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Effects of the H-3 Highway Stormwater Runoff on the Water Quality of Halawa Stream, Oahu, Hawaii, November 1998 to August 2004

Scientific Investigations Report 2008–5034

U.S. Department of the Interior
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By Reuben H. Wolff and Michael F. Wong

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DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia: 2008

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Conversion Factors

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	4,047	square meter (m^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic inch (in^3)	16.39	cubic centimeter (cm^3)
Flow rate		
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer (m^3/s)/km^2]
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
gallon per day per square mile [(gal/d)/mi^2]	0.001461	cubic meter per day per square kilometer [(m^3/d)/km^2]
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
million gallons per day per square mile [(Mgal/d)/mi^2]	1,461	cubic meter per day per square kilometer [(m^3/d)/km^2]

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8×°C)+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Vertical coordinate information is referenced to local mean sea level.

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

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Abstract

Since November 1998, water-quality data have been collected from the H-3 Highway Storm Drain C, which collects runoff from a 4-mi-long viaduct, and from Halawa Stream on Oahu, Hawaii. From January 2001 to August 2004, data were collected from the storm drain and four stream sites in the Halawa Stream drainage basin as part of the State of Hawaii Department of Transportation Storm Water Monitoring Program. Data from the stormwater monitoring program have been published in annual reports. This report uses these water-quality data to explore how the highway storm-drain runoff affects Halawa Stream and the factors that might be controlling the water quality in the drainage basin.

In general, concentrations of nutrients, total dissolved solids, and total suspended solids were lower in highway runoff from Storm Drain C than at stream sites upstream and downstream of Storm Drain C. The opposite trend was observed for most trace metals, which generally occurred in higher concentrations in the highway runoff from Storm Drain C than in the samples collected from Halawa Stream. The absolute contribution from Storm Drain C highway runoff, in terms of total storm loads, was much smaller than at stations upstream and downstream, whereas the constituent yields (the relative contribution per unit drainage basin area) at Storm Drain C were comparable to or higher than storm yields at stations upstream and downstream. Most constituent concentrations and loads in stormwater runoff increased in a downstream direction.

The timing of the storm sampling is an important factor controlling constituent concentrations observed in stormwater runoff samples. Automated point samplers were used to collect grab samples during the period of increasing discharge of the storm throughout the stormflow peak and during the period of decreasing discharge of the storm, whereas manually collected grab samples were generally collected during the later stages near the end of the storm. Grab samples were analyzed to determine concentrations and loads at a particular point in time. Flow-weighted time composite samples from the automated point samplers were analyzed to determine mean constituent concentrations or loads during a storm. Chemical analysis of individual grab samples from the automated point sampler at Storm Drain C demonstrated the "first flush" phenomenon—higher constituent concentrations at the beginning of runoff events—for the trace metals cadmium, lead, zinc, and copper, whose concentrations were initially high during the period of increasing discharge and gradually decreased over the duration of the storm.

Water-quality data from Storm Drain C and four stream sites were compared to the State of Hawaii Department of Health (HDOH) water-quality standards to determine the effects of highway storm runoff on the water quality of Halawa Stream. The geometric-mean standards and the 10- and 2-percent-of-the-time concentration standards for total nitrogen, nitrite plus nitrate, total phosphorus, total suspended solids, and turbidity were exceeded in many of the comparisons. However, these standards were not designed for stormwater sampling, in which constituent concentrations would be expected to increase for short periods of time.

With the aim of enhancing the usefulness of the water-quality data, several modifications to the stormwater monitoring program are suggested. These suggestions include (1) the periodic analyzing of discrete samples from the automated point samplers over the course of a storm to get a clearer profile of the storm, from first flush to the end of the receding discharge; (2) adding an analysis of the dissolved fractions of metals to the sampling plan; (3) installation of an automatic sampler at Bridge 8 to enable sampling earlier in the storms; (4) a one-time sampling and analysis of soils upstream of Bridge 8 for base-line contaminant concentrations; (5) collection of samples from Halawa Stream during low-flow conditions to determine base-line conditions; (6) addition of the dissolved fraction of the metals chromium and nickel to the sampling plan; (7) elimination of fecal coliform and biochemical oxygen demand (BOD) analyses from the sampling plan; and (8) a study to examine the efficiency of the highway street sweeping.

Introduction

The H-3 Highway is a major roadway that crosses the Koolau Range on the eastern part of the Island of Oahu, Hawaii (fig. 1). Potential effects of construction, such as soil erosion and stream sedimentation, which would degrade the water quality of streams along the route, were an issue of public concern, and construction began in 1987 only after years of environmental evaluation (U.S. Department of Transportation and others, 1987). In 1983, the U.S. Geological Survey (USGS), in cooperation with the State of Hawaii Department of Transportation (HDOT) and in collaboration with the Federal Highway Administration (FHA), began a study to help assess water-quality conditions in these streams before, during and after highway construction (Wong and Yeatts, 2002; Wong and Young, 2001; Wong, 2004).

After the completion of the H-3 Highway in 1998, a monitoring program examining the quality of highway runoff from the North Halawa Valley highway segment was initiated (State of Hawaii Department of Transportation, 2000). The purpose of this additional monitoring was to identify the factors that control the quality of highway runoff and to determine if constituents from highway runoff would adversely affect the quality of water in Halawa Stream. During 2001 to 2004, data were collected as part of a National Pollutant Discharge Elimination System (NPDES) for the HDOT Storm Water Monitoring Program (State of Hawaii Department of Transportation, 2000). Data from the Storm Water Monitoring Program have been published in annual reports (Presley, 2001, 2002; Young and Ball, 2003, 2004); these data are used in this report to evaluate how the highway storm-drain runoff affects Halawa Stream (fig. 1) and the factors that might be controlling the water quality in the drainage basin.

The purpose of the sampling, aside from fulfilling requirements for the HDOT NPDES permit, is to determine whether highway runoff is adversely affecting the quality of water in Halawa Stream. Preliminary analyses have been done on an annual basis by a contractor to the HDOT (State of Hawaii Department of Transportation, 2002, 2003, 2004). However, detailed characterizations of the loadings at each site, the differences between types of sampling techniques, or the changes in constituent concentrations during a storm have not been documented. Additionally, the data set has not been compared to water-quality standards using statistical methods, nor has it been compared to other water-quality data in Hawaii or elsewhere in the United States. Furthermore, no studies have been done to determine the factors, such as traffic volume, storm intensity, total stream discharge related to the storm, and the particular antecedent conditions, that contribute to the constituent loadings.

Purpose and Scope

The purpose of this report is to characterize water quality in the Halawa Stream drainage basin by (1) comparing data among sites to determine how the H-3 highway Storm Drain C affects water quality in the stream, (2) comparing water-quality data with State of Hawaii Department of Health water-quality standards (State of Hawaii Department of Health, 2000), and (3) comparing water quality in the Halawa Stream drainage basin with other highway and urban runoff studies, both in Hawaii and elsewhere. In addition, water-quality data are presented to show how the constituent concentrations vary with the rise and fall of the storm hydrograph. Storm characteristics, including volume of discharge, intensity of rainfall, storm duration, number of cars during storm, and number of dry days before storm, were evaluated using rainfall, discharge, and traffic data to determine relations between the constituent concentrations measured at Storm Drain C and the storm characteristics. Finally, suggestions for modifying the stormwater monitoring program are made to help improve the usefulness of this program for assessing the effects of highway runoff on stream water quality and evaluating the effectiveness of storm water management procedures. Water-quality data for this report were collected between November 17, 1998, and August 4, 2004.

This report describes the Halawa drainage basins and the methods used for water-quality data collection, and it presents a statistical analysis of the water-quality data collected. Data were collected in Halawa (station 16227100) and North Halawa (stations 212356157531801, 212353157533001, 16226200, 16226400) drainage basins (fig. 1); stations are referred to by their abbreviated station names throughout the report (table 1).

Water-quality data used in the analyses in this report have been published in the USGS's annual water-resources data reports for Hawaii for water years 1999 through 2004 (Hill and others, 2000; Taogoshi and others, 2001; Taogoshi and others, 2002; Wong and others, 2004; Teeters and others, 2005; Shimizu and others, 2005). Water-quality data collected for the H-3 monitoring program have been summarized and published in USGS open-file reports (Presley, 2001, 2002; Young and Ball, 2003, 2004).

Description of Study Area

The study area is located in the leeward part of Oahu and is mainly defined by the drainage basin of North Halawa Stream (fig. 1). The study area is bounded by the ridge between North Halawa Stream and South Halawa Stream Valleys on the south, the topographic crest of the Koolau Range on the northeast, the ridge between North Halawa and Kalauao Stream Valleys on the north, and Pearl Harbor on the southwest. North Halawa Stream originates near the topographic crest of the Koolau Range at an altitude of about 2,600 ft and terminates near sea level at the coast.

The Koolau Range is the eroded remnant of the larger and younger of the two major shield volcanoes that formed the Island of Oahu (Hunt, 1996). Much of the windward (east) side of the original Koolau Volcano has been eroded, leaving
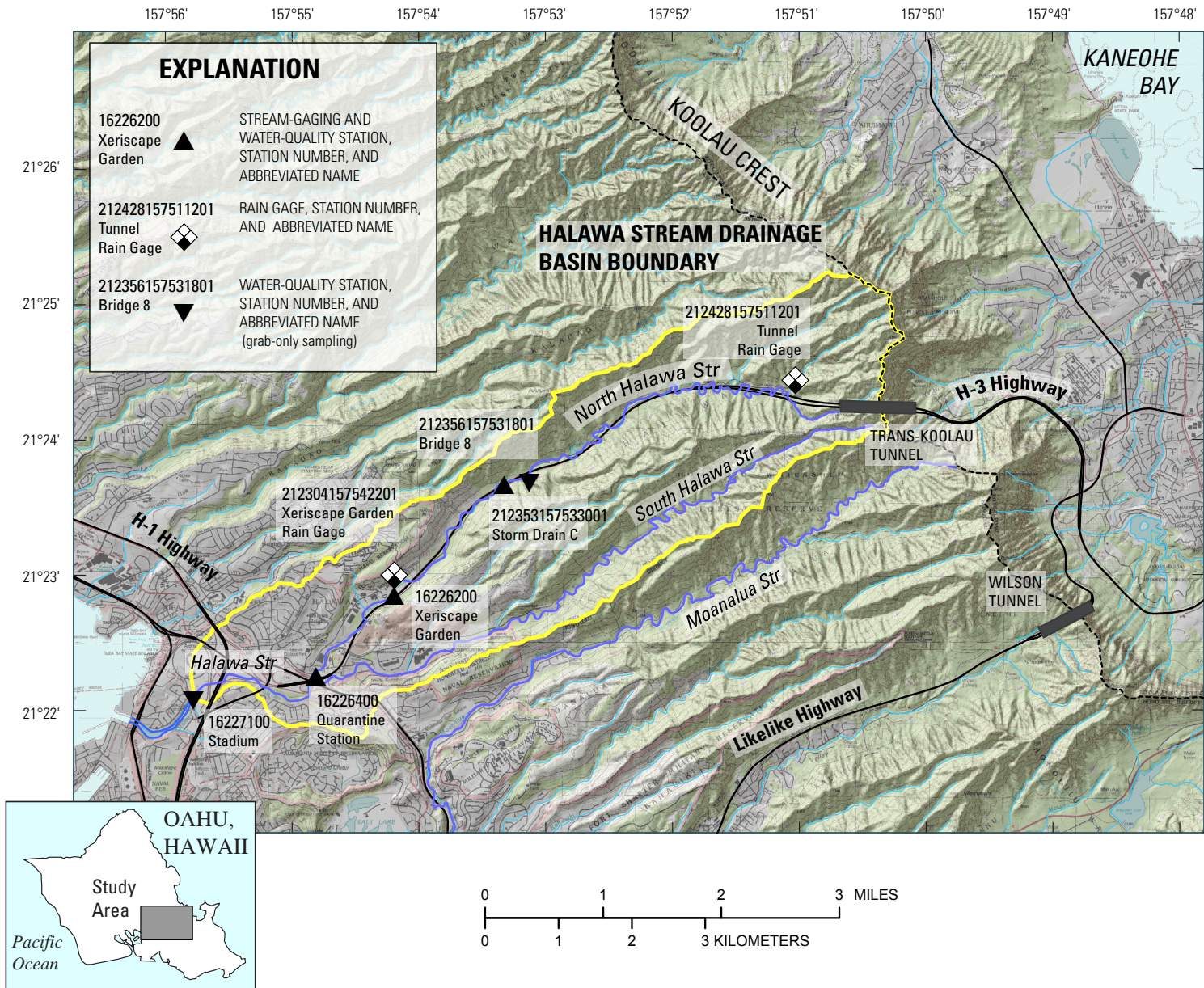
Figure 1. Selected stream- and rain-gaging stations and drainage basins in the study area, Oahu, Hawaii.

a steep windward slope indented with short, broad, amphitheater-shaped valleys (Hinds, 1925). In contrast, the gentle leeward (west) slope is deeply dissected by long, roughly linear valleys. Ridges on the leeward side approximate the original morphology of the Koolau volcanic dome (Wentworth, 1943). Geology of the study area consists primarily of Koolau Basalt that was extruded in numerous gently dipping, thin (less than 10 ft) flows of lava that are intruded by near-vertical dense basaltic dikes near the crest of the present Koolau Range (Hunt, 1996). The valley floor of the North Halawa drainage basin is overlain by alluvium derived from erosion of the Koolau Range (Takasaki and others, 1969; Izuka, 1992).

