DISCHARGE, WATER-QUALITY CHARACTERISTICS, AND NUTRIENT LOADS FROM MCKAY BAY, DELANEY CREEK, AND EAST BAY, TAMPA, FLORIDA, 1991–1993

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 95-4167

Prepared in cooperation with the

TAMPA BAY REGIONAL PLANNING COUNCIL

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By Yvonne E. Stoker, Victor A. Levesque, *and* Eric M. Fritz

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6–30. Graphs showing:

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CONVERSION FACTORS, VERTICAL DATUM, AND ADDITIONAL ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	25.40	millimeter
foot (ft)	0.3048	meter
foot per second (ft/s)	0.3048	meter per second
square foot (ft^2)	0.0929	square meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
million gallons per day (Mgal/d)	0.04381	cubic meter per second
ton, short	0.9072	megagram
ton per day (ton/d)	0.9072	megagram per day

Degree Fahrenheit (°F) may be converted to degree Celsius (°C) by using the following equation:

°C = 5/9 (°F-32).

Sea level: In this report “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviated water-quality units:

mg/L	milligram per liter
µS/cm	microsiemens per centimeter at 25 degrees Celsius

Additional abbreviations:

AVM	acoustic velocity meter
BBADCP	broad band acoustic doppler current profiler
EMCM	electromagnetic current meter
NEP	National Estuary Program
NOAA	National Oceanic and Atmospheric Administration
PVC	polyvinyl chloride
R^2	coefficient of determination
TBNEP	Tampa Bay National Estuary Program
USGS	U.S. Geological Survey

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Abstract

Nutrient enrichment in Tampa Bay has caused a decline in water quality in the estuary. Efforts to reduce the nutrient loading to Tampa Bay have resulted in improvements in water quality from 1981 to 1991. However, Tampa Bay still is considered enriched with nutrients. Water quality in East Bay (located at the northeastern part of Hillsborough Bay, which is an embayment in Tampa Bay) is not improving at the same rate as the rest of the bay. East Bay is the center of shipping activity in Tampa Bay and the seventh largest port in the United States. One of the primary cargoes is phosphate ore and related products such as fertilizer. The potential for nutrient loading to East Bay from shipping activities is high and has not previously been measured.

Nitrogen and phosphorus loads from East Bay to Hillsborough Bay were measured during selected time periods during June 1992 through May 1993; these data were used to estimate seasonal and annual loads. These loads were evaluated to determine whether the loss of fertilizer products from shipping activities resulted in increased nutrient loading to Hillsborough Bay. Discharge was measured, and water-quality samples were collected at the head of East Bay (exiting McKay Bay), at the mouth of Delaney Creek (a tributary to East Bay), and at the mouth of East Bay. Discharge and nitrogen and phosphorus concentrations for the period June 1992 through May 1993 were used to compute loads.

Discharges from McKay Bay, Delaney Creek, and East Bay are highly variable because of the effect of tide. Flow patterns during discharge measurements generally were unidirectional in McKay Bay and Delaney Creek, but more complex, bidirectional patterns were observed at the mouth of East Bay. Tidally affected discharge data were digitally filtered with the Godin filter to remove the effects of tide so that residual, or net, discharge could be determined. Daily mean discharge from McKay Bay ranged from -1,900 to 2,420 cubic feet per second; from Delaney Creek, -3.8 to 162 cubic feet per second; and from East Bay, -437 to 3,780 cubic feet per second.

Water quality in McKay Bay, Delaney Creek, and East Bay varies vertically, areally, and seasonally. Specific conductance and concentrations of phosphorus and ammonia nitrogen were greater near the bottom than near the surface at the head and mouth of East Bay. Concentrations of total nitrogen and ammonia plus organic nitrogen generally were greater at the head of East Bay than at the mouth, indicating that McKay Bay is the primary source of nitrogen to East Bay. Concentrations of total ammonia nitrogen, nitrite plus nitrate nitrogen, phosphorus, orthophosphorus, and suspended solids and values of turbidity and specific conductance generally were greater at the mouth of East Bay than at the head. The greatest concentrations of nitrogen and phosphorus were measured in Delaney Creek. In East Bay and McKay Bay, the greatest concentrations of nitrogen, phosphorus, and ammonia plus organic nitrogen occurred in summer, whereas turbidity, specific conductance, and concentrations of suspended solids were greater in winter.

The greatest daily mean loads from McKay Bay and East Bay occurred in late June 1992 and April and May 1993 and coincided with periods of daily mean discharge greater than about 2,000 cubic feet per second. Although concentrations of nitrogen and phosphorus were greater in Delaney Creek than in McKay Bay and East Bay, loads were minimal because of minimal discharges from Delaney Creek.

Monthly loads of total nitrogen ranged from about 20 tons to about 83 tons at McKay Bay; from about 1 ton to 4.2 tons at Delaney Creek; and from about 17 tons to 76 tons at the mouth of East Bay. Monthly loads of phosphorus ranged from about 11 tons to about 45 tons at McKay Bay; from about 0.62 ton to 2.6 tons at Delaney Creek; and from about 10 tons to about 45 tons at the mouth of East Bay.

The results of this study indicate that nitrogen and phosphorus loads from the basin draining directly to East Bay (excluding loads from the McKay Bay and Delaney Creek basins) are minimal. Nitrogen and phosphorus loads from East Bay to Hillsborough Bay largely were the result of loads from McKay Bay and Delaney Creek. Therefore, losses of fertilizer products during shipping activities in East Bay were not a significant source of nitrogen and phosphorus to Hillsborough Bay during the study.

INTRODUCTION

Water quality in the Tampa Bay estuary (fig. 1) has long been affected by anthropogenic physical alterations, by point- and nonpoint-source discharges, and by changes in the quality and quantity of water entering the bay. Located on the west-central coast of Florida, Tampa Bay is flanked by large urban areas (the cities of Tampa, St. Petersburg, Clearwater, and surrounding metropolitan areas), has a major port, and receives freshwater inflow from basins with multiple land uses. The Port of Tampa, located in East Bay, a highly modified part of Hillsborough Bay, is the Nation’s seventh largest harbor (Dittner, 1992). Phosphate and related products, such as fertilizer; petroleum and related products; and dry bulk, such as lumber, rock, metal, and cement, are the principal cargoes handled at the port.

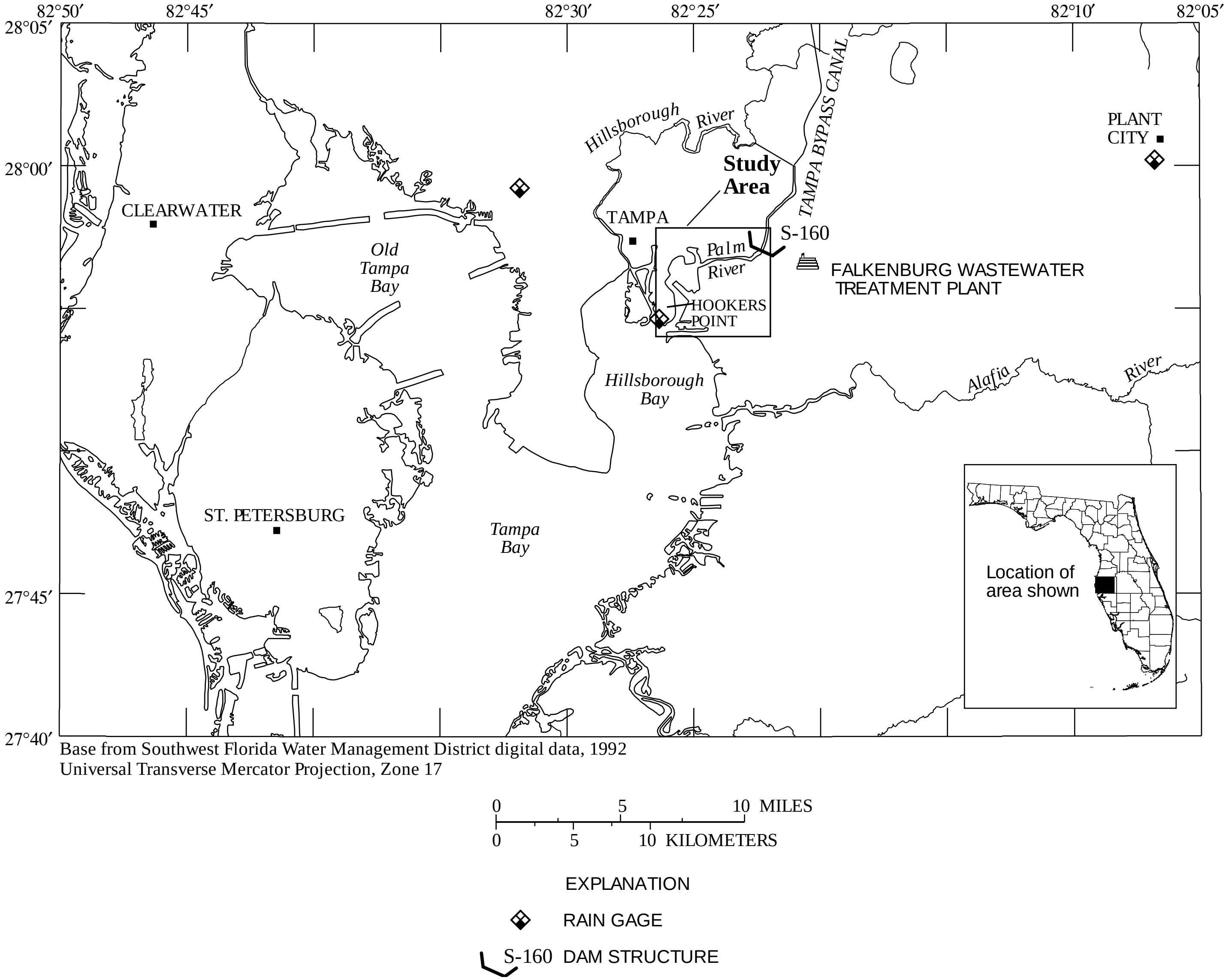
Nutrient loading to the Tampa Bay estuary is recognized as a significant cause of the decline in water quality in the estuary. Hillsborough Bay is affected by excess nutrients more than any other part of Tampa Bay. Hillsborough Bay receives freshwater inflow from several rivers, treated domestic sewage effluent, stormwater runoff, nonpoint-source runoff, and permitted point-source discharges. In response to concerns about the eutrophication of Hillsborough Bay, the city of Tampa wastewater treatment plant at Hookers Point, which discharges an average of 60 Mgal/d of effluent to Hillsborough Bay, was upgraded from primary treatment to tertiary treatment in 1979 (Johansson, 1991).

Although the water quality in Tampa Bay, including Hillsborough Bay, improved from 1981 through 1991, nitrogen and phosphorus concentrations still are considered enriched (Boler, 1992). East Bay, located at the northeastern part of Hillsborough Bay (fig. 1), has not improved at the same rate as the rest of the bay (Cardinale and Dunn, 1991). East Bay is bounded by McKay Bay at the north end and by Hillsborough Bay at the south end. Delaney Creek discharges directly to the southeast part of East Bay. The City of Tampa Bay Study Group determined that the source of excessive nutrients in East Bay may be shipping activity and near-shore land uses.

In early 1990, the Hillsborough County Environmental Protection Commission began a study of water quality in East Bay. Study results showed that stormwater discharge into East Bay was contaminated by fertilizer, one of the main products handled in the East Bay area. Some stormwater discharge samples contained concentrations of total nitrogen and phosphorus in excess of 1,000 mg/L and 2,800 mg/L, respectively (Cardinale and Dunn, 1991). In 1990, five shipping facilities in East Bay were issued warning notices by the Hillsborough County Environmental Protection Commission and the Florida Department of Environmental Regulation. Each facility signed consent orders in 1991, which, in part, agreed to correct the problems associated with fertilizer product losses that occurred during shipping activities (Thomas Cardinale, Hillsborough County Environmental Protection Commission, oral commun., 1991).

The potential for nutrient loading from East Bay to Hillsborough Bay caused by the loss of fertilizer products during shipping activities is high. Cardinale and Dunn (1991) estimated that over 800 tons of total nitrogen and over 2,000 tons of total phosphorus may have entered East Bay in 1989 from shipping activities and land uses, assuming that 0.05 percent of the product was lost. AScI Corporation (1993) estimated similar losses for total phosphorus and over 600 tons per year of total nitrogen during 1989 to 1991.

In 1990, the U.S. Environmental Protection Agency added Tampa Bay to the National Estuary Program (TBNEP). The TBNEP duties are to assess the conditions in Tampa Bay, identify restoration and enhancement needs, and develop a comprehensive long-range plan to manage and protect the estuary (TBNEP, 1993). Because nutrient enrichment still is considered a significant problem in Tampa Bay, the TBNEP funded several studies to determine the sources and amount of nitrogen and phosphorus loading to the estuary.



Base from Southwest Florida Water Management District digital data, 1992
Universal Transverse Mercator Projection, Zone 17

Figure 1. Location of the study area.

A U.S. Geological Survey (USGS) project was cooperatively funded by the Tampa Bay Regional Planning Council on behalf of the TBNEP to determine nitrogen and phosphorus loads from East Bay to Hillsborough Bay.

Purpose and Scope

The purpose of this report is to describe the discharge, water-quality characteristics, and nutrient loading from McKay Bay, Delaney Creek, and East Bay during October 1991 and June 1992, through May 1993. The effects of tide and freshwater inflows on discharge and water-quality characteristics are evaluated. Nutrient loads calculated from discharge and water- quality data are used to estimate nutrient loads for periods when water-quality data are not available. These estimated loads are described in the report. Seasonal loading patterns are described and are compared with freshwater inflow patterns. Loads from the East Bay basin are evaluated to determine the effects of shipping activities on nutrient loads to Hillsborough Bay.

Description of the Study Area

Since the early 19th century, the Port of Tampa has been an important transportation link for the west-central Florida region. With the discovery of phosphate in the region during the late 19th century, the principal cargo changed from local agricultural products to phosphate products. The development of the port has resulted in dramatic changes in Tampa Bay's physical dimensions. In the late 1960's, the Tampa Port Authority dredged the southeastern part of McKay Bay and created several hundred acres of land in the southwestern part of McKay Bay, called Hookers Point, for the development of new phosphate shipping terminals. The dredged area of McKay Bay, south of the 22nd Street Causeway Bridge, became known as East Bay (fig. 2).

East Bay currently (1995) has an area of about 0.76 mi^2, and the average depth of the bay is about 35 ft. Prior to dredging, the average depth was about 5 ft. Freshwater inflow from the Tampa Bypass Canal (fig. 1) enters the northeastern part of McKay Bay, and eventually enters East Bay. East Bay also receives freshwater inflow from stormwater runoff, rainfall, and Delaney Creek. Because the drainage area of the Tampa Bypass Canal is indeterminate, the total drainage area of East Bay also is indeterminate.

The water quality in East Bay is affected by land uses in the basin. In addition to potential effects on water quality from shipping activities described previously, water quality is affected by effluent from two permitted industrial sources and from one domestic source. Effluent from a fertilizer processing plant and from a domestic wastewater treatment plant is discharged into the Palm River, and effluent from a fertilizer processing plant is discharged into Delaney Creek (Boler, 1992).

The study area is characterized by a humid, subtropical climate. Rainfall is highly variable from one location to another. Monthly rainfall records from stations located at the city of Tampa wastewater treatment plant at Hookers Point and National Oceanic and Atmospheric Administration (NOAA) stations located in Tampa and Plant City are shown in figure 3 (National Oceanic and Atmospheric Administration, 1993a; 1993b). Maximum monthly rainfall occurred in June 1992, and minimum monthly rainfall occurred in December 1992. The normal annual rainfall (defined as average rainfall during June 1951 to May 1980) at the Tampa and Plant City rainfall stations is 46.73 and 53.49 in., respectively. During the study, the annual rainfall at the Tampa gage was about 6.1 in. below normal, whereas annual rainfall at the Plant City gage was about 9.4 in. above normal. Annual rainfall at Hookers Point was 40.98 in. during the study. Long-term rainfall records were not available, but rainfall near East Bay probably was below normal, based on normal annual rainfall at the NOAA stations.

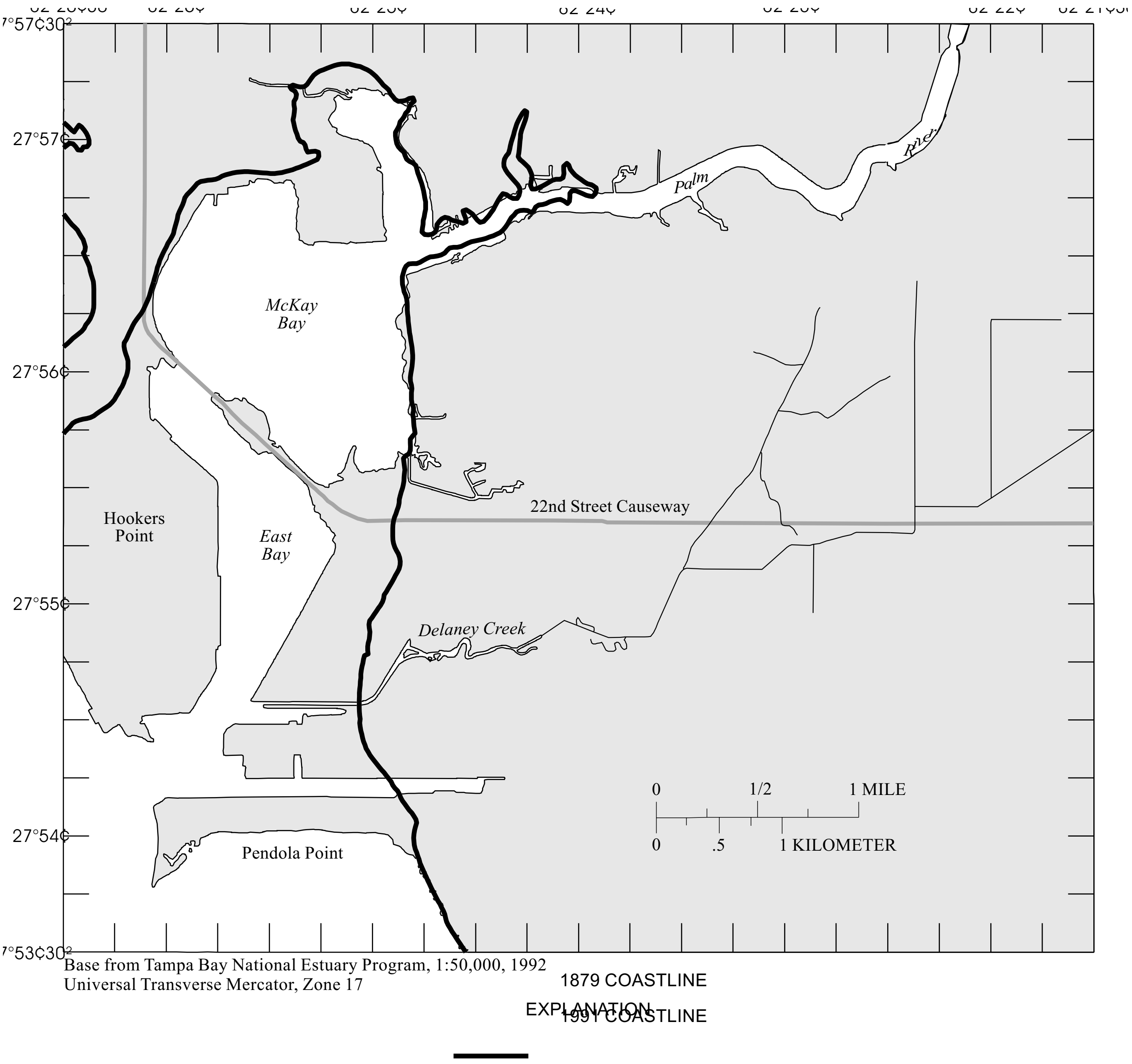
Acknowledgments

The authors would like to extend appreciation to the Florida Department of Transportation and to Rosa Lee Traina for allowing the installation of monitoring equipment on their properties and allowing access to their properties for the collection of water-quality samples. Rainfall records at Hookers Point were provided by the city of Tampa, and discharge data at the Tampa Bypass Canal at Structure 160 were provided by the Southwest Florida Water Management District.

METHODS

This study consisted of two phases: a reconnaissance phase and a data-collection phase. Results of the reconnaissance phase were used in the selection of study sites and to establish protocols for data collection for the remainder of the study.

The bathymetry and general flow patterns at potential discharge-measurement sites were determined during the reconnaissance phase. Evaluation of site characteristics was used to select gage locations for discharge



Base from Tampa Bay National Estuary Program, 1:50,000, 1992
Universal Transverse Mercator, Zone 17

Figure 2. Shoreline changes between 1879 and 1991 in the vicinity of East Bay.

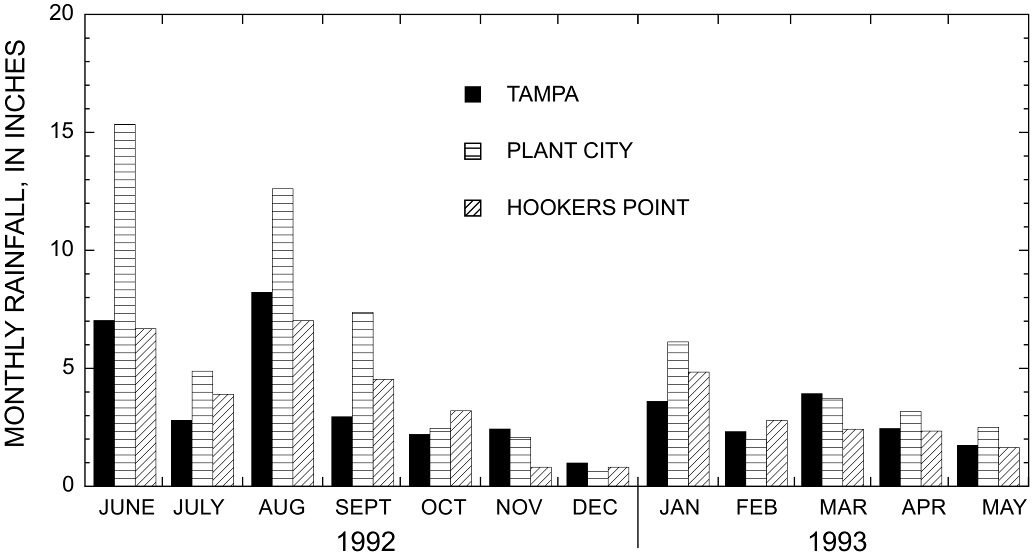


Figure 3. Monthly rainfall at stations located at Tampa, Plant City, and Hookers Point, June 1992

computations during the data-collection phase. Water-surface elevation (stage) and velocity gages were established at McKay Bay and Delaney Creek.

Reconnaissance water-quality sampling was done in October 1991 to evaluate water-quality variations in East Bay and to guide design of the data-collection network for the study. Water-quality samples for total nitrite plus nitrate nitrogen, ammonia nitrogen, ammonia plus organic nitrogen, phosphorus, orthophosphorus, turbidity, suspended solids, color, and specific conductance were collected at 10-day to 2-week intervals during June 1992 to May 1993, the data-collection phase. Sites were located in McKay Bay, East Bay, and Delaney Creek. Field measurements of pH, dissolved oxygen, temperature, specific conductance, and water transparency were made during each sampling event. Continuous records of specific conductance and temperature were made at fixed sites in McKay Bay and Delaney Creek.

The following sections provide detailed descriptions of the data-collection network that was established during this study.

