EFFECTIVENESS OF A STORMWATER COLLECTION AND DETENTION SYSTEM FOR REDUCING CONSTITUENT LOADS FROM BRIDGE RUNOFF IN PINELLAS COUNTY, FLORIDA

By YVONNE E. STOKER

U.S. GEOLOGICAL SURVEY

Open-File Report 96-484

Prepared in cooperation with

PINELLAS COUNTY

Tampa, Florida

1996

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Gordon P. Eaton, Director

For additional information, write to:

District Chief
U.S. Geological Survey
Suite 3015
227 North Bronough Street
Tallahassee, Florida 32301

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286
Denver, Colorado 80225-0286

CONTENTS

FIGURES

TABLES

EFFECTIVENESS OF A STORMWATER COLLECTION AND DETENTION SYSTEM FOR REDUCING CONSTITUENT LOADS FROM BRIDGE RUNOFF IN PINELLAS COUNTY, FLORIDA

By Yvonne E. Stoker

ABSTRACT

The quantity and quality of stormwater runoff from the Bayside Bridge were evaluated to determine the effectiveness of the stormwater collection and detention pond system of the bridge in reducing constituent loads to Old Tampa Bay. Water-quality samples of stormwater runoff from the bridge, and outflow from the detention pond, were collected during and after selected storms. These samples were used to compute loads for selected constituents.

Stormwater on the Bayside Bridge drained rapidly during rain events. The volume of stormwater runoff from 24 storms measured during the study ranged from 4,086 to 103,705 cubic feet. Storms were most frequent during July through September and were least frequent from February through May.

Concentrations of most constituents in stormwater runoff before the bridge opened to traffic were less than or equal to concentrations measured after the bridge was opened to traffic. However, concentrations of arsenic in the outflow from the detention pond generally were greater before the bridge opened than concentrations after, and concentrations of orthophosphorus in the stormwater runoff and outflow from the pond were greater before the bridge opened than during over half the sampled storms after the bridge opened.

Concentrations of most constituents measured in stormwater runoff from the bridge were greatest at the beginning of the storm and decreased as the storm continued. Variations in suspended solids, nutrients, and trace element concentrations were not always concurrent with each other. The source of the measured constituent (rainfall or road debris) and the phase of the constituent (suspended or dissolved) probably affected the timing of concentration changes.

The quality of stormwater runoff from the Bayside Bridge varied with total runoff volume, with the length of the dry period before the storm, and with season. Average concentrations of suspended solids, ammonia plus organic nitrogen, nitrite plus nitrate nitrogen, orthophosphorus, phosphorus, total organic carbon, aluminum, arsenic, copper, and zinc in stormwater runoff generally were inversely related to runoff volume.

The quality of outflow from the detention pond also varied during a storm event and with season. Maximum concentrations generally occurred near the beginning of a storm, and decreased as the storm continued. Maximum concentrations of many constituents occurred in June and July 1995. During the summer months, pH exceeded 9.0 while inorganic nitrogen concentrations were very low. These high pH values and low inorganic nitrogen concentrations are most likely associated with photosynthesis by algae or aquatic plants in the pond.

Concentrations of nitrogen, phosphorus, and nickel in stormwater runoff were correlated with total organic carbon concentrations. Concentrations of chromium, copper, iron, nickel, lead, and zinc in stormwater runoff were correlated with aluminum concentrations. The source of these metals is probably the bridge materials and metallic debris from vehicles.

The northern detention pond system of the Bayside Bridge effectively reduced concentrations of suspended solids, ammonia nitrogen, nitrite plus nitrate nitrogen, phosphorus, aluminum, cadmium, chromium, copper, iron, lead, nickel, and zinc in stormwater runoff before water discharged from the pond. However, concentrations of ammonia plus organic nitrogen, organic carbon, arsenic, and values for alkalinity, pH, and specific conductance generally were greater in outflow from the pond than in stormwater runoff from the bridge.

Stormwater runoff and pond outflow for three storm events were evaluated to determine the effective-

ness of the detention pond system in removing selected constituents from the stormwater runoff. Most constituents and constituent loads were reduced in the outflow from the pond. Suspended solids loads were reduced about 30 to 45 percent, inorganic nitrogen loads were reduced by about 60 to 90 percent, and loads of most trace elements were reduced by about 40 to 99 percent. However, the pond exports ammonia plus organic nitrogen, organic carbon, arsenic, and phosphorus. The source of most of these constituents probably is biological activity in the pond. The export of arsenic and the elevated concentrations of arsenic in the pond outflow before the bridge opened implies that arsenic is stored in the pond sediments and is being released to the overlying pond water.

INTRODUCTION

Stormwater runoff quality was not considered in the design of drainage systems before the 1960's. Drainage from urban areas often was diverted directly to receiving water bodies such as streams, lakes, and estuaries. Studies of urban runoff indicated that stormwater runoff from urban areas contained high concentrations of suspended solids, nitrogen, phosphorus, trace elements, oils and grease, and organic chemicals. The Federal Clean Water Act required the development of management plans to control both point and nonpoint sources of pollution (Livingston, 1989). In response to this regulation, the quality and quantity of stormwater runoff is regulated in the design of new drainage projects.

State of Florida regulations currently (1996) require retention or detention with filtration of the runoff from the first inch of rainfall (Florida Department of Environmental Protection, 1993). Stormwater retention or detention ponds often are required to store and treat stormwater runoff from urban areas. New stormwater management systems that discharge to Outstanding Florida Waters are required to reduce at least 95 percent of the average annual load of pollutants (Florida Department of Environmental Protection, 1995).

Studies have shown that wet detention ponds can be effective in the removal of some contaminants in stormwater. Martin and Smoot (1986) reported that a detention pond and wetlands storage system was effective in the removal of suspended solids, nitrogen, phosphorus, lead, and zinc. Schiffer (1989) studied the water quality of two wetlands that receive stormwater and reported that water quality improved significantly from the inlet to the outlet of the pond and wetland system. Rushton and Dye (1993) reported that removal rates of selected nutrients and metals in a wet detention pond were between 30 to 60 percent. Kantrowitz and Woodham (1995) reported that a wet detention pond in Pinellas County was effective in removing selected metals, nutrients, suspended solids, and in reducing oxygen demand.

Factors Affecting Effectiveness of Stormwater Collection and Detention Systems

Detention and retention basins generally remove or reduce suspended and dissolved constituents in stormwater by physical, chemical, and biological processes (Yousef and others, 1986). The pond and outflow design are important factors in the ability of the pond to remove pollutants from storm runoff. Cunningham (1993) reported that the depth of a pond influenced the rate of total suspended solids removal. Pond design also controls the storage capacity of the pond and the detention time of stormwater within the pond. Zarriello (1989) reported that detention of suspended sediments, phosphorus, lead, and zinc was greater in maximum-storage ponds (wet ponds) than in temporary-storage ponds. Generally, longer detention times result in greater removal of suspended sediments.

Water-quality characteristics of stormwater generally are affected by basin characteristics and the quantity and quality of rainfall. A national study of urban runoff in the United States showed that total storm rainfall, total contributing drainage area, impervious area, land-use, and climatic characteristics were statistically significant variables that can be used to estimate storm runoff loads (Driver and Tasker, 1990).

Problem

The State of Florida has designated the surface waters of Pinellas County as an aquatic preserve (Florida Department of Environmental Protection, 1996). This designation classifies these waters as an Outstanding Florida Water and is intended to protect the Pinellas County part of Old Tampa Bay from non-permitted water-quality degradation. The Bayside Bridge runs north-south, traversing the western section of Old Tampa Bay (fig. 1). Because the designation provides State-mandated water-quality protection, the bridge design required a specialized stormwater collection and treatment system. The design of the stormwater collection system of the Bayside Bridge added considerably to the bridge construction costs. The effectiveness of this type of stormwater collection and detention system in reducing pollutant concentrations and loads has not previously been studied. The unique stormwater collection and detention system of the Bayside Bridge also provides an opportunity to study stormwater runoff from only one source, roadway runoff.

Purpose and Scope

This report describes the results of a 3.5-year study designed to determine the quantity and quality of roadway runoff from the Bayside Bridge and to evaluate the effectiveness of the stormwater collection and detention pond system in reducing constituent concentrations and loads to Old Tampa Bay. The study began in April 1993 and ended in September 1996 and focused on the collection and detention system for the northern end of the bridge. Background water and sediment quality of the stormwater detention system were assessed before the bridge was opened to traffic. After the bridge was opened to traffic, water-quality samples were collected during and after selected storms to characterize stormwater runoff and pond outflow. Samples for pH, specific conductance, alkalinity, total organic carbon, nutrients (ammonia nitrogen, nitrite plus nitrate nitrogen, nitrite nitrogen, ammonia plus organic nitrogen, orthophosphorus, phosphorus), and selected trace elements (aluminum, arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, and zinc) were collected during selected storms from May 1993 to September 1995. Continuous stage and rainfall data were collected during May 1993 to October 1995. Flow measurements were made to calculate inflow and outflow. Constituent loads into and out of the pond were calculated for selected storms during the study to evaluate the effect of the wet-pond detention system.

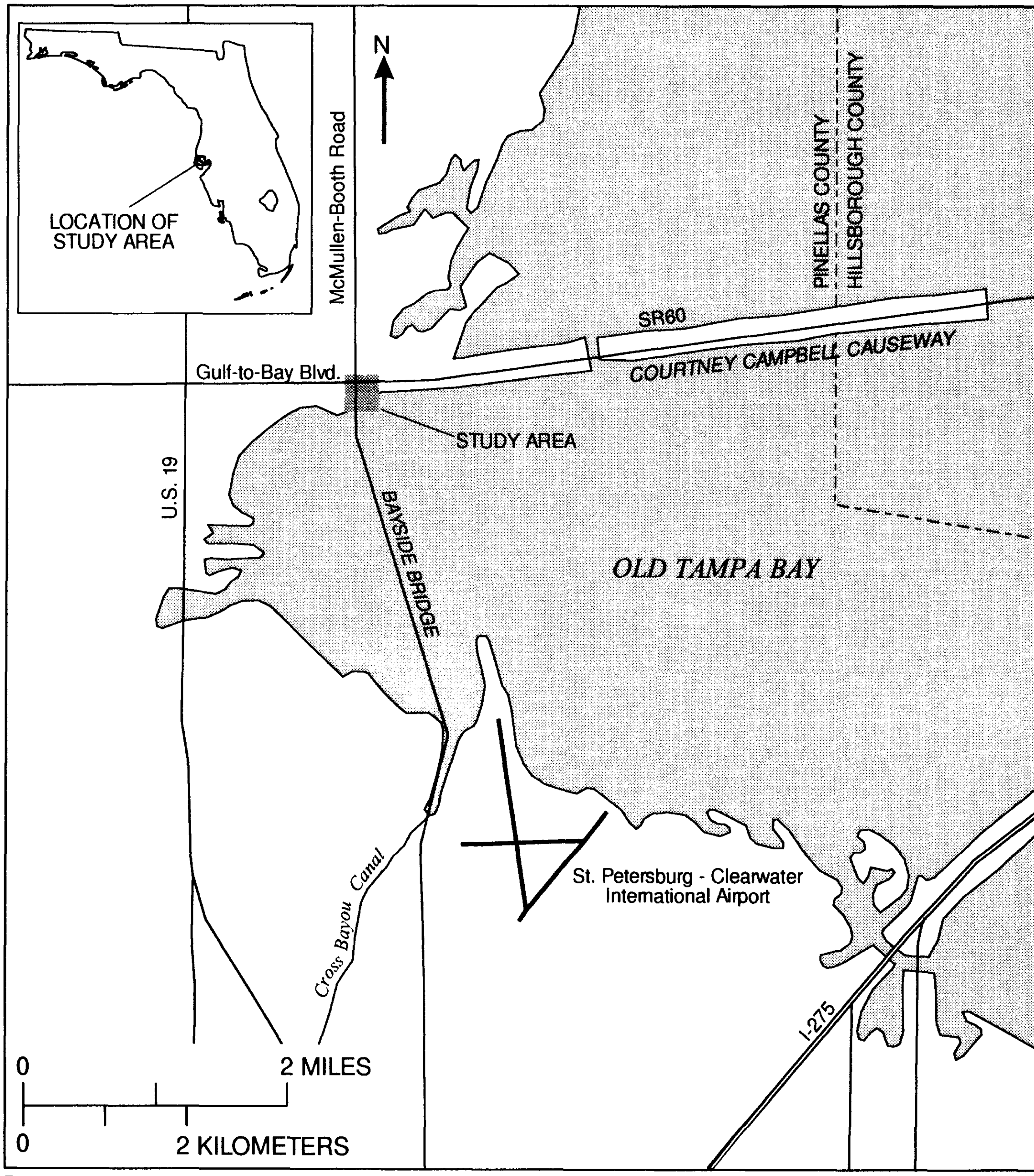
Acknowledgments

The author is grateful to the Metropolitan Planning Organization for providing information on traffic patterns on the Bayside Bridge and the staff at the Clearwater Wastewater Treatment Plant for rainfall data. The assistance of Terrie Lee, Paul Boetcher, Victor Levesque, and Horace Blankenship, U.S. Geological Survey, in the design of the project and in programming and data collection is greatly appreciated. Special thanks also go to Erik Staub, intern with the Environmental Careers Organization, for his help in collecting and displaying the data for the project.

DESCRIPTION OF STUDY AREA

The Bayside Bridge is located in Pinellas County in west-central Florida and crosses the western part of Old Tampa Bay, south of State Road 60 (fig. 1). The bridge is about 2.7 miles (mi) in length with a separate northbound and southbound span. The road surface is concrete and the surface elevation ranges from about 14 feet (ft) above sea level near the ends of the bridge to about 53 ft above sea level at an elevated center crest (James Collins, Pinellas County, oral commun., 1996). The center is elevated to provide clearance for a boat channel in Old Tampa Bay. The bridge was opened to traffic on June 2, 1993.

The stormwater collection and detention system of the Bayside Bridge was designed to convey and store the water volume equivalent to 1.5 inch (in.) of rainfall on the bridge. Stormwater on the bridge drains through iron grating to 12- to 30-in. fiberglass resin stormwater collection pipes under the bridge (fig. 2). Stormwater in the pipe flows by gravity to either the north or south end of the bridge; the elevated crest is the drainage divide for the bridge. Rainfall exceeding the 1.5-in. capacity of the collection system discharges directly to Old Tampa Bay through overflow scuppers located adjacent to the stormwater collection drains. The study area includes the northern section of the bridge drainage system.



Base from U.S. Geological Survey
Safety Harbor, 1:24,000, photorevised 1987

Figure 1. Study area.

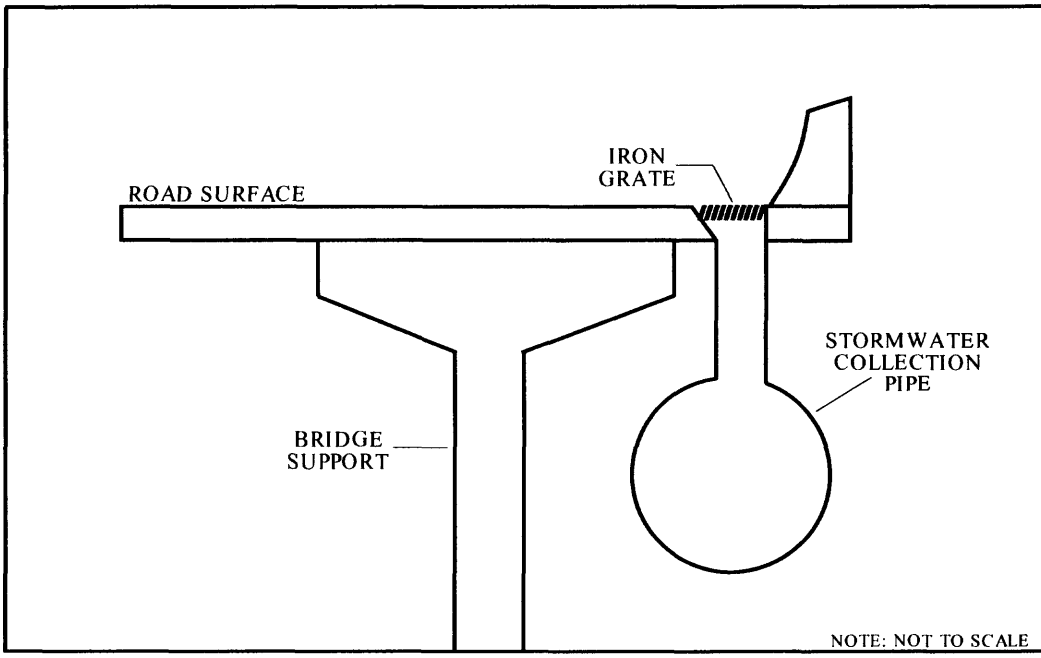


Figure 2. Schematic of the stormwater collection system.

