DAS computer. The host PC receives a new screen each time the DAS receives new data, and serves as a link between the DAS and the third component.

The third component is the Voice Data Response System (VDRS). An Envoy interface card installed in the host PC provides a physical and logical connection between the host PC/486 and the voice processor. The voice processor is a Syntellect Infobot Voice System, Ambassador model. The primary function of the voice processor is to read the data message on the host PC and create a voice message for dissemination. The VDRS application software program was developed using a fourth generation programming language and is custom tailored to "read", recognize, interpret, and eventually "speak" what appears on the host computer screen. When a call is received and the appropriate touch tone number is entered by the caller, the voice processor makes a request for data from the host screen. Having been told by the software what fields to expect and where they will appear on the screen, the voice processor uses the information to create speech. Prerecorded fixed messages are combined with the dynamic host screen fields, and a continuous voice message is created.

Two primary modes of dissemination are employed by the VDRS. The first mode of dissemination is a voice message generated by the VDRS that can provide PORTS information to any touch tone phone caller. The VDRS is available 24 hours a day, seven days a week from any touch tone phone. The phone number for the voice system is (707) 642-4337. For the voice system, the caller will be greeted with an initial message identifying the system by name and welcoming the caller. This is followed by a menu of data possibilities to chose. The menu presents six possibilities.

1 - For Current data press 1
2 - For Water Level data press 2
3 - For Meteorological data press 3
4 - For Salinity data press 4
5 - For Bottom Temperature data press 5
6 - For PORTS information press 9

The second mode is a screen text message generated by the DAS. This is a single screen, 23-line message that is sent to the DAS CRT screen and is available by dialing the DAS from any personal computer. The DAS CRT at CMA receives the text message on a continuous basis, always reflecting the latest information. A sample screen display is shown in Figure 3.3. The telephone number for the PC screen display is (707) 642-4608. Modem settings are 2400 baud, N,8,1 and the password is ports.

Both primary modes of dissemination provide the same quantity and quality of data but differ in the amount of information the user can receive at one time. The screen text message provides all of the information for all of the instruments at all locations on one screen. The voice system allows the user to choose what data to hear by providing a menu that the user selects from by pressing the appropriate touch tone keys on the phone. If the user wants to hear all the information, about three minutes expire while navigating through the entire menu. The voice system plays a very important role in providing a safe and convenient method for users that are not located in office environments or for those without access to a computer.

All data received to the DAS is archived by NOS. For access to the archived data, see Appendix D.

```
                              San Francisco PORTS
                      at  5:56 am PST  December  5, 1995
                National Oceanic and Atmospheric Administration
                            National Ocean Service
.....................................................................
             TIDES                :              CURRENTS
Golden Gate          3.6 ft.,Rising  : Benicia Bridge     0.7 kts.(E), 235°T
Alameda              3.1 ft.,Rising  :
Port Chicago         1.4 ft.,Falling : (F)lood, (S)lack, (E)bb, towards °True
.................................:...................................
            SALINITY              :              WATER TEMP
                  Surface    Bottom :                        Surface   Bottom
Benicia Bridge      10.3 psu  13.3 psu : Benicia Bridge        58°F      58°F
Grizzly Bay       ( 6.1 psu)  6.1 psu : Grizzly Bay           (58°F)     58°F
Honker Bay        ( 3.9 psu)  3.9 psu : Honker Bay            (58°F)     58°F
.................................:...................................
                                 METEOROLOGICAL
                     Wind Speed/Dir              Air Pressure     Air Temp
Port Chicago      4 knots from SSW, gusts to   6      1019 mb          56°F

.....................................................................
To receive a description of PORTS, please contact Dr. Kurt Hess of NOAA
at 301-713-2809.
```

Figure 3.3. Sample San Francisco PORTS Screen showing data from the project instruments. (Later screens show additional dada collected from sensors added after this project was completed.) Note that at the Grizzly and Honker Bay sites, both CTs are located approximately 0.5 m above the bottom; the value in parentheses serves as a QC check on the other value, which is used in the voice message. The current is for a depth of 4.7 m below MLLW.

4. ANALYSIS OF PROJECT DATA

This section contains plots and preliminary analyses of the data collected during March through September 1995. Data quality and occurrences of missing data are described in Appendix D.

Major Trends in Salinity

Although the early 1990s were dry in California, the late winter and spring of 1995 were among the wettest on record. During the January-to-April period of 1995, the average Sacramento/San Joaquin River daily flow was 3300.5 m^3/s, and the average daily flow for the June-to-September period was 823.5 m^3/s. Using data from 1955 to 1992, 1995 had the third wettest spring and the second wettest summer. (Flow data are the estimated daily net delta outflow values.)

The input of fresh water significantly reduced salinity throughout Suisun Bay for much of the measurement period (March 1 to September 30, 1995). Even at the near-bottom Benicia Bridge CT sensor (Figure 4.1), which because of its proximity to the ocean, is expected to record the highest salinities of any of the NOS sensors, showed an essentially zero salinity (below 0.2) from March 13 to May 23.

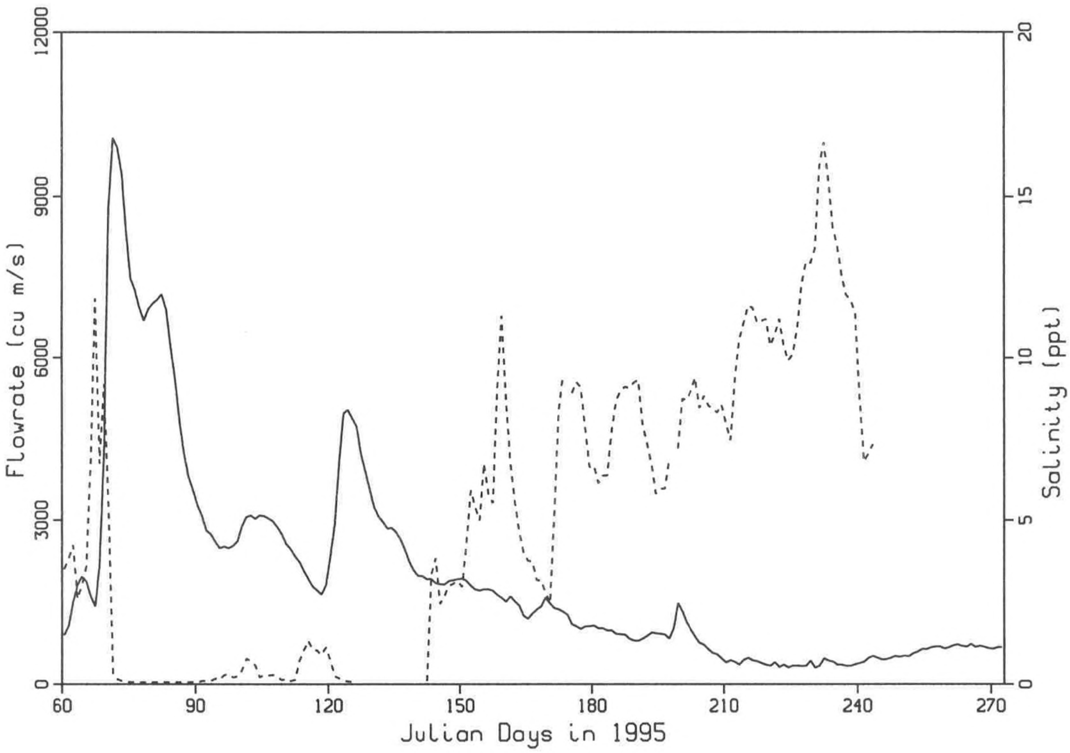

Figure 4.1. Significantly reduced salinities in Suisun Bay occur with high rates of freshwater inflow. The above shows daily Sacramento/San Joaquin River flowrates (solid line) and the daily-averaged near-bottom salinity (the section on data quality describes the handling of missing data) at Benicia Bridge (dashed line). Note that salinity values for Julian days 125 to 142 (May 5 to 22) are missing and values for days 90 to 125 (March 31 to May 5) are from the near-surface sensor.

As the rate of fresh water inflow declined, the salinity throughout Suisun Bay slowly rose (Figure 4.2). Data collected shows that the daily-averaged Grizzly Bay station salinity reached 0.2 psu value on Julian day 177 and the daily-averaged Honker Bay station salinity was greater than 0.2 psu by Julian day 191, for a lag of 13 days. Another measure of the lag is the Julian day at which the minimum daily value is greater than 0.2 psu for 2 consecutive days. This was Julian day 159 for Benicia Bridge bottom; Benicia Bridge surface lagged by 14 days, Grizzly Bay lagged by 51 days, and Honker Bay lagged by 63 days.

At Benicia Bridge, salt is transported into Suisun Bay near the bottom during the flood part of the tidal cycle (Figure 4.3). Therefore, salinities will be highest at the end of the flood phase. If the water near the western end of Suisun Bay has zero salinity, then at or near the end of the ebb phase the salinity will have returned to zero.

