MEASUREMENTS OF SALINITY, TEMPERATURE, AND TIDES IN SOUTH SAN FRANCISCO BAY, CALIFORNIA, AT DUMBARTON BRIDGE: 1990-93 WATER YEARS.

by Laurence E. Schemel

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CONVERSION FACTORS

Metric units are used in this report. For readers who prefer inch-pound units, the conversion factors for the terms used in this report are listed below.

Multiply	By	To obtain
m^3/s (cubic meters per second)	35.31	cubic feet per second
cm (centimeter)	0.3937	inch
m (meter)	3.281	foot
m^2 (square meters)	10.76	square feet

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 is given in units of the Practical Salinity Scale (psu).

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ABSTRACT

The U.S. Geological Survey measures salinity, temperature, and water levels (tides) in southern San Francisco Bay at Dumbarton Bridge as part of a cooperative program with the California State Department of Water Resources. During water years 1990-93, measurements were made at 15-minute intervals with electonic sensors located approximately one meter above the substrate in approximately six meters of water (at mean water level). During March and April of 1991 and 1992, salinity and temperature also were measured with a self-contained system floating one meter below the surface of the water. Sections of the data set were selected to illustrate influences of tidal currents, weather events, and seasonal and interannual variations in climate on salinity, temperature, and water levels at this location. The edited data are provided on high-density disks in comma-delimited, ASCII text files.

INTRODUCTION

During the summer of 1989, the U.S. Geological Survey (USGS) and the California State Department of Water Resources (CDWR) established a monitoring and research site in southern San Francisco Bay on the east span of the old Dumbarton Bridge (fig. 1). During water years 1990-93 (October 1989 through September 1993), salinity, temperature, and water level were measured at 15-minute intervals by electronic sensors. The objectives of this study, were to observe changes in salinity and temperature and to relate variations in the values to tides (measured by water level) and to other variables, particularly those associated with interannual and seasonal climate variability and weather-related events (winds, rainfall, and runoff to the bay). In addition, this study contributed water quality and hydrodynamic data to on-going ecosystem and hydrodynamic research conducted by USGS, CDWR, and other federal and state agencies. This report presents numerical values of measurements collected over the four years and provides details of the methods employed in this study. Hydrographic characteristics of southern San Francisco Bay and hydrologic characteristics of the 1990-93 water years are also described.

Hydrographic Characteristics of Southern San Francisco Bay

Southern San Francisco Bay (South Bay) is a tributary estuary of northern San Francisco Bay (North Bay), the estuary of the Sacramento-San Joaquin River system (fig.1). South Bay is often described as a lagoon-like system, because its drainage basin is small and direct runoff is small relative to the volume of the bay. Because inflow from local streams is largely limited to winter and early spring, discharges from municipal waste facilities account for most of the freshwater inflow to South Bay most of the year. Salinity and other water-column variables in South Bay are affected by changes in water quality conditions in the main estuary (North Bay). Over the last two decades, much research has focused on the complex interactions between North Bay and the seaward reach of South Bay (for example see Walters and others, 1985). However, less information has been available to document the response of the landward reach of South Bay to a variety of climate- and weather-related factors, including inflow from local streams. A key objective of this study was to characterize the effects of seasonal climate change and weather events on the water-column variables in the landward reach at Dumbarton Bridge.

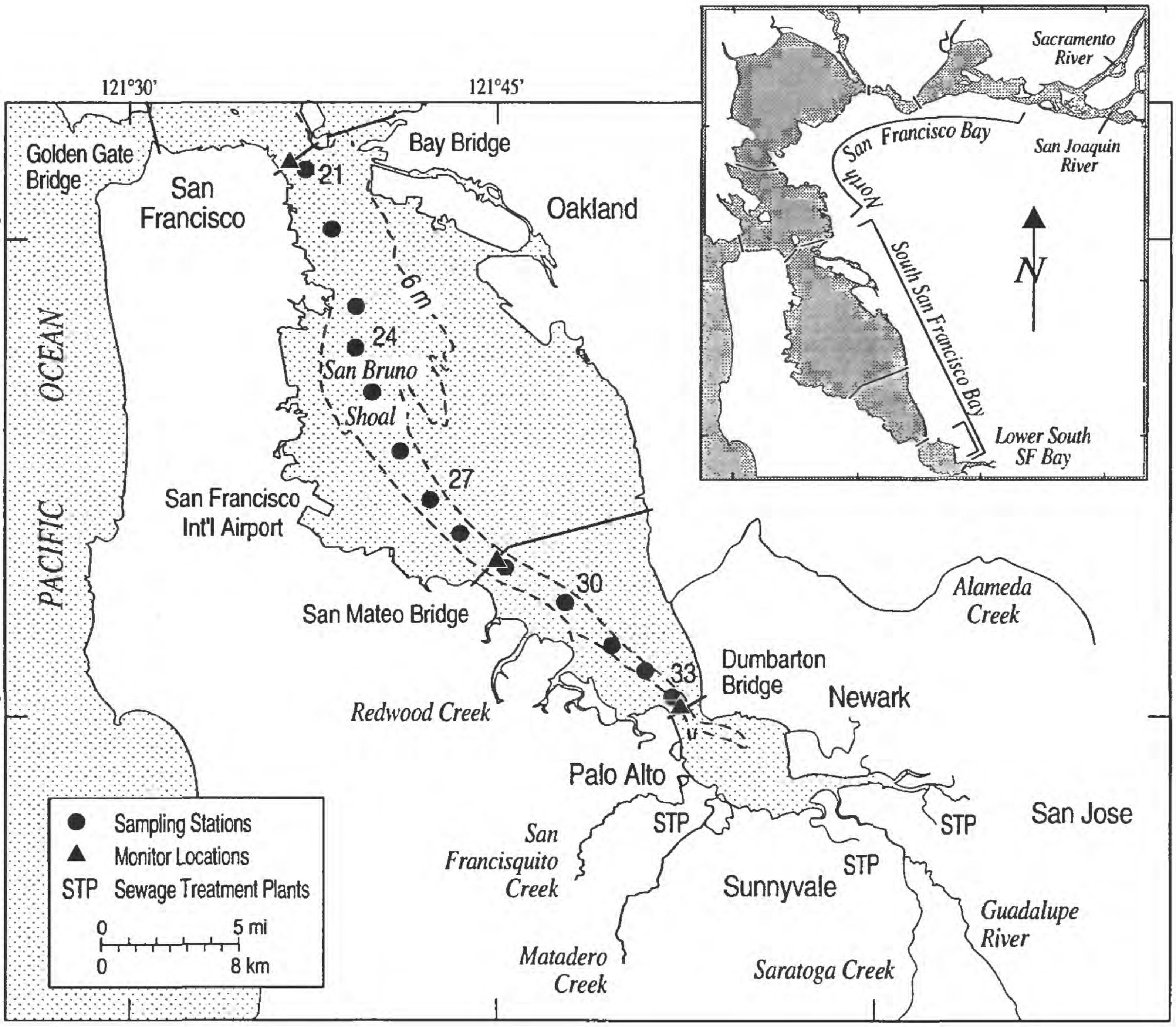

Figure 1. Map showing San Francisco Bay and locations in South San Francisco Bay.

Table 1. Hydrographic and geographic characteristics of southern San Francisco Bay (South Bay). Values are based on relations between tidal height and sectional volumes and areas presented by Selleck and others (1966). HH = Higher High; LL = Lower Low

Section	Area in $10^8 m^2$			Volume in $10^9 m^3$		
	Mean LL	Mean Water Level	Mean HH	Mean LL	Mean Water Level	Mean HH
Bay Bridge to San Mateo Bridge	3.5	3.7	3.8	1.8	2.1	2.4
San Mateo Bridge to Dumbarton Bridge	0.68	0.88	0.10	0.26	0.34	0.42
South of Dumbarton Bridge	0.19	0.34	0.46	0.058	0.086	0.12

Hydrographic characteristics (sectional water volumes and areas; table 1) vary greatly between the landward and seaward reaches of South Bay. Approximately 83 percent of the mean-tide volume of South Bay is contained in the reach bounded by the San Francisco Bay Bridge (Bay Bridge) and the San Mateo Bridge (fig.1), which is subsequently referred to as the seaward reach. The landward reach also contains 75 percent of the surface area at mean tide level. South Bay narrows considerably landward of San Mateo Bridge to a strait at Dumbarton Bridge. The small basin landward of Dumbarton Bridge, Lower South Bay, is about 20 percent of the total volume of South Bay landward of San Mateo Bridge at mean tide level. The term, landward reach, refers to areas landward of San Mateo Bridge, including Lower South Bay. Landward and seaward reaches as defined here do, in fact, coincide with zones that appear to have different circulation characteristics (Powell and others 1986).

In addition to its smaller volume, other important features distinguish the landward reach from the seaward reach of South Bay. Water depth at mean tide in the landward reach averages 3.5m, compared to about 6m in the seaward reach. The average water depth in Lower South Bay is only 2.6m at mean tide, and there are large changes in surface area, volume, and depth over the tidal range (table 1.). About 85 percent of the South Bay watershed drains into the landward reach (USGS 1962; U.S. Environmental Protection Agency, USEPA, 1992). Therefore, effects of inflow from local streams are potentially greatest in the landward reach, where the surface area and water volume and depth are small relative to the seaward reach. The direct influence of mixing with North Bay waters is greatest in the seaward reach. However, most of South Bay can be affected by conditions in North Bay when delta outflows (see below) are extrememly high (McCulloch and others, 1970; Imberger and others, 1977). An objective of this study at Dumbarton Bridge was to identify effects of local stream inflows and mixing with waters from North Bay in the landward reach.

About half the total municipal waste flow to South Bay discharges into the small basin of Lower South Bay (USEPA, 1991). Most of the remaining waste enters South Bay in the seaward reach near the Bay Bridge, where it is rapidly dispersed into a large volume of water. Dumbarton Bridge is an important location to characterize variability in water-column properties because municipal waste entering Lower South Bay must travel through Dumbarton Strait to leave the estuary. Municipal waste discharge to Lower South Bay contributes to strong longitudinal gradients in salinity and in concentrations of waste-derived solutes in the landward reach (Conomos and others, 1979). Consequently, the movement of water by tides alone contributes to large, short-term variations in water-column properties at fixed sites in the landward reach, such as the Dumbarton Bridge site in this study.

Diurnal range of the tide increases landward in South Bay, increasing from about 1.7m at Golden Gate to 2.6m at Dumbarton Bridge (Selleck and others, 1966). This increase in tidal range combined with shallow water depths in the landward reach results in tidal prisms (the volume of water that is moved by the tide) that are large compared to the volumes of water at mean tide level. This is greatest in Lower South Bay, where the volume at mean lower low water is less than half the volume at mean higher high water. In addition, the area covered by water in Lower South Bay at mean lower low water is less than half the surface area at mean higher high water, indicating that over half of Lower South Bay consists of shallow mud flats that are exposed at low tides. The tidal prism of Lower South Bay is equivalent to about 24 percent of the volume of the basin bounded by the San Mateo and Dumbarton Bridges at mean lower low water.

Currents generated by the tides not only move water masses, but also mix the water column, particularly during periods of strong tides. In addition to two high tides and two low tides each lunar day (24.8 hr), there are diurnal differences between the two high and the two low waters and the corresponding current speeds. The tides and the tidal currents also vary on about a two-week period, with two periods of stronger (spring) tides and two periods of weaker (neap) tides per month. Likewise, semi-annual cycles with two periods of weak tides near the equinoxes and periods of strong tides near the solstices are apparent in the tidal record. Thus, longitudinal transport and mixing due to tides varies on time scales from hours to months.

Weather and climate variables are also important to transport and mixing in South Bay. Winds can be effective in mixing the water column in South Bay and in generating currents that move watermasses (Walters and others 1985; Huzzey and others 1990). Depending on wind speed and direction and the bathymetry of South Bay, wind can produce net currents that enhance or oppose residual circulation driven by tides or other processes. An annual pattern in wind speeds in South Bay is apparent, with generally stronger daily mean wind speeds in late spring through summer (Conomos and others 1985). These seasonal winds are typically from the west or north-west, and vary in speed over the day. Wind speeds are low at night, then increase during daylight hours to maximum values in the late afternoon. During winter and spring, storm fronts and other weather-related phenomena produce strong winds that usually last for a few days. During storms, winds will often increase in speed from the south, then blow from the north after passage of the front. Strong winds from the north are particularly effective in moving surface waters landward in South Bay (Walters 1982). Strong winds, in general, are effective in mixing the water column in most areas of South Bay.

Hydrologic Characteristics of the 1990-1993 Water Years

Rainfall and runoff were below normal in northern California during water years 1987-92. Rainfall during water year 1993 was greater than normal, marking the end of 6 years of drought conditions. This is illustrated by records from the San Francisco International Airport (SFO; fig. 2) showing that rainfall during most winter months was below normal (long term average) from water-years 1990 through 1992. However, the number of storms and the amount of rainfall increased with each year over the four years of this study. Therefore, results for 1990-93 encompass a range of climatic conditions during winter, progressing from very dry to wetter than normal.

As shown in figure 2, the amount of rainfall varies greatly over the seasons. As a consequence, evaporation from South Bay can exceed the supply of water from precipitation and runoff many months of the year. Evaporation exceeded precipitation in the landward reach of South Bay (Newark; fig.2) during most months of this study. During the first three years, precipitation exceeded evaporation only during March 1991 and February 1992. Particularly large excesses in evaporation were seen year round in 1990. Direct effects of evaporation on concentrations of dissolved substances would be most apparent in the landward reach, because of shallow water depths and large intertidal areas.

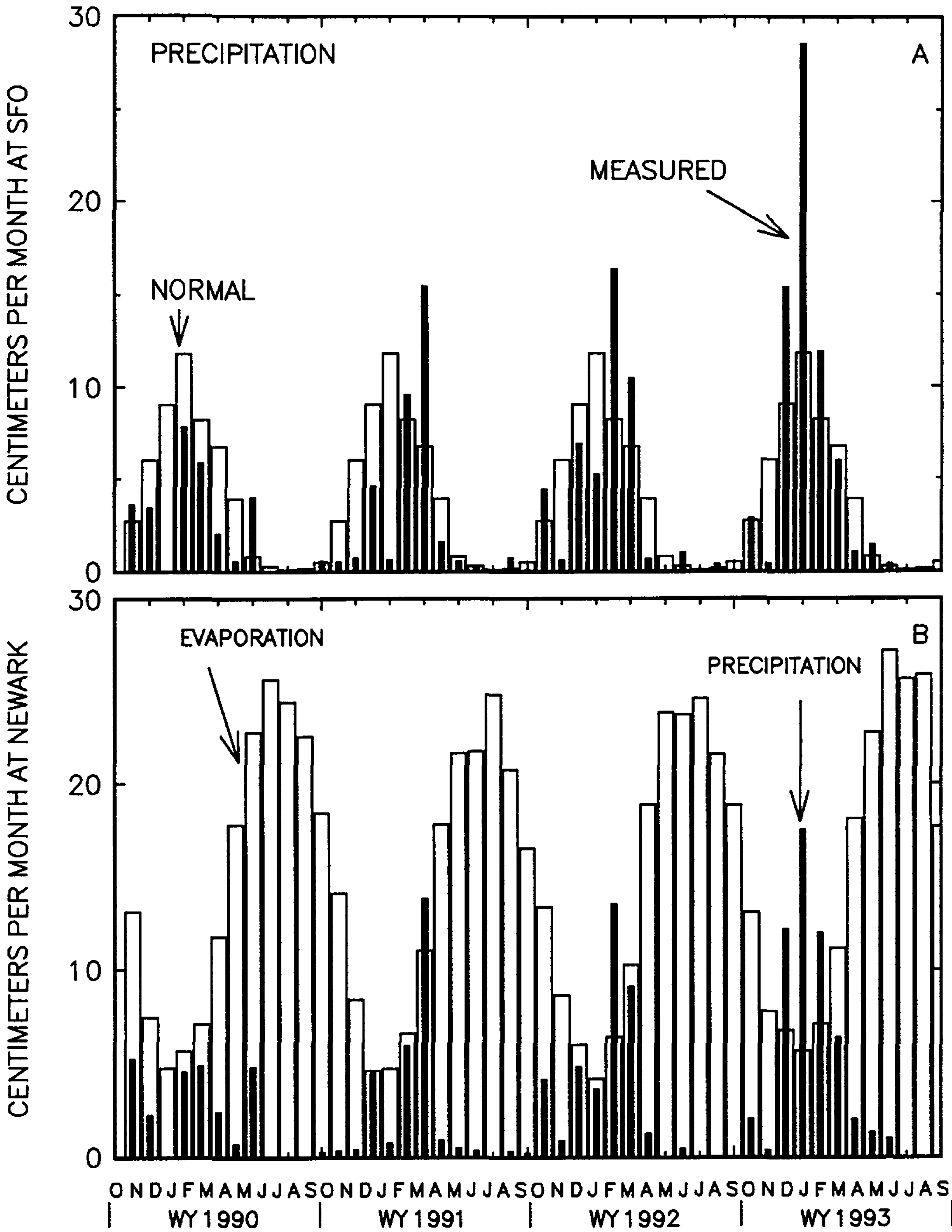

Figure 2. Bar graphs showing A) monthly values for precipitation, 1990-93 water years, and long-term average (normal) values for the San Francisco International Airport (SFO) and B) measured evaporation and precipitation, 1990-93 water years, at Newark, California.

The four-year trend of increasing precipitation in northern California is reflected in the flow of major rivers into North Bay (delta outflow) and in runoff from local streams into the landward reach of South Bay (fig.3). Delta outflow directly affects the salinity field and a suite of other water-column variables in North Bay, which in turn influences conditions in South Bay (Conomos and others, 1979). During water-years 1990 through 1992, delta outflow was generally low, but exhibited peaks during major storms primarily in winter and spring (fig.3). In contrast, flow was much greater during most of the 1993 water year. Annual mean flows over the first three years (1990, 155 m^3/s; 1991, 172 m^3/s; 1992, 203 m^3/s) indicate a small increase, but mean flow for the 1993 water year, 748 m^3/s, was much greater and close to the annual mean delta outflow for the previous 38 years (780 m^3/s). These values for delta outflow were computed with the DAYFLOW program, which is based on measured river flows and diversions from the delta (CDWR, 1986).

Flows in gaged streams that discharge into the landward reach of South Bay showed a similar increase in runoff over the term of this study (fig.3). Gaged streams that flow to Lower South Bay account for only about one-quarter of the watershed (USGS annual reports, 1990-93), in part because many streams are impounded by reservoirs and percolation ponds. Therefore, the actual amount of freshwater discharge by streams and urban runoff is unknown. Annual mean flow to the landward reach of South Bay (Patterson Creek plus gaged streamflow to Lower South Bay) increased by a small amount over the first three years of this study (1990, 0.75 m^3/s; 1991, 1.09 m^3/s; 1992, 1.44 m^3/s), but was greatest during 1993 (5.92 m^3/s). In most cases, flow in these local streams was significant only during and immediately following storms in winter and spring. Exceptions for the Patterson Creek distributary of Alameda Creek (fig. 1) included times when waters were released from upstream reservoirs.