The bridge's road surface area that drains to the northern part of the stormwater collection system is about 561,000 square feet (ft^2) (12.9 acres). Stormwater drains into the detention pond and an overflow pond at the north end of the bridge (fig. 3). The main detention pond is connected to the overflow pond by a buried 18-in. pipe under the northbound exit ramp. The surface area of the detention and overflow ponds is 82,800 ft^2 (1.9 acres) at an elevation of 4.0 ft above sea level, which is the elevation at which the ponds are hydraulically connected. The detention pond is very shallow; at an elevation of 4.0 ft above sea level, most of the pond is less than 1 ft deep, with a maximum depth of about 1.5 ft. Sides of the pond are lined with an impervious material, so that leakage from the berm surrounding the pond does not occur. Sediments below the detention pond are fine-grained and clayey, creating an effective confining layer on much of the pond bottom. Excess water in the detention pond currently (1996) flows out of the pond through a bleed-down pipe and a concrete weir into a ditch along the east side of the pond. Flow from the ditch enters Old Tampa Bay about 350 ft south of the weir. A bleed-down pipe was not installed during the original pond construction but was installed on the north end of the detention pond in December 1993, 7 months after the pond was built. In April 1994, a new bleed-down pipe was installed near the outflow gage so that outflow samples could be collected by an automatic sampler. In May 1994, the old outflow pipe was capped.

The volume of traffic on the Bayside Bridge has been periodically monitored by the Pinellas County Metropolitan Planning Organization (MPO). Traffic counts for selected days are listed in table 1. These counts represent the average of traffic counts made during several days. Most count periods were Tuesday through Thursday (Gina Goodwin, MPO, oral commun., 1993).

The volume of traffic on the Bayside Bridge varied with time of day and with season. The average annual daily traffic count was 37,398 vehicles per day in 1993, the first year the bridge was opened, and was 48,788 vehicles per day in 1994 (Gina Goodwin, MPO, oral commun., 1996). This represents a 30 percent increase in traffic between 1993 and 1994.

Climate in the study area is subtropical and humid. Normal annual rainfall (June 1961 to May 1990) is 43.92 in. at Tampa (National Oceanic and Atmospheric Administration, 1994). Rainfall at Tampa was 12.16 in. below normal June 1993 to May 1994, and was 5.74 above normal the following year. Monthly rainfall recorded at the detention pond during the study is shown in figure 4.

Table 1. Total daily traffic counts for the Bayside Bridge on selected days

Start date	Total daily traffic count
June 8, 1993	35,891
June 15, 1993	36,081
July 20, 1993	37,751
Sept. 21, 1993	39,498
Feb. 7, 1994	44,197
Sept. 20, 1994	46,027
Feb. 22, 1995	55,725
Mar. 21, 1995	53,574

METHODS

Pond elevation, rainfall, the quality of stormwater into and out of the detention pond, and sediment quality were determined for this study. These data were used to evaluate the quality of stormwater runoff from the Bayside Bridge and to evaluate the loading of selected constituents from the bridge. The quality of water entering Old Tampa Bay from the Bayside Bridge detention pond system also was evaluated from these data and constituent loads from the detention pond were determined for selected storms.

Gages to measure pond elevation and rainfall were constructed near the inflow and outflow points of the detention pond (fig. 3) and were operated from May 1993 through September 1995. Pond elevation at the inflow and outflow gages was measured using a float and weight assembly that was connected to a shaft encoder and an electronic data logger. Rainfall was measured at the inflow gage using a tipping bucket rainfall gage and was recorded with an electronic data logger. The recording interval for both the inflow and outflow elevation gages and rainfall gage was 5 minutes. A storage rainfall gage was used to check the tipping bucket rainfall gage.

Water-quality samples were collected near the inflow and outflow of the detention pond with programmable automated refrigerated samplers. Each sampler used a peristaltic pump to deliver samples to eight 2-liter polyethylene sample bottles. The sampler intake lines were purged with air before and after each sample was collected during a storm. The sampler included a datalogger that stored the sampling dates and times. The automated sampler was used to collect inflow and outflow samples during selected storms from late July 1993 to September 1995.

Outflow Discharge and Volume Computations

Outflow discharge from the detention pond was computed using ratings developed from discharge measurements made during selected outflow conditions. Ratings were developed for both the concrete weir and for the bleed-down pipe installed in April 1994.

The weir rating is based on 21 measurements made between June 1 and Sept. 8, 1993. Both a standard current meter method and a volumetric discharge measurement method (Rantz and others, 1982) were used to determine discharge over the concrete weir. Discharge over the weir occurred when the pond elevation exceeded 4.43 ft above sea level.

The bleed-down pipe rating is based on 17 measurements made between Nov. 7, 1994 and Dec. 4, 1995. Measurements were made using a volumetric method modified from Rantz and others (1982). The bleed-down pipe had a downward facing elbow on the pond side of the pipe which resulted in a siphon effect in the pipe during discharge from the pipe. Discharge from the pipe began when pond elevation was greater than 3.56 ft above sea level. The siphon effect could not occur unless the pond elevation exceeded about 3.85 ft above sea level. The bleed-down pipe was completely submerged above this elevation.

The volume of selected storms was computed as a sum of the discharges that occurred from the beginning of the storm to the end of the storm effect. The end of the storm effect was determined from the pond elevation data. This volume includes the volume of direct rainfall on the pond.

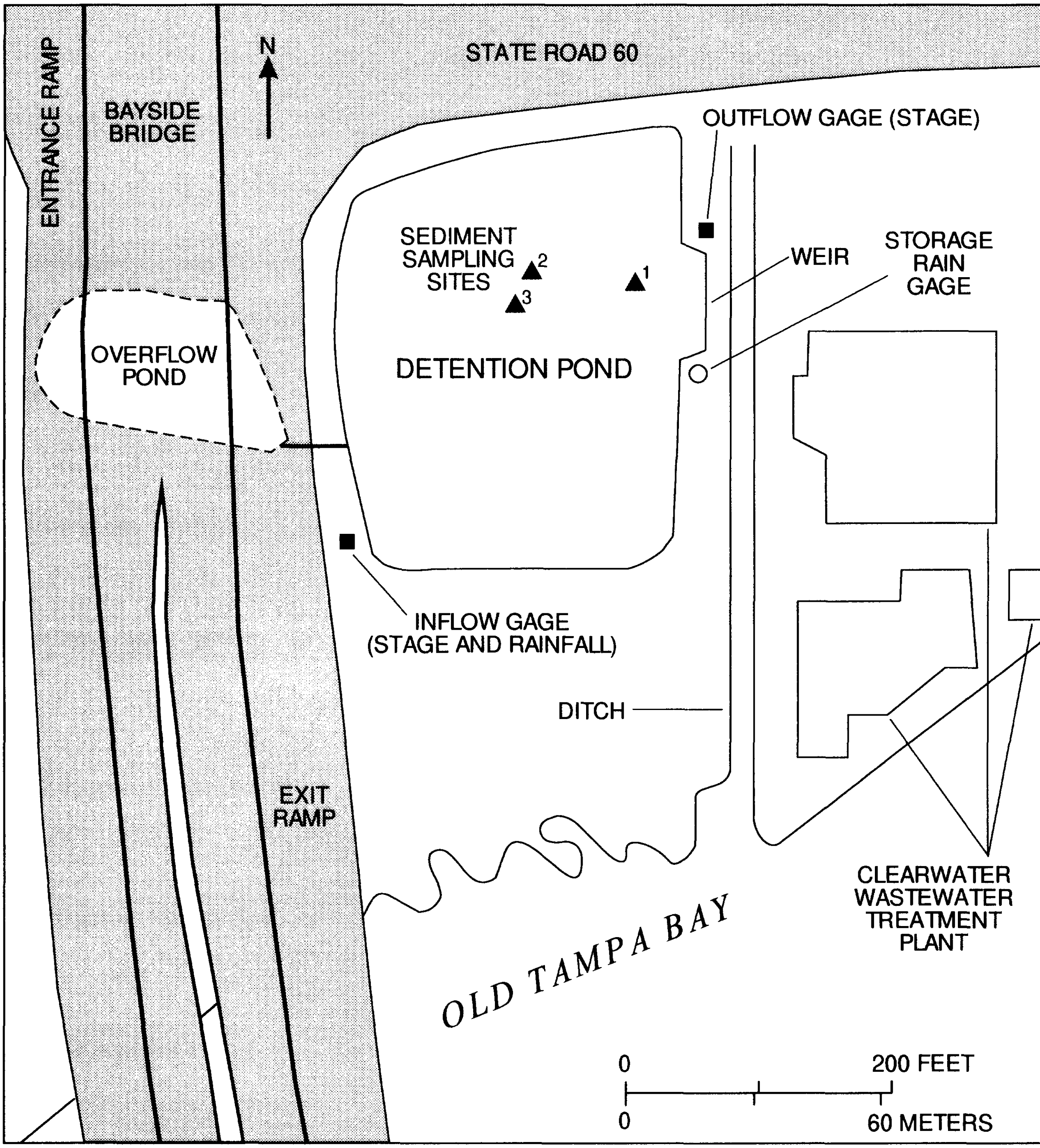


Figure 3. The northern stormwater detention pond system of the Bayside Bridge and location of study gages.

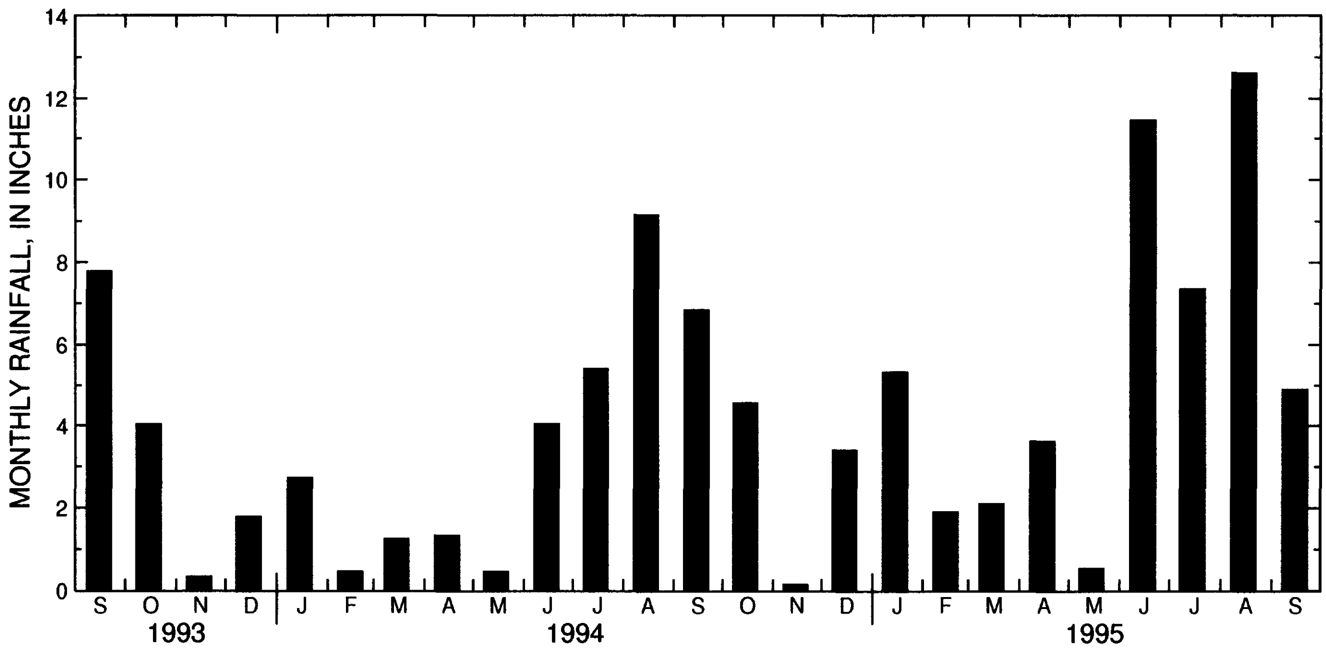


Figure 4. Monthly rainfall at the detention pond during the study.

Inflow Discharge and Volume Computations

In order to consider all rainfall conditions, the stormwater runoff volume of selected storms was determined by two methods. The first method used the weir and pipe ratings developed for the outflow gages. The amount of discharge from the detention pond that was generated from a storm event was summed to estimate the total runoff volume into the detention pond from the Bayside Bridge. This method could not be used when subsequent storms occurred before the pond elevation returned to its original level prior to the storm event. The runoff volumes were computed for 14 storms using this method. The second method, more suitable for frequent storm occurrences, was based on the relation between pond elevation and pond volume. An elevation-volume rating was developed from bathymetric data for both the detention pond and the connected overflow pond. This method was not affected by subsequent storms. Runoff volume was computed for 24 storms using this method. The volume of direct rainfall on the pond was subtracted from the total volume in both methods. Although the elevation-volume rating allowed volume computations for more storms, it could not easily be applied to the outflow volume computations.

Runoff coefficients for the northern part of the Bayside Bridge were calculated from the runoff volume, storm rainfall totals, and the surface area of that part of the bridge that drains to the north as follows:

$$C = \frac{V/A}{R/12} \qquad (1)$$

where

C is the runoff coefficient;

V is the runoff volume, in cubic feet;

A is 561,000 ft^2, the area of the bridge that drains to the north; and

R is the storm rainfall, in inches.

Sample Collection and Analyses

Water-quality samples were collected at the inflow to the detention pond to describe stormwater characteristics of the bridge runoff. Samples also were collected near the outflow weir in the detention pond to describe the quality of runoff to Old Tampa Bay and the effect of the pond on stormwater quality. Whole-water samples were collected and analyzed for pH, specific conductance, alkalinity, total organic carbon, nutrients (ammonia nitrogen, nitrite plus nitrate nitrogen, nitrite nitrogen, ammonia plus organic nitrogen, orthophosphorus, and phosphorus), and selected trace elements (aluminum, arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, and zinc).

Samples at both sites were collected manually and with an automated refrigerated sampler. Once samples were collected, the rainfall and stage data were examined in the field. At times, the rain event ended before the end of the automated sampling sequence at the inflow site. When this happened, some of the samples did not represent stormwater inflow to the pond, but represented standing water in the pond. These samples were discarded.

The samples were brought to the laboratory for processing and preservation. Samples were mixed using a magnetic stirrer while water was divided into individual sample bottles. Once processed, the samples were sent to the USGS laboratory in Ocala, Fla., for analyses. The analytical methods are documented in Fishman and Friedman (1989) and in Wershaw and others (1987). A total of 33 storms were sampled at the inflow to the detention pond, and 24 storms were sampled at the outflow.

The automatic samplers were programmed to begin sampling when the pond elevation increased above a set threshold in a 5-minute period. The threshold was periodically reset to increase or decrease the sensitivity of the sampler. For example, the threshold at the inflow gage was set to 0.04 ft for much of the study. If the pond elevation at the inflow increased more than 0.04 ft in a 5-minute interval, a signal was sent by the datalogger to the automatic sampler to begin sampling.

The inflow sampler was programmed to sample at the beginning of a storm event and at an interval sequence of 2, 5, 8, 12, 15, 15, and 30 minutes after sampling was triggered. This sampling sequence spanned 87 minutes from start to completion.

The outflow sampler was programmed to sample at the beginning of a storm event and at 15-minute intervals during July 1993 to July 1994. This sampling sequence spanned 105 minutes. In July 1994, a new program was installed that changed the total sampling interval to 24 hours, with eight evenly-spaced sampling increments. This change was made because discharge out of the detention pond after a storm event often exceeded the previous sampling time span.

Load Computations

Incremental constituent loads into the detention pond were computed from the measured concentrations of selected constituents at the inflow and the volume of stormwater inflow at the time of sampling. At times, the concentrations of a constituent were below analytical reporting limits (these data are called "censored data"). Calculation of loads using censored data can only be done if a value is substituted for the censored data. However, simple substitution of a value for censored data introduces a bias in the results because the actual concentration is unknown. Substituting a value of zero for all censored data will bias the results low, whereas substituting the reporting limit biases the results high (Helsel and Hirsch, 1995). For load computation and graphical display of such data, censored data were assigned a value of one half the analytical reporting limit. For example, the reporting limit for arsenic was 1 microgram per liter (µg/L). Values below the reporting limit were set to 0.5 µg/L for load computations.

Recorded rainfall was used to divide the total storm volume into increments that matched the time of sampling and were related to rainfall intensity. For example, if 20 percent of the total rainfall had occurred when the first sample was collected, then it was assumed that 20 percent of the total storm volume had entered the detention pond. The load calculated from the first sample would, therefore, represent the first 20 percent of the total storm load. Calculations of load using this method resulted in a load that was weighted by the incremental storm volume. The concentration of selected constituents in the first and last sample collected was used to estimate the load for the portion of the storm before and after automated sampling was completed. The total stormwater inflow load for a storm was calculated as the sum of the incremental loads calculated for individual samples. Loads were calculated for 24 of the 33 storms sampled at the inflow. Loads could not be computed for the remaining storms because of missing stage or rainfall data.

Calculation of loads out of the detention pond for a selected storm was more difficult because the effect of a storm on pond outflow lasted from several hours to several weeks. Often after a sampled storm, other storm events occurred before the pond elevation returned to the level prior to the sampled storm. Because these subsequent storms were not sampled, the outflow load could not be attributed to a single storm.