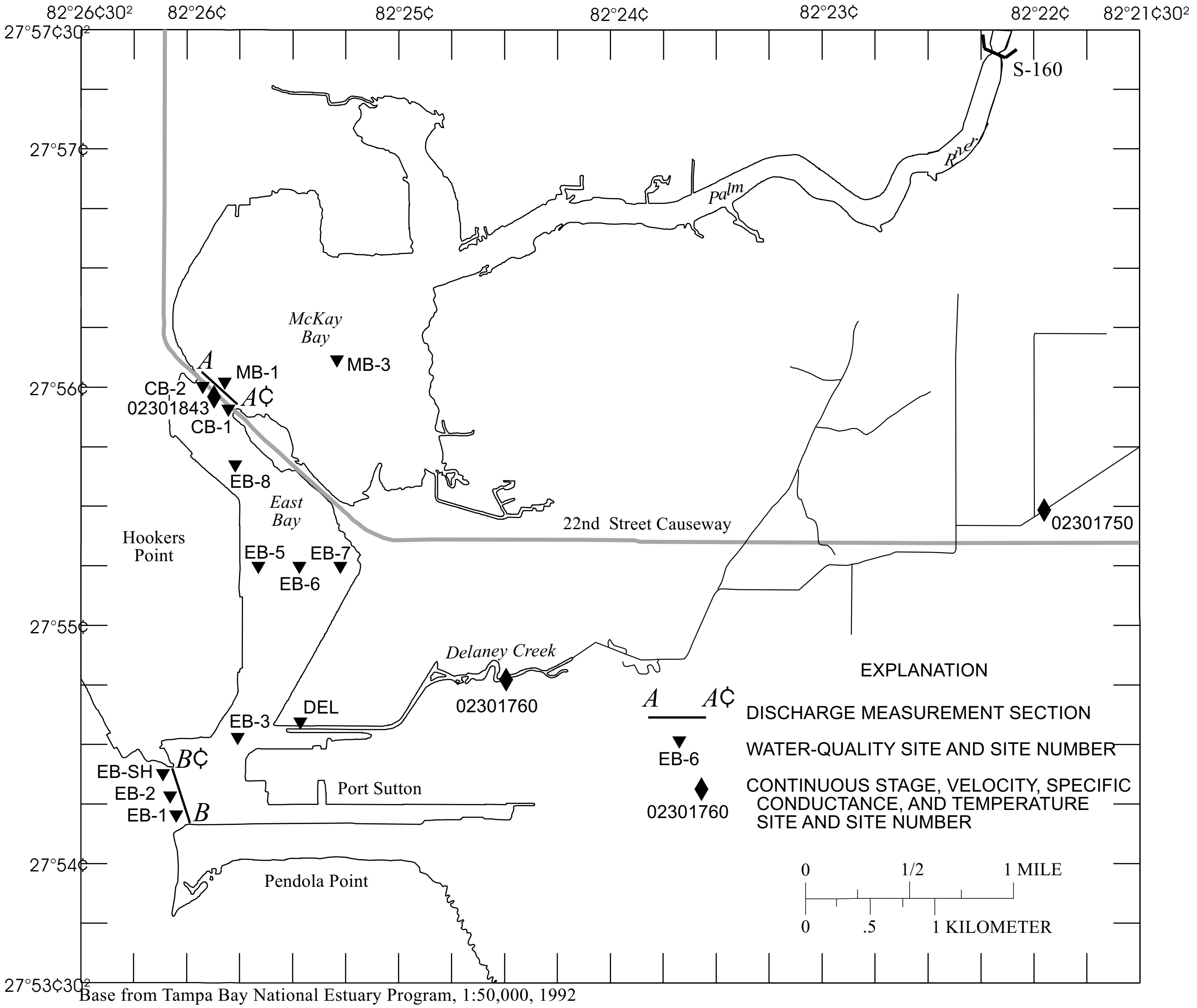
Discharge

Discharges from East Bay include discharges from McKay Bay and Delaney Creek, as well as discharge from the basin surrounding East Bay. Therefore, discharge was computed for three sites in the study area: (1) McKay Bay, (2) Delaney Creek, and (3) East Bay at the mouth. The discharge-measurement and computation methods used at each site varied because of characteristics at each site. The following sections provide details on methods used to measure and compute discharge at each of the study sites.

McKay Bay

Water level at McKay Bay is tidally affected, so standard stage-discharge-rating methods could not be used to compute continuous discharge. However, a stage-velocity-discharge relation can be used to compute discharge in tidally affected waters. In this type of discharge computation, stage is related to the cross- section area, and an index velocity (velocity in a portion of the cross section) is related to the mean velocity in the cross section. Once these relations are established, discharge can be computed by multiplying the mean velocity by the area (Rantz and others, 1982).

Index velocity and stage gages were established at McKay Bay at the 22nd Street Causeway Bridge (site 02301843, fig. 4). An acoustic velocity meter (AVM) was used to measure the index velocity. Two sets of AVM transducers were used in a cross-path configuration, with a path length of about 92.5 ft at an angle of about 40 degrees to the flow direction (fig. 5). The four AVM transducers were about 6 ft above the channel bottom. Stage was measured using a pressure transducer mounted inside a 2-in. pipe that had below-surface perforations. The pipe was used to dampen the effects of



Base from Tampa Bay National Estuary Program, 1:50,000, 1992
Universal Transverse Mercator, Zone 17

Figure 4. Location of water-quality sampling sites and continuous-record sites in McKay Bay, Delaney Creek, and East Bay.

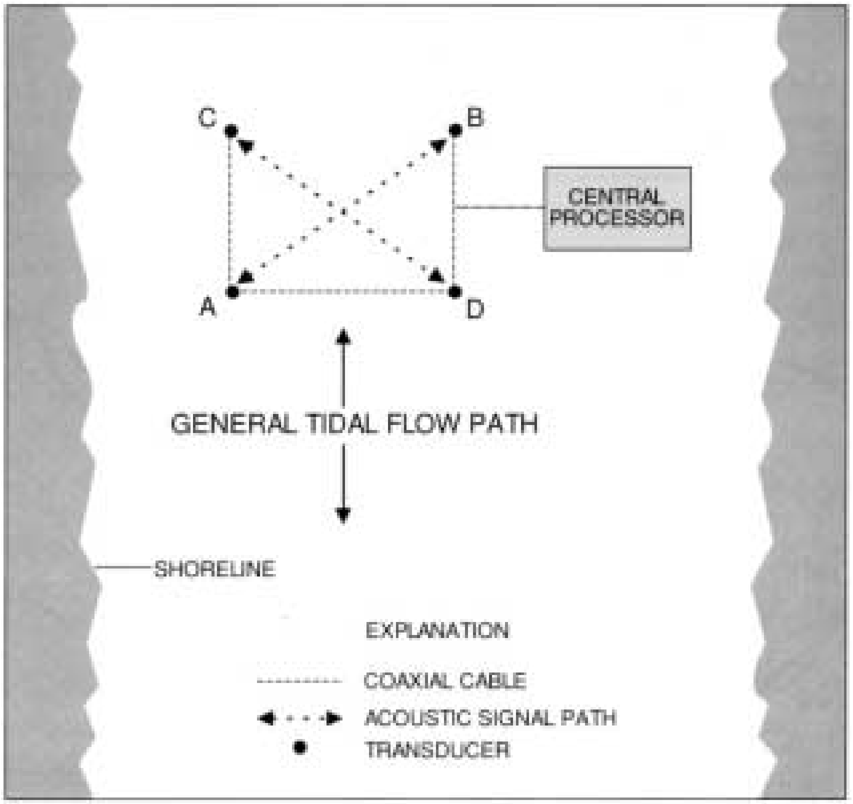


Figure 5. Generalized configuration of the index velocity gage at McKay Bay at 22nd Street Causeway.

surface waves on pressure measurements. Pressure measurements were converted to elevation, in feet above sea level. The recording interval at each gage was 15 minutes.

Discharge measurements were used to develop the index velocity-mean velocity rating and stage-area rating for McKay Bay. Discharge measurements were made over a range of tide and freshwater inflow conditions. Discharge measurements at McKay Bay were made using a Broad Band Acoustic Doppler Current Profiler (BBADCP). The BBADCP uses an acoustic Doppler technique to measure vertical profiles of water currents and is operated from a moving boat. Discharge is computed using computer software. This technique for measuring discharge in estuaries is described in Simpson and Oltmann, 1992. The measurement section at the 22nd Street Causeway Bridge was located in McKay Bay about 200 ft upestuary from the bridge (section A-A', fig. 4) and was characterized by a mostly sand and mud bottom with little or no vegetation. The measurement cross section had a gradually sloping bottom with a small (about a 100-ft section) steeper sloped channel near the center of the cross section. The average depth and length of the measurement cross section was about 9 ft and 1,400 ft, respectively. The right edge of water (looking down-estuary) was confined by a concrete wall; the average depth of water at the right edge was 2 ft. The left edge of water was confined by a concrete wall; the average depth of water at the left edge was less than 1 ft. The length of the cross section that was measured using the BBADCP was approximately 1,100 ft, with starting and ending points located in approximately 6 ft of water. A total of 101 individual measurements were made on seven separate days between June 16, 1992, and March 8, 1993. Measurements made on March 8, 1993, were not used to develop the index velocity-mean velocity rating because the index velocity gage malfunctioned on that day.

One index velocity-mean velocity rating was developed for McKay Bay. The rating was applied to either AVM path 1 or AVM path 2 to compute the mean velocity. The average velocity of AVM path 1 and AVM path 2 was not used because there were periods of missing record for each path. If discharge could only be computed when both paths were operational, then the discharge record during the study would have been less than the record computed using a rating that was valid for each path. One stage-area rating was developed for discharge computations at McKay Bay. Two fathometer transects and field surveying were used to define the stage-area rating.

AVM equipment failures were responsible for a significant loss of index-velocity data at McKay Bay during the study. The principle cause of failure was related to the submerged acoustic transducers filling with water. The leaking transducers were probably caused by fish pecking at barnacles on the cables that went into the transducers, causing water to seep into the cable and contact the transducer terminal strip. The saline water provided an electrical path between the terminals within the transducer body, causing a failure of the acoustic transducer. As a result of lost data, only one AVM path was used to calculate discharge for any given time period.

The index velocity-mean velocity rating and the stage-area rating were used to compute discharge at McKay Bay. During periods when both AVM paths were operational, AVM path 2 was used to compute discharge. Discharge values were computed for each 15-minute interval recorded at the gages (“instantaneous” discharge in this report). The instantaneous discharge was highly variable because of the effects of tide. A low-pass digital filter called the Godin filter was used to remove short-term variations in the data caused by tide (Walters and Heston, 1982). Because the duration of a full-tide cycle is longer than a day, removal of the variations in the data caused by tide allows a more accurate computation of daily mean values.

Delaney Creek

Delaney Creek drains about 21.5 mi^2 and empties into eastern East Bay (fig. 4). A long-term USGS discharge gage is located on Delaney Creek at a nontidally affected site (site 02301750 in fig. 4). This gage represents about 75 percent of the total drainage basin of Delaney Creek. Because an accurate estimate of total discharge from Delaney Creek was needed for load computations for this study, a gage was established near the mouth of Delaney Creek and represents discharge from about 96 percent of the Delaney Creek basin. Because of tide effects at this gage, a stage-velocity-discharge rating was established at the gage for the computation of discharge.

Index velocity and stage gages were established about 1.2 mi upstream of the mouth of Delaney Creek (site 02301760, fig. 4). An electromagnetic velocity (EMV) meter was used to measure the index velocity. The EMV measured velocity in an area less than 1 square foot (ft^2) and was located approximately 3 ft above the channel bottom. Stage was measured using a pressure transducer mounted inside a 2-in. pipe. The recording interval at each gage was 15 minutes.

Discharge measurements at Delaney Creek were made using a conventional current-meter method using a low-velocity AA-Price current meter (Rantz and others, 1982). The measurement section was located about 75 ft downstream of the gage and was characterized by a sand and mud bottom with no vegetation. The creek bank was relatively steep, and the cross section bottom configuration was a rounded “U” shape. Average depth in the cross section was about 4 ft. A total of 54 individual discharge measurements were made at Delaney Creek on 9 separate days between September 3, 1992, and July 13, 1993.

One index velocity-mean velocity rating was developed for Delaney Creek. Fifty-two measurements were used to develop the index velocity-mean velocity rating, with two measurements disregarded because the index velocities recorded during the measurements were much lower than expected, possibly due to debris temporarily enveloping the sensor. Three measurements made later in the same day were not affected by the debris and were included in the rating. Fifty-three measurements were used to develop the stage-area rating, with one measurement disregarded because of poor measurement conditions (a large change in stage during the measurement).

The index velocity-mean velocity rating and the stage-area rating were used to compute discharge at Delaney Creek. The stage-area rating was adjusted during selected periods to account for scour and fill that occurred at the measurement cross section, but the index velocity-mean velocity rating was stable throughout the study period. Analyses of the stage-area rating indicated that bottom scour occurred during periods of higher freshwater discharges in the wet season, whereas bottom fill occurred during extended periods of lower freshwater discharge and increased specific conductance. Discharge values were computed for each 15-minute interval recorded at the gages. The Godin filter was used to remove short-term, tidal variations in the data before daily mean values were computed.

East Bay

Discharge from East Bay could not be measured the same way as at McKay Bay because of logistical problems caused by the shipping activities at the mouth of East Bay. The depth of the shipping channel (about 45 to 50 ft), the frequency of shipping traffic, and the lack of existing structures that could be used to mount velocity and stage gages in the main channel prevented the establishment of a permanent gage at the mouth of East Bay.

Early in the project, an attempt was made to relate discharge measurements made at the mouth of East Bay to the index velocity and stage gages at McKay Bay. The discharge measurement section at the mouth of East Bay was located between an undeveloped point of land at the southern end of Hookers Point and the northwestern edge of Pendola Point (section B-B’, fig. 4). The measurement section was approximately 1,300 ft in length with a total section width of approximately 1,600 ft and depths ranging from less than 1 ft on the northern edge to about 50 ft in the middle of the shipping channel. The bottom was characterized by a sand and mud bottom with no vegetation, and the measurement cross section had a gradual slope from the northern edge of the measurement section to the shipping channel where the bottom changed to a steeply sloped “U” shaped bottom that continued to the southern edge.

Analyses of approximately 70 discharge measurements made during 4 days showed that complex flow patterns occur near the mouth of East Bay. These patterns will be discussed in the following section of the report. Because of the occurrence of complex flow patterns in East Bay, the attempt to develop ratings based on gages located in McKay Bay was discontinued.

Discharge from East Bay at the mouth was estimated from the discharges computed for McKay Bay and Delaney Creek and from local rainfall. For days when no rainfall occurred, discharge from East Bay was estimated by summing the instantaneous discharges (15-minute interval) from McKay Bay and adjusted instantaneous discharges from Delaney Creek. Delaney Creek discharges were increased by a factor of 1.042 to account for the 4 percent ungaged basin area. Ground-water discharges were not estimated. Discharges were summed without any correction for phase differences because phase differences between McKay Bay and Delaney Creek were variable and generally of short duration.

For days when rainfall occurred locally, estimated discharges for East Bay were adjusted for rainfall. Rainfall data collected by the city of Tampa at Hookers Point were used in the computation. Estimated instantaneous discharges for East Bay were filtered using the Godin filter before daily mean values were computed.

Water Quality

Water-quality samples were collected early in the study to evaluate potential water-quality variations in East Bay and lower McKay Bay and to provide information to guide design of the data-collection network to be used for the remainder of the study. Samples were collected on October 10, 1991, and October 29–30, 1991. Water samples, collected at selected depths at sites shown in figure 4, were analyzed for unfiltered nutrients (ammonia nitrogen, ammonia plus organic nitrogen, nitrite nitrogen, nitrite plus nitrate nitrogen, phosphorus, and orthophosphorus), turbidity, suspended solids, color (October 29–30, 1991, only), and specific conductance. Field measurements of specific conductance, pH, water temperature, and dissolved oxygen were made at intervals sufficient to describe vertical variability.

Based on the results of the analyses of these water-quality samples, sites were selected in three general locations for more in-depth study: near the mouth of East Bay, near the mouth of Delaney Creek, and at the head of East Bay at the 22nd Street Causeway Bridge (McKay Bay) (fig. 4). Samples at East Bay (sites EB-1 and EB-2) and McKay Bay (sites CB-1 and CB-2) were collected near the surface and near the bottom and were depth integrated at Delaney Creek (site DEL) and at a site located in shallow water near the mouth of East Bay (site EB-SH). Samples were collected from June 1992 to May 1993 at sites EB-1, EB-2, CB-1, and CB-2 at approximately 2-week intervals and at two different times on each day of sample collection. Sampling frequencies during the wet season increased to approximately 10-day intervals, and the number of sampling sites was increased to include mid-depth samples at EB-1 and EB-2, and depth-integrated samples at site EB-SH. Water samples for unfiltered nutrients, turbidity, suspended solids, color, and specific conductance were collected, and field measurements of water temperature, pH, dissolved oxygen, specific conductance, and Secchi disk transparency were made at the time of sampling. All water-quality samples were analyzed at the USGS laboratory in Ocala, Fla. The analytical methods are documented in Fishman and Friedman, 1989.

About 20 percent of the water samples collected were field quality-assurance samples. Three types of quality-assurance samples were collected: (1) duplicate samples, (2) blind reference samples, and (3) blanks. Field quality-assurance samples were sent to the laboratory with the routine samples.

To determine the variation in specific conductance and temperature at the discharge gaging sites, specific conductance and temperature were recorded at McKay Bay at the 22nd Street Causeway Bridge (site 02301843) and at Delaney Creek near Port Sutton (site 02301760 (fig. 4). Probes were installed about 1 ft and 6 ft from the bottom at McKay Bay and about 3 ft from the bottom at Delaney Creek; data were recorded at 15-minute intervals.

Nutrient Loads

Constituent load is a measure of the amount of a constituent that is transported in water during a specified time interval. The load is expressed as a weight per unit time, such as pounds per day, or tons per year. The constituent load at any given time can be determined if the constituent concentration and the discharge at the time of sampling is known. In this report, this load is called the measured load and is computed as follows:

$$L = C \times Q \times 0.002697$$

where

L is the constituent load, in short tons per day;

C is the constituent concentration, in milligrams per liter;

Q is discharge, in cubic feet per second; and

0.002697 is a conversion factor.

DISCHARGE CHARACTERISTICS OF MCKAY BAY, DELANEY CREEK, AND EAST BAY

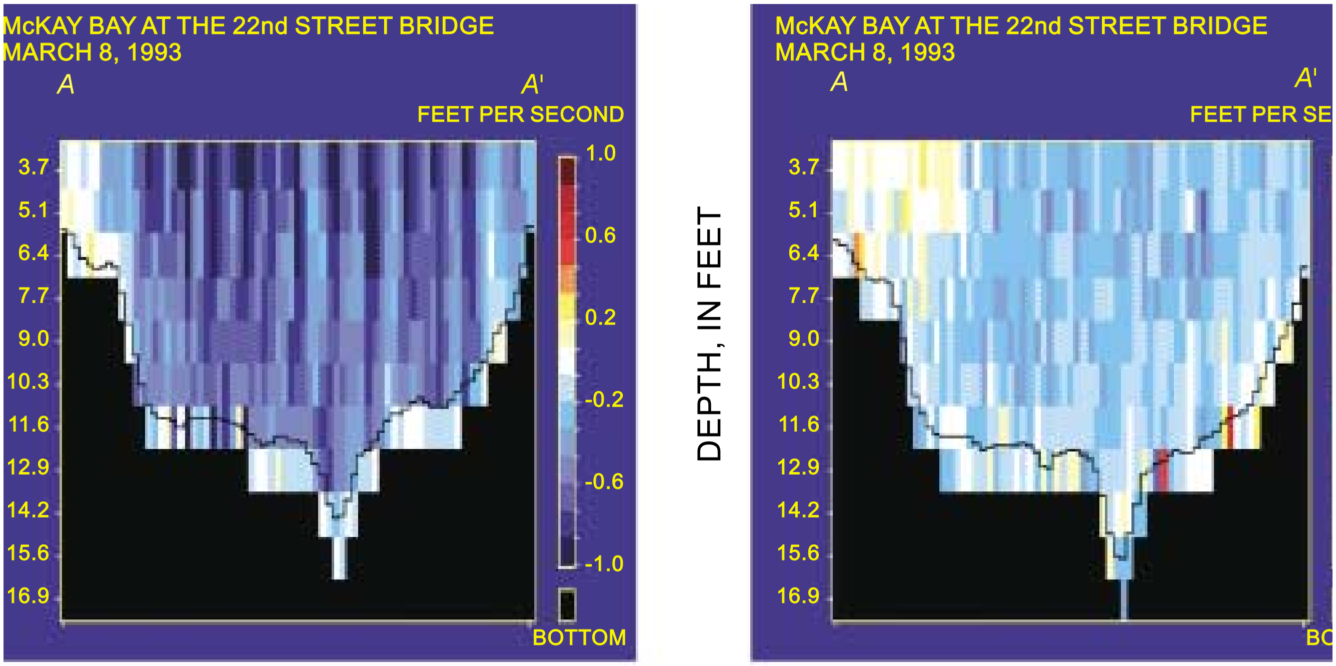
Discharge characteristics of the three water bodies in this study (McKay Bay, a shallow estuarine bay; Delaney Creek, a small tidal creek; and East Bay, an artificially deepened estuarine bay) were analyzed to determine net discharges from the East Bay system and to improve the techniques for measuring discharge in estuarine systems. In the following section, flow patterns in McKay Bay, Delaney Creek, and East Bay determined during discharge measurements are described. Instantaneous, daily mean, and seasonal discharges are described and compared with rainfall and freshwater inflow patterns. Because constituent loads are dependent on the transport of water, an understanding of discharge characteristics is needed to characterize constituent loads.

McKay Bay

Tidal fluctuations are the dominant forces that affect flow patterns in McKay Bay. Flow reversals occur daily and correspond to flood and ebb patterns. The constant variations in flow caused by tide can result in large errors for a discharge measurement when the measurement takes too long to complete. These errors are caused by large changes in velocity and cross-sectional area during the measurement. However, discharge measurements made with the BBADCP generally took only about 7 to 9 minutes to complete. Therefore, errors caused by variations in velocity and area during the discharge measurement were minimal.

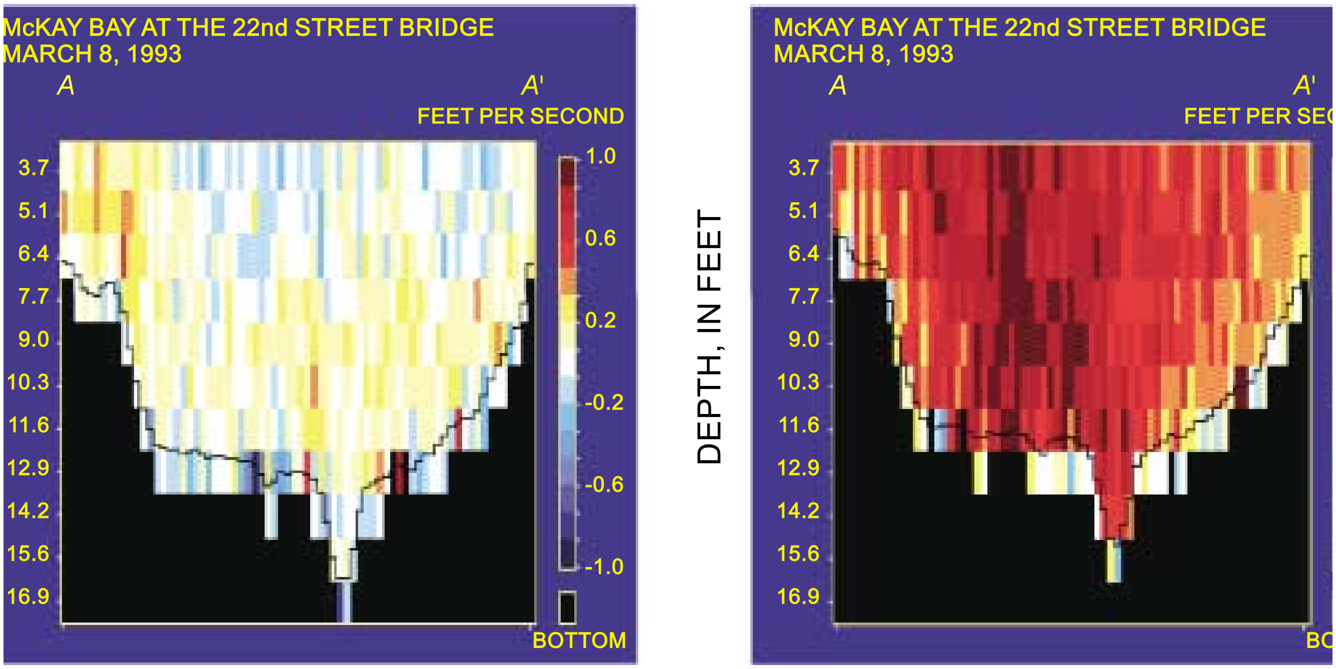
Discharge measurements made during the study at McKay Bay at the 22nd Street Causeway Bridge (cross section A-A’, fig. 4) showed that flows generally were unidirectional; either flow at all points in the cross section was upestuary (into McKay Bay) or was downestuary (toward East Bay). Typical flow patterns during flood-, ebb-, and slacktides are shown in figure 6. Flows in cross section A-A’ were upestuary during floodtide (figs. 6a and 6b). Negative discharge and velocity values denote upestuary flow. Flow patterns during flow reversal (fig. 6c) were more complex, but these complex flow patterns were of short duration (about 10 min). Flows were downestuary during ebbtide (fig. 6d). Discharges measured during the study ranged from -12,400 to 10,000 ft^3/s. Mean velocity from the discharge measurements ranged from -1.5 to 1.3 ft/s, and stage ranged from -1.2 to 2.4 ft above sea level. The discharge measurements made with the BBADCP were used to develop an index velocity-mean velocity rating and a stage-area rating for use in the computation of discharge.