The climate of Oahu is warm and humid. Average annual temperature near the study area is about 74°F, and monthly averages range from 65°F to 84°F (Owenby and Ezell, 1992). Temperatures above 95°F and below 50°F are rare on Oahu (Blumenstock and Price, 1967). The distribution of rainfall is affected by the prevailing northeasterly trade winds and the topography of the island. Orographic lifting and cooling of marine air masses moving with the trade winds cause heavier and more frequent rainfall on the windward side and near the crest of the Koolau Range. The highest average rainfall occurs about 0.5 to 1 mi leeward of the crest (Wentworth, 1942; Mink, 1960). Rainfall varies seasonally, with most rainfall falling between November and April. Median annual rainfall ranges from 40 to more than 120 in. (Giambelluca and others, 1986).

The temporal and spatial distributions of streamflow are determined almost exclusively by geology and rainfall. Streamflow in North Halawa Stream is intermittent and is dependent primarily on direct runoff that occurs during periods of rainfall. Most infiltrating rainfall in the North Halawa Valley percolates to the basal aquifer and does not contribute to base flows in the streams located there (Izuka, 1992). Streamflow is supplemented by the discharge of small quantities of ground water from alluvial aquifers that extend recession flows only to a minor extent (Izuka, 1992).

Soils in the Halawa drainage basin are classified as low permeability, very stony clays of the Kaena series, with Kawaihapai clay loam soils near the mouth of Halawa Stream (Foote and others, 1972). The majority of the mountainous areas within the study area are classified as rough mountainous land, rock land, or rock outcrop (Foote and others, 1972), and little information is available on the soils of these areas. Vegetation in the North Halawa Valley is representative of undisturbed forest in the leeward Koolau Range and includes native and introduced species.

Halawa Drainage Basin

The Halawa drainage basin is on the leeward side of the crest of the Koolau Range and has a drainage area of 8.90 mi^2 upstream of the Stadium station. Halawa Stream originates at the confluence of North and South Halawa Streams, upstream of the Moanalua Freeway, and flows into the East Loch of Pearl Harbor (fig. 1). Data collection in the Halawa drainage basin was concentrated in the North Halawa Valley. The water-quality data collected at the Stadium station, on Halawa Stream (fig. 1), were the only data collected outside of North Halawa Valley. Between Stadium and Xeriscape Garden, the land is developed and consists of a light industrial park and residential areas near the Moanalua Freeway and H-1 Highway. The H-3 Highway constitutes about 3 percent of the drainage area upstream of Stadium station and about 4 percent of the 4.01 mi^2 drainage area of North Halawa Stream upstream of Xeriscape Garden.

Before highway construction in North Halawa Valley began in November 1987, this drainage basin was undeveloped. The lower valley was used for agriculture from 1850 to 1947 (Spear, 1990). A major water source, the Halawa Shaft, was built by the Honolulu Board of Water Supply in 1940 to develop ground water from the basal aquifer. It is located 200 ft downstream from Xeriscape Garden. Pumping from the Halawa Shaft does not affect streamflow at Xeriscape Garden (Izuka, 1992). There are no streamflow diversions in the drainage basin except for the temporary channel diversions that were related to highway construction. The temporary diversions did not transfer surface water out of the drainage basin. The Lower North Halawa Valley is deeply incised, with only a few small ephemeral tributaries. The stream channel in the lower valley is cut about 3 to 6 ft into the alluvium that forms the valley floor. The steep, upper part of North Halawa Valley is less deeply incised and consists of a dendritic drainage pattern with several intermittent tributaries. In the upper part of the drainage basin, channels are cut into bedrock and include several waterfalls. The stream is more than 100 ft above the basal water table throughout the valley (Izuka, 1992), and flow in the main channel is intermittent in most years. About 20 percent of the stream channel has been channelized, mostly upstream of the discharge point of Storm Drain C (Wong and Yeatts, 2002).

Most of the highway in the upper valley is raised viaduct, designed to minimize effects from highway runoff on the ground-water resource of North Halawa Valley. Storm runoff from the viaduct is collected and transported through iron pipes and aluminum culverts to a discharge point, Storm Drain C, in the lower valley. The storm drain collects water from about 2.5 miles of twin two-lane viaducts, a total of about 0.04 mi^2 of concrete area that is isolated from the surrounding vegetated land cover. An additional 1.4 mi of highway, part viaduct and part on-grade, is located between Storm Drain C and Xeriscape Garden. Runoff from this part of the highway discharges in North Halawa Stream as both diffuse and smaller point discharges. Total concrete paved area upstream of Xeriscape Garden is about 0.06 mi^2. There are no entry or exit points along the H-3 Highway, so all traffic recorded at the Trans-Koolau Tunnels (fig. 1) by the HDOT must travel the entire length of the highway.

Acknowledgements

Definitions of Terms Used in this Report

Grab sample: a discrete sample collected manually or with an automated point sampler with no regard to flow or time; instantaneous sample that is analyzed separately.

Flow-weighted composite sample: a blended sample collected with an automated point sampler consisting of a mixture of aliquots, where the volume of each aliquot is proportional to the flow rate of the discharge.

Time composite sample: a blended sample collected with an automated point sampler that consists of fixed volume aliquots collected at specified time intervals.

Flow-weighted time-composite sample: a blended sample collected with an automated point sampler consisting of a mixture of aliquots collected at specified time intervals, where the volume of each aliquot is proportional to the flow rate of the discharge.

Previous Studies

There are a number of investigations from other locations on water-quality of runoff from highways (for example: Horner and Mar, 1983; Hoffman and others, 1985; Harned, 1988; Barrett and others, 1995a; Irish and others, 1995, 1998; Tasker and Granato, 2000). These studies have identified the constituents that are commonly associated with highway runoff, including nutrients, sediments, organochlorine compounds, and trace metals. Some of these studies have attempted to identify the factors that affect the water quality of highway runoff by regression analysis. Significant factors identified include the duration of the runoff, runoff volume, runoff intensity, traffic volume both before and during the period of runoff, the length of the antecedent dry period, and the duration, volume, and intensity of the previous period of runoff (Barrett and others, 1995a; Irish and others, 1998). Even though traffic volume was not a significant factor for all the constituents analyzed by Barrett and others (1995a), vehicles, along with atmospheric deposition (Harned, 1988), are the major sources of some constituents in highway runoff. Vehicles can transport and deposit metals, sulfates, oil and grease, particulate matter, and nutrients to highway surfaces and runoff. Regression models may be useful tools for identifying constituent-specific factors that affect water quality and to predict the quality of highway runoff (Tasker and Granato, 2000).

Studies on urban stormwater runoff on Oahu from storm-drain systems have been conducted by Fujiwara (1973) and Yamane and Lum (1985). Fujiwara (1973) sampled storm drains in residential, commercial, and industrial areas in urban Honolulu and detected elevated concentrations of suspended solids, chemical oxygen demand (COD), fecal coliform, nutrients, and lead. Yamane and Lum (1985) sampled residential-area storm drains in central Oahu and found high concentrations of turbidity, suspended solids, total ammonia plus organic nitrogen, and total phosphorus in the majority of the samples collected. Neither of these two study areas included any high-speed highways.

A statistical summary of hydrologic and water-quality data collected before, during, and after construction of the H-3 Highway (October 1982 to September 1989) was presented by Wong and Hill (1992). Wong and Young (2001) presented an updated statistical summary of hydrologic and water-quality data for 1983–99. This summary presented annual rainfall, discharge, suspended-sediment loads and concentrations, particle-size distributions, and water-quality data from discharge and suspended-sediment gaging stations.

Constituents and Sources

Most of the material that accumulates on urban roadways consists of inert minerals. Stormwater runoff washes this material into storm drains and eventually into streams. This material has the potential to be harmful to the environment because it can transport nutrients, pesticides, organic constituents, and microbial forms that may be sorbed to the sediments (Sartor and Boyd, 1972; Irish and others, 1995; Wagner and Mitchell, 1987 as cited in Irish and others, 1995).

Determining the sources of the constituents in highway runoff is often a complicated matter greatly influenced by complex environmental conditions. Constituents can have multiple sources, making it difficult to distinguish the dominant source. The accumulation pattern of materials on roadways involves materials continually being blown on and off the roadway. Stormwater washes constituents from the road surface and from the exteriors and undercarriages of vehicles. Periodic roadway cleaning reduces the amount of accumulated material. Additionally, biological and chemical processes, such as volatilization, chemical decay, and biodegradation, can break down and remove constituents (Irish and others, 1995).

Suspended sediment is that portion of the total sediment load that is carried in the water column. Particulates and sediment in runoff can also cause problems by decreasing flow capacity in drainage ways, reducing storage volume in ponds and lakes, smothering benthic organisms, decreasing water

clarity, and interfering with the respiration of small fish. Furthermore, toxic materials often are sorbed to and transported by suspended solids. These toxic materials include metals, hydrocarbons, chlorinated pesticides, and polychlorinated biphenyls (PCBs), and they present acute and chronic threats to organisms living in or using the water (Barrett and others, 1995b; Irish and others, 1995).

The concentration of nitrogen and phosphorus in highway runoff is a concern because these compounds stimulate the growth of aquatic plants in surface waters, increasing the potential for eutrophication and depletion of the oxygen required by aquatic organisms (Barrett and others, 1995b; Irish and others, 1995). Nutrients in stormwater may be derived from both natural and anthropogenic sources. Nitrogen may be derived from rainfall, fixation of atmospheric nitrogen by plants, fertilizers, human and animal waste, or automobile emissions. Phosphate may be derived from volcanic rocks, continental dust, or fertilizers. Because phosphate is retained by minerals common in Hawaiian soils, total phosphorus concentrations in stormwater runoff commonly increase with increasing suspended-sediment concentrations (Hoover, 2002; DeVito and others, 1995; Yim and Dugan, 1975). Thus, unpaved areas may represent a main source of some nutrients in stormwater runoff. Riparian buffer zones along streams help to reduce effects of runoff, and the loss of riparian buffer zones can lead to increased nutrient and sediment problems (Laws and Ferrentinos, 2003).

Research in Hawaii has shown that trace metals, including lead, cadmium, zinc, and copper are transported into streams and estuaries as a result of soil erosion (Sutherland, 2000; De Carlo and Spencer, 1995; De Carlo and Spencer, 1997; De Carlo and Anthony, 2002; Andrews and Sutherland, 2004; Beltran and De Carlo, 2005; De Carlo and others, 2005). Vehicles are considered to be the primary source of anthropogenic trace-metal inputs by way of emissions, wear and tear, brake linings, and vehicle fluids or lubricants. Secondary sources include leaded paints and agricultural and industrial inputs (Sutherland, 2000; Sutherland and others, 2003). Naturally occurring trace metals in the soils and geologic formations of Hawaii have been investigated using isotope-ratio data to determine baseline trace-metal concentrations. Naturally occurring lead from geological deposits in east Oahu are low—less than 10 mg/kg (Sutherland and others, 2003). De Carlo and Spencer (1997) stated that naturally occurring lead concentrations in soils in Hawaii rarely are above 40 mg/kg and are usually much lower, with the highest concentrations occurring in a few basins where the soils are enriched with lead by local geological and hydrological conditions. Sediment concentrations of the trace metals aluminum, cobalt, iron, manganese, and nickel are primarily controlled by natural source variations, whereas other trace metals such as copper, zinc, and lead are influenced by anthropogenic activities (De Carlo and Spencer, 1997; Sutherland and others, 2000; De Carlo and Anthony, 2002; De Carlo and others, 2004; De Carlo and others, 2005).

The introduction of alkyl-lead fuel additives in 1923 has been identified as a major anthropogenic contributor of lead input to the atmosphere in Hawaii (Chow and Earl, 1972; De Carlo and Spencer, 1995; De Carlo and Spencer, 1997; Sutherland and others, 2000; Sutherland and Tolosa, 2000; De Carlo and Anthony, 2002). Leaded gasoline was the source of an estimated 450 tons of lead released in Hawaii in 1971 alone (Eshelman, 1973). The use of alkyl-lead additives was restricted in Hawaii by legislation starting in 1975, but it was not entirely eliminated in Hawaii until 1989, according to the State of Hawaii Department of Business and Economic Development records (De Carlo and Spencer, 1997). Before the 1975 legislation, Jernigan and others (1971) reported that the average urban curbside atmospheric concentrations of lead in and around urban Honolulu, Hawaii, was 0.0077 µg/L, with the highest curbside atmospheric concentration of lead, 0.0235 µg/L, found at the Wilson Tunnel (fig. 1).

De Carlo and Spencer (1997) determined that the distribution of lead in bed sediment cores from the Ala Wai Canal paralleled the use of alkyl-lead fuel additives on Oahu. Anthropogenic sources accounted for more than 90 percent of the lead in some sediment core intervals. An analysis of the stable lead isotope ratios indicated that the lead in the sediment cores was distinct from natural sources. Anthropogenic activity was also determined to be the source of the trace metals cadmium, copper, and zinc (De Carlo and Spencer, 1997). Beltran and De Carlo (2005) observed that during storms in the urban Ala Wai Canal Watershed, particulate lead, zinc, copper, barium, and cobalt had elevated concentrations and particulate loads. DeCarlo and others (2004) also noted that the highest concentrations of trace elements occurred during the "first flush," the early stages of the hydrograph before peaks in discharge, for particulate lead, zinc, and copper and to a lesser degree for barium and cobalt.

Road-deposited sediment in the Manoa basin in leeward Oahu was examined by Sutherland and Tolosa (2000). They determined that the road-deposited sediment had a significant amount of lead, antimony, and zinc that were attributed to vehicles and the past use of leaded gasoline. These sediments are transported into Manoa Stream, where elevated concentrations have been found in bed sediments and fish tissue (Andrews and Sutherland, 2004; Brasher and Anthony, 2000; Brasher and Wolff, 2004; De Carlo and others, 2005; Schmitt and Brumbaugh, 1990; Sutherland, 2000). Sutherland and others (2003), using isotope ratios, determined that the erosion of roadside soils contaminated with lead from the past use of leaded gasoline was the major contributor of lead to the present-day road sediments.