Incremental loads out of the detention pond were calculated from the measured concentrations of selected constituents at the outflow and the volume of outflow from the beginning of the storm to the time of the sample. Constituent concentrations below the analytical reporting limit were set to values one half the reporting limits, as described above. At times, outflow from the pond was occurring before selected storms. Incremental loads were calculated from the time the storm began to the day and time when the pond returned to pre-storm conditions. The concentration of the first and last collected sample was used to estimate the load for the unsampled portion of the storm before and after automated sampling was completed. The total outflow load for a storm was calculated as the sum of the loads calculated for individual samples. Loads were calculated for 3 of the 24 storms sampled at the outflow and only for those storms that had computed inflow loads.

RESULTS OF SAMPLING AND ANALYSES

The results of this investigation consist of the hydrology of the Bayside Bridge and detention pond, the quality of bridge runoff, and the quality of the detention pond sediments.

Hydrology of Bayside Bridge Drainage Area and Detention Pond

The volume of stormwater runoff from the Bayside Bridge to the detention pond is controlled primarily by the amount of rainfall. The duration of rainfall and climate conditions such as wind, temperature, and humidity can affect evaporation rates of rainfall on the bridge surface. An intense storm may exceed the capacity of the stormwater collection system and result in stormwater flow out of the overflow scuppers directly to Old Tampa Bay. High evaporation rates during a storm with low total rainfall and long duration would result in less stormwater runoff than a storm with a shorter duration.

Stormwater was rapidly drained from the roadway during rainfall. Pond elevation began to rise almost instantaneously after rainfall began (fig. 5). Because the pond storage capacity is small (a maximum storage of about 86,800 ft^3 at a pond elevation of 4.43 ft above sea level), outflow from the pond occurred during most storms. Before the bleed-down pipe was installed, pond elevations during the summer remained near the crest of the weir, resulting in little or no storage capacity in the pond. Stormwater entering the pond was rapidly discharged over the weir. Once the bleed-down pipe was installed, the pond elevation could decrease below the crest of the weir, thus increasing the storage potential of the pond before the next storm. Stormwater discharge over the weir continued to occur after some storms, but the detention time of stormwater in the pond was increased.

Rainfall-runoff characteristics were examined for the 24 storms that were used in constituent load calculations. Rainfall totals for these storms ranged from 0.12 to 3.15 in. The average storm duration was about 140 minutes and ranged from 10 to 395 minutes. The volume of stormwater runoff associated with these 24 storms is shown as a function of total storm rainfall (fig. 6). Runoff volume ranged from 4,086 to 103,705 cubic feet (ft^3). The largest runoff volume was not associated with the largest rainfall; rainfall during this storm was 2.37 in. Although rainfall was 3.15 in. on Jan. 14, 1995, runoff volume was only 91,733 ft^3 on this date.

Rainfall-runoff coefficients, as computed in equation 1, represent the percentage of rainfall that becomes runoff. Rainfall-runoff coefficients calculated for the 24 selected storms ranged from 0.44 to 1.46 (two storms) with a mean coefficient of 0.79. The highest coefficients are associated with two storms with the most intense rainfall. Rainfall for the most intense storm was 0.41 in. and the storm duration was only 10 minutes; the other storm with a coefficient of 1.46 had a rainfall total of 0.60 in. in 30 minutes. The variation in the runoff-rainfall coefficients can be explained by variations in rainfall (rain at the gage may not be representative of rain on the bridge), rainfall intensity (the tipping bucket gage tends to undermeasure very intense rainfall, so actual rainfall may be greater than recorded rainfall), time of day and season (evaporation rates on the bridge vary with temperature), and storm duration.

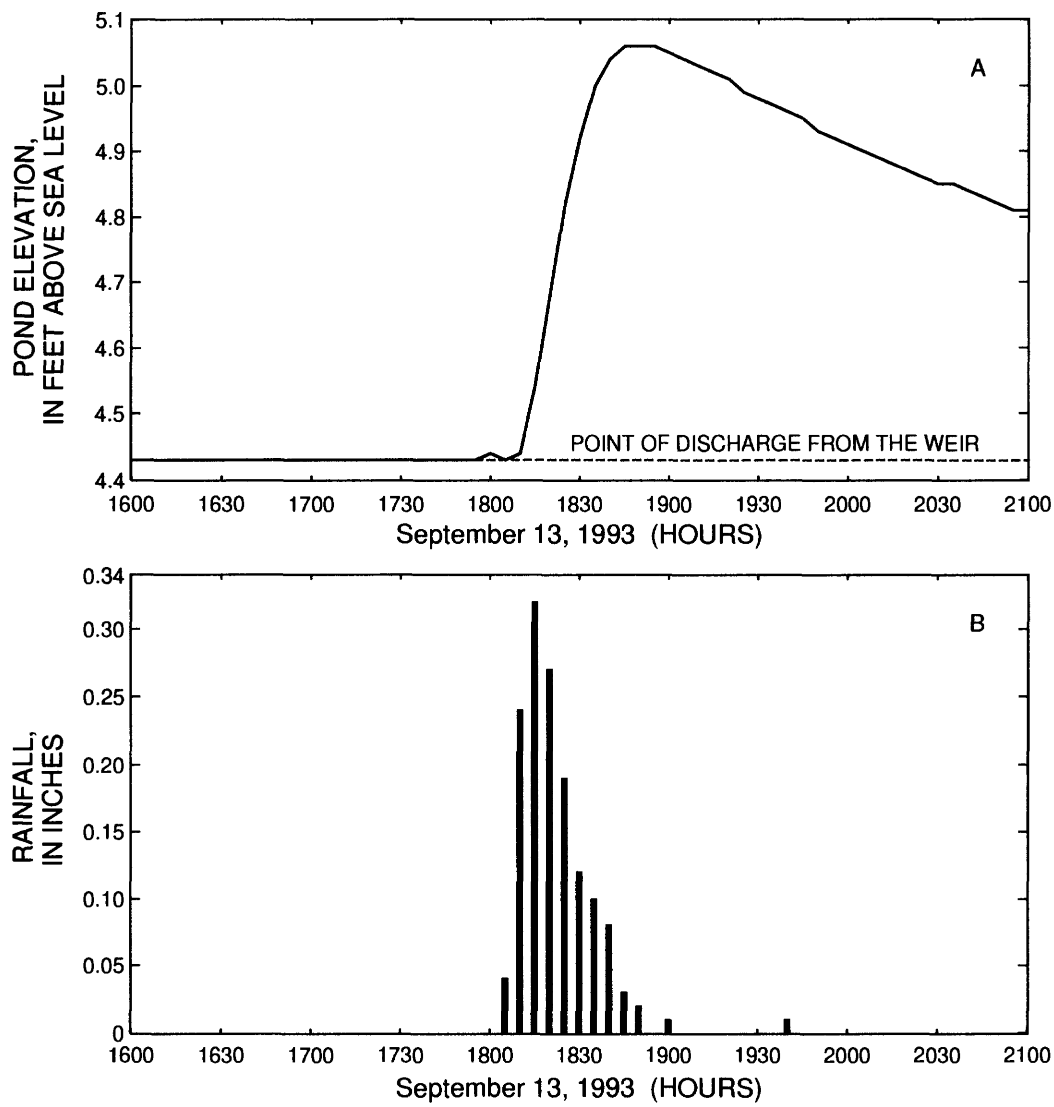


Figure 5. Response of the detention pond to rainfall during September 13, 1993.

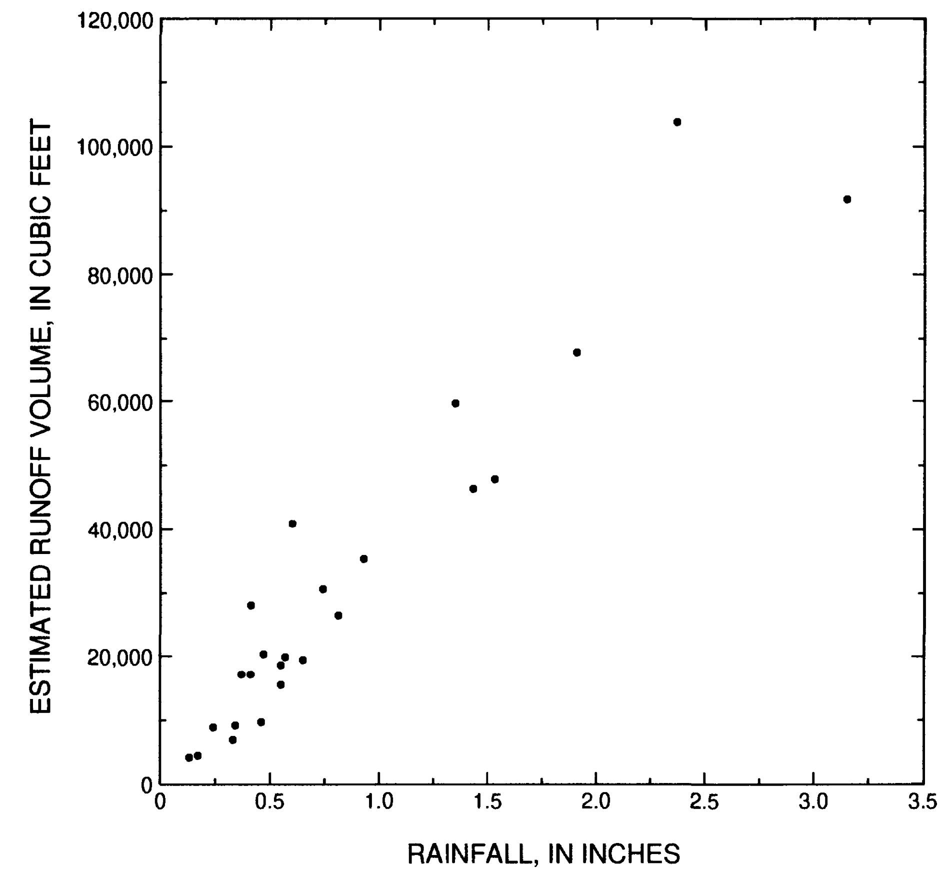


Figure 6. Volume of stormwater runoff to the detention pond as a function of rainfall for 24 selected storms.

The frequency of storms during the study varied with season. Storms were most frequent during July through September and generally were least frequent during February through May. Monthly rainfall ranged from 0.16 in. during November 1994 to 12.62 in. during August 1995 (fig. 3).

The detention pond became vegetated by natural recruitment of plants. This resulted in primarily Typha sp. (cattails) as the most common emergent species and Hydrilla sp. as the most common submerged macrophyte. At times, a glyphosate herbicide thickened with oil was sprayed around the perimeter of the pond and about 20 ft into the pond to control emergent vegetation (Lisa Baltus, Pinellas County, oral commun., 1995). Several weeks after spraying, dead and dying vegetation remained in the pond while vegetation in the center of the pond was healthy. Herbicide spraying occurred in October 1993; March and September 1994; and May, June, and September 1995.

Detention time in the pond was dependent on the antecedent conditions in the pond and on the volume of runoff entering the pond. During the early part of the study, the pond had virtually no storage capacity because the elevation of the pond remained at the crest of the weir. Storms sampled in August and September 1993 resulted in immediate outflow from the pond. Once the bleed-down pipe was installed, storage capacity of the pond could be increased between storm events. Of the 24 storms used in load computation, the volumes of 12 storms exceeded the storage capacity of the pond before the storm. (The storage capacity was computed as the volume of the pond at the crest of the weir minus the volume of water in the pond before the storm.) Detention time of these storms was minimal. Because of the bleed-down pipe, outflow from the pond occurred after most storms. However, outflow through the bleed-down pipe was at a much slower rate than outflow over the weir.

Quality of Runoff

Stormwater runoff and outflow samples were collected in May and June 1993 before the Bayside Bridge was opened to traffic. Concentrations of most constituents in the stormwater inflow to the detention pond and the outflow from the pond were less than or similar to concentrations measured during the study. Concentrations of arsenic in the outflow before the bridge opened were greater than concentrations measured for most of the sampled storms. Concentrations of orthophosphorus in both the inflow and outflow samples were greater before the bridge opened than concentrations in more than half the sampled storms. Specific conductance in the outflow was about 500 microsiemens per centimeter at 25 °C (μS/cm) in June 1993, a value that was exceeded in only two other sampled storms. The quality of stormwater runoff prior to the bridge opening probably was affected by construction vehicles and construction materials. Outflow quality was probably affected by recent pond construction activities. Results from these samples were used as a baseline of comparison for samples collected during the study.

Concentrations of many constituents measured for this study varied during a given storm event. Concentrations of most constituents were greatest in the first stormwater runoff sample collected during a storm event. The first sample represents the "first flush" of the bridge surface. As rainfall during a storm continues, concentrations of most constituents generally decreased as the bridge surface was washed off and as the additional rain diluted the runoff concentrations (fig. 7a). However, variations in suspended solids, nutrients, and trace elements concentrations during a given storm often were not concurrent with each other (fig. 7b). Variation in the timing of concentration changes in the stormwater runoff could be related to the source of the constituent (rain or road debris) and the phase of the constituent (suspended or dissolved). Suspended materials in the stormwater ranged from large debris to fine grained particles. Constituents that are associated with heavier particles are washed off the bridge at a different rate than dissolved constituents or those associated with fine-grained particles.

The quality of stormwater inflow to the detention pond varied with storm volume, the number of antecedent dry days before the storm, and with season. Maximum alkalinity and specific conductance values and concentrations of total suspended solids, volatile suspended solids, ammonia nitrogen, nitrite nitrogen, ammonia plus organic nitrogen, nitrite plus nitrate nitrogen, orthophosphorus, phosphorus, organic carbon, lead, nickel, and zinc generally occurred in the spring of 1994. These high concentrations correspond to low monthly rainfall totals for February through May 1994 (fig. 4). Mean concentrations of selected constituents for each storm sampled are shown in figure 8.

The quality of outflow from the detention pond varied during a given storm event. Maximum constituent concentrations generally occurred near the start of outflow from the pond. Similar to constituents in the stormwater runoff from the bridge, peak concentrations of each constituent did not always occur at the same time in a given storm (fig. 9). For example, on June 29, 1994, a storm with 1.91 in. of rain occurred; nitrite plus nitrate nitrogen concentrations peaked one hour after the storm began (fig. 9a) whereas zinc concentration peaked at the beginning of the storm (fig. 9b).

Seasonal patterns in outflow quality differed from those in the stormwater inflow to the detention pond. Maximum concentrations of total suspended solids, volatile suspended solids, ammonia nitrogen, nitrite nitrogen, nitrite plus nitrate nitrogen, aluminum, arsenic, chromium, copper, iron, and zinc occurred in June and July 1995. During the summer months of 1993, 1994, and 1995, pH exceeded 9.0 in the outflow. Dissolved oxygen and pH increase during high rates of photosynthesis (Goldman and Horne, 1983, p. 98). The high pH values in the pond outflow are associated with very low inorganic nitrogen concentrations, indicating that high levels of photosynthesis by algae or aquatic plants in the pond probably resulted in uptake of inorganic nitrogen and an increase in pH during the summer. Mean concentrations of selected constituents are shown in figure 8 to illustrate these general seasonal patterns.

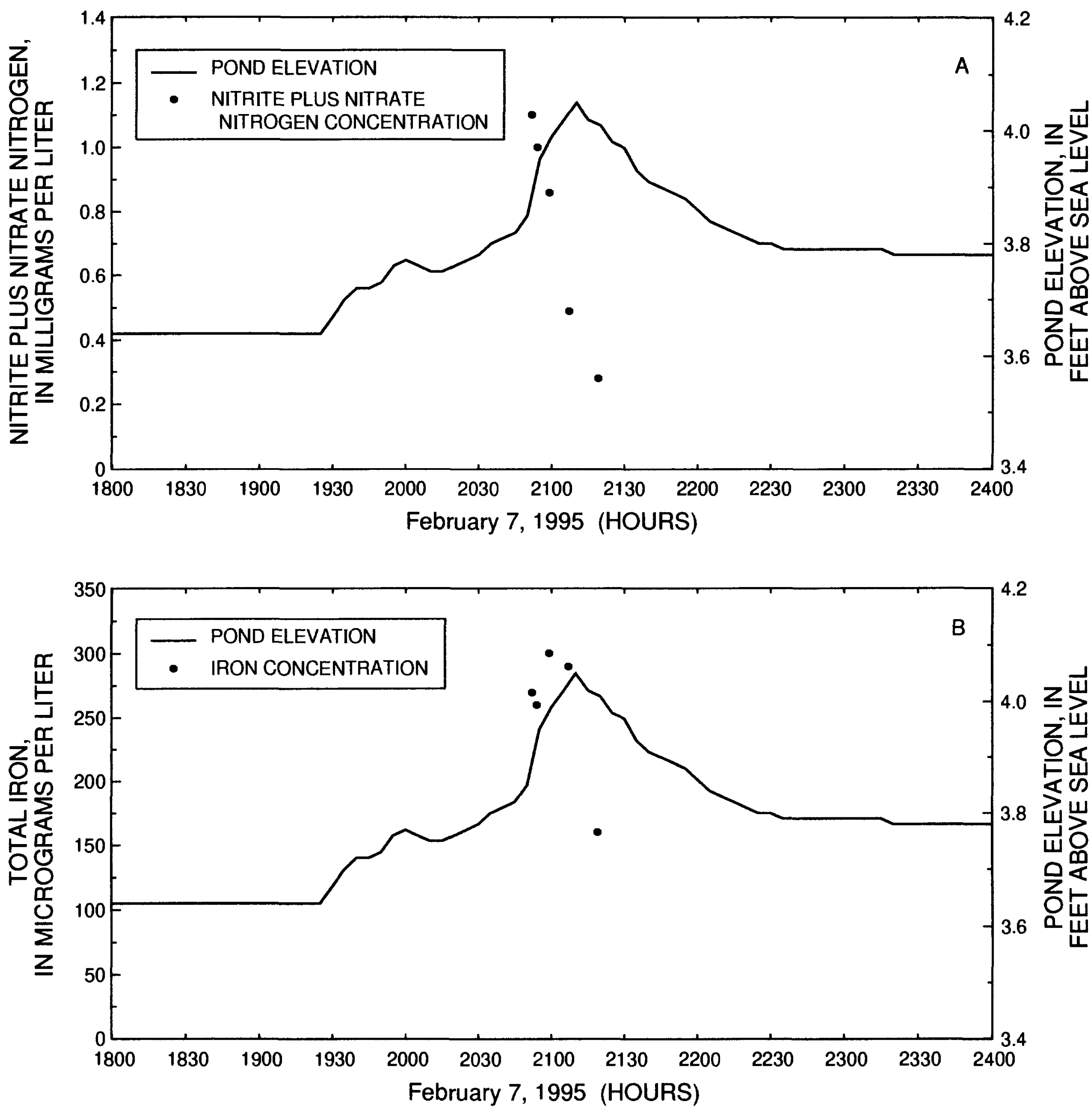


Figure 7. Concentrations of nitrite plus nitrate nitrogen and iron in inflow to the detention pond on February 7, 1995.