Before the ratings were used to compute discharge from McKay Bay, the recorded stage and index velocity data were examined. Erroneous data were identified and deleted prior to discharge computations. The stage during the study generally ranged from about -2.2 to 3.9 ft above sea level; however, an unusually high stage of about 5.8 ft above sea level occurred on March 13, 1993, at this site. This high stage was caused by strong westerly winds associated with an extremely strong cold front. This cold front resulted in coastal flooding over much of central Florida. Typical variations in stage and the maximum stage measured during the study are shown in figure 7. Typical variations in stage occurred during March 1 through 12, and the maximum stage occurred on March 13. Tide patterns were affected by the March 13 storm for about 1 week. The long-term



. Floodtide, 11:15 am
Total discharge = -8,140 ft^3/s

B. Floodtide, 12:15 am
Total discharge = -2,820



. Slacktide, 2:45 pm
Total discharge = 850 ft^3/s

D. Ebbtide, 5:00 pm
Total discharge = 9,820

Figure 6. Current profiles near McKay Bay at 22nd Street Causeway during selected tide conditions on March 8,

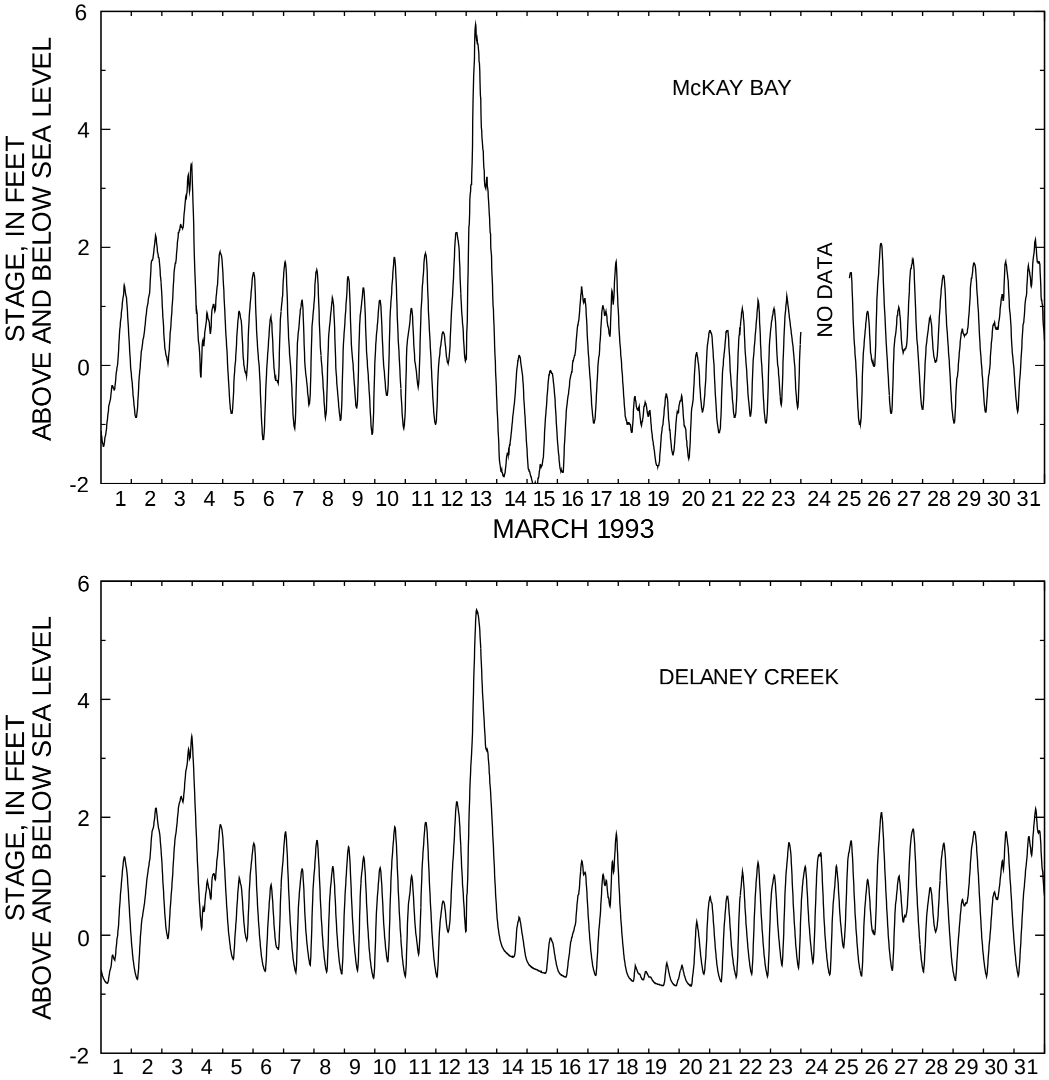


Figure 7. Variations in stage at McKay Bay and Delaney Creek during March 1993.

effects of this storm on tide patterns might be related to a large seiche in Tampa Bay or possibly the Gulf of Mexico that was caused by the extreme high tide on March 13, 1993.

The index velocities recorded for AVM path 1 and AVM path 2 were used in the computation of discharge. Instantaneous velocities ranged from about -4 to 4 ft/s and typically were between -1.5 to 1.5 ft/s. Maximum velocities (both up- and downestuary) occurred during periods of rapid change in stage (fig. 8). Minimum velocities occurred near slacktide conditions.

Instantaneous discharge (15-minute interval) for McKay Bay was computed from the index velocity-mean velocity and stage-area ratings. Instantaneous discharge from McKay Bay for the study period ranged from about -16,900 to 24,000 ft^3/s. As with instantaneous stage and velocity, large short-term variations in discharge were caused by tidal fluctuations. These large tidal variations in discharge obscured variations that were caused by freshwater inflows to McKay Bay.

The instantaneous discharges were digitally filtered with the Godin filter to remove the tidal variations. The Godin filter, a low-pass digital filter, completely eliminates the diurnal and higher frequency patterns in the discharge data. An undesirable effect of the filter is that it also attenuates, or lessens the magnitude of patterns with a lower frequency, such as 2- to 4-day periods (Walters and Heston, 1982). The filtered data represents the residual or net patterns in the discharge data that occur independent of tidal variations. Once filtered, a daily mean net discharge value can be computed. Variations in instantaneous discharge, filtered discharge, and

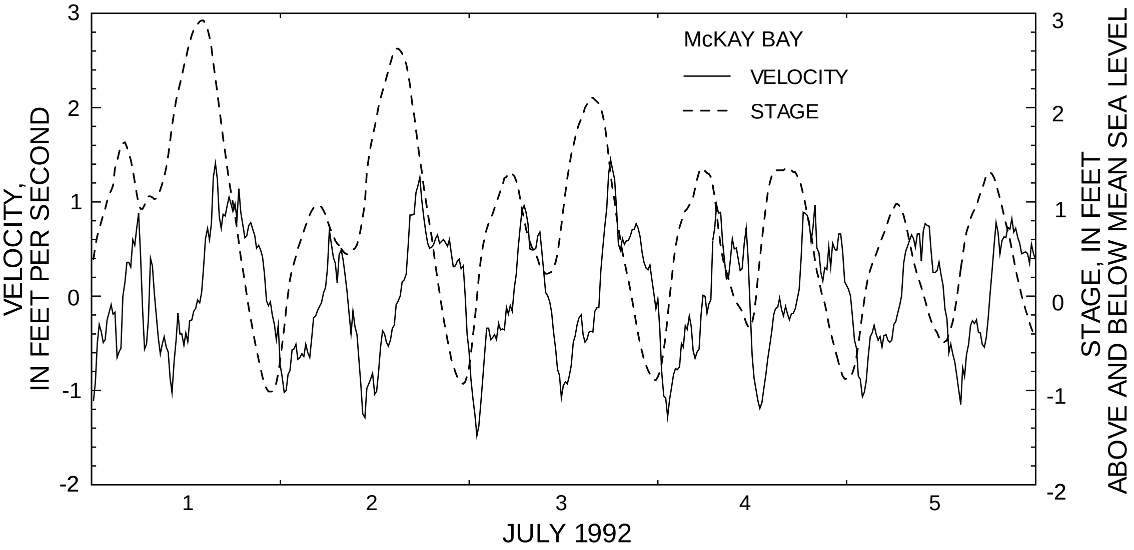


Figure 8. Velocity and stage at McKay Bay at 22nd Street Causeway during July 1–5, 1992.

instantaneous gage height during July 1–3, 1992, are shown in figure 9. The instantaneous discharge varied from about -14,000 ft^3/s to 14,000 ft^3/s, and it is difficult to see the freshwater inflow component in the data. Once variations caused by tide were removed, the net discharges represent the freshwater inflow. Net discharges for July 1–3, 1992, ranged from about 900 ft^3/s to 1,460 ft^3/s. All net discharges are positive or toward East Bay during this period.

The Godin filter was applied to all instantaneous discharges computed for McKay Bay during the study. Filtered discharges were used to compute net daily mean discharges for June 1992 through May 1993. Daily mean discharges from McKay Bay generally were positive (toward East Bay) during June 1992 through August 1992 and during late March 1993 through May 1993 (fig. 10). Large periods of missing record occurred in October 1992 and January through March 1993. Errors in the AVM velocity data were the main cause of missing record. Daily mean discharges during September 1992 through January 1993 at times were negative. Negative discharges indicate that net flows were into McKay Bay from East Bay. Daily mean discharges ranged from -1,900 ft^3/s to 2,420 ft^3/s with a mean of 664 ft^3/s.

Sources of freshwater inflow to McKay Bay are the Tampa Bypass Canal, several small drainage canals, rainfall, and the Falkenburg wastewater treatment plant. The Falkenburg wastewater treatment plant discharges approximately 2 ft^3/s (Hillsborough County Department of Wastewater Utilities, 1993, written commun.). Much of the daily mean discharge from McKay Bay is caused by freshwater inflow from the Tampa Bypass Canal (fig. 10). During the study, skimmer discharge from the Tampa Bypass Canal at Structure 160 (S-160) ranged from 34.3 to 1,080 ft^3/s with a median discharge of 129 ft^3/s, and a mean discharge of 190 ft^3/s (Richard Lee, Southwest Florida Water Management District, written commun., 1994). However, skimmer discharge does not include discharge as a result of periodic lift-gate operations, leakage from the structure, or variations in individual skimmer gate elevations. Skimmer discharge represents less than total discharge from the Tampa Bypass Canal. The negative daily mean discharges from McKay Bay generally correspond to extended periods of limited discharge from the Tampa Bypass Canal and low rainfall (figs. 3 and 10).

Analyses of the filtered discharge data indicated that there was some uncertainty in accurately gaging net discharges using a short distance AVM cross path. Two sources of error in the determination of discharge were the uncertainty in the index velocity-mean velocity rating and the large cross-sectional area of the measurement sections (about 15,000 to 18,000 ft^2). A small error in mean velocity multiplied by the cross-sectional area could result in a significantly large error in the calculated discharge. The standard error of the index velocity-mean velocity rating was about 0.025 ft/s, which results in an error range in discharge at McKay Bay of about ±375 to

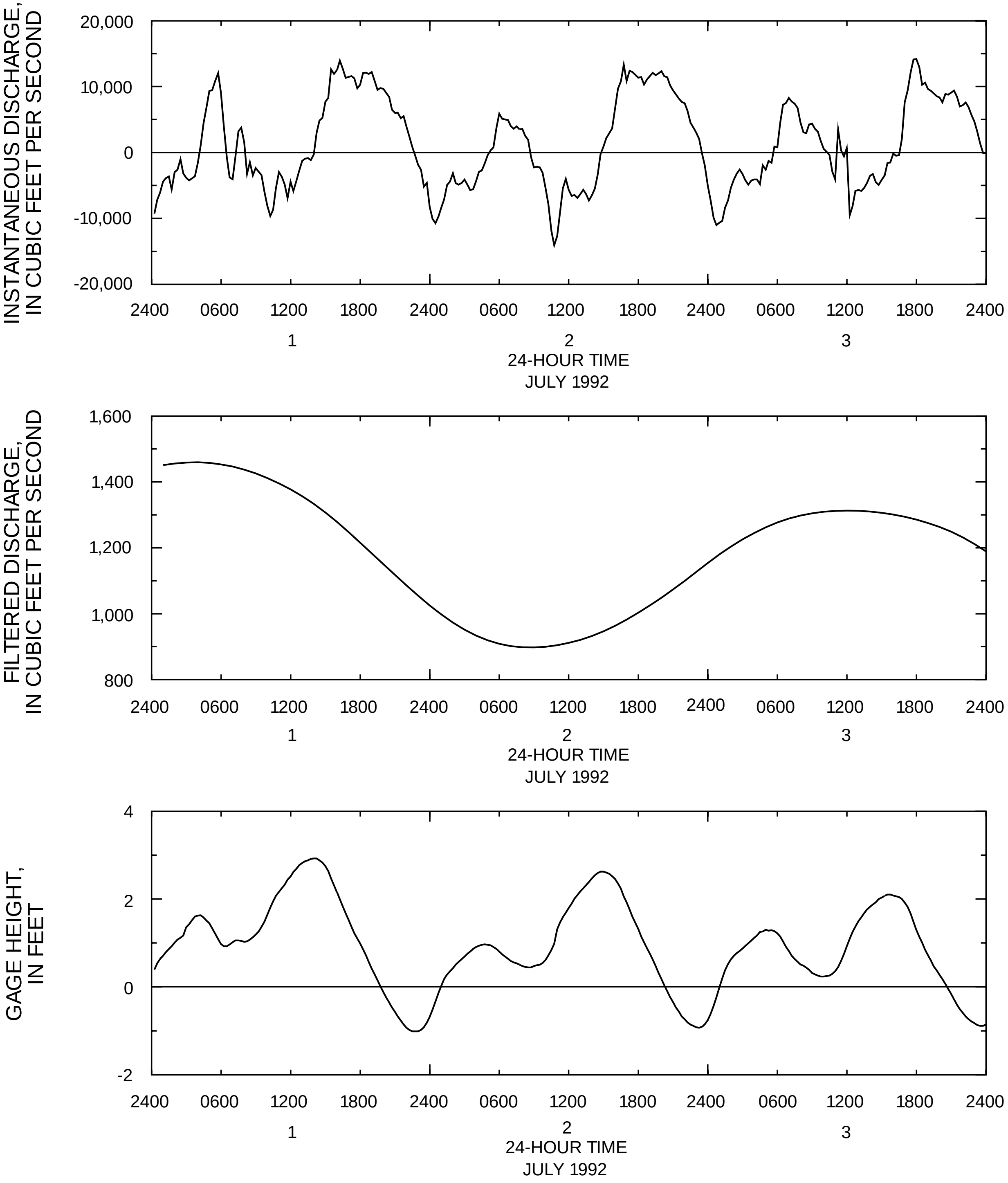


Figure 9. Instantaneous discharge, filtered discharge, and gage height at McKay Bay at 22nd Street Causeway,

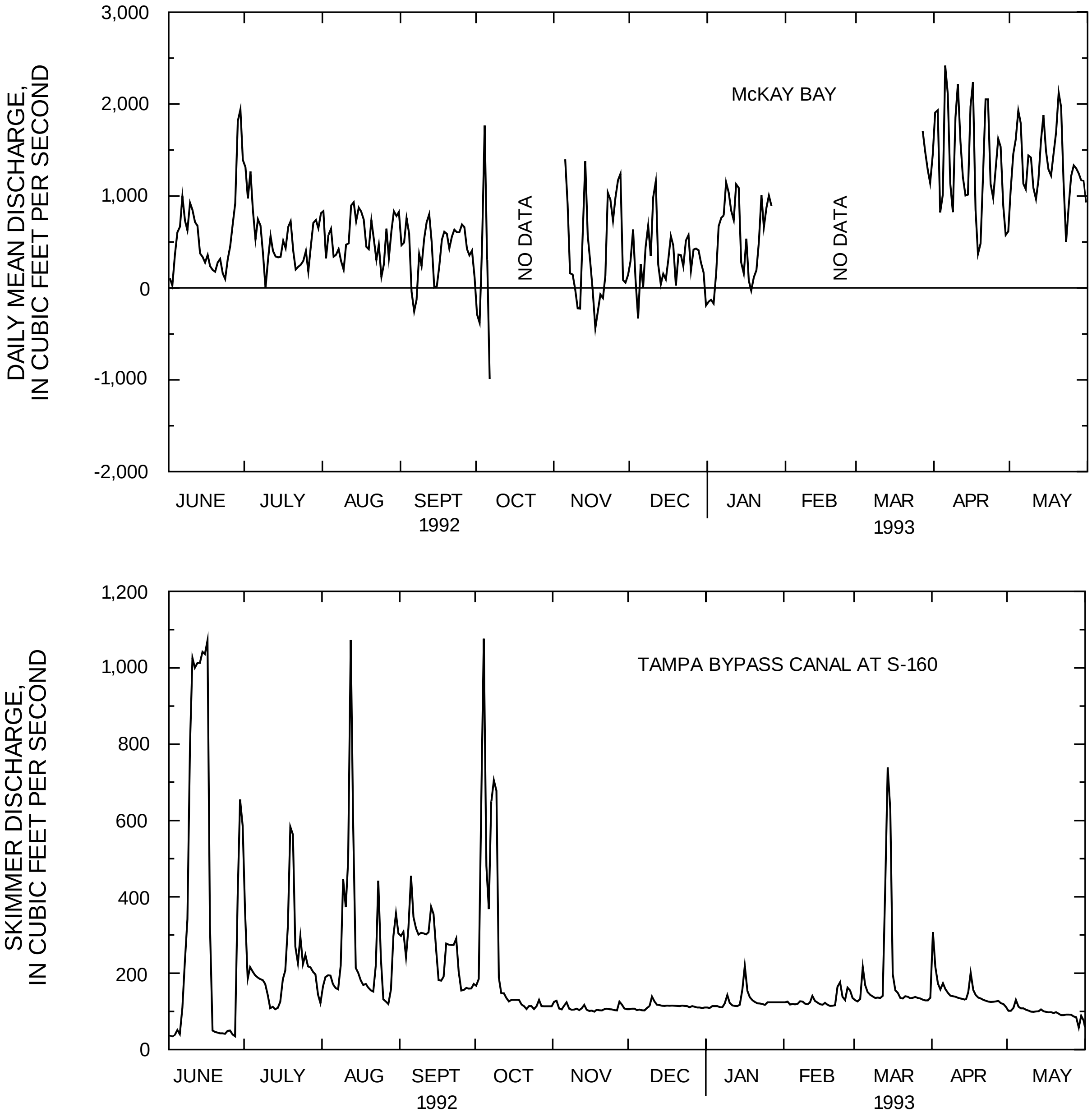


Figure 10. Daily mean discharge at McKay Bay at 22nd Street Causeway and skimmer discharge at the Tampa

±450 ft^3/s (index velocity standard error multiplied by cross-sectional area = standard error of discharge). Errors in gaging discharge in tidally affected areas that have a relatively small net freshwater component and a large cross-sectional area could be reduced by using a more complex system of index velocity measurements such as a longer cross path, several cross paths, or cross paths located at different depths.

Delaney Creek

Discharge near the mouth of Delaney Creek is affected by tide. Discharge measurements made at the gage showed that flows generally were unidirectional during most of the tide cycle. Measured discharge ranged from -50.7 ft^3/s to 61.3 ft^3/s. The discharge measurements were used to develop an index velocity-mean velocity rating and a stage-area rating for the computation of discharge.

Before the ratings were used to compute discharge from Delaney Creek, the recorded stage and index velocity data were examined. Erroneous data were identified and deleted prior to discharge computations. The stage during the study generally ranged from about -1.0 to 3.8 ft above sea level. The maximum stage during the study was about 5.5 ft above sea level and was caused by the March 13, 1993, cold front (fig. 7). Variations in stage at Delaney Creek during March 13 through about March 20 were affected by the March 13 cold front. Instantaneous velocities during the study ranged from about -0.6 to 1.3 ft/s and typically were between -0.5 to 0.5 ft/s. Maximum velocities (both upstream and downstream) occurred during periods of rapid change in stage. Minimum velocities occur near slacktide conditions.

Instantaneous discharge (15-minute interval) for Delaney Creek was computed from the index velocity-mean velocity and stage-area ratings developed from the discharge measurements. Instantaneous discharges ranged from about -325 to +600 ft^3/s during the study. The mean was about 13 ft^3/s during the same period.

The Godin filter was used to remove tidal variations in the discharge data. Once tidal variations were removed, daily mean discharges were computed for Delaney Creek at site 02301760. Daily mean discharges ranged from about -3.8 ft^3/s to 162 ft^3/s. The greatest daily mean discharges from Delaney Creek occurred in June, August, and September 1992, and the least discharges occurred in late October 1992 through mid-January 1993 and in late April through May 1993 (fig. 11). At times, discharges were negative or upstream, indicating that freshwater inflow was zero or negligible during these periods. Daily mean discharges near the mouth of Delaney Creek were compared with the upstream, nontidally affected gage (site 02301750). Discharges near the mouth of the creek sometimes were less than those measured upstream. The apparent loss of flow from Delaney Creek may be caused by storage between the gage locations or diversion of discharge from the creek somewhere between the gage locations. Numerous drainage ditches have been dredged in the lower Delaney Creek basin, and it is possible that some flow may be diverted from the creek. Errors in discharge computations at the downstream gage combined with minimal flows also might be a factor in the difference in discharges between the two gages.

East Bay

Complex flow patterns occur at the mouth of East Bay. Flows generally were vertically stratified and bidirectional, as determined from discharge measurements made at the mouth of East Bay using the BBADCP. Bidirectional flow was observed for every day of measurement and was the result of localized gyres at the mouth of East Bay. Gyres are circulation features that are caused by tide and bottom configuration and result in a spiral pattern of flow. Such spiral flow patterns are described in Dyer, 1979. East Bay was artificially deepened from a depth of about 5 ft to depths of 35 to 40 ft, which is deeper than average water depths for Tampa Bay (about 12 ft). Significantly altered depths adjacent to shallower waters have provided a mechanism that allows the formation of gyres.

Both horizontal and vertical gyres were observed during measurements made near the mouth of East Bay. On one occasion, a large gyre was measured that spanned from about the middle of East Bay to the mouth. Typical bidirectional flows caused by these gyres are shown in figure 12. Flows generally were downestuary during maximum ebbtide discharges on October 18, 1992, but some flows near the bottom of cross section B-B′ were upestuary (fig. 12a). As discharges decreased with changing ebbtide conditions, the bidirectional flow patterns became more prominent (figs. 12a and b). After the tide reversed, bidirectional flow patterns also occurred during floodtide (fig. 12c). During floodtide on July 29, 1992, flows near the left bank were downestuary and flows near the center of the section were upestuary (fig. 12d).