Legacy contaminants, those contaminants that continue to persist in the environment although they are no longer in use, have been shown to be related to both past and present land use in a watershed (Nowell and others, 1999). The use of organochlorine pesticides for agriculture and urban pest control was widespread from the mid-1940s to the mid-1980s (Wong and others, 2000; Brasher and Anthony, 2000). Although these pesticides were largely banned in the United

States in the 1970s and 1980s, they continue to persist in the soils. Studies in Hawaii have shown that concentrations of certain organochlorine pesticides such as chlordane and dieldrin continue to be among the highest in the nation (Bevenue and others, 1972; Tanita and others, 1976; Schmitt and others, 1981, 1985; Schmitt and Brumbaugh, 1990; Hunter and others, 1995; Brasher and Anthony, 2000). Considerable amounts of pesticides, including chlordane, aldrin, dieldrin, and heptachlor, were used in Hawaii to control termites (Brasher and Wolff, 2004).

Industrial compounds such as polychlorinated biphenyls (PCBs) and other semivolatile organochlorines (SVOCs) are extremely persistent anthropogenic organic compounds (Smith and others, 1988; Lopes and Furlong, 2001). PCBs, while no longer produced in the United States, are still found in transformers and capacitors (Smith and others, 1988). Other SVOCs are commonly used in a variety of industrial products and are widespread in the environment. SVOCs include phthalates, phenols, and polycyclic aromatic hydrocarbons (PAHs). PAHs are produced during incomplete combustion and commonly occur in vehicle exhaust and waste incinerators (Lopes and Furlong, 2001; Brasher and Wolff, 2004).

Data-Collection Network

Stream-stage, stream-discharge, rainfall, and water-quality data were collected at selected stations in the Halawa Stream drainage basin (table 1). Rainfall data were collected at the Tunnel rain gage and the Xeriscape Garden rain gage. Continuous discharge data have been collected at three stations in North Halawa Valley since 1998, 1983, and 2001, respectively, for Storm Drain C, Xeriscape Garden, and Quarantine Station. These stations are equipped with automated point samplers. The Quarantine station was put into service on July 10, 2001, destroyed on December 7, 2003, and rebuilt in June 2005. Rainfall and discharge data were collected using variable time steps, depending on rainfall or discharge rates. Data from the two rain gages and the discharge gaging stations are transferred daily to the USGS National Water Information System (NWIS) database using cellular-phone telemetry and can be viewed at http://hi.water.usgs.gov/ by selecting the appropriate USGS station numbers.

Water-quality data were collected at five stations (fig. 1): Bridge 8; Storm Drain C; Xeriscape Garden; Quarantine station; and Stadium. The Bridge 8 station is about 0.75 mi upstream from the discharge point of Storm Drain C on North Halawa Stream. Storm Drain C collects runoff from an approximately 2.5-mi length of freeway, starting at the leeward Tetsuo Harano (Trans-Koolau) tunnel portal and extending to mid-valley, and discharges directly to North Halawa Stream (fig. 1). The Xeriscape Garden station is directly upstream from a light-industrial area near North Halawa Stream and about 1.48 mi downstream of the discharge point of Storm Drain C. The Quarantine station is about 1 mi downstream of Xeriscape Garden and near the downstream end of the light-industrial area that borders the North Halawa Stream. The Stadium station is about 1.5 mi downstream of the Quarantine station, below the confluence of North and South Halawa Streams, downstream from the crossing of H-1 freeway, and directly upstream from the mouth at Pearl Harbor. Discharge peaks from Storm Drain C occur about 60 to 90 minutes before peaks at Xeriscape Garden when the stream is flowing. When the stream is dry before a storm, peaks from Storm Drain C can occur about 6 hours before peaks at Xeriscape Garden. Available water-quality data can be viewed at http://waterdata.usgs.gov/hi/nwis/qwdata by selecting the appropriate USGS station numbers.

Table 1. Station characteristics and types of samples collected. Stations listed in downstream order.

[Horizontal datum for latitude and longitude coordinates is Old Hawaiian; mi^2, square miles; na, not applicable; N., North; numbers in parentheses are the State key numbers]

USGS Station Number	Station Name	Abbreviated station name	Latitude	Longitude	Drainage Area (mi^2)	Types of samples collected
212428157511201	N. Halawa Valley Rain Gage at tunnel (771.11)	Tunnel rain gage	21°24′28″	157°51′12″	na	na
212356157531801	N. Halawa Stream at Bridge 8 near Halawa	Bridge 8	21°23′56″	157°53′18″	3.17	Grab Only
212353157533001	N. Halawa Valley, Storm Drain C near Aiea	Storm Drain C	21°23′53″	157°53′30″	0.04[a]	Grab and Composite
16226200	N. Halawa Stream near Honolulu	Xeriscape Garden	21°23′04″	157°54′22″	4.01	Grab and Composite
212304157542201	N. Halawa Rain Gage near Honolulu (771.9)	Xeriscape Garden rain gage	21°23′04″	157°54′22″	na	na
16226400	N. Halawa Stream near Quarantine station at Halawa	Quarantine Station	21°22′28″	157°54′59″	4.68	Grab and Composite
16227100	Halawa Stream below H-1	Stadium	21°22′17″	157°55′57″	8.9	Grab Only

[a] Estimated area of elevated highway from Trans-Koolau Tunnel to storm drain.

Methods

This section describes the methods used to collect and process discharge data, rainfall data, water-quality samples, traffic data, and the quality-control (QC) measures used in the study.

Rainfall

Rainfall was recorded at two stations using a standard 8-in. National Weather Service collector attached to a 7 5/16-in. rain can with float-type recorder system. The float-type rain gages were put into service in May 1983 at the Xeriscape Garden rain gage and in July 1998 at the Tunnel rain gage. A float-type gage records continuous change in rainfall volumes that are captured in a storage can connected to the 8-in. rain collector.

Discharge

Direct measurements of discharge were made periodically at all stream-gaging and stream water-quality stations using standard practices (Rantz and others, 1982). Peak flows that could not be measured with current meters were measured using the slope-area method (Dalrymple and Benson, 1968) or using float measurements (Buchanan and Somers, 1969: Rantz and others, 1982). Data were computed using the discharge measurements and water level or stage recorded at each of the stations as described by Rantz and others (1982). Total annual discharge is determined by summing the daily mean values of discharge for the water year.

Water Quality

Water-quality samples obtained during January 1998 to September 2004 were collected using techniques described in Young and Ball (2005). Five water-quality sampling stations in the Halawa drainage basin were used for this study: Bridge 8, Storm Drain C, Xeriscape Garden, Quarantine Station, and Stadium (fig. 1). The Bridge 8 site is located upstream of the discharge point of Storm Drain C, and the Xeriscape Garden, Quarantine Station, and Stadium sites are downstream of the discharge point of the storm drain. The Quarantine Station and Stadium sites are located within a light-industrial and urban area and also receive runoff from the highway downstream from Storm Drain C. Storm Drain C, Xeriscape Garden, and the Quarantine Station sites are equipped with automated point samplers.

Sample Collection and Analysis

Measurements of discharge, water temperature, specific conductance, pH, and dissolved oxygen were made in the field. Additionally, samples were collected and analyzed for turbidity, total suspended solids (TSS), major ions, nutrients, trace metals, and organic constituents such as total organic carbon (TOC), oil and grease, pesticides, herbicides, and polychlorinated compounds. All field measurements and samples for chemical constituent analyses were collected, processed, and treated according to guidelines in Ward and Harr (1990), Sylvester and others (1990), and Shelton (1994).

Samples collected before the beginning of the NPDES sampling program in 2001 were primarily grab samples collected manually or with the automated point samplers at Storm Drain C and Xeriscape Garden. Grab samples were collected manually using isokinetic, depth-integrating samplers and equal-width increment (EWI) techniques when flow conditions (stream widths greater than 3 ft and depths greater than 0.5 ft) permitted. Otherwise, single vertical sampling techniques were used at the centroid of streamflow. Samples for inorganic analysis were collected using a DH-81 sampler with 1-liter polyethylene bottles when depths were greater than 0.5 ft. An open-mouth polyethylene bottle was used to collect samples from shallower depths. A churn splitter (Ward and Harr, 1990) was used to composite and split samples for inorganic analysis.

Each automatic sampler collected water from a fixed point in the stream channel after predetermined stage thresholds were met. The automatic samplers had a capacity of 24 bottles and were programmed to collect over various time intervals. Sampling before 2001 was conducted with no strict guidelines; the intent was to explore possible contaminant concentrations within the stream and storm drain with respect to the recently opened highway viaduct.

Samples collected for the NPDES program included grab samples, collected using manual techniques and/or the automatic sampler at the five sites, and flow-weighted, time-composite samples, collected at the three sites with automatic samplers. The composite sample was created by combining volumes from each sample bottle proportional to the stream discharge volume between the sample-collection times. Flow-weighted, time-composite samples were collected over a period that sometimes lasted several hours. A consistent set of analyses, including constituent analyses for four trace metals (copper, zinc, cadmium, and lead), a NPDES nutrient schedule, TDS and TSS, COD, oil and grease, and a few other analyses, was used for each sample.

A mean discharge was calculated for each composite sample. The mean discharge was equal to the total volume of water that passed by the gaging station during sample collection, divided by the total elapsed time during sample collection, using the data from only the samples used for the composite. To determine the total volume, the discharge at the time of sample collection was multiplied by the elapsed time since the previous sample was collected. The same time increment between the first and second samples was also assigned to the first sample. These volumes were summed, and the total volume was divided by the sum of all the time increments.

The DOT Stormwater Monitoring Program Plan (State of Hawaii Department of Transportation, 2000) states that water-

quality samples will be collected at least once per quarter during periods of storm runoff from each of the five water-quality monitoring stations (fig. 1). Grab samples are to be collected during the period of increasing discharge of the storm whenever possible to characterize the first flush. In practice, this was difficult to accomplish except for sites with automated point samplers. The plan also states that efforts will be made to sample all five water-quality monitoring stations during the same storm, and if a storm does not occur during a quarter, no samples will be collected for the quarter.

A complete set of samples for a storm consisted of five grab samples (one from each of the five stations), three flow-weighted time-composite samples, and one quality-assurance and quality-control (QA/QC) sample. However, some storms were brief and did not produce adequate runoff to sample all five stations for both inorganic and organic analysis. In practice, these storms have been sampled as thoroughly as possible and analyzed for an assortment of constituents. Several storms, however, lasted for two to three days (table 2). A total of 9 storms were sampled at all five stations, while the rest of the approximately 29 storms were sampled at some combination of one to four sites. Even though the HDOT Stormwater Monitoring Program Plan required only one QA/QC sample to be collected per storm, three QA/QC samples were collected in previous years and considered part of a complete storm sample. Since December 2003, however, the number of QA/QC samples was reduced to the required one sample per storm (Young and Ball, 2005).

The U.S. Environmental Protection Agency's (USEPA) Storm Water Sampling Guidance Manual (U.S. Environmental Protection Agency, 1993) provides guidelines for stormwater-sampling criteria. The first criterion requires at least 0.1 in. of accumulated rainfall. Rainfall accumulations exceeded 0.1 in. at both rain gages when stormwater sampling was conducted. The second criterion requires that samples be collected only for storms preceded by at least 72 hours of dry weather. The second criterion would prevent sampling of most storms on North Halawa Stream because the Halawa Stream drainage basin, as well as many other parts of Oahu, receives tradewind showers almost daily (Blumenstock and Price, 1967). Instead, the criteria used to initiate sampling of the stream and storm drain were based on the rate of rainfall accumulation and the rise of stage in Storm Drain C and at Xeriscape Garden stations. Each automatic sampler was triggered at predetermined station-specific stream-stage thresholds (3 cfs for Storm Drain C and 40 cfs for Xeriscape Garden).

The methods used for the analyses of all the water-quality properties and constituents followed those in Wershaw and others (1987), Britton and Greeson (1989), Fishman and Friedman (1989), and Fishman (1993). All laboratory analyses were conducted by the U.S. Geological Survey's National Water Quality Laboratory (NWQL) in Colorado. Quality control practices at NWQL are documented in Friedman and Erdmann (1982) and in Pritt and Rease (1992). In January 1993, laboratory analysis for total nitrate and nitrite was discontinued and only dissolved nitrate and nitrite were analyzed after that date,

because values for total and dissolved nitrate and nitrite were statistically indistinguishable (U.S. Geological Survey Office of Water Quality Technical Memorandum 93.04). Samples were analyzed for trace metals by ICP-AES (Inductively Coupled Plasma - Atomic Emission Spectrometry) from 1983 to 1998, then GFAA (Graphite Furnace - Atomic Adsorption) from 1998 to 1999, and then ICP-MS (Inductively Coupled Plasma - Mass Spectrometry) from 2000 to present. Samples were analyzed for organic compounds by GC/MS (Gas Chromatography/Mass Spectrometry).

Calculation of Loads and Yields

The analysis of the storm runoff data differs from previous USGS H-3 Highway reports because the purpose of this study was to determine the effects of the operation of the H-3 Highway on North Halawa Stream water quality. The approach in this report used data from automatic water-quality samplers as well as manual grab samples collected during storms, especially those storms with sufficient rainfall to cause high discharge at the Xeriscape Garden station, in order to compare water quality from the highway runoff to water-quality criteria and to determine the factors contributing to the highway runoff.