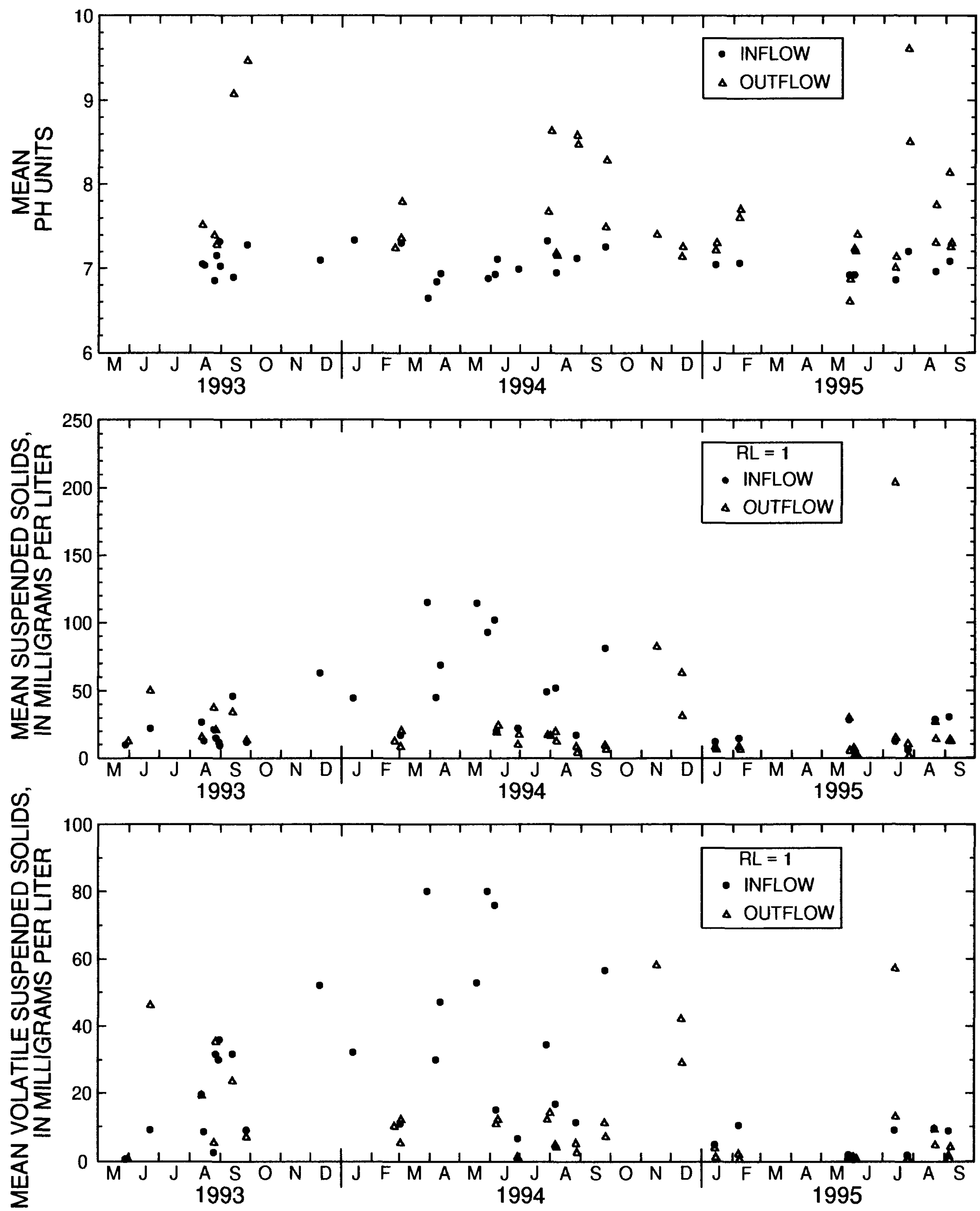


Figure 8. Mean concentrations of selected constituents in stormwater inflow and outflow from the detention pond. (RL is laboratory reporting limit.)

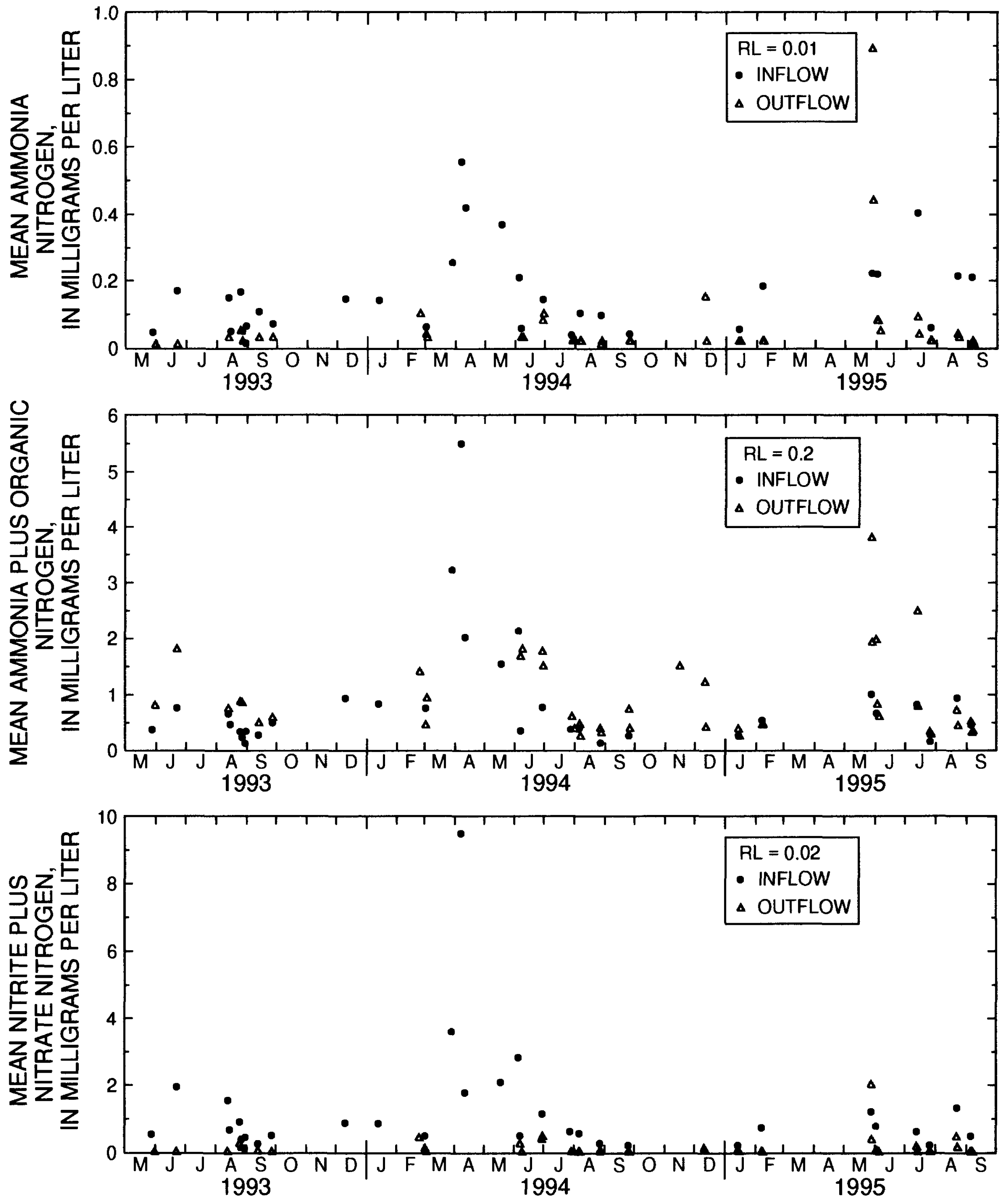


Figure 8. Mean concentrations of selected constituents in stormwater inflow and outflow from the detention pond. (RL is laboratory reporting limit.) (continued)

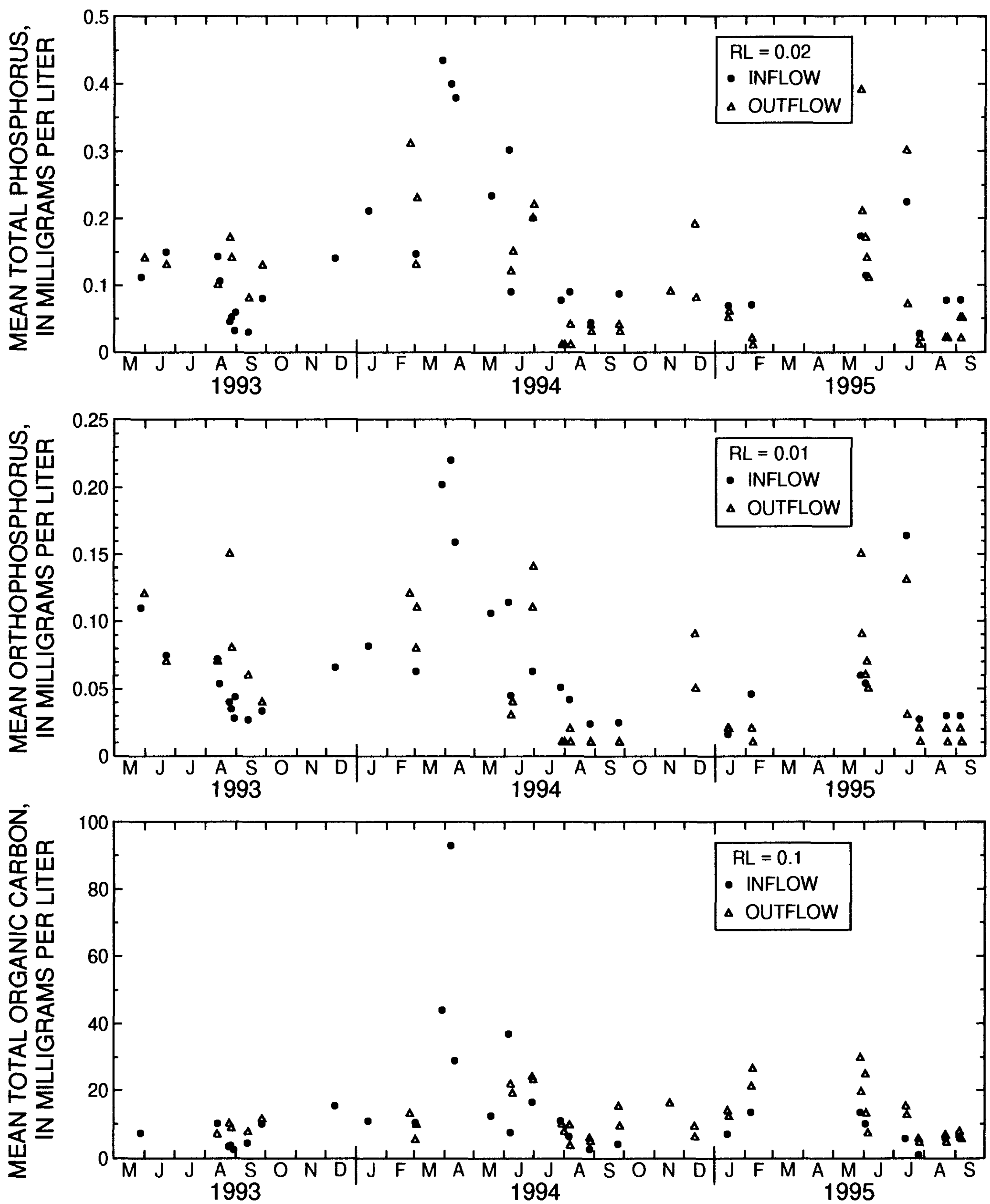


Figure 8. Mean concentrations of selected constituents in stormwater inflow and outflow from the detention pond. (RL is laboratory reporting limit.) (continued)

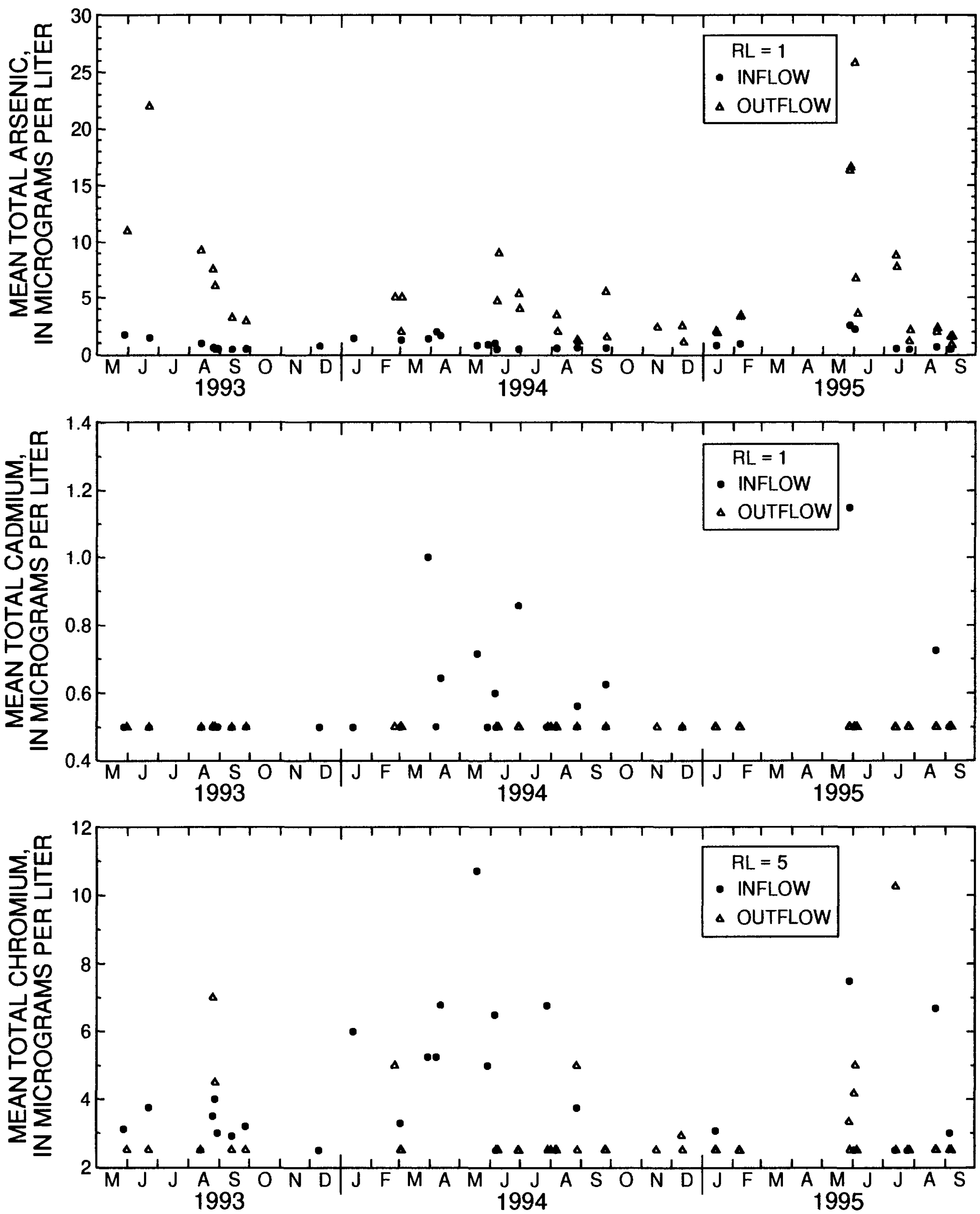


Figure 8. Mean concentrations of selected constituents in stormwater inflow and outflow from the detention pond. (RL is laboratory reporting limit.) (continued)