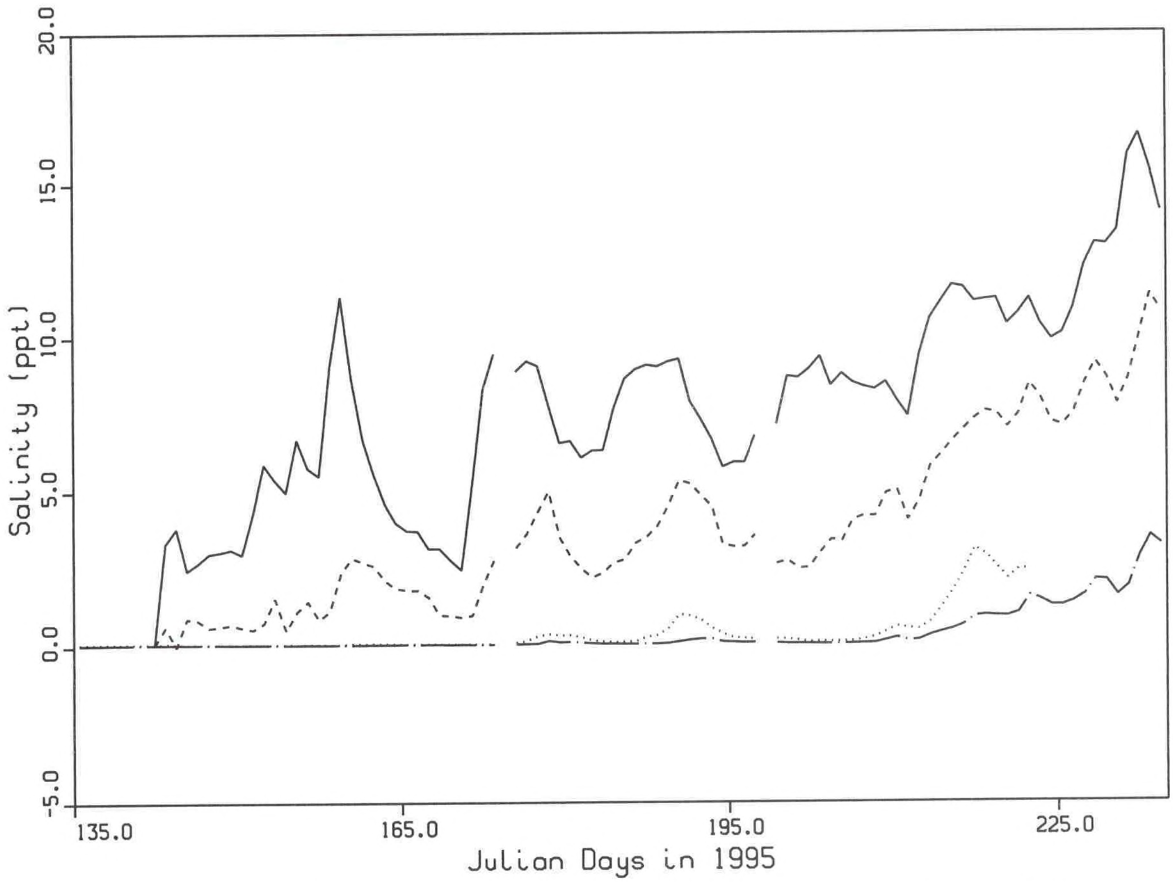

Figure 4.2. Increases in salinity in Suisun Bay as fresh water inflow declines. Daily-averaged salinity at Benicia Bridge surface (solid line), Benicia Bridge surface (dashed line), Grizzly Bay (dotted line), and Honker Bay (dash-dot line). Note that Benicia Bridge data before Julian day 143 (May 23) are missing.

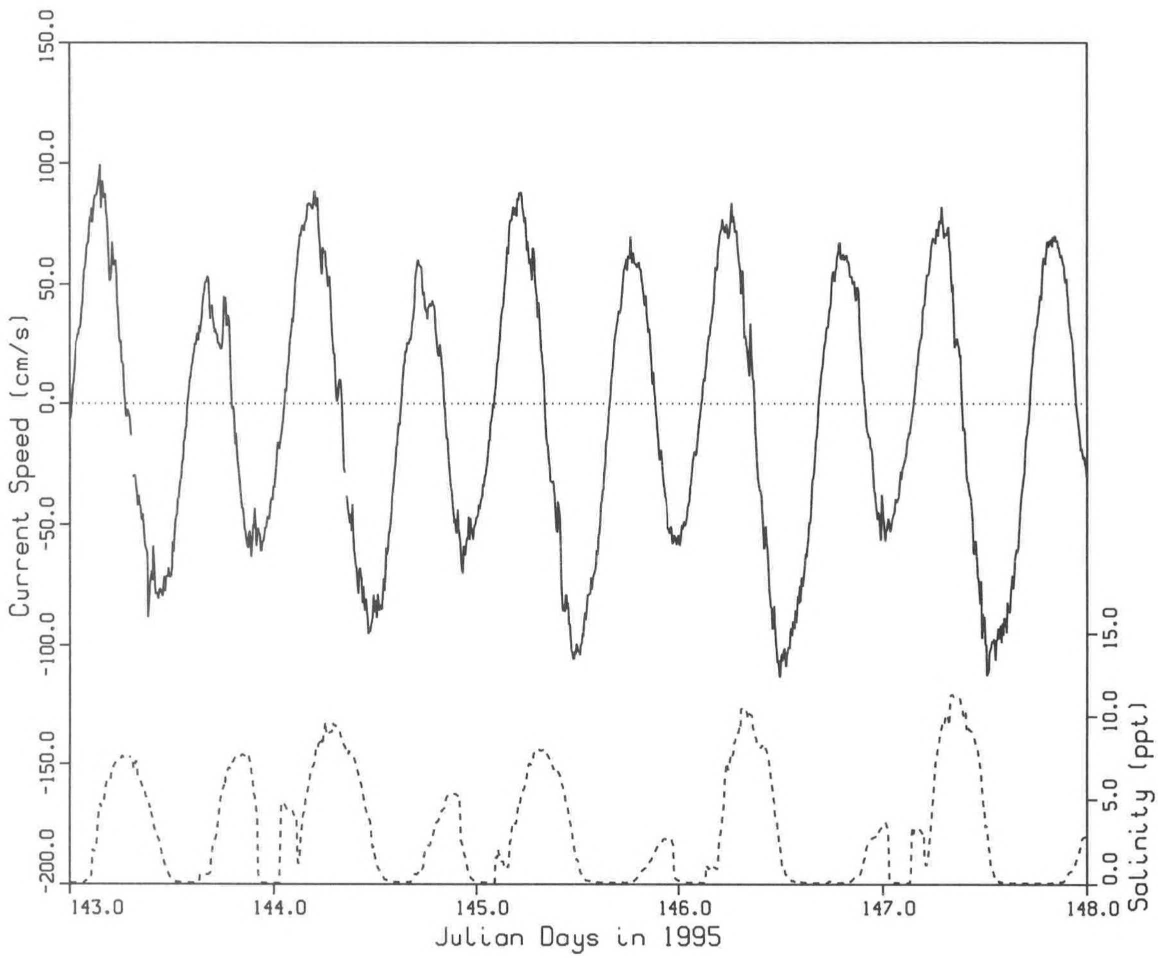

Figure 4.3. Salt transport by tidal currents at Benicia Bridge. Near-bottom currents (solid line) and near-bottom salinities (dashed line) are plotted at 6-min intervals. Times are GMT and ticks show start of the Julian day.

Water Levels

Water level data from the gauges at Golden Gate, Alameda, and Port Chicago show significant amplitude and phase differences (Figure 4.4). The NOS tide tables show that for high water, Port Chicago (Naval Weapons Station) lags Alameda by 1 hr 59 min and Golden Gate by 2 h 31 min. Low water at Port Chicago lags Alameda by 2 h 27 min and Golden Gate by 3 h 8 min.

Water levels in Grizzly Bay were computed from pressure data collected at the salinity station by the CTD. These levels were used to estimate tidal differences with Port Chicago (Figure 4.5). These data show that tide range at the Grizzly Bay station can be as much as 10 cm smaller than at Port Chicago, and that phase differences of several minutes are typical.

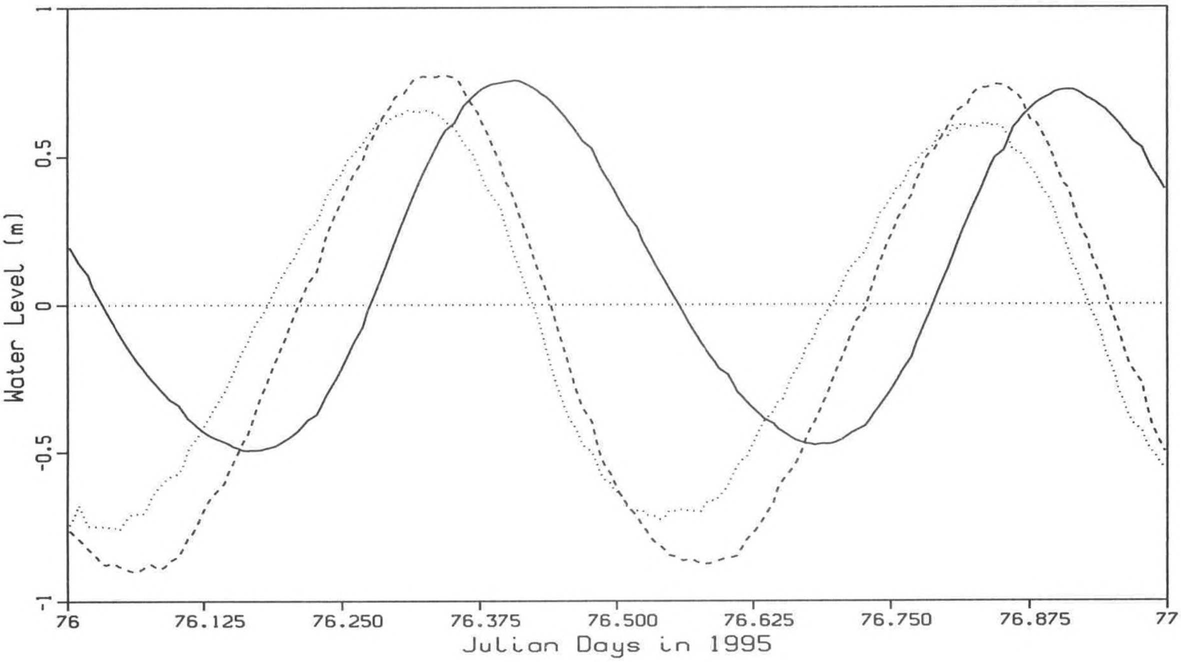

Figure 4.4. Water level data from the water level gauges at Golden Gate (dotted line), Alameda (dashed line), and Port Chicago (solid line) for March 17, 1995, show the progression of tides up the bay. For each series, the mean value for March has been subtracted. Times are GMT and ticks show each 3-hr interval.

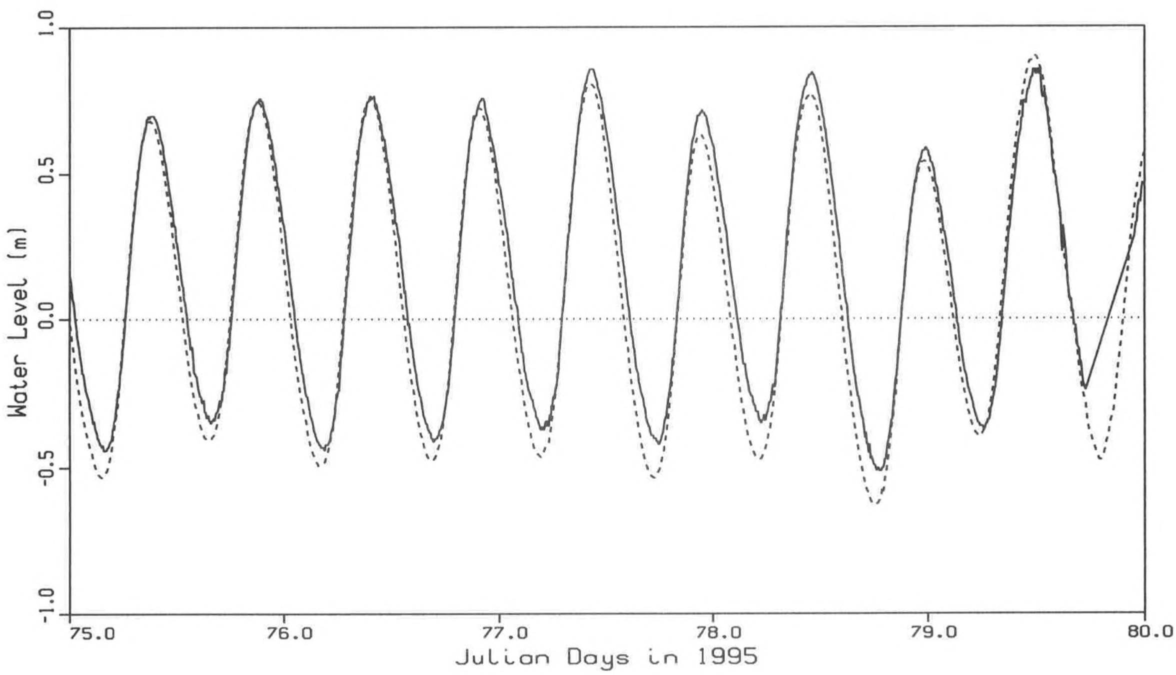

Figure 4.5. Water levels in Suisun Bay at Port Chicago (dashed line) and the Grizzly Bay CTD location (solid line). The mean value of each series for March has been subtracted. Times are GMT and ticks show start of Julian day.