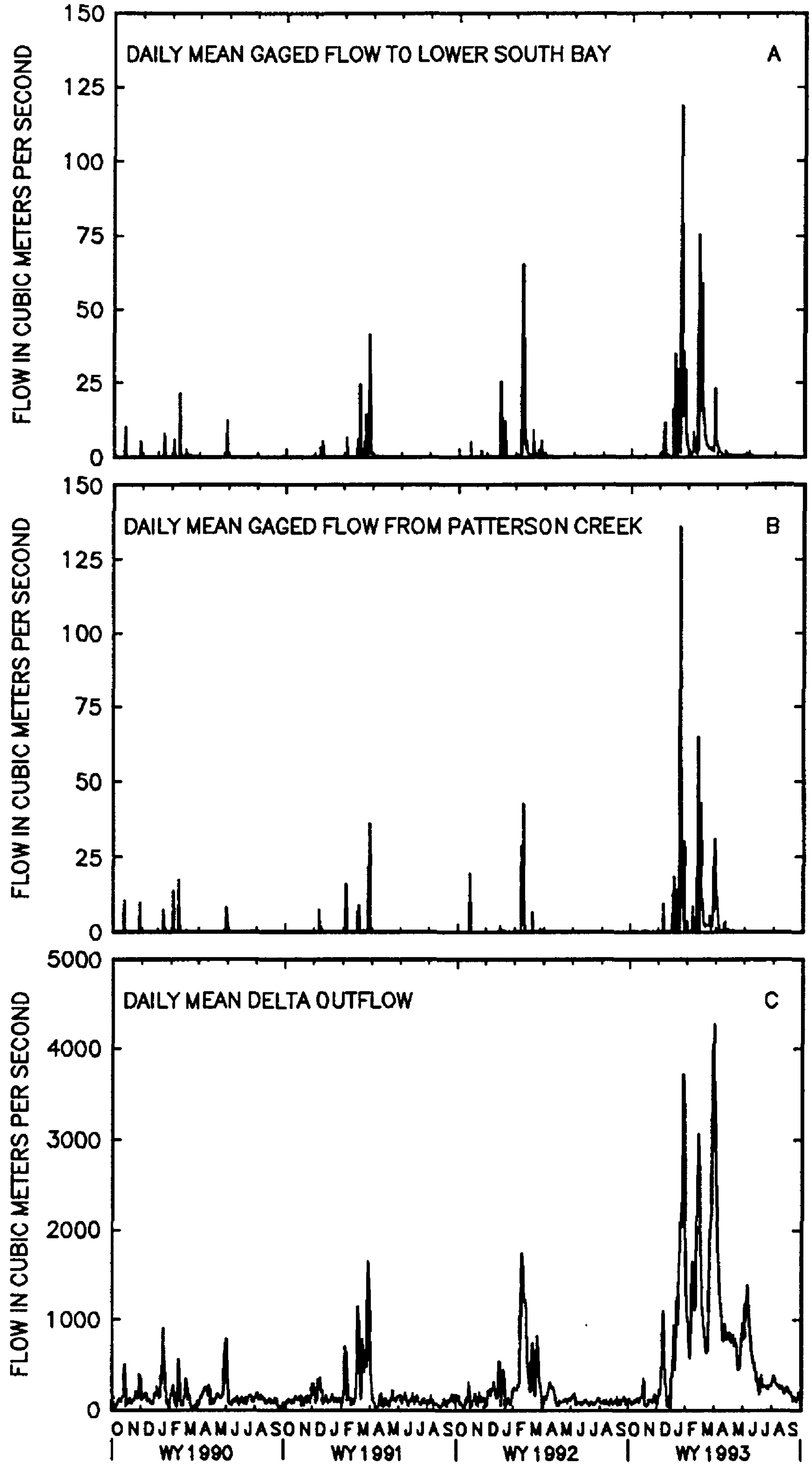

Figure 3. Graphs showing A) daily mean values for gaged flow to Lower South Bay, B) flow from Patterson Creek, and C) Delta Outflow to North San Francisco Bay.

Acknowledgments

This study would not have been possible were it not for a group of dedicated volunteers who assisted in a wide range of activities. In particular, I would like to thank Norton Bell for writing computer programs for system operations, data reduction, and data analysis, and Lars and Amy Olander, Stan Brown, Cindy Lee, Katie Schemel, and Kathy Peacock for assistance in maintaining and calibrating the field instruments. I also thank the staff of the San Francisco Bay National Wildlife Recreation Complex, U.S. Fish and Wildlife Service, for their help in establishing the monitoring and research site and for maintaining the pier. I gratefully acknowledge support from the California Department of Water Resources and specifically thank Randy Brown and Sheila Greene for their assistance during this study. Helpful reviews of this manuscript by Jeff Gartner and Sheila Greene are appreciated, as well as other contributions by my colleagues at the U.S. Geological Survey. Evaporation data presented in this report was provided by Cargill Salt of Newark, California.

METHODS

After construction of the new Dumbarton Bridge, which parallels the old bridge approximately 50m seaward, the center section of the old Dumbarton Bridge was demolished and the remaining eastern causeway was converted to a public fishing pier. The California State Department of Water Resources constructed a small structure near the west end of the fishing pier during summer 1989. Water depth at the site is about 6m at mean tide level. The U.S. Geological Survey installed sensors for salinity, temperature, and water level, then began data collection in October 1989.

Two instrument wells were cut into the floor of the structure, each with a hand winch, stainless steel cable, and a 50 kg cement weight. A sensor package was suspended in the water column about 1m above the substrate in one well during 1990-1993. The sensor package consisted of an electrodeless conductivity sensor, linearized thermistor elements, and a strain-gage pressure transducer mounted on a stainless steel pressure vessel that contained associated electronic circuitry. Analog circuitry within the sensor package produced an output voltage proportional to salinity from the conductivity signal and a thermistor network. Sensors and electronic designs were similar to those described by Dedini and Schemel (1980). The sensor package was connected by cable to a battery power supply and a solid-state data logger located within the structure on the pier. Near-surface-water salinity and temperature were measured during March and April of 1991 and 1992 using a self-contained version of the instrument system suspended 1m below the water surface from a float deployed from the other instrument well. All field measurements were made at 15-minute intervals.

Sensors were calibrated in the laboratory for temperature (5 to 25 degrees Celsius, °C) and salinity (2 to 33 practical salinity units, psu; Lewis 1980). In addition, data from the near-bottom sensor package were corrected for small differences between instrument readings and values for surface-water samples collected (by bucket) next to the sensors in the field (see Appendix Table 1). Originally, these field corrections were intended to compensate for linear (with time) electronic drift, but most discrepancies between sensor readings and field samples appeared related to variability in the water column, biological fouling, or a combination of both. Consequently, bucket sample temperatures were not used for corrections at times during spring when strong water-column heating was apparent, and no corrections were made for salinity when the conductivity sensor was heavily fouled (see below).

Salinity of calibration samples was determined in the laboratory. The conductivity ratio of each sample was measured on a Guildline Autosal salinometer that was calibrated with a secondary standard of Pacific Ocean sea water. Salinity was computed using equations consistent with the Practical Salinity Scale of 1978 (Lewis 1980). Salinity and conductivity ratio values for the secondary standard were established by comparison with standard seawater (IAPSO Standard Seawater Service). The accuracy of the salinity measurements for bottle samples was approximately 0.01 practical salinity units (psu); however, the accuracy of measurements made by the sensors at Dumbarton Bridge was probably 0.1 to 0.2 psu. To assure the accuracy of salinity measurements in the laboratory, 10 to 25 percent of the samples from each analytical run were re-analyzed during the following run. These results are shown in Appendix Table 2. As expected, values were typically higher for the second analysis due to evaporation. The maximum value for the difference over the four-year period was 0.050 psu; however, values for 105 of the 116 comparisions were less than 0.020 psu. In addition to demonstrating a high degree of reproducibility in the measurement of salinity, these results suggest that the laboratory measurements were consistent from one analytical run to the next.

The electrodeless conductivity sensors were sensitive to obstructions in the approximately 2.5cm central bore of the sensor head. Because the near-bottom sensor was mounted deep in the water column, plant growth progressed slowly in the subdued light and was usually not a major problem. However, small fish and invertebrates often obstructed the sensor bore during spring and summer, and efforts to discourage them were largely unsuccessful. The invertebrates would infest the sensor when a small amount of plant growth was present, and the effect on the conductivity signal was similar to major fouling by plant growth alone. Fortunately, sections of the data record that were affected in this manner were easily identified and the affected block of data was removed from the data base. However, in the case of small fish periodically seeking shelter in the sensor head, affected sections of the data record were not easily identified and some questionable data still remains in the final data set. For example, decreases in sensitivity were often indicated for only a few hours of the day or during periods of relatively weak tidal currents. On several occasions a fish was found in the sensor head after an anomalously low calibration value was recorded. Various preventative measures were unsuccessful, leading us to believe that a different design of conductivity sensor is needed when fouling by small fish is a problem.

Measurements of water level were made with a strain-gage pressure sensor that was not corrected for variations in atmospheric pressure or ambient temperature. Consequently, these data are considered relative, and only differences that are greater than 0.1m might be significant. The primary value of these data is to identify the stage of the tide and thus the movement of water in and out of the Lower South Bay basin. For convenience in comparing the salinity and temperature data to measured tides, the mean water depth was removed from each data record (one to two weeks long) after adjustment for small changes in sensor offset voltage. The mean value from a data record is not the same as mean tide height and the value can vary with the length of the record and the characteristics (primarily amplitudes) of the tides.

In the presentation of the data below, measurements of water level from this study (tide heights) and values predicted from results of harmonic analyses of tide records (Cheng and Gartner, 1984) are utilized. Tide heights shown with measurements from the near-surface sensors were predicted; measured tide heights are shown with the values from the near-bottom sensors.

RESULTS

Measurements from this study are contained in files on the four IBM-formatted, high-density disks provided with this report. These data files are free-format, comma delimited, ASCII text files. Column headers are shown in Table 2. Measurements were made over most of the four-year period by the near-bottom sensor and during March and April of 1991 and 1992 with the 1m-depth sensor in 1991 and 1992. Time-series plots of all measurements are presented in the appendix figures 1-17, which correspond to the data in the files. An overview of the near-bottom sensor results is presented below. Variations in salinity and temperature are described here first relative to daily tides and the fortnightly, spring-neap tidal cycle, then daily mean values are used to examine variability over longer time scales.

Table 2. Column identification for comma-delimited, ASCII files containing 15-minute-interval measurements.

File Name(s)	Column Number, header, and units	
NEAR-BOTTOM SENSORS		
RDMBYRA-D.DAT	C1	Calendar Year
(YR = Calendar	C2	Day of Calendar Year with Decimal Time
year 90-93)	C3	Time in HRMN (HR = hour; MN = minute)
(A-D = annual	C4	Salinity in psu
quarters)	C5	Temperature in degrees Celsius
	C6	Relative water level (tide) in meters
NEAR-SURFACE SENSORS		
RBYBYR.DAT	C1	Calendar Year, YR
(YR = Calendar	C2	Day of Calendar Year with Decimal Time
year 90-93)	C3	Time in HRMN (HR = hour; MN = minute)
	C4	Salinity in practical salinity units
	C5	Temperature in degrees Celsius
	C6	Predicted water level in meters

Variability on Tidal Time Scales

Transport of water by tidal currents is a major cause of short-term variability in water-column properties at Dumbarton Bridge. The levels of variability are directly related to the magnitudes of longitudinal gradients in water-column properties in this reach of South Bay (Conomos and others, 1979). These gradients result from stream and municipal waste inflows, the bathymetry, and other factors that were described above. In addition to variations in tidal energy over daily (diurnal), fortnightly, and semi-annual time scales, longitudinal gradients in water-column properties also change in response to a variety of hydrologic and climatic variables. An example of effects of tides and freshwater inflow on salinity at Dumbarton Bridge is described below.

Figures 4 and 5 show measured and predicted water levels and salinity at Dumbarton Bridge for two six-day periods. During the period in November 1992 (fig. 4), no appreciable rainfall or runoff was recorded, but the variability in water level (tidal energy) increased. Measured water levels were very similar to those predicted for the same time period. At the beginning of the period, the two low tides of each day were nearly equal and the tidal range was not as great as that a few days later. Salinity varied in a manner that was consistent with the longitudinal gradient in salinity and the transport of water by the tides. Salinity was highest at high water, then lowest at low water. The salinity at the lowest tide of each day decreased over the period, indicating the greater influence of water from Lower South Bay that is continually diluted by waste inflows. The increase in tidal range over the period was primarily the result of decreases in the water level at the lower-low tide. The increase in water level at the higher-high tide was small over the period, corresponding to a small increase in salinity at higher-high tides.

Tides were decreasing in strength over the record of measured and predicted tides and salinity at Dumbarton Bridge from January 1993 (fig.5). Mid-record, however, discharge from local streams increased in response to a major storm. Daily flows in streams to Lower South Bay on January 13 were the highest of the 1993 water year. The variability in salinity indicated a longitudinal gradient of higher salinity seaward, but a large decrease in the salinity particularly at low tides was clearly evident in the latter half of the record. In spite of the decreasing range of the tide, the range in salinity over the tide cycle increased, indicating a steeper longitudinal gradient with the advent of freshwater inflow.

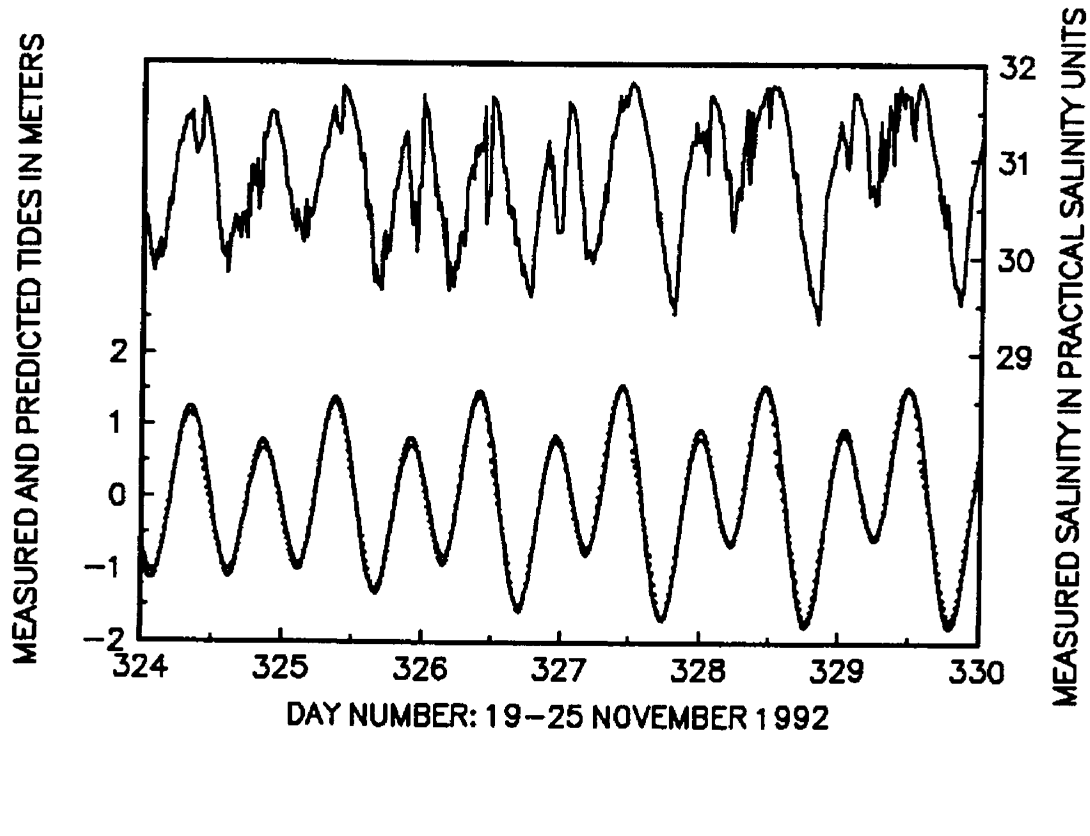

Figure 4. Salinity and measured (dots) and predicted (lines) values for tides at Dumbarton Bridge during November 19-25,1992.

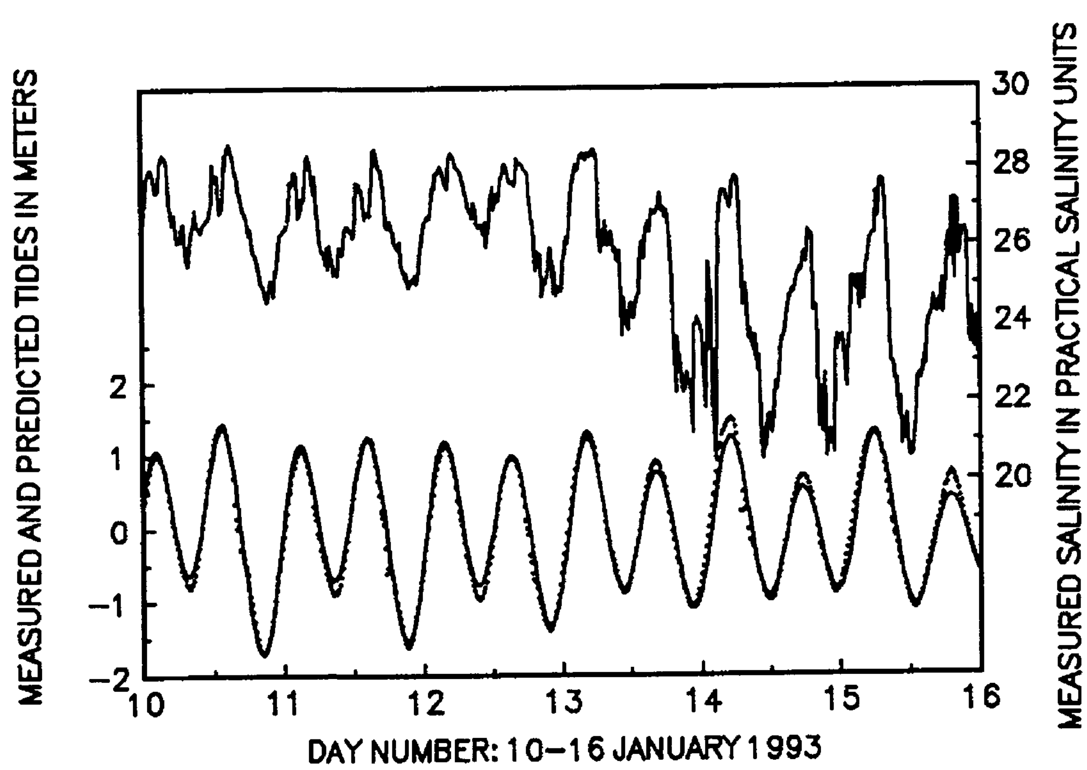

Figure 5. Salinity and measured (dots) and predicted (lines) values for tides at Dumbarton Bridge during January 10-16, 1993.

A decrease in barometric pressure (as great as 21millibars, mb, in 24 hours) and strong southerly winds accompanied the passage of the storm front in mid-January 1993. Storms such as these have been related to episodic increases in sea level at the Golden Gate, in the seaward reach of South Bay, and in North Bay (Walters 1982; Walters and Gartner 1985). Measured tide heights at Dumbarton Bridge exceeded predicted values by as much as 0.3 m during periods of low barometric pressure over January 13-16 (fig.4). Strong southerly winds along the coast also increase water depth in the bay, but strong winds are probably more important in vertically mixing the water column in South Bay. Vertical mixing reduces salinity stratification, and might have been a factor in the large and rapid response of the near-bottom salinity sensor to inflow from local streams.

In general, the daily range in salinity at Dumbarton Bridge appeared to be greatest during times of local stream inflow to Lower South Bay. Although dependent on tides, the daily range in salinity was typically about 2 psu. During times of local stream inflow, however, daily ranges were as great as 8 psu.