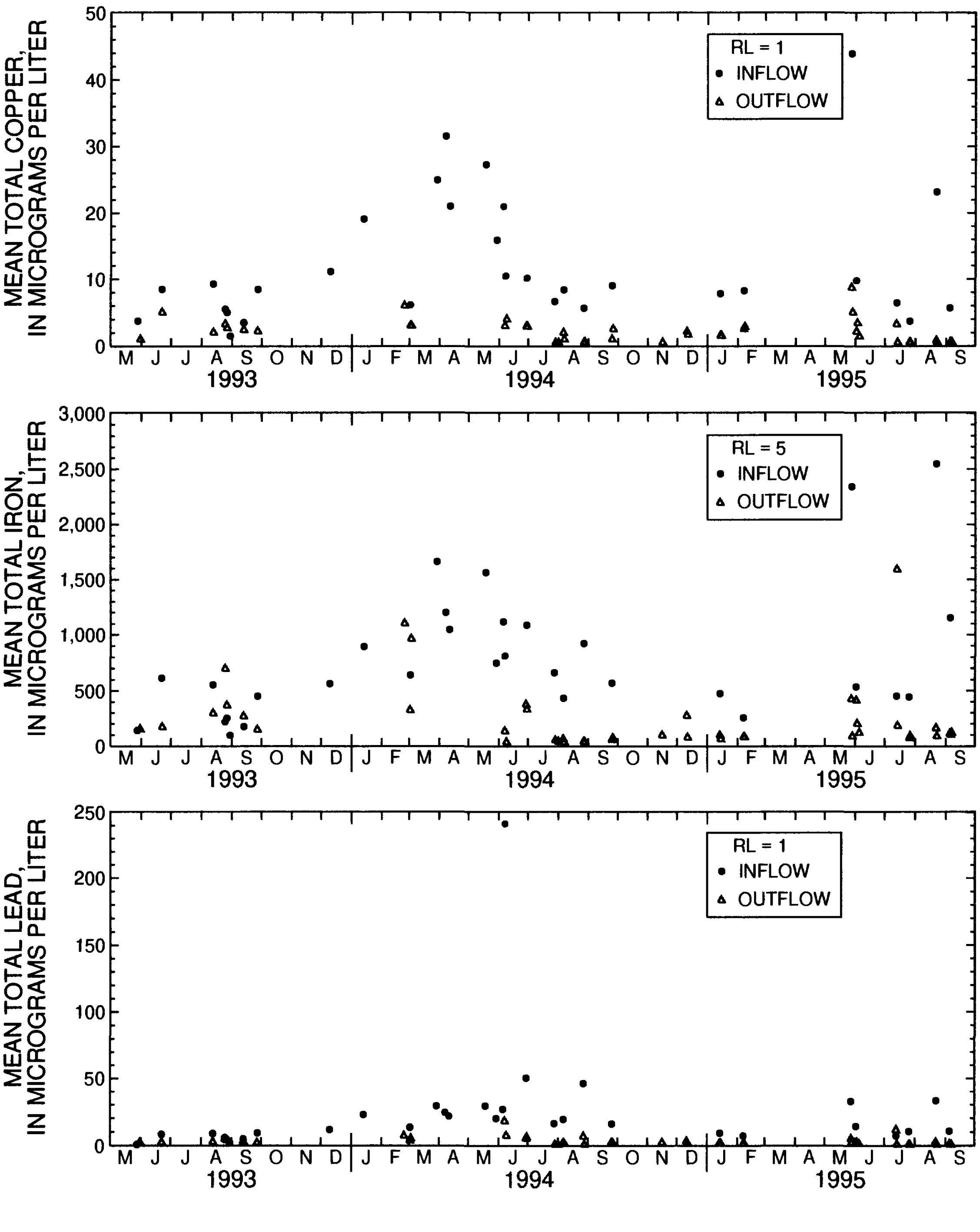


Figure 8. Mean concentrations of selected constituents in stormwater inflow and outflow from the detention pond. (RL is laboratory reporting limit.) (continued)

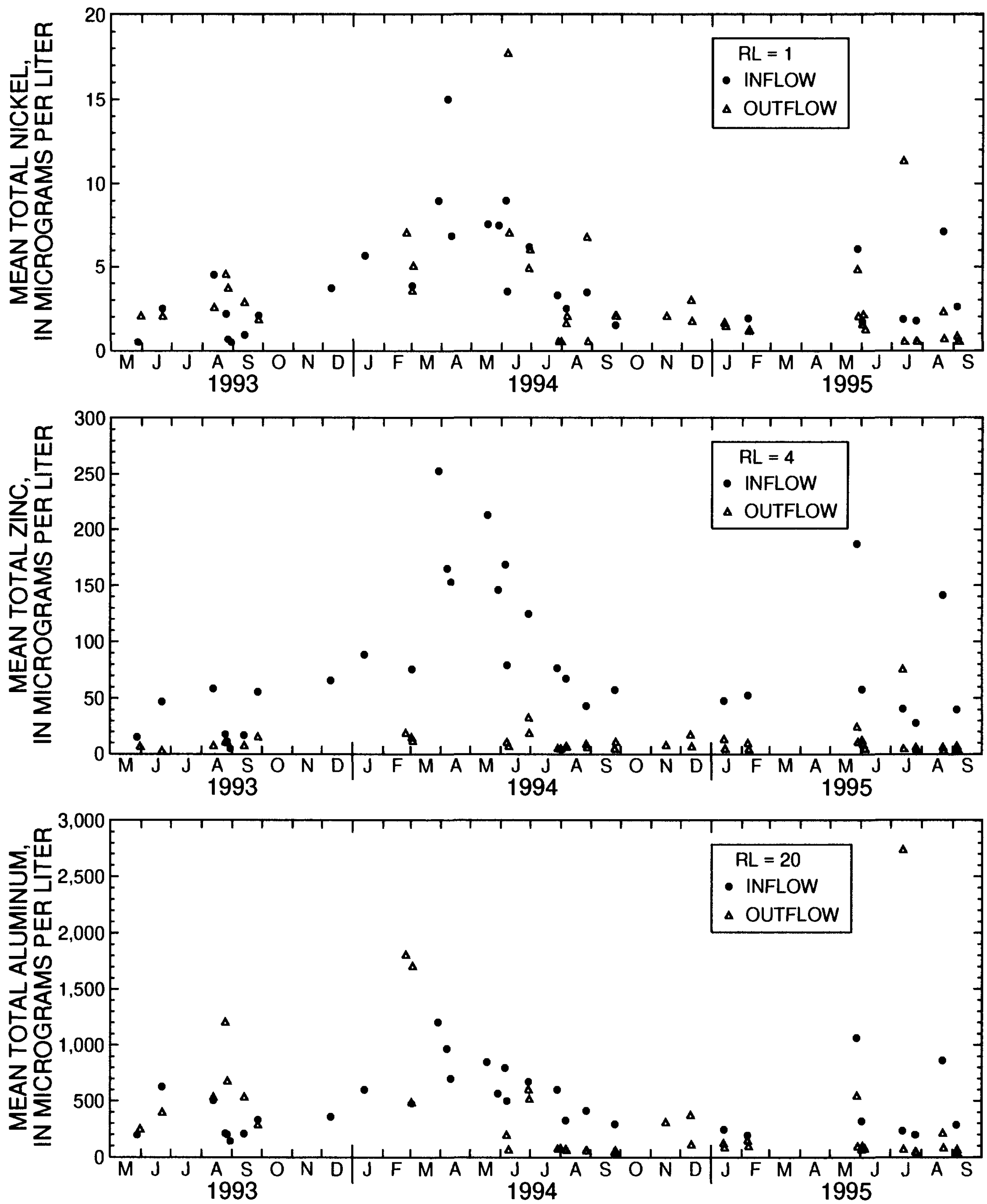


Figure 8. Mean concentrations of selected constituents in stormwater inflow and outflow from the detention pond. (RL is laboratory reporting limit.) (continued)

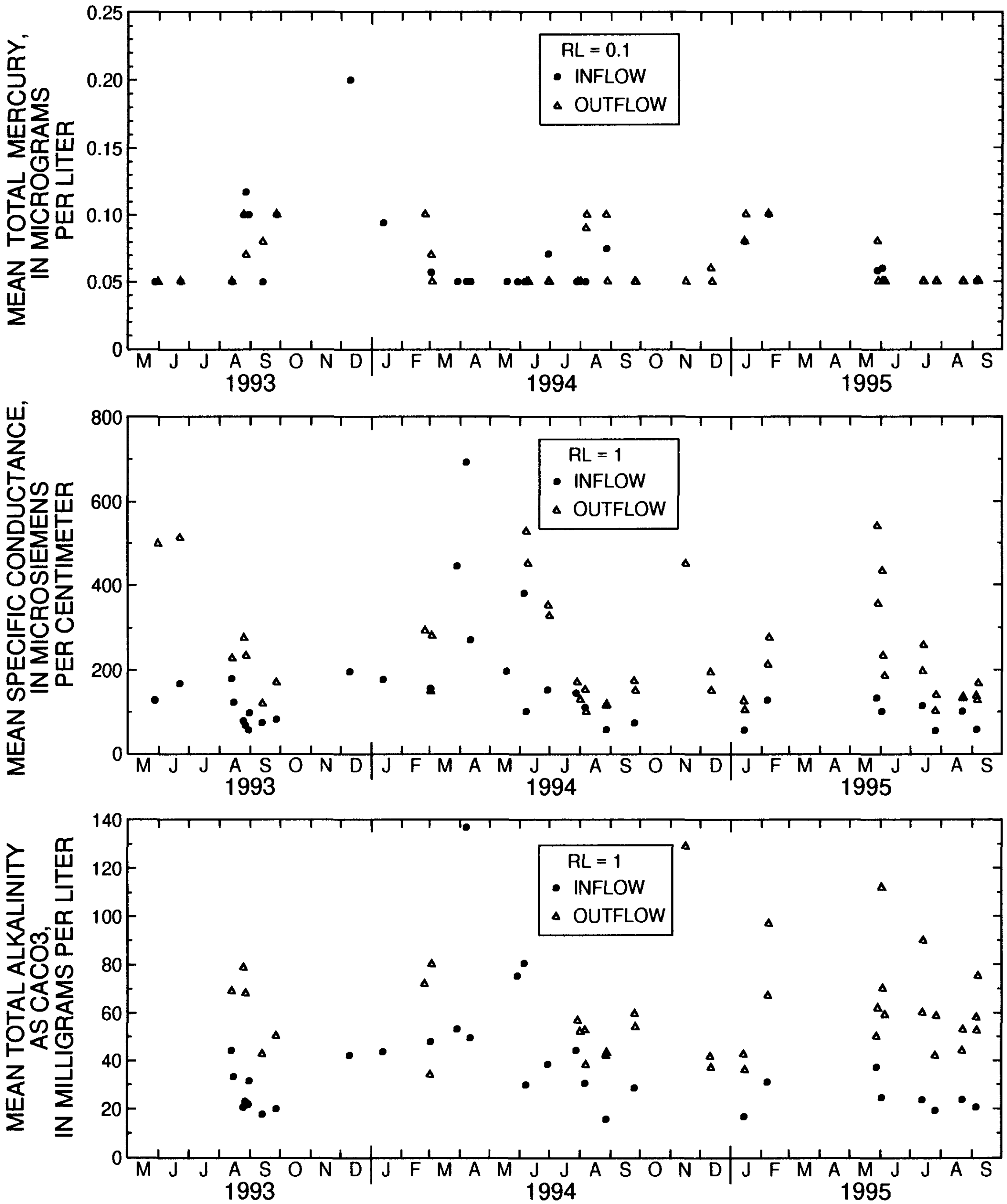


Figure 8. Mean concentrations of selected constituents in stormwater inflow and outflow from the detention pond. (RL is laboratory reporting limit.) (continued)

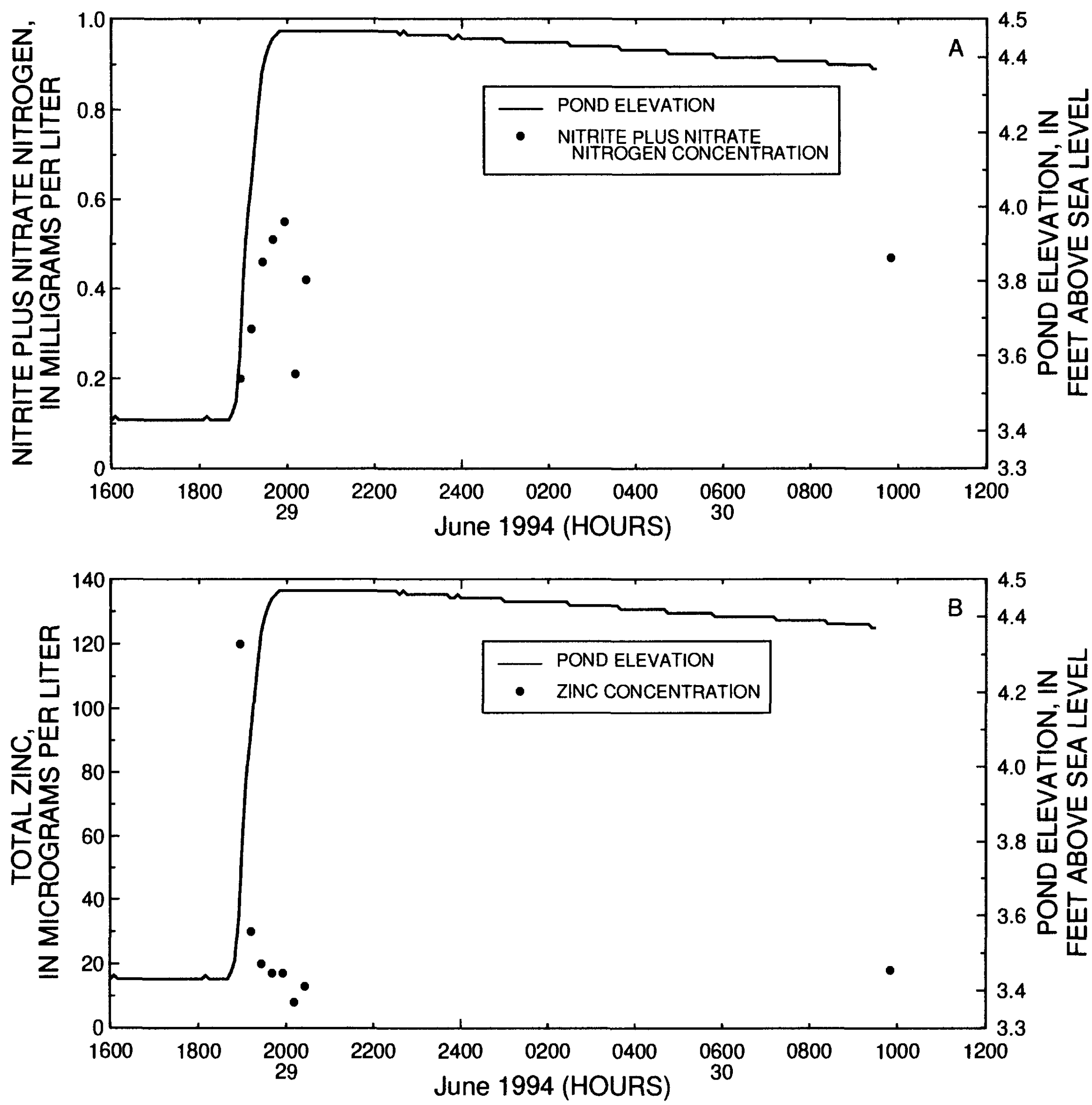


Figure 9. Concentrations of nitrite plus nitrate nitrogen and zinc in outflow from the detention pond on June 29-30, 1994.

Runoff volume was an important factor in the concentrations of selected constituents in stormwater runoff from the Bayside Bridge. Volume-weighted mean concentrations of suspended solids, volatile suspended solids, ammonia plus organic nitrogen, nitrite plus nitrate nitrogen, orthophosphorus, phosphorus, total organic carbon, aluminum, arsenic, copper, and zinc generally were inversely related to total runoff volume (fig. 10). The inverse relation between most constituents and runoff volume indicates that a dilution of these constituents occurs during large storms.

The Pearson's r correlation coefficients (Helsel and Hirsch, 1995, p. 210) were calculated for water-quality constituents in the stormwater runoff. Constituents with correlation coefficients greater than 0.70 also were examined visually. These analyses showed that nitrogen, phosphorus, and nickel concentrations in the stormwater runoff from the Bayside Bridge were correlated with total organic carbon concentrations (fig. 11). Nitrogen, phosphorus, and nickel also were correlated with specific conductance and alkalinity. Concentrations of chromium, copper, iron, nickel, and zinc in stormwater runoff from the bridge were correlated to aluminum concentrations (fig. 12). If two lead concentration values greater than 200 μg/L are not included in the correlation analysis, lead also is correlated with aluminum. Because the runoff from the bridge is isolated from surrounding soils, the source of these metals to stormwater runoff is probably the bridge itself (metal drain covers and other parts on the bridge) and debris related to vehicles on the bridge (rust, paint flakes, dirt and sand falling from vehicles). Ferrous metal flakes were observed in some stormwater samples.