Currents

The current meter was placed in water approximately 19 m deep at MLLW (as estimated from NOS charts of the area showing typical depths from the 1989 hydrographic survey); it gives an average speed and direction for segments of the water column (called bins) which are 2-m thick. Since the instrument head was 0.5 m above the bottom and has a blanking distance (distance to the bottom of the first bin) of 1.0 m, the distance from the bottom to the center of bin N is

$$Z_N = 0.5 + 1 + (2N - 1) = 0.5 + 2N \qquad (4.1)$$

Therefore, bin # 8 extends from 15.5 m to 17.5 m above bottom and has a central level of 16.5 m above bottom, while bin # 9 extends from 17.5 m to 19.5 m above bottom and has a central level of 18.5 m above bottom. Because the upper limit for bin # 9 is above MLLW, and because the percentage of usable signal returns from bin # 9 was unacceptably low, bin # 8 is considered the highest bin with useful data.

Near-bottom currents (bin # 1 at 2.5 m above bottom) southeast of the Benicia Bridge for the month of September are shown in Figure 4.6. Maximum ebb speeds are on the order of 1.1 m/s and are oriented toward the SW (225 degrees). Maximum flood speeds average 1.0 m/s and are directed toward the NNE (27 to 30 degrees). Net, or estuarine, flow can be seen by plotting the component of the mean current along the direction of 45 degrees for each month (Figure 4.7). This direction corresponds to the near-bottom ebb direction. River flow is so strong during the spring (March to May) that the net flow is out of Suisun Bay at all depths. Later (especially during July, August, and September), as salinities increase, the classical estuarine pattern of up-bay flow at the bottom and out-bay net flow at the surface appears.

Water Temperatures

Water temperatures followed the air temperature over the period, warming consistently until late July or early August, then cooling thereafter. Water temperatures in Grizzly and Honker Bays were close to those at Benicia Bridge until early May, when the two were consistently above Benicia by 1.0 to 1.5 C (Figure 4.8).

Data Access

Archived salinity, temperature, current, water level, and meteorological data are available upon request from NOS. Send inquiries to

Chief, Information Products and Services Section
NOAA, N/OES33
SSMC4, Rm 6540
1305 East-West Highway
Silver Spring, MD 20910

Telephone requests will be taken on 301-713-2815 and fax requests on 301-713-4501.

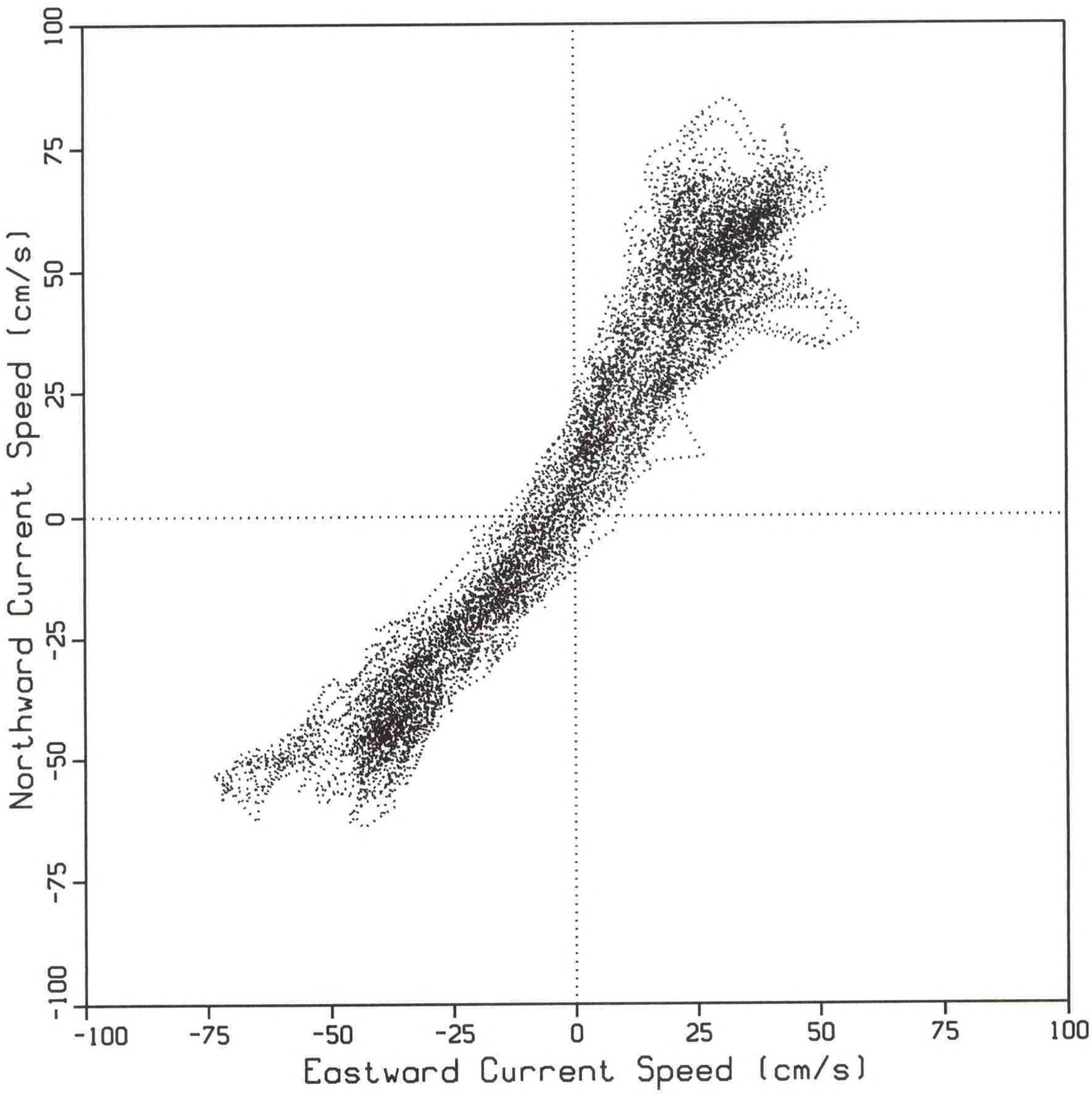

Figure 4.6. Near-bottom currents (bin # 1 at 2.5 m above bottom) at Benicia Bridge for September 1995.

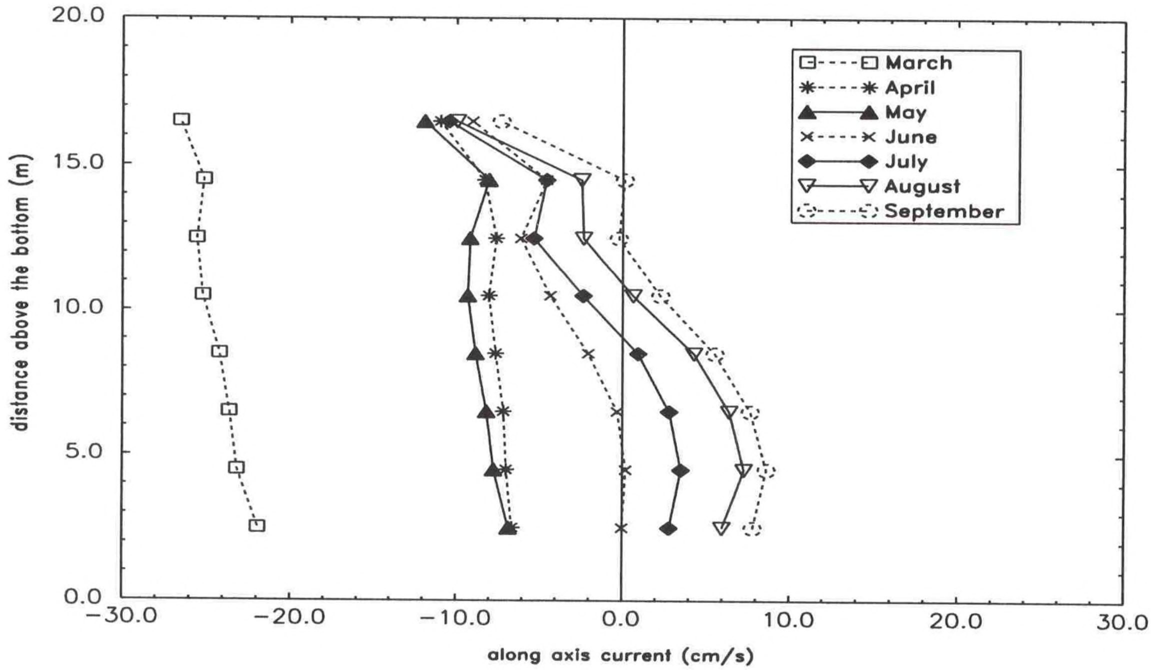

Figure 4.7. The net, or estuarine, flow can be seen in the component of the monthly mean current along the up-bay (45 degrees) direction at Benicia Bridge. The MLLW surface is approximately 19 m above the bottom.

