SALINITY AND TEMPERATURE IN SOUTH SAN FRANCISCO BAY, CALIFORNIA, AT DUMBARTON BRIDGE: RESULTS FROM THE 1999-2002 WATER YEARS AND AN OVERVIEW OF PREVIOUS DATA

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Appendix A: Illustrations

CONVERSION FACTORS

Metric units are used in this report.
Conversion factors to inch-pound units are provided here for the measurements used in this study.

Multiply	By	To obtain
kg (kilogram)	2.205	lb (pound)
m^3 (cubic meter)	35.3	ft^3 (cubic feet)
m (meter)	3.381	ft (foot)

Temperature is given in degrees Celsius (C) and can be converted to degrees Fahrenheit (F) using the following equation: (F) = 1.80 (C) + 32

Salinity and temperature in South San Francisco Bay, California, at Dumbarton Bridge: Results from the 1999-2002 water years and an overview of previous data.

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ABSTRACT

Salinity and temperature were measured in near-surface waters at Dumbarton Bridge in South San Francisco Bay during the 1999-2002 water years (1999WY-2002WY). The complete data set from this site, which included 1990WY-1993WY and 1995WY-1998WY, provided a time-series of observations covering a wide range of hydrologic conditions. These conditions included critically dry years and years with above normal and near-record precipitation and discharges from the major rivers and local streams. Data collection at 15-minute intervals allowed resolution of variability associated with daily tides and other short-term phenomena. Both local stream discharges to South San Francisco Bay and Sacramento-San Joaquin River discharges to North San Francisco Bay affected salinity at Dumbarton Bridge. Salinity at Dumbarton Bridge varied with the daily tides, and the lowest salinity values (annual) coincided with precipitation and freshwater inflows usually in winter. Short-term and seasonal variations in temperature at Dumbarton Bridge typically followed changes in air temperature and solar irradiance.

INTRODUCTION

San Francisco Bay and the major rivers that flow into this estuary, the Sacramento and San Joaquin rivers, have been greatly modified and perturbed over the 150 years since the gold rush (Hedgepeth, 1979; Nichols and others, 1986; Fig. 1). Urbanization of the areas surrounding San Francisco Bay accelerated greatly after World War II, which resulted in large increases in anthropogenic waste loading to the estuary from homes and industries (Pearson and others, 1969; Davis and others, 1991). Degradation of water quality and other issues in the estuary during the 1950s and 1960s prompted the construction of many waste treatment and water pollution control facilities. Efforts to improve waste treatment and reduce pollutant discharges to the estuary continue today. Among the embayments of San Francisco Bay, the southern reach, South San Francisco Bay, and particularly the small, landward basin, Lower South Bay, have been severely impacted by municipal waste discharges (Pearson, 1958; McCulloch and others, 1970; Conomos and others, 1979). Consequently, wetlands and open-water areas near Dumbarton Bridge remain the focus of research studies and aquatic habitat restoration projects.

The abundance of waste-derived substances in waters of South San Francisco Bay (South Bay) is related to the locations of the waste dischargers and processes that dilute and transport wastes in and from South Bay (Conomos and others, 1979; Hager and Schemel, 1996). Seawater from the Pacific Ocean and discharges from local streams are two important sources of water that dilute wastes and influence circulation in South Bay. Major river discharges to North San Francisco Bay (North Bay) affect the supply of brackish water (seawater diluted by freshwater) to South Bay, which also influences mixing and transport processes (McCulloch and others, 1970; Walters and others, 1985). Salinity and density (calculated from salinity and temperature) are two fundamental water properties that are easily measured and can provide essential information on mixing and transport processes in estuaries. Seawater is the major source of salt to the estuary. In general, decreases in salinity in South Bay indicate mixing with local stream or wastewater sources, whereas increases in salinity primarily indicate mixing with sea and brackish water that enters South Bay at the Bay Bridge (Fig. 1). Density-driven circulation is most affected by salinity, but stratification of the water column can be affected by both salinity and temperature.

The U.S. Geological Survey (USGS) and the California Department of Water Resources (CDWR) have established a network of continuous water monitoring stations throughout the San Francisco Bay estuary. The monitoring and research site on the east span of the old Dumbarton Bridge was built during the summer of 1989, and data collection for salinity, temperature, and tides began with the 1990 water year (1990WY = October 1, 1989 through September 30, 1990). Time-series data were collected during each water year with the exception of 1994WY, when intensive studies and instrument evaluations were conducted (1990WY-1993WY in Schemel, 1995a; 1995WY-1998WY in Schemel, 1998a).

This report presents the measurements collected over the most-recent years, 1999WY-2002WY, and provides an overview of the entire 12-year time-series record of salinity and temperature at Dumbarton Bridge. General aspects of South Bay hydrology involving tides, wastewater inflow, and influences of seasonal and short-term variations in weather and freshwater inflow are described. The 1990WY-2002WY time-series record encompasses a wide range of environmental conditions that affected salinity and temperature and modulated important mixing and transport processes. This record includes periods of unusually high precipitation and streamflow and drought conditions as well as short episodes of very strong winds and high-energy tides.

Hydrologic Characteristics of the 1990-2002 Water Years

The long-term record from Mission Dolores in downtown San Francisco shows a large amount of variability in annual precipitation in this area of California (Fig. 2). The 1990WY-2002WY period began with annual precipitation levels that were well below the mean (referred to as “normal” in the figures and below) and among the lowest 25 percent in the long-term record. Annual precipitations for two years, 1995WY and 1998WY, were among the highest 25 percent in the long-term record, and the 1998WY value ranked second, exceeded only by 1862WY, the year of record flooding throughout California. Annual precipitation values for 1993WY, 1996WY, 1997WY, and the last four years, 1999WY-2002WY, were near the long-term mean. It is important to note that 1993WY was the first greater than normal precipitation since the drought that began in 1987WY. This 6-year period of below normal precipitation was comparable to the extreme drought of the 1930s (Fig. 2).

Discharge to San Francisco Bay from the Sacramento and San Joaquin rivers and other smaller rivers that flow to the inland delta (the Delta) reflects precipitation and snow melt over about 40 percent of northern California (Conomos and others, 1985). However, a large fraction of the river discharge typically is diverted before it reaches the estuary (Nichols and others, 1986; Schemel and others, 1996). A daily value for the discharge to the estuary, Delta Outflow, has been estimated by CDWR since 1956WY (CDWR, 2002). High levels of Delta Outflow affect salinity throughout the estuary, including the reach of South Bay landward of the San Mateo Bridge (landward reach; McCulloch and others, 1970; Imberger and others, 1977; Walters and others, 1985; Hager and Schemel, 1996).

Annual mean Delta Outflow computed from daily values for 1956WY-2001WY (data for 2002WY were not available) showed that only 1995WY-1998WY were greater than the 46-year mean during our study (Fig. 3). Lowest values corresponded to the 1987WY-1992WY drought at the beginning of our study as well as 1995WY and 1999WY. Preliminary data suggest that the annual mean Delta Outflow for 2002WY also was below the long-term mean value.

Local streams that discharge directly to South Bay have a greater effect on salinity at Dumbarton Bridge than Delta Outflow during dry years (Schemel and Hager, 1996). These local streams typically exhibit episodic discharges that are primarily responses to rainfall and runoff (for example Alameda Creek, Fig. 4). Most local streams are impounded to some extent, and late season flows can reflect discharge from reservoirs. The total amount of freshwater discharged by local streams to South Bay is not measured. In many cases, flows are measured at up-stream locations and might not represent discharge to South Bay. In addition, many of the small streams and runoff from urban areas are not gauged. A comparison of estimated total local stream and wastewater inflows to South Bay shows that wastewater inflows are greater than local stream flows on an annual basis (Hager and Schemel, 1996). For example, even though many gauged streams discharge to Lower South Bay, the annual measured stream flow is about one-half the wastewater inflow. However, since the local streams discharge over relatively short periods, episodic stormwater discharges are a major factor affecting salinity at Dumbarton Bridge (Schemel, 1995a and 1998a; Schemel and Hager, 1996). Most of the local streams discharge to the landward reach, and dilution effects typically are greatest in Lower South Bay, in part because of its relatively small volume.

Discharges from municipal wastewater treatment plants are major sources of freshwater and many pollutants to South Bay (Fig. 5). Wastewater inflow varies over the year mostly because of contributions from urban runoff, but the variability is small compared to local stream flows (Hager and Schemel, 1996). Long-term changes in wastewater discharge to South Bay are illustrated by monthly mean values for the San Jose/Santa Clara Water Pollution Control Plant (Fig. 6). In general, increases in population have increased waste water discharges over the years. However, water conservation during the drought years, 1987-1992, reduced wastewater flows, and wastewater recycling has further reduced discharges to Lower South Bay in recent years. In addition to changes in discharge, treatment has improved over the years and the loads of many pollutants have been reduced. Recent research has shown that reductions in metal pollutant discharges have improved conditions for aquatic species near Dumbarton Bridge (Hornberger and others, 2000). Similar reductions in waste-derived nutrients have reduced concentrations measured in the water column (Hager and Schemel, 1996; Schemel and others, 1999).

Hydrography, Tides, and Weather

Various aspects of the hydrography of South Bay have been reviewed by Conomos and others (1979) and Hager and Schemel (1996), and short summaries have been included in previous data reports (Schemel, 1995a and 1998a). It is important to note that only 17 percent of the (mean tide) volume of South Bay is contained in the landward reach. In addition, Lower South Bay is a small basin that contains only 20 percent of the volume of the landward reach. Conditions in the water column near Dumbarton Bridge are sensitive to freshwater inflows and weather in part because of the relatively small volume of water and shallow water depths (Schemel and Hager, 1996). This is also a factor leading to generally increasing concentrations of waste-derived substances landward in South Bay.

Tides have greater amplitude at Dumbarton Bridge than where tides enter the estuary at the Golden Gate Bridge (Fig. 7). The RMS (daily root-mean-square) tide height is a measure of variability over the daily tidal cycle, and greater values (spring tides) indicate larger differences in water levels between high and low tide and stronger tidal currents compared to neap tides. Spring-neap variability in RMS tide height results in biweekly variations in tidal mixing. Bi-weekly variability in tidal flow and in turbulent mixing around the many structures and pilings near Dumbarton Bridge is a factor controlling salinity stratification (Schemel and Hager, 1996). The importance of tidal energy and salinity stratification have been recognized for ecosystem processes such as phytoplankton productivity in South Bay (Cloern, 1984, 1991, and 1996).