Although the solar cycle causes daily variations in water temperatures, shorter-term variability with tides was also seen in temperature at Dumbarton Bridge (see appendix figures). Diurnal ranges of about 2 degrees were typical except during spring and late fall. It appeared that changes in air temperature and insolation during spring and fall affected the shallower waters of Lower South Bay to a greater extent than the deeper waters seaward. This resulted in highest temperatures at Dumbarton Bridge at the lowest tides during spring, when even short periods of unusually high air temperatures resulted in increases in the daily range in temperature to values as great as 4 degrees. Similarly, when air temperatures dropped during fall, temperatures were lowest at low tides and the diurnal range increased at Dumbarton Bridge.

Variability on Time Scales of Days

Close examination of the daily mean values for salinity and temperature showed changes in values that often coincided with the passages of storms and other weather-related events, such as high speed winds, over just a few days. The following descriptions emphasize short-term or event-scale changes in (daily mean) salinity and temperature at Dumbarton Bridge during the 1993 water year. Daily mean values reduce the variability directly caused by daily tides; however, effects of tides are not eliminated, in part because the tidal period is slightly longer (24.8h) than a solar day.

During 1992-94, meteorological data were collected hourly at the Port of Redwood City (RWC; fig. 1) to aid in identifying weather-related variations in water-column properties in the landward reach (Schemel, 1995). Daily mean values for solar irradiance (insolation) and air temperature at RWC and water temperature at Dumbarton Bridge are shown in figure 6. These irradiance values followed the annual solar cycle, but also showed the influence of cloud and fog cover. Both air temperature at RWC and water temperature at Dumbarton Bridge exhibited an annual cycle, but both also showed shorter term variability associated with weather-related events. Short periods of cold air temperatures during winter and warm air temperatures during summer at RWC coincided with similar variations in water temperature at Dumbarton Bridge, demonstrating a high degree of atmosphere-water coupling in this shallow reach of the bay.

Rapid decreases in salinity at Dumbarton Bridge during December through April 1993 coincided with storms that produced largely-episodic increases in streamflow to Lower South Bay (fig. 7). Response of salinity to large inflows of freshwater was nearly immediate, even though the sensor was near the bottom of the water column. Periods of sustained flow from local streams, such as in late January, corresponded with continued decreases in salinity at Dumbarton Bridge. Local streamflow to lower South Bay was minimal after mid-April, and salinity increased at Dumbarton Bridge. Although local streamflow alone appeared to explain much of the variability observed at Dumbarton Bridge during winter 1993, observations made by USGS at other locations in South Bay will be needed to differentiate between effects of local stream inflow and circulation processes. This analysis was beyond the scope of this report.

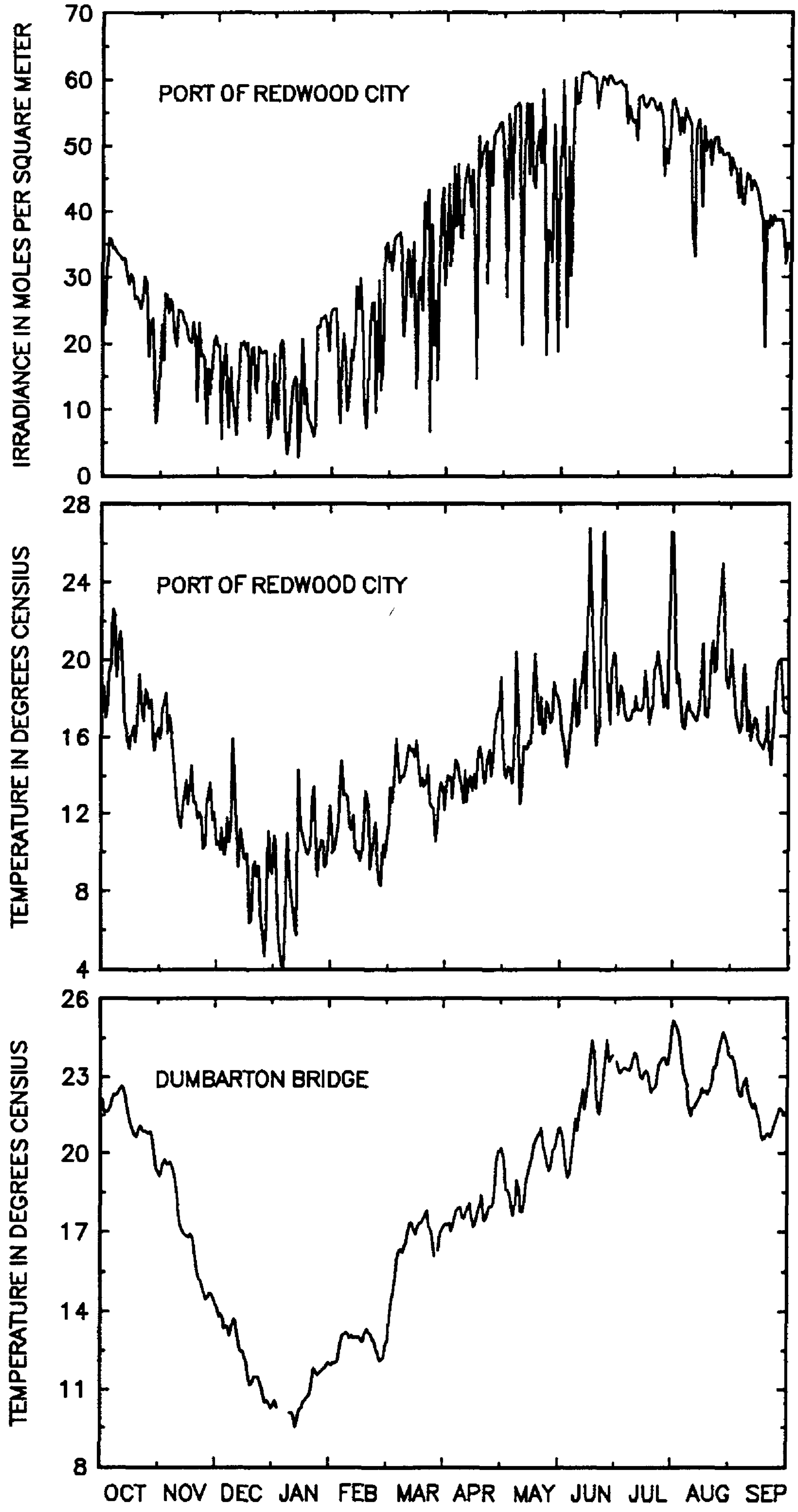

Figure 6. Solar irradiance and air temperature at the Port of Redwood City and water temperature at Dumbarton Bridge, 1993 water year.

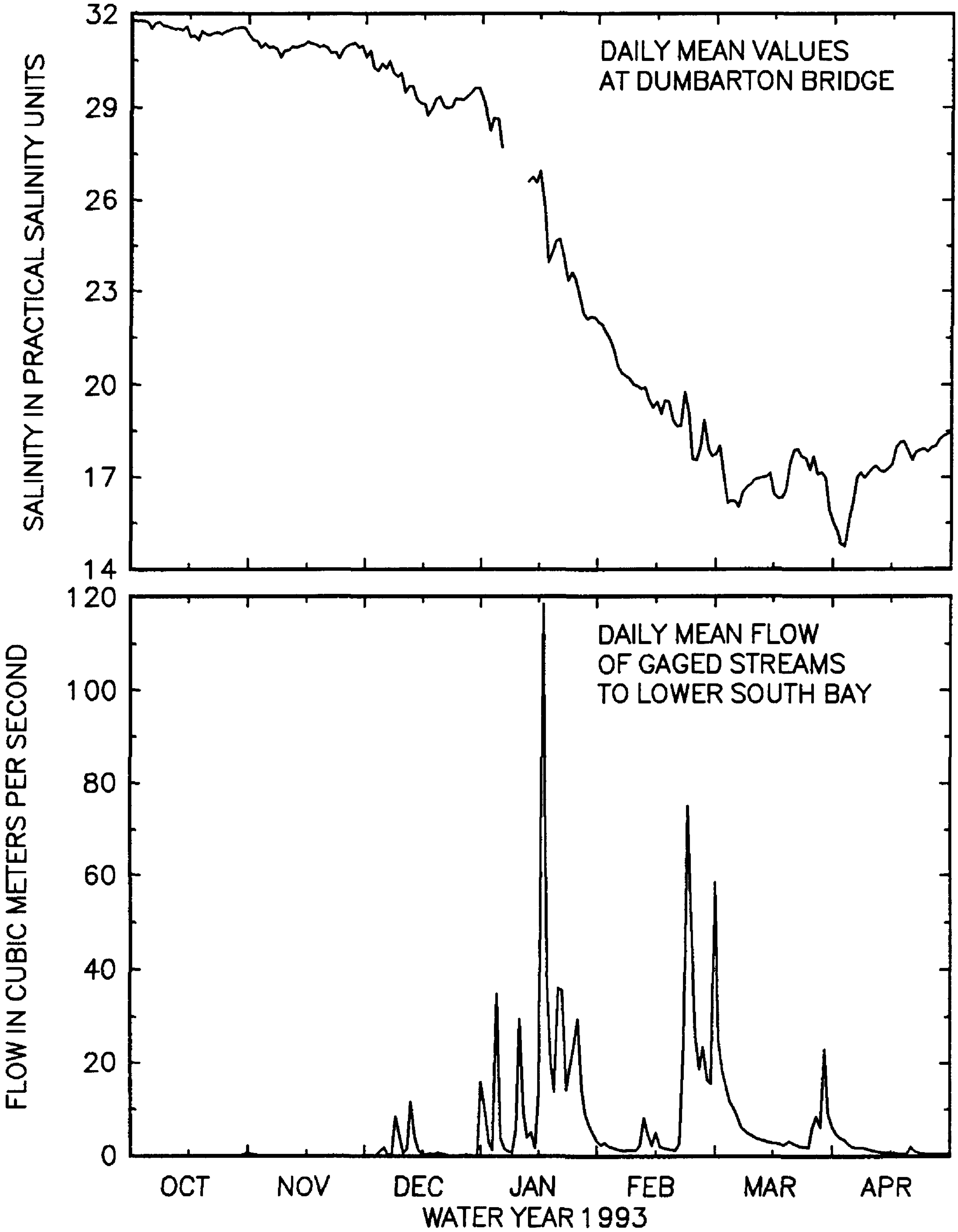

Figure 7. Daily mean values for salinity at Dumbarton Bridge and gaged streamflow to Lower South Bay, October 1992 - April 1993.

Seasonal and Interannual Variability

The largest time-dependent variations in the four-year record were associated with seasonal changes in weather and year-to-year variability in climate. Time courses for daily mean values and values for calibration samples for salinity and temperature at Dumbarton Bridge are shown in Figure 8 for all four years of this study. Even though values for the calibration samples were affected by tide height during the sampling, these values did show the same pattern as daily mean values for the near-bottom sensors. In some cases, the differences are due to thermal and salinity stratification of the water column.

The seasonal range in water temperature was about 15 degrees, roughly 10 to 25 degrees Celsius. Unusually low mean values of about 8 degrees were observed during late December 1990, during a period when air temperatures were below normal for several days. The annual pattern in daily mean water temperature generally followed the annual solar cycle. Water temperatures were highest during summer, peak values typically occurring in July or August. Water temperatures typically were lowest during December or early winter.

Salinity reached maximum values (typically 32 to 33 psu) during late summer. However during 1993, the year with the highest local stream inflow and the highest delta outflows, late-summer values for salinity were lower than in previous years. This was confirmed by independent measurements of near-surface waters near Dumbarton Bridge (Caffrey and others, 1994). Lowest salinities were observed during the winter storm season, and the minimum values were progressively lower in magnitude each year, which is consistent with the increase in precipitation and runoff over the four-year study.

Salinity typically decreased over fall even when relatively little precipitation, local streamflow, or increase in delta outflow occurred. An analysis beyond the scope of this report would be required to explain this phenomenon. However, one possible explanation links the decrease in salinity during fall to the seasonal decrease in evaporation rates. Alternatively, enhanced longitudinal circulation during fall might be a factor.

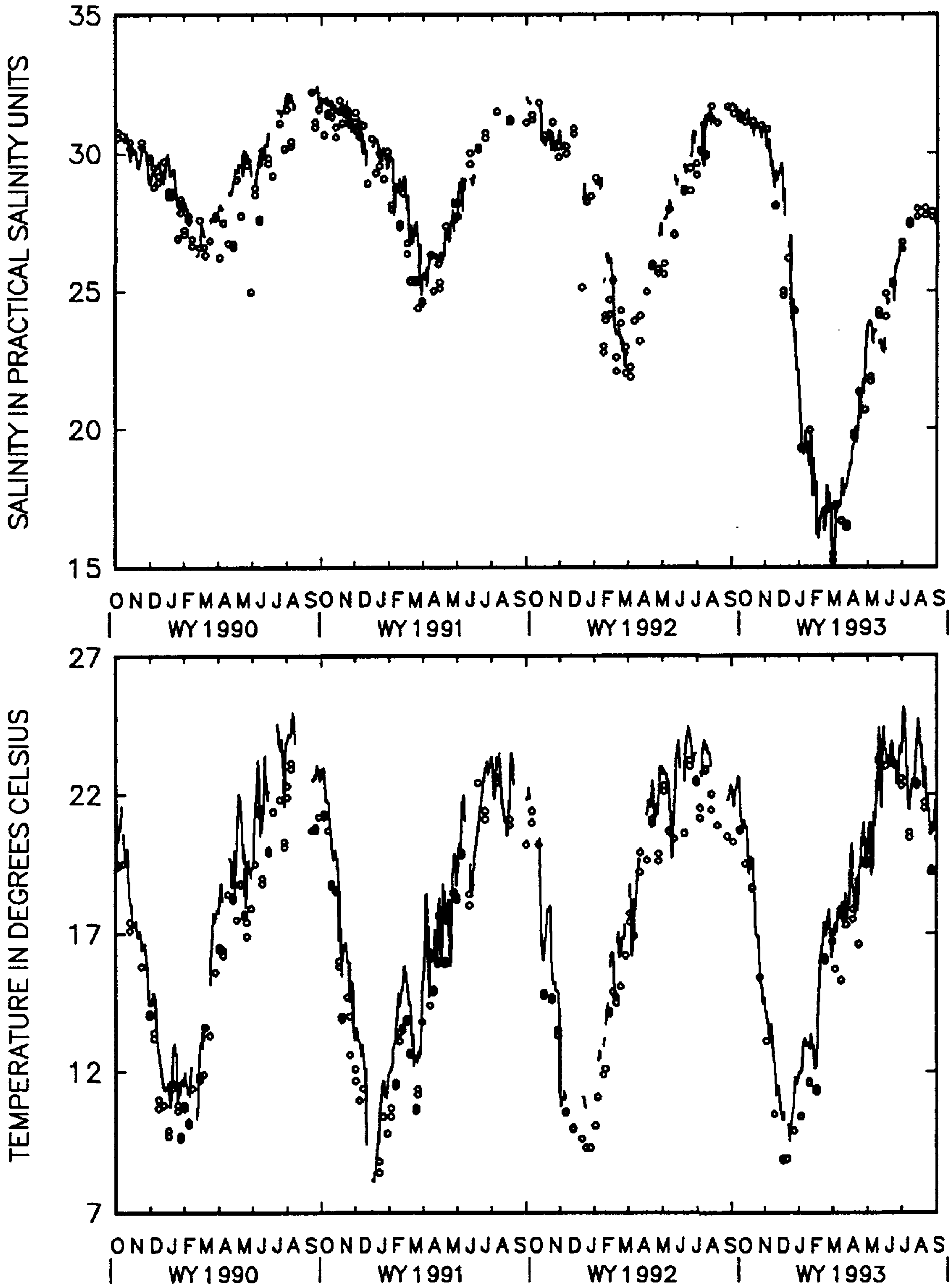

Figure 8. Daily mean values for salinity and temperature at Dumbarton Bridge, 1990-93 water years.

SUMMARY

Measurements of salinity, temperature, and water level (tides) were made at Dumbarton Bridge during water years 1990-93 using electronic sensors located 1m above the substrate in approximately 6m of water (at mean tide level). Salinity and temperature were also measured in near-surface waters (1m depth) during March and April of 1991-1992 using a self-contained floating version of the instrument system. Results from this study showed that salinity and temperature were strongly influenced by tides, and that factors related to climate and weather caused variations on time scales ranging from hours to years. Time-series plots are provided in the appendix, which correspond to the data contained in comma-delimited ASCII text files on the enclosed high-density disks.

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 (page A 2 follows)

Appendix Table 1. Calibration sample (standard, STD) values and near-bottom sensor (SENSOR) values for salinity in practical salinity units and temperature in degrees Celsius and corrections applied to the field data at Dumbarton Bridge.