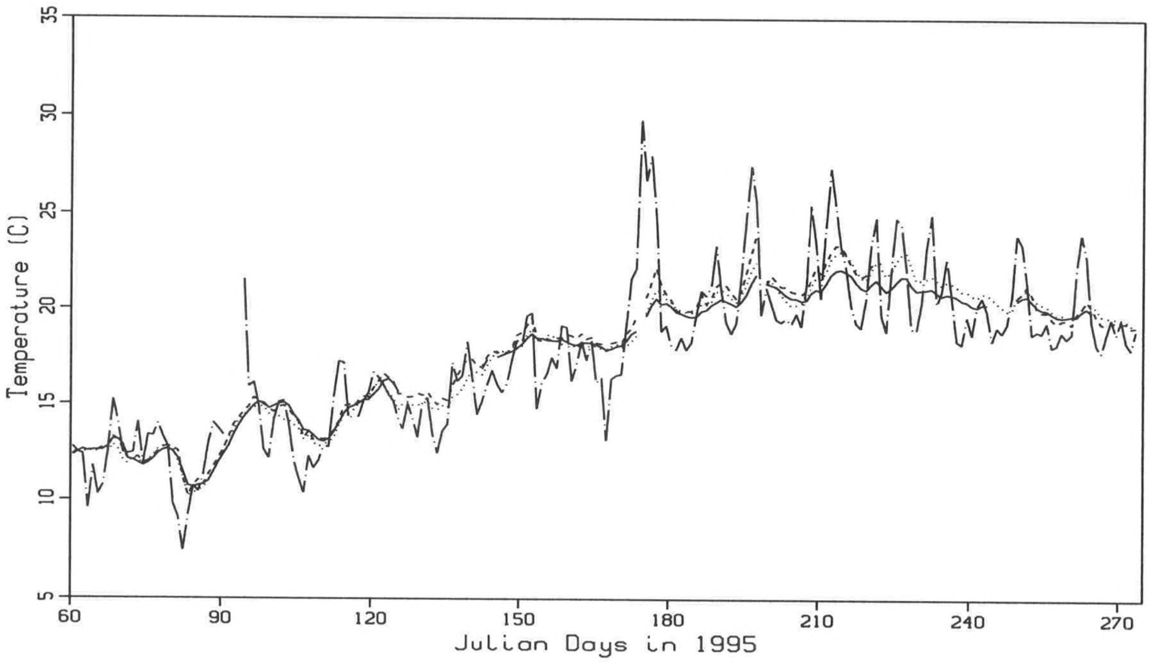

Figure 4.8. Water and air temperatures in Suisun Bay. The near-surface water temperatures at Benicia Bridge (solid line), Grizzly Bay (dashed line) and Honker Bay (dotted line) generally follow the trend of the air temperatures (dashed and dotted line) but do not show fluctuations at periods of 5 to 10 days.

5. DISCUSSION

This project, which proved to be an interesting and exciting endeavor, was completed within the allotted time limit and within the total budget. All important goals were accomplished. Initially, the goals of the Partnership were not completely accepted by all of the local parties in California. They did not support the concept of real-time data collection or who thought that NOS could better spend the funds on either strengthening the existing monitoring projects or by analyzing more historical data. However, many of these concerns vanished when EPA and the State of California came to an agreement on salinity monitoring requirements.

Initially it was difficult to agree on a strategy for placement of the NOS salinity sensors, given the existing network of monitoring programs already established in Suisun Bay. An important breakthrough occurred when participants at the ORCA-led meeting in Contra Costa decided that monitoring in the shallows of Grizzly Bay would have more benefit than adding to the existing monitoring in lower Suisun Bay.

Ironically, after the often-expressed concern over rising salinities, the spring of 1995 saw near-record rainfall amounts. Suisun Bay became essentially a fresh water body during most of March and April, and salinity values rose slowly throughout the summer. It is obvious that a long-term baseline of data is required to assess the utility of this project.

Much of the project's success is due to the early and continuing support of several of the local groups. Both the DWR and the USGS in Sacramento were extremely helpful in supplying data, providing information on existing monitoring installations, and assisting in site selection activities. Both USGS/Sacramento and DWR donated ship time and personnel to assist project staff. In addition, CMA's and SFSU Tiburon Laboratory's continuing support have been essential to the success of the project.

NOS will continue to maintain a presence in the bay monitoring scene after the termination of this project. A follow-on NOS Partnership (Galt et al., 1995) and the subsequent San Francisco Demonstration Project (NOS, 1995) have increased NOS's activities in the region. Although the focus of real-time monitoring has broadened out from environmental monitoring for salinity toward navigational safety, the present installation remains intact and has formed the cornerstone of the San Francisco Bay PORTS.

Knowledge gained during the Partnership has led to several insights about NOS's planned activities. Potential improvements in the monitoring system would include replacing the CES computers at the remote sites to simple radios (to improve system reliability), and adding relative density as a parameter in the voice message (for ship loading considerations). Additional instrumentation could include a dissolved oxygen sensor, and work could be done on measuring Delta inflow directly. The opportunity to share and exchange data with other state and local groups, and with the California Data Exchange in Sacramento should be pursued.

6. SUMMARY AND CONCLUSIONS

In the spring of 1994, the National Ocean Service (NOS) began the Partnership Project, "Real-Time Environmental Monitoring in Upper San Francisco Bay", to gain more information about a critically stressed habitat, namely Suisun Bay CA, by analyzing the historical data and installing *in situ* monitoring instruments. Project activities began in April 1994 and continued until September 1995. The project focused on the potential for negative impacts of fresh water withdrawal from San Francisco Bay tributaries for agricultural and municipal uses which could lead to increased salinity in upper San Francisco Bay, especially in Suisun Bay and in the Sacramento-San Joaquin River Delta, thereby altering the habitat. At risk are the marsh and slough areas around the perimeter of Suisun Bay which provide nurseries for fish and cover for wildlife. In addition, NOAA's National Marine Fisheries Service has designated the Chinook salmon, which spawns in the Sacramento River and passes through Suisun Bay, an endangered species.

Participants in the NOS partnership included NOS's Office of Ocean and Earth Sciences (OES), NOS's Office of Ocean Resource Conservation and Assessment (ORCA), and San Francisco State University (SFSU). The project consisted of a data analysis and assessment component, a real-time monitoring component, and a data management and dissemination component. NOS/ORCA inventoried historical data, analyzed real-time conductivity and temperature data and used the results to assess existing resources, and compared data from the study period to its historical context. These analyses furthered the understanding of the impact of management alternatives for pollution abatement and helped develop future NOS monitoring plans. NOS/OES designed, installed, and maintained (from March to September 1995) a real-time monitoring system for salinity and currents in the Suisun Bay. This system was designed to help monitor the habitat for changes due to fresh water withdrawal, to provide timely data for local estuarine research and management, and to use the information for improving navigational safety and hazardous materials spill response. SFSU, the local lead agency for the San Francisco Bay components of the National Estuarine Research Reserve System (NERRS), provided coordination with local management agencies, planned a workshop on the partnership program, and coordinated local press releases.

The partnership has two main accomplishments: (1) the analysis of historical salinity data which led to new ways of understanding and categorizing salinity variability, and (2) the design and implementation of a real-time monitoring system in Suisun and San Francisco Bays.

Based on analysis of the historical salinity data, the forcing mechanisms (freshwater inflow, tides, and winds) affect salinities in the Bay over several different time scales, including hours, days to weeks, months, seasons, and years. The importance of each of these forcing mechanisms varies, depending on the time scale being considered. In order to clarify the forcing mechanisms and time scales of variability in Suisun Bay, NOS scientists examined the changes in salinity at five stations over five different time scales, and analyzed the salinity data for both the dry season (July to September) and the wet season (February to April). These are the periods of highest and lowest salinity respectively. These data were then sorted by flow into the estuary (using daily flow values) in order to categorize the years into dry, normal, and wet. In order to categorize flows for a season, the flows for the three months in the season along with flow from the antecedent month (i.e. January for wet and June for dry) were used. The variability of salinity for each time scale for each station and each year type was analyzed.

Based on a preliminary analysis of the historical data obtained so far, we can make the following conclusions. Reduced river flow in the recent dry years of 1987 to 1992 have caused the following changes:

- The seasonally-averaged position of X2 during the February-to-April high river flow period shifted upstream from around Port Chicago (its position in normal years) to around Collinsville.

- Because of this shift, the moving-habitat region of high productivity associated with X2 has changed from the productive stationary habitat of central Suisun Bay to the less productive habitat of the river confluence.

- In addition, the amplitudes and time scales of salinity variability associated with X2 have changed. Not only are the amplitudes less, but variability at the tidal scale, which dominates at Port Chicago, is reduced at Collinsville, where weekly-to-monthly variability dominates.

Also, a non-linear relationship exists between freshwater inflow and X2 when X2 is located near Port Chicago. That is, freshwater inflows exceeding a certain threshold value in this area tend to compress longitudinal salinity gradients without significantly changing X2. Finally, the analysis concentrated on data from the lower portion of Suisun Bay in the natural and dredged navigation channel. Relatively little is known about salinity variations in more northerly portions of the bay. Therefore,

- Additional data from within Grizzly and Honker Bays are required to examine the salinity structure and variability relationships between the shallow embayments and the deep channels where most of the monitoring stations are located.

The real-time monitoring system was designed and installed in order to provide information on north-south salinity variations for bay scientists, modelers, and managers and to begin building a more extensive PORTS for San Francisco Bay. Station locations were selected after discussions with scientists in NOS's ORCA and with the US Geological Survey (Sacramento), the California Department of Water Resources, and the Contra Costa Water District. Instrumentation included:

- Two sets of solar-powered, radio-linked real-time Conductivity-Temperature (CT) sensors were installed in the shallow areas of Suisun Bay not covered by existing fixed-location monitoring programs. In Grizzly Bay, there is a CT and a CTD, each located within 200 ft of the dolphin in about 5 ft of water. In Honker Bay, there are two CTs, each located about 200 ft from the dolphin in about 8 ft of water.

- A real-time current meter (an acoustic Doppler current profiler or ADCP) was installed in about 60 ft of water in Carquinez Strait south of Benicia to provide information for salt flux estimation and ship maneuverability. The ADCP is located approximately 0.3 nmi due west of pier # 8 of the bridge. Also there are two CTs to provide salinity and buoyancy information. One is near-surface and another near-bottom just east of highway bridge pier # 7 in 83 ft of water.

- Real-time water level data from NOS's existing gauges at Port Chicago, Alameda, and Golden Gate are accessed by phone line. Meteorological sensors were installed at NOS's Port Chicago tide gauge site.

- All information is available by phone from the voice-data response system (VDRS) was installed at CMA. The data are available in voice form via a menu-driven program on a local phone line (707-642-4337) and as a PC screen display (707-642-4608).

7. ACKNOWLEDGEMENTS

This project would not have been possible without the vision and support of Dr. Stanley Wilson, NOAA Assistant Administrator for Ocean Services and Coastal Zone Management, and Dr. David Evans, NOS Senior Scientist. Support from CAPT Francesca Cava, OCRM, was important for gaining support, and letters from Messrs. Harlan Proctor, DWR, and Larry Smith, USGS, were vital in establishing links to the Bay Area's monitoring programs. CMA's Mr. Lloyd Kitazono was equally important in initiating an alliance with the Academy.