Weather and climate variables are also important to transport and mixing processes in South Bay. Winds can be effective in mixing the water column and in generating currents that move water masses (Walters and others, 1985; Huzzey and others, 1990; Schemel and Hager, 1996a; Cheng and others, 1998). Wind-driven currents can enhance or oppose residual circulation driven by tides and stratification. Winds during late spring and summer are generally strong during the day and typically blow from the west or north-west (Conomos and others, 1985). Storm fronts primarily during winter and early spring produce winds from the south before the front passes and strong winds from the north after the front. Winds from the north are particularly effective in moving surface waters landward in South Bay (Walters, 1982). Shallow water depths in the landward reach increase air-water interactions, which is a factor controlling water temperatures and effects of evaporation on salinity (Schemel and Hager, 1996).

Acknowledgments

Many volunteers have been critically important to this project since its beginning. We gratefully acknowledge support from CDWR, and the efforts to establish this and other monitoring stations in the estuary. The U.S. Fish and Wildlife Service maintained the pier facilities and provided other services needed to secure the location. We also appreciate field help and reviews from our colleagues.

METHODS

After construction of the new Dumbarton Bridge, the eastern causeway of the old bridge was converted to a public fishing pier. CDWR built a small structure near the west end of the pier during the summer of 1989 to house equipment and instrumentation for monitoring water-column properties. Water depth at the site was approximately 6m. The USGS installed sensors approximately 2m above the bottom of the water-column to measure salinity, temperature, and water level (tides). Data were collected from these sensors at 15-minute intervals during 1990WY-1993WY (Schemel, 1995a). From November 1994 through 1998WY, salinity and temperature were monitored with self-contained sensor and data-logger systems that floated 1m below the surface of the water (Schemel, 1998a). The instrument float assembly was redesigned and smaller instruments were purchased for evaluation during 1999WY. Falmouth Scientific, Inc.,(FSI) micro-j, specific conductance and temperature recorders were purchased in 2000WY and deployed through 2002WY. Special studies of stratification events have utilized both surface and near-bottom sensors (see RESULTS and Schemel and Hager, 1996).

The FSI recorders were factory calibrated, but field samples were collected to check for large errors. Agreement between values for field samples and recorded values was not as good as the expected accuracy of the FSI recorders. Laboratory checks of the FSI recorders were conducted semi-annually for temperature and specific conductance. Temperature was typically within factory specifications, but small adjustments in the sensitivity of the specific conductance output were often necessary. Changes were mostly attributed to thinning of the ablative coating on the head. Correction algorithms were based on laboratory measurements of seawater plus two seawater-freshwater mixtures. Field and laboratory samples were analyzed on a Guildline Autosal salinometer that was calibrated with standard sea water (IAPSO Standard Seawater Service). Conversions between specific conductance, temperature, and salinity used in the calibration process were based on the practical salinity scale of 1978 (Lewis, 1980). The accuracy of the field records was difficult to assess because of the potential effects of rapid changes in the water, but laboratory calibrations indicated that temperature was within 0.1 degree Celsius and salinity was within 0.1 practical units (psu) for 2000WY-2002WY. Data collected during 1999WY were less accurate largely because of inadequate designs of the sensors that were deployed.

There were two major causes of data loss by the FSI instruments. The small bore of the electrodeless specific conductance sensor was easily fouled by organisms and algae from April through October. Deployments longer than two weeks typically resulted in loss of some data. The instruments were generally not affected by fouling during the late fall and winter when the largest changes in salinity occurred. The second major cause of data loss was due to problems in the instrument firmware. In many cases this was related to calendar and data processing problems that had not been recognized by the manufacturer.

Meteorological measurements have been recorded by USGS at the Port of Redwood City (Redwood Creek; Fig. 1) since April 1992 to support hydrologic studies in South Bay (Schemel, 1995b, 1998b, and 2002). Discharge data for the local streams were obtained from Internet sites maintained by USGS (http://water.usgs.gov/nwis/discharge). Salinity and water temperature measurements from other locations in South Bay were obtained from P.A. Buchanan (see Buchanan, 2002).

RESULTS AND DISCUSSION

Compressed ASCII text files containing the most-recent data and the two previous reports and data sets can be accessed from the Internet home page for this report. It is likely that written reports will be less frequent in the future, but that data updates will be available on the home page. Ambient temperature, calculated salinity, and specific conductance at the ambient temperature are provided along with water year day and time for 1999WY-2002WY. Specific conductance values were not normalized to a specific temperature, for example 25C, which is often the case for monitoring data (Schemel, 2001).

Plots of daily mean values presented here include field results and supporting data for all three data collection periods, 1990WY-1993WY, 1995WY-1998WY, and 1999WY-2002WY. This allows comparisons among years and an overview of the entire data set. More-detailed analyses of the data through 1998WY were provided in the earlier reports (Schemel, 1995a, 1998a, and 1998c). Daily mean values for salinity and temperature were used to illustrate seasonal and interannual variability because mean values largely remove effects of daily tidal flow.

Seasonal and Interannual Variability

Precipitation, local stream flow, Delta Outflow, and other climate- and weather-related variables affect both salinity and temperature over a wide range of time scales. Values for monthly total precipitation at San Francisco International Airport (SFO; Fig. 1) identify large differences in the seasonal patterns of precipitation among the years (Fig. 8). In a typical (normal) year, most precipitation falls from December through March (wet season); whereas very little precipitation falls from May through September (dry season). Although this pattern was seen in most of the years, less than normal precipitation was observed during the wet season of many years, particularly 1990WY. In 1991WY and 1992WY precipitation exceeded the normal levels for only two months of the wet season. Precipitation exceeded the normal levels for most of the wet season months in 1993WY, 1996WY, and 1998WY, whereas patterns of precipitation varied greatly over the wet season months of 1999WY-2002wy Some patterns were particularly unusual, such as a very dry February in 1995WY, a very dry February through April in 1997WY, and an above normal November and December followed by a dry January through April in 2002WY.

Local stream flows reflected the seasonal patterns in precipitation (Figs. 4 and 9). During dry years, such as 1990WY-1992WY and 2001WY-2002WY, even the relatively low discharges from the local streams can have major influences on salinity at Dumbarton Bridge (Fig. 10; Schemel, 1995a). This was partly because Delta Discharge was low during dry years (Fig. 11)and its influence on the landward reach of South Bay was minimal (Schemel and Hager, 1996). Local stream discharge to Lower South Bay is particularly important to salinity at Dumbarton Bridge because waters mix rapidly in the strongly tidal lower basin, and the tidal prism is about one-half of the volume at mean high tide (Hager and Schemel, 1996a). Consequently, about half the volume of Lower South Bay is transported past Dumbarton Bridge between low and high water. Although generally greater than the other local streams, discharge from Alameda Creek might not cause immediate or large changes in salinity at Dumbarton Bridge because, as shown by aerial photographs, the inflow tends to drift northward along the shallows of South Bay.

Major features of the salinity records from each year included an often-sharp drop in late fall or early winter coinciding with freshwater flow to the estuary, an increase in salinity during spring and summer as seawater mixed landward, and highest salinity values near the end of the typically dry summer (Fig. 10). The reduction in salinity at Dumbarton Bridge was directly related to the level and timing of freshwater discharges. For example, unusual discharge sequences such as the two large, separated peaks in 1995WY corresponded to distinct decreases in salinity (Figs. 9 and 10). Other examples can be found in previous reports (Schemel, 1995a and 1998a). Even relatively low levels of local stream flow during the very dry years, 1990WY-1992WY, resulted in small reductions in salinity. During most years, salinity increased rapidly during spring, but lower salinity persisted longer during 1998WY, when Delta Outflows were higher than normal through summer (Figs. 10 and 11). The (annual) highest salinity value varied among the water years, primarily reflecting the amount of freshwater inflow during the previous winter and spring. The years with the highest levels of freshwater inflow (local stream and Delta Outflow), 1995WY and 1998WY, had the lowest annual maximum salinity values. In the most recent years, annual maximum salinity values for years with nearly average levels of freshwater inflow, 1999WY and 2000WY, were lower than for years with below average freshwater inflow, 2001WY and 2002WY. The influence of Delta Outflow in regulating the salinity in the main estuary (seaward of Bay Bridge), and therefore the transport of salt into South Bay, was apparent by the low values during wet years. Very high salinity values in 1990-1992WY followed several years of unusually low freshwater discharge and possibly also reflected the lower wastewater inflows during the extended drought (Fig. 6).

Seasonal changes in water temperature at Dumbarton Bridge (Fig. 12) reflected variations in solar irradiance and air temperature measured at the USGS Redwood Creek meteorological station (Fig. 13; Schemel, 1998b and 2002). Although small differences were often apparent, there were few major differences in the seasonal water temperature patterns among the years (Schemel, 1998a). Maximum water temperatures at Dumbarton Bridge were near 25C in summer, and lowest temperatures were near 10C in early winter of most years. Colder than normal water temperatures were observed in autumn 1999WY, which coincided with unusually low air temperatures. Changes in air temperatures over just a few days were often reflected in water temperature variations at Dumbarton Bridge. Lower South Bay waters are sensitive to even brief changes in air temperature in part because of extensive shallow-water areas and rapid tidal mixing (Schemel and Hager, 1996).

Variability on Tidal Time Scales

Mixed tides from the Pacific Ocean produce two high-water and two low-water events each lunar day (24h 50m). Tidal flow coupled with often-strong longitudinal gradients in salinity and water temperature result in large and rapid changes in these variables at Dumbarton Bridge. The greater tidal action during (biweekly) spring tides produces greater variability compared to neap tides, and freshwater inflow further intensifies the longitudinal gradients and increases variability.

The response of salinity at Dumbarton Bridge to runoff from a Winter 2000WY storm and tides is shown in Fig. 14. Salinity was highest at high tide throughout the record, indicating that waters in Lower South Bay were diluted by freshwater inflows to a greater extent than the waters seaward. The brief pulse in local stream inflow sharply lowered surface salinity, but the effect was reduced by mixing over the following week. Salinity stratification (bottom minus surface salinity) was greatest when surface salinities were lowest on the third day of local stream discharge. There was a short lag between low tide and the greatest salinity stratification, which probably corresponded to slack water after propagation of the tide into Lower South Bay. Mixing had reduced salinity stratification to low levels a week after the peak in discharge.