Date	Temperature		Salinity		Corrections Applied	
MO/DA/YR	STD	SENSOR	STD	SENSOR	Temperature	Salinity
09/26/89	20.3	20.38	31.08	31.00	-0.08	+0.08
10/04/89	19.4	19.52	30.57	30.58	-0.08	+0.05
10/04/89	19.5	19.52	30.77	30.78	-0.02	+0.01
10/12/89	19.65	19.81	-----	30.41	-0.16	-----
10/12/89	19.5	19.71	30.66	30.62	-0.21	+0.04
10/25/89	17.1	17.31	30.42	30.29	-0.21	+0.13
10/25/89	17.4	17.36	30.20	30.14	+0.04	+0.06
11/08/89	----	16.08	30.10	29.90	-----	+0.20
11/08/89	----	16.03	29.95	29.93	-----	+0.02
11/15/89	15.8	15.85	30.24	30.02	-0.05	+0.12
11/15/89	15.8	15.86	30.42	30.19	-0.06	+0.23
11/29/89	14.1	14.24	29.87	29.94	-0.14	-0.07
11/29/89	14.0	14.19	29.75	30.39	-0.19	-0.64
12/07/89	13.4	13.39	29.50	29.42	+0.01	+0.08
12/07/89	13.2	13.21	28.77	28.73	-0.01	+0.04
12/15/89	10.7	10.81	28.95	29.02	-0.11	-0.07
12/15/89	11.0	11.16	29.18	29.27	-0.16	-0.09
12/24/89	10.8	10.79	29.71	29.99	-0.01	-0.28
01/02/90	9.9	9.99	28.45	28.48	-0.09	-0.03
01/02/90	9.7	9.80	28.61	28.62	-0.10	-0.01
01/08/90	11.6	11.24	28.60	28.62	-0.36	-0.02
01/08/90	11.4	11.32	28.46	28.53	+0.08	-0.07
01/18/90	10.6	10.73	26.92	26.95	-0.13	-0.03
01/18/90	10.8	10.96	26.87	26.37	-0.16	+0.50
01/23/90	9.6	9.89	27.83	28.52	-0.29	+0.31
01/23/90	9.75	9.93	28.33	28.42	-0.18	-0.09
01/30/90	10.7	10.79	27.05	27.29	-0.09	-0.24
01/30/90	10.8	10.85	27.21	27.28	-0.05	-0.07

Appendix Table 1. -- Continued

Date	Temperature		Salinity		Corrections Applied	
MO/DA/YR	STD	SENSOR	STD	SENSOR	Temperature	Salinity
02/06/90	10.2	10.24	27.71	27.77	-0.04	-0.06
02/06/90	10.1	10.27	27.55	27.62	-0.17	-0.07
02/12/90	11.4	11.51	26.64	-----	-0.11	-----
02/12/90	11.4	11.51	26.87	-----	-0.11	-----
02/20/90	----	8.56	24.72	26.58	-----	-----
02/20/90	----	8.62	24.93	27.64	-----	-----
02/26/90	11.85	12.02	26.57	-----	-0.17	-----
02/26/90	11.7	11.54	27.56	27.80	+0.16	-0.24
03/05/90	11.9	12.05	26.60	26.73	-0.15	-0.13
03/05/90	11.9	12.03	26.58	26.62	-0.13	-0.04
03/08/90	13.6	13.52	26.30	26.37	+0.08	-0.07
03/16/90	13.3	13.09	26.82	26.86	+0.21	-0.04
03/26/90	15.6	15.65	27.64	27.66	-0.05	-0.02
03/26/90	15.6	15.52	27.72	27.80	+0.08	-0.08
04/02/90	16.4	16.30	26.22	26.28	+0.10	-0.06
04/02/90	16.5	16.34	26.20	26.24	+0.16	-0.04
04/09/90	16.4	16.22	27.44	27.44	+0.18	+0.00
04/09/90	16.2	16.20	27.48	27.54	0.00	-0.06
04/18/90	18.4	18.25	26.71	26.74	+0.15	+0.03
04/27/90	18.2	18.19	26.70	26.59	+0.01	+0.11
04/27/90	18.3	18.26	26.57	26.57	+0.04	+0.00
05/03/90	17.5	17.51	29.04	29.03	-0.01	+0.01
05/03/90	17.5	17.50	29.07	29.13	0.00	-0.06
05/10/90	18.8	19.08	27.70	27.70	-0.28	+0.00
05/10/90	18.75	19.09	27.72	27.73	-0.34	-0.01
05/17/90	17.6	17.74	29.92	27.08	+0.06	-----
05/17/90	17.7	17.72	29.79	29.82	-0.02	-0.03
05/21/90	16.9	16.39	29.74	29.88	+0.30	-0.14
05/21/90	17.4	16.72	29.57	29.80	+0.68	-0.03

Appendix Table 1. -- Continued

Date	Temperature		Salinity		Corrections Applied	
MO/DA/YR	STD	SENSOR	STD	SENSOR	Temperature	Salinity
05/29/90	17.9	17.51	24.96	25.30	+0.39	-0.34
05/29/90	17.9	17.63	24.96	25.24	+0.27	-0.28
06/04/90	19.5	19.56	28.50	28.68	-0.06	-0.18
06/04/90	19.5	19.44	28.74	29.00	+0.06	-0.26
06/12/90	21.5	20.70	27.51	27.45	+0.80	+0.06
06/12/90	21.3	20.68	27.59	27.52	+0.62	+0.07
06/18/90	18.8	18.99	30.10	30.10	-0.19	0.00
06/18/90	19.0	19.16	29.91	29.99	-0.16	-0.08
06/28/90	19.9	19.89	29.83	29.76	+0.01	+0.07
06/28/90	20.0	20.00	29.63	29.64	0.00	-0.01
07/05/90	21.4	25.55	29.20	24.54	-----	-----
07/13/90	----	22.87	30.02	30.12	-----	-0.10
07/18/90	21.8	21.92	31.13	31.16	-0.12	-0.03
07/18/90	21.8	21.88	31.11	31.25	-0.08	-0.14
07/26/90	20.1	20.19	30.21	30.26	-0.09	-0.05
07/26/90	20.3	20.10	30.17	30.21	+0.20	-0.04
07/31/90	21.9	21.96	31.61	31.67	-0.06	-0.06
07/31/90	22.3	22.30	31.62	31.64	0.00	-0.02
08/07/90	23.1	23.12	30.28	30.30	-0.02	-0.02
08/07/90	22.9	22.95	30.44	30.55	-0.05	-0.11
09/13/90	20.7	20.63	32.23	32.20	+0.07	+0.03
09/19/90	20.7	20.73	30.96	30.94	-0.03	+0.02
09/19/90	20.8	20.82	31.15	31.12	-0.02	+0.03
09/25/90	21.2	21.24	31.63	31.60	-0.04	+0.03
09/25/90	21.2	21.20	31.60	31.55	0.00	+0.05
10/05/90	21.2	21.35	30.66	30.55	-0.15	+0.11
10/05/90	21.3	21.36	30.69	30.69	-0.06	0.00
10/12/90	20.7	20.54	31.39	31.34	+0.16	+0.05
10/12/90	20.7	20.37	31.47	31.37	+0.33	+0.10

Appendix Table 1. -- Continued

Date	Temperature		Salinity		Corrections Applied	
MO/DA/YR	STD	SENSOR	STD	SENSOR	Temperature	Salinity
10/19/90	18.8	18.76	31.35	31.38	+0.04	+0.03
10/19/90	18.7	18.80	31.52	31.44	-0.10	+0.08
10/26/90	18.6	18.34	30.59	30.82	+0.26	-0.23
10/26/90	18.5	18.38	30.95	30.94	+0.12	+0.01
11/02/90	15.8	15.37	31.54	31.50	+0.43	+0.04
11/02/90	16.0	15.94	31.94	31.91	+0.06	+0.03
11/06/90	14.0	13.93	31.09	31.09	+0.07	0.00
11/06/90	13.9	13.94	31.12	31.13	-0.04	-0.01
11/16/90	14.7	14.69	31.49	31.34	+0.01	+0.05
11/16/90	14.7	14.69	31.57	31.59	+0.01	-0.02
11/20/90	14.0	14.06	31.07	31.20	-0.06	-0.13
11/20/90	12.6	12.33	31.18	31.22	+0.27	-0.04
11/30/90	11.7	11.73	31.14	31.33	-0.03	-0.19
11/30/90	12.1	12.05	31.50	31.59	+0.05	-0.09
12/07/90	11.0	10.89	30.71	30.87	+0.11	-0.16
12/07/90	11.0	10.85	30.61	30.68	+0.15	-0.07
12/14/90	11.4	11.35	31.02	31.08	+0.05	-0.06
12/14/90	11.4	11.27	31.03	31.07	+0.13	-0.04
12/21/90	6.4	6.70	28.88	28.92	-0.30	-0.04
12/21/90	6.4	6.62	28.93	28.91	-0.22	+0.02
12/29/90	6.8	6.87	30.54	30.61	-0.07	-0.07
12/29/90	6.9	6.81	30.53	30.59	+0.09	-0.06
01/05/91	6.45	6.41	29.28	29.36	+0.04	-0.08
01/05/91	6.5	6.06	29.27	29.19	+0.44	+0.08
01/12/91	8.8	8.49	29.53	29.67	+0.31	-0.14
01/12/91	8.4	8.17	30.01	30.00	+0.23	+0.01
01/19/91	10.4	10.38	29.05	29.07	+0.02	-0.02
01/19/91	10.4	10.30	29.08	29.05	+0.10	+0.03
01/26/91	9.8	9.63	30.06	30.19	+0.17	-0.11
01/26/91	9.8	9.51	30.07	30.14	+0.29	-0.07

Appendix Table 1. -- Continued

Date MO/DA/YR	Temperature STD	Temperature SENSOR	Salinity STD	Salinity SENSOR	Corrections Applied Temperature	Corrections Applied Salinity
02/02/91	10.7	10.41	27.95	28.00	+0.29	-0.05
02/02/91	10.4	10.54	28.12	28.19	-0.14	-0.07
02/09/91	11.5	11.53	28.73	28.74	-0.03	-0.01
02/09/91	11.6	11.66	28.66	28.65	-0.06	+0.01
02/17/91	13.1	13.07	27.42	27.39	+0.03	+0.03
02/17/91	13.4	13.38	27.30	27.33	+0.02	-0.03
02/23/91	13.6	13.51	28.82	28.86	+0.09	-0.04
02/23/91	13.5	13.37	28.54	28.53	+0.13	+0.01
03/02/91	13.8	13.75	26.34	26.35	+0.05	-0.01
03/02/91	13.9	13.74	26.71	26.67	+0.16	+0.04
03/09/91	12.6	12.48	25.35	25.33	+0.12	+0.02
03/09/91	12.7	12.62	25.38	25.24	+0.08	+0.14
03/18/91	10.6	10.55	25.40	25.36	+0.05	+0.14
03/18/91	10.7	10.52	25.31	25.33	+0.18	-0.02
03/22/91	11.2	11.26	24.38	24.28	-0.06	+0.10
03/22/91	11.4	11.30	24.38	24.33	+0.10	+0.05
03/30/91	13.8	13.78	24.56	24.57	+0.02	-0.01
03/30/91	13.8	13.80	24.64	24.60	0.00	+0.04
04/05/91	----	15.71	23.88	24.03	-----	-0.15
04/05/91	----	15.63	23.89	24.14	-----	-0.25
04/13/91	14.4	14.21	26.30	26.17	+0.19	+0.13
04/13/91	----	14.21	26.29	26.22	-----	+0.07
04/19/91	14.9	14.96	25.00	24.82	-0.06	+0.18
04/19/91	15.0	15.10	24.99	24.83	-0.10	+0.16
04/27/91	15.9	15.77	25.96	25.66	+0.13	+0.30
04/27/91	16.0	15.84	25.98	25.72	+0.16	+0.26
04/30/91	17.65	17.66	25.09	24.84	-0.01	+0.25
04/30/91	17.6	17.60	25.32	25.24	0.00	+0.08
05/10/91	16.0	15.99	27.33	27.16	+0.01	+0.17
05/10/91	15.9	15.89	27.33	27.22	+0.01	+0.11

Appendix Table 1. -- Continued

Date MO/DA/YR	Temperature STD	Temperature SENSOR	Salinity STD	Salinity SENSOR	Corrections Applied Temperature	Corrections Applied Salinity
05/25/91	18.5	18.49	28.14	27.80	+0.01	+0.34
05/25/91	18.4	18.40	28.21	27.94	0.00	+0.27
05/31/91	18.3	18.29	27.68	27.27	+0.01	+0.41
05/31/91	18.2	17.98	28.16	27.92	+0.22	+0.24
06/07/91	19.9	19.77	28.84	28.54	+0.13	+0.30
06/07/91	19.8	19.63	28.73	28.64	+0.17	+0.09
06/22/91	18.0	17.98	30.01	29.81	+0.02	+0.20
06/22/91	18.4	18.19	29.60	29.86	+0.21	-0.26
07/06/91	22.4	22.24	30.23	30.14	+0.16	+0.09
07/06/91	22.4	22.21	30.15	30.01	+0.19	+0.14
07/19/91	21.1	21.12	30.75	30.52	-0.02	+0.23
07/19/91	21.4	21.24	30.57	30.55	-0.16	+0.02
08/09/91	22.4	22.21	31.52	-----	+0.19	-----
08/09/91	22.6	22.26	31.51	31.40	+0.34	+0.11
08/31/91	21.1	21.12	31.16	-----	-0.02	-----
08/31/91	20.9	21.03	31.26	31.08	-0.13	+0.12
09/30/91	20.2	20.31	31.13	31.27	-0.11	-0.14
10/10/91	21.0	20.87	31.23	31.39	+0.13	-0.17
10/10/91	21.4	21.01	31.40	31.63	+0.39	-0.23
10/22/91	20.2	20.26	31.84	31.98	-0.06	-0.14
11/01/91	14.75	14.81	30.50	30.68	-0.06	-0.18
11/01/91	14.85	14.83	30.64	30.75	+0.02	-0.11
11/15/91	14.7	14.65	31.14	30.84	-0.05	+0.30
11/15/91	14.6	14.68	31.12	31.26	-0.08	0.14
11/26/91	13.3	13.38	29.86	30.14	-0.08	-0.28
11/26/91	13.5	13.59	30.25	30.34	-0.09	-0.09
12/10/91	10.6	10.63	30.00	30.12	-0.03	-0.12
12/10/91	10.55	10.54	30.24	30.54	+0.01	-0.30
12/23/91	9.95	9.97	30.91	31.13	-0.02	-0.22
12/23/91	10.0	9.93	30.72	30.90	+0.07	-0.18

Appendix Table 1. -- Continued

Date MO/DA/YR	Temperature STD	Temperature SENSOR	Salinity STD	Salinity SENSOR	Corrections Applied Temperature	Corrections Applied Salinity
01/08/92	9.6	9.55	25.13	25.12	+0.05	+0.01
01/15/92	9.3	9.31	28.21	28.27	-0.01	-0.06
01/23/92	9.3	9.33	28.42	28.57	-0.03	-0.15
01/31/92	10.1	10.09	29.09	29.41	+0.01	-0.32
02/05/92	11.1	11.15	28.94	29.10	-0.05	-0.16
02/15/92	11.9	11.95	22.99	22.56	-0.05	+0.43
02/15/91	11.9	11.91	22.77	22.81	-0.01	-0.04
02/19/92	12.1	12.11	23.94	24.03	-0.01	-0.09
02/19/92	12.1	12.11	24.10	24.14	-0.01	-0.04
02/26/92	14.1	14.29	24.67	24.86	-0.19	-0.19
02/26/92	14.2	13.90	24.14	25.10	+0.30	-0.96
03/03/92	14.9	15.06	25.39	25.34	-0.16	+0.05
03/03/92	14.9	15.07	25.37	25.35	-0.17	+0.02
03/09/92	14.5	14.22	22.10	22.16	+0.28	-0.06
03/09/92	14.7	14.91	22.59	22.46	-0.21	+0.13
03/17/92	15.1	15.07	24.30	23.85	+0.03	+0.45
03/17/92	15.1	15.04	23.83	23.73	+0.06	+0.10
03/26/92	16.2	16.27	22.97	-----	-0.07	-----
03/26/92	16.2	16.20	22.02	21.95	0.00	+0.07
04/03/92	17.4	17.37	21.88	22.08	+0.03	-0.20
04/03/92	17.7	17.61	22.24	22.16	+0.09	+0.08
04/10/92	16.9	16.98	23.91	23.89	-0.08	+0.02
04/10/92	16.9	16.93	23.91	23.77	-0.03	+0.14
04/20/92	19.9	19.58	23.19	-----	+0.32	-----
04/20/92	19.2	19.15	24.09	23.98	+0.05	+0.11
05/01/92	19.65	19.69	24.96	24.81	-0.04	+0.15
05/11/92	21.1	21.13	25.96	25.82	-0.03	+0.14
05/11/92	20.95	21.06	25.84	25.65	-0.11	+0.19

Appendix Table 1. -- Continued

Date MO/DA/YR	Temperature STD	Temperature SENSOR	Salinity STD	Salinity SENSOR	Corrections Applied Temperature	Corrections Applied Salinity
05/22/92	19.6	19.81	25.77	-----	-0.21	-----
05/22/92	19.85	19.95	25.63	25.42	-0.10	+0.21
06/01/92	22.3	22.62	25.59	25.35	-0.32	+0.24
06/01/92	22.1	22.15	25.97	25.75	-0.05	+0.22
06/10/92	20.65	20.84	27.91	27.42	-0.19	+0.49
06/10/92	20.7	20.97	27.94	27.70	-0.27	+0.24
06/19/92	20.4	20.14	27.00	-----	+0.26	-----
06/19/92	20.4	20.13	27.04	26.64	+0.27	+0.40
07/06/92	20.6	20.78	28.67	-----	-0.18	-----
07/06/92	20.6	20.82	28.58	28.49	-0.22	+0.09
07/17/92	23.0	23.08	28.61	-----	-0.08	-----
07/17/92	23.2	23.27	29.44	29.58	-0.07	-0.14
07/28/92	22.5	22.60	29.20	29.11	-0.10	+0.09
07/28/92	22.4	22.57	29.61	29.60	-0.17	+0.01
08/04/92	21.15	21.27	30.06	29.53	-0.12	+0.53
08/04/92	21.5	21.45	30.11	30.22	+0.05	-0.11
08/14/92	22.85	22.95	29.90	29.98	-0.10	-0.08
08/14/92	22.9	23.01	29.95	30.02	-0.11	-0.07
08/24/92	21.45	21.57	31.70	-----	-0.12	-----
08/24/92	22.0	21.95	31.27	31.29	+0.05	-0.02
09/03/92	20.9	20.89	31.11	31.17	+0.01	-0.07
09/21/92	20.5	20.52	31.69	31.84	-0.02	+0.15
10/02/92	20.3	20.56	31.44	31.49	-0.26	-0.05
10/14/92	20.75	20.78	31.25	31.39	-0.03	-0.14
10/14/92	20.7	20.61	31.38	-----	+0.09	-----
10/23/93	19.5	19.61	31.13	31.20	-0.11	-0.07
10/23/92	19.5	19.64	31.14	31.31	-0.14	-0.17
11/05/92	18.6	18.68	31.15	31.34	-0.08	-0.19
11/05/92	18.65	18.72	31.17	31.38	-0.07	-0.21

Appendix Table 1. -- Continued

Date MO/DA/YR	Temperature STD	Temperature SENSOR	Salinity STD	Salinity SENSOR	Corrections Applied Temperature	Corrections Applied Salinity
11/19/92	15.4	15.56	31.00	31.20	-0.16	-0.20
11/19/92	15.4	15.56	30.99	31.22	-0.16	-0.23
12/01/92	13.1	13.24	30.87	-----	-0.14	-----
12/16/92	10.5	10.49	28.08	28.15	+0.01	-0.07
12/16/92	10.5	10.45	28.04	28.24	+0.05	-0.20
12/31/92	8.85	8.90	24.99	25.27	-0.05	-0.28
12/31/92	8.9	8.94	24.83	25.03	-0.04	-0.20
01/08/93	8.9	8.95	26.18	26.32	-0.05	-0.14
01/20/93	9.9	9.97	24.29	24.34	-0.07	-0.05
02/01/93	10.4	10.36	19.25	19.11	+0.04	+0.14
02/01/93	10.45	10.45	19.33	19.41	0.00	-0.08
02/16/93	11.6	11.71	19.92	-----	-0.11	-----
02/16/93	11.65	11.73	19.95	19.97	-0.08	-0.02
03/01/93	11.4	11.36	14.77	14.73	+0.04	+0.04
03/01/93	11.3	11.25	14.77	14.70	+0.05	+0.07
03/16/93	16.1	16.15	17.01	16.85	-0.05	+0.16
03/16/93	16.0	16.13	17.05	16.97	-0.13	+0.08
03/29/93	17.0	17.01	15.45	15.31	-0.01	+0.14
03/29/93	16.7	16.52	15.21	15.16	+0.18	+0.05
04/02/93	15.7	15.66	17.16	16.97	+0.04	+0.19
04/02/93	15.7	15.80	17.22	16.81	-0.10	+0.41
04/13/93	15.3	15.28	16.68	-----	+0.02	-----
04/13/93	15.3	15.28	16.63	16.46	+0.02	+0.17
04/22/93	17.3	17.42	16.41	16.23	-0.12	+0.18
04/22/93	17.3	17.50	16.53	16.52	-0.20	+0.01
05/04/93	17.5	17.56	19.67	19.47	-0.06	+0.20
05/04/93	17.85	18.00	19.83	19.75	+0.05	+0.08
05/14/93	16.6	16.59	21.34	21.25	+0.01	+0.09
05/14/93	16.6	16.60	21.31	21.19	0.00	+0.12

Appendix Table 1. -- Continued

Date MO/DA/YR	Temperature STD	Temperature SENSOR	Salinity STD	Salinity SENSOR	Corrections Applied Temperature	Corrections Applied Salinity
05/24/93	19.6	19.69	20.69	-----	-0.09	-----
05/24/93	19.5	19.85	20.66	20.77	-0.35	-0.11
06/04/93	19.5	19.62	21.73	21.37	-0.12	+0.36
06/04/93	19.6	19.71	21.88	21.79	-0.11	+0.09
06/18/93	23.2	23.03	24.12	-----	+0.17	-----
06/18/93	23.25	23.13	24.27	24.57	+0.12	-0.30
07/01/93	23.0	23.04	24.06	-----	-0.04	-----
07/01/93	23.0	22.91	24.89	25.30	+0.09	-0.41
07/13/93	23.1	23.09	25.22	26.05	+0.01	-0.83
07/13/93	23.2	23.40	25.32	25.96	-0.20	-0.64
07/29/93	22.3	22.16	26.75	26.28	+0.14	+0.47
07/29/93	22.55	22.43	26.50	27.79	+0.12	-1.29
08/12/93	20.65	20.45	27.37	-----	+0.20	-----
08/12/93	20.45	20.72	27.49	29.09	-0.27	-1.60
08/25/93	22.3	22.32	27.93	28.02	-0.02	-0.11
08/25/93	22.4	22.33	27.65	29.04	+0.07	-1.39
09/08/93	21.7	21.63	27.97	27.27	+0.07	+0.70
09/08/93	21.5	21.44	27.70	28.21	+0.06	-0.51
09/20/93	19.3	19.30	27.84	27.38	0.00	+0.46
09/20/93	19.2	19.20	27.65	26.84	0.00	+0.81
10/01/93	20.4	20.40	27.45	26.22	0.00	+1.23

Appendix Table 2. Values for the initial and second analyses of calibration samples for salinity in practical salinity units.