Several principal sources of historical river flow and salinity/temperature/conductivity data deserve recognition, including Messrs. Ralph Finch and Steve Hayes and Ms. Andrea Laboro (DWR), Ms. Sheryl Baughman (USBR), Mr. John Burau (USGS, Sacramento), and Ms. Jane Caffrey (USGS, Menlo Park). We would also like to thank the members of the technical review meeting held to discuss ORCA's historical data analysis: Mr. Richard Denton (Contra Costa Water Management District), Mr. James Arthur (USBR), Messrs. Hank Gebhard and Steve Hayes (DWR), Mr. Larry Smith (USGS, Sacramento), and Dr. Steve Monismith (Stanford University).

Within OES, many people worked hard to make the project a success. Dr. Kate Bosley led planning meetings and successfully performed as Principal Investigator on the major field installation trip. Ms. Karen Earwaker spent numerous hours preparing contracts for installation of the telephone lines. Messrs. Jerry Appell and Jim Sprenke, of OSDG, provided early enthusiastic support, designed, procured, and tested the remote salinity communication systems, and insured that they were correctly installed. Messrs. Mike Connolly and Richard Bourgerie arranged for ship time, oversaw the access to the electrical power at the Benicia Bridge, and led the field crews during the installation and during subsequent maintenance trips. Messrs. James Bascom and OSDG's Charles Payton also provided valuable assistance in the field. Mr. Bascom was instrumental in establishing ties with CMA, where he was a student. Ms. Brenda Via and Mr. Philip Richardson helped in producing graphical displays and other presentation materials. The contributions of Messrs. Tom Bethem, Mike Evans, and Geoff French in purchasing, testing, installing, and maintaining the system computers and real-time voice-based dissemination system were essential.

Within ORCA, the work of many individuals was integral to the development and successful completion of this report. Ms. Naomi Wender-Milliner served as the senior editor, designed the layout, and worked on the graphics. Mr. Mitchell J. Katz also provided an editorial review of the final draft, and Mr. Douglas Pirhalla provided graphics support.

Support from the many groups in California were critical to the project's success. The USGS's Mr. Jon Burau provided reconnaissance, including the taking of still and video pictures of pilings in Honker and Grizzly Bays and providing NOS with the results, and Dr. Larry Smith provided meeting rooms at the Sacramento facility. DWR's Mr. Hank Gephard provided access and detailed explanations of the Department's monitoring sites and he field checked some of the potential sites for NOS's data receiving station, including Mt. Diablo. Mr. Harlan Proctor provided the R/V *San Carlos* to give us a first-hand view of the estuary. CMA's Mr. Lloyd Kitazono provided help in both video-taping the Benicia Bridge site and toll plaza and in checking components of the data receiving station. Captain Dave Morgan of the R/V *Questuary* provided excellent piloting and shared his advice and local knowledge. LT Simmons of the toll plaza at the Benicia-Martinez Bridge

coordinated access to the building power, monitored CALTRANS inspections, suggested best locations for our radio receiver and monitored the Pacific Bell installation of a dedicated data line. Mr. Randy Ferrel, the CALTRANS engineer at the bridge, provided essential support for the data receiving station as well as the power supply at the bridge. The USCG provided ship support in deploying the current meter and storage space at their Yerba Buena Island facility.

Installation of communication phone lines was critical to the projects's success. Ms. Sheila Doyle of Pacific Bell was extremely helpful in providing us with numerous price estimates for analog dedicated data lines between CMA and remote sites in Suisun Bay. Ms. Doyle coordinated the installation of all the data lines at each of the remote locations in the San Francisco Bay area. On several occasions she placed a rush on investigations of data line availability so that decisions on placement of instrumentation was expedited. Assistance from the following volunteers in the Bay Area were instrumental in allowing Pacific Bell and AT&T access to the water level gauges for installation of the dedicated data lines. Ms. Christine Gary of the Gulf of the Farallones National Marine Sanctuary, Mr. Doug Graftas of Alameda (Naval Air Station), and Mr. Sam Evans of the Naval Weapons Station Concord monitored the installation of the data lines and provided the NOS coordinator with progress and completion information. Mr. Evans provided vital information for possible deployment of instrumentation near Roe Island in Suisun Bay. The CMA telephone coordinator, Donna Lichty, provided Pacific Bell with access to the Admiral Rizza Auditorium building which houses the central computer system from which all data are received from the remote locations (Golden Gate, Alameda, Concord, and Benicia Bridge).

After the system was installed, letters of support from LTJG Kenneth Baltz of NMFS's Tiburon Laboratory and especially DWR's Mr. Randy Brown were fundamental to continuing support from NOS.

8. REFERENCES

Appell, G. F., T. N. Mero, T. D. Bethem, and G. W. French, 1994: Development of a Real-Time Port Information System. **IEEE Journal of Ocean Engineering**, v. 19 (2), 149 - 157.

Bethem, T. D, 1995: Tampa PORTS Voice Data Response System Description and Access Statistics: May 1993 - May 1995. **NOAA Technical Report** NOS OES 009. US Department of Commerce, NOAA, National Ocean Service, Office of Ocean and Earth Sciences. pp 38.

Bethem, T. D., 1991: Operational Physical Oceanographic Real-Time Data Dissemination. **IEEE Oceans Proceedings**, 864 - 867.

Dennis, K. C., and C. J. Kline, 1995: *Salinity Characterization of Suisun Bay, California.* Silver Spring, MD. NOAA, NOS, Office of Ocean Resources Conservation and Assessment. 10 pp.

Frey, H. R., 1991: Physical Oceanographic Real-Time Systems for Operational Purposes. **IEEE Oceans Proceedings**, 855 - 858.

Galt, J. A., R. T. Cheng, and W. L. Wilmot, 1995: Current Pattern Analysis for Oil Spill Response. NOS Partnership Program Proposal. Office of Ocean Resources Conservation and Assessment, NOS. 35 pp.

Hess, K. W., C. J. Klein III, and M. Vasey, 1994: Real-Time Environmental Monitoring in Upper San Francisco Bay: NOS Partnership Program Proposal. Coastal and Estuarine Oceanography Branch, Marine Analysis and Interpretation Division, Office of Ocean and Earth Sciences, NOS. 19 pp.

NOAA, 1987: San Francisco Bay: Issues, Resources, Status, and Management. **NOAA Estuary of the Month Seminar Series** No. 6, Estuarine Programs Office. 159 pp.

NOS, 1995: San Francisco Bay Demonstration Project Plan. Office of Ocean Resources Conservation and Assessment. 27 pp.

___, 1990: The Tampa Bay Oceanography Project: Plan for FY 1990 to FY 1992. Estuarine and Ocean Physics Branch, Physical Oceanography Division, Office of Oceanography and Marine Assessment, NOS, 68 pp.

Rozengurt, M. A., 1983: On Environmental Approach to Protecting Estuaries from Salt water Intrusion. Proceedings, Coastal Zone 83, San Diego, CA. 2279 - 2293.

SFEP, 1993: Managing Freshwater Discharge to the San Francisco Bay/Sacramento-San Joaquin Delta Estuary: The Scientific Basis for an Estuarine Standard. San Francisco Estuary Program, 106 pp.

UNESCO, 1981: Tenth report of the Joint Panel on Oceanographic Tables and Standards. **UNESCO Technical Papers in Marine Science** 36, 25 pp.

Wilmot, W. L., J. A. Galt, and D. B. Enabnit, 1994: NY/NJ Harbor Maritime Commerce Safety Partnership: NOS Partnership Program Proposal. Coastal and Estuarine Oceanography Branch, Marine Analysis and Interpretation Division, Office of Ocean and Earth Sciences, NOS. 26 pp.

APPENDIX A. PROJECT STAFF

OFFICE OF OCEAN AND EARTH SCIENCES

Principal Investigator:	Kurt Hess
Duties:	Planning, coordination, financial authority
Co-Principal Investigator:	Kate Bosley
Duties:	Planning, coordination, science
Chief Engineers:	Jerry Appell, Jim Sprenke
Duties:	Instrument system design, specification, procurement, integration
DAS/VDRS System:	Tom Bethem, Mike Evans, Geoff French
Duties:	Voice system and DAS design, specification, procurement, data delivery
Field Team Leaders:	Mike Connolly, Richard Bourgerie
Duties:	Deploy instruments, obtain ship & diver support, fabricate platforms, refurbish instruments
Data Analyst:	Karen Earwaker
Duties:	QA and analyze incoming data, assess historical NOS survey data, arrange for telephone connections
Water Level Data:	Manoj Samant
Duties:	Coordinate OLLD water level data collection

OFFICE OF OCEAN RESOURCES CONSERVATION AND ASSESSMENT

Principal Investigator:	C. John Klein III
Duties:	Planning, coordination, financial authority
Data Analyst:	Karen Dennis
Duties:	QA and analyze historical data

SAN FRANCISCO STATE UNIVERSITY

Principal Investigator:	Michael Vasey
Duties:	Planning, coordination, financial authority

APPENDIX B. LOCAL SCIENTISTS

Lloyd Kitazono, Chair
Department of Oceanography
California Maritime Academy
Vallejo, CA
707-648-4256

Harlan Proctor
CA Department of Water Resources
Environmental Services Office
Central District
3251 S Street
Sacramento, CA 95816-7017
916-445-7517

Hank Gebhard
CA Department of Water Resources
Environmental Services Office
Central District
3251 S Street
Sacramento, CA 95816-7017
916-445-4749

Ralph Finch
CA Department of Water Resources
rfinch@water.ca.gov

Dr. Francis Chung
CA Department of Water Resources
Division of Planning
1416 Ninth St.
PO Box 942836
Sacramento CA 94236
916-653-5601

Larry Smith
United States Geological Survey
Water Resources Division
Federal Building, Rm. W-2233
2800 Cottage Way
Sacramento, CA 95825
916-978-4648 x395
lhsmith@animar.wr.usgs.gov

Jon Burau
United States Geological Survey
Water Resources Division
Federal Building, Rm. W-2233
2800 Cottage Way
Sacramento, CA 95825
916-978-4648 x324
burau@animar.wr.usgs.gov

Dr. Ralph Cheng
United States Geological Survey
Water Resources Division
Menlo Park, CA
415-354-3363
rtcheng@rcamnl.wr.usgs.gov

Jim Arthur
US Bureau of Reclamation
Federal Building, Rm. W-2127
2800 Cottage Way
Sacramento, CA 95825
916-978-4923

Dr. Stephen Monismith
Department of Civil Engineering
Stanford University
Stanford, CA 94305-4020
415-723-4764
monismit@cive.stanford.edu

Wim Kimmerer
Biosystems, Inc.
Tiburon CA
415-435-0399
w.kimmerer@omnet.com

Richard Denton
Contra Costa Water District
PO Box H20
Concord, CA 94524
510-674-8187
wrccwd@delphi.com

APPENDIX C. DESCRIPTION OF SITE INSTALLATIONS

C.1. The Complete System

The complete system consists of hardware installations at eight geographic locations around San Francisco Bay, including (1) the Information Dissemination System (IDS) at the California Maritime Academy in Vallejo, (2) a CT, a CTD, and a current meter at the Benicia-Martinez Bridge, (3) the Suisun remote data receiving station at the Benicia Bridge Toll Plaza, (4) a CT and a CTD in Grizzly Bay, (5) two CTs in Honker Bay, (6) a water level gauge and a meteorological sensor at the US Navy's Port Chicago facility in Concord, (7) a water level gauge in Alameda, and (8) a water level gauge in San Francisco, southeast of the Golden Gate Bridge. The three water level gauges and the meteorological sensor are connected to the central site at CMA via dedicated telephone lines. The Benicia Bridge CT, CTD, and current meter; the Grizzly Bay CTs; and the Honker Bay CTs are linked by radio to the Suisun data receiving station, which is connected to CMA via dedicated telephone line. A schematic of the system and the communications appears in Figure C.1.