Tidal energy is a key factor affecting the development of salinity stratification in South Bay. At Dumbarton Bridge, freshwater inflow caused stratification that intensified during the biweekly neap tides, but stratification was reduced when tidal energy was greater during spring tides (Fig. 15). In some cases local stream discharges coincided with the timing of weak tides, but stratification did not persist through the following period of strong tides even when the levels of discharge were high. The amount of mixing induced by tides is enhanced by the many obstructions to flow near Dumbarton Bridge (highway and railroad bridge piers, pipeline and fishing pier structures, and power cable towers). Consequently, observations of stratification at Dumbarton Bridge might not be representative of open-water areas of South Bay.

Brackish water from the North Bay flows into South Bay with the tides and during periods when stratification enhances density-driven currents. Therefore, the salinity of water at Bay Bridge affects salt transport to South Bay and can cause large bay-wide changes in salinity particularly when Delta Outflow is high and tidal energy is weak. Salinity at Bay

Bridge was reduced sharply by increasing Delta Outflow in February 2000WY (Fig. 16). Salinity stratification, however, did not increase until tidal energy was reduced during the subsequent neap tide. It is likely that this inflow to South Bay contributed to reduced salinity as far landward as Dumbarton Bridge (Fig. 10). Although Delta Outflow remained high for nearly a month, stratification was reduced when tidal energy was high. Stratification increased during weak tides in early spring, even though salinity had increased and Delta Outflow was greatly reduced. This example illustrates the importance of both Delta Outflow and tidal energy on processes that affect mixing and exchange of South Bay waters with the North Bay estuary. A more-detailed example showing salinity changes at Bay Bridge, San Mateo Bridge, and Dumbarton Bridge that were related to high levels of Delta Outflow during 1997WY was presented in a previous report (Schemel, 1998a). The direct influence of local streamflow and Delta Outflow on salinity variations at the Dumbarton and Bay bridges has been described for the relatively wet period of 1995WY-1998WY (Schemel, 1998c).

Implications for Wastewater Dilution and Transport

Salinity and temperature measurements are the basis for models that can simulate wastewater dilution and transport and predict effects of changes to hydrologic systems. In addition, these properties of South Bay waters are easy to measure compared to most waste-derived pollutants. The link between salinity variations and wastewater dilution and transport can be demonstrated with dissolved inorganic nutrients, which are often used as tracers of pollutants because wastewater is the largest source in South Bay (McCulloch and others, 1970; Conomos and others, 1979). During times of the year when Delta Outflow and local stream flows are low and dilution processes are limited, concentrations of dissolved inorganic nutrients typically reach their highest levels of the year, and their concentrations are inversely related to the salinity in South Bay (Hager and Schemel, 1996). Many processes that dilute and transport wastewaters also affect salinity. Wastewaters are transported from South Bay by slow processes such as dispersive mixing and by relatively fast processes driven by hydrodynamic forces. For example, mixing with seawater progresses slowly over the summer months, increasing the salinity of South Bay. In contrast, very rapid reductions in salinity occur when Delta Outflow and local stream flows are high during winters with above normal precipitation and runoff. Both of these processes promote dilution of ambient waters and transport wastewaters from South

Bay. However, the rapid reduction in salinity during some winters indicates that the transport is much greater in magnitude over a short period of time. Density-driven currents, which are related to gradients in salinity and temperature, also enhance circulation in South Bay particularly when the water column is stratified and tides are weak. Distributions of salinity and dissolved nutrients can identify these circulation patterns that transport pollutants from South Bay.

SUMMARY

Salinity and temperature measurements at the Dumbarton Bridge covered a range of hydrologic conditions, including critically dry years and years with above normal and near-record precipitation and runoff. Data collection at 15-minute intervals allowed resolution of variability associated with daily tides and other short-term phenomena. Salinity and temperature were monitored during 12 of a 13-year time series, enabling comparisons among years and between sequential dry and wet periods. Discharges from local streams and the Delta were major factors affecting variability in salinity over a wide range of time scales. Short-term and seasonal variations in water temperature followed changes in air temperature and solar irradiance.

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APPENDIX A: ILLUSTRATIONS

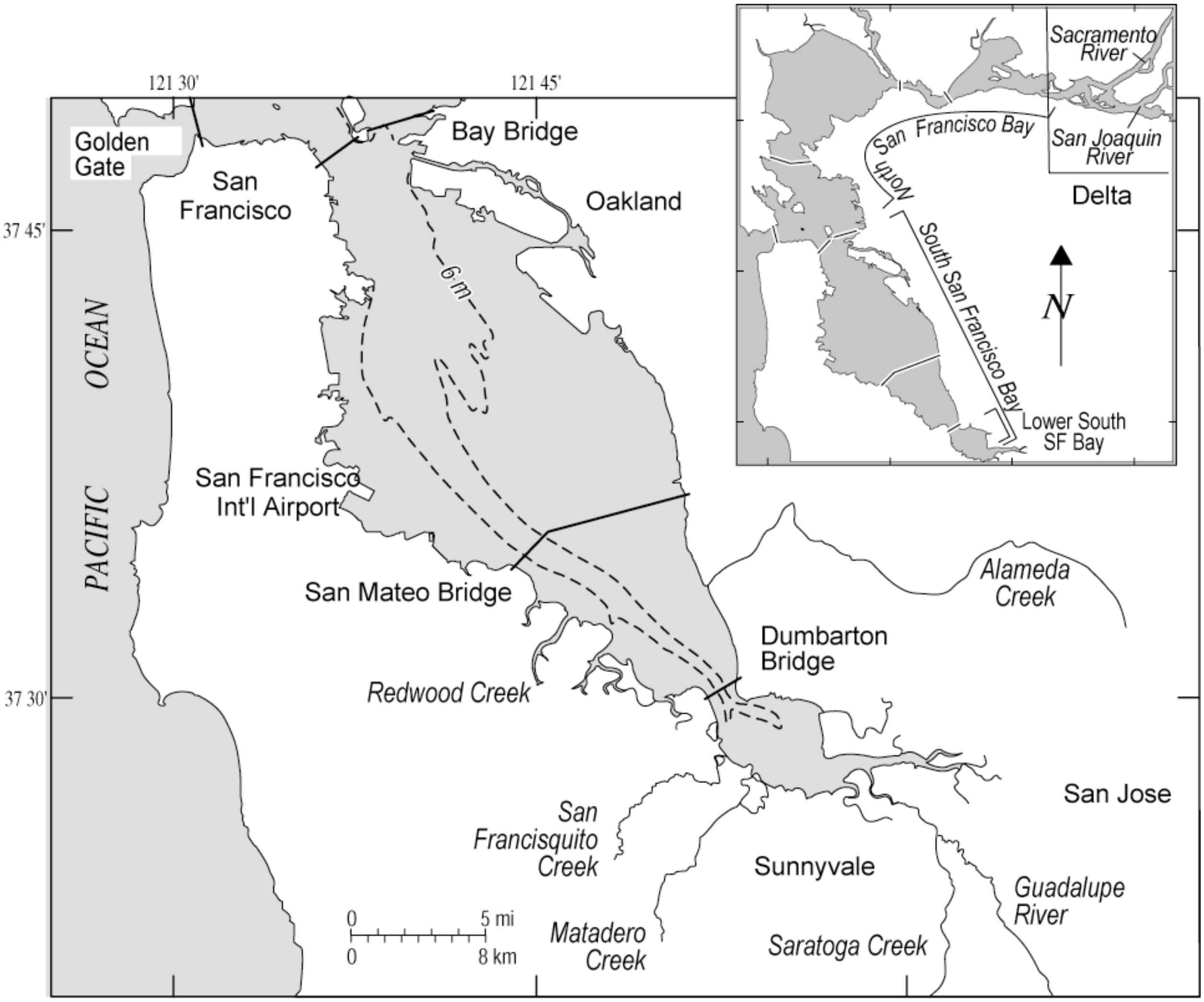

Fig. 1. Map showing the San Francisco Bay Estuary and Delta and locations in South San Francisco Bay.

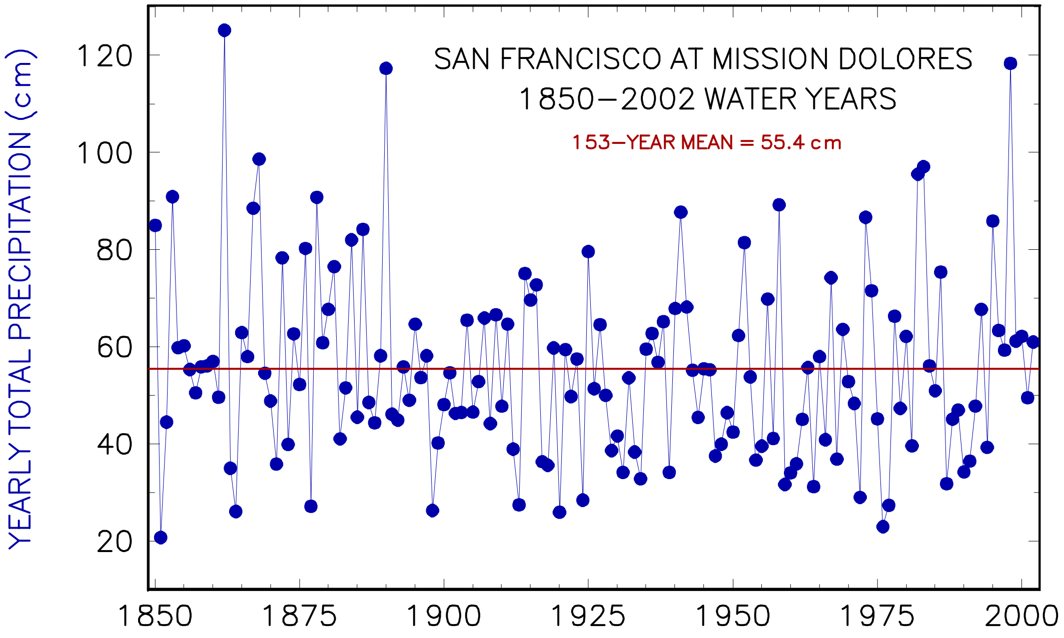

Fig. 2. Time-series plot of yearly total precipitation for the 1850-2002 water years (October through September) at Mission Dolores, San Francisco, California.