Date of Sample	Bottle Number	Initial Salinity	Second Analysis	Initial minus Second analysis
11/15/89	247	30.421	30.430	-.009
12/07/89	58	28.772	28.771	.001
1/02/90	40	28.453	28.456	-.003
1/08/90	404	28.457	28.465	-.008
1/12/90	45	30.008	30.016	-.008
1/23/90	70	27.832	27.847	-.015
1/30/90	221	27.048	27.067	-.019
2/12/90	32	26.869	26.886	-.017
2/20/90	229	24.928	24.951	-.023
3/05/90	247	26.581	26.617	-.036
4/09/90	3	27.435	27.442	-.007
4/27/90	23	26.695	26.705	-.010
5/03/90	90	29.039	29.049	-.010
5/10/90	241	27.696	27.702	-.006
5/17/90	5	29.921	29.918	.003
5/17/90	60	29.793	29.791	.002
5/21/90	413	29.738	29.734	.004
5/21/90	416	29.572	29.570	.002
5/29/90	201	24.964	24.965	-.001
5/29/90	204	24.959	24.959	0.000
6/04/90	214	28.774	28.767	.007
6/04/90	414	28.510	28.507	.003
6/12/90	209	27.505	27.507	-.002
6/12/90	222	27.592	27.594	-.002
6/18/90	208	29.913	29.916	-.003
6/18/90	211	30.098	30.096	.002

Appendix Table 2. --- Continued

Date of Sample	Bottle Number	Initial Salinity	Second Analysis	Initial minus Second analysis
6/28/90	57	29.827	29.811	.016
7/18/90	207	31.126	31.134	-.008
7/18/90	244	31.113	31.114	-.001
7/31/90	120	31.607	31.629	-.022
8/07/90	210	30.442	30.454	-.012
9/11/90	55	31.854	31.853	.001
9/19/90	65	31.153	31.152	.001
10/05/90	201	30.694	30.693	.001
10/05/90	228	30.663	30.661	.002
10/12/90	220	31.468	31.467	.001
10/26/90	416	30.951	30.952	-.001
10/30/90	233	31.667	31.683	-.016
11/13/90	57	31.511	31.502	.009
11/16/90	222	31.490	31.540	-.050
11/16/90	50	31.567	31.583	-.016
11/20/90	209	31.069	31.085	-.016
11/20/90	48	31.180	31.181	-.001
11/30/90	211	31.498	31.503	-.005
11/30/90	60	31.144	31.172	-.028
12/07/90	202	30.709	30.728	-.019
12/07/90	213	30.606	30.626	-.020
12/07/90	90	30.779	30.801	-.022
12/11/90	64	29.650	29.669	-.019
12/14/90	14	31.029	31.043	-.014
12/18/90	59	29.350	29.370	-.020
12/21/90	405	28.931	28.933	-.002
12/29/90	228	30.532	30.529	.003

Appendix Table 2. --- Continued

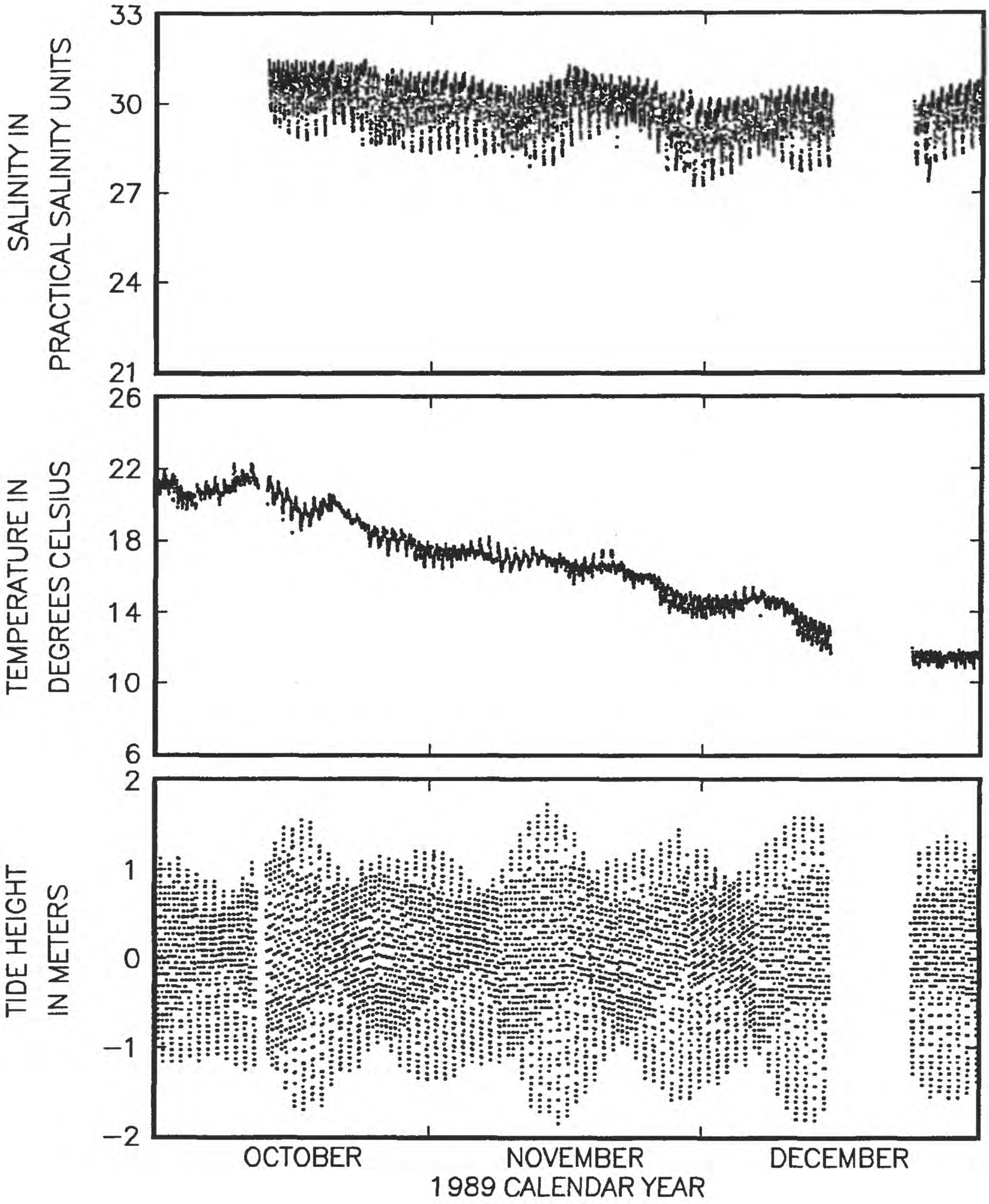
Date of Sample	Bottle Number	Initial Salinity	Second Analysis	Initial minus Second analysis
01/05/91	216	29.277	29.283	-.006
02/02/91	120	27.954	27.963	-.009
02/08/91	212	28.081	28.089	-.008
02/17/91	244	27.300	27.304	-.004
03/02/91	57	26.710	26.706	.004
03/09/91	213	25.376	25.380	-.004
03/18/91	204	25.396	25.401	-.005
03/30/91	48	24.561	24.567	-.006
04/05/91	63	23.888	23.894	-.006
05/10/91	43	27.333	27.320	+.013
06/07/91	5	28.840	28.859	-.019
07/06/91	55	30.145	30.165	-.020
07/19/91	53	30.748	30.757	-.009
08/02/91	3	31.776	31.782	-.006
08/09/91	61	31.506	31.515	-.009
08/31/91	68	31.257	31.296	-.039
10/10/91	74	31.403	31.406	-.003
11/26/91	87	30.248	30.252	-.004
12/23/91	1	30.723	30.730	-.007
01/31/92	67	29.094	29.099	-.005
02/15/92	23	22.770	22.774	-.004
02/26/92	46	24.872	24.878	-.006
03/09/92	64	22.103	22.106	-.003
03/09/92	90	22.589	22.594	-.005

Appendix Table 2. --- Continued

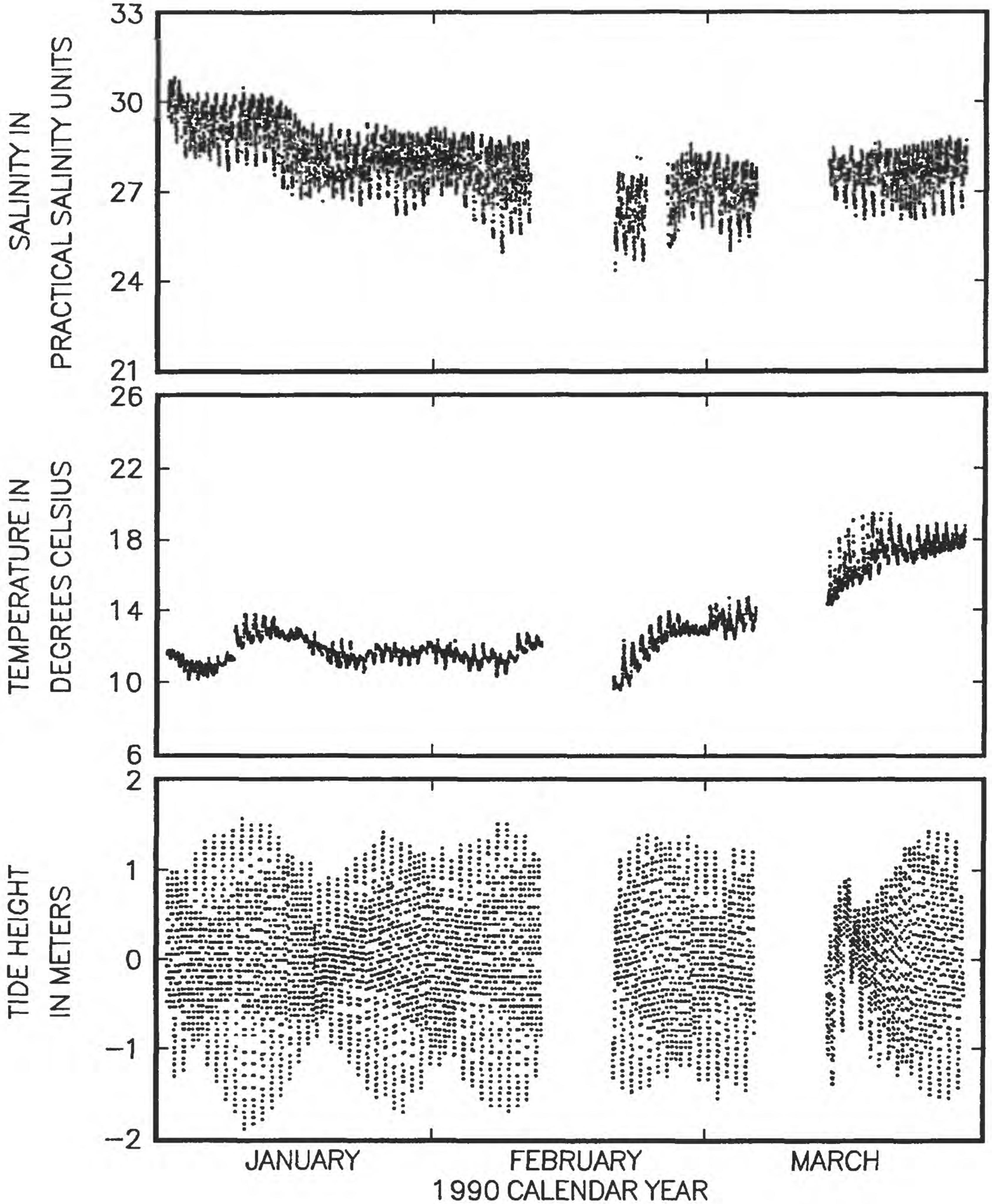
Date of Sample	Bottle Number	Initial Salinity	Second Analysis	Initial minus Second analysis
03/17/92	8	23.829	23.830	-.001
03/17/92	55	23.852	23.852	.000
03/26/92	33	22.969	22.970	-.001
04/03/92	65	21.883	21.884	-.001
04/10/92	92	23.429	23.431	-.002
04/20/92	63	24.094	24.097	-.003
04/24/92	40	23.598	23.601	-.003
04/24/92	56	24.073	24.076	-.003
05/01/92	69	24.961	24.962	-.001
05/01/92	57	25.045	25.049	-.004
05/11/92	1	25.839	25.849	-.010
06/01/92	87	25.592	25.599	-.007
06/10/92	3	27.913	27.923	-.010
07/06/92	53	28.674	28.685	-.011
07/17/92	66	28.611	28.615	-.004
07/28/92	65	29.613	29.617	-.004
08/14/92	50	29.898	29.903	-.005
08/24/92	61	31.273	31.279	-.006
10/14/92	67	31.245	31.251	-.006
10/23/92	48	31.137	31.138	-.001
11/05/92	88	31.152	31.152	-.000
12/16/92	57	28.037	28.037	-.000
01/08/93	14	26.180	26.184	-.004
01/20/93	40	24.285	24.289	-.004
02/01/93	60	19.251	19.256	-.005

Appendix Table 2. --- Continued

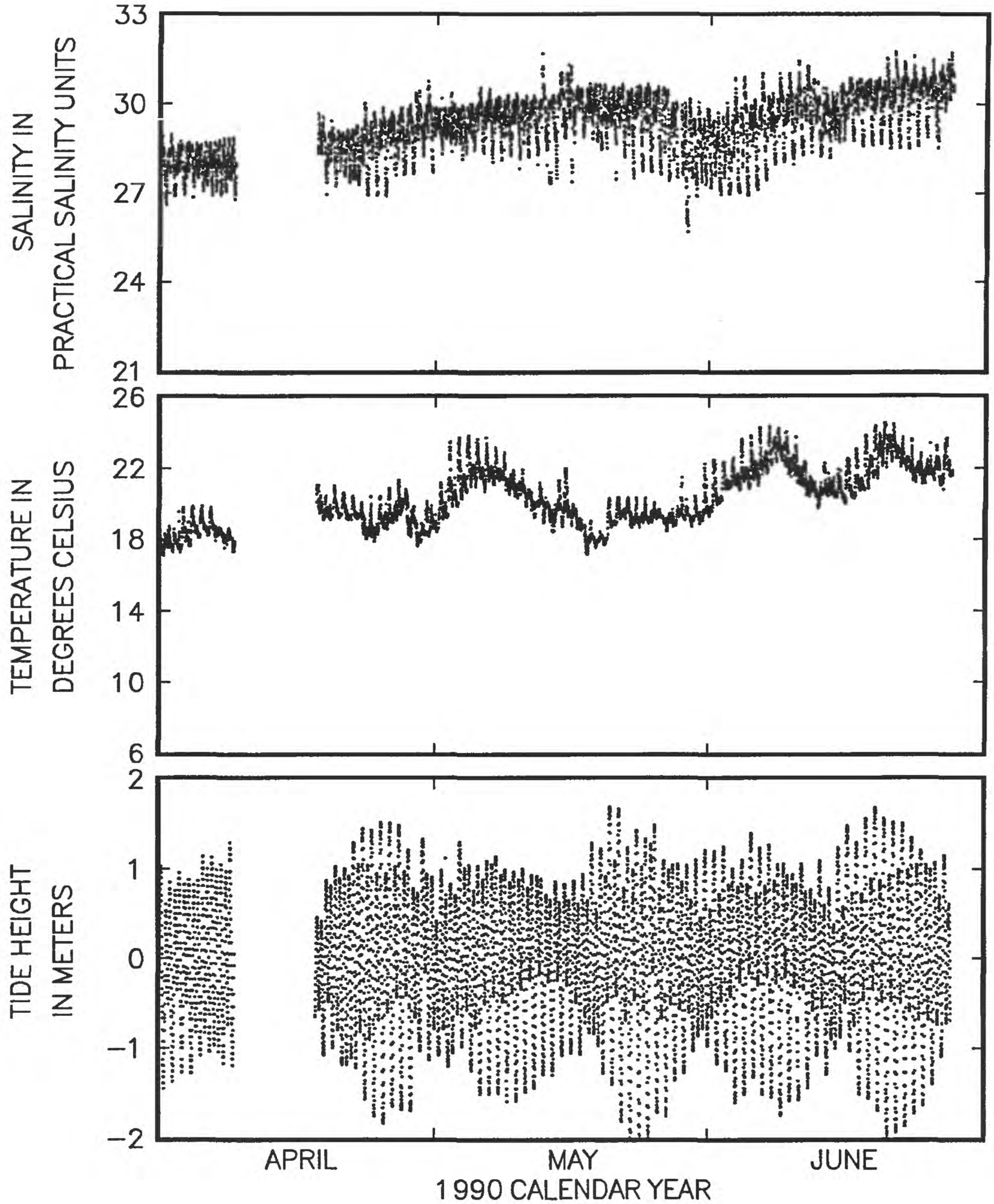
Date of Sample	Bottle Number	Initial Salinity	Second Analysis	Initial minus Second analysis
02/01/93	68	19.324	19.327	-.003
03/01/93	69	14.771	14.764	+0.007
03/16/93	7	17.048	17.041	+0.007
04/02/93	8	17.162	17.158	+0.004
04/13/93	61	16.680	16.675	+0.005
04/22/93	92	16.530	16.541	+0.011
05/14/93	65	21.337	21.349	+0.012
05/24/93	63	20.692	20.704	+0.012
06/04/93	48	21.726	21.739	+0.013
07/01/93	33	24.062	24.083	+0.021
07/13/93	43	25.321	25.324	+0.003
08/12/93	5	27.373	27.382	+0.009
08/25/93	50	27.649	27.654	+0.005
09/08/93	52	27.701	27.706	+0.005