Instantaneous constituent loads for all analyses are reported in pounds per day (lbs/day) and were calculated as the product of the constituent concentration (Event Mean Concentration (EMC) for composite samples) multiplied by the associated discharge (instantaneous for discrete samples, event mean for composite samples) and the appropriate conversion factor using the equation:

$$L = Q \times C \times K \tag{1}$$

(Terrio, 1995; East and others, 1998; Sneck-Fahrer and others, 2005) where:

L = constituent load in pounds per day,

Q = discharge, in cubic feet per second,

C = constituent concentration, in milligrams per liter or micrograms per liter, and

K = conversion factor.

Instantaneous constituent yields are reported in pounds per square mile per day and were calculated using the equation:

$$Y = L/DA \tag{2}$$

where:

Y = constituent yield, in pounds per square mile per day,

L = constituent load, in pounds per day, and

DA = area of contributing drainage basin, in square miles.

Table 2. Number of samples collected at each station and date of sampling event.

[–, no samples; dates in *italics* indicate storm sampling continued from previous day; includes grab and composite samples]

Date	Bridge 8	Storm Drain C	Xeriscape Garden	Quarantine Station	Stadium
17-Nov-98	–	–	1	–	1
18-Nov-98	–	1	4	–	–
2-Mar-99	–	–	1	–	–
6-Jun-99	–	1	–	–	–
9-Jun-99	–	1	–	–	–
15-Jun-99	–	1	–	–	–
16-Oct-99	–	2	–	–	–
19-Oct-99	–	5	4	–	–
20-Oct-99	–	–	1	–	–
4-Nov-99	–	6	9	–	–
7-Nov-99	–	1	–	–	–
9-Nov-99	–	1	–	–	–
11-Nov-99	–	1	–	–	–
30-Nov-99	–	1	–	–	–
1-Dec-99	–	1	5	–	–
13-Jan-00	–	2	–	–	–
26-Jan-00	–	4	1	–	–
23-Mar-00	–	1	–	–	–
25-Mar-00	–	1	–	–	–
26-Mar-00	–	2	–	–	–
27-Mar-00	–	2	1	–	–
31-Mar-00	–	–	4	–	–
7-Jun-00	–	1	–	–	–
31-Jul-00	–	–	1	–	–
20-Aug-00	–	–	4	–	–
5-Jun-01	1	1	1	1	1
16-Sep-01	1	2	2	1	1
28-Oct-01	1	1	2	1	1
26-Jan-02	–	2	2	1	–
28-Jan-02	–	1	1	–	–
29-Jan-02	1	1	1	2	1
20-Apr-02	–	8	1	3	–
5-May-02	–	1	1	1	–
6-May-02	1	1	1	1	1
14-Oct-02	–	1	–	–	–
15-Oct-02	–	1	1	1	–
15-Jan-03	–	2	–	–	–
30-Jan-03	–	1	–	–	–
31-Jan-03	1	2	2	2	1
14-Feb-03	1	2	2	2	1
16-Mar-03	–	1	1	1	–
17-Mar-03	–	–	1	1	–
26-Jul-03	1	2	2	1	–
29-Nov-03	1	2	4	3	–
22-Jan-04	–	1	2	–	–
23-Jan-04	–	–	1	–	–
25-Jan-04	–	1	1	–	–
26-Feb-04	–	2	1	–	–
27-Feb-04	1	1	1	1	1
3-Aug-04	–	1	–	–	–
4-Aug-04	1	1	1	1	1

Storm loads were calculated using equation 1 by replacing the instantaneous discharge and concentration values with the event mean discharge and concentration values for the storm of interest. Storm yields were calculated using equation 2 by replacing the instantaneous constituent load with the storm constituent load. The event mean discharge is equal to the total volume of water that flowed by the gaging station during sample collection, divided by the total elapsed time required to collect the samples. The event-mean concentration (EMC) was used whenever more than one sample was collected for a storm event. The EMC is the constituent concentration determined by analyzing a flow-weighted composite sample or by weighting the concentration data from multiple grab samples collected over various times of a storm by the storm volume, as shown in equation 3:

$$EMC = (C_i V_i + C_j V_j + ... + C_n V_n) / VOL \qquad (3)$$

where:

$C_i V_i$ = the concentration at a specific time multiplied by the flow volume (V) during the time interval beginning one-half way between i and the time of the previous sample or beginning of a storm and ending half way between i and the time of the next sample or end of the storm. There were times when only one sample set was collected during a storm. In such cases, the concentration values from this one set were used as the EMC.

Statistical Methods for Censored Data

Water-quality data are often reported as less than the analytical laboratory minimum reporting level (MRL), defined as the smallest measured concentration of a constituent that may be reliably reported using a given analytical method (Timme, 1995; Childress and others, 1999). These results are reported with a remark code '<', indicating the actual value is known to be less than the value shown. This means that the actual result can range anywhere from zero up to the MRL, but cannot be known with certainty. Therefore, a value reported as less than the MRL does not necessarily mean that the constituent is not present in the sample. It may be absent or may be present at a concentration below the reporting level currently in use by the laboratory.

Reporting levels can be increased or decreased over time because of improved sampling and laboratory techniques or greater understanding of the analytical methods involved. Results can also be reported as estimated values (remark code 'E'). Some MRL changes at the NWQL during the course of this study are listed in table 3. More information regarding analytical detection limits can be found in Childress and others (1999). Constituents with multiple detection limits were analyzed in this report using the detection limit applicable at the time the samples were originally collected.

Table 3. Changes in Minimum Reporting Levels (MRL) by the analytical laboratory over the study period.

[The five-digit USGS parameter code is used to uniquely identify a specific constituent or property; Start date, date that the reporting level went into effect; End date, date the reporting level was superseded; ESP, end of the study period; mg/L, milligrams per liter; µg/L, micrograms per liter]

Constituent name	USGS parameter code	Start date	End date	Minimum Reporting Level	Units
Nitrogen, nitrite, dissolved	00613	13-Oct-94	3-Oct-00	0.01	mg/L
		4-Oct-00	14-May-01	0.006	mg/L
		1-Oct-01	ESP	0.008	mg/L
Phosphorus, dissolved	00666	21-Jan-99	3-Oct-00	0.05	mg/L
		15-May-01	30-Sep-02	0.06	mg/L
		1-Oct-03	ESP	0.04	mg/L
Total phosphorus	00665	1-Oct-98	20-Jan-99	0.05	mg/L
		4-Oct-00	14-May-01	0.06	mg/L
		1-Oct-02	ESP	0.04	mg/L
Total suspended sediment	00530	1-Jan-92	31-Mar-00	1	mg/L
		1-Apr-00	ESP	10	mg/L
Oil and grease	00556	23-Jul-96	30-Sep-01	1	mg/L
		1-Oct-01	ESP	7	mg/L
Nitrogen, ammonia, dissolved	00608	14-Nov-97	3-Oct-00	0.02	mg/L
		1-Oct-03	ESP	0.04	mg/L
Nitrogen, nitrite + nitrate	00631	14-Oct-94	3-Oct-00	0.05	mg/L
		1-Oct-02	ESP	0.06	mg/L
Total cadmium	01027	8-Feb-00	7-Nov-00	1	µg/L
		1-Oct-03	30-Sep-06	0.04	µg/L
Chromium, dissolved	01030	1-Jan-92	30-Sep-99	1	µg/L
		15-May-01	30-Sep-05	0.8	µg/L
Nickel, dissolved	01065	1-Jan-92	30-Sep-99	1	µg/L
		1-Oct-99	17-Oct-00	1.4	µg/L
Total nickel	01067	1-Jan-92	30-Sep-99	1	µg/L
		1-Oct-99	14-May-01	1.8	µg/L
Total zinc	01092C	1-Oct-99	14-May-01	31	µg/L
	01092D	8-Feb-00	30-Sep-02	1	µg/L
		1-Oct-02	ESP	2	µg/L

Methods for computing summary statistics, including mean, standard deviation, and geometric mean, for data reported as less than the MRL are summarized in Helsel (1990, 2005). The method recommended by Helsel (2005) for computing means is the robust approach to "regression on order statistics" (Robust ROS), also called the log-probability regression method (Gilliom and Helsel, 1986; Helsel and Gilliom, 1986) and extended for multiple detection limits in Helsel and Cohn (1988). This method is suitable for small to moderate sized datasets, multiple detection limits, and non-normally distributed data, and it avoids transformation bias where logarithmic summary statistics are re-transformed. Individual censored values are estimated by first fitting the log-transformed detected values to a regression equation. Censored values are predicted from the regression equation on the probability plot on the basis of their normal scores. These esti-

mated values are then back-transformed to the original units, substituted into the dataset, and used for the limited basis of calculating the summary statistics. This method is explained fully in Helsel (2005) and Shumway and others (2002). The Robust-ROS estimates were calculated with a SAS macro modified by Helsel and available on the World Wide Web at *http://www.practicalstats.com/Pages/software.html* using SAS/STAT® software, Version 9.1 of the SAS System for Windows, copyright© 2002-2003 by SAS Institute, Inc.

Quality Assurance

Field and laboratory quality-assurance (QA) and quality-control (QC) procedures were implemented as described in the DOT Storm Water Monitoring Program Plan (State of Hawaii Department of Transportation, 2000). The automatic-sampler

intake lines were routinely cleaned. To confirm that the sampling equipment was effectively cleaned, rinsate blanks, using inorganic blank water (IBW), were collected from the automatic samplers after cleaning the intake lines. Additional rinsate samples were periodically collected from the DH-81 isokinetic sampler after cleaning and from the Teflon® bottle liner used in the automatic samplers. The rinsate blanks were analyzed for nutrients and for cadmium, copper, lead, and zinc. All grab-sample collection equipment was cleaned before each storm and sampling.

With regard to potential cross-contamination in the intake lines, it is important to note that the automatic sampler pumps a rinse cycle before every sample collected. Water is first purged, then sucked up the line to a sensor located before the sample bottles, and finally purged before the sample is collected. After the sample is collected, the line is purged again. The purge, rinse, purge, sample collection, and third-purge cycle minimizes possible contamination from water pumped during earlier storms and from previously pumped samples during the same storm.

The results of the rinsate blank analyses for the automatic samplers at Storm Drain C, Xeriscape Garden, and Quarantine Station are provided in appendix A. The most noteworthy information provided by the rinsate blank analyses are the results for total zinc. Concentrations of total zinc were reported above the minimum reporting level (1 µg/L before October 2002; 2 µg/L beginning in October 2002) in 67 percent (14 out of 21) of the QA samples collected between April 2, 2001, and September 8, 2004. The highest zinc concentration of 27 µg/L was reported on July 15, 2003 at Storm Drain C. The high concentrations of zinc in the blank samples need to be considered when interpreting the storm sampling analytical results of zinc (Office of Water Quality Technical Memorandum 2001.02).

Traffic Data

The bidirectional, hourly traffic-volume data provided by the HDOT of all vehicles passing through the Tetsuo Harano (Trans-Koolau) tunnel exhibited a consistent pattern of highway use. Weekends and holidays were characteristically unimodal, with a single peak around midday. Non-holiday weekdays were characteristically bimodal, with two peaks representative of the morning and evening rush hours. Large storms tended to reduce or delay highway vehicular usage. Traffic on Hawaii's roadways has increased as the resident population of Honolulu County has increased from 875,377 in 2000 to 899,562 in 2004 (U.S. Census Bureau, 2007) and the number of registered motor vehicles in Honolulu County has increased from 614,985 in 2000 to 688,163 in 2004 (State of Hawaii Department of Business, Economic Development and Tourism, 2005). A street-sweeping schedule was not available at the time of this report.

H-3 Stormwater Data Analysis

Rainfall

Rainfall records for this study spanned from 1999 to 2004 at both rain gages. Annual rainfall totals were approximately four times greater at the Tunnel rain gage than at the Xeriscape Garden rain gage, except in 2004, when it was only approximately two times greater. This marked difference highlights the localized difference in rainfall between the leeward mountain slopes and the leeward lowlands, as discussed in Blumenstock and Price (1967). The lowest annual rainfall totals were in water year 2001, and the highest were in water year 2004.

Discharge

Storm Drain C drains only the surface area of the elevated H-3 highway and only flows during periods of rainfall. Flow at Storm Drain C during the 6-year study period averaged 0.18 cfs and exceeded 1.0 cfs less than 10 percent of the time (fig. 2). The Xeriscape Garden station on North Halawa Stream has a much larger drainage area and therefore higher flows. The average discharge at the Xeriscape Garden station was 4.2 cfs during the 6-year study period (fig. 2). Both Storm Drain C and Xeriscape Garden stations had periods of zero flow.

Discharges at Storm Drain C and Xeriscape Garden were associated with rainfall at the Tunnel rain gage (appendix B). Periods of high-intensity rainfall coincided with peaks on the discharge hydrographs. Stormwater samples were collected from about 38 of these storms (appendix B). A total of 187 water-quality samples were collected over the 6-year period. The exact number of storms is difficult to discern because some rainy periods produced multiple hydrograph peaks.