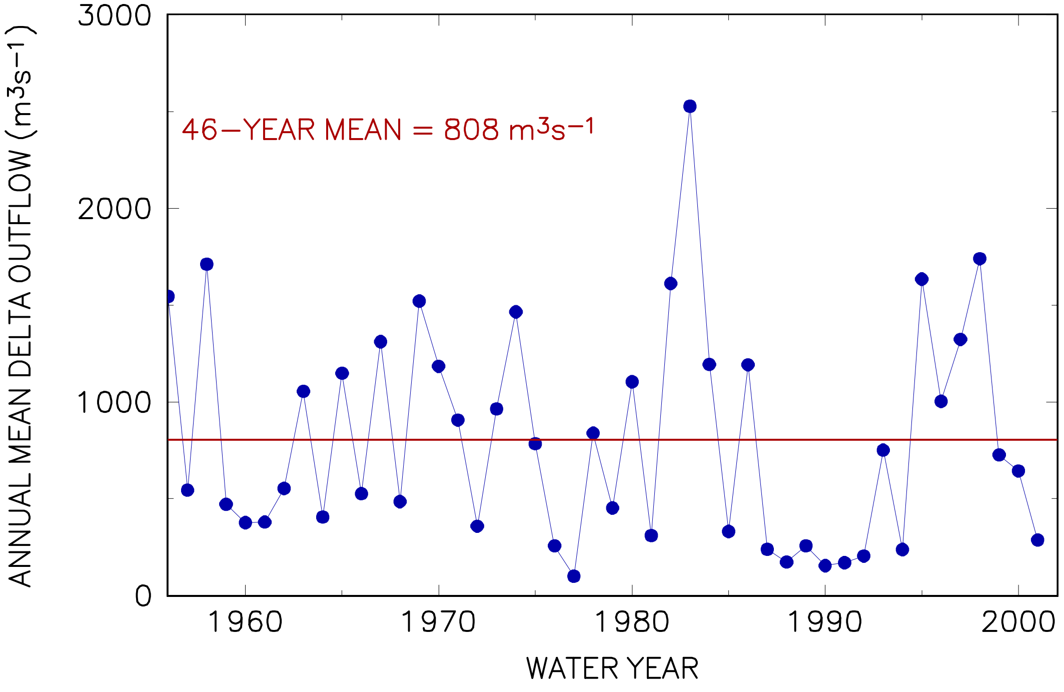

Fig. 3. Time-series plot of annual mean Delta Outflow for the 1956-2001 water years. Data for the 2002 water year were not available.

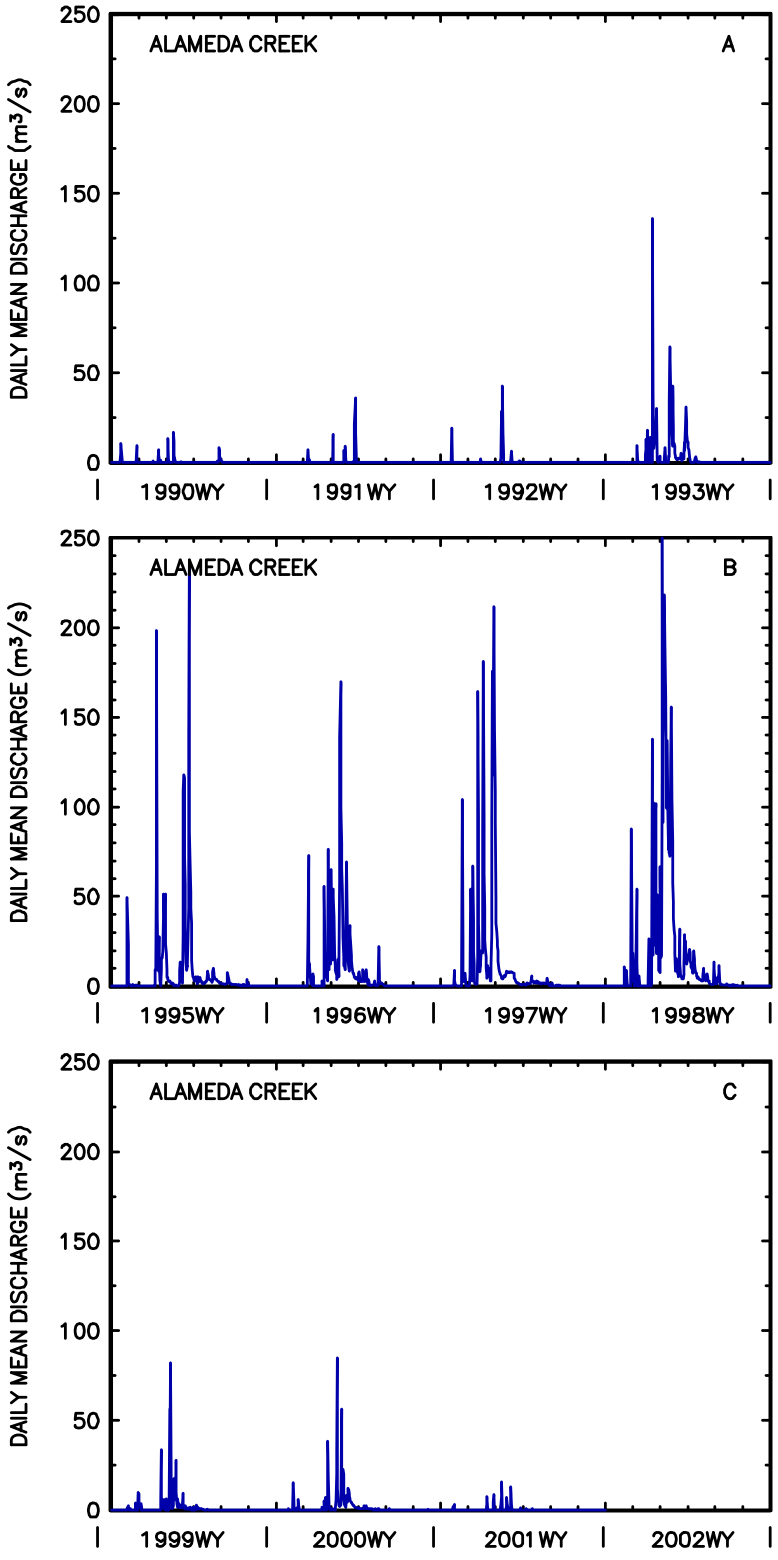

Fig. 4. Time-series plots of daily mean discharge from Alameda Creek for 1990WY-1993WY, 1994WY-1998WY, and 1999WY-2001WY. Data for 2002WY were not available.

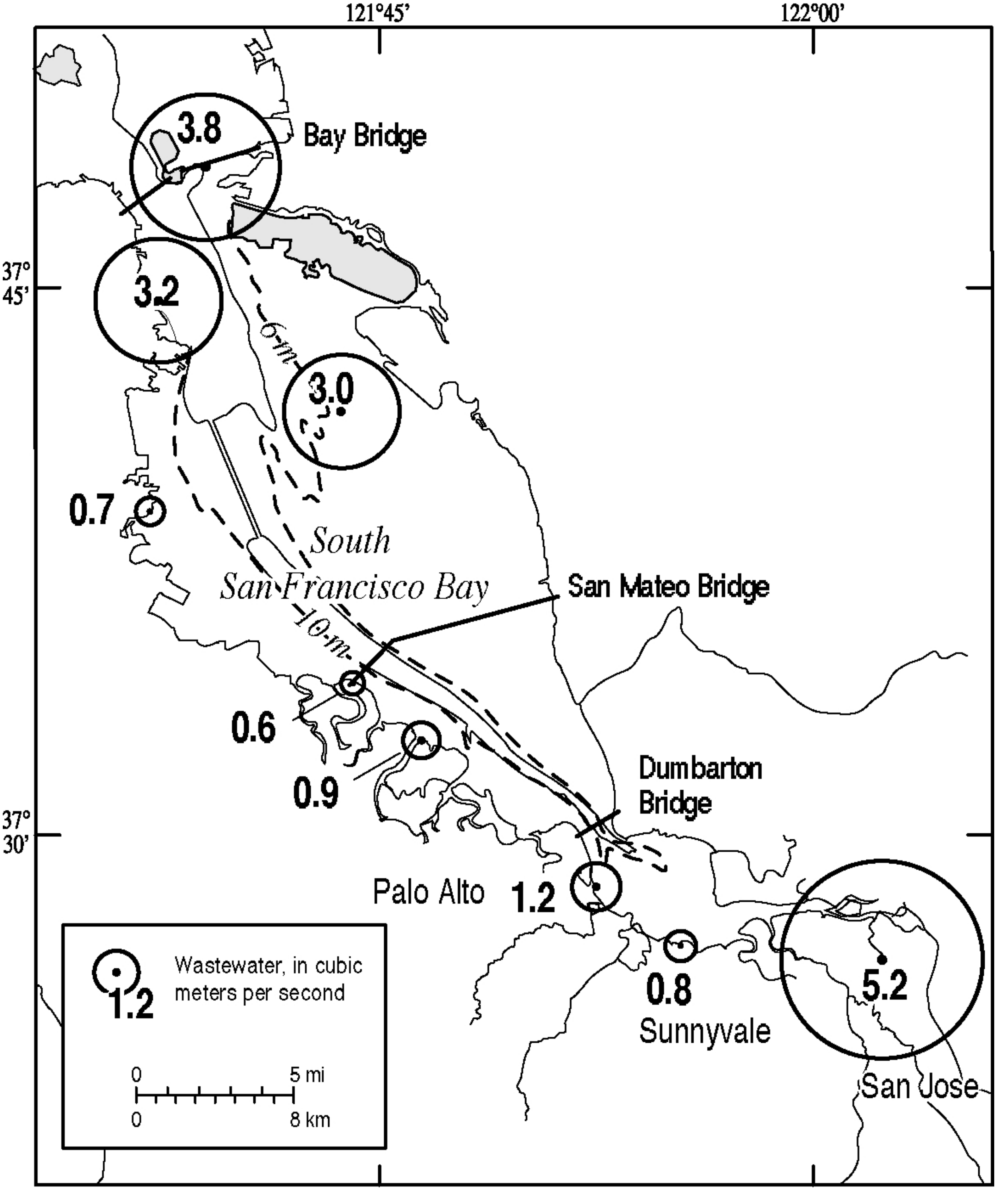

Fig. 5. Locations of major municipal waste treatment plants in South San Francisco Bay and their estimated discharges based on data from Davis and others (1991).