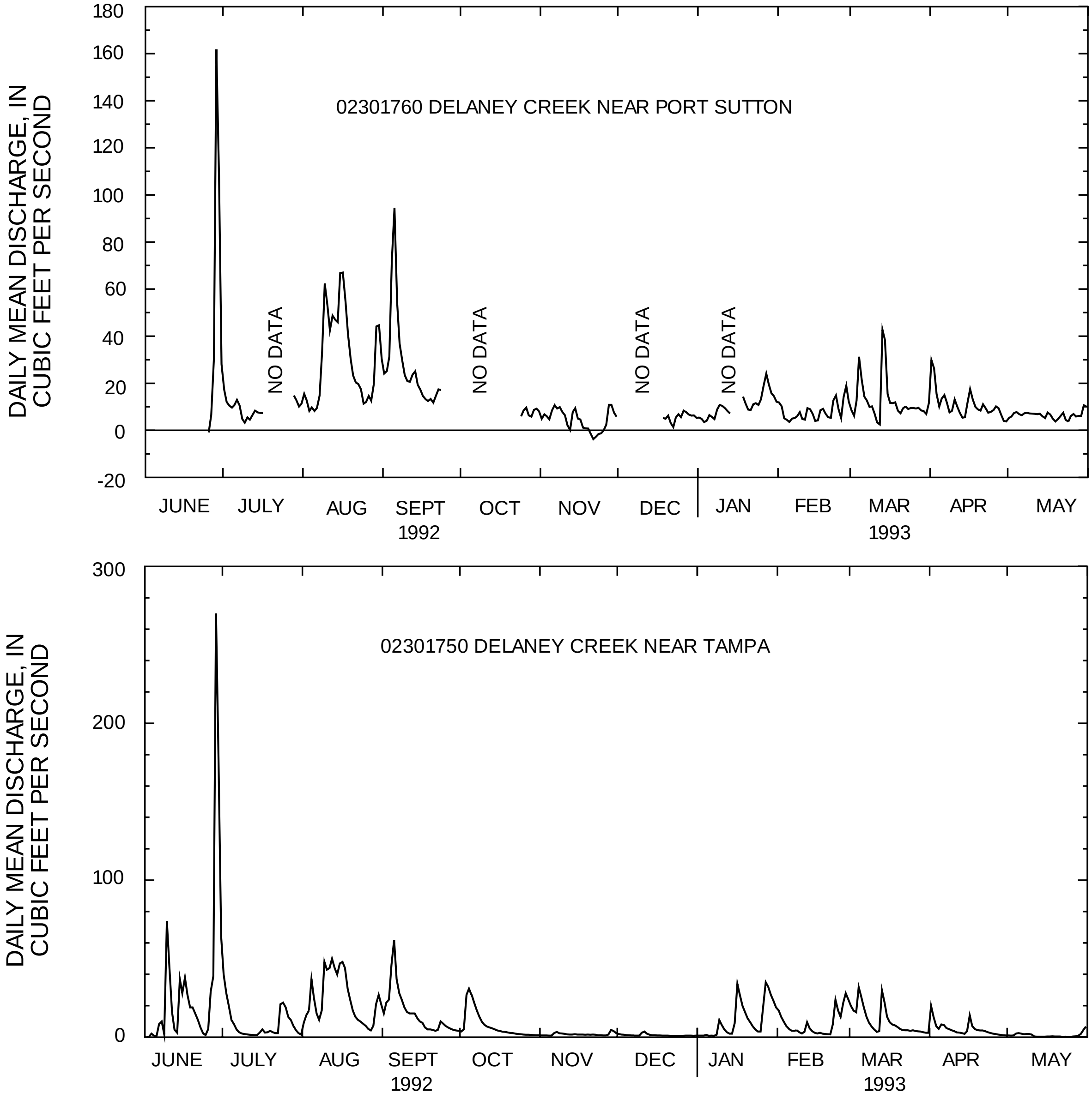
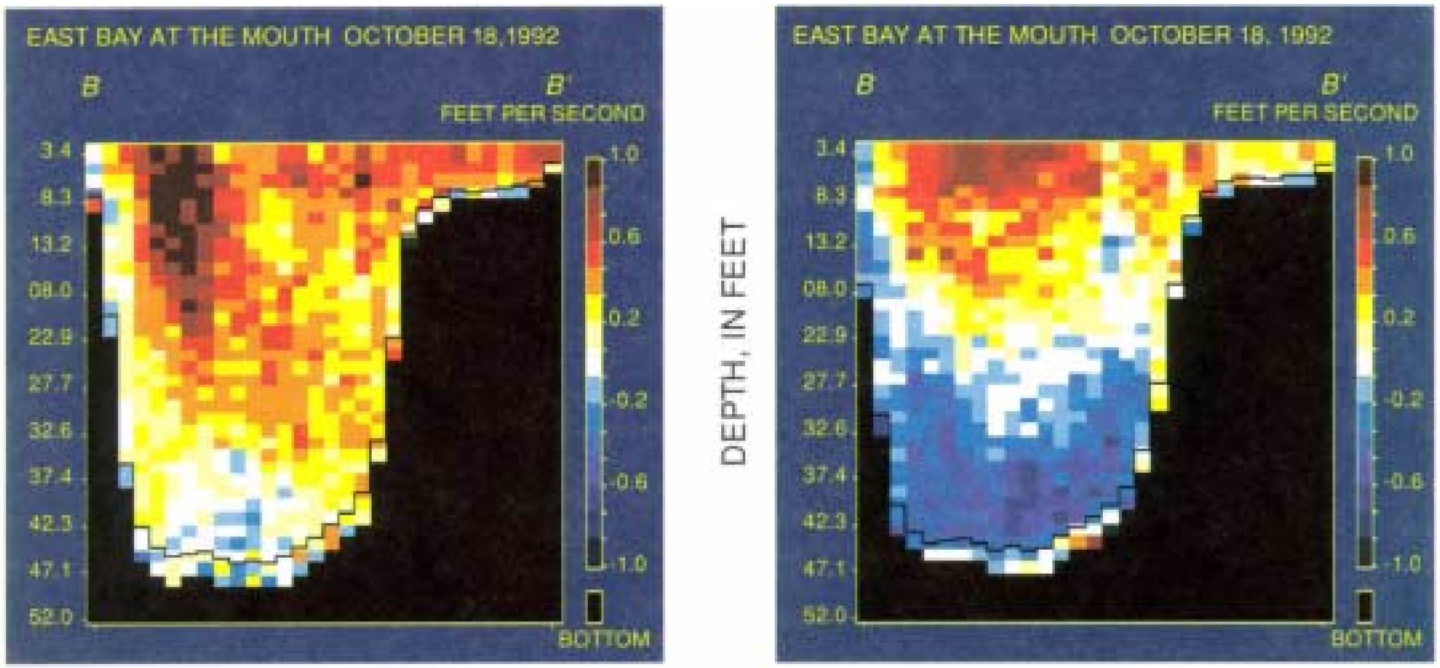
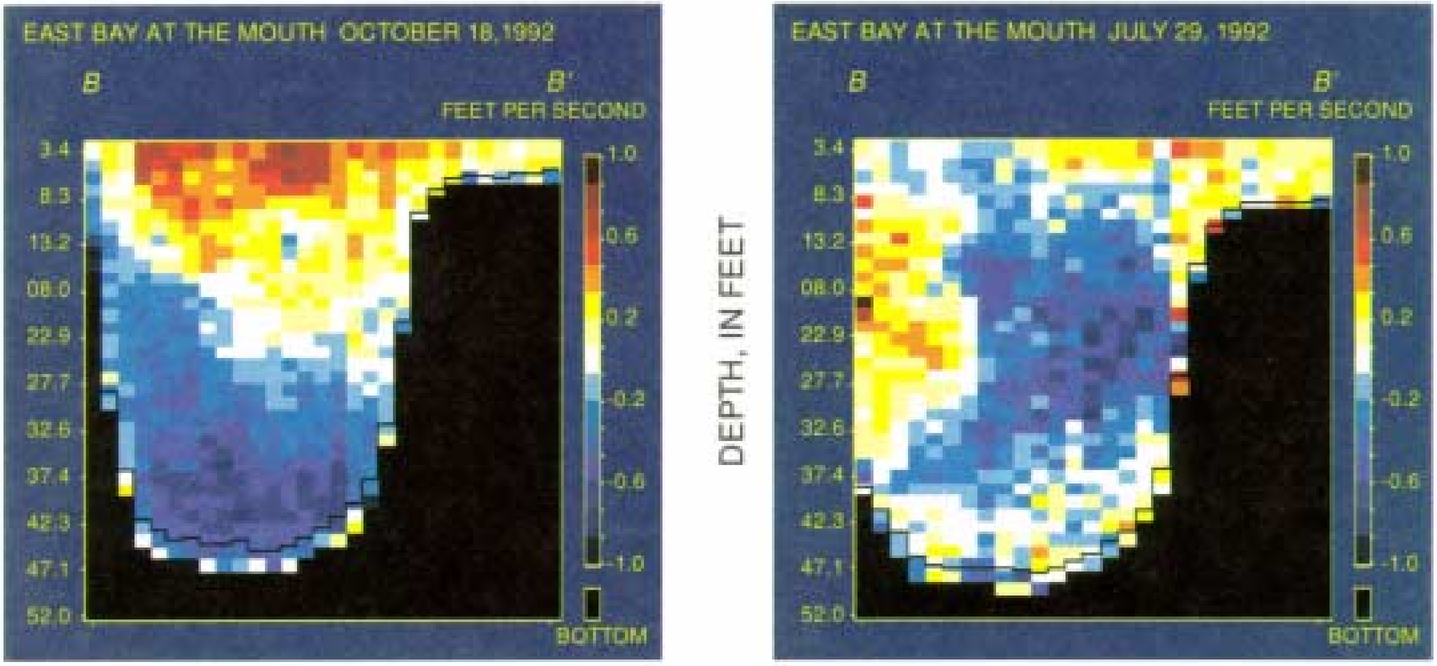


Figure 11. Daily mean discharge at Delaney Creek near Port Sutton and at Delaney Creek near Tampa,



A. Ebbtide, 9:45 am
Total discharge = 14,600

B. Ebbtide, 1:15 pm
Total discharge = 1,720



C. Floodtide, 1:30 pm
Total discharge = -2,250

D. Floodtide, 11:30
Total discharge = -4,700

Figure 12. Current profiles at the mouth of East Bay during selected tide conditions on October 18, 1992, and July 29, 1992.

Because the complex flow patterns found at the mouth of East Bay prevented the development of ratings based on gages at McKay Bay, instantaneous discharges were estimated as described in the Methods section of the report. Several assumptions were used in the estimates of rainfall-generated discharge: (1) all rain falling on the water surface of East Bay stayed in the bay (no evaporation losses), (2) all rain falling in the ungaged part of the basin entered East Bay the same day of the rain (no retention), and (3) all rain falling on the ungaged part of the basin entered the bay (no losses from evaporation or storage). These assumptions were intended to result in an estimate of the maximum discharge that could occur during a day with rain. Instantaneous discharges estimated using rainfall were compared with instantaneous discharges estimated without rain-generated discharge; the differences were minimal and averaged 0.2 percent.

Tidal variations in the instantaneous discharge data were removed with the Godin filter. Daily mean discharges were computed from the net discharges. The daily mean discharges that were estimated with and without rain-generated discharges were compared; differences averaged about 2.5 percent. Therefore, the additional discharge generated by rainfall on ungaged parts of the East Bay basin is negligible. Although the additional discharge is negligible, daily mean discharges used in this report include these rain-generated discharges.

Daily mean discharges from East Bay generally were positive (toward Hillsborough Bay) during late June 1992 through September 1992 and during late March 1993 through May 1993 (fig. 13). Large periods of missing record are the result of missing records at McKay Bay and Delaney Creek. Daily mean discharges during November 1992 through January 1993 were less than during the rest of the study, and discharges at times were negative. Negative discharges indicate that flows were toward McKay Bay. Daily mean discharges ranged from about -437 ft^3/s to 3,780 ft^3/s.

WATER-QUALITY CHARACTERISTICS

Results from the two reconnaissance samplings were assessed to evaluate areal and short-term temporal variations in water quality in East Bay. Samples collected on October 10, 1991, were analyzed and used to evaluate areal variations in water quality in East Bay and at the mouth of Delaney Creek. Results indicated that water in East Bay was well-mixed on October 10, 1991 (table 1). Concentrations of nitrite plus nitrate nitrogen at most sites were below the detection limit of 0.02 mg/L. Concentrations of nitrite nitrogen generally were 0.01 mg/L, phosphorus ranged from 0.37 to 0.49 mg/L, and orthophosphorus ranged from 0.33 to 0.36 mg/L. Concentrations of total phosphorus, orthophosphorus, ammonia nitrogen, ammonia plus organic nitrogen, and nitrite plus nitrate nitrogen, however, were greater near the mouth of Delaney Creek (site DEL) than at any other sampled site. Specific conductance at sampled sites ranged from 33,200 µS/cm near the mouth of Delaney Creek to 38,900 µS/cm near the mouth of East Bay. Vertical stratification was minimal; specific conductance measured near the water surface was about 300 to 1,800 µS/cm less than those measured near the bottom.

Samples collected at about 2-hour intervals during daylight hours near the mouth of East Bay at sites EB-1, EB-2, and EB-SH on October 29 and 30, 1991, were used to evaluate the variations in water quality caused by tidal fluctuation. Water samples were collected near the surface, near the bottom, and at middepth at EB-1 and EB-2 and were depth-integrated at site EB-SH.

Specific conductance of water collected near the surface was about 2,000 µS/cm less than in samples collected near the bottom, indicating a moderate vertical stratification of water quality at the mouth (fig. 14). Turbidity and concentrations of ammonia nitrogen in samples collected near the bottom generally were greater than in those collected from near the surface, whereas, near-surface orthophosphorus concentrations were greater than in water sampled near the bottom. Concentrations of total phosphorus and ammonia plus organic nitrogen varied with depth and time. Concentrations of nitrite plus nitrate generally were below the laboratory method reporting limit.

Analysis of samples collected on October 10 and October 29–30, 1991, indicated that: (1) constituent concentrations and physical measurements (pH and specific conductance) vary vertically in East Bay, (2) Delaney Creek may be an important source of nutrients to East Bay, and (3) concentrations of most constituents varied with fluctuations in tide. Based on these results, sampling for the remainder of the study was designed to evaluate vertical variations in water quality, variations with tide, and areal variations. Samples collected for the remainder of the study were collected at sites EB-1, EB-2, EB-SH, DEL, CB-1, and CB-2 (fig. 4).

Water-quality data collected during the remainder of the study, June 1992 through May 1993, are summarized in table 2. Total nitrogen concentrations at all sites

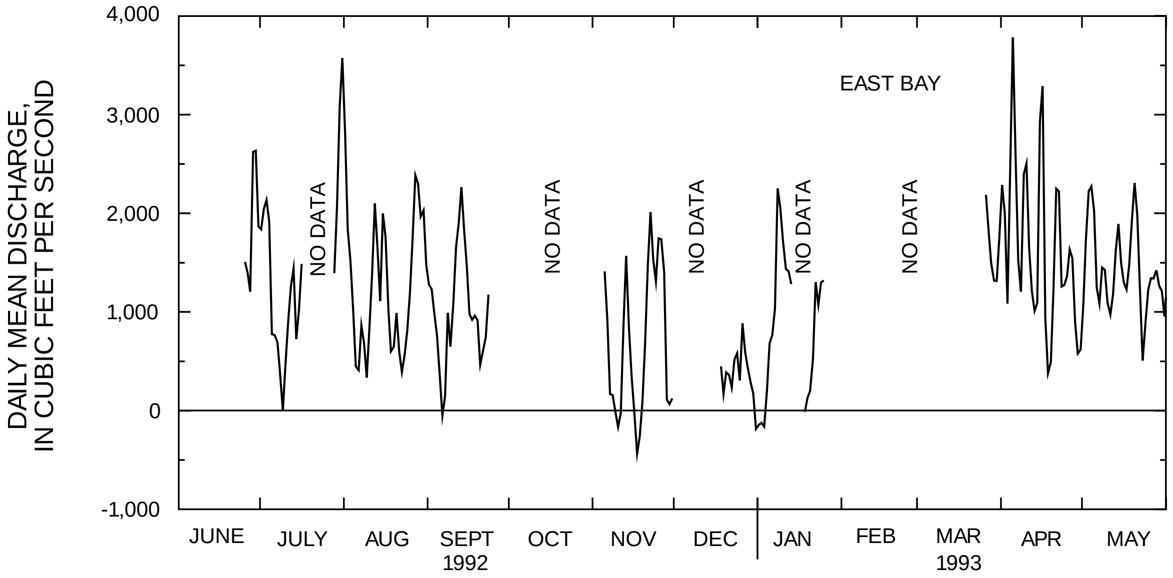


Figure 13. Daily mean discharge at East Bay near the mouth, June 1992 through May 1993.

Table 1. Concentrations of selected water-quality constituents in East Bay, Delaney Creek, and McKay Bay on October 10, 1991

[Concentrations are in milligrams per liter unless otherwise noted; ft, feet; NTU, nephelometric turbidity units; µS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than; site locations are shown on fig. 4]

Site	Time	Depth (ft)	Turbidity (NTU)	Suspended solids	Ammonia	Nitrite	Ammonia plus organic nitrogen	Nitrite plus nitrate	Phosphorus	Orthophosphorus	Specific conductance (µS/cm)
EB-1	1030	1	2.3	10	0.13	0.01	0.67	0.02	0.44	0.36	38,000
EB-1	1045	25	2.6	24	.10	.01	.65	<.02	.39	.33	38,300
EB-2	1115	1	1.3	28	.10	.01	.65	<.02	.39	.35	38,100
EB-2	1125	40	12	57	.07	.01	.85	<.02	.49	.34	38,900
EB-3	1145	1	1.2	23	.11	.01	.56	<.02	.39	.34	37,700
EB-3	1150	40	2.6	20	.08	.01	.66	<.02	.39	.33	38,700
DEL	1215	1.5	2.2	25	.27	.03	.80	.18	.53	.47	33,200
EB-5	1300	1	1.8	6	.08	.01	.70	<.02	.39	.33	36,900
EB-5	1310	30	2.6	9	.08	.01	.60	<.02	.39	.33	38,000
EB-6	1320	1	2.0	19	.08	.01	.75	<.02	.45	.34	36,600
EB-6	1335	33	1.6	25	.09	.01	.69	<.02	.37	.34	38,400
EB-7	1345	1	2.6	11	.09	.01	.63	<.02	.39	.34	36,600
EB-7	1400	35	1.3	29	.09	.01	.69	<.02	.38	.34	38,300
EB-8	1420	1	1.9	9	.07	.01	.69	<.02	.40	.34	36,300
EB-8	1430	36	1.8	10	.09	.01	.62	<.02	.39	.34	38,200
MB-1	1445	--[1]	1.1	6	.10	.01	.82	<.02	.40	.34	37,700
MB-3	1500	--[1]	2.3	13	.09	.01	.66	<.02	.42	.33	37,000

[1] Samples were depth-integrated.

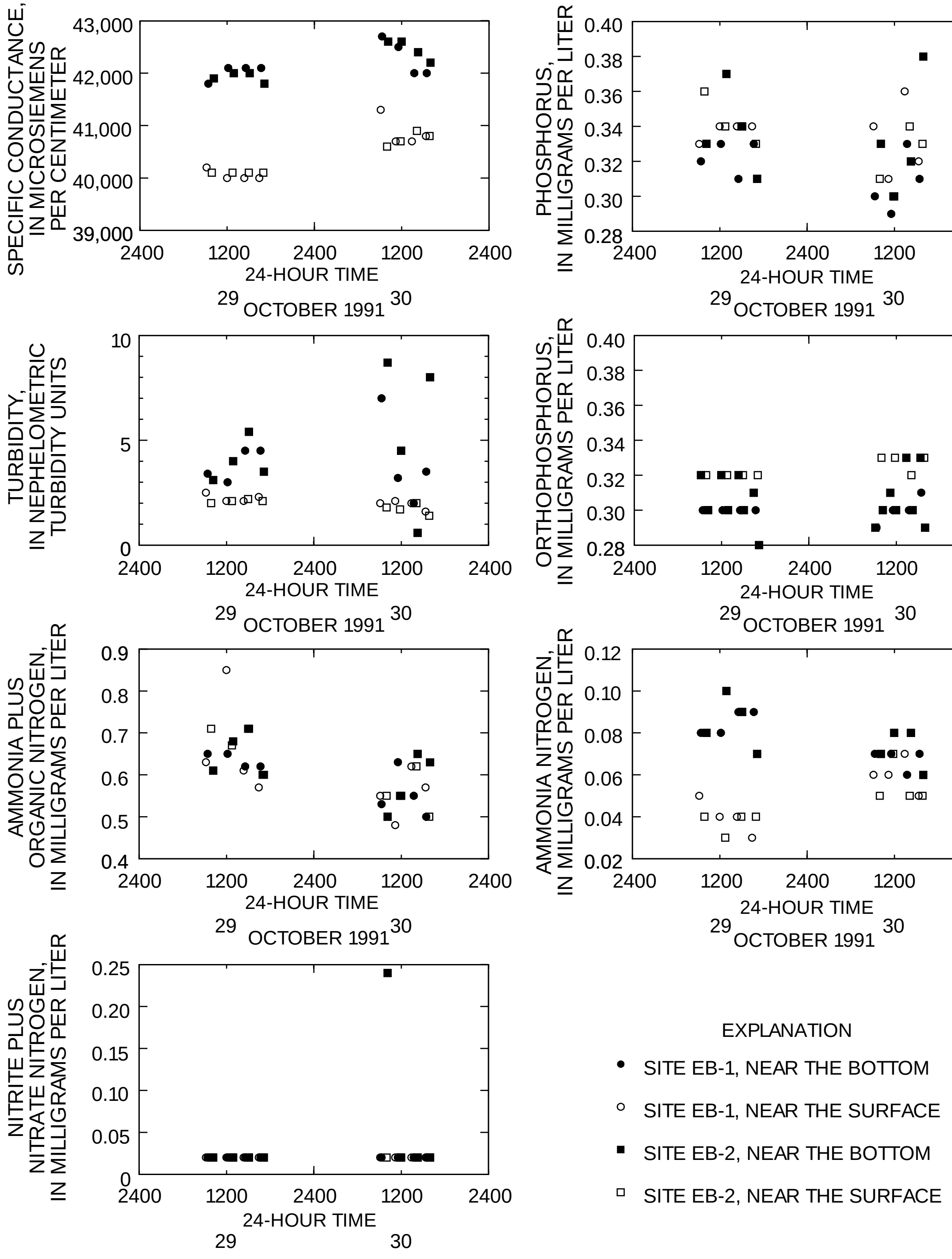


Figure 14. Concentrations of selected constituents at the mouth of East Bay during October 29 and 30, 1991.