Analysis of Water Quality Data

The results of the chemical analyses performed on H-3 stormwater samples are summarized in appendix B. Additionally, for the stations with automatic samplers, the summary statistics are provided for each sample type, composite or grab (appendix C). These analytical results can be compared to results from rinsate blank samples (appendix A) to evaluate if contamination of the automatic sampling equipment may have affected the composite results. The detection of total zinc in the rinsate blank samples from Storm Drain C ranged from 2 to 27 µg/L, and the concentration of total zinc in the composite samples ranged from 12 to 290 µg/L with a mean of 119 µg/L. Of 24 sample analyses, only 3 Storm Drain C results were equal to or less than the highest reported concentration in blank samples. Therefore, contamination from the automatic-sampling equipment was not an issue.
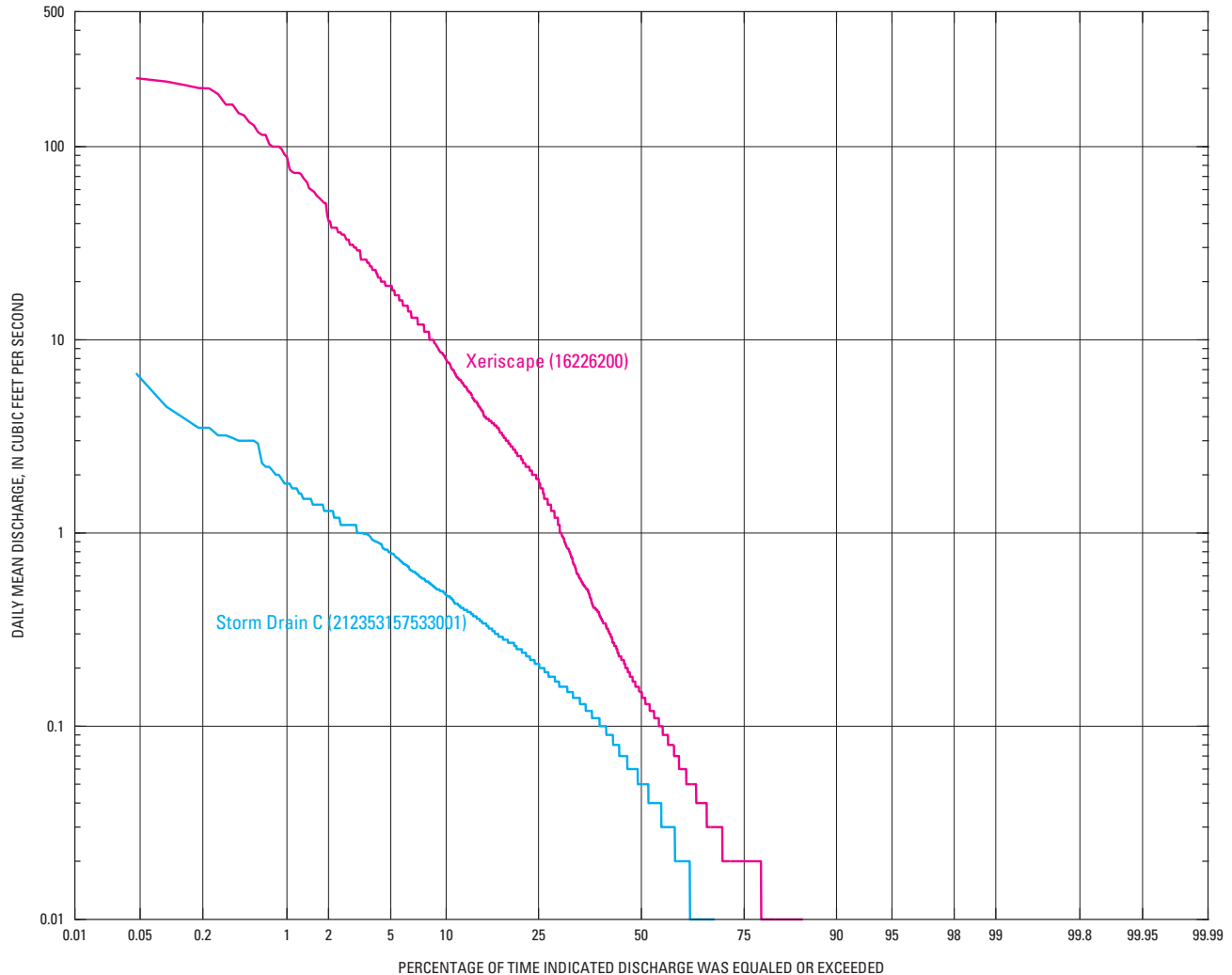
Figure 2. Flow-duration curves for Xeriscape Garden and Storm Drain C gaging stations, October 1998 to September 2004.

Constituent Concentrations during the Storm of April 20, 2002

For the storm of April 20, 2002, grab samples from the automated point sampler were analyzed for trace metals separately instead of being analyzed as a composite. Because of the flashy nature of streams in Hawaii, it is often difficult to manually obtain a sample during the early "first flush" of a storm. An automated point sampler, which is capable of collecting samples over the full extent of a storm, can eliminate this problem (fig. 3). Analysis of individual samples from an automated point sampler provided a profile of the constituent concentrations during the storm (fig. 4). These profiles can vary for individual constituents or groups of constituents. Concentrations of the trace metals cadmium, lead, zinc, and copper behaved in a similar manner with respect to the stream hydrograph during the course of the storm—initially high during the period of increasing discharge, decreasing over the

next three samples to the peak flow, increasing slightly after the peak flow, and remaining nearly stationary through the final sample taken about one hour later. The profile for pH was relatively flat, fluctuating between 7.4 and 7.7 standard units with minor variations similar to the pattern of the metal concentrations. The profile for specific conductance did not have the variations that the metals and pH had. Instead, specific conductance gradually declined from the initial sample to the post-peak sample, and then remained relatively constant.

The "first flush" phenomenon, higher concentrations at the beginning of runoff events, has been documented in studies elsewhere (Sartor and Boyd, 1972; Howell, 1978; Barrett and others, 1995a; Irish and others, 1995; Barber and others, 2006) and in Hawaii (De Carlo and others, 2004; Beltran and De Carlo, 2005). This occurs as the particulate matter that has accumulated on the road surface is mobilized by storm runoff moving downgradient toward the roadway drainage. The

amount of particulate matter and the speed with which it will travel depend on the mass of the matter, the volume of runoff, and the roadway gradient. The "first flush" phenomenon necessitates that the rising limbs of storms be sampled in order to identify high-end concentrations and determine unbiased event-mean concentrations for the storms.

Temporal and Spatial Distribution of Samples and Constituents During a Storm

As mentioned earlier, a complete set of samples for a storm consisted of five grab samples (one from each of the five stations), three flow-weighted time-composite samples, and one QA/QC sample. The collection of a complete set of samples begins when stormwater runoff reaches the predetermined stage thresholds of the automatic samplers. Because many storms happened late at night, the stations were often not accessed until the next morning. Thus, grab samples were frequently collected during the period of decreasing discharge of the storms, hours after the storms had peaked and the automatic samplers had completed their cycle.

The temporal and spatial pattern of sampling for a complete set of samples is described using the storm of February 14, 2003, as an example. The record at the Storm Drain C gage showed a relatively dry period of about two weeks following a January 1, 2003, storm that registered a maximum discharge of 27 cfs. Bidirectional traffic during this time averaged about 42,000 vehicles per 24-hour period. The record also showed a very brief elevation in discharge (9.5 cfs) during the night of February 13, 2003, about 4 hours before the sampling had begun, but it was below the threshold set for sampling. The automatic sampler at Storm Drain C was triggered to collect samples at 2:53 AM on February 14, 2003, when the discharge was 14.11 cfs, and continued to collect samples until 5:28 AM (fig. 5). The automatic sampler at Xeriscape Garden started to collect samples at 12:55 AM, at a discharge of 174.8 cfs, and continued to collect samples until 5:04 AM. The automatic sampler at Quarantine Station was triggered to collect samples at 3:14 AM, at a discharge of 58.5 cfs, and continued to collect samples until 8:06 AM. The grab sample from Stadium was collected at 9:30 AM, more than an hour after the Quarantine Station automatic sampler had collected its last sample. The Bridge 8 grab sample was collected at 10:00 AM, approxi-
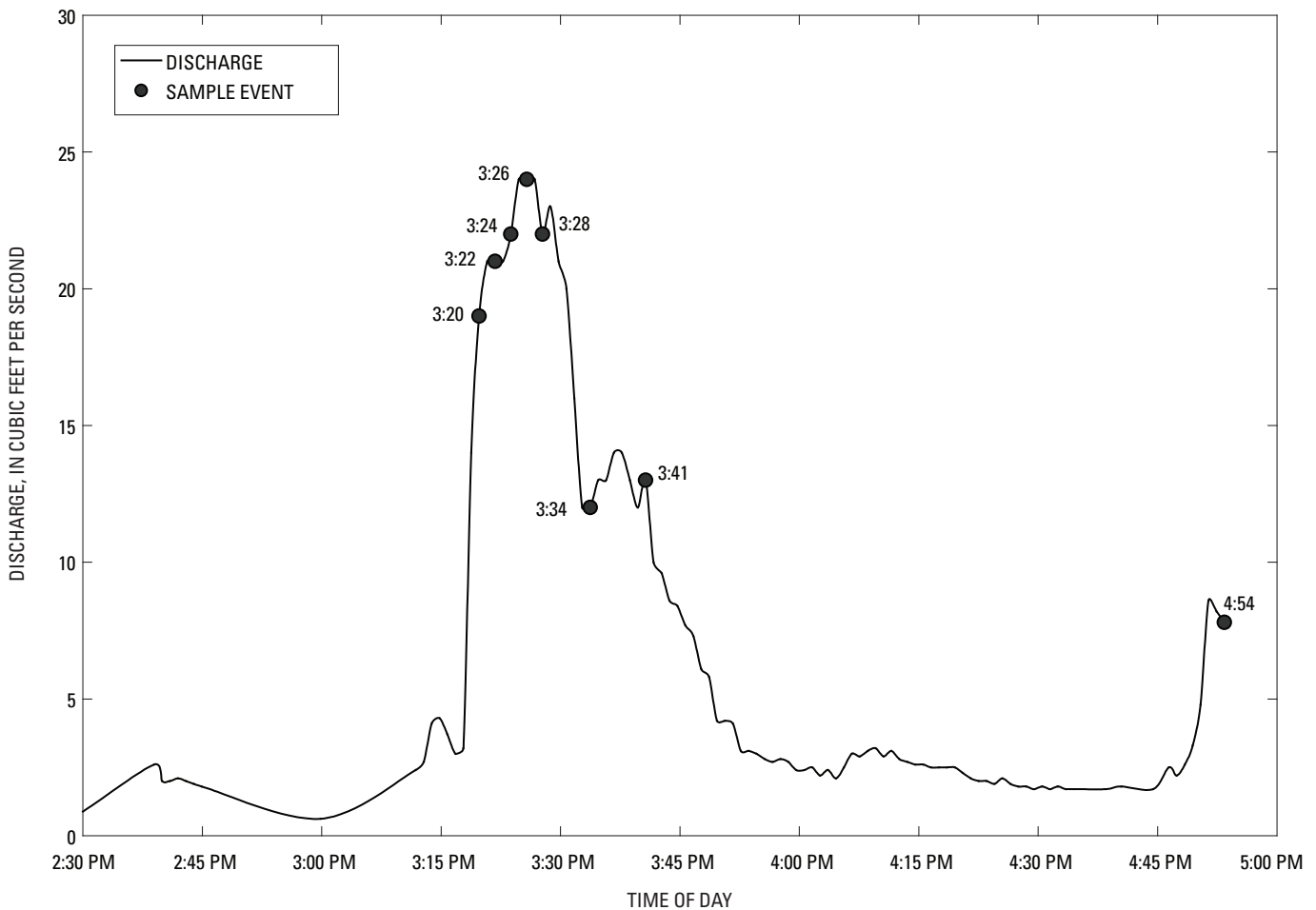
Figure 3. Discharge and sampling times for storm of April 20, 2002, at Storm Drain C.
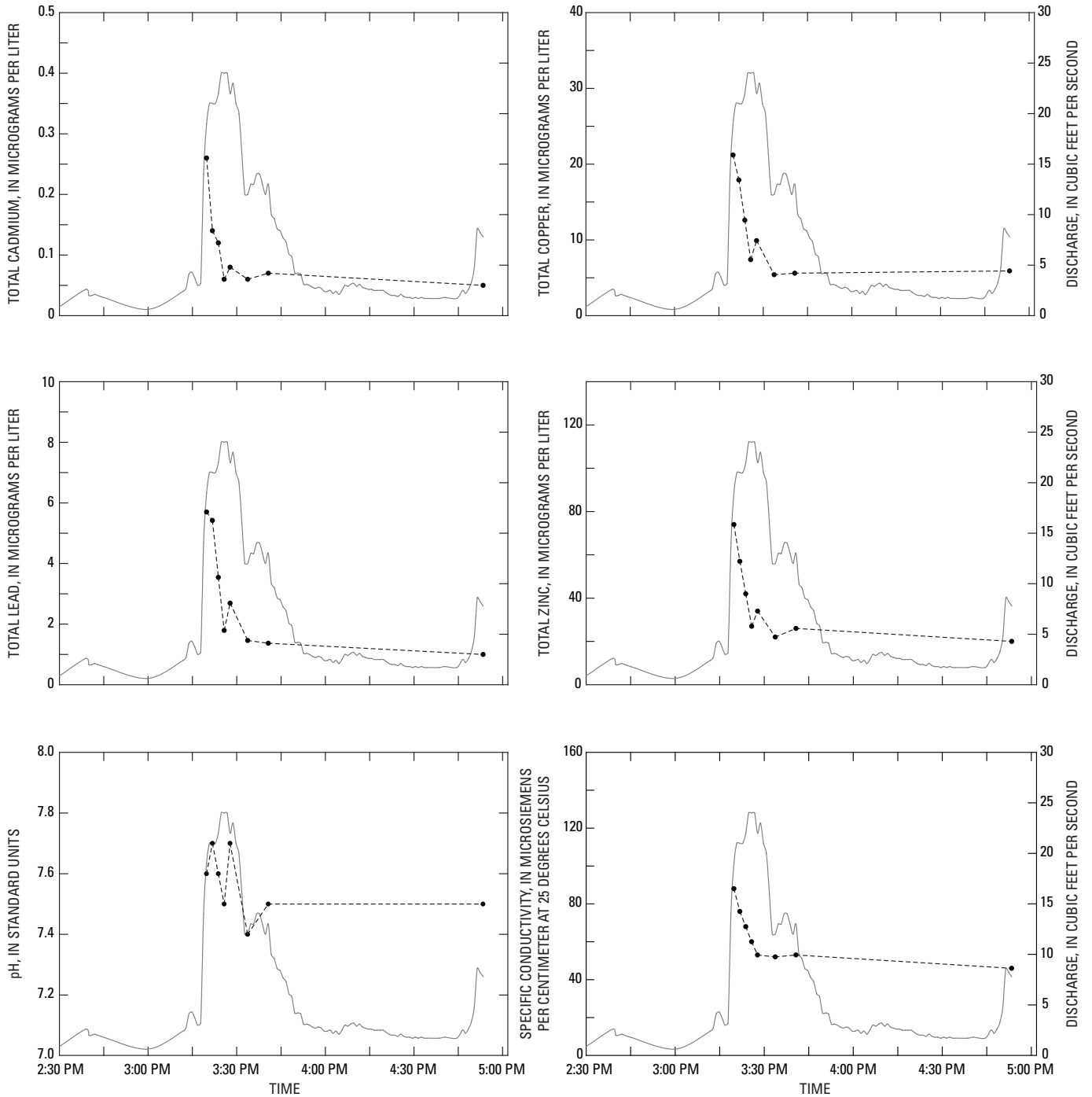
Figure 4. Selected physical properties and constituents measured in water samples collected from Storm Drain C during the storm of April 20, 2002.

mately 7 hours after the sampler at Storm Drain C was first triggered. Grab samples from Storm Drain C, Xeriscape Garden, and Quarantine Station were all collected after 10:30 AM.