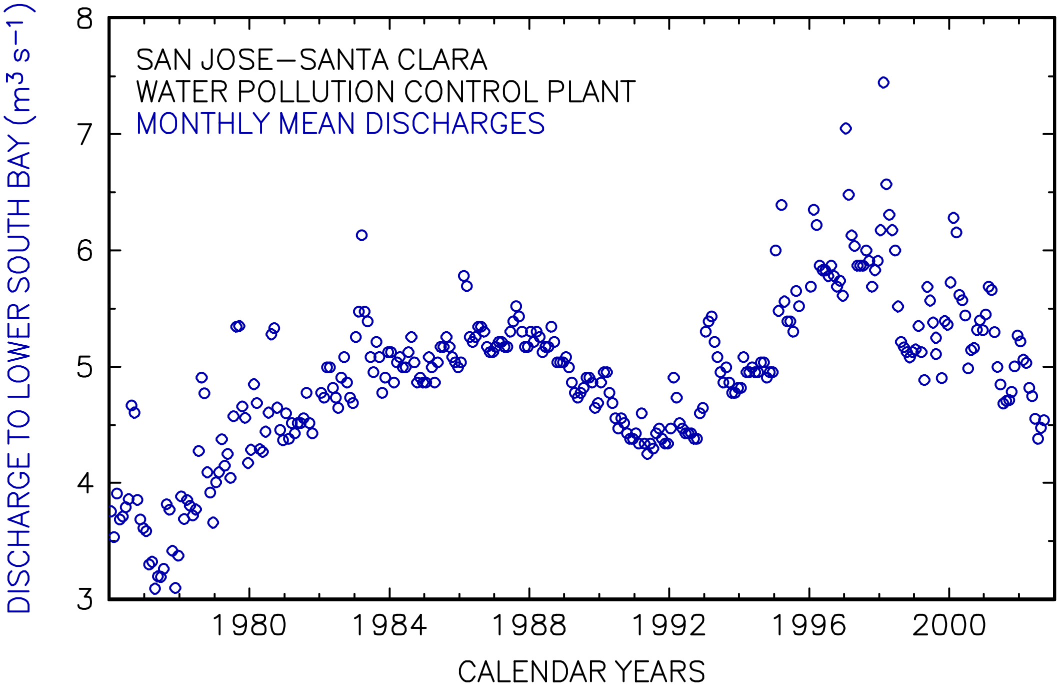

Fig. 6. Time-series plot of mean monthly discharge from the San Jose-Santa Clara Water pollution control plant for 1976-2002 from monthly reports to the Regional Water Quality Control Board.

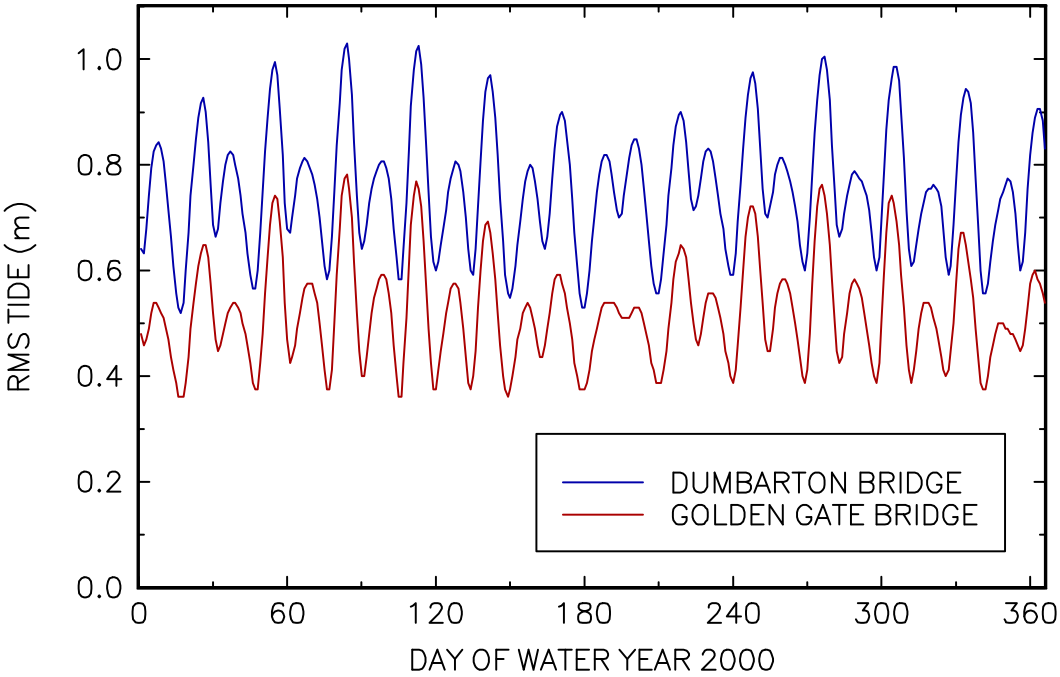

Fig. 7. Time-series plot of daily RMS (root-mean-square) Tide (height) at Dumbarton Bridge and the Golden Gate Bridge during 2000WY.

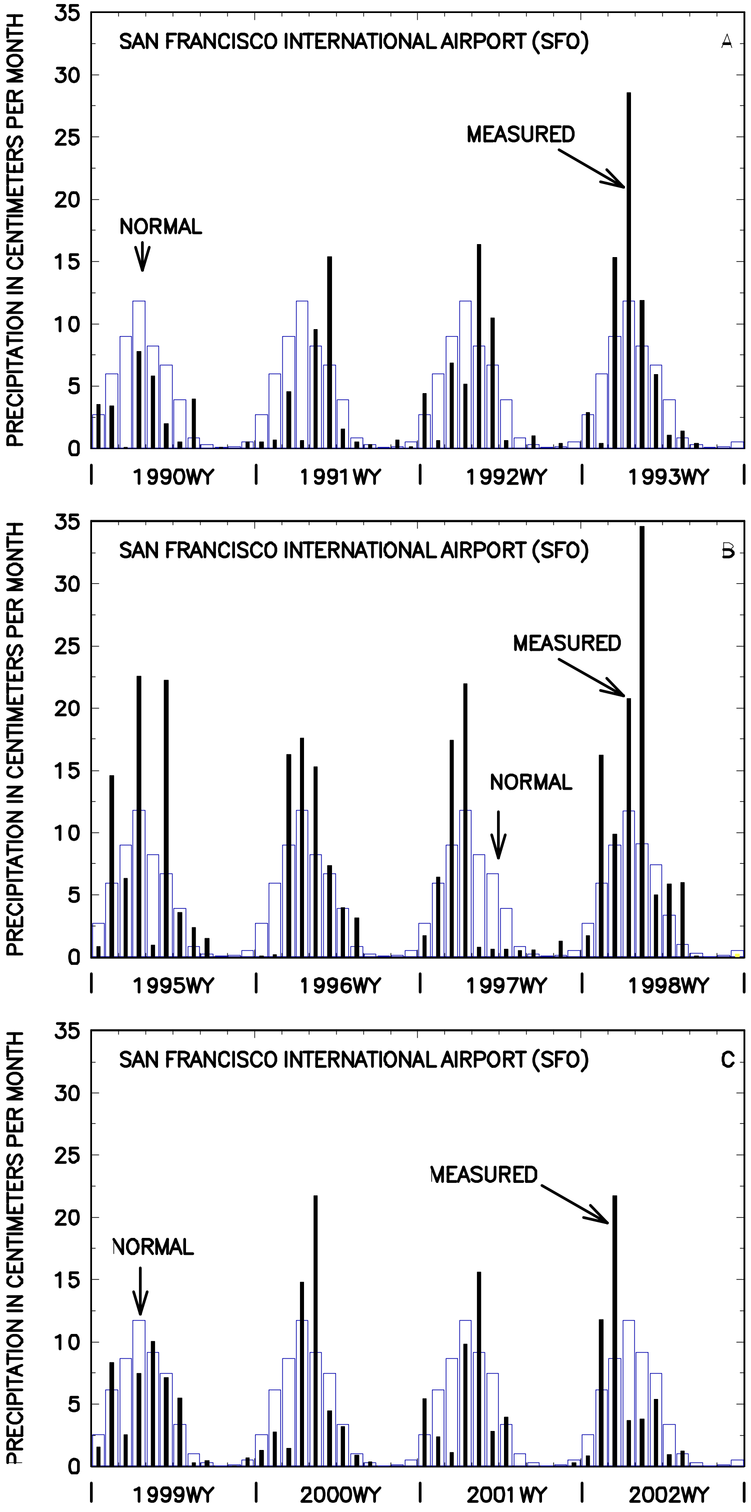

Fig. 8. Bar graphs of normal and measured monthly total precipitation at San Francisco International Airport (SFO) for 1990WY-1993WY, 1994WY-1998WY, and 1999WY-2001WY.