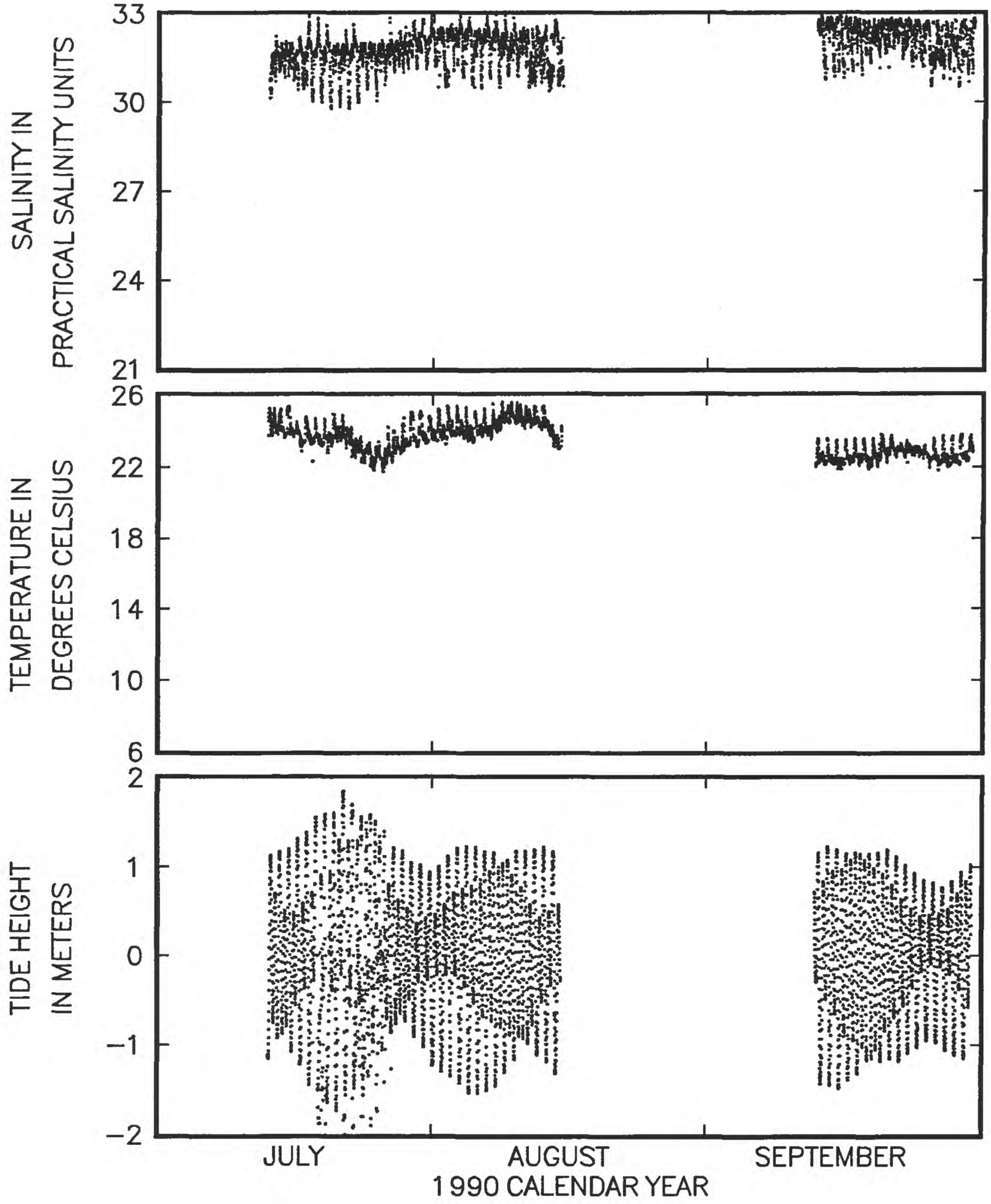
Appendix Figure 1. Measured values for salinity, temperature, and water depth (tides) at Dumbarton Bridge (near-bottom sensor): October-December, 1989.



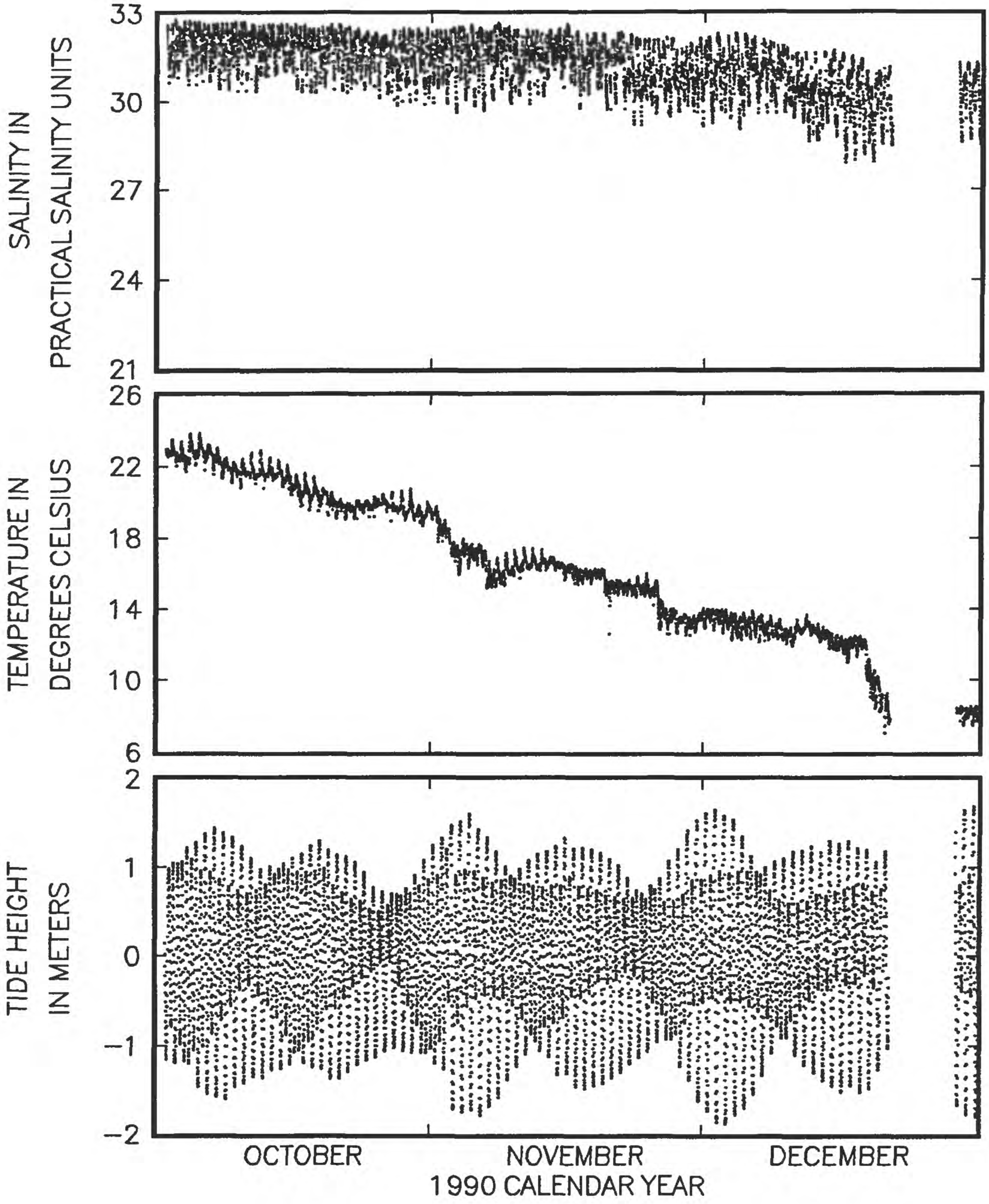
Appendix Figure 2. Measured values for salinity, temperature, and water depth (tides) at Dumbarton Bridge (near-bottom sensor): January-March, 1990.



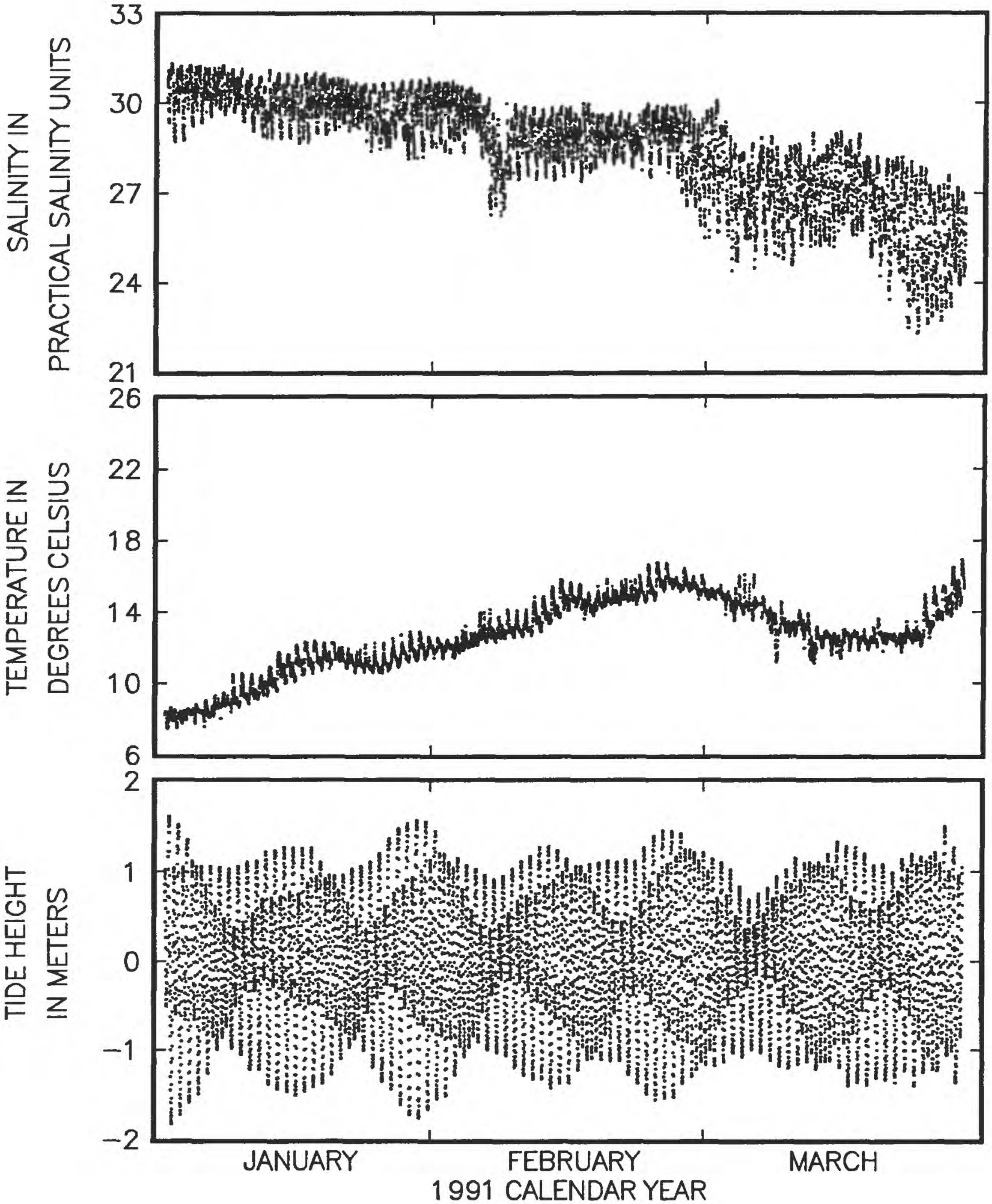
Appendix Figure 3. Measured values for salinity, temperature, and water depth (tides) at Dumbarton Bridge (near-bottom sensor): April-June, 1990.



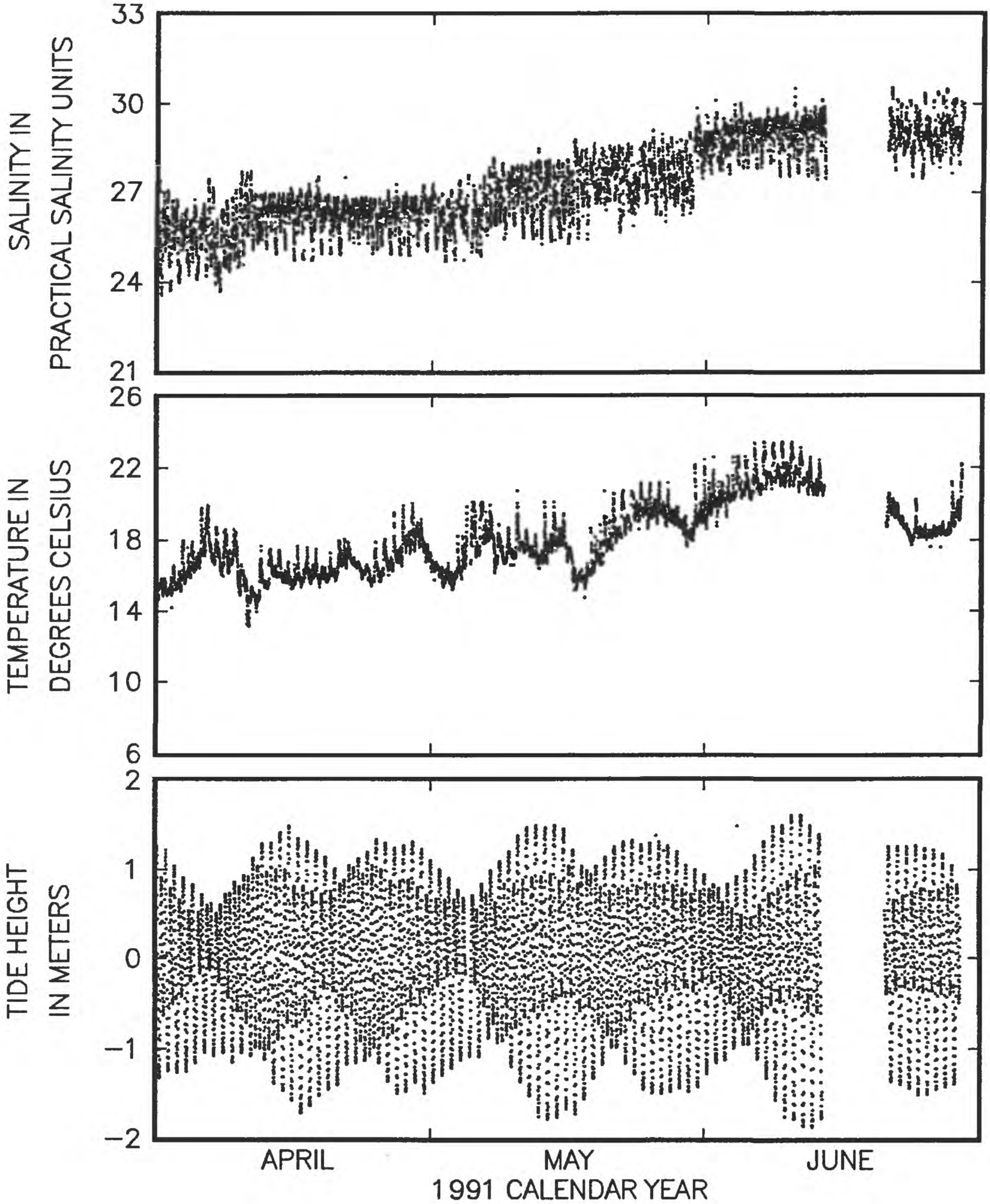
Appendix Figure 4. Measured values for salinity, temperature, and water depth (tides) at Dumbarton Bridge (near-bottom sensor): July-September, 1990.



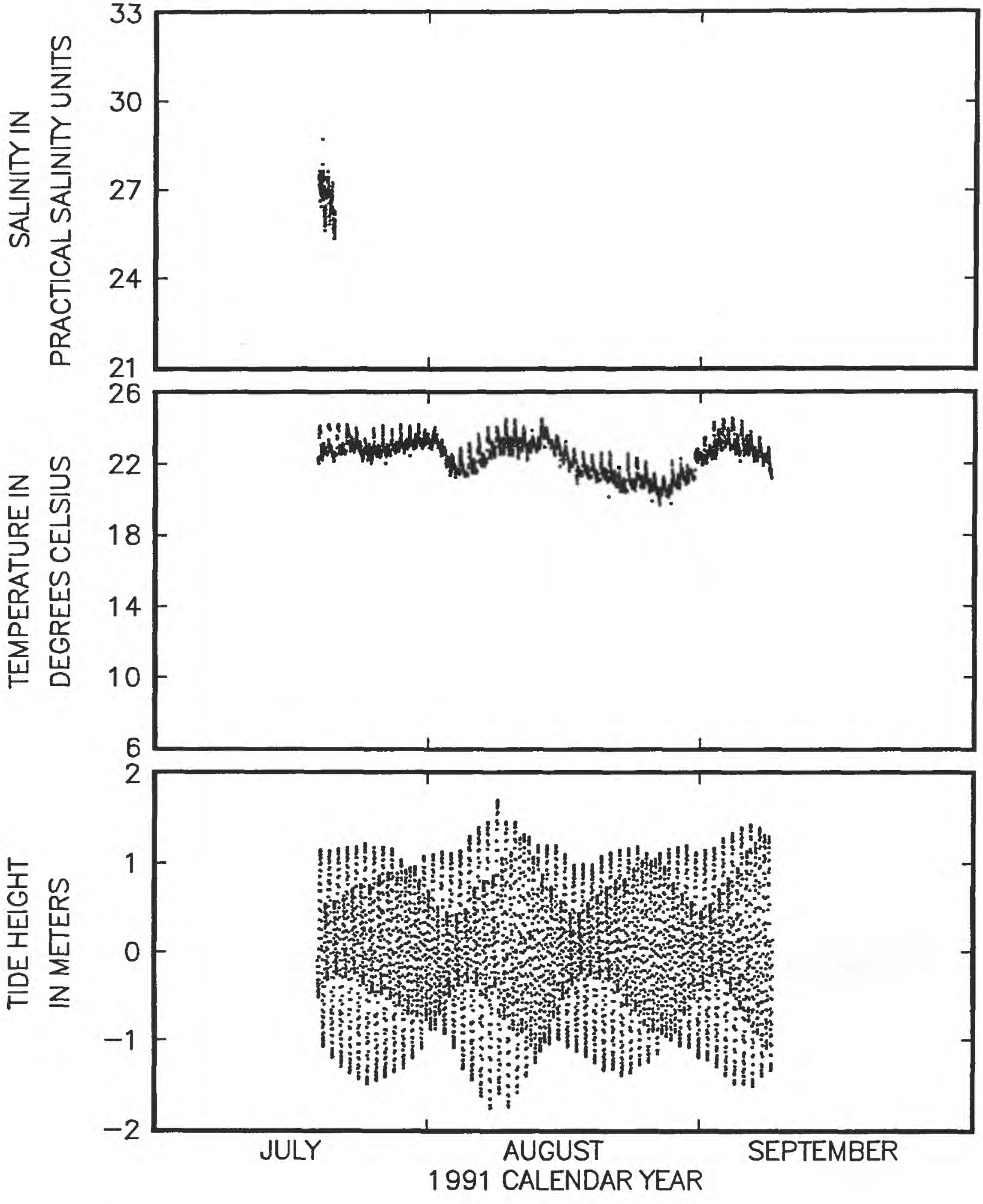
Appendix Figure 5. Measured values for salinity, temperature, and water depth (tides) at Dumbarton Bridge (near-bottom sensor): October-December, 1990.