Mean discharge for the composite sample at Storm Drain C was 9.4 cfs, whereas mean discharge for the Xeriscape Garden composite sample was much greater, 265 cfs, and mean discharge for the Quarantine Station composite sample was only 49 cfs (table 4). The instantaneous discharge measured

when the grab samples were collected varied among the sites but had dropped considerably from the peak or mean storm discharge. For Storm Drain C, this was a 94-percent decrease (9.4 to 0.56 cfs), and for Xeriscape Garden it was a 70-percent decrease (265 to 79 cfs). Discharge remained relatively constant between composite and grab samples at Quarantine Station.
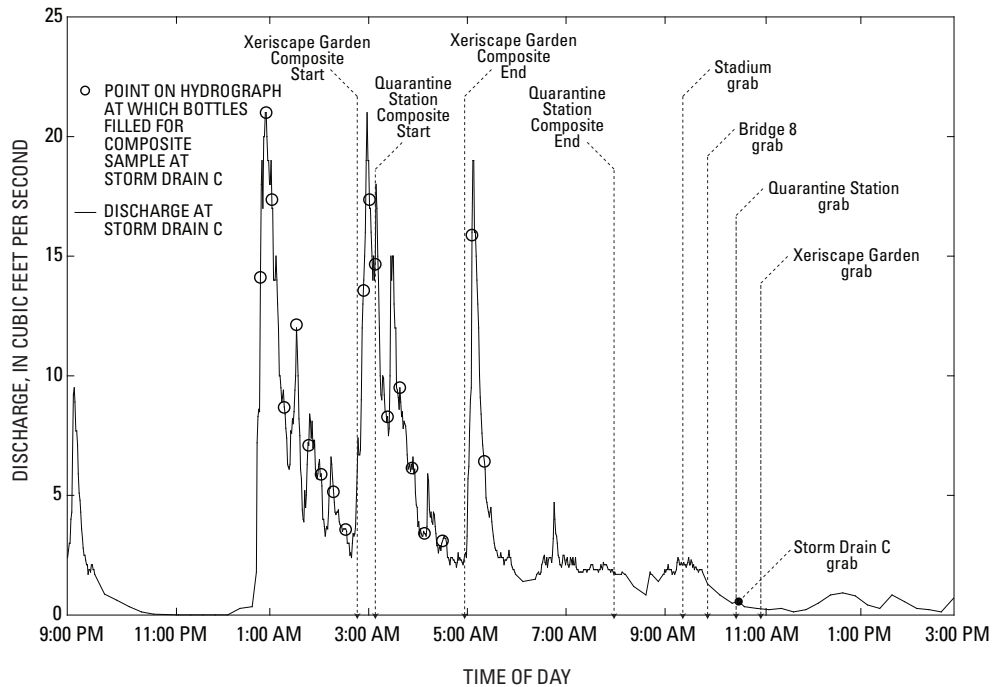
Figure 5. Sampling times at all stations for storm of February 14, 2003, based on discharge at Storm Drain C. The start time and end time for the composite sampling at Xeriscape Garden and Quarantine Station are denoted by dashed lines.

The concentration of TSS was relatively low in the Storm Drain C composite sample, 13 mg/L, much greater in the downstream composite sample collected at Xeriscape Garden, 692 mg/L, and even greater in the composite sample collected farther downstream at Quarantine Station, 760 mg/L (table 4). TSS concentration followed the same pattern as discharge, decreasing between the time of the composite sampling and the time of the grab sampling. At Xeriscape Garden, TSS concentration was 96 percent lower in the grab sample relative to the composite sample collected approximately 8 hours earlier. At the Quarantine Station, TSS concentration was 91 percent lower in the grab sample relative to the composite sample collected approximately 5 hours earlier. TSS concentrations were greater in the Bridge 8 grab sample than in the Storm Drain C grab sample collected within 40 minutes of each other late in the storm.

Trace metal concentrations were all lower in the Storm Drain C composite sample than in the Xeriscape Garden composite sample, possibly because runoff on February 13, 2003, may have partly cleansed the highway of trace metals before that sample was collected (table 4). Trace metal concentrations in the Quarantine Station composite samples were all slightly lower than in the Xeriscape Garden composite sample but still higher than at Storm Drain C. Trace metal concentrations were considerably lower in the composite samples than in the grab samples at Xeriscape Garden and Quarantine Station and, to a lesser degree, in the Storm Drain C samples. Trace metal concentrations were relatively low in the grab samples collected at Stadium and Bridge 8. Of the trace metals, total copper concentrations exhibited the largest differences among com-

posite samples. The concentration of total copper at Xeriscape Garden (67.8 μg/L) was approximately 7 times greater and that at Quarantine Station (58.4 μg/L) approximately 6 times greater than at Storm Drain C (9.5 μg/L). The total nitrogen and phosphorus constituents followed the same trends as the trace metals.

The constituent concentrations of the Storm Drain C composite sample represent the water quality of the H-3 Highway runoff for the duration of the February 14, 2003, storm, and the constituent concentrations of the Bridge 8 grab sample represent the water quality of runoff from the undeveloped part of the North Halawa Stream drainage basin after the bulk of the storm had passed. Figure 13 illustrates that trace metal concentrations during a storm (at Storm Drain C in this example) can be higher during the early period of the hydrograph, before peak flow, and tend to decline as runoff decreases. Because of the time delay in sampling at Bridge 8, constituent concentrations may be lower than if collected during the period of increasing discharge; therefore, the total input of the undeveloped part of the North Halawa Stream drainage basin may be underestimated. Supporting evidence for this was provided during the storms of February 26—27, 2004, when Bridge 8 was sampled during a very high flow. The initial storm on the afternoon of February 26 triggered the Storm Drain C automatic sampler at 1:47 PM. By the time the sample at Bridge 8 was collected, 12:06 PM on February 27, a second rainstorm had increased flow in the stream. At the time of sampling at Bridge 8, the discharge had increased to 721 cfs, the highest flow measured at Bridge 8 during this study. The trace metal concentrations in this sample were also the

Table 4. Constituent concentrations and loads at all stations during the storm of February 14, 2003.

[<, less than; –, no data; E, estimated; cfs, cubic feet per second; µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; N, nitrogen; µg/L, micrograms per liter; lb/day, pounds per day]

Property or constituent	Units	Sampling sites and times on February 14, 2003							
		Storm Drain C Composite	Xeriscape Garden Composite	Quarantine Station Composite	Stadium Grab	Bridge 8 Grab	Quarantine Station Grab	Storm Drain C grab	Xeriscape Garden Grab
		3:11 AM	3:58 AM	5:40 AM	9:30 AM	10:00 AM	10:35 AM	10:38 AM	11:45 AM
Temperature, water	degrees Celsius	17.2	20.3	19.7	19.5	17.9	18.3	19.5	18.3
Discharge	cfs	9.4	265	49	–	–	–	–	–
Discharge, instantaneous	cfs	–	–	–	235	47	51	0.56	79
Gage height	feet	–	–	–	1.5	96.79	5.13	1.31	7.7
Specific conductance, field	µS/cm at 25°C	–	43	–	74	76	78	89	86
Specific conductance, lab	µS/cm at 25°C	36	50	55	78	78	84	85	88
Chemical oxygen demand	mg/L	<10	160	40	10	<10	10	<10	10
load	lb/day	<507	228,706	10,572	12,676	<2,535	2,751	<30	4,261
pH, field	standard units	–	6.3	–	7.2	5.8	7.5	6.9	6.7
pH, lab	standard units	7.6	6.9	7.3	7.6	7.3	7.5	7.7	7.7
Total suspended solids	mg/L	13	692	760	91	46	65	<10	30
load	lb/day	659	989,152	200,873	115,351	11,662	17,881	<30	12,784
Oil and grease	mg/L	–	–	–	<7	<7	<7	<7	<7
load	lb/day	–	–	–	<8873	<1775	<1926	<21	<2983
Total nitrogen	mg/L	0.28	3.5	3.4	0.77	0.44	0.56	0.24	0.4
load	lb/day	14	5,003	899	976	112	154	0.73	170
Nitrogen ammonia dissolved	mg/L as N	E0.03	E0.03	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
load	lb/day	E1.5	E43	<11	<51	<10	<11	<0.12	<17
Nitrogen, nitrite, dissolved	mg/L as N	<0.008	<0.008	E0.004	E0.005	<0.008	E0.007	E0.007	<0.008
load	lb/day	<0.4	<11	E1	E6	<2	E2	E0.02	<3
Nitrogen, ammonia + organic, total	mg/L as N	0.25	3.4	3.3	0.59	0.33	0.43	0.12	0.27
load	lb/day	13	4,860	872	748	84	118	0.36	115
Nitrogen, nitrite + nitrate, dissolved	mg/L as N	<0.06	0.09	0.1	0.18	0.12	0.13	0.12	0.14
load	lb/day	<3	129	26	228	30	36	0.36	60
Total phosphorus	mg/L	E0.04	1.12	1.07	0.19	0.1	0.13	E0.04	0.06
load	lb/day	E2	1,601	283	241	25	36	E0.12	26
Phosphorus dissolved	mg/L	<0.04	E0.03	<0.04	0.04	<0.04	<0.04	E0.03	<0.04
load	lb/day	<2	E43	<11	51	<10	<11	E0.09	<17
Total cadmium	µg/L	0.06	0.25	0.17	<0.04	<0.04	0.04	E0.03	<0.04
load	lb/day	0.003	0.4	0.05	<0.05	<0.01	0.01	E0.0001	<0.02
Total copper	µg/L	9.5	67.8	58.4	13.1	5.3	7.6	5.7	4.6
load	lb/day	0.482	96.91	15.44	16.61	1.34	2.09	0.02	1.96
Total lead	µg/L	2.47	6.03	5.59	2.85	0.25	0.68	1.1	0.43
load	lb/day	0.125	8.6	1.5	3.6	0.063	0.187	0.003	0.183
Total zinc	µg/L	38	91	85	28	7	14	27	6
load	lb/day	1.93	130.08	22.47	35.49	1.77	3.85	0.08	2.56
Total petroleum hydrocarbons	mg/L	–	–	–	3	<2	<2	<2	<2
load	lb/day	–	–	–	3803	<507	<550	<6	<852
Total dissolved solids	mg/L	16	32	37	54	47	53	56	60
load	lb/day	811	45,741	9,779	68,450	11,915	14,580	169	25,568

highest measured at Bridge 8 during this study and are denoted as the Bridge 8 maximum observations in appendix C, table C1, for copper (99.4 µg/L), lead (7.95 µg/L), zinc (129 µg/L), and cadmium (0.4 µg/L).

Spearman-Rank correlation analysis (SAS Institute, 1990) was conducted to examine the relationship between discharge and constituent concentration at Bridge 8. This nonparametric procedure provides a measure of the intensity of association between two variables. The correlation coefficient, rho (ρ), is computed using ranks of the data rather than actual data values (Helsel and Hirsh, 1992). Correlation coefficient values range between -1 and +1, with a negative value indicating an inverse relationship between the data ranks and zero representing no relationship. The probability that the null hypothesis, defined as no correlation existing between the variables, is true is expressed as the p-value (p). A p-value of 0.05 was used as the cutoff in the analyses to identify significant correlations. Correlations with p-values at or below the 0.05 significance level presume a 95-percent or greater confidence that the correlations are scientifically valid. The analysis using Spearman-Rank correlation (n = 11) determined that the instantaneous discharge measurements at Bridge 8 were positively correlated with concentrations of the trace metals copper ($\rho = 0.81$, $p = 0.0026$), lead ($\rho = 0.76$, $p = 0.0062$,), zinc ($\rho = 0.78$, $p = 0.0042$), and cadmium ($\rho = 0.85$, $p = 0.0008$). This suggests that the undeveloped basin upstream of Bridge 8 may be contributing trace metals into North Halawa Stream.