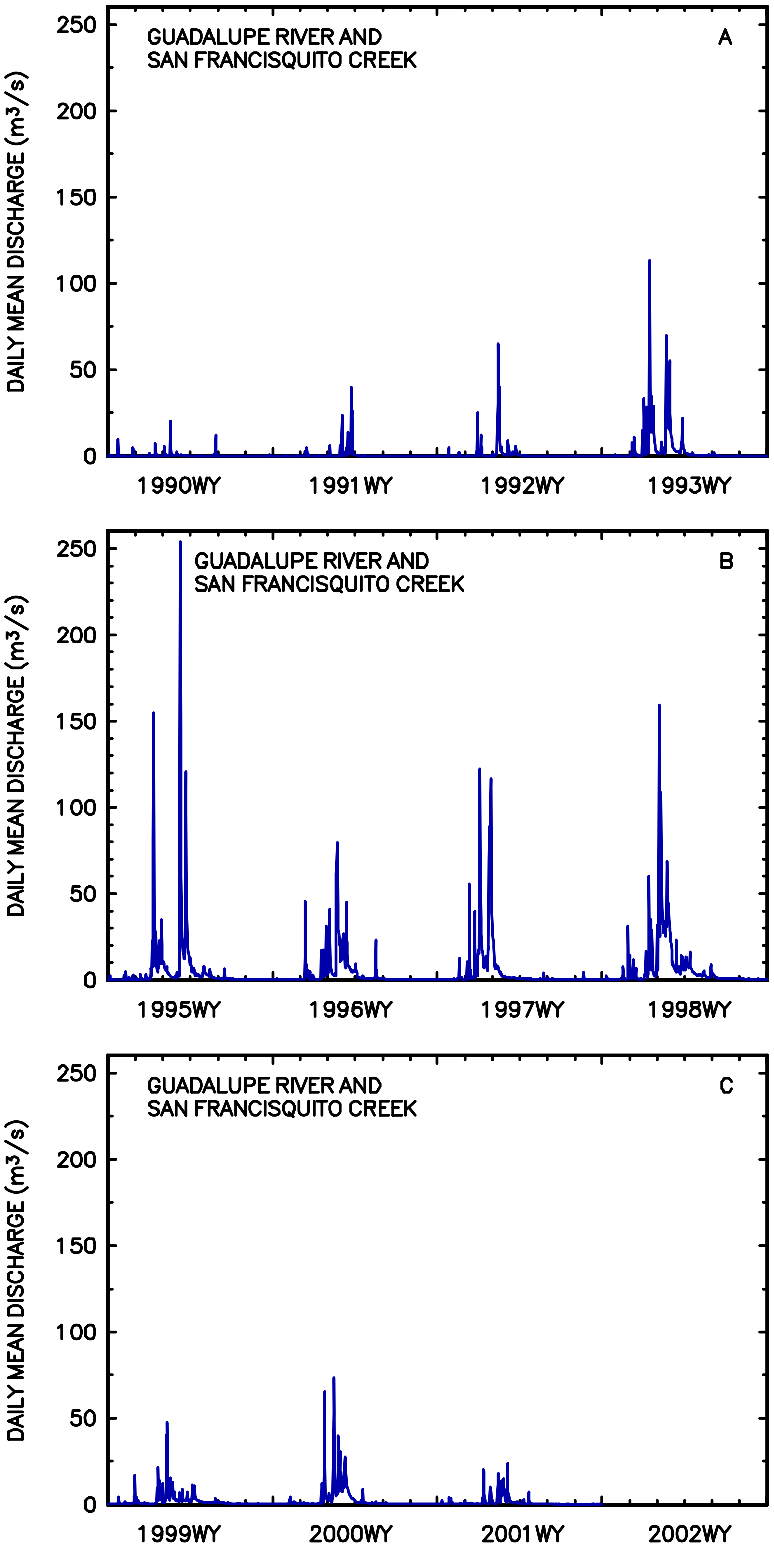

Fig. 9. Time-series plots of total daily mean discharge from the Guadalupe River and San Francisquito Creek to Lower South Bay for 1990WY-1993WY, 1994WY-1998WY, and 1999WY-2001WY. Data for 2002WY were not available.

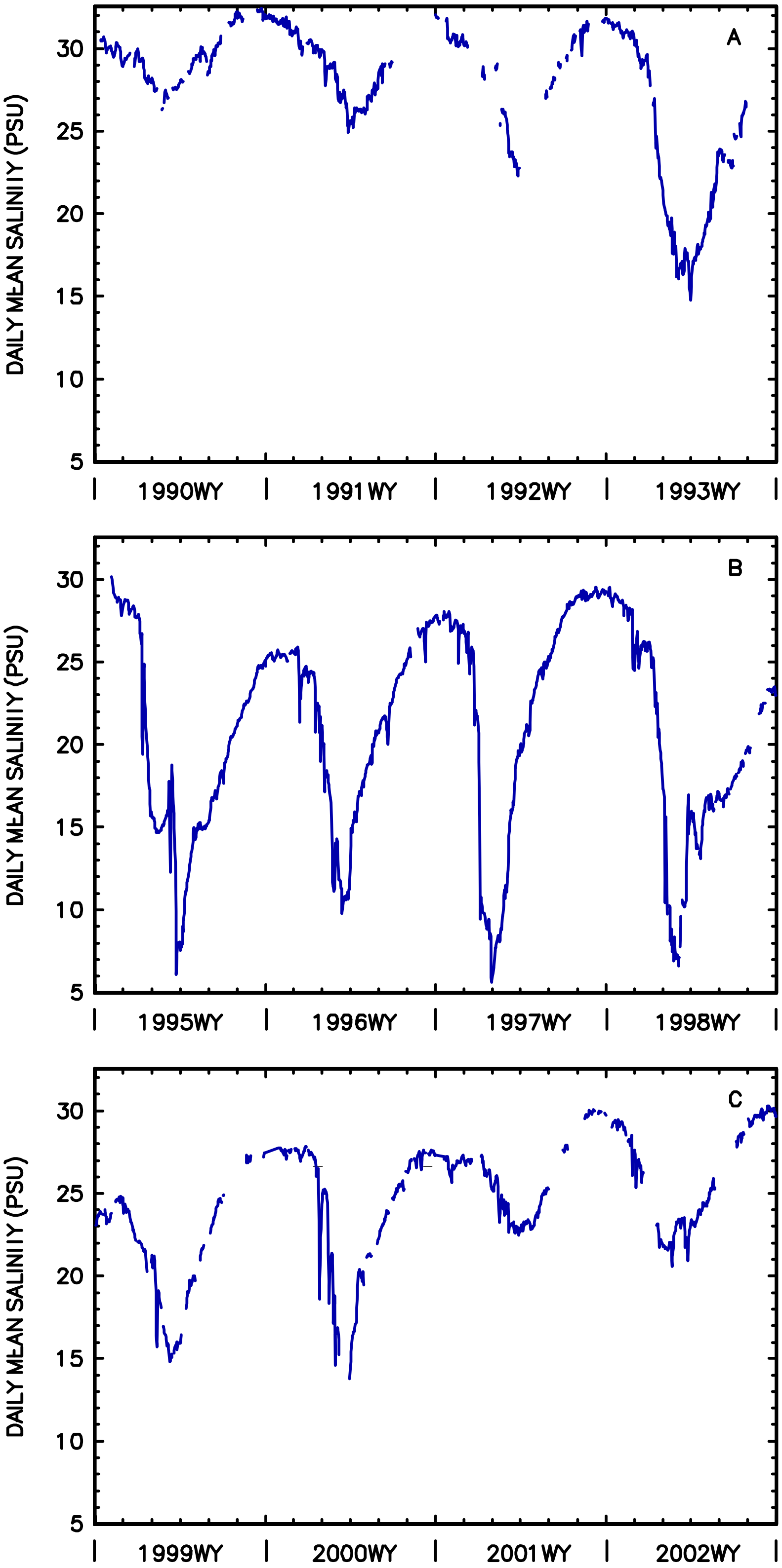

Fig. 10. Time-series plots of daily mean salinity at Dumbarton Bridge for 1990WY-1993WY, 1994WY-1998WY, and 1999WY-2001WY.

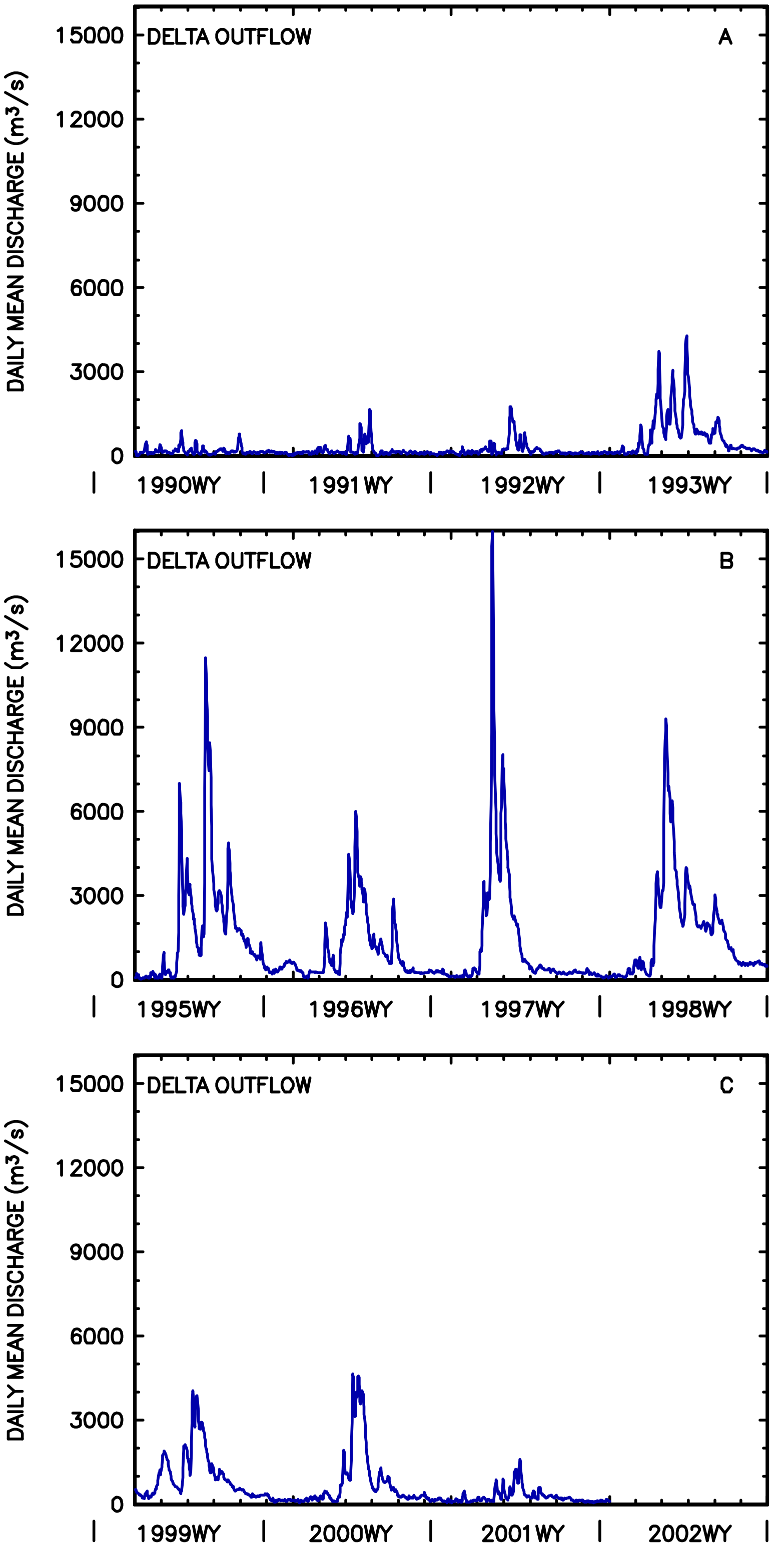

Fig. 11. Time-series plots of daily mean Delta Outflow for 1990WY-1993WY, 1994WY-1998WY, and 1999WY-2001WY. Data for 2002WY were not available.