Table 2. Summary of selected water-quality constituents at selected sampling sites in East Bay, Delaney Creek, and McKay Bay, June 1992 through May 1993

[Concentrations are in milligrams per liter unless otherwise noted. µS/cm, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; <, less than; N, number of analyses; site locations are shown on fig. 4]

	Specific conductance (µS/cm)	Total nitrogen	Total phosphorus	Ammonia plus organic nitrogen	Ammonia	Nitrite plus nitrate	Nitrite	Orthophosphorus	Turbidity (NTU)	Color (platinum-cobalt units)	Suspended solids
Site EB-1											
Mean	37,900	0.66	0.41	0.64	0.10	[1].0.02	[1].0.01	0.34	5.4	[1]6.8	26.1
Maximum	43,500	1.1	.68	1.1	.26	.12	.03	.56	26	30	92
Minimum	26,400	.25	.25	.23	.03	<.02	<.01	.04	1.0	<5	1.0
N	133	133	133	133	133	133	133	133	133	133	133
Site EB-2											
Mean	37,500	.67	.40	.64	.08	[1].01	[1].01	.34	5.3	[1]6.6	27.9
Maximum	43,300	1.2	.72	1.2	.22	.07	.03	.62	25	20	112
Minimum	26,200	.29	.24	.27	.02	<.02	<.01	.22	1.0	<5	1.0
N	136	136	135	136	136	136	136	136	136	136	135
Site EB-SH											
Mean	35,900	.76	.42	.73	.07	[1].02	[1].01	.38	2.8	[1]8.5	[1]17.6
Maximum	38,300	1.3	.61	1.3	.22	.1	.02	.57	4.7	20	40
Minimum	27,000	.42	.32	.40	.03	<.02	<.01	.26	1.3	<5	<1
N	27	27	27	27	27	27	27	27	27	27	27
Site DEL											
Mean	30,400	1.5	1.1	1.1	.48	[1].38	[1].02	1.0	3.9	19.6	[1]21.4
Maximum	39,600	13	16	9.4	9.4	4.5	.09	15	10	160	82
Minimum	1,650	.38	.25	.35	.02	<.02	<.01	.23	1	5	<1
N	59	59	59	59	59	59	59	59	59	59	59
Site CB-1											
Mean	35,800	.70	.39	.68	.06	[1].01	[1].01	.32	3.7	[1]6.8	24.4
Maximum	42,400	1.1	1.5	1.1	.25	.06	.05	.45	26	20	102
Minimum	28,300	.23	.24	.21	.01	<.02	<.01	.17	1.4	<5	1
N	104	104	103	104	104	104	104	104	104	104	103
Site CB-2											
Mean	35,800	.66	.37	.64	.06	[1].01	[1].01	.32	3.6	[1]6.8	23.4
Maximum	42,500	1.2	.61	1.2	.22	.07	.06	.47	25	20	106
Minimum	28,300	.24	.22	.22	.02	<.02	<.01	.03	1.0	<5	1.0
N	104	104	104	104	104	104	104	104	104	104	104

[1] Mean value is estimated by using a log-probability regression to predict the values of data below the detection limit (Helsel, 1990).

in McKay Bay and East Bay ranged from 0.23 to 1.3 mg/L; and in Delaney Creek near the mouth, concentrations ranged from 0.38 mg/L to 13 mg/L. More than 80 percent of the total nitrogen in McKay Bay and East Bay was in the form of organic nitrogen, and about 10 to 15 percent was in the ammonia form. About 68 percent of the total nitrogen in Delaney Creek was organic nitrogen, and about 18 percent was ammonia. Total phosphorus at all sites in McKay Bay and East Bay ranged from 0.22 mg/L to 1.5 mg/L; and in Delaney Creek, concentrations ranged from 0.25 mg/L to 16 mg/L. Between 85 and 90 percent of the total phosphorus at all sites was orthophosphorus.

Areal Patterns

Average concentrations of selected constituents were computed for each day of sampling. Data for sites EB-1, EB-2, and EB-SH were averaged to represent water-quality conditions at the mouth of East Bay, and data for sites CB-1 and CB-2 were averaged to represent conditions at the head of East Bay. Concentrations of total nitrogen and ammonia plus organic nitrogen were greater at the head of East Bay than at the mouth during much of the study, indicating that McKay Bay is the primary source of nitrogen in East Bay (fig. 15). The difference between concentrations of nitrogen at the head and mouth of East Bay was greater during June through August 1992, and in May 1993, coinciding with periods of greater discharge from McKay Bay to East Bay. Concentrations of total ammonia nitrogen, nitrite plus nitrate nitrogen, phosphorus, orthophosphorus, and suspended solids, as well as the magnitude of turbidity and specific conductance generally were greater at the mouth than at the head of East Bay. Greater ammonia nitrogen, nitrite plus nitrate nitrogen, orthophosphorus, and phosphorus concentrations at the mouth of East Bay may occur because of input of these constituents from Delaney Creek and from shipping activities in the basin.

Water-quality samples collected at the mouth of East Bay indicated that water quality at the mouth varies with depth and location in the cross section. Depth-integrated constituent concentrations at EB-SH were similar to near-surface concentrations at sites EB-1 and EB-2 but were different from near-bottom water quality at these sites (figs. 16 and 17). The similarity between near-surface water quality at EB-1 and EB-2 and depth-integrated water quality at EB-SH is consistent with observations of BBADCP measurements of layered flow at the mouth of East Bay, which would tend to reduce the amount of vertical mixing in the cross section.

Phosphorus and ammonia nitrogen concentrations and specific conductance values were greater at near-bottom sampling sites at the mouth of East Bay, but nitrite plus nitrate nitrogen and orthophosphorus concentrations and values for color were greater near the surface (figs. 16 and 17). Concentrations of total nitrogen and ammonia plus organic nitrogen did not indicate a consistent trend with depth. The difference between water-quality characteristics of the near-surface and near-bottom water samples indicates vertical stratification at the mouth of East Bay.

Variations in water quality at the mouth of East Bay are complex. For example, for samples collected on the same day, near-bottom total nitrogen concentrations collected during ebb flows were less than during flood flows about half the time. However, flow direction near the bottom during sample collection is unknown. The vertical stratification of water-quality characteristics at the mouth of East Bay most likely is related to bidirectional flows, but density gradients caused by specific conductance and temperature also can influence vertical stratification of water quality. Because discharge measurements were not made during water-quality sampling, the effects of bidirectional flows on water quality cannot be determined from the data.

Water-quality samples collected at sites CB-1 and CB-2 indicated that vertical stratification occurs at the head of East Bay, although the 10-ft water depth is relatively shallow. Concentrations of ammonia nitrogen, phosphorus, orthophosphorus, and specific conductance generally were greater near the bottom (figs. 18 and 19). Color values generally were greater near the surface. Nitrite plus nitrate nitrogen concentrations typically were below the detection limit of 0.02 mg/L. Total nitrogen and ammonia plus organic nitrogen concentrations did not show a consistent trend or pattern with depth.

Vertical stratification at sites CB-1 and CB-2 most likely was not caused by bidirectional flows because such flows were not commonly observed during discharge measurements. Stratification probably is influenced by bottom configuration upstream and downstream of the sampling sites and by density gradients.

Seasonal Patterns

Seasonal patterns in water quality in East Bay and Delaney Creek were evaluated by grouping data into four seasons consisting of 3 months in each season. Data for June through August 1992 were grouped to represent summer, data for September through November

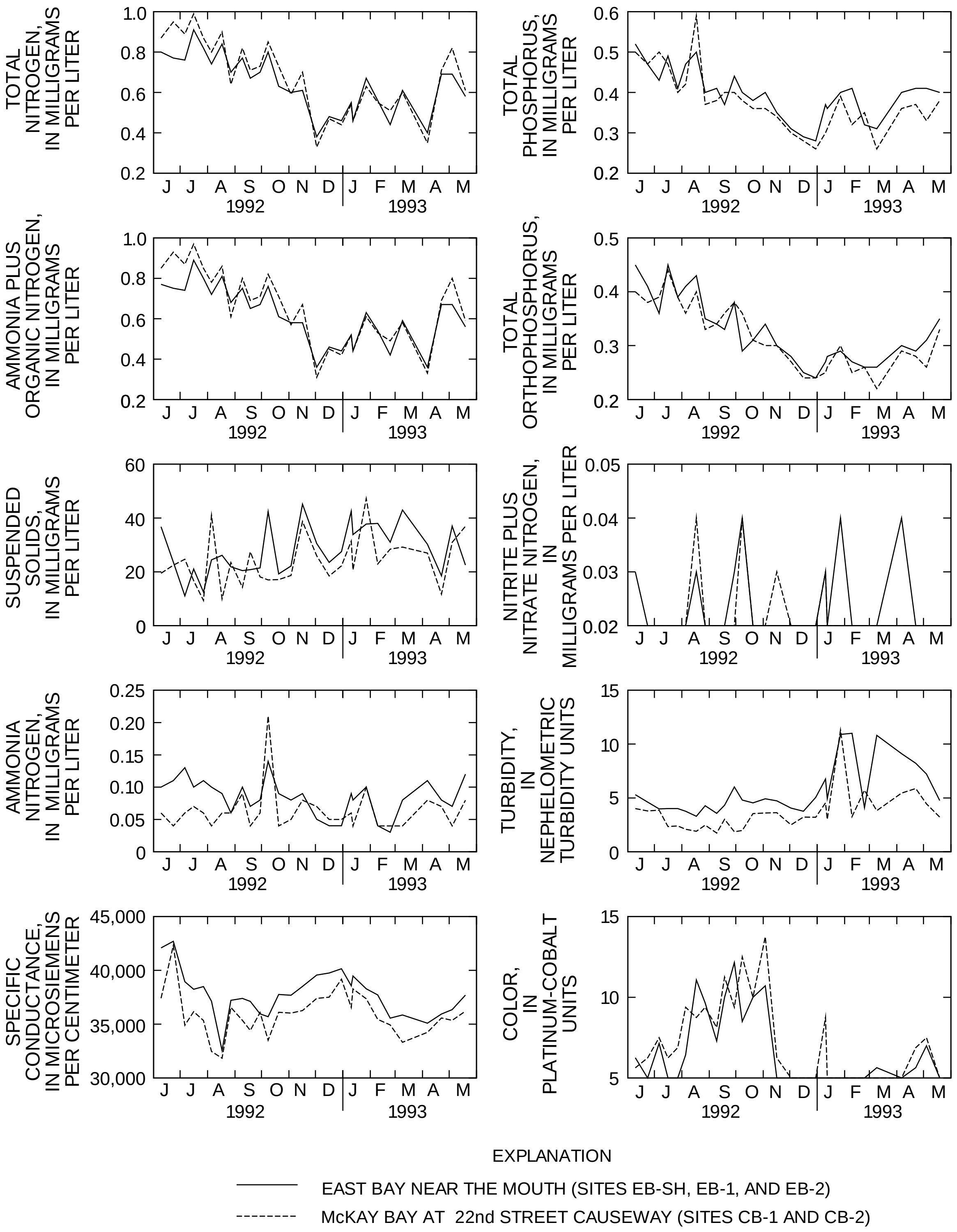


Figure 15. Mean concentrations of selected constituents at East Bay near the mouth and McKay Bay at 22nd Street Causeway, June 1992 through May 1993.

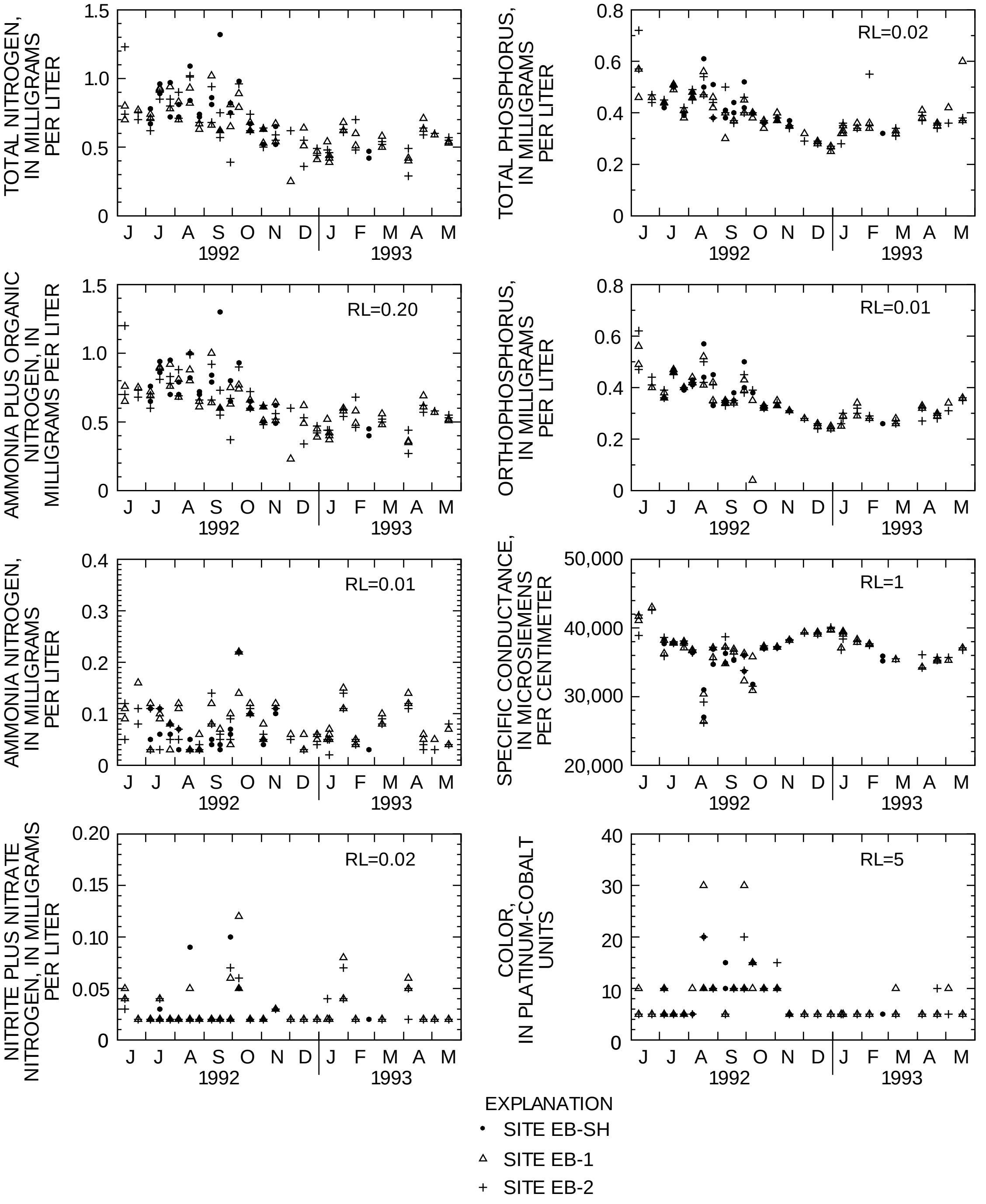


Figure 16. Concentrations of selected constituents at sites EB-1 and EB-2 (collected near the surface) and

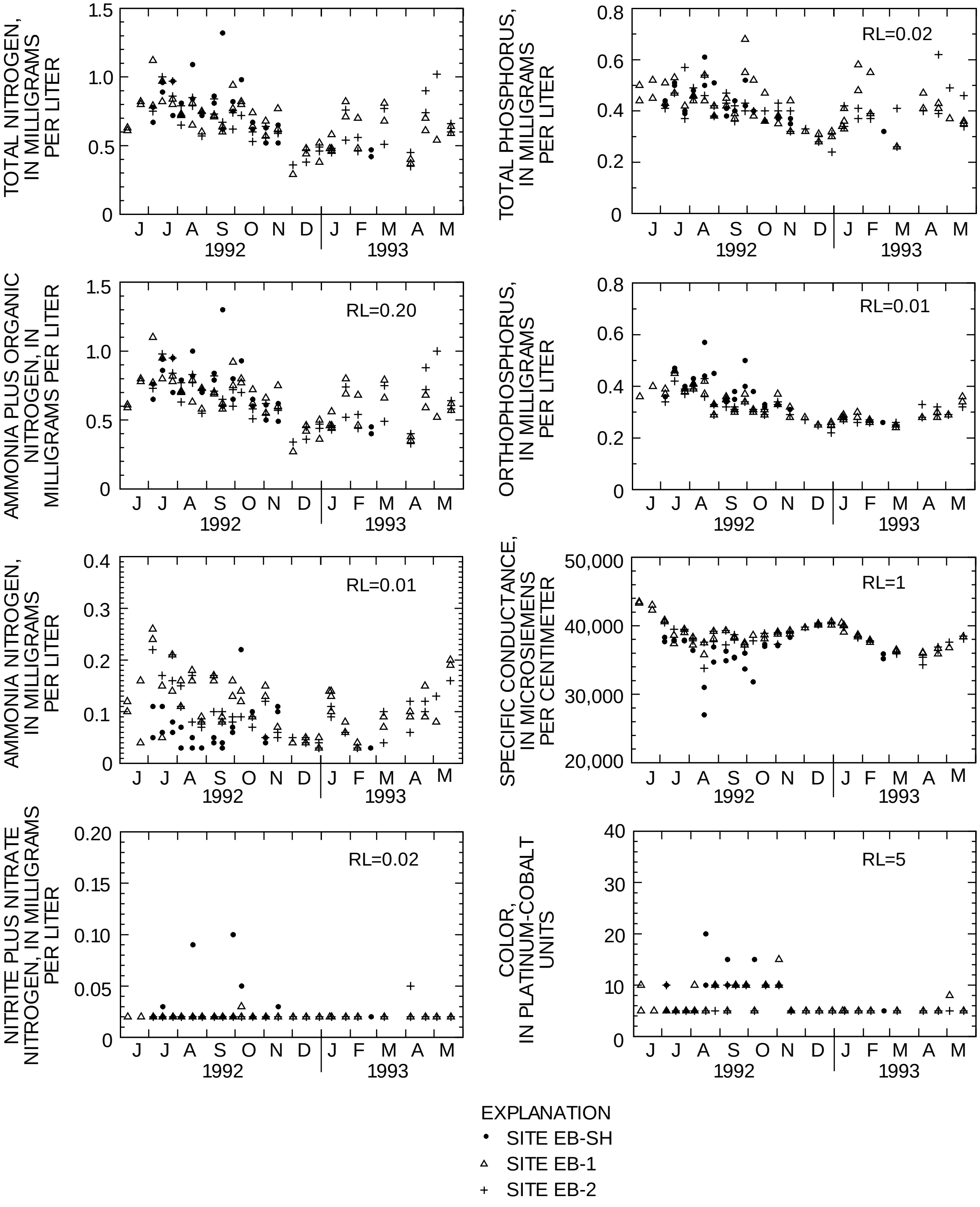


Figure 17. Concentrations of selected constituents at sites EB-1 and EB-2 (collected near the bottom)

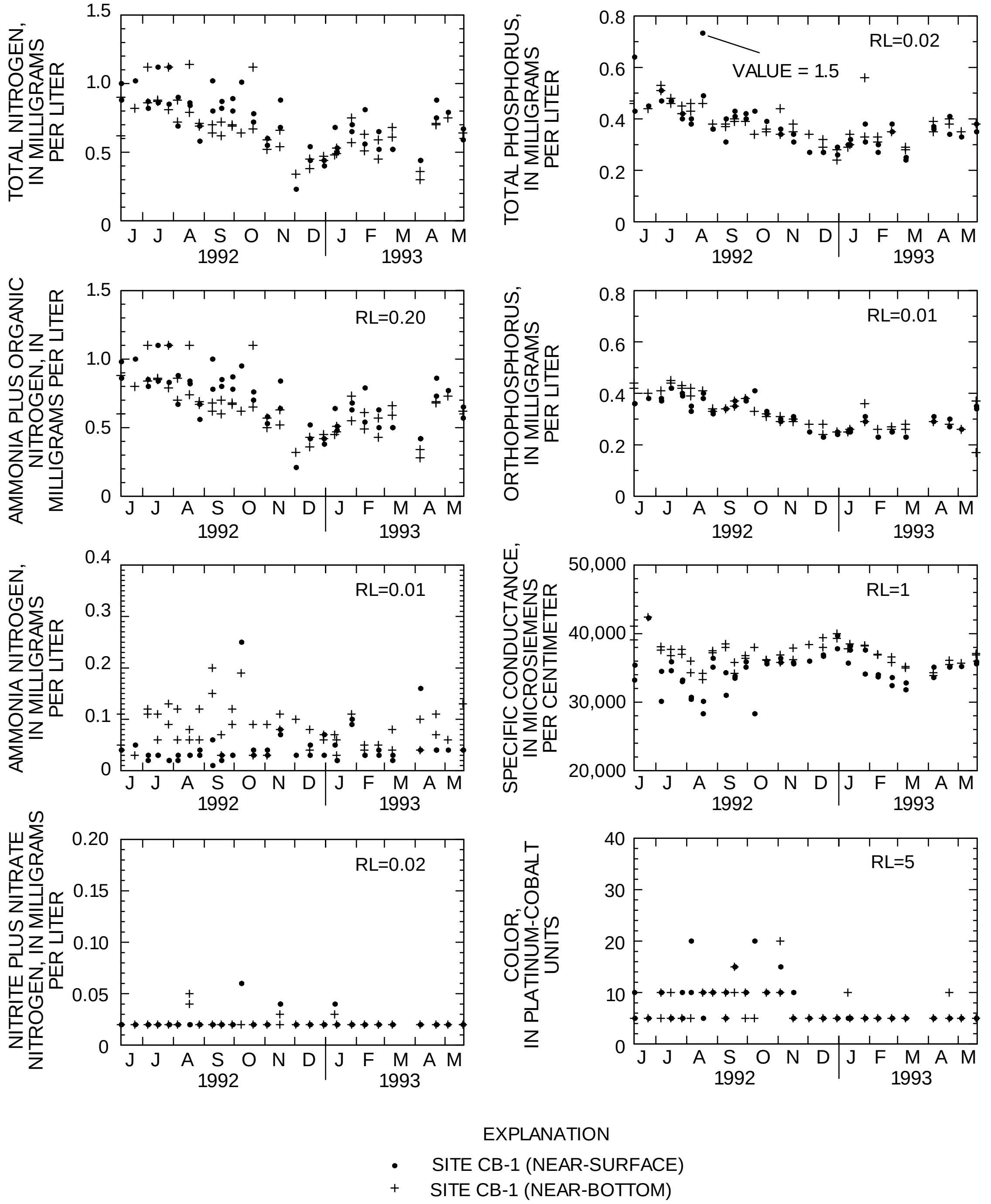


Figure 18. Concentrations of selected constituents at site CB-1, June 1992 through May 1993.

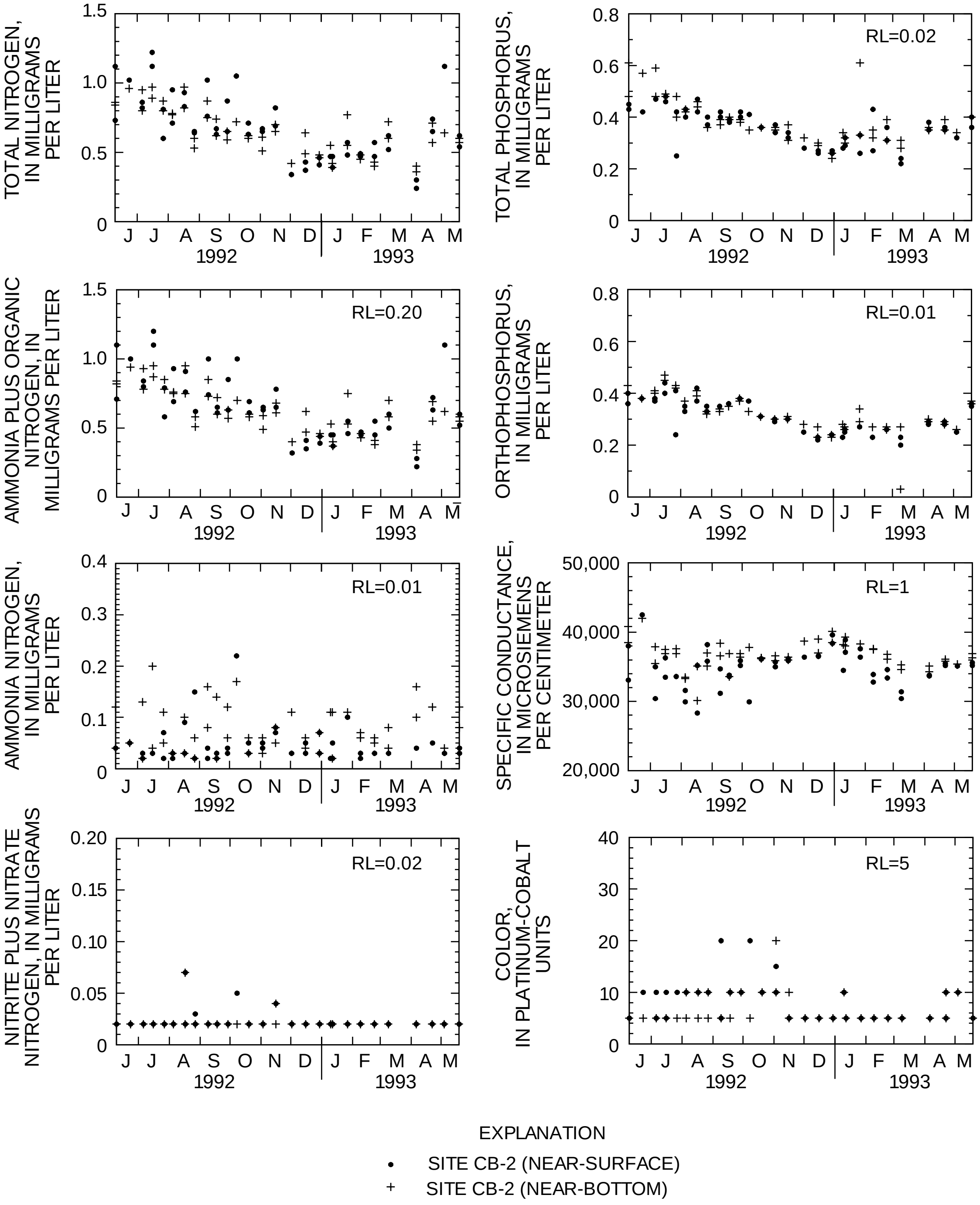


Figure 19. Concentrations of selected constituents at site CB-2, June 1992 through May 1993.

represent fall, and so on. Seasonal patterns in water quality at the head of East Bay (at sites CB-1 and CB-2) and near the mouth (sites EB-1, EB-2, and EB-SH) generally were similar (fig. 20), but concentrations of ammonia nitrogen were greater near the mouth of East Bay than at the head. Concentrations of nitrogen, phosphorus, orthophosphorus, ammonia nitrogen, and ammonia plus organic nitrogen and values for color were least in the winter, whereas values for specific conductance and turbidity and concentrations of suspended solids generally were greatest in the winter. Suspended solids and turbidity may have been affected by dredging that occurred near the mouth of East Bay and in East Bay during February, March, and April 1993 (figs. 15 and 20). Maximum concentrations of total nitrogen, phosphorus, orthophosphorus, and ammonia plus organic nitrogen occurred in summer.