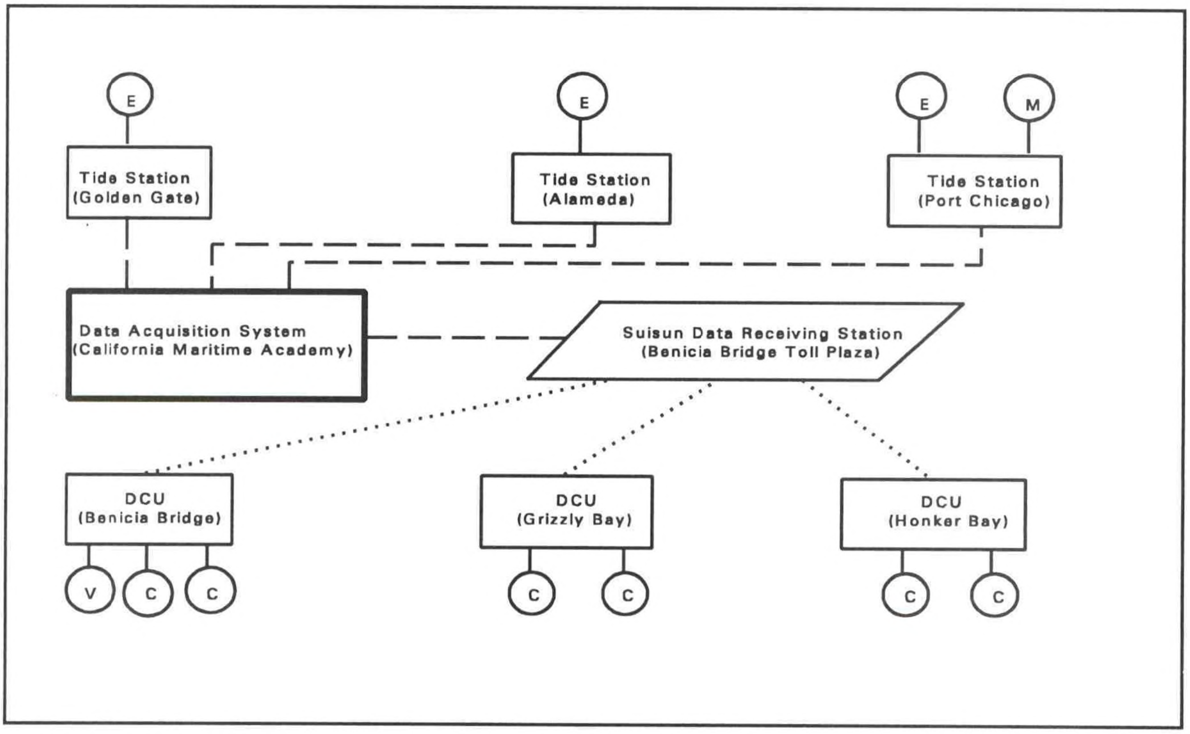

Figure C.1. Schematic overview of the entire real-time monitoring and communications system installed in this project. Circles represent the in-water sensors: E is a water level gauge, C is a conductivity-temperature sensor, M is a meteorological sensor, and V is a current velocity meter. Data from the three tide gauges (top row) is transmitted via dedicated telephone lines (dashed lines) to the IDS (middle row, left). Data from the remote data collection units (DCUs) (bottom row) are transmitted via radio (dotted lines) to the Suisun Data Receiving Station, where they are transmitted via dedicated phone lines to the IDS.

C.2. California Maritime Academy

The Information Dissemination System resides at CMA in the secured audio-visual room on the second floor of the Admiral Rizza Auditorium building and consist of (1) the data acquisition system (DAS); (2) the Voice Host and voice-data response system (VDRS); (3) six telephone modems; and (4) seven telephone lines. Figure C.2 has a schematic of the installation.

With respect to the phone lines (numbers in circles in Figure C.2), Line 1 allows users to display data on a screen, Line 2 allows NOS access, Line 3 is the digitized voice, Line 4 connects CMA to the data receiving station at Benicia Bridge, Line 5 brings meteorological and water level data in from the tide gauge installation at Port Chicago, Line 6 brings water level data in from the tide gauge installation at Alameda, and Line 7 brings water level data in from the tide gauge installation at San Francisco.

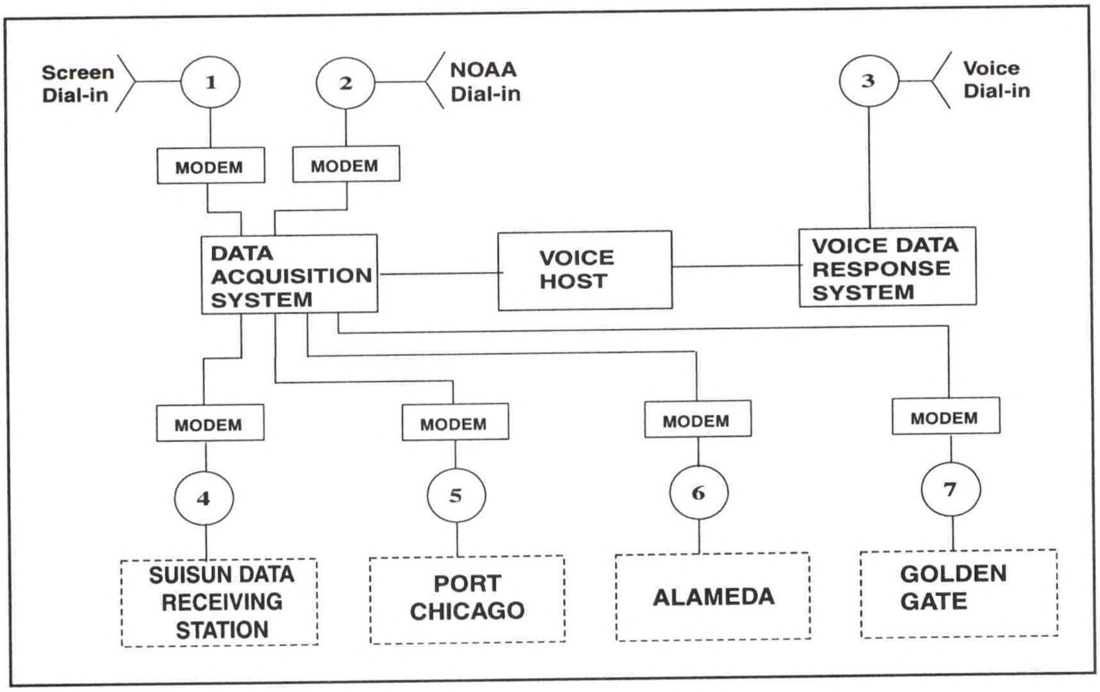

Figure C.2. Schematic of the installation at California Maritime Academy. Telephone lines are numbered in the circles and equiptmentt locations outside of CMA are shown within dashed line boxes.

C.3. Benicia-Martinez Bridge

The largest number of sensors are located near the Benecia-Martinez Bridge. One SeaBird Electronics (SBE) CT is located approximately 1 m below MLLW and attached to a PVC pipe on the inside face of the wooden fencing surrounding pier # 7. An SBE CTD is mounted on a PVC pipe imbedded in a small (0.5 m square by 0.2-m thick) concrete platform lying on the bottom several meters from the pier. The CT and the CTD are connected by cable to a CES Data Collection Unit

(DCU) located on the bridge pier platform about 3 m above the water line. The cables supply DC power and transmit data. The current meter, an RD Instruments 600 khz narrow-band ADCP, is mounted in an upward-looking mode in a protective concrete platform located about 0.115 nmi due west of pier # 8. The ADCP gets AC power directly from an electrical supply on the bridge and is connected by cable to the DCU. The AC power also charges the battery used by the CT, the CTD, and the DCU. The DCU contains a radio to transmit data to the Suisun Data Receiving Station. Figure C.3 shows a schematic of the installation, and geographic locations are shown in Figure C.4.

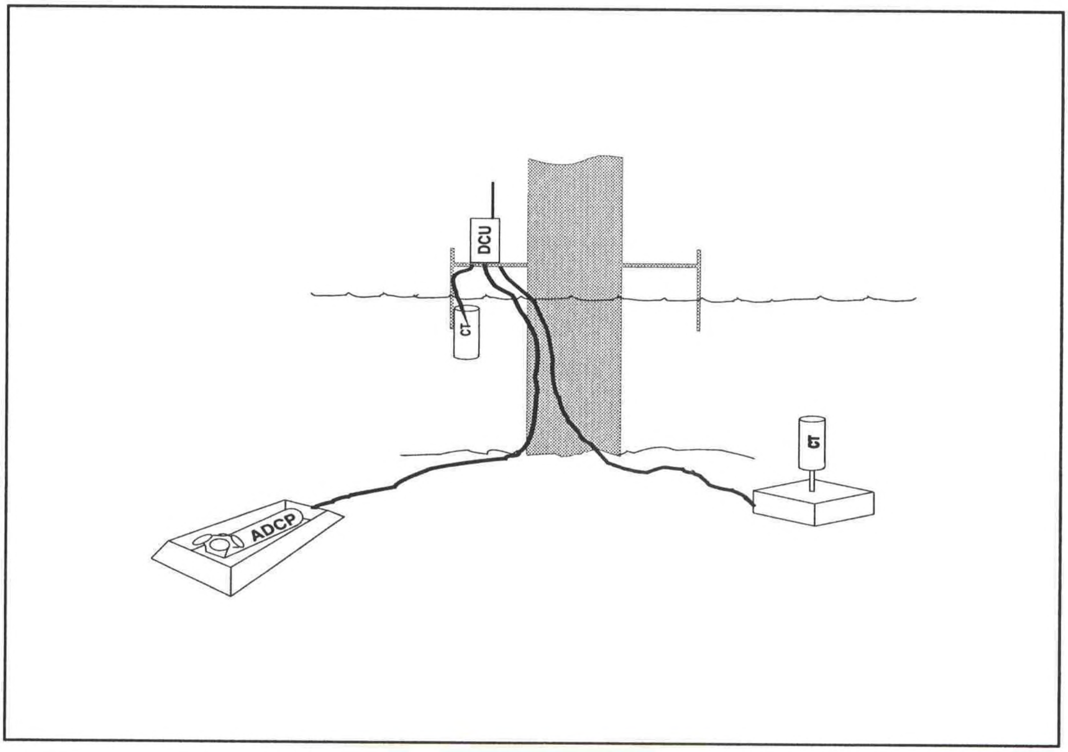

Figure C.3. Schematic of the installation at the Benicia-Martinez Bridge.