Ammonia plus organic nitrogen concentrations in outflow from the detention pond were correlated with total organic carbon, although total concentrations of each generally were less than in the stormwater inflow. Nitrogen and phosphorus concentrations also are generally related to copper. Only chromium, iron, and zinc were related to aluminum in the outflow from the detention pond. Copper, lead, and nickel can interact with pond sediments (adsorption, desorption, cation exchange, chemical bonding), thus resulting in a change in the relation of these constituents to aluminum.

Stormwater quality before the bridge opened was compared to quality after the bridge opened to traffic. Stormwater concentrations of organic carbon, aluminum, cadmium, chromium, copper, iron, lead, mercury, nickel, and zinc generally were greater in 1994 and 1995 than in 1993. In some cases, concentrations of nitrogen, phosphorus, and arsenic were less after the bridge opened to traffic than they were before it opened.

Quality of Pond Sediments

Sediments at the bottom of the pond consist of sediments at the site after the pond was excavated. Because the pond is adjacent to Old Tampa Bay, these sediments are of marine origin. Sediments in the pond were sampled prior to the bridge opening to traffic and after the bridge was opened for about 24 months. Concentrations of volatile suspended solids and nitrite plus nitrate nitrogen in the pond sediments were greater before the bridge opened to traffic than 2 years later (table 2 and fig. 3). Sediment concentrations of ammonia plus organic nitrogen, phosphorus, aluminum, chromium, iron, and mercury were greater in samples collected near the center of the pond in June 1995 than before the bridge was opened to traffic. Sediment concentrations of ammonia plus organic nitrogen, chromium, and iron were greater near the weir 2 years after the bridge was opened to traffic than before. Sediment concentrations of cadmium and nickel were below laboratory reporting limits during both periods and concentrations of copper, manganese, and zinc were similar before and after bridge traffic occurred. The concentrations of aluminum, chromium, copper, lead, nickel, and zinc in the pond sediments are within ranges measured in natural estuarine sediments (Schropp and Windom, 1988).

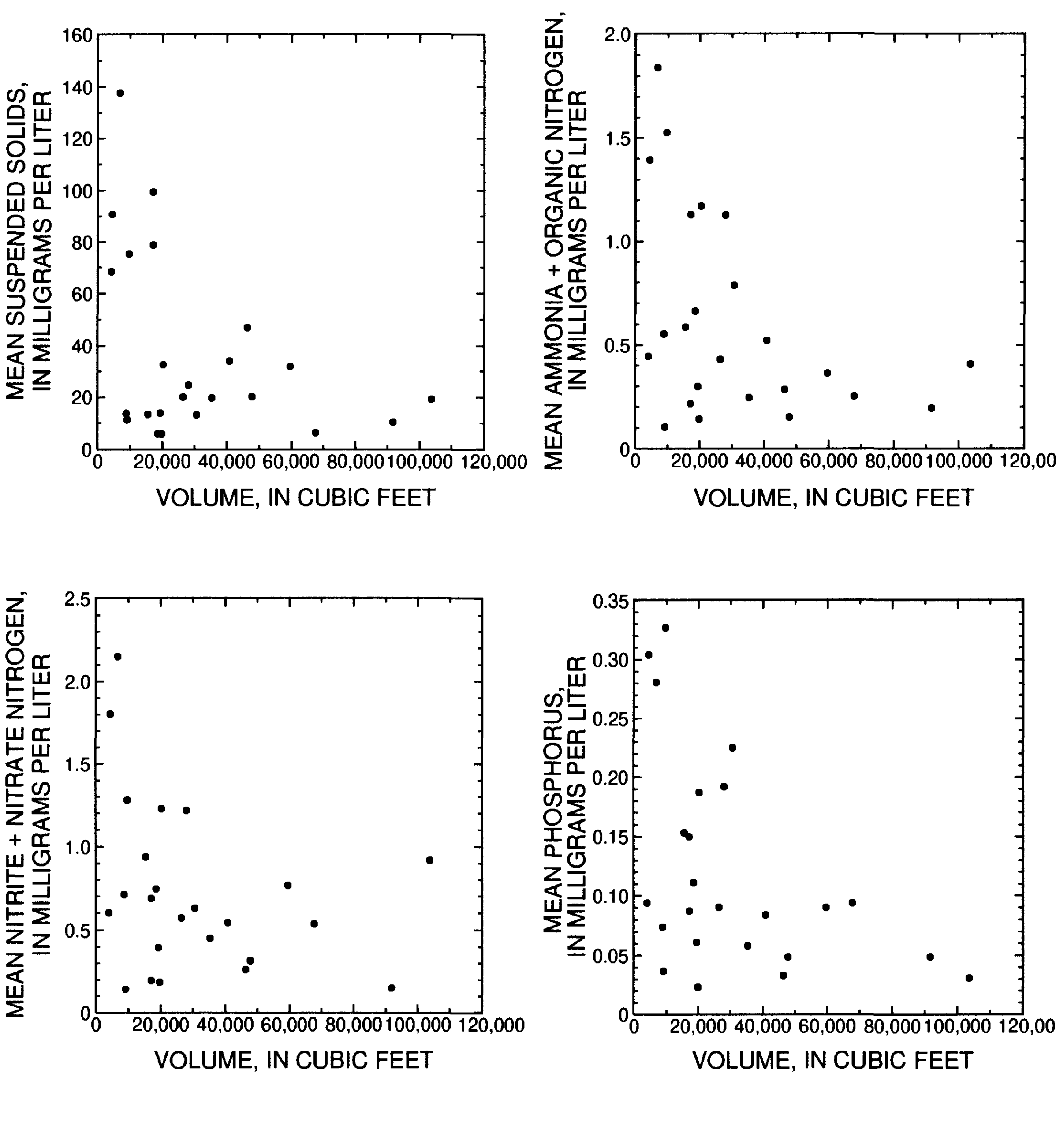


Figure 10. Relation between concentrations of selected water-quality constituents and Bayside Bridge runoff volume.

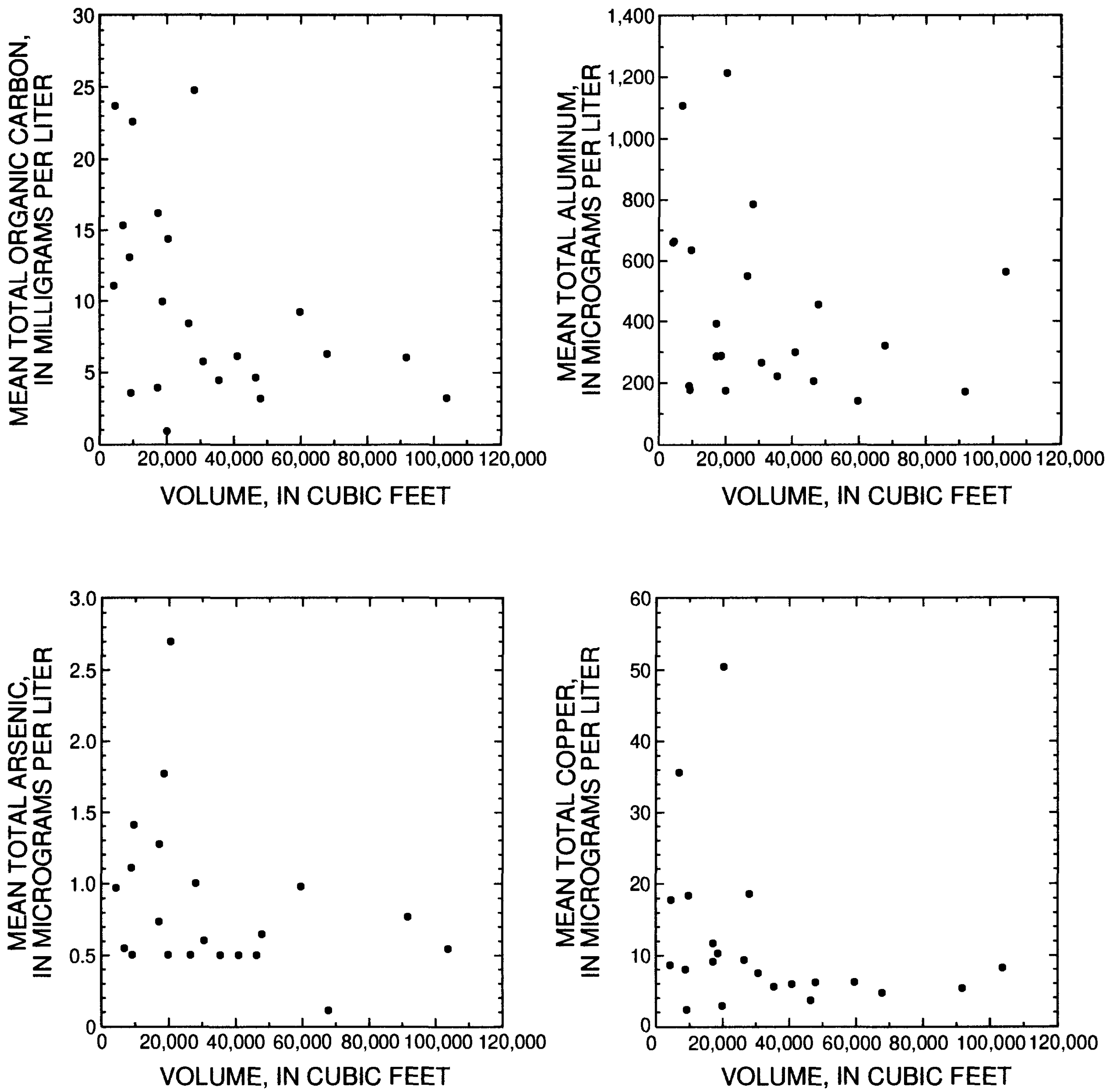


Figure 10. Relation between concentrations of selected water-quality constituents and Bayside Bridge runoff volume. (continued)

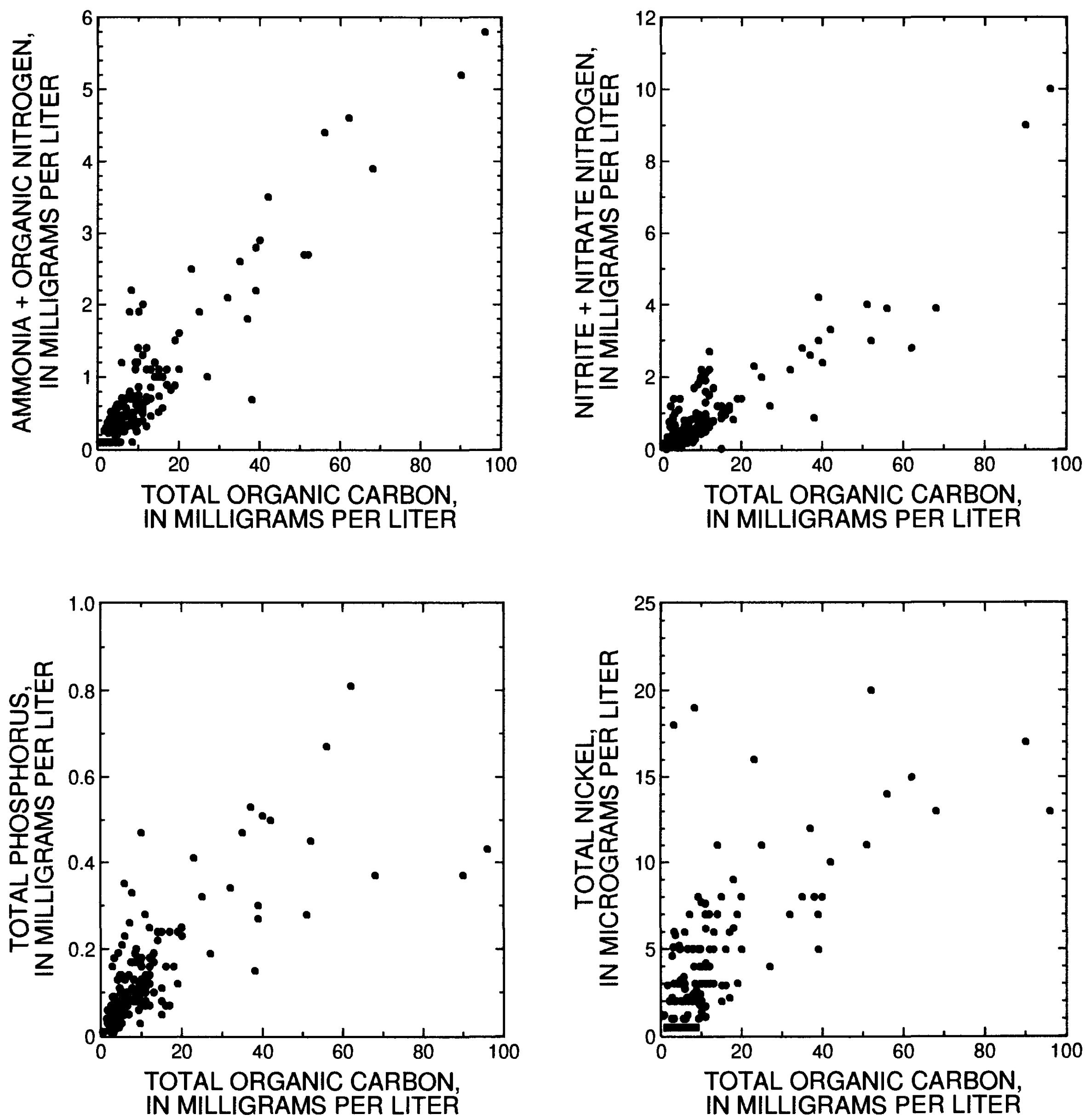


Figure 11. Concentrations of nitrogen and phosphorus as a function of total organic carbon in stormwater inflow to the detention pond.

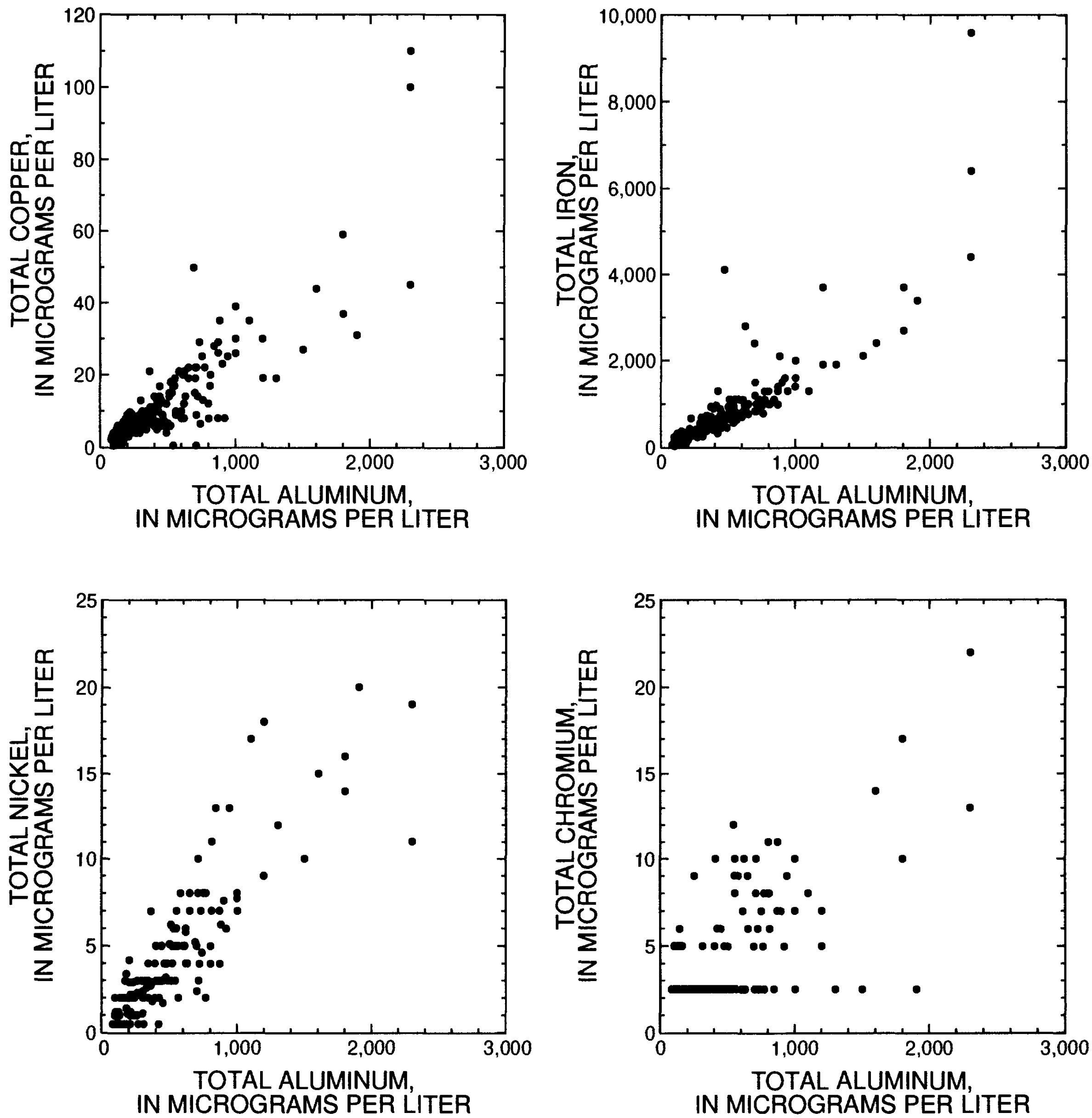


Figure 12. Concentrations of chromium, copper, iron, nickel, lead, and zinc as a function of aluminum in stormwater inflow to the detention pond.