Concentrations of selected constituents near the mouth of Delaney Creek grouped by season (fig. 21) were as much as 10 times greater than seasonal mean concentrations in East Bay. Throughout the year, significantly greater concentrations of nitrogen, phosphorus, and color and lower concentrations of suspended solids and lower turbidity and specific conductance were detected at Delaney Creek (fig. 21) than at East Bay (fig. 20).

Near the mouth of Delaney Creek, concentrations of nitrogen, phosphorus, orthophosphorus, ammonia nitrogen, ammonia plus organic nitrogen, and values for color were least in the fall and spring and were greatest in summer. Maximum concentrations of nitrite plus nitrate nitrogen occurred in winter. The mean concentrations of nutrients at Delaney Creek during winter are influenced by one sample collected on January 27. On this date, concentrations of ammonia nitrogen, nitrite plus nitrate nitrogen, phosphorous and orthophosphorus were greater than during any other sampled date. The high nutrient concentrations probably were caused by a contaminant spill in Delaney Creek or the basin. Rainfall preceding the sampling event might have washed contaminants into the creek. Although rainfall preceded about 10 sampling events in Delaney Creek, only samples collected on January 27 showed excessive nutrient concentrations.

Specific Conductance

The specific conductance of water in estuaries and tidal rivers is primarily affected by the ambient specific conductance of adjacent water bodies and by the amount of freshwater inflow. Specific conductances in McKay Bay and Delaney Creek were monitored to provide continuous records to supplement the interpretation of the discharge and water-quality data. Specific conductance probes were placed at two depths in McKay Bay to evaluate the degree of vertical mixing in the cross section during the study.

Specific conductance varied continually in McKay Bay and in the tidal reach of Delaney Creek. Short-term variability in specific conductance generally was the result of tidal effects (fig. 22). Specific conductance generally increased during floodtide and decreased during ebbtide.

Long-term variability in specific conductance resulted from variations in freshwater inflow volume. Daily mean specific conductance values in McKay Bay and Delaney Creek generally were inversely related to daily mean discharge. The lowest specific conductance occurred during periods of higher freshwater discharges (figs. 10, 11, and 23). Maximum daily mean specific conductances at both McKay Bay and Delaney Creek occurred during extended periods of low freshwater inflows.

Daily mean specific conductance data indicated that near-bottom and near-surface specific conductances in McKay Bay were similar during periods of relatively low net discharge (figs. 10 and 23), indicating that water in the cross section is well mixed. Near-surface specific conductances generally were less than near-bottom specific conductances during July through December 1992 and March through May 1993, when daily mean discharges generally were above zero (figs. 10 and 23). Near-surface values of specific conductance that are less than near-bottom values of specific conductance indicate vertical stratification.

Specific conductance at Delaney Creek was more variable than in East Bay and responded more rapidly to changes in discharge. Specific conductance generally was less than 20,000 μS/cm in July and August 1992, when discharge was generally greater than 30 ft^3/s (figs. 23 and 11). Daily mean specific conductances increased from about 12,000 μS/cm in mid-October 1992 to about 35,000 μS/cm in mid-January 1993, coinciding with minimal discharges. The variability in specific conductance in Delaney Creek compared to East Bay, probably is the result of the relatively small volume of water in the tidal creek.

NUTRIENT LOADS

Constituent loading from an estuary is controlled by freshwater inflow, constituent concentrations, and the effects of tide. Both freshwater inflow and tide provide the forces that move a constituent in water, but which forcing mechanism dominates in any estuary can vary. In Tampa Bay, both mechanisms are important, and dominance varies by geographic area. The primary mechanism control-

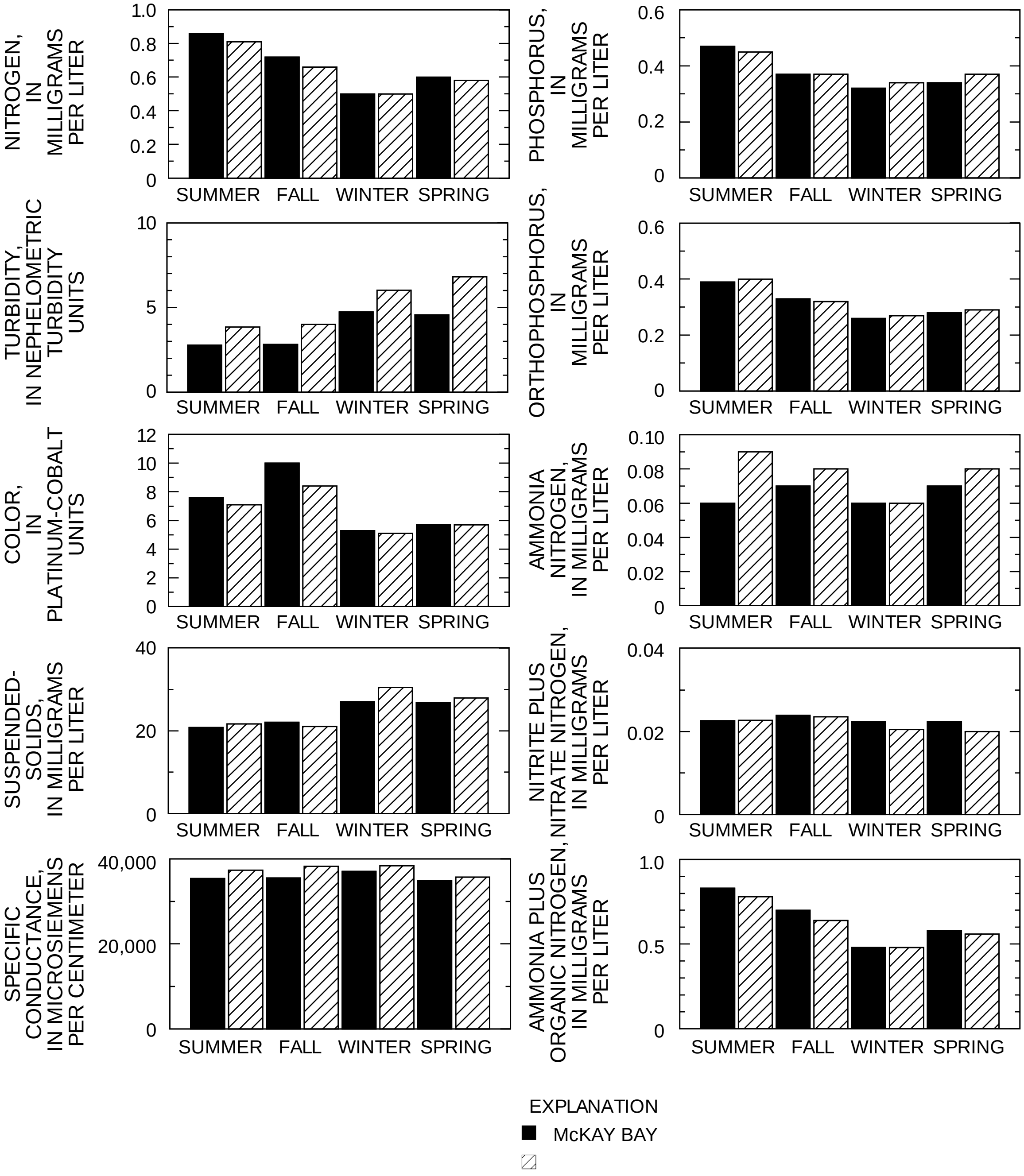


Figure 20. Seasonal water-quality conditions at McKay Bay at 22nd Street Causeway and near the mouth

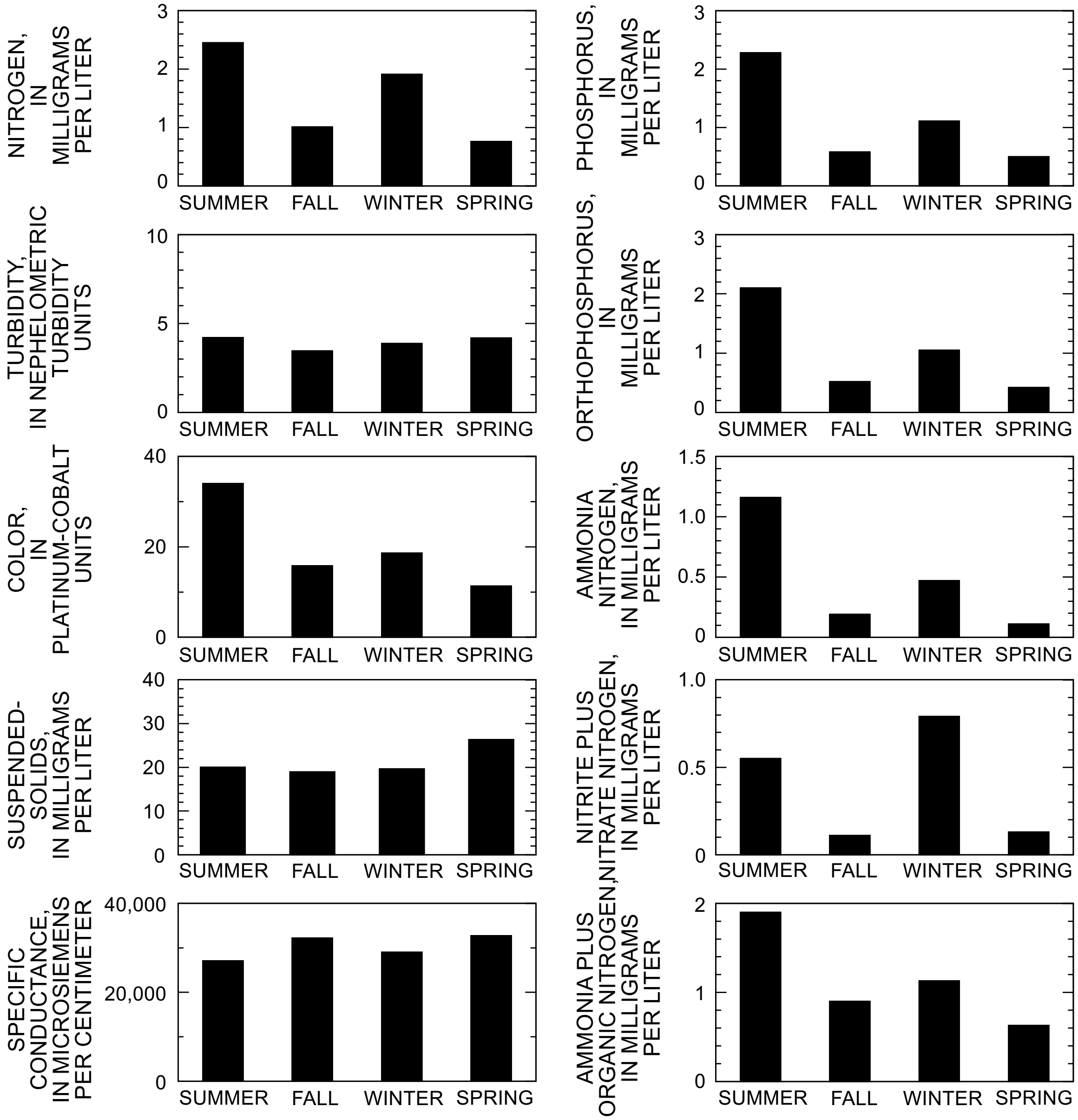


Figure 21. Seasonal water-quality conditions near the mouth of Delaney Creek, June 1992 through May 1993.

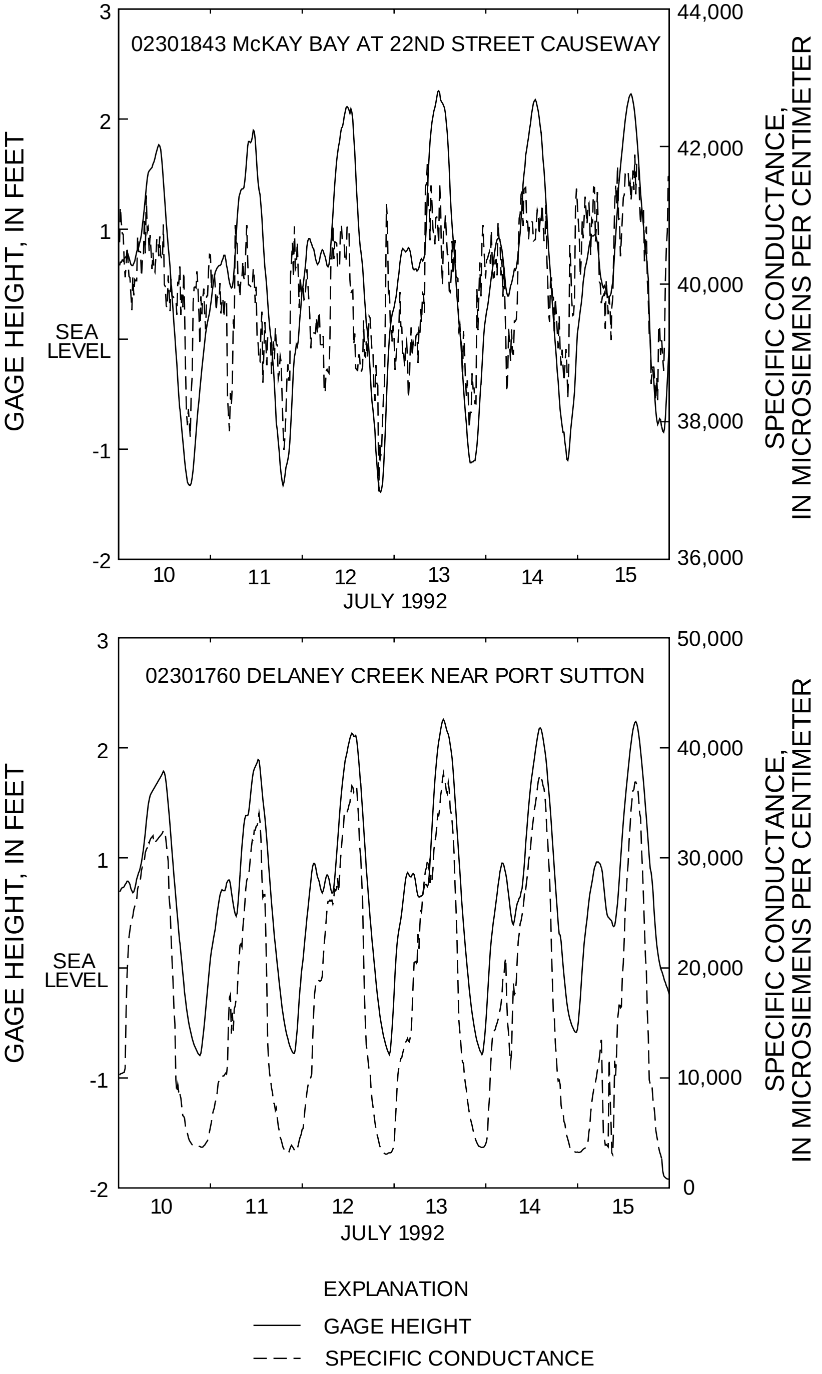


Figure 22. Short-term variations in gage height and specific conductance

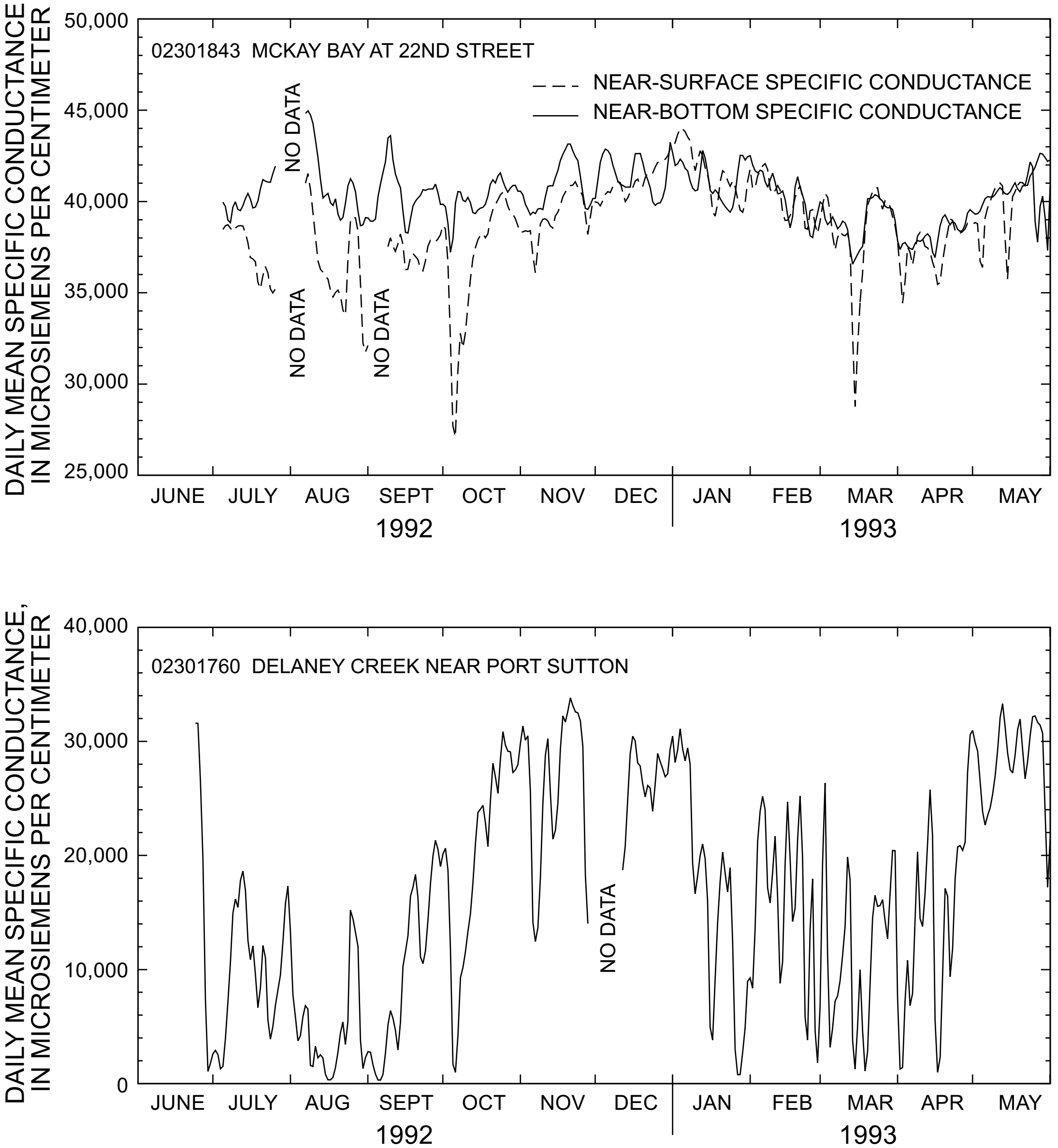


Figure 23. Daily mean specific conductance at McKay Bay and Delaney Creek, June 1992 through

ling constituent loading in Hills-borough Bay, including McKay Bay and East Bay is tributary freshwater inflow (Goodwin, 1987). During periods of low tributary freshwater inflow, very little loading from McKay Bay and East Bay would occur.

Discharge data and constituent concentrations were used to compute constituent loads. The term “measured loads” in this report refers to loads that are computed using water-quality data and discharge at the time of sampling. Measured loads represent loads at discrete times, and these loads can be used to estimate loads for periods when measured loads are not available. Estimates can be based on continuous-discharge data if the relation between constituent concentration and discharge does not significantly change between sampling events. However, this assumption generally results in an underestimate of the total load in urbanized, industrial, or agricultural land uses because contributions of a constituent to the water body that occur between sampling dates may not be included in the estimate. For example, if a constituent is estimated using the above technique and a periodic, unmeasured discharge of an effluent contains concentrations of a constituent greater than the background concentration of that constituent in the water body, the effluent discharge would add to the total load of that constituent. This additional load could not be estimated from a relation that was developed from data collected when the effluent source was not discharging. Collection of water-quality and discharge data at frequent intervals minimizes such errors in the load estimate.

In this study, data were collected at 10- or 14-day intervals. Generally, two samples were collected per day. Measured loads were used to develop equations that could be used to estimate loads based on continuous discharge. Simple linear regression analyses were used to develop the equations. The loads estimated from these techniques are presented and evaluated in the following section.

McKay Bay

Measured total nitrogen and phosphorus loads from McKay Bay to East Bay were computed from total nitrogen and phosphorus concentrations and from instantaneous discharge at McKay Bay at the 22nd Street Causeway Bridge. Measured loads could not be computed for some water-quality data collected at this site because the discharge record was incomplete. Loads from McKay Bay varied in response to tidal fluctuations, thus measured loads represent the load only during the time of sampling. Measured loads plotted as a function of discharge at the time of sampling (instantaneous discharge) are shown in figure 24. Measured total nitrogen loads ranged from about -25 tons/d to about 24 tons/d, and measured total phosphorus loads ranged from about -14 tons/d to about 14 tons/d. Discharge used to compute measured loads ranged from about -14,000 ft^3/s to about 10,000 ft^3/s.

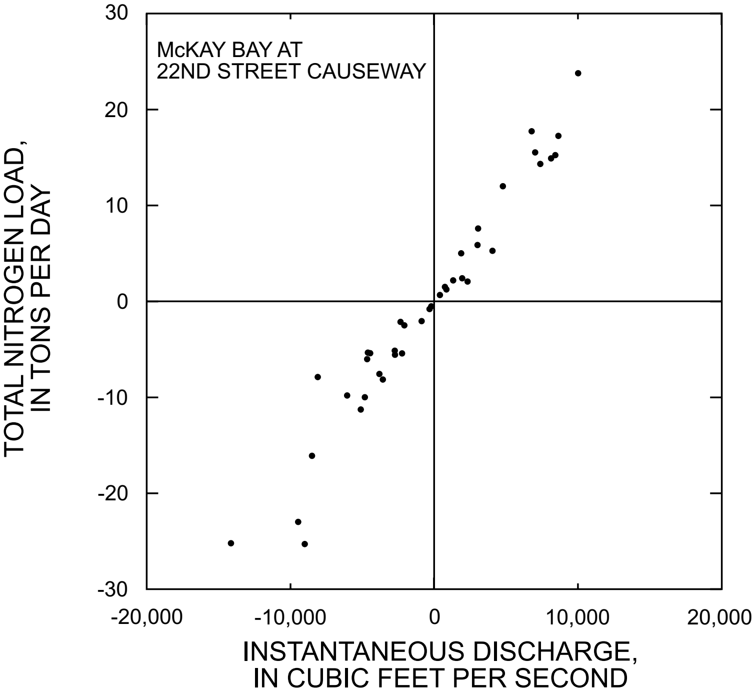
Simple linear regression analysis was used to develop equations that relate measured load to instantaneous discharge. The regression equations were fitted to pass through the origin because, by definition, a constituent load is zero when discharge is zero. The resulting equations and associated regression parameters are shown in table 3.