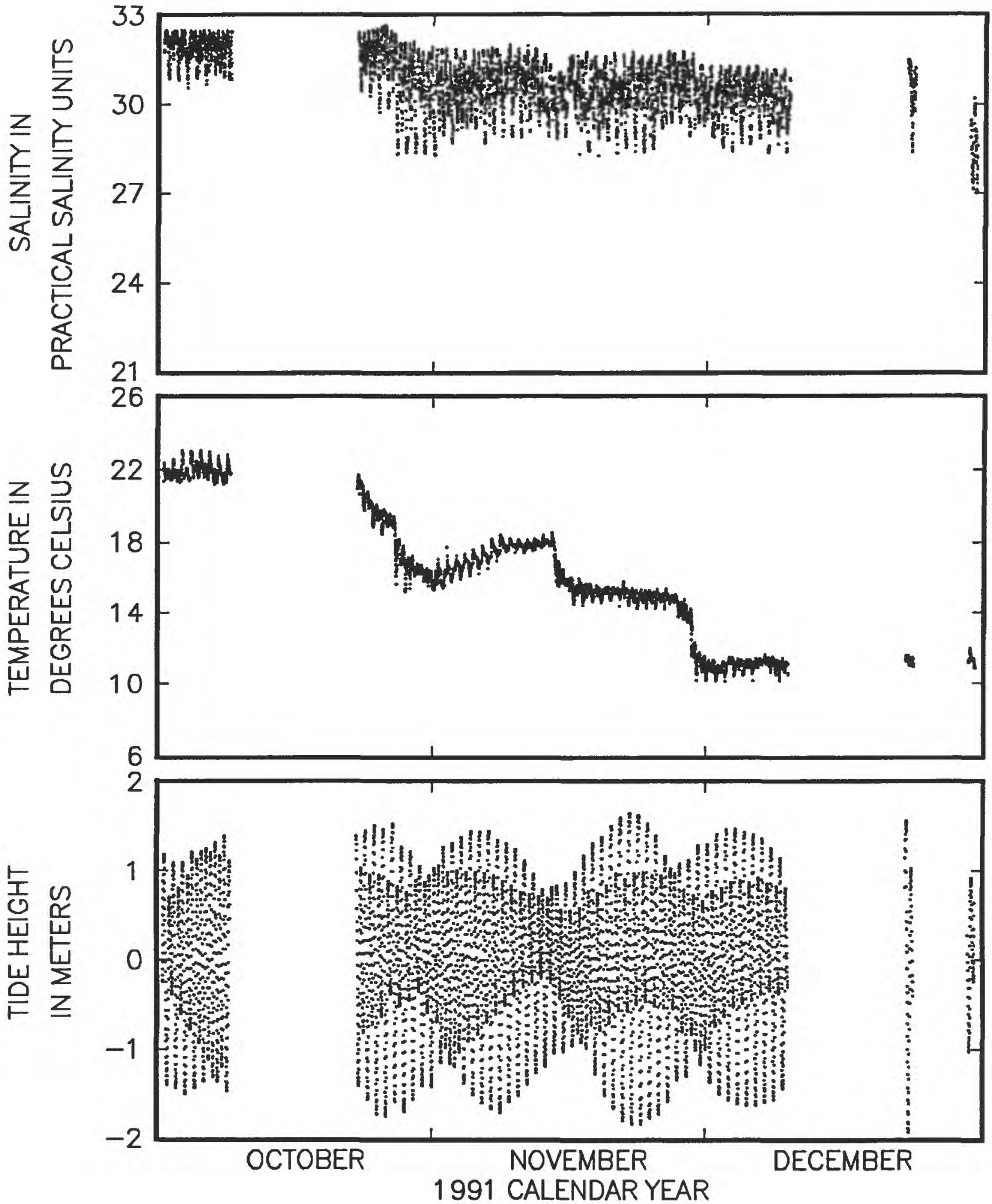
Appendix Figure 6. Measured values for salinity, temperature, and water depth (tides) at Dumbarton Bridge (near-bottom sensor): January-March, 1991.



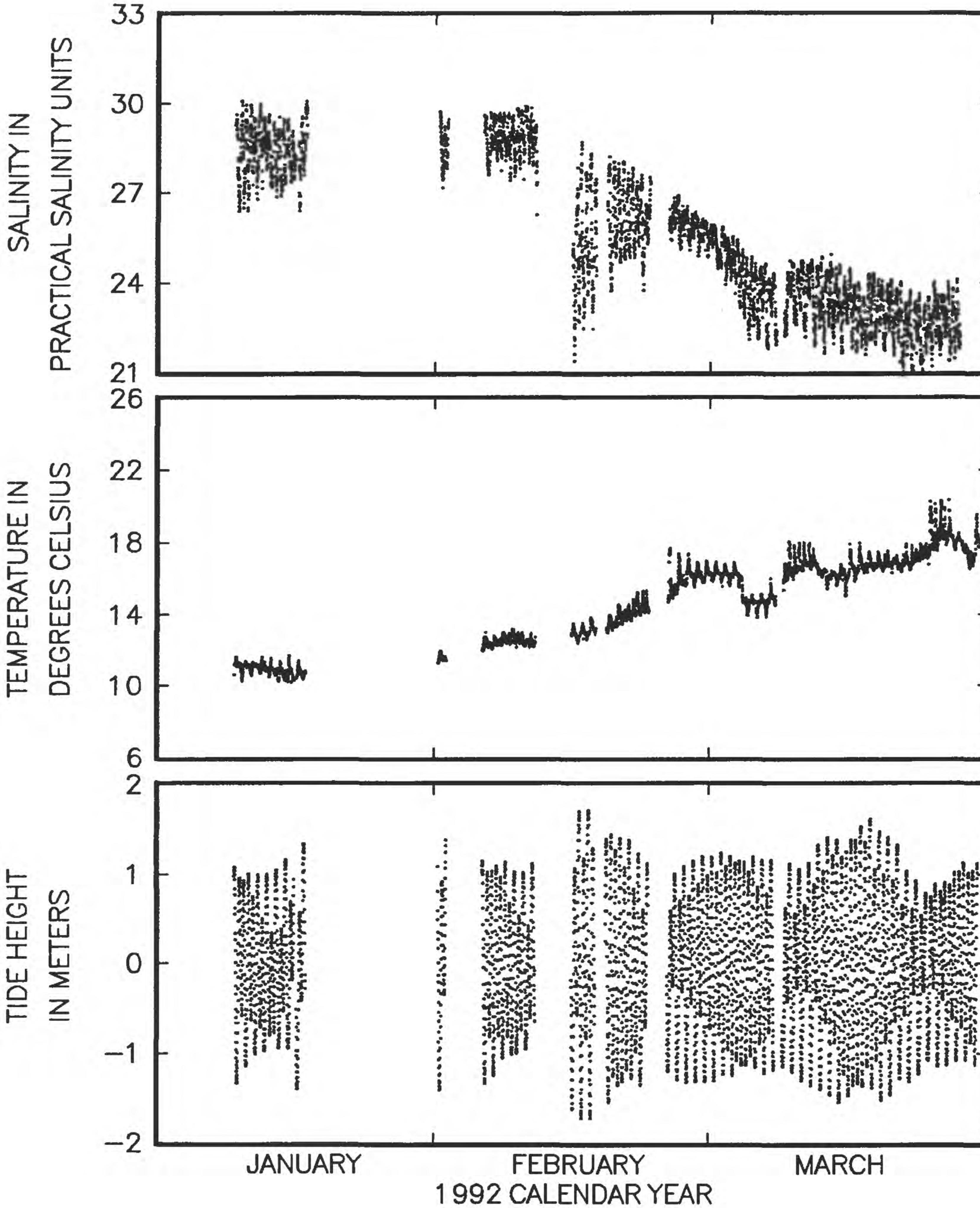
Appendix Figure 7. Measured values for salinity, temperature, and water depth (tides) at Dumbarton Bridge (near-bottom sensor): April-June, 1991.



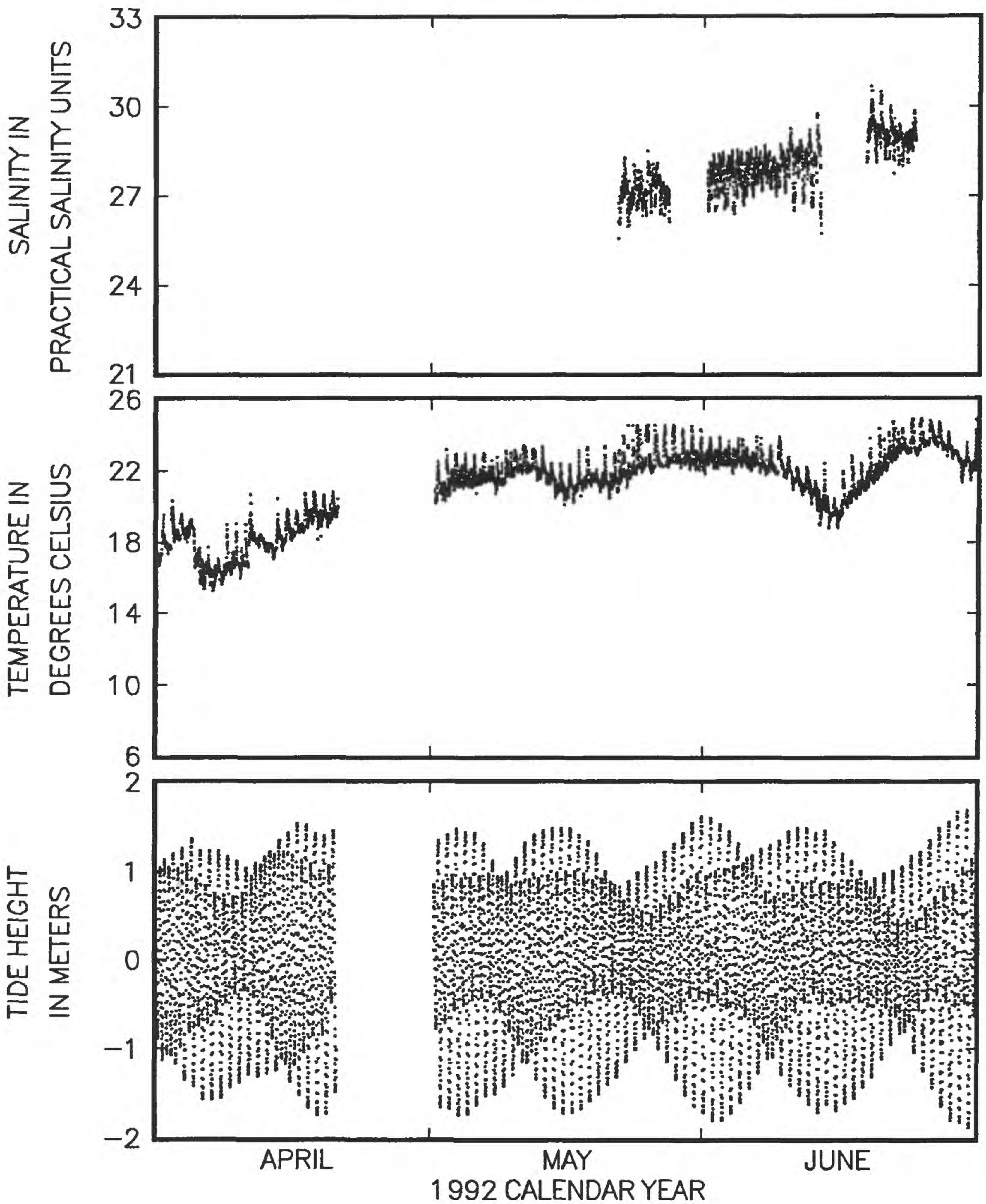
Appendix Figure 8. Measured values for salinity, temperature, and water depth (tides) at Dumbarton Bridge (near-bottom sensor): July-September, 1991



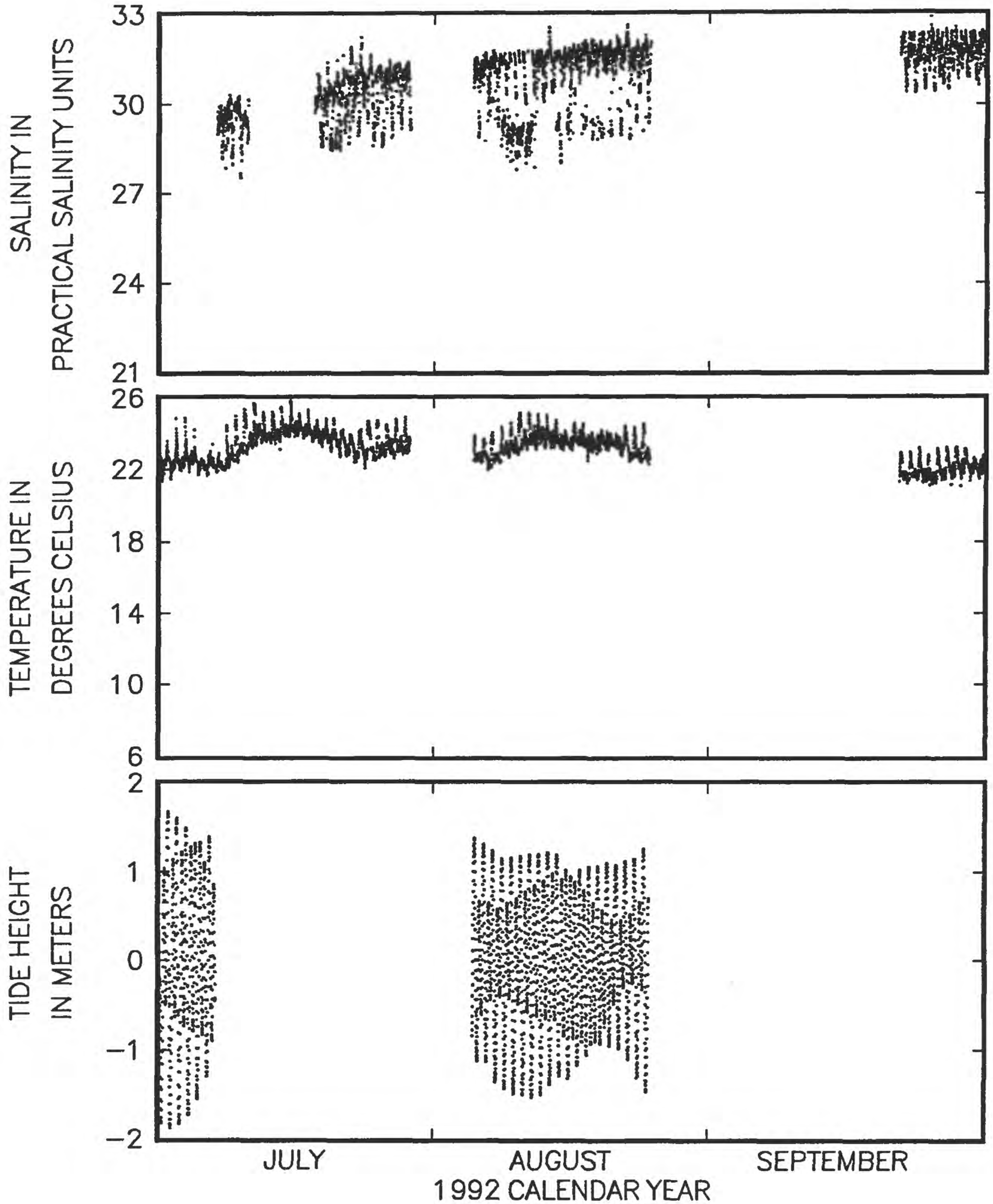
Appendix Figure 9. Measured values for salinity, temperature, and water depth (tides) at Dumbarton Bridge (near-bottom sensor): October-December, 1991.



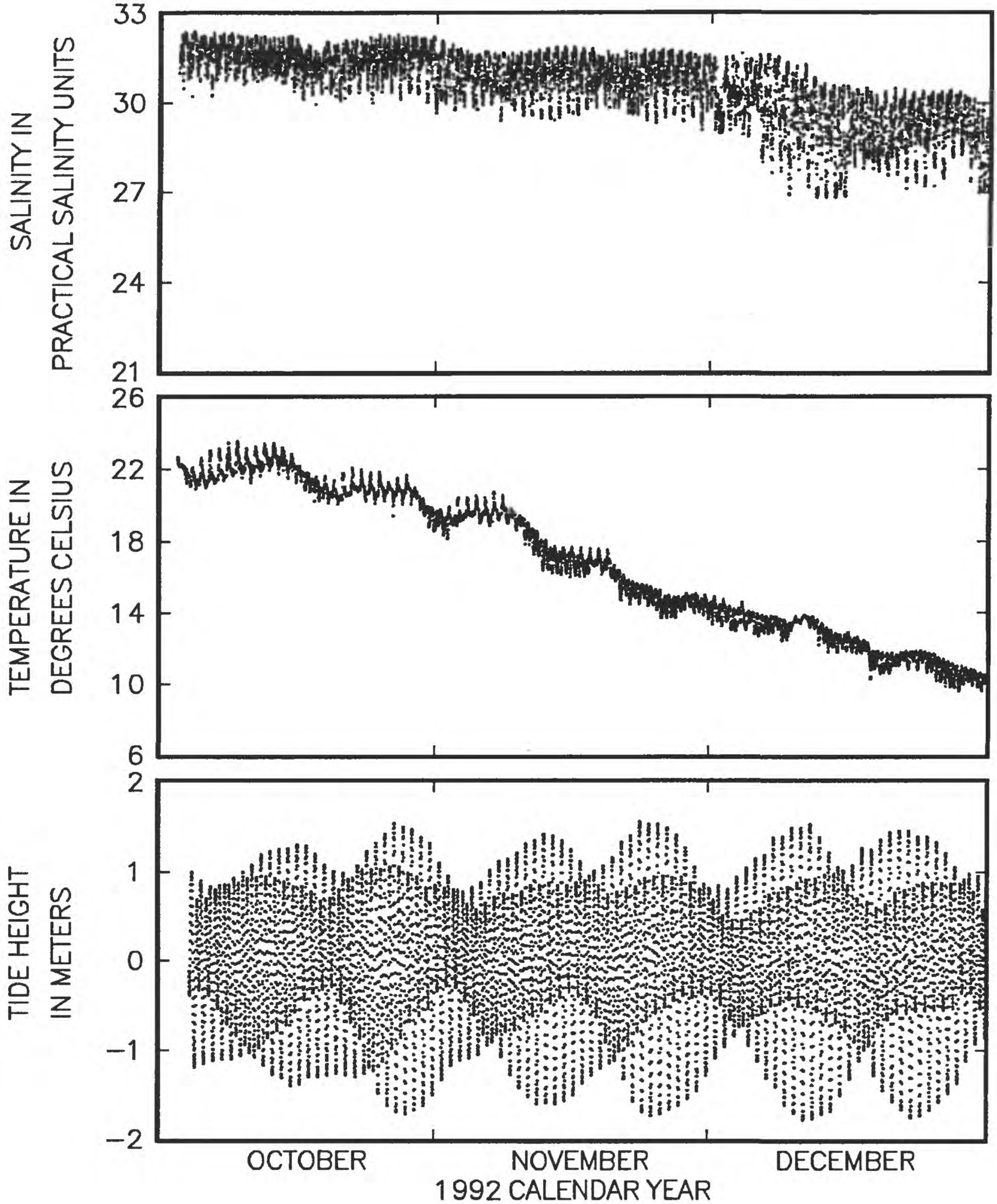
Appendix Figure 10. Measured values for salinity, temperature, and water depth (tides) at Dumbarton Bridge (near-bottom sensor): January-March, 1992.