Site Comparison of Water-Quality Data

The results of chemical analyses indicate some important spatial trends (figs. 6, 7). The boxplots in figures 6 and 7 were computed without estimates for censored data. For that reason, boxplots of data that included censored results are displayed using the "boxplot at sunrise" method from Helsel (2005) without estimated arithmetic means and distributions below the highest minimum reporting level (MRL; if more than one; see table 3). This graphic method provides an accurate portrayal of the dataset. The unseen proportion of the boxplot below the MRL illustrates the amount of censored data in the dataset. In general, for both composite samples and grab samples, nutrient, TDS, and TSS concentrations were lower at Storm Drain C than at both the upstream station, Bridge 8, and the downstream stations. In most cases, the concentrations in the actual stream decreased in a downstream order because of the larger volume of water downstream causing greater dilution of the constituents. This trend is reversed for most trace metals, which tended to have higher concentrations at Storm Drain C than at the upstream and downstream stations. These trends suggest different source areas for the different constituents. Higher amounts of trace metals are deposited onto the roadway surface by vehicular traffic, whereas the forested basin contributes greater amounts of nutrients and eroded sediments into the stream.

Overall, the composite samples tended to have higher constituent concentrations than the grab samples, probably because grab samples were generally collected after the first flush of the storm. However, specific conductance and the concentrations of TDS were notably lower in the composite samples. Total cadmium concentrations were higher in the composite samples, but show little difference among the sites, whereas in the grab samples, Storm Drain C appears to have higher concentrations of cadmium than the other stations. The differences between the sampling methods may account for the differences in the constituent concentrations. The composite samples cover a much broader period of the storm runoff, including the earlier "first flush" and peak flows that can mobilize the greater part of the road-deposited material, whereas most grab samples were collected after a majority of the runoff had passed.

The contributing drainage area and resultant storm runoff volume are much smaller at Storm Drain C (table 1) than at stations along Halawa Stream. The influence of discharge is made more evident when comparing daily loads (fig. 8*A*). The boxplots in figure 8 were computed using Robust ROS estimates for censored data. Daily loads were calculated using equation 1, taking into account discharge—instantaneous for discrete samples and event mean for composite samples. Because of the comparatively small discharge, the absolute contribution from Storm Drain C, in terms of constituent loads, was much smaller than at the stations downstream. Storm Drain C has a much smaller drainage area, and therefore the pattern is different when comparing daily yields (calculated using equation 2). The relative contribution of Storm Drain C is in general much greater than from the stations downstream. Notably,however, concentrations and loads of TDS and TSS were consistently lower at Storm Drain C. This is because of the low amounts of sediments deposited on the highway as compared to the amounts of sediments being eroded from nonpaved areas and carried into the stream during rainstorms.

Comparison of Wet and Dry Seasons

In general, there were only minor differences in the ranges and distributions of constituent concentrations between the wet and dry seasons. The HDOH defines the wet season as November 1 to April 30 and the dry season as May 1 to October 31 (State of Hawaii Department of Health, 2000). There were no obvious differences between seasons for composite samples or grab samples at Storm Drain C for any of the constituents. The buildup of material on the roadway during the longer dry periods of the dry season is most likely offset by more frequent street sweeping. There were, however, noticeable differences between seasons at some sites for nitrite plus nitrate (fig. 9) and total copper (fig. 10). Concentrations of nitrite plus nitrate were higher during the wet season at Bridge 8, Xeriscape Garden, and Stadium. Concentrations of total Cu were higher during the wet season in the composite samples from Xeriscape Garden and Quarantine Station.
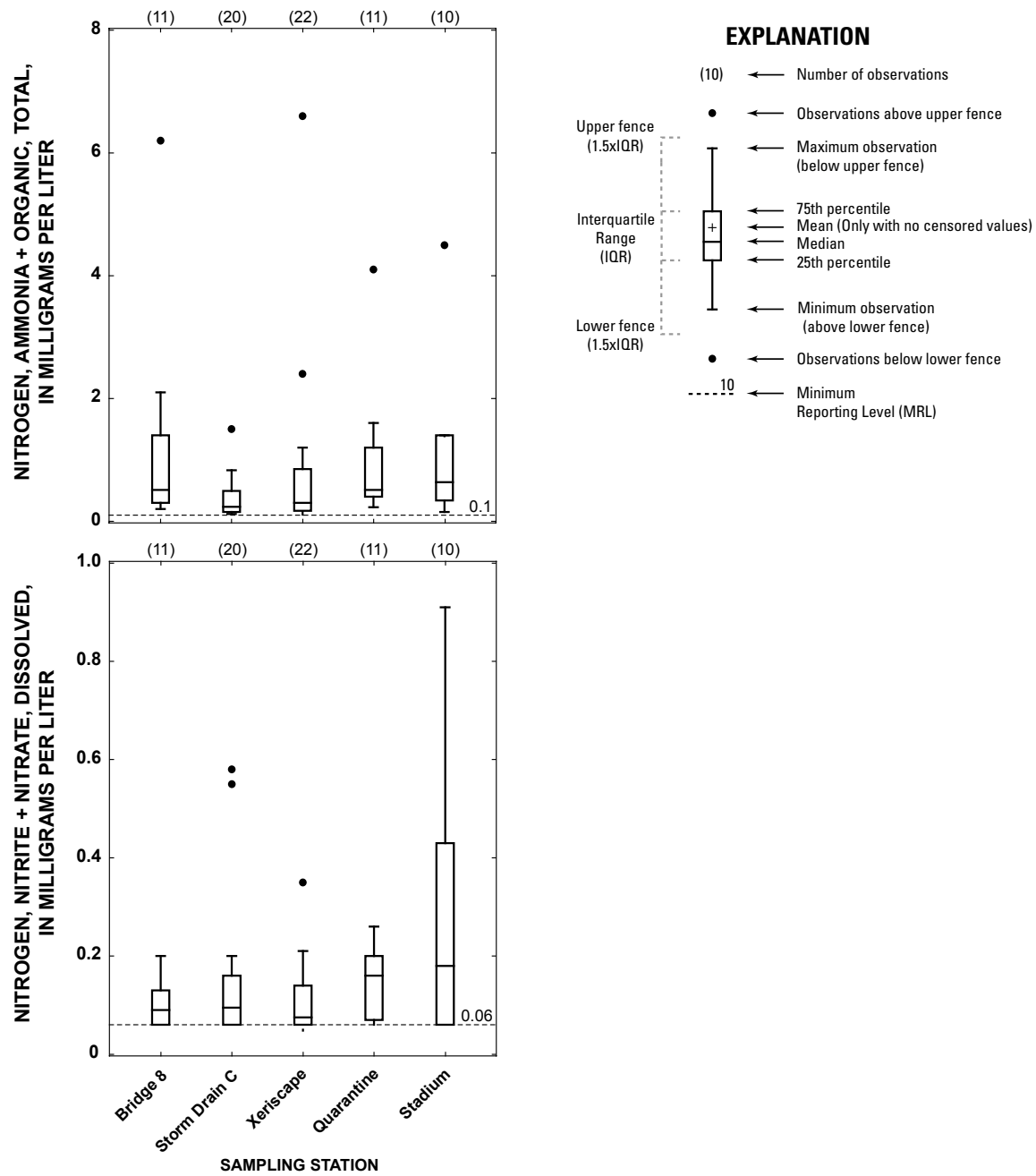
EXPLANATION