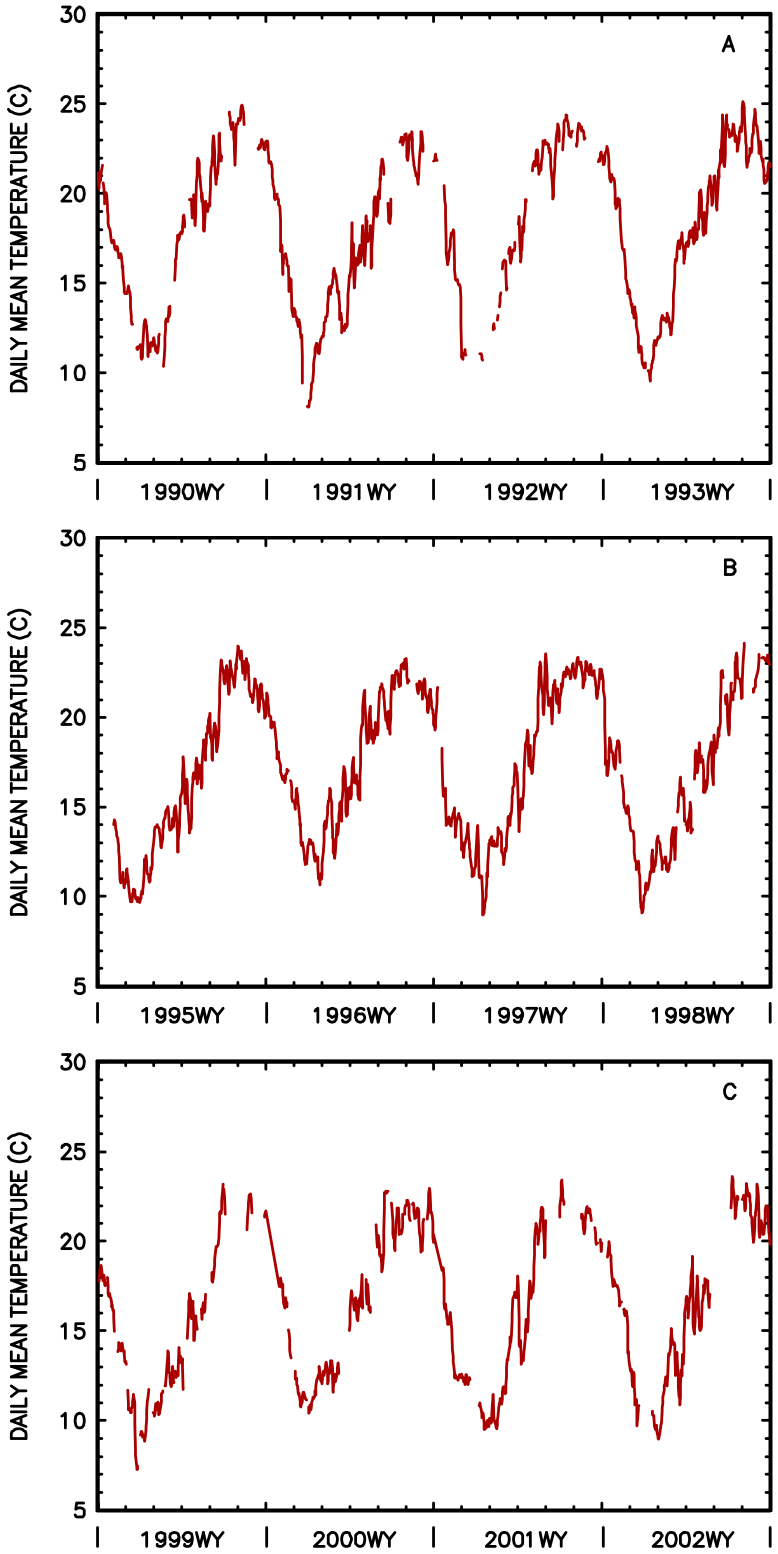

Fig. 12. Time-series plots of daily mean water temperature at Dumbarton Bridge for 1990WY-1993WY, 1994WY-1998WY, and 1999WY-2001WY.

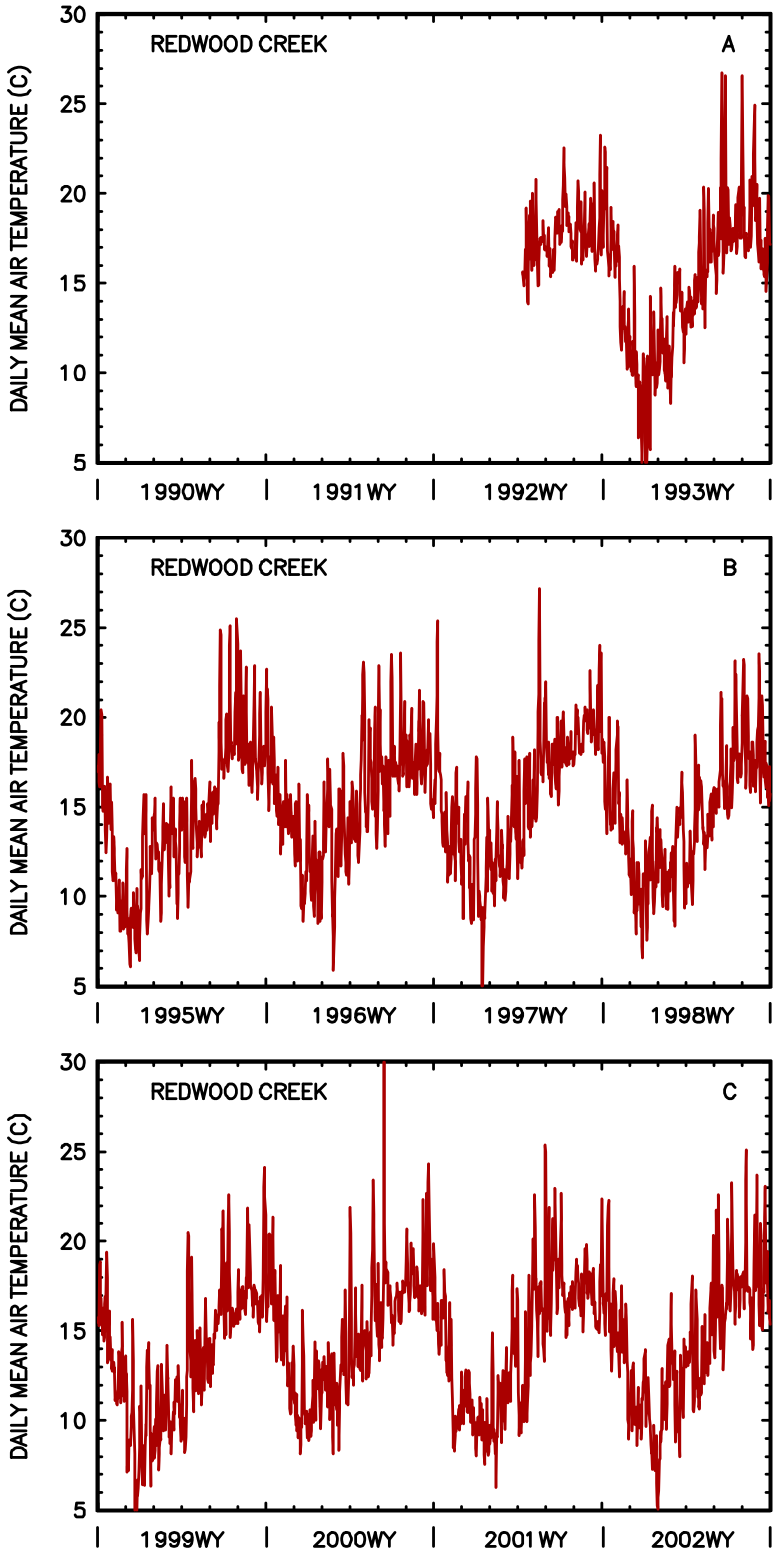

Fig. 13. Time-series plots of daily mean air temperature at Redwood Creek, Port of Redwood City, California, for 1990WY-1993WY, 1994WY-1998WY, and 1999WY-2001WY.