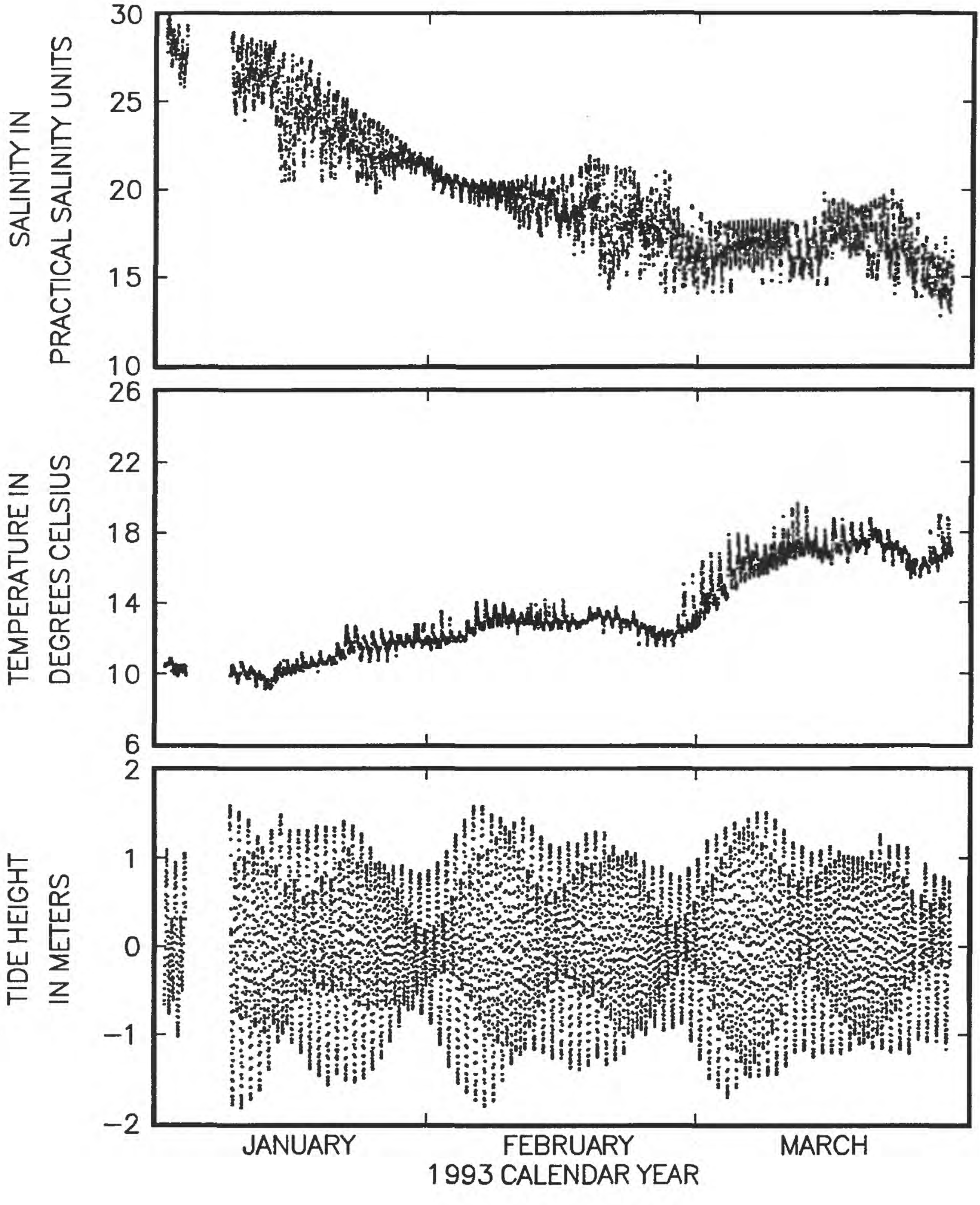
Appendix Figure 11. Measured values for salinity, temperature, and water depth (tides) at Dumbarton Bridge (near-bottom sensor): April-June, 1992.



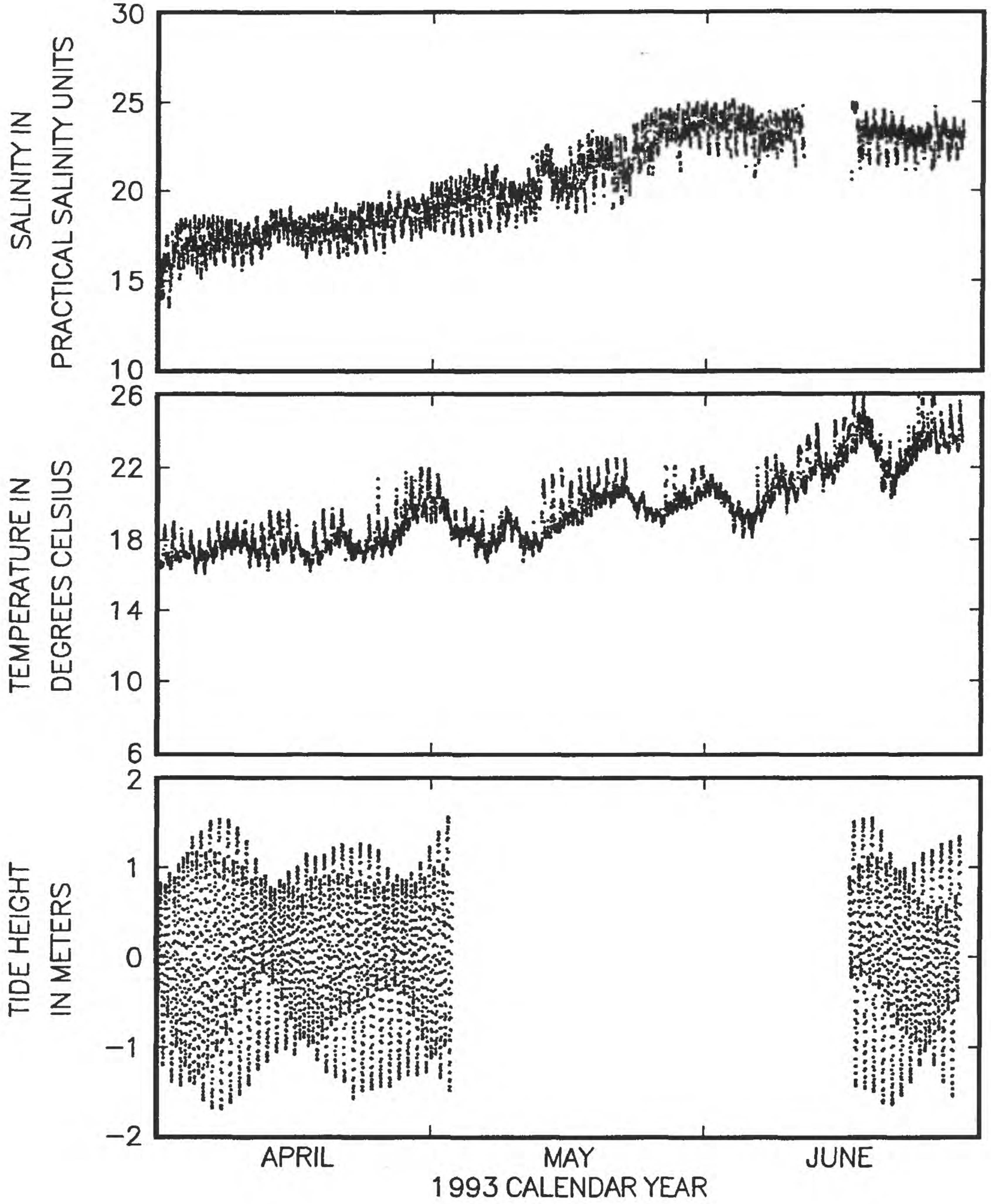
Appendix Figure 12. Measured values for salinity, temperature, and water depth (tides) at Dumbarton Bridge (near-bottom sensor): July-September, 1992.



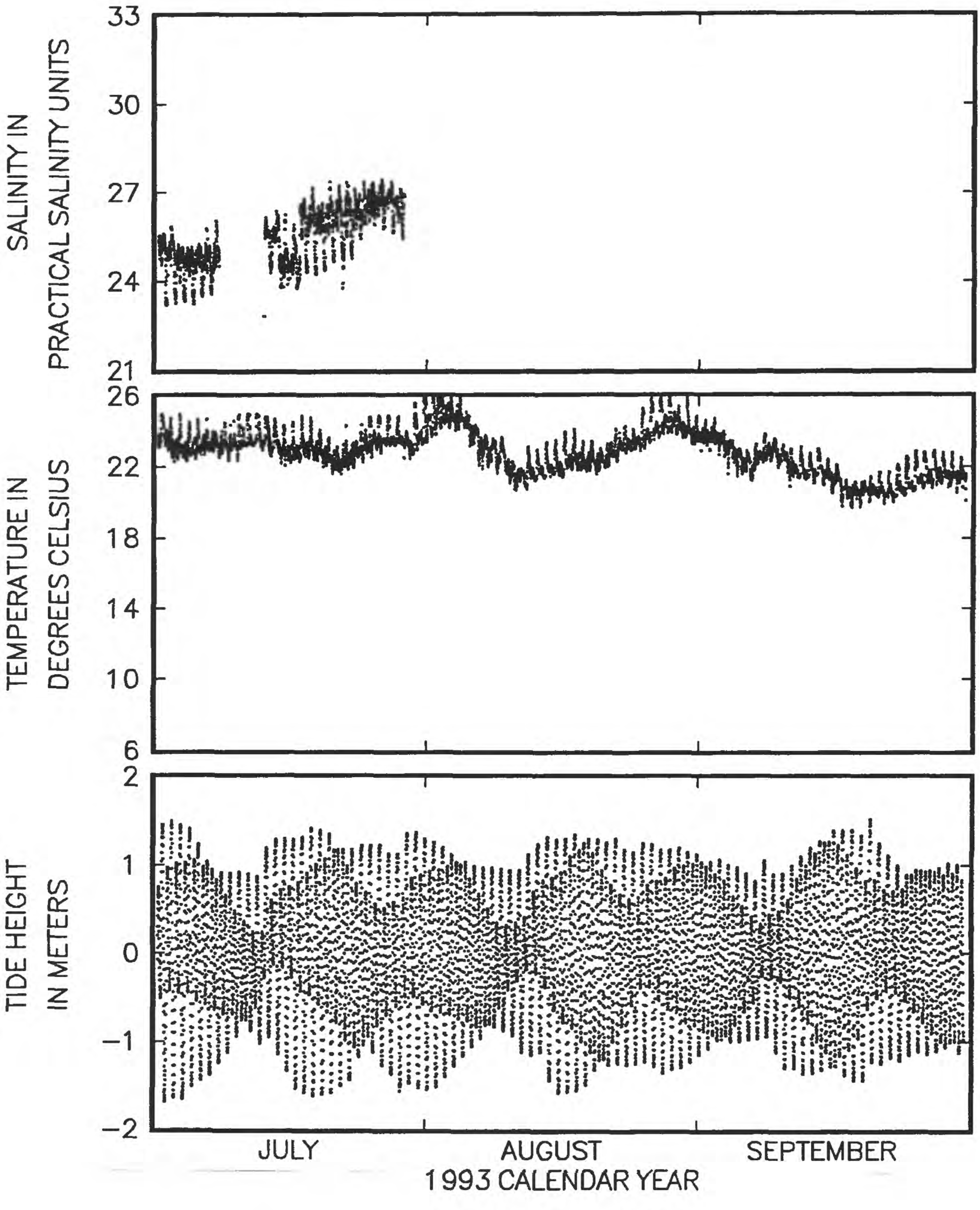
Appendix Figure 13. Measured values for salinity, temperature, and water depth (tides) at Dumbarton Bridge (near-bottom sensor): October-December, 1992.



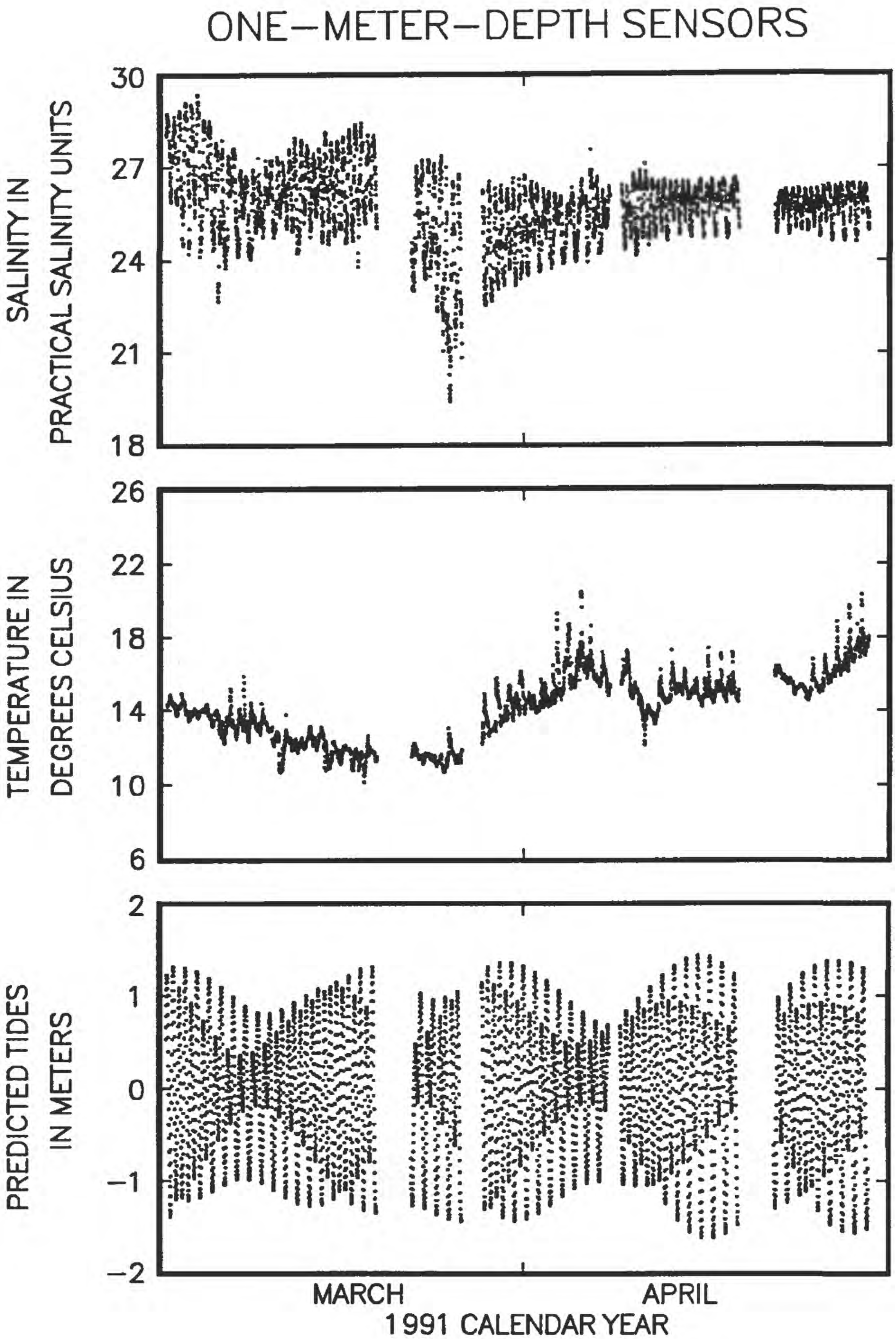
Appendix Figure 14. Measured values for salinity, temperature, and water depth (tides) at Dumbarton Bridge (near-bottom sensor): January-March, 1993.



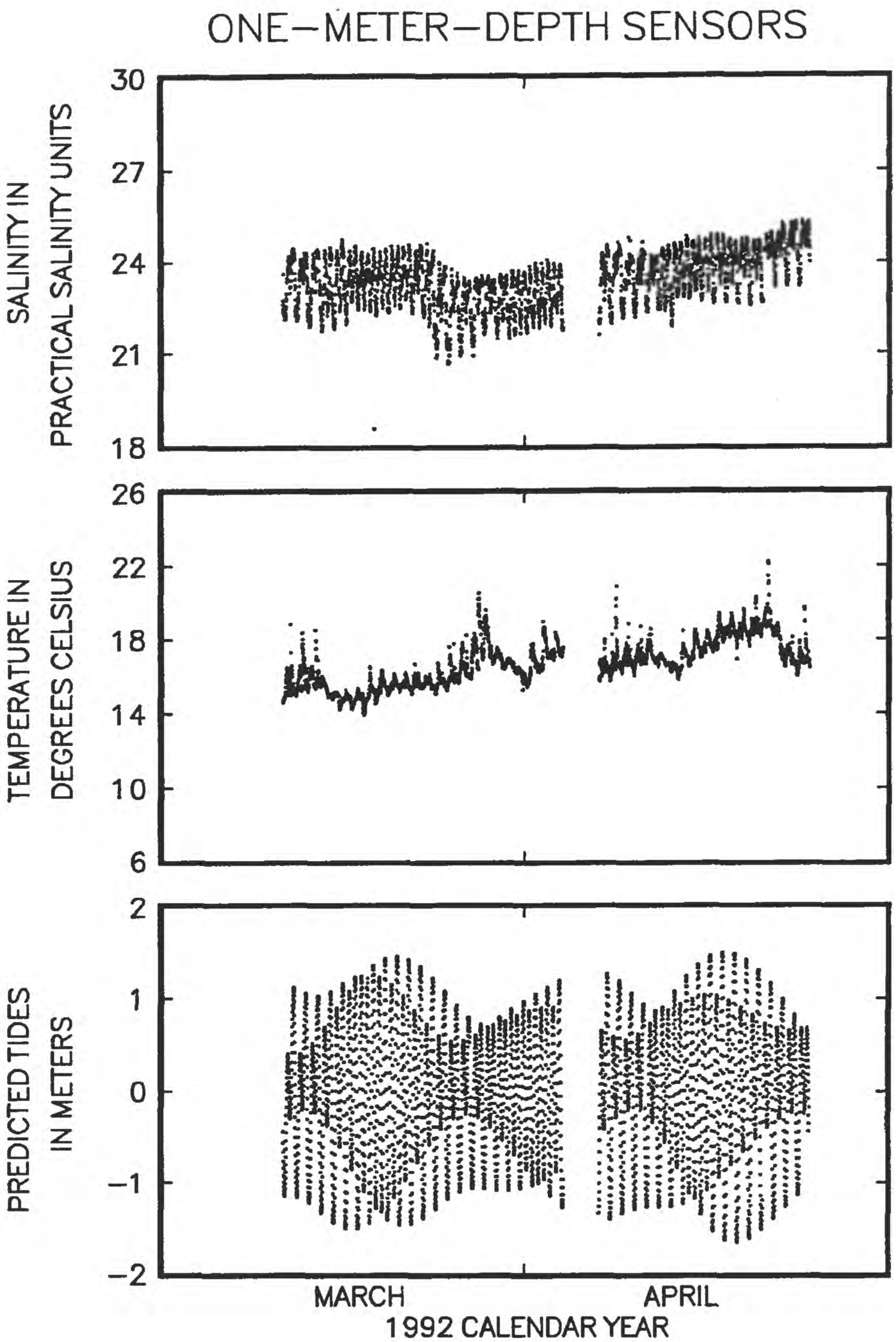
Appendix Figure 15. Measured values for salinity, temperature, and water depth (tides) at Dumbarton Bridge (near-bottom sensor): April-June, 1993.



Appendix Figure 15. Measured values for salinity, temperature, and water depth (tides) at Dumbarton Bridge (near-bottom sensor): July-September, 1993.



Appendix Figure 16. Measured values for salinity and temperature (one-meter-depth sensor) and predicted values for tides at Dumbarton Bridge, March and April 1991.



Appendix Figure 17. Measured values for salinity and temperature (one-meter-depth sensor) and predicted values for tides at Dumbarton Bridge, March and April 1992.