C.4. Suisun Data Receiving Station (Benicia Bridge Toll Plaza).

The Suisun Data Receiving Station is located near the Benicia Bridge Toll Plaza at the north end of the highway bridge. The system consists of a DCU, antenna, and modem attached to a light pole located on the east side of the CALTRANS administration building. The system is linked by a modem and phone line to the building and from there via dedicated phone line (Line 4 in Figure C.2) to CMA. The system receives DC power from a transformer in the administration building. A schematic of this installation is shown in Figure C.5.

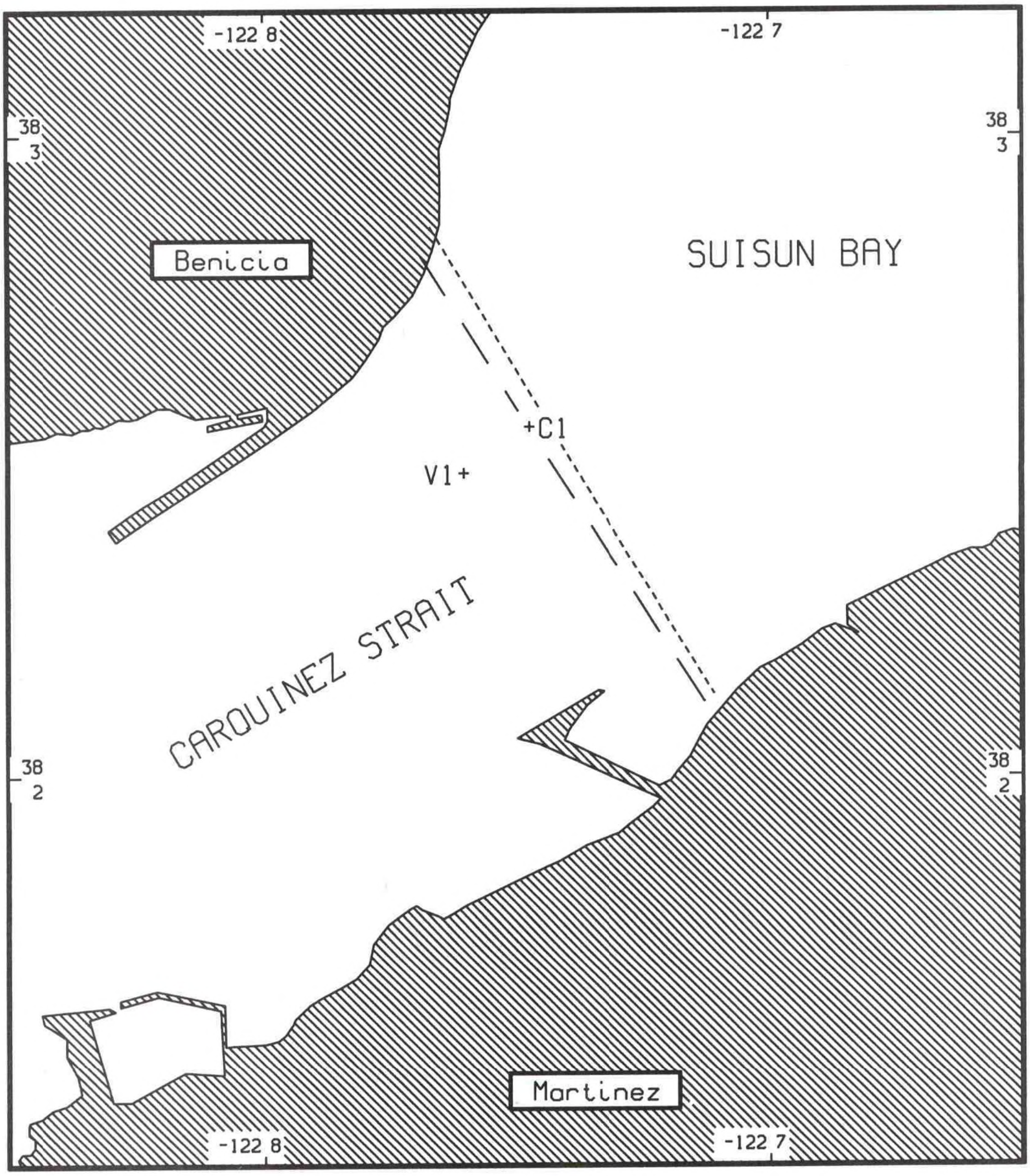

Figure C.4. Location of instruments at Benicia Bridge. C1 denotes the location of the CT and CTD and V1 the location of the current meter. The highway bridge is denoted by a dashed line and the nearby rail road bridge is denoted by a dotted line.

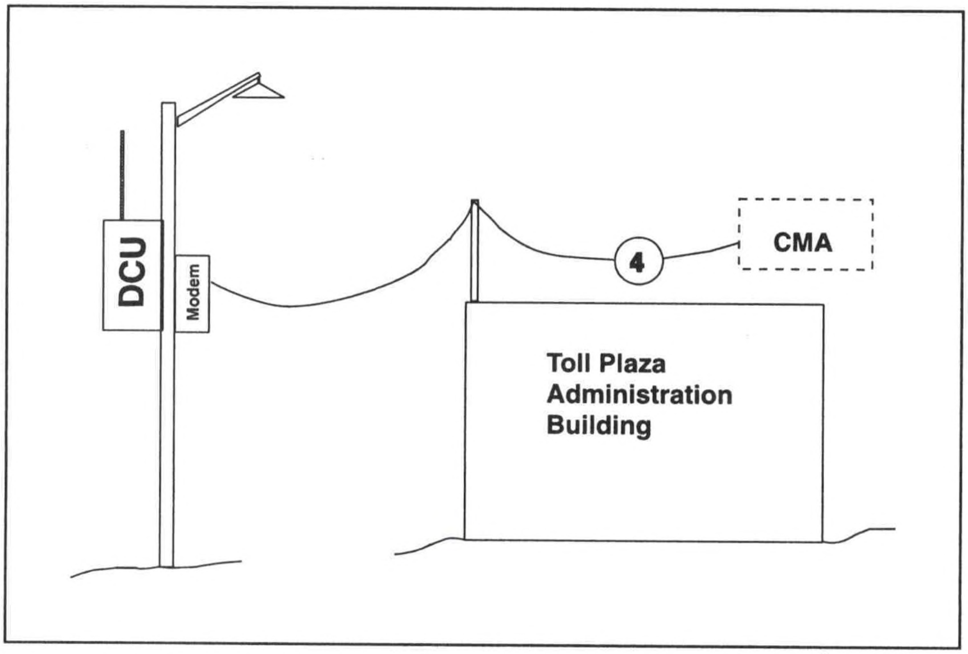

Figure C.5. Schematic of the Suisun Data Receiving Station at the Benicia Bridge Toll Plaza.

C.5. CT/CTD Sites in Grizzly Bay and Honker Bay

The remote sensor systems at Grizzly Bay and Honker Bay are nearly identical. A schematic of the installation is shown in Figure C.6 and the locations are shown in Figure C.7. Each consists of two bottom-mounted SBE CTs (one of the sensors at Grizzly Bay is a CTD) attached to a 60-cm-long PVC pipe extending from a 0.5 m square by 0.2-m thick concrete platform located as much as 180 m from the piling. These are connected by a rubber-coated cable to the pile-mounted CES DCU. The DCU consists of a controller and data logger inside a 20 cm by 30 cm by 45 cm stainless steel enclosure, one or more 60-cm square solar panels, and a YAGI antenna.

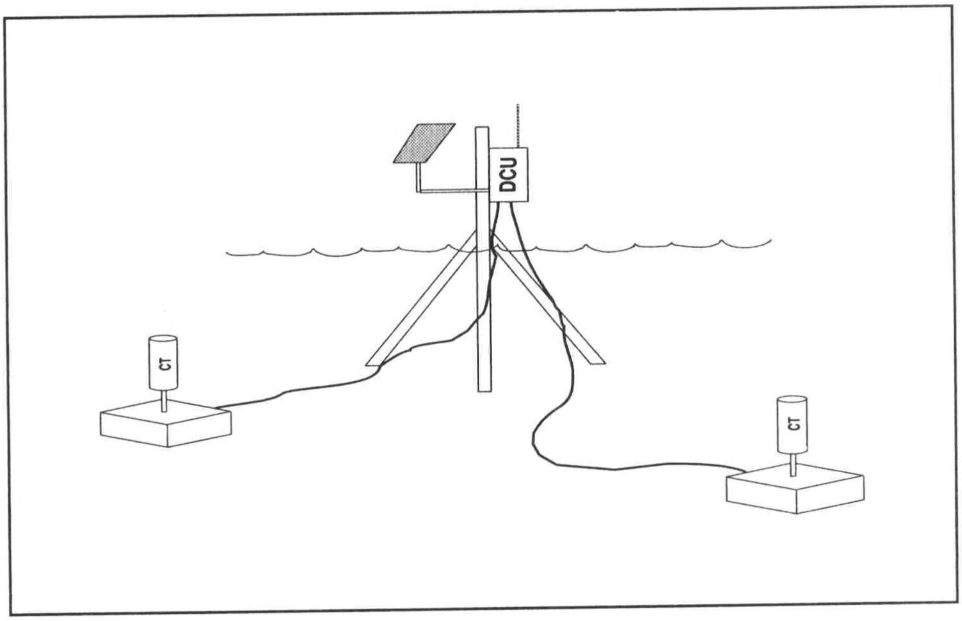

Figure C.6. Schematic of the CT/CTD site in Grizzly Bay and the CT site in Honker Bay. The DCU is powered by a battery that is charged by the solar panel.