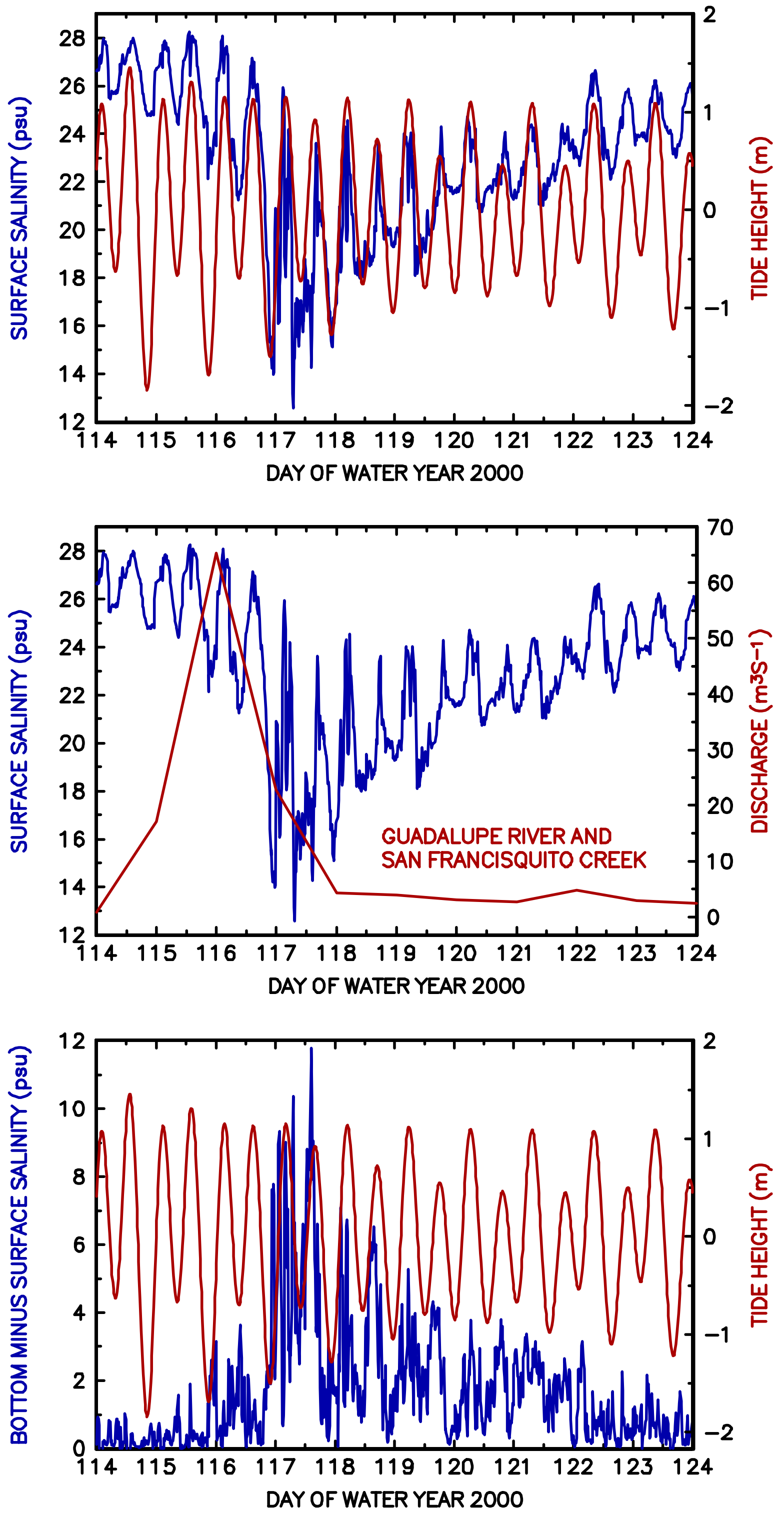

Fig. 14. Time-series plots showing surface salinity, tide height, stream discharge, and salinity stratification at Dumbarton Bridge during winter 2000.

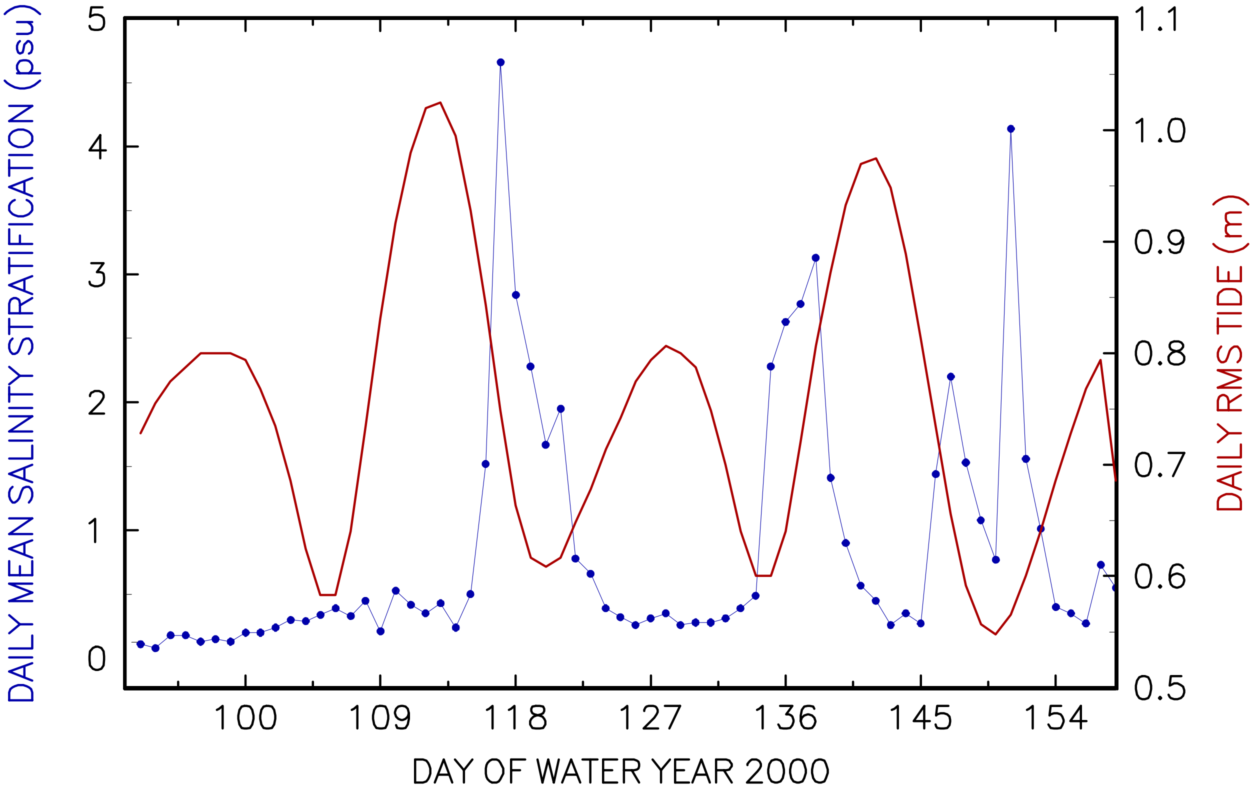

Fig. 15. Time-series plot showing daily mean salinity stratification and RMS tide at Dumbarton Bridge during winter 2000.

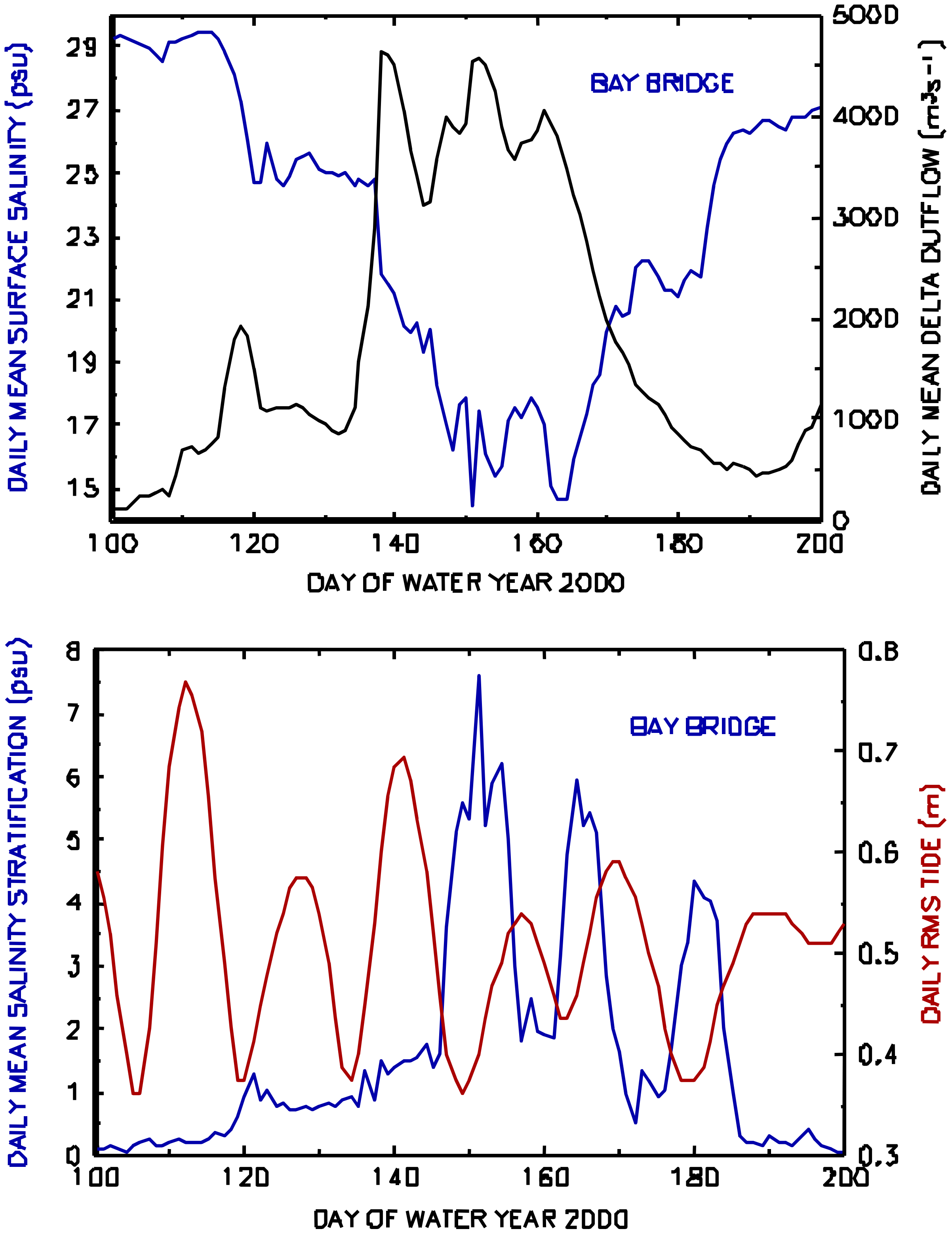

Fig. 16. Time-series plots showing daily mean surface salinity, Delta Outflow, salinity stratification, and RMS tide at Bay Bridge during winter and early spring, 2000.