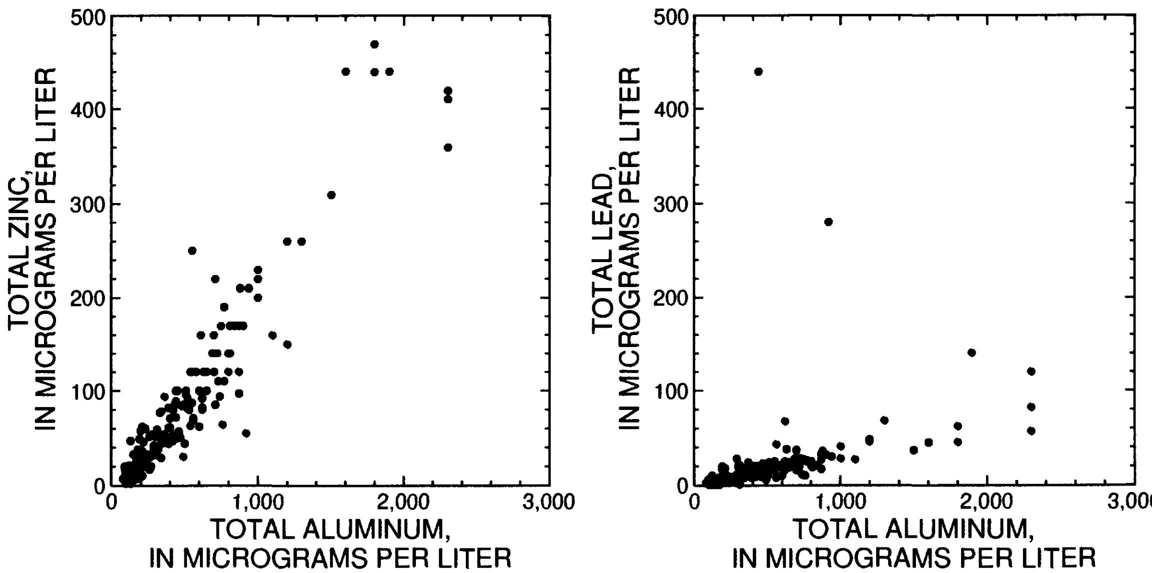


Figure 12. Concentrations of chromium, copper, iron, nickel, lead, and zinc as a function of aluminum in stormwater inflow to the detention pond. (continued)

Table 2. Sediment quality of the detention pond

[All concentrations are in micrograms per kilogram unless otherwise noted. >, greater than; mg/kg, milligrams per kilogram; <, less than]

	May 27, 1993 12:00	May 27, 1993 12:30	May 27, 1993 13:00	June 20, 1995 11:00	June 20, 1995 11:30
Location	Site 1	Site 2	Site 3	Site 1	Site 2
Sampling depth	> 4 inches	top 2 inches	2-4 inches	top 2 inches	top 2 inches
Volatile suspended solids (mg/kg)	1,000,000	487,000	589,000	39,000	52,000
Ammonia + organic nitrogen (mg/kg)	120	550	470	1,100	1,300
Nitrite + nitrate nitrogen (mg/kg)	12	54	18	<2.0	<2.0
Phosphorus (mg/kg)	92	290	190	420	330
Aluminum	5,500	5,000	5,200	8,100	5,900
Cadmium	<1	<1	<1	<1	<1
Chromium	20	10	20	40	30
Copper	<1	5	5	3	6
Iron	1,900	3,000	3,000	5,800	4,800
Lead	<10	10	10	10	10
Manganese	<1	19	17	10	26
Mercury	<.01	.02	.02	.03	.03
Nickel	<10	<10	<10	<10	<10
Zinc	<1	20	10	20	20

EFFECTIVENESS OF THE STORMWATER COLLECTION AND DETENTION SYSTEM

The effectiveness of the Bayside Bridge stormwater collection and detention system in removing pollutants from stormwater was evaluated. Constituent concentrations in the runoff were compared with constituent concentration in the outflow for selected storms. Constituent loads in runoff and in the outflow were evaluated as well.

Changes in Constituent Concentrations

The nonparametric rank-sum test (Helsel and Hirsch, 1995, p. 118-124) was used to compare concentrations of the measured water-quality constituents in the stormwater runoff with concentrations in the outflow from the pond. This analysis showed that significant differences between stormwater runoff and pond outflow occurred for all constituents except mercury. Concentrations of total suspended solids, volatile suspended solids, ammonia nitrogen, nitrite plus nitrate nitrogen, orthophosphorus, phosphorus, aluminum, cadmium, chromium, copper, iron, lead, nickel, and zinc generally were greater in the stormwater inflow to the detention pond than in outflow from the pond. The reduction in concentrations of these constituents is probably related to physical removal of sediments in the runoff and biological and geochemical processes in the pond.

Concentrations of ammonia plus organic nitrogen, organic carbon, arsenic, and values for alkalinity, pH, and specific conductance generally were greater in the outflow from the pond than in stormwater inflow. The quality of outflow from the detention pond was affected by the quality of stormwater input to the pond, biological activity, the quality of direct precipitation on the pond, and by physical and geochemical processes within the pond. At times, the pond was intensely used by wading birds such as egrets, herons, and roseate spoonbills, and water fowl such as ducks. Songbirds were also observed perching or nesting in the cattails near the center of the pond. The use of the pond by these birds may cause increases in concentrations of nitrogen and organic carbon in the pond. Also, herbicide spraying probably contributed to increases in nitrogen and carbon as vegetation decayed in the pond. The simple mean concentration of these constituents in the stormwater runoff and in outflow from the bridge is shown in figure 8.

Summary statistics of stormwater runoff quality from the bridge and outflow from the detention pond are listed in table 3. Concentrations of aluminum, copper, iron, lead, mercury, nickel, and zinc and values for pH at times exceeded State of Florida water-quality standards for Class II waters (Florida Department of Environmental Protection, 1996).

Table 3. Summary of selected water-quality characteristics of stormwater inflow to the detention pond and outflow from the detention pond during the study

[All concentrations are in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than; µg/L, micrograms per liter]

Constituent	Class II surface water-quality standards	Minimum	Maximum	Mean	Median	Number of samples
				Inflow		
pH (pH units)	6.5-8.5	6.6	7.8	7.0	7.0	173
Specific conductance (µS/cm)	--	29	730	142	109	182
Alkalinity	--	11	137	34.2	28.0	172
Total suspended solids	--	1.0	270	36.8	20.0	186
Volatile suspended solids	--	<1	250	24.9	[3]16	186
Total organic carbon	--	.5	96	11.9	8.0	166
Nitrite nitrogen	--	.01	.42	.04	.03	182
Nitrite nitrogen + nitrate nitrogen	[4]--	.02	10.0	.99	.64	182
Ammonia nitrogen	[4]--	.01	1.4	.16	.13	182
Ammonia nitrogen + organic nitrogen	[4]--	<.01	5.8	[3].78	[3].46	182
Orthophosphorus as P	[4]--	.01	.27	.06	.05	182
Phosphorus	[4]--	.02	.81	.14	.10	182
Aluminum (µg/L)	≤1,500	80	2,300	483	370	173
Arsenic (µg/L)	≤50	<1	4	[3].98	[3].77	159
Cadmium (µg/L)	≤9.3	<1	3	[3].29	[3].14	173
Chromium (µg/L)	≤50	<5	22	[3]4.3	[3]3.2	173
Copper (µg/L)	≤2.9	1.0	110	12.4	8.0	173
Iron (µg/L)	≤300	30	9,600	823	530	173
Lead (µg/L)	≤5.6	1.0	440	21	11	173
Mercury (µg/L)	≤.025	<.1	.2	[3].08	[3].07	172
Nickel (µg/L)	≤8.3	<1	20	[3]4.0	[3]3.0	173
Zinc (µg/L)	≤86	4.0	470	84	50	173

Table 3. Summary of selected water-quality characteristics of stormwater inflow to the detention pond and outflow from the detention pond during the study --Continued

[All concentrations are in milligrams per liter unless otherwise noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; <, less than; µg/L, micrograms per liter]

Constituent	Class II surface water-quality standards	Minimum	Maximum	Mean	Median	Number of samples
				Outflow		
pH (pH units)	[2]6.5-8.5	6.5	10.0	7.7	7.4	105
Specific conductance (µS/cm)	--	62	605	222	178	118
Alkalinity	--	21	129	57.4	53.0	105
Total suspended solids	--	1.0	390	21.2	14.0	119
Volatile suspended solids	--	<1	100	[3]10.8	[3]4.0	119
Total organic carbon	--	3.6	35	12.1	9.6	117
Nitrite nitrogen	[4]--	<.01	.41	[3].024	[3].01	118
Nitrite nitrogen + nitrate nitrogen	[4]--	<.02	2.6	[3].16	[3].04	118
Ammonia nitrogen	[4]--	<.01	1.0	[3].08	[3].03	118
Ammonia nitrogen + organic nitrogen	[4]--	.2	4.5	.92	.57	119
Orthophosphorus as P	[4]--	.01	.22	.05	.03	118
Phosphorus	[4]--	<.01	.50	[3].11	[3].09	119
Aluminum (µg/L)	≤1,500	20	5,300	321	100	119
Arsenic (µg/L)	≤50	<1	34	[3]5.4	[3]3.0	115
Cadmium (µg/L)	≤9.3			All values less than 1		
Chromium (µg/L)	[5]≤50	<5	18	[3]2.1	[3]1.5	119
Copper (µg/L)	≤2.9	<1	9	[3]2.2	[3]2.0	119
Iron (µg/L)	≤300	30	3,000	224	110	119
Lead (µg/L)	≤5.6	<1	29	[3]2.8	[3]2.0	119
Mercury (µg/L)	≤.025	<.1	.2	[3].09	[3].09	119
Nickel (µg/L)	≤8.3	<1	4.0	[3]1.2	[3]1.0	119
Zinc (µg/L)	≤86	<4	140	[3]11.0	[3]6.0	119

[1]Florida Department of Environmental Protection, 1996.

[2]Shall not vary more than one unit above or below natural background.

[3]Mean and median values are estimated by using a log-probability regression to predict the values of data below the detection limit (Helsel, 1990).

[4]Specific criteria do not exist. However, nutrient concentrations in a water body may not be altered so as to cause an imbalance in natural populations of aquatic flora or fauna.

[5]Hexavalent form only.

Changes in Constituent Loads

Constituent loads for 24 storms were evaluated to describe stormwater load characteristics from the Bayside Bridge to the detention pond. Loads out of the detention pond were evaluated for 3 storms. The outflow loads for these 3 storms were compared to inflow loads to evaluate the effectiveness of the detention pond in the removal of selected constituents.

Stormwater and constituent loading to the Bayside Bridge detention system was rapid. Recorded rainfall and stage data showed that pond elevation began to increase within minutes of the start of a storm. Constituent loading often peaked near the beginning of a storm and decreased as the storm progressed (fig. 13). The decrease in loading is related to the decrease in concentration that usually occurred during a storm.

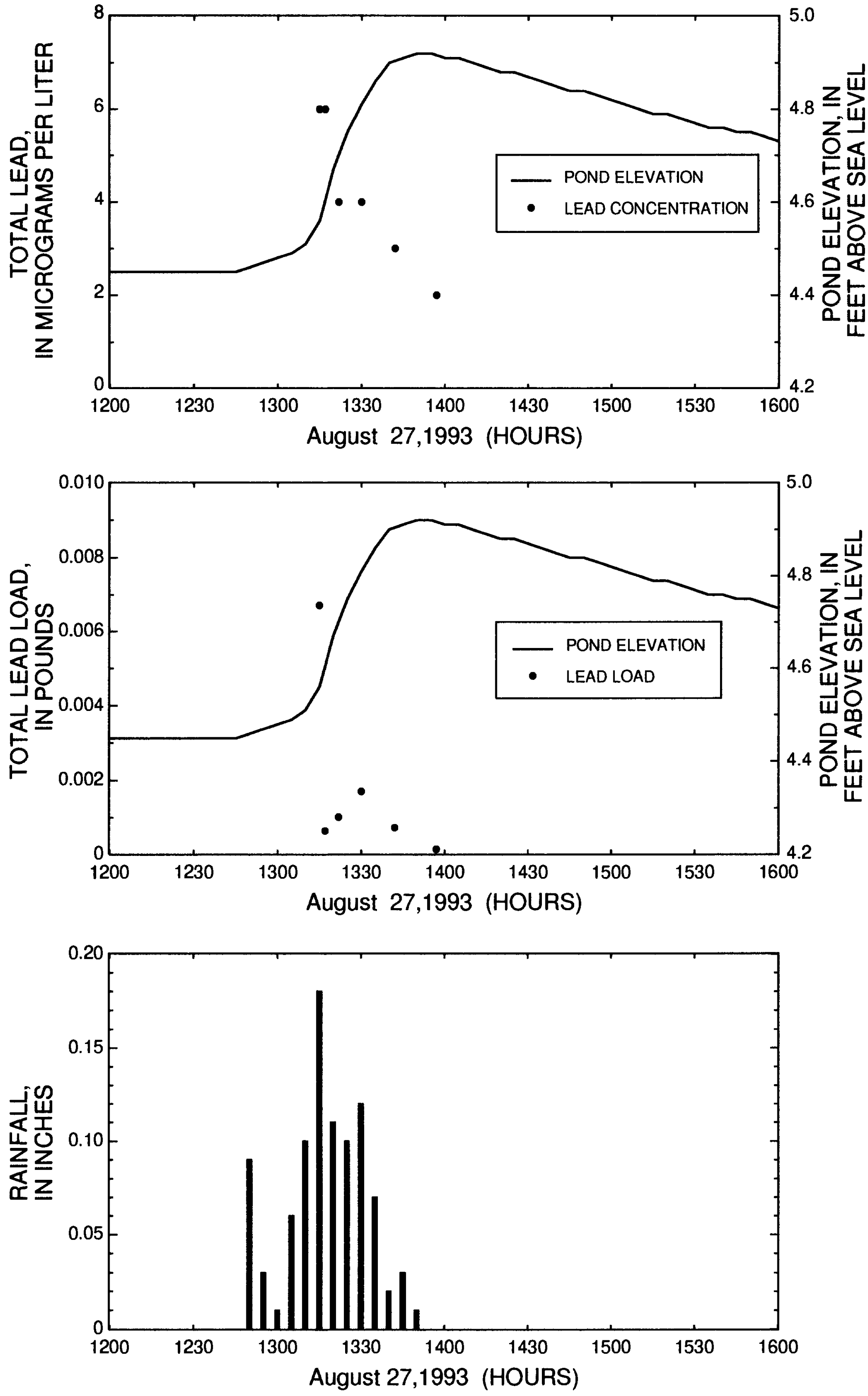
The maximum total stormwater loads of nitrogen, iron, aluminum, nickel, and zinc coincided with the maximum runoff volume measured on Aug. 22, 1995 (tables 4 and 5). The maximum load of arsenic was from the Jan. 14, 1995, storm, which had a similar runoff volume to that of Aug. 22. Stormwater loads of most constituents from the bridge to the pond were low in total mass because of the small contributing drainage area.

The smallest sampled storm volume and rainfall measured was 4, 086 ft^3 and 0.12 in, respectively, on July 28, 1994. Ammonia nitrogen and orthophosphorus loads during this storm were the smallest measured. Although storm volume and rainfall was 9,107 ft^3 and 0.34 in, respectively, on Aug. 30, 1993, the least loads of suspended solids, ammonia plus organic nitrogen, nitrite plus nitrate nitrogen, phosphorus, aluminum, copper, iron, lead, nickel, and zinc occurred during this storm. The bridge had been opened to traffic for about 3 months at the time of the Aug. 30, 1993, storm. These low loads most likely reflect the young age of the bridge, which would have relatively little accumulation of petroleum products and debris on the bridge surface and minimal corrosion of metal bridge parts, and the effect of recent rains on washing off the bridge surface.

Stormwater and constituent loads out of the detention pond only occurred when the pond elevation was above the weir or the bleed-down pipe. Some storms did not result in any loads out of the pond. Outflow volumes and loads for three storms were computed and compared to stormwater runoff loads (tables 4 and 5). Outflow volumes computed for these storms include the volume of direct rainfall on the pond. Comparison of inflow and outflow loads for these storms showed that the detention pond is effective in reducing the concentrations and loads of many constituents from Bayside Bridge stormwater runoff. Suspended solids loads were reduced about 30 to 45 percent, inorganic nitrogen loads were reduced by about 60 to 90 percent, and loads of most trace elements were reduced by about 40 to 99 percent.