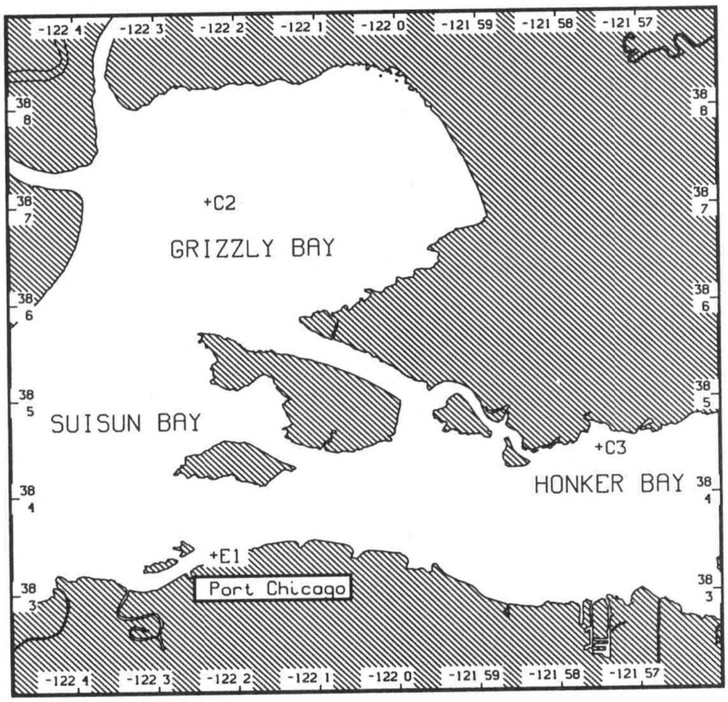

Figure C.7. Location of stations in Grizzly and Honker Bays. Salinity/conductivity stations are C2 and C3, and water level station is E1.

C.6. Port Chicago Tide Gauge and Meteorological Sensors

The installation at the pier at the US Naval Weapons Station in Concord consists of (1) a meteorological sensor system, (2) a telephone line (Line 5) connected to (3) a modem, which is connected to the existing NOS tide gauge. A schematic is shown in Figure C.8.

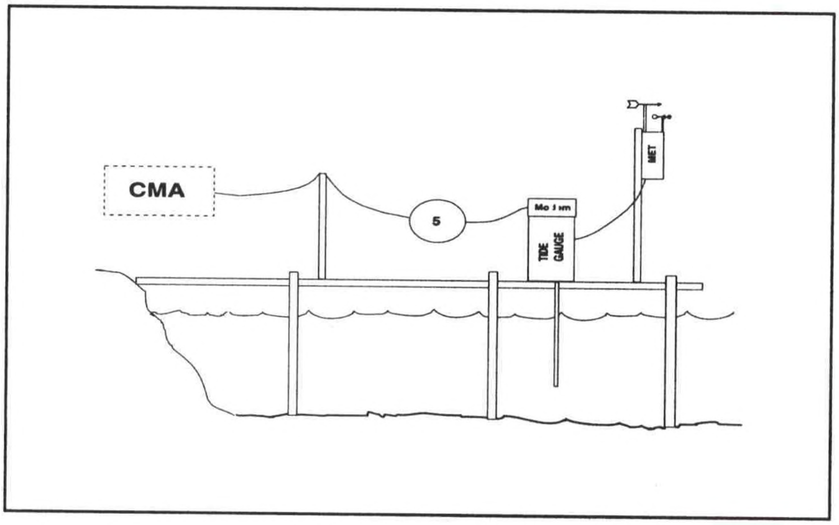

Figure C.8. Schematic of the tide gauge and meteorological sensor installation at Port Chicago.

C.7. Alameda and San Francisco Tide Gauge Stations

The water level gauge installations at these sites consists of (1) a telephone line (Line 6 for Alameda and Line 7 for San Francisco) connected to (2) a modem, which is connected the existing NOS tide gauge. A schematic is shown in Figure C.9.

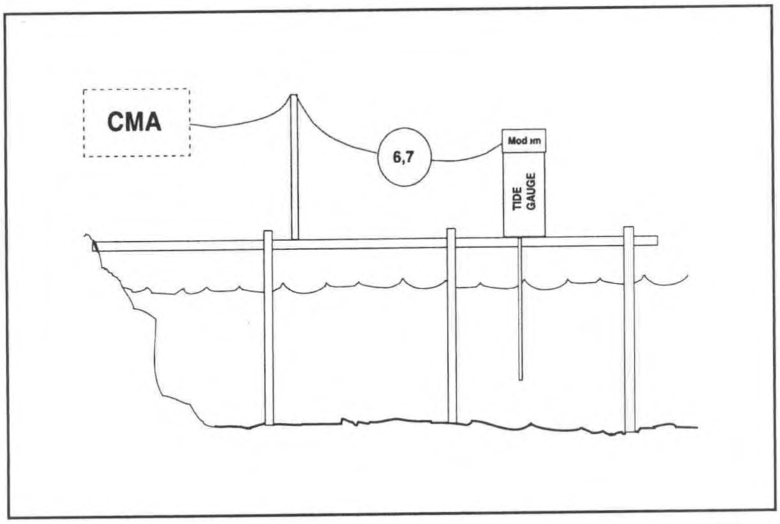

Figure C.9. Schematic of the water level sensor installations at Alameda and San Francisco.

APPENDIX D. DATA QUALITY

Data were quality assessed by examining time series plots for errors. A summary of the percentage data return for 1995 is shown in Table D.1.

Major gaps for the current meter include: May 5-22 (radio failure at Benicia Bridge), July 21 - 25 (bridge power cable disconnection), and September 21 - October 7 (radio failure at Benicia Bridge).

Major gaps in the CT time series at Benicia Bridge include: May 5-22 (radio failure at Benecia Bridge) and September 21 - October 7 (radio failure at Benicia Bridge).

There were no major data gaps in the data collected in Honker Bay.

Major gaps in the CT time series at Grizzly Bay include: March (nightly failure due to battery drainage), May 10 - 24 (nightly failure due to battery drainage), August 10 - September 6 (data collection unit removed for repair). The communications system at Grizzly Bay suffered by the failure of the solar cells to keep the batteries recharged. Battery drainage occurred because the data collection unit (DCU) drew current at a rate several times higher than the level the manufacturer specified. This led to the loss of data during the night and early morning (Figure D.1). However, when operating, the CT pairs showed remarkable consistency at Grizzly and Honker, being within 0.1 psu most of the time. To overcome some of the missing data problems, the plots of Grizzly Bay data (Figures 4.2 and 4.8) show daily averages of the non-missing values.

Table D.1. A summary of the percentage data return for the current meter and the CTs by location and month.

Instrument	March	April	May	June	July	August	Sept.
Benicia Bridge Current Meter	92.6	99.9	45.0	96.2	83.9	98.9	45.4
Benicia Bridge CTs	94.7	99.8	45.1	96.2	96.1	98.7	45.4
Grizzly Bay CTs	68.7	93.5	78.4	95.9	63.0	16.0	79.9
Honker Bay CTs	95.2	97.2	99.7	95.5	96.1	97.2	99.3

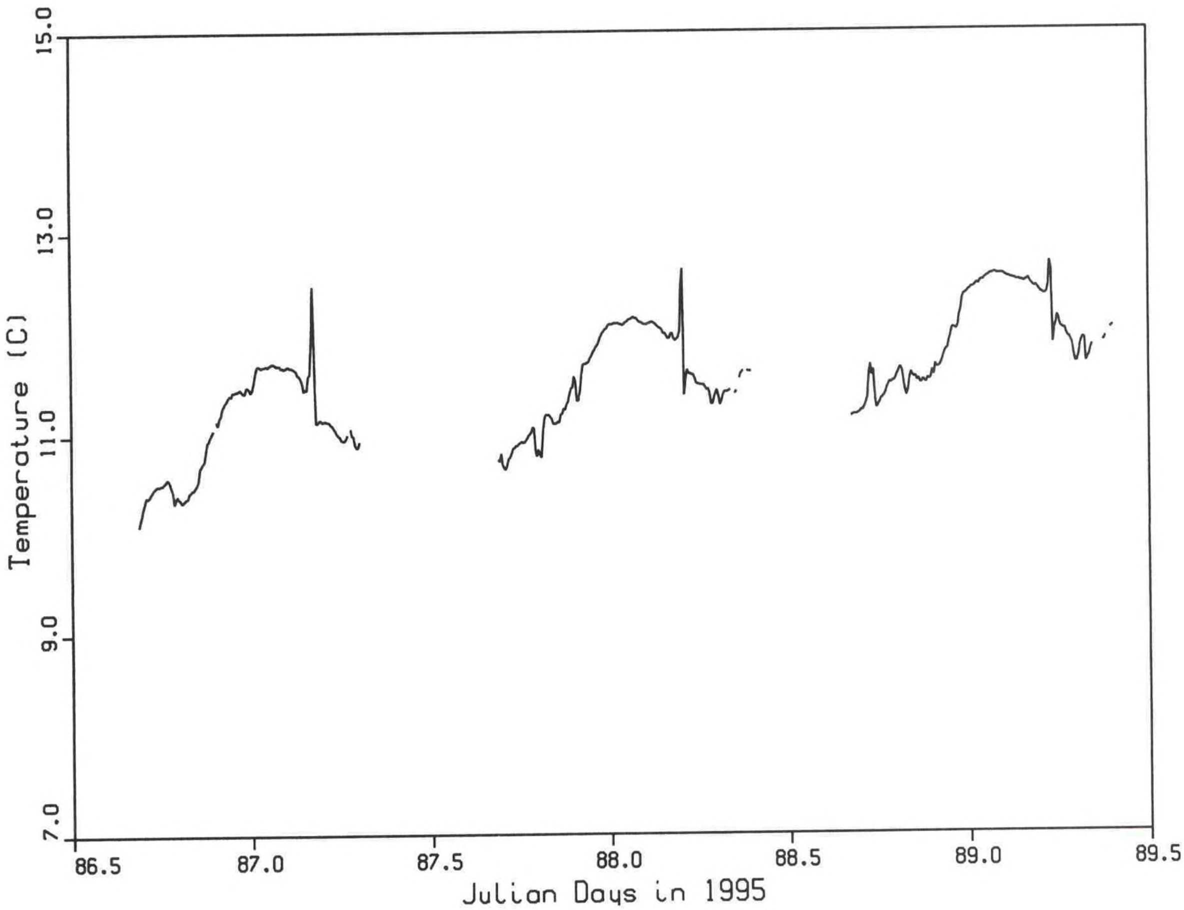

Figure D.1. Temperature time series data at Grizzly Bay showing periodic loss of data when the battery charge was too low (generally from midnight to 8 AM local time, or 0.33 to 0.66 universal time).