Total nitrogen and total phosphorus loads at 15-minute intervals (instantaneous loads) at McKay Bay were computed using the equations derived from regression analyses. Instantaneous loads were highly variable because of the effects of tide on discharge patterns in McKay Bay. Tide effects on loads were removed using the Godin filter. Filtered and instantaneous total nitrogen loads for April 1993 are shown in figure 25 to illustrate the effect of the Godin filter on the data. Nitrogen loads prior to the removal of tidal variations were both positive (downestuary) and negative (upestuary) during April 1993. The filtered data represents the residual or net load, which is the load that occurs independent of the load caused by tidal movement of the water. The residual load for most of April 1993 was positive.

The greatest daily mean loads from McKay Bay occurred in late June 1992 and in April and May 1993 (fig. 26) and coincided with periods of discharge greater than about 2,000 ft^3/s (fig. 10). Daily mean nitrogen loads ranged from about -2.0 tons/d to about 4.8 tons/d, and daily mean phosphorus loads ranged from about -1.1 tons/d to about 2.6 tons/d. Most of the total nitrogen load from McKay Bay to East Bay was in the organic nitrogen form.

Nitrogen and phosphorus loads occasionally were negligible or less than zero for selected periods during September 1992 through January 1993. The loads are less than zero because the discharge used to compute the loads is less than zero. The negative discharges and loads indicate a net upestuary movement of water and the associated water-quality constituents. Both positive and negative loads include errors resulting from errors in the computation of discharge and the measurement of constituent concentration.

Monthly total nitrogen and total phosphorus loads from McKay Bay to East Bay were computed by summing the daily loads during each month. For months with incomplete record and at least 14 days of data, monthly



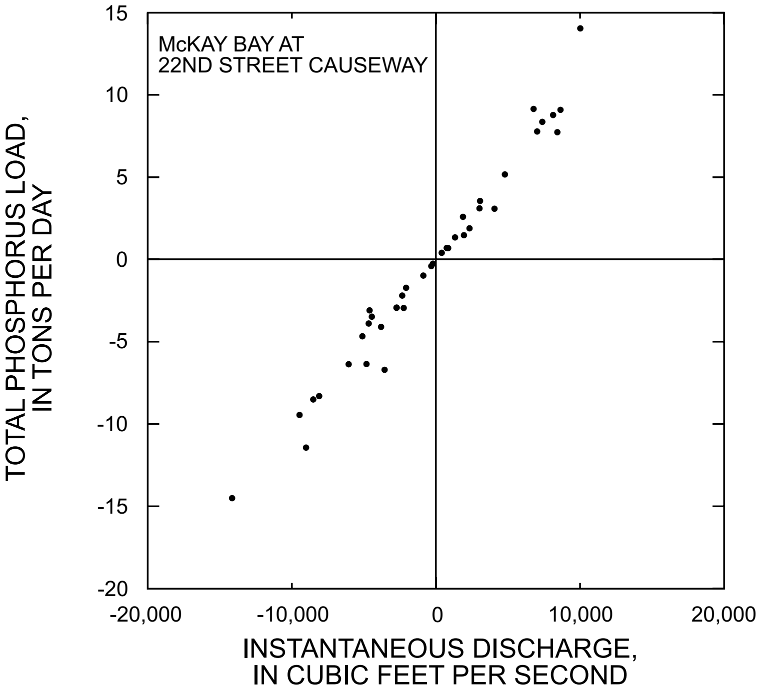


Figure 24. Total nitrogen and phosphorus loads as a function of instantaneous discharge at McKay Bay at 22nd Street Causeway, June 1992 through May 1993.

Table 3. Results of regression analyses relating load to discharge

[R^2, coefficient of determination; N, nitrogen load; P, phosphorus load; Q, instantaneous discharge, in cubic feet per second]

Site	Dependent variable, in tons per day	Independent variable, in cubic feet per second	R^2	Standard error, in percent	Equation
McKay Bay	Nitrogen load (N)	Instantaneous discharge (Q)	0.95	30	$N = 0.001976 \times Q$
McKay Bay	Phosphorus load (P)	Instantaneous discharge	.97	21	$P = 0.001084 \times Q$
Delaney Creek	Nitrogen load (N)	Instantaneous discharge	.77	63	[1] $N = (-0.0016957) \times \left(\left\lvert \frac{Q}{0.96} \right\rvert\right)^{1.06044}$
					[2] $N = (0.0031949) \times \left(\left\lvert \frac{Q}{0.96} \right\rvert\right)^{1.06044}$
Delaney Creek	Phosphorus load (P)	Instantaneous discharge	.76	66	[1] $P = (-0.0010769) \times \left(\left\lvert \frac{Q}{0.96} \right\rvert\right)^{1.05524}$
					[2] $P = (0.0019945) \times \left(\left\lvert \frac{Q}{0.96} \right\rvert\right)^{1.05524}$
East Bay	Nitrogen load (N)	Instantaneous discharge	.96	26	$N = 0.001815 \times Q$
East Bay	Nitrogen load (P)	Instantaneous discharge	.98	19	$P = 0.001059 \times Q$

[1] For discharges that are less than zero.

[2] For discharges that are greater than or equal to zero.

loads were estimated by multiplying the monthly daily mean load (based on the partial record) by the number of days in the month. Monthly nitrogen loads ranged from about 20 tons to about 83 tons, and monthly phosphorus loads ranged from about 11 tons to about 45 tons (table 4). Minimum loads occurred from September through December 1992 and coincided with low and negative discharges. The greatest total nitrogen and phosphorus loads occurred in April and May 1993 and coincided with maximum discharges from McKay Bay (fig. 10).

The magnitude of nitrogen and phosphorus loads from McKay Bay is affected more by discharge than by the concentration of the constituent in the water. For example, the concentrations of total nitrogen and phosphorus were greater during June through September 1992 than during April and May 1993, but loads were greater in April and May 1993.

Delaney Creek

Measured total nitrogen and total phosphorus loads at Delaney Creek were computed by multiplying the concentration near the mouth of the creek (site DEL) by an adjusted instantaneous discharge at the gage 1.1 mi upstream. The discharge was adjusted by dividing the instantaneous discharge by 0.96 to estimate the total discharge from the basin. A plot of measured loads at the mouth of Delaney Creek as a function of discharge is shown in figure 27. The measured total nitrogen loads ranged from about -0.13 ton/d to about 0.73 ton/d, and measured total phosphorus loads ranged from about -0.08 ton/d to about 0.45 ton/d.

The measured loads and discharge were log-transformed before linear regression equations were developed to estimate total nitrogen and total phosphorus loads for the study period. The summary of the regression analyses is shown in table 3.

Instantaneous nitrogen and phosphorus loads for June 1992 through May 1993 were computed from the equations shown in table 3. As in McKay Bay, instantaneous loads were highly variable because of the effects of tide. Tide effects on the loads were removed with the Godin filter.

The greatest daily mean loads for total nitrogen and total phosphorus loads occurred in late June 1992, and the least loads occurred in November and December 1992 (fig. 28). Periods of missing record correspond to periods of missing discharge data.

Monthly total nitrogen and total phosphorus loads from Delaney Creek to East Bay were computed by summing the daily loads. For months with incomplete record, monthly loads were estimated by multiplying the monthly daily mean load by the number of days in the month. Monthly nitrogen loads ranged from about

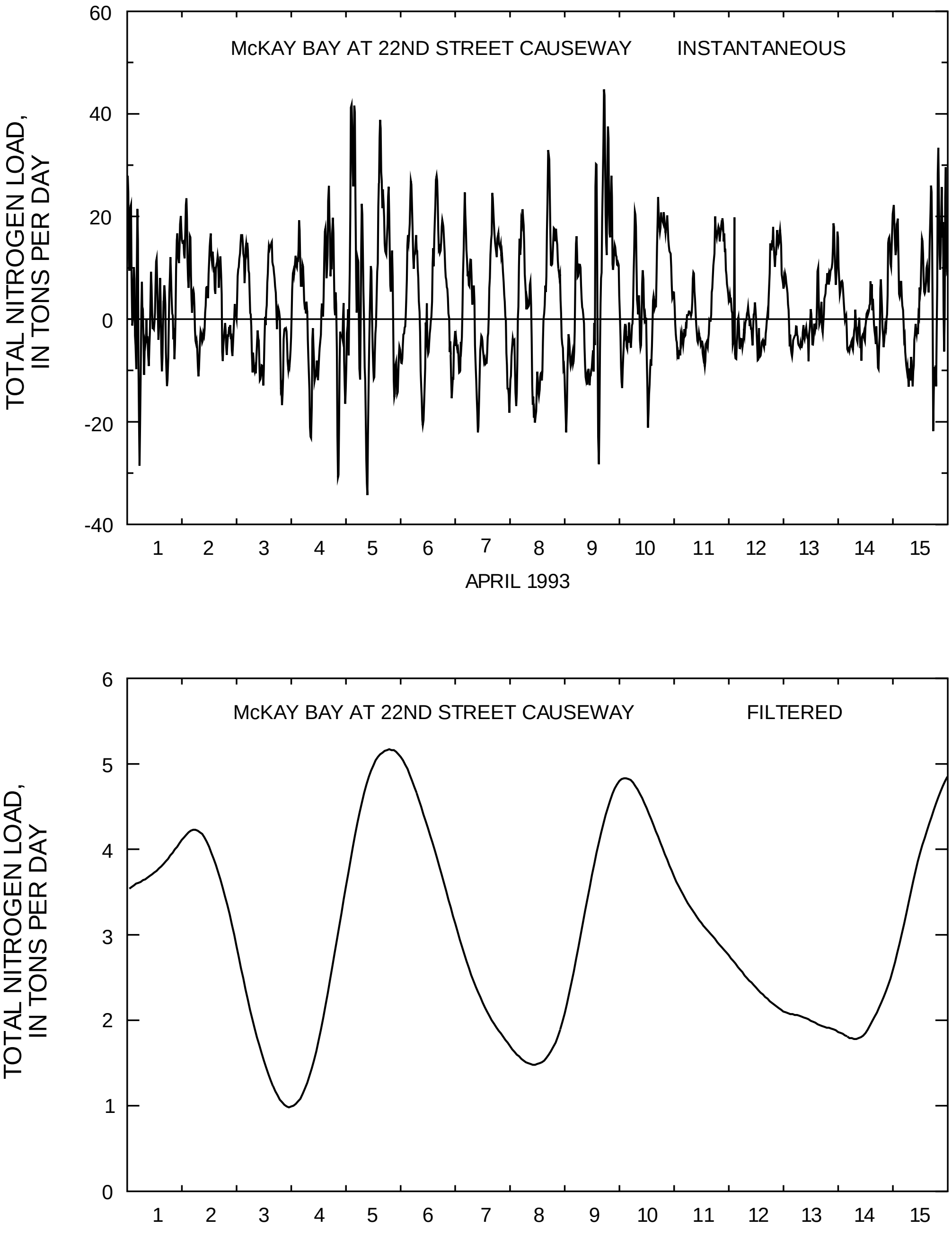


Figure 25. Instantaneous and filtered total nitrogen load at McKay Bay at 22nd Street Causeway, April 1–15, 1993.

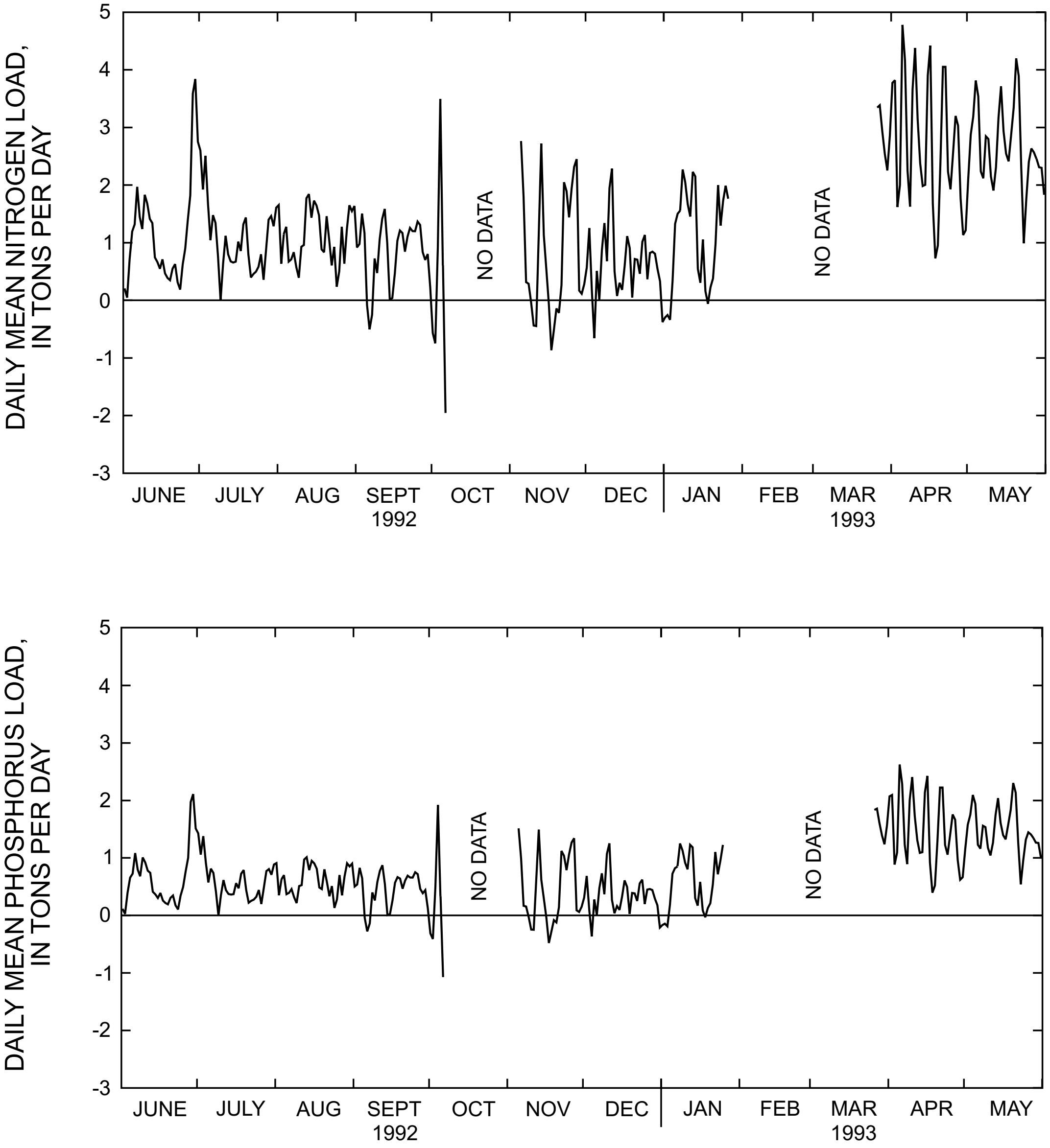


Figure 26. Daily mean total nitrogen and total phosphorus loads at McKay Bay at 22nd Street Causeway, June 1992 through May 1993.

Table 4. Monthly nitrogen and phosphorus loads from McKay Bay, Delaney Creek, and East Bay

[All loads are in tons; -- represents missing data]

	1992							**1993**				
	June	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Nitrogen load												
McKay Bay	34.89	33.06	34.13	24.72	--	24.10	20.13	32.87	--	--	80.82	82.54
Delaney Creek	--	1.47	4.23	3.85	--	1.18	1.01	1.70	1.32	1.94	1.61	1.21
East Bay	--	35.86	34.33	24.56	--	22.49	17.08	34.47	--	--	75.27	76.46
Phosphorus load												
McKay Bay	19.17	18.16	18.75	13.58	--	13.24	11.07	18.06	--	--	44.37	45.32
Delaney Creek	--	.90	2.58	2.35	--	.71	.62	1.03	.80	1.18	.99	.74
East Bay	--	20.93	20.04	14.34	--	13.13	9.97	20.13	--	--	43.94	44.64

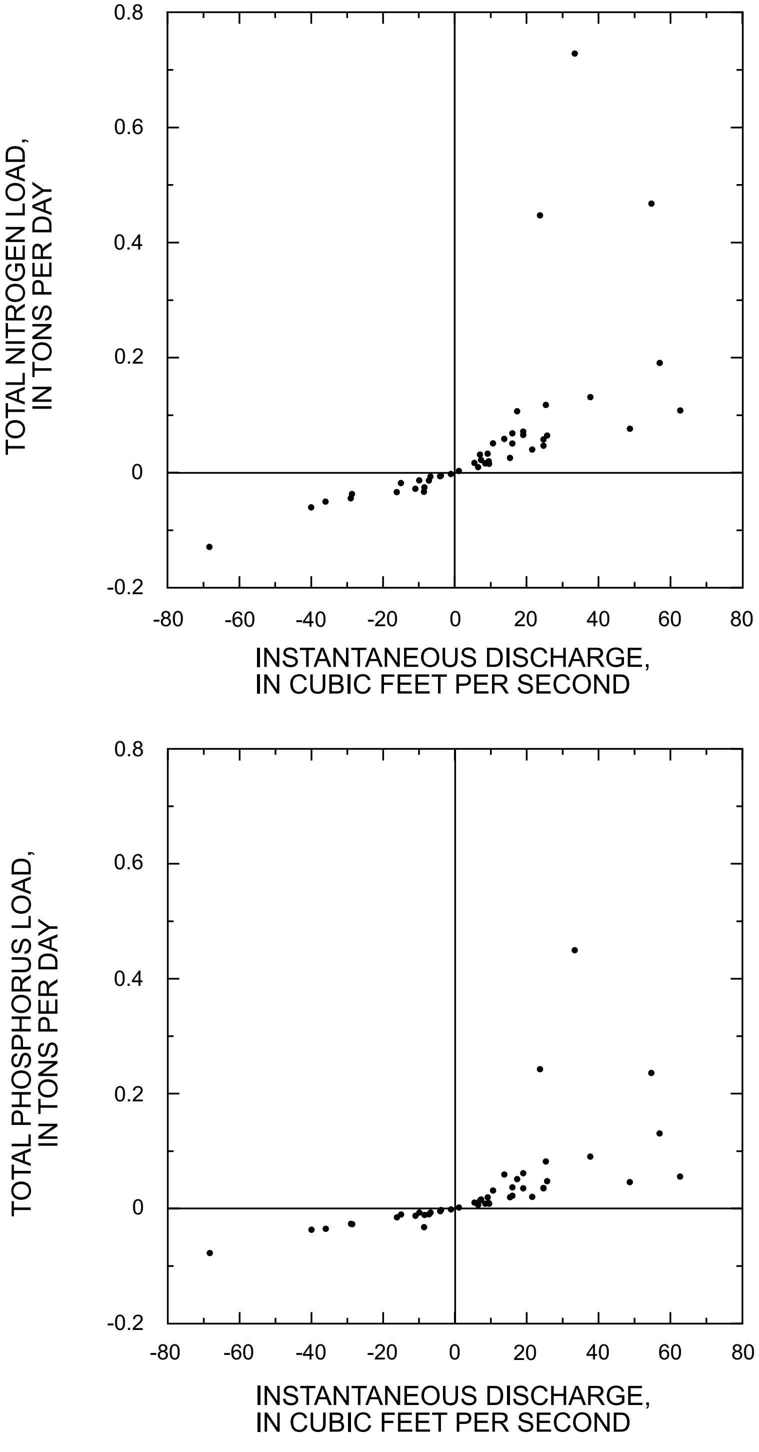


Figure 27. Measured total nitrogen and phosphorus loads as a function of instantaneous discharge at the mouth of Delaney Creek, June 1992 through May 1993.

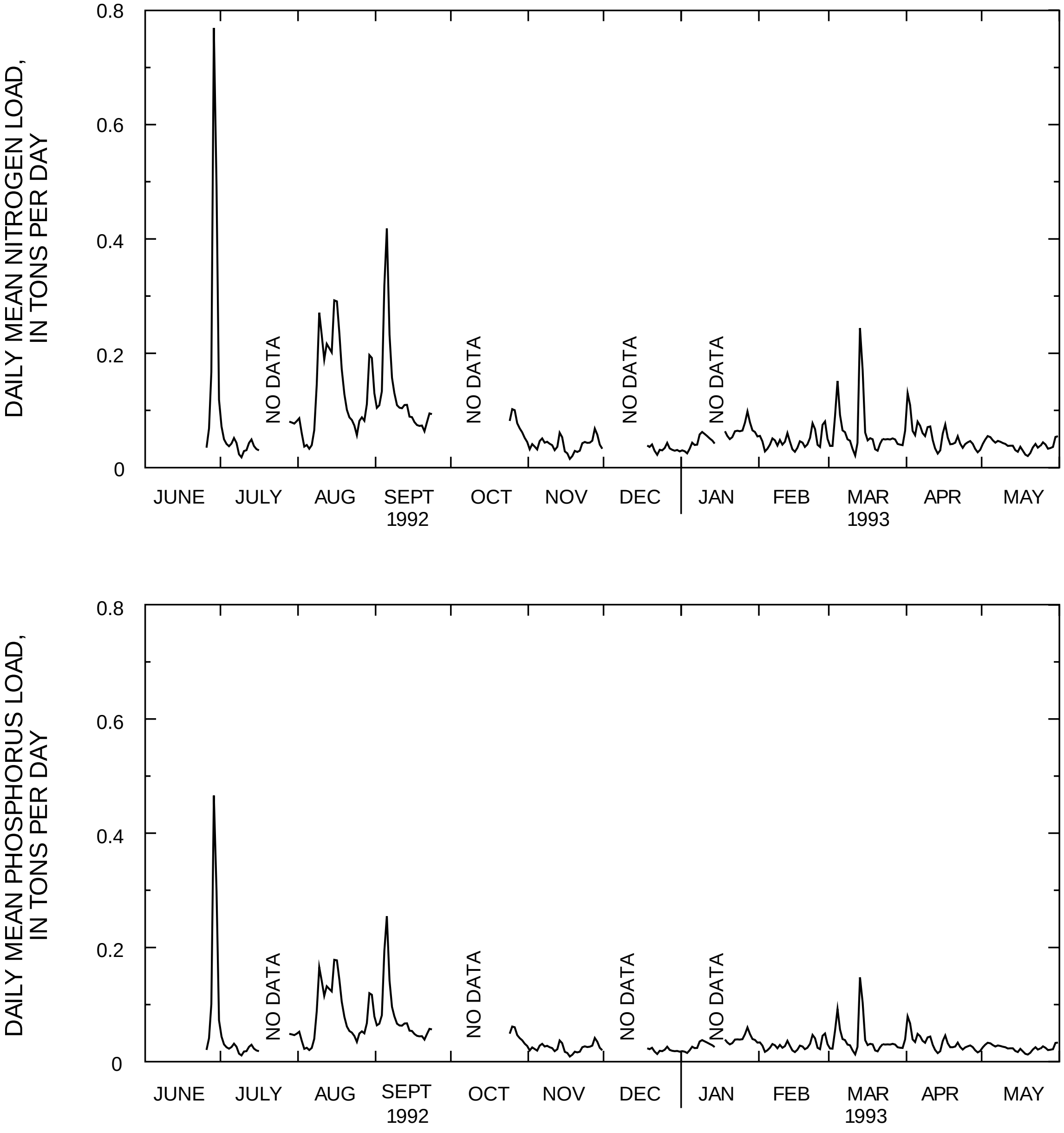


Figure 28. Daily mean total nitrogen and total phosphorus loads at the mouth of Delaney Creek,

1.0 ton to about 4.2 tons, and monthly phosphorus loads ranged from about 0.62 ton to about 2.6 tons. Monthly nitrogen loads were greatest in August 1992 and were least in December 1992 (table 4).