However, the pond has a net export of ammonia plus organic nitrogen, organic carbon, arsenic, and at times, phosphorus. Loads of ammonia plus organic nitrogen increased about 150 to 290 percent above inflow loads. Total nitrogen load can be computed by summing the load for nitrite plus nitrate nitrogen and the load for ammonia plus organic nitrogen. Although much of the reduction in inorganic nitrogen load is a result of conversion of inorganic nitrogen to organic nitrogen (table 4), a net export of total nitrogen occurs, and the increase in total nitrogen load ranged from about 10 to 25 percent above inflow loads. Phosphorus loads in the outflow were increased in only one of the three storms evaluated, and were decreased in the other 2 storms. Organic carbon loads in the outflow were about 120 to 540 percent greater than inflow loads. The reduction in inorganic nitrogen loads and the export of nitrogen and organic carbon suggests that biological activity in the pond is the most likely source of additional nitrogen and carbon load in the outflow.

Loads of arsenic in the outflow from the detention pond were about 190 to 410 percent greater than inflow loads. The source of arsenic in the detention pond is unknown. However, the export of arsenic and the elevated arsenic concentrations before the bridge opened implies that arsenic is stored in the pond sediments and is being released to the overlying pond water.



Fiqure 13. Lead concentrations and loads in stormwater inflow to the

Table 4. Rainfall, runoff volume, rainfall-runoff coefficients, and total storm loads of selected constituents and nutrients into the detention pond from the Bayside Bridge

[Rainfall is in inches; runoff volume is in cubic feet; loads are in pounds; -- represents missing data]

Date	Total rainfall	Runoff volume	Rainfall-runoff coefficient	Total suspended solids load	Volatile suspended solids load	Ammonia nitrogen load	Ammonia + organic nitrogen load	Nitrite + nitrate nitrogen load	Orthophosphorus load	Phosphorus load	Organic carbon load
					Inflow						
Aug. 15, 1993	0.55	15,547	0.60	13.06	10.39	0.04840	0.5674	0.9119	0.06396	0.14820	--
Aug. 27, 1993	.93	35,385	.81	43.55	75.67	.1331	.5406	.9991	.07911	.1273	9.817
Aug. 30, 1993	.34	9,107	.57	6.483	18.78	.01024	.05869	.08043	.01631	.02104	2.028
Aug. 31, 1993	.65	19,382	.64	16.86	44.71	.06470	.3617	.4789	.04604	.07357	--
Sept. 13, 1993	1.43	46,359	.69	135.9	94.75	.3204	.8188	.7515	.07784	.09544	13.32
Sept. 27, 1993	.41	28,080	1.46	43.27	35.04	.2768	1.979	2.132	.1327	.3367	43.36
Dec. 10, 1993	.41	17,120	.89	106.2	94.42	.1320	1.210	.7335	.05963	.1607	17.30
Apr. 11, 1994	.45	9,672	.46	45.44	32.54	.1979	.9215	.7718	.07674	.1972	13.64
May 18, 1994	.33	6,832	.44	58.73	28.45	.1698	.7847	.9162	.05036	.1200	6.537
June 5, 1994	.17	4,425	.56	25.08	19.86	.03656	.3846	.4972	.02417	.08404	6.539
June 7, 1994	.81	26,439	.70	33.00	26.07	.1122	.7114	.9424	.08086	.1485	13.85
June 29, 1994	1.91	67,748	.76	26.43	7.125	.4344	1.065	2.262	.1637	.3980	26.45
July 28, 1994	.12	4,086	.73	17.43	11.12	.009914	.1135	.1535	.01337	.02401	2.816
Aug. 6, 1994	1.35	59,596	.94	118.6	26.04	.2283	1.350	2.851	.1486	.3340	34.17
Aug. 27, 1994	1.53	47,844	.67	60.24	37.07	.3357	.4511	.9477	.07454	.1470	9.529
Sept. 25, 1994	.37	17,118	.99	84.19	58.84	.04319	.2306	.2071	.02298	.09325	4.150
Jan. 14, 1995	3.15	91,733	.62	60.21	15.66	.3106	1.119	.8555	.07396	.2818	34.26
Feb. 7, 1995	.24	8,832	.79	7.587	6.558	.09892	.3050	.3918	.02489	.04060	7.210
May 28, 1995	.47	20,313	.92	41.37	1.928	.2802	1.484	1.556	.07810	.2374	18.21
June 2, 1995	.55	18,547	.72	6.936	.5787	.2264	.7652	.8632	.05656	.1284	11.48
July 13, 1995	.74	30,646	.89	25.28	18.89	.6403	1.504	1.202	.3087	.4307	10.89
July 26, 1995	.57	19,825	.74	7.241	1.758	.06994	.1758	.2279	.03126	.02865	1.128
Aug. 22, 1995	2.37	103,705	.94	124.5	36.70	1.110	2.628	5.939	.1495	.1978	20.72
Sept. 5, 1995	.60	40,828	1.46	86.62	27.28	.5629	1.330	1.392	.08221	.2148	15.60
					Outflow						
Aug. 27, 1994	1.53	60,507	--	33.02	21.00	.04422	1.478	.08947	.03937	.1019	20.77
Jan. 14, 1995	3.15	110,236	--	44.56	11.58	.1300	2.079	.3414	.1533	.4028	83.43
July 26, 1995	.57	26,782	--	4.979	.8356	.02309	.4454	.01671	.01944	.02401	7.186

Table 5. Rainfall, runoff volume, rainfall-runoff coefficients, and total storm loads of selected trace elements into the detention pond from the Bayside Bridge

[Rainfall is in inches; runoff volume is in cubic feet; loads are in pounds; -- represents missing data]

Date	Total rainfall	Runoff volume	Rainfall-runoff coefficient	Aluminum load	Arsenic load	Copper load	Iron load	Lead load	Nickel load	Zinc load
Inflow										
Aug. 15, 1993	0.55	15,547	0.60	--	--	--	--	--	--	--
Aug. 27, 1993	.93	35,385	.81	.4858	.001104	.01212	.5829	.01090	.001714	.03300
Aug. 30, 1993	.34	9,107	.57	.1005	.000284	.001363	.09121	.001738	.000284	.004780
Aug. 31, 1993	.65	19,382	.64	--	--	--	--	--	--	--
Sept. 13, 1993	1.43	46,359	.69	.5932	.001446	.01050	.5146	.01453	.002771	.05069
Sept. 27, 1993	.41	28,080	1.46	1.375	.001752	.03248	1.851	.03855	.008365	.2397
Dec. 10, 1993	.41	17,120	.89	.4190	.001357	.01242	.7266	.01364	.004618	.09100
Apr. 11, 1994	.45	9,672	.46	.3837	.000849	.01104	.6595	.01360	.003581	.07732
May 18, 1994	.33	6,832	.44	.4717	.000234	.01516	.9099	.01590	.004129	.1205
June 5, 1994	.17	4,425	.56	.1832	.000268	.004886	.2713	.006633	.001882	.03875
June 7, 1994	.81	26,439	.70	.9043	.000825	.01534	1.244	.1356	.003788	.1171
June 29, 1994	1.91	67,748	.76	1.353	.000460	.01969	2.098	.1163	.01135	.1829
July 28, 1994	.12	4,086	.73	.1684	--	.002185	.1967	.005157	.000912	.02370
Aug. 6, 1994	1.35	59,596	.94	.5238	.003641	.02276	.4810	.02490	.007543	.1798
Aug. 27, 1994	1.53	47,844	.67	1.351	.001924	.01813	2.999	.1910	.009959	.1382
Sept. 25, 1994	.37	17,118	.99	.3052	.000785	.009729	.5922	.01566	.001614	.05765
Jan. 14, 1995	3.15	91,733	.62	.9775	.004418	.03027	1.705	.03597	.005894	.1714
Feb. 7, 1995	.24	8,832	.79	.1049	.000610	.004374	.1344	.003870	.000878	.02786
May 28, 1995	.47	20,313	.92	1.536	.003418	.06389	3.278	.04557	.008473	.2752
June 2, 1995	.55	18,547	.72	.3321	.002051	.011870	.5071	.01787	.001586	.05583
July 13, 1995	.74	30,646	.89	.5055	.001147	.01422	1.064	.01656	.004393	.08982
July 26, 1995	.57	19,828	.74	.2148	.000619	.003490	.4155	.01015	.002038	.02777
Aug. 22, 1995	2.37	103,705	.94	3.629	.003514	.05337	7.032	.07502	.03301	.3928
Sept. 5, 1995	.60	40,828	1.46	.7588	.001274	.01511	2.890	.02994	.006449	.1060
Outflow										
Aug. 27, 1994	1.53	60,507	--	.2075	.006603	.001976	.1631	.002055	.001888	.02214
Jan. 14, 1995	3.15	110,236	--	.5880	.01266	.01084	.5488	.01071	.003439	.03572
July 26, 1995	.57	26,782	--	.05651	.003167	.0008356	.1415	.0008356	.0008356	.004891

SUMMARY AND CONCLUSIONS

A study was designed to evaluate the quantity and quality of stormwater runoff from the Bayside Bridge and to evaluate the effectiveness of the stormwater collection and detention pond system of the bridge in reducing constituent loads to Old Tampa Bay, Florida. The roadway runoff drains by gravity to both the north and south ends of the bridge, with the divide in drainage at an elevated crest in the bridge. The stormwater collection and detention pond system at the north end was evaluated in a study conducted between April 1993 and September 1996. Water-quality samples of stormwater runoff from the bridge and outflow from the detention pond were collected during and after selected storms. These samples were used to compute loads for selected constituents.

Stormwater on the Bayside Bridge drained rapidly during a given rain event. The water level in the detention pond on the north end of the bridge increased within several minutes after rainfall began. The volume of stormwater runoff from 24 storms measured during the study ranged from 4,086 to 103,705 ft^3. Storms were most frequent during July through September and were least frequent between February through May.

Stormwater inflow and outflow from the detention pond were sampled before the bridge was opened to traffic. Concentrations of most constituents were less than or equal to concentrations measured after the bridge was opened to traffic. However, concentrations of arsenic in the outflow from the detention pond generally were greater before the bridge opened than concentrations after, and concentrations of orthophosphorus in the stormwater runoff and outflow from the pond were greater before the bridge opened than during more than half the sampled storms after the bridge opened.

Concentrations of most constituents measured in stormwater runoff from the bridge were greatest at the beginning of the storm. As rainfall continued during a storm event, concentrations generally decreased. However, variations in suspended solids, nutrients, and trace elements were not always concurrent with each other. The source of the measured constituent (rainfall or road debris) and the phase of the constituent (suspended or dissolved) probably affected the variation in concentration changes during a storm.

The quality of stormwater runoff from the Bayside Bridge varied with runoff volume, the length of the dry period before the storm, and with the season. Maximum values of most measured constituents occurred in the spring of 1994, when rainfall was minimal.

The quality of outflow from the detention pond varied during a storm event and with season. Maximum concentrations generally occurred near the beginning of a storm, and decreased as the storm continued. During the summer months, pH exceeded 9.0 while inorganic nitrogen concentrations were very low. These high pH values and low inorganic nitrogen concentrations are associated with increased photosynthesis by algae or other aquatic plants in the pond during the summer months. Maximum concentrations of many constituents occurred in June and July 1995.

Average concentrations of suspended solids, ammonia plus organic nitrogen, nitrite plus nitrate nitrogen, orthophosphorus, phosphorus, total organic carbon, aluminum, arsenic, copper, and zinc in stormwater runoff generally were inversely related to runoff volume. This inverse relation is caused by dilution effects.

Concentrations of nitrogen, phosphorus, and nickel in stormwater runoff were correlated with total organic carbon concentrations. Concentrations of chromium, copper, iron, nickel, lead, and zinc in stormwater runoff were correlated to aluminum concentrations. The source of these metals is probably from the bridge materials and metallic debris from vehicles.

Pond sediments were sampled before the bridge was opened to traffic and again after the bridge had been open for about 2 years. Concentrations of ammonia plus organic nitrogen, phosphorus, aluminum, chromium, iron, and mercury increased after the bridge opened, while concentrations of cadmium, nickel, copper, manganese, and zinc were similar during both periods.

The northern detention pond system of the Bayside Bridge effectively reduced concentrations of suspended solids, ammonia nitrogen, nitrite plus nitrate nitrogen, phosphorus, aluminum, cadmium, chromium, copper, iron, lead, nickel, and zinc in stormwater runoff before water discharged from the pond. However, concentrations of ammonia plus organic nitrogen, organic carbon, arsenic, and values for alkalinity, pH, and specific conductance generally were greater in the pond outflow than in stormwater runoff from the bridge.

Stormwater and constituent loading from the bridge to the pond was rapid, usually within minutes of the start of a storm. Constituent loadings often peaked near the beginning of a storm and decreased as the storm continued. Maximum stormwater loads of nitrogen, iron, aluminum, nickel, and zinc coincided with the maximum measured storm volume on Aug. 22, 1995. The least loads of most constituents occurred on Aug. 30, 1993. Although the storm volume was low on this date, four storms had less volume, but greater loads. The low loads associated with the Aug. 30, 1993, storm are associated with the young age of the bridge and the effect of recent rains which washed off the bridge surface.

Stormwater runoff and pond outflow for three storm events were evaluated to determine the effectiveness of the detention pond system in removing selected constituents from the stormwater runoff. Most constituents and constituent loads were reduced in outflow from the pond. Suspended solids loads were reduced about 30 to 45 percent, inorganic nitrogen loads were reduced by about 60 to 90 percent, and loads of most trace elements were reduced by about 40 to 99 percent. However, the pond has a net export of ammonia plus organic nitrogen, organic carbon, arsenic, and phosphorus. The export of nutrients and organic carbon indicates that the source of most of these constituents is biological activity in the pond. The export of arsenic and elevated concentrations of arsenic in the pond outflow before the bridge opened implies that arsenic is stored in the pond sediments and is being released to the overlying pond water.

REFERENCES

Cunningham, Jeffrey, 1993, Comparative water quality data of a deep and a shallow wet detention pond, *in* Proceedings of the 3rd Biennial Stormwater Research Conference, October 7-8, 1993, Tampa, Florida: Southwest Florida Water Management District, Brooksville, Fla., p. 348-361.

Driver, N.E., and Tasker, G.D., 1990, Techniques for estimation of storm-runoff loads, volumes, and selected constituent concentrations in urban watersheds in the United States: U.S. Geological Survey Water-Supply Paper 2363, 44 p.

Fishman, M.J., and Friedman, L.C., eds., 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 Protection, 1993, Regulation of stormwater discharge: Florida Administrative Code Chapter 17-25.

____ 1995, Water policy: Florida Administrative Code, Chapter 62-40.

____ 1996, Surface water quality standards: Florida Administrative Code, Chapter 62-302.

Goldman, C.R., and Horne, A.J., 1983, Limnology: New York, McGraw-Hill, Inc., 464 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.

Helsel, D.R., and Hirsch, R.M., 1995, Statistical methods in water resources: Amsterdam, The Netherlands, Elsevier Science, 529 p.

Kantrowitz, I.H., and Woodham, W.M., 1995, Efficiency of a stormwater detention pond in reducing loads of chemical and physical constituents in urban streamflow, Pinellas County, Florida: U.S. Geological Survey Water-Resources Investigations Report 94-3217, 18 p.

Livingston, E.H., 1989, State perspectives on water quality criteria, *in* Roesner, L.A., Urbonas, Ben, and Sonnen, M.B., eds., Proceedings, Design of urban runoff quality controls, July 10-15, 1988: New York, American Society of Civil Engineers, p. 49-66.

Martin, E.H., and Smoot, J.L., 1986, Constituent-load changes in urban stormwater runoff routed through a detention pond-wetlands system in central Florida: U.S. Geological Survey Water-Resources Investigations Report 85-4310, 74 p.

National Oceanic and Atmospheric Administration, 1994, Climatological data, annual summary: U.S. Department of Commerce, National Climate Center.

____ 1995, Monthly climatological data, January through December: 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.

Rushton, B.T., and Dye, C.W., 1993, An in-depth analysis of a wet detention stormwater system: Southwest Florida Water Management District, Brooksville, Fla., 59 p.

Schiffer, D.M., 1989, Effects of highway runoff on the quality of water and bed sediments of two wetlands in central Florida: U.S. Geological Survey Water-Resources Investigations Report 88-4200, 63 p.

Schropp, S.J., and Windom, H.L., eds., 1988, A guide to the interpretation of metal concentrations in

estuarine sediments: Florida Department of Environmental Regulation, Tallahassee, Fla., 44 p.
Wershaw, R.L., Fishman, M.J., Grabbe, R.R., and Lowe, L.E., eds., 1987, Methods for the determination of organic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chap. A3, 80 p.
Yousef, Y.A., Wanielista, M.P., and Harper, H.H., 1986, Design and effectiveness of urban retention basins, *in* Urbonas, Ben, and Roesner, L.A., eds., Proceedings, Urban runoff quality-Impact and quality enhancement technology, June 23-27, 1986: New York, American Society of Civil Engineers, p. 338-350.
Zarriello, P.J., 1989, Simulated water-quality changes in detention basins, *in* Roesner, L.A., Urbonas, Ben, and Sonnen, M.B., eds., Proceedings, Design of urban runoff quality controls, July10-15, 1988: New York, American Society of Civil Engineers, p. 268-279.