The monthly loading estimates indicate that Delaney Creek was not a significant source of nitrogen and phosphorus to East Bay during much of the study period. Although concentrations of total nitrogen and total phosphorus in Delaney Creek at times were much greater than in East Bay, the minimal discharges associated with these high concentrations resulted in low loading rates.

East Bay

Measured total nitrogen and phosphorus loads at the mouth of East Bay (loads from East Bay into Hillsborough Bay) were computed from total nitrogen and phosphorus concentrations measured at the mouth of East Bay at sites EB-SH, EB-1, and EB-2 and from the estimated discharge at the time of sampling (the sum of discharges from McKay Bay, Delaney Creek, rainfall, and the East Bay basin). Instantaneous discharge (15-minute interval) was used in the development of regression equations. Some water-quality data were not included in the computation of measured loads because loads could not be computed for periods of missing discharge record. Measured load as a function of instantaneous discharge is shown in figure 29 and results of the regression analyses are shown in table 3.

Daily and monthly total nitrogen and phosphorus loads were computed using the same procedures described for McKay Bay and Delaney Creek. Daily mean nitrogen loads ranged from about -0.8 ton/d to about 4.5 tons/d, and daily mean phosphorus loads ranged from about -0.5 ton/d to about 2.6 tons/d (fig. 30). The greatest loads occurred in June 1992 and in April and May 1993. Daily mean loads generally were least in November through December 1992. Monthly nitrogen loads ranged from about 17 tons to about 76 tons, and monthly phosphorus loads ranged from about 10 tons to about 45 tons (table 4). The greatest monthly loads occurred in April and May 1993, and the least loads occurred in December 1992. Patterns in daily mean load and monthly loads at East Bay near the mouth are similar to patterns at McKay Bay at 22nd Street Causeway Bridge because most of the discharge from East Bay near the mouth is caused by discharges from McKay Bay.

The nitrogen and phosphorus load that is generated in the East Bay basin, excluding the load from the McKay Bay basin and from Delaney Creek, can be estimated by subtracting the load from McKay Bay and Delaney Creek from the load at the mouth of East Bay. This net load represents the sum of loads from direct rainfall to East Bay, runoff from the East Bay basin, and dry deposition from nearby shipping terminals. Net loads from East Bay were evaluated for monthly loads. The greatest net load from East Bay occurred in July 1992 and was about 1.3 tons of nitrogen and about 1.9 tons of phosphorus, representing about 4 and 9 percent, respectively, of the total load from East Bay to Hillsborough Bay in July 1992. The net phosphorus load for January 1993 was about 1 ton. For the remaining months, the net load from East Bay was negative, which indicates that East Bay may store nutrients during those months. The results of this analysis show that the net load of nitrogen and phosphorus from East Bay to Hillsborough Bay during the study was minimal.

The results of this study indicate that losses of fertilizer products during handling and transportation activities at the various shipping terminals surrounding East Bay were not a significant source of nitrogen and phosphorus loading to Hillsborough Bay during the study. Two factors explain why loads from the East Bay basin are minimal. Regulatory actions by the Florida Department of Environmental Protection and the Commission have resulted in changes in shipping and industrial practices in the East Bay and Delaney Creek basins. These changes were implemented around 1991-92 and have resulted in decreased nitrogen and phosphorus loads to waters affecting Hillsborough Bay (Boler, 1992). Loads from the East Bay basin during June 1992 through May 1993 probably were minimal because of these changes and because the net discharge from the East Bay basin to Hillsborough Bay was small, relative to the amount of water that moves in and out of East Bay as a result of tidal fluctuations. Therefore, most of the nitrogen and phosphorus load from East Bay to Hillsborough Bay is the result of loads from McKay Bay into East Bay.

Loads of nitrogen and phosphorus to East Bay from shipping activities have been estimated from assumed rates of product losses from handling and transportation activities. The estimated average-annual loads for 1985–91 were about 270 tons of nitrogen and about 360 tons of phosphorus (with an assumed 0.02 percent product-loss rate) (Zarbock and others, 1994). Much of the phosphate product that has been lost to East Bay may be stored in the bottom sediments, especially if discharge from East Bay during this period was low. A sediment study in the vicinity of several shipping terminals in East

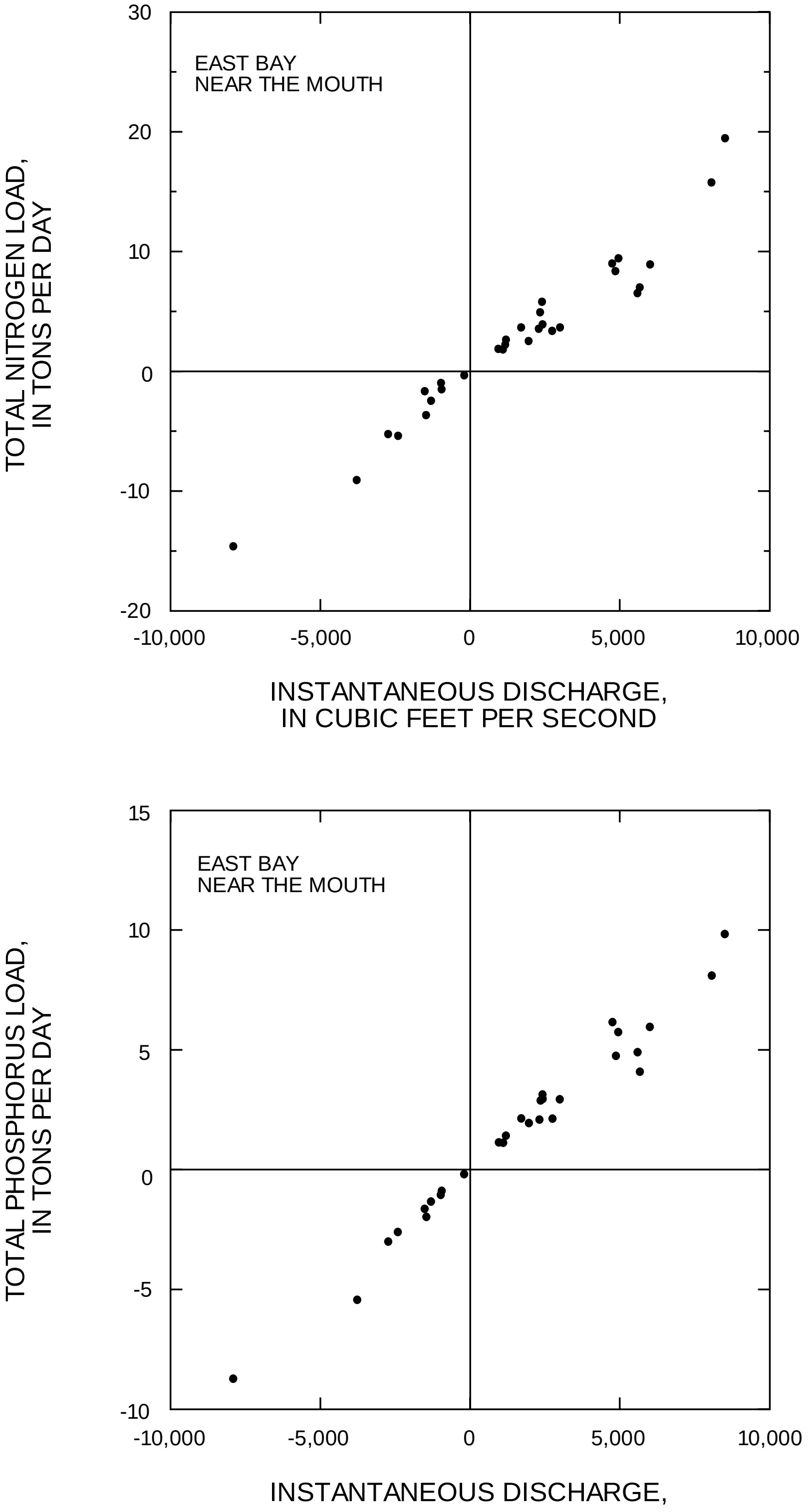


Figure 29. Measured total nitrogen and phosphorus loads as a function of instantaneous discharge at the mouth of East Bay, June 1992 through

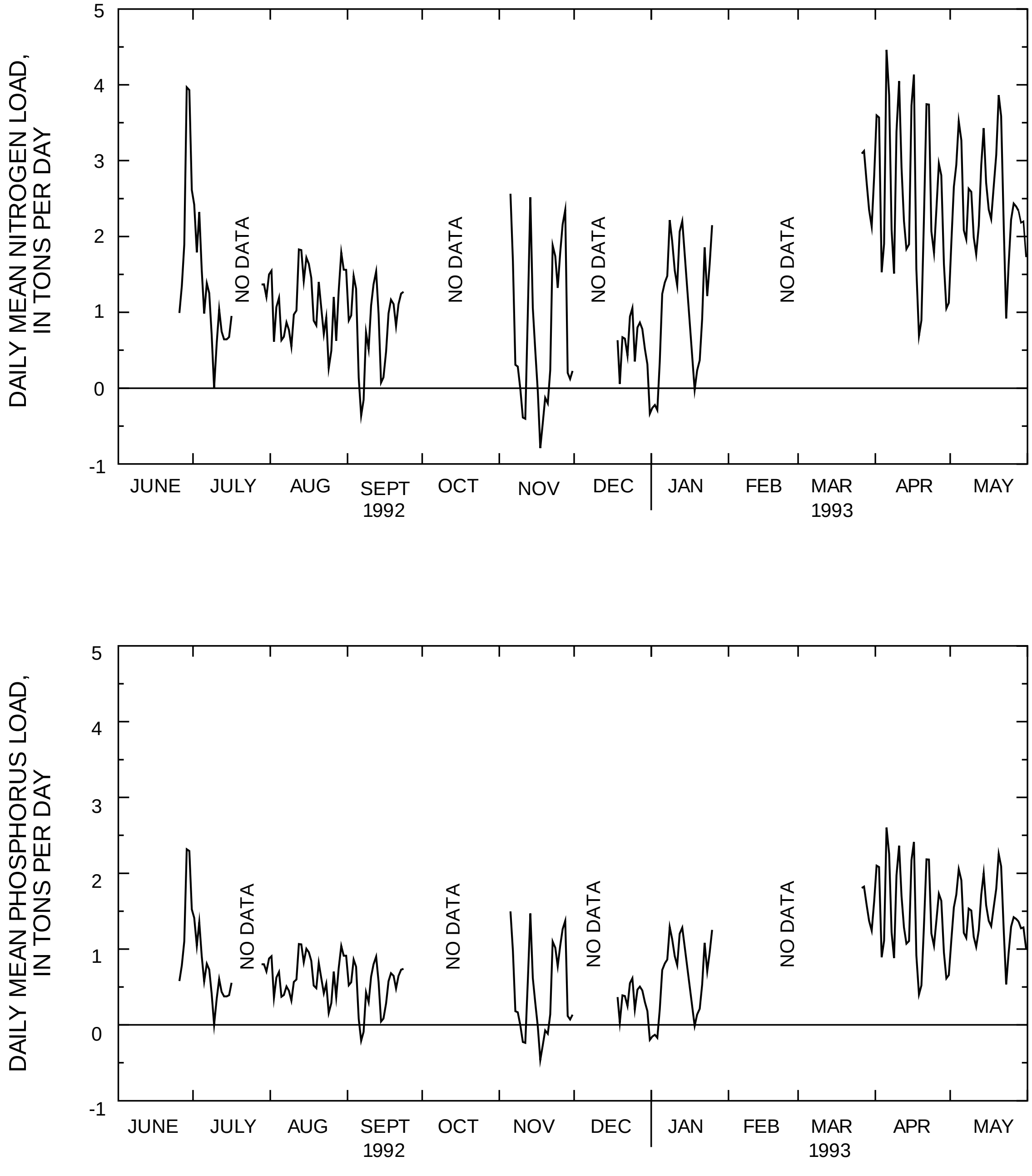


Figure 30. Daily mean total nitrogen and total phosphorus loads at the mouth of East Bay, June 1992

Bay determined that (1) sediment concentrations of nitrogen and phosphorus are variable, (2) concentrations of nitrogen and phosphorus generally are positively correlated with sediment mud content, and (3) concentrations are greater near the terminals than in areas located away from the terminals (Chastain-Skillman, Inc., 1993). Nutrient-rich bottom sediments can be resuspended in the water column by increased water velocities caused by increased discharges, by dredging activities, by wind, or by propeller wash from ships. Resuspension of bottom sediments, especially those near the shipping terminals, could result in an increase in the rate of nutrient loading from East Bay to Hillsborough Bay during periods of increased discharges.

SUMMARY AND CONCLUSIONS

Nutrient enrichment in Tampa Bay has been recognized as the most significant factor affecting water quality in Tampa Bay. The Port of Tampa, the seventh largest harbor in the United States, is located in East Bay, a highly modified part of Hillsborough Bay. East Bay was created when depths in part of McKay Bay were increased from about 5 ft to about 35 to 40 ft by dredging, and the shoreline was altered by fill. Phosphate and related products such as fertilizer are main products handled at the port. Because the potential for nutrient loading from shipping activity is high, a study was initiated to evaluate the load of nitrogen and phosphorus from East Bay to Hillsborough Bay.

Discharge and water-quality conditions were measured at the head of East Bay (McKay Bay), at the mouth of Delaney Creek (a tributary to East Bay), and at the mouth of East Bay during October 1991 and June 1992 through May 1993. Discharge and constituent concentration data were used in load computations.

Evaluation of discharge data indicates that discharges in McKay Bay, East Bay, and Delaney Creek are highly variable because of the effect of tide. Flow patterns generally are unidirectional at McKay Bay and Delaney Creek but are more complex at the mouth of East Bay. Bidirectional flows were observed during all discharge measurements made at the mouth of East Bay. Measured discharges were used to develop ratings that could be used to compute instantaneous discharges (15-minute interval) at McKay Bay and Delaney Creek. Variations in the instantaneous discharge data that were caused by tide were removed using the Godin filter. Once filtered, a net daily mean discharge was computed.

Instantaneous discharge from McKay Bay during June 1992 through May 1993 ranged from about -16,900 ft^3/s to about 24,000 ft^3/s. Net daily mean discharge was much less than instantaneous discharge and ranged from about -1,900 ft^3/s to 2,420 ft^3/s during the study. Instantaneous discharge from Delaney Creek ranged from about -325 ft^3/s to 600 ft^3/s, and daily mean discharge ranged from -3.8 ft^3/s to 162 ft^3/s. Because of the complex flow patterns caused by gyres at the mouth of East Bay, discharge ratings could not be developed for this site. Instantaneous discharges for East Bay were estimated by summing the instantaneous discharges from McKay Bay and Delaney Creek and from estimates of rainfall-generated discharge.

Discharges from McKay Bay, Delaney Creek, and East Bay generally were greatest during June through mid-September 1992 and during late March through May 1993. Discharges during November 1992 through January 1993 generally were less than during the rest of the study, and discharges at times were negative.

Results from two reconnaissance samplings in October 1991 showed that constituent concentrations vary vertically in East Bay, nutrient concentrations in Delaney Creek are greater than in East Bay, and concentrations of most constituents vary with tide. These results were used to design data-collection activities for the remainder of the study.

Water-quality data collected during June 1992 through May 1993 showed that more than 80 percent of the total nitrogen in East Bay was as organic nitrogen and about 10 to 15 percent was as ammonia. In Delaney Creek, total nitrogen and phosphorus concentrations were greater than in McKay Bay and East Bay. About 68 percent of the total nitrogen in Delaney Creek was as organic nitrogen, and about 18 percent was as ammonia. Orthophosphorus accounted for about 85 to 90 percent of the total phosphorus in McKay Bay, East Bay, and Delaney Creek.

Concentrations of total nitrogen and ammonia plus organic nitrogen generally were greater at the head of East Bay than at the mouth of East Bay, indicating that McKay Bay is the primary source of nitrogen in East Bay. Concentrations of total ammonia nitrogen, nitrite plus nitrate nitrogen, phosphorus, orthophosphorus, and suspended solids and the magnitude of turbidity and specific conductance generally were greater at the mouth than at the head of East Bay. Greater concentrations of total ammonia nitrogen, nitrite plus nitrate nitrogen, orthophosphorus, and phosphorus may occur at the mouth of East Bay because of inputs of these constituents from Delaney Creek and from shipping activities in the East Bay basin.

Water-quality conditions at the mouth of East Bay varied with depth and location in the cross section. Specific-conductance values and phosphorus and ammonia nitrogen concentrations were greater near the bottom, but water color and nitrite plus nitrate nitrogen and orthophosphorus concentrations were greater near the surface. These patterns indicate that vertical stratification in water quality exists at the mouth of East Bay.

Water-quality conditions at the head of East Bay at McKay Bay indicate that vertical stratification of selected constituents occurs. Specific-conductance values and ammonia nitrogen, phosphorus, and orthophosphorus concentrations generally were greater near the bottom. Water color generally was greater near the surface.

Water quality varied seasonally in East Bay (at the head and at the mouth). The greatest concentrations of nitrogen, phosphorus, orthophosphorus, and ammonia plus organic nitrogen occurred in summer, whereas turbidity, specific conductance, and concentrations of suspended solids were greater in winter. Seasonal variations in water quality also occurred at the mouth of Delaney Creek. The greatest concentrations of nitrogen, phosphorus, orthophosphorus, ammonia nitrogen, ammonia plus organic nitrogen, and values for color occurred in summer, whereas the least concentrations of these occurred in fall and spring.

The specific conductance of water in McKay Bay and Delaney Creek varied continually because of the effects of tide. Specific conductance generally increased during floodtide and decreased during ebbtide. Seasonal variations in specific conductance generally were the result of variations in freshwater inflow. The lowest specific conductance occurred during periods of highest freshwater inflows.

The discharge and constituent concentration data collected during the study were used to compute nutrient loads from McKay Bay, Delaney Creek, and East Bay. These measured loads represent loads at the time of water-quality sampling. Simple linear regression analysis was used to develop equations that relate measured loads to discharge. These equations were then used to estimate nutrient loads for the period June 1992 through May 1993.

Instantaneous nitrogen and phosphorus loads (computed at 15-minute intervals) were highly variable because of the effects of tide. Tidal variations in the data were removed with the Godin filter, and filtered data were used to compute net daily mean loads from McKay Bay, Delaney Creek and East Bay.

The greatest daily mean loads from McKay Bay and East Bay during the study occurred in June 1992, and in April and May 1993. These loads coincided with periods of discharge greater than about 2,000 ft^3/s. Nitrogen and phosphorus loads occasionally were negligible or less than zero. Negative loads occurred because the corresponding discharges were negative. Negative discharges and loads indicate a net upestuary movement of water and the associated water-quality constituents.

Although concentrations of nitrogen and phosphorus are much greater in Delaney Creek than in McKay Bay and East Bay, loads of these constituents from Delaney Creek are minimal. Minimal loads occur because the net discharge from Delaney Creek typically is small.

Monthly loads of nitrogen ranged from about 20 tons to about 83 tons at McKay Bay; from 1 ton to 4.2 tons at Delaney Creek; and from about 17 tons to 76 tons at the mouth of East Bay. Monthly loads of phosphorus ranged from about 11 tons to about 45 tons at McKay Bay; from about 0.62 ton to 2.6 tons at Delaney Creek; and from about 10 tons to about 45 tons at the mouth of East Bay. The greatest monthly loads from McKay Bay and East Bay occurred in April and May 1993. The least monthly loads occurred in December 1992.

July 1992 was the only month during the study when a measurable load of both nitrogen and phosphorus occurred from the East Bay basin (1.3 tons and 1.9 tons, respectively), excluding the load from McKay Bay and Delaney Creek. During the remainder of the study, nitrogen and phosphorus loads from East Bay to Hillsborough Bay primarily were the result of loads from McKay Bay and Delaney Creek. These results indicate that the net load of nitrogen and phosphorus from East Bay to Hillsborough Bay during the study was minimal.

The results of this study indicate that losses of fertilizer products during shipping activities are not a significant source of nitrogen and phosphorus to Hillsborough Bay. The two factors that explain these minimal loads are (1) changes in shipping and industrial practices in the East Bay and Delaney Creek basin have resulted in reduced nitrogen and phosphorus loading to Hillsborough Bay from these sources; and (2) the small net discharges from the East Bay basin to Hillsborough Bay during June 1992 through May 1993 have resulted in minimal loads during this period. If discharges from East Bay increase, then loads would increase.

REFERENCES CITED

ASCI Corporation, 1993, Phase I—Tampa Bay water quality model: Prepared for the Southwest Florida Water Management District, Tampa, Fla., 124 p., plus app.

Boler, Richard, 1992, Surface water quality, Hillsborough County, 1990–1991: Hillsborough County Environmental Protection Commission, 196 p.

Cardinale, T., and Dunn, C., 1991, Hillsborough County Environmental Protection Commission East Bay study, *in* Treat, S.F., and Clark, P.A., eds., Proceedings, Tampa Bay Area Scientific Information Symposium 2, February 27–March 1, 1991: Tampa Bay Regional Planning Council, p. 439–455.

Chastain-Skillman, Inc., 1993, Sediment sampling results summary report: Prepared for CF Industries, Inc., Tampa, Fla., 13 p., plus apps.

Dittner, Elizabeth, ed., 1992, Tampa Port Authority official directory, 1992: Coral Gables, Fla., Charter North America, Inc., p. 4–7.

Dyer, K.R., ed., 1979, Estuarine hydrography and sedimentation—A handbook: London, Cambridge University Press, 230 p.

Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

Florida Department of Environmental Regulation, 1990, Surface Water Improvement and Management Act: Florida Administrative Code, chap. 17–43, May 3, 1990, 10 p.

Goodwin, C.R., 1987, Tidal-flow, circulation, and flushing changes caused by dredge and fill in Tampa Bay, Florida: U.S. Geological Survey Water-Supply Paper 2282, 88 p.

Helsel, D.R., 1990, Less than obvious; statistical treatment of data below the reporting limit: Environmental Science and Technology, v. 24, no. 12, p. 1766–1774.

Johansson, J.O.R., 1991, Long-term trends of nitrogen loading, water quality and biological indicators in Hillsborough Bay, Florida, *in* Treat, S.F., and Clark, P.A., eds., Proceedings, Tampa Bay Area Scientific Information Symposium 2, February 27-March 1, 1991: Tampa Bay Regional Planning Council, p. 157–176.

National Oceanic and Atmospheric Administration, 1993a, Climatological data, annual summary 1992: U.S. Department of Commerce, National Climate Center.

____1993b, Climatological data, monthly summaries, January through May 1993: U.S. Department of Commerce, National Climate Center.

Rantz, S.E., and others, 1982, Measurement and computation of streamflow, Volume 1, Measurement of stage and discharge: U.S. Geological Survey Water-Supply Paper 2175, 641 p.

Simpson, M.R., and Oltmann, R.N., 1992, Discharge-measurement system using an acoustic Doppler current profiler with applications to large rivers and estuaries: U.S. Geological Survey Open-File Report 91-487, 49 p.

Tampa Bay National Estuary Program, 1993, Tampa Bay status and trends: St. Petersburg, Fla., Tampa Bay National Estuary Program, 44 p.

Walters, R.A., and Heston, Cynthia, 1982, Removing tidal-period variations from time-series data using low-pass filters: Journal of Physical Oceanography, v. 12, no. 1, p. 112–115.

Zarbock, Hans, Janicki, Anthony, Wade David, Heimbuch, Douglas, and Wilson, Harold, 1994, Estimates of total nitrogen, total phosphorus, and total suspended solids loadings to Tampa Bay, Florida: Tampa Bay National Estuary Program Technical Publication 04-94, 113 p., plus apps.