Figure 6. Boxplots of select constituent concentrations from grab samples collected over the entire period of the study.
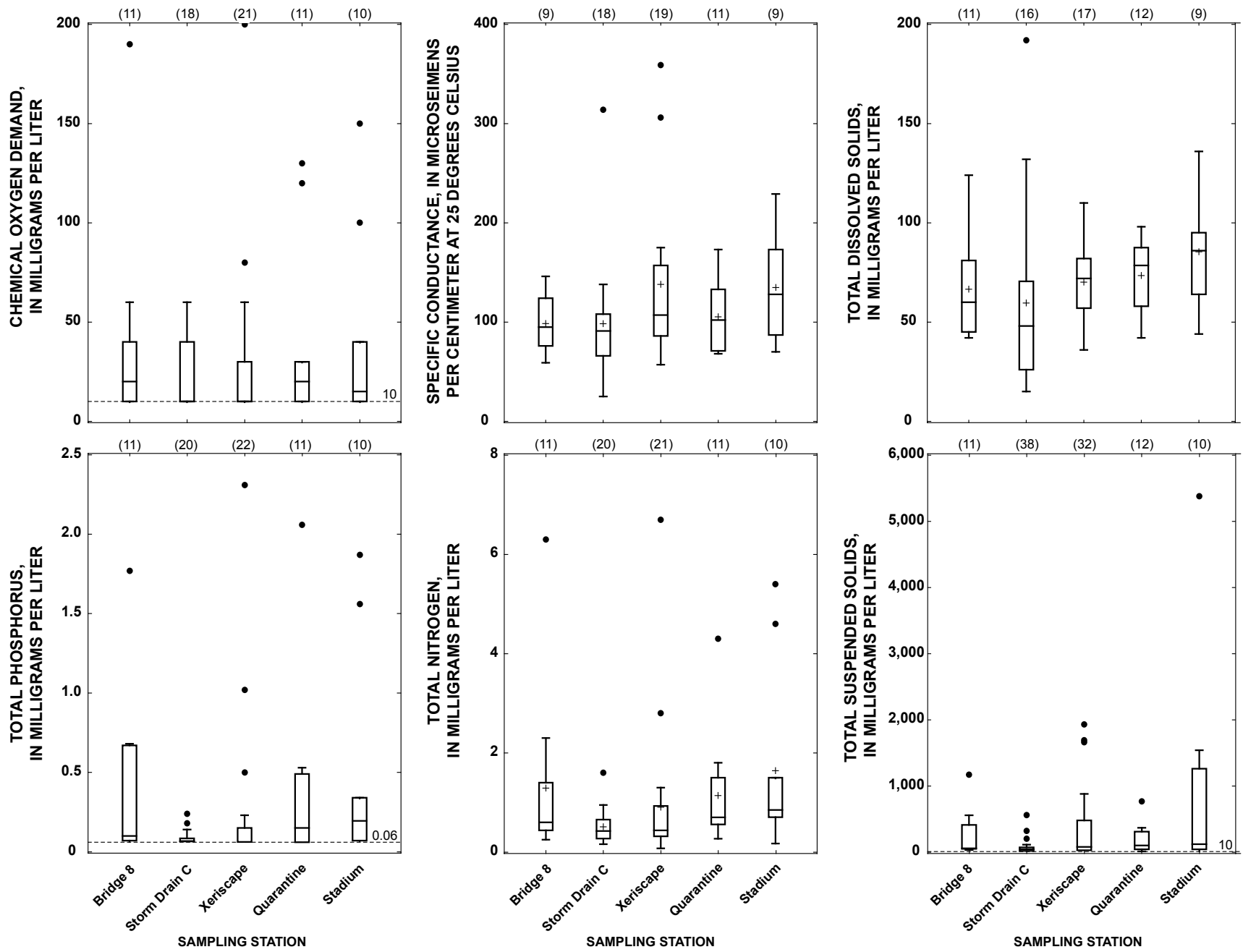
Figure 6. Boxplots of select constituent concentrations from grab samples collected over the entire period of the study—Continued.
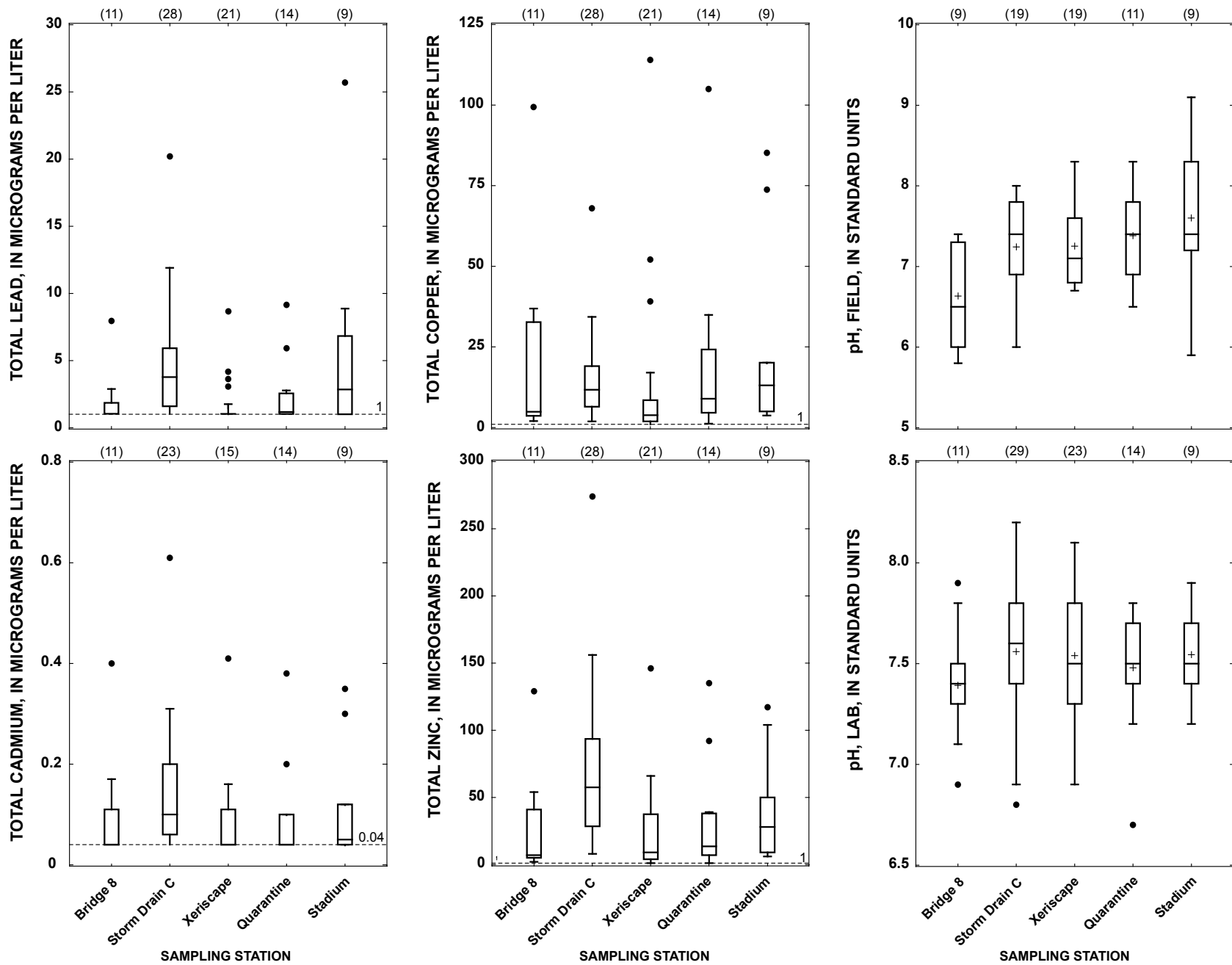
Figure 6. Boxplots of select constituent concentrations from grab samples collected over the entire period of the study—Continued.
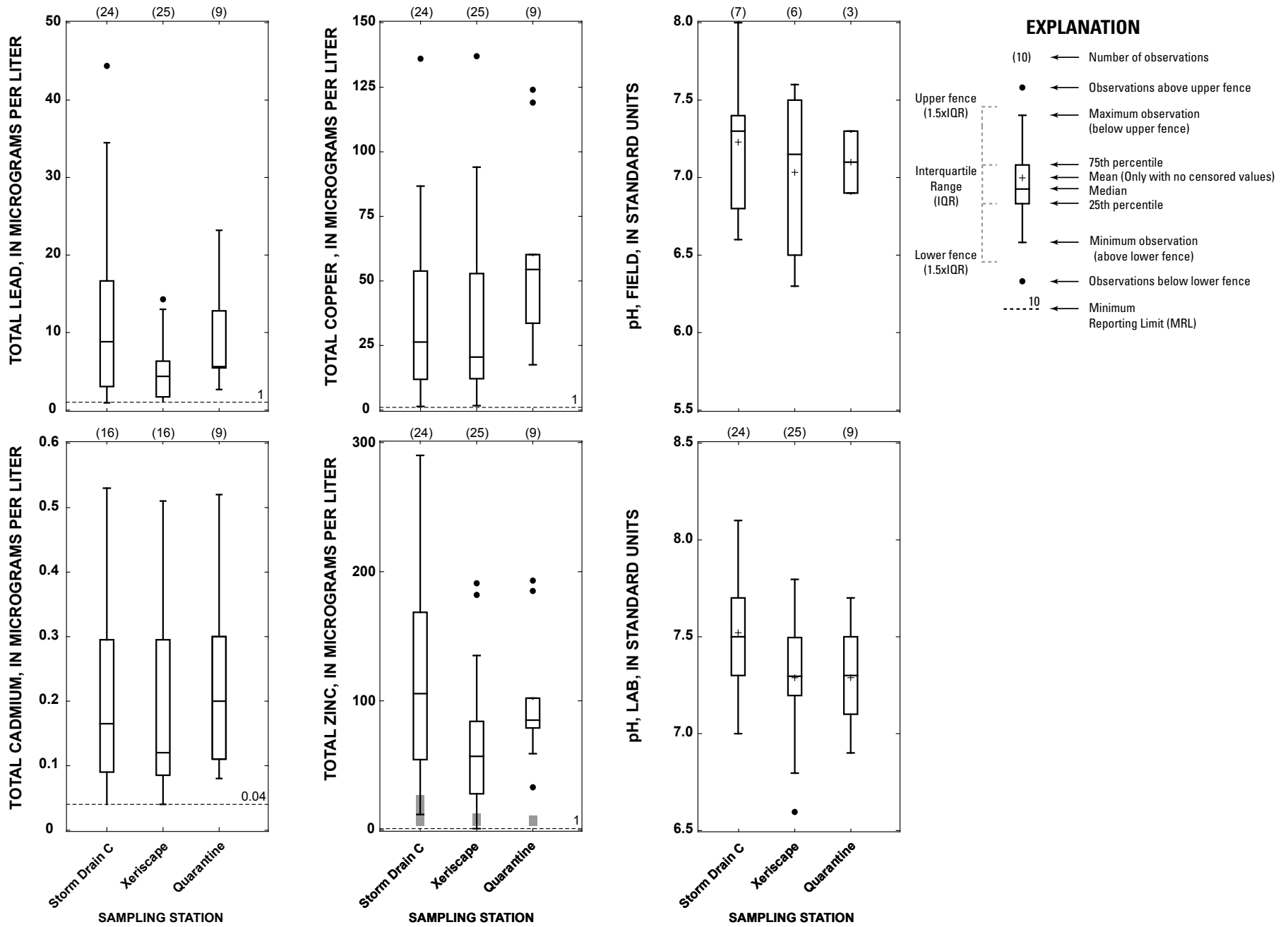
Figure 7. Boxplots of select constituent concentrations from composite samples collected over the entire period of the study. Shaded bars in the zinc boxplot represent quality control rinsate blank concentration ranges.
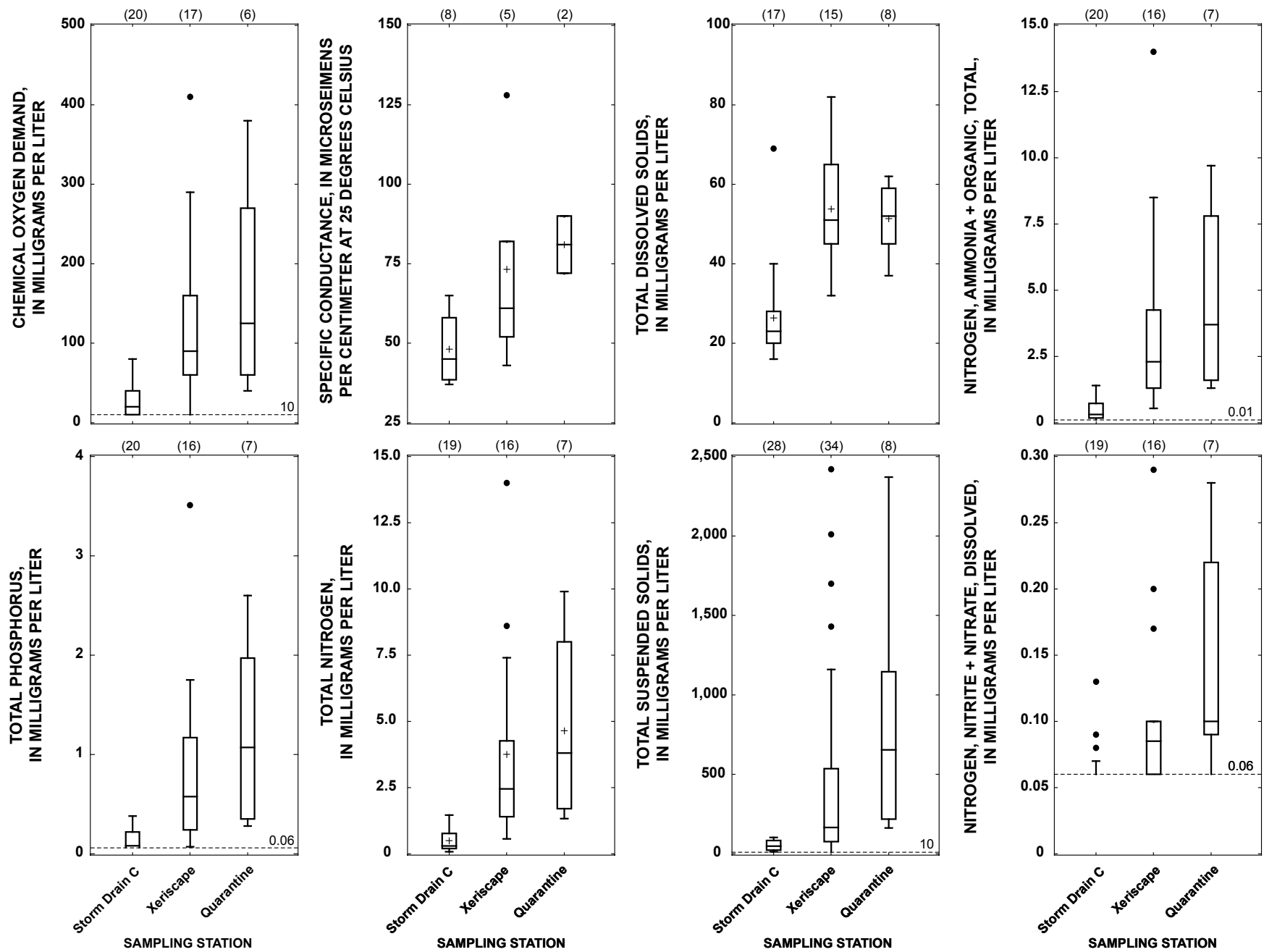
Figure 7. Boxplots of select constituent concentrations from composite samples collected over the entire period of the study. Shaded bars in the zinc boxplot represent quality control rinsate blank concentration ranges—Continued.
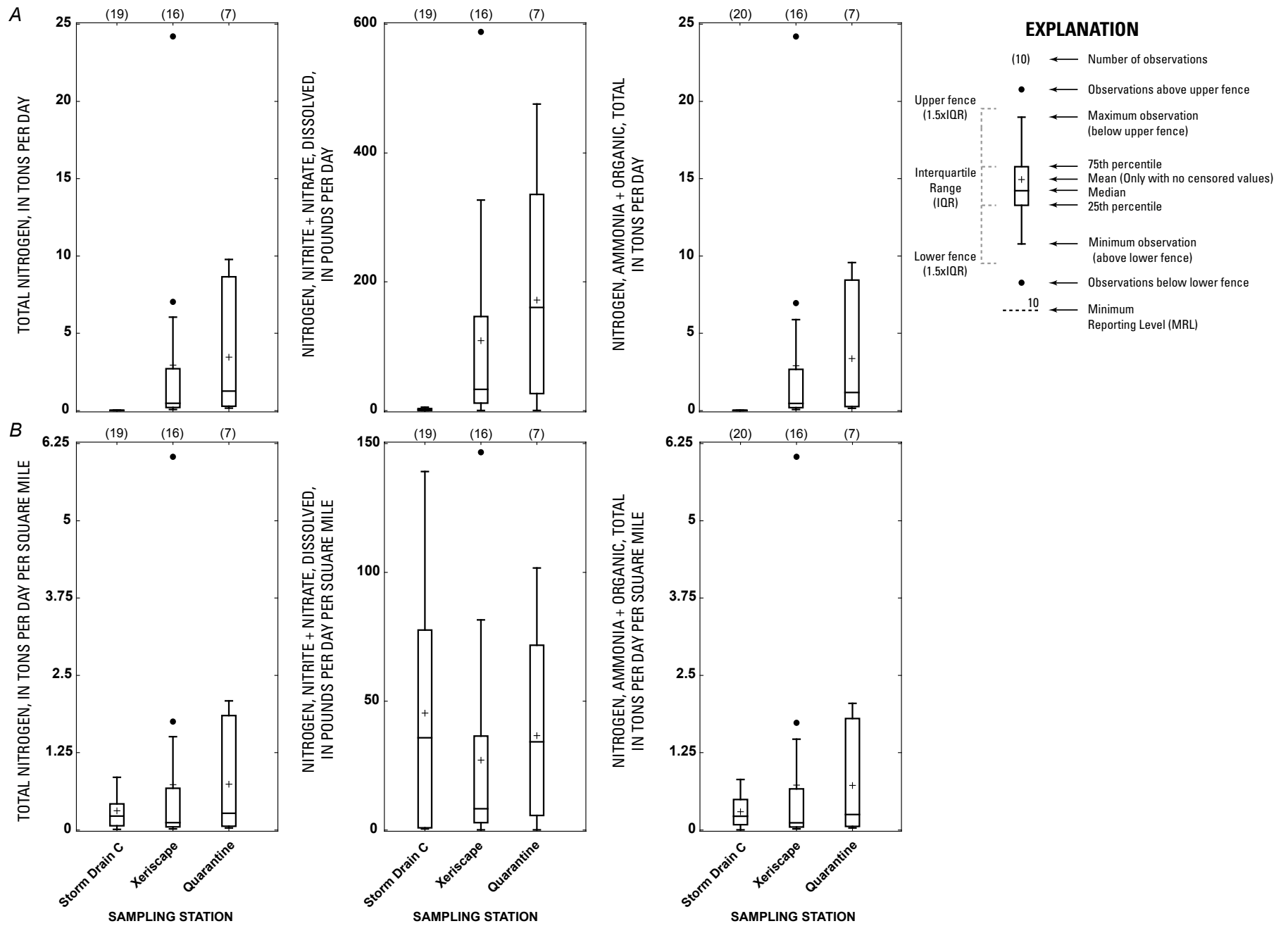
Figure 8. Boxplots of daily loads (*A*) and yields (*B*) for select constituents from composite samples only, collected over the entire period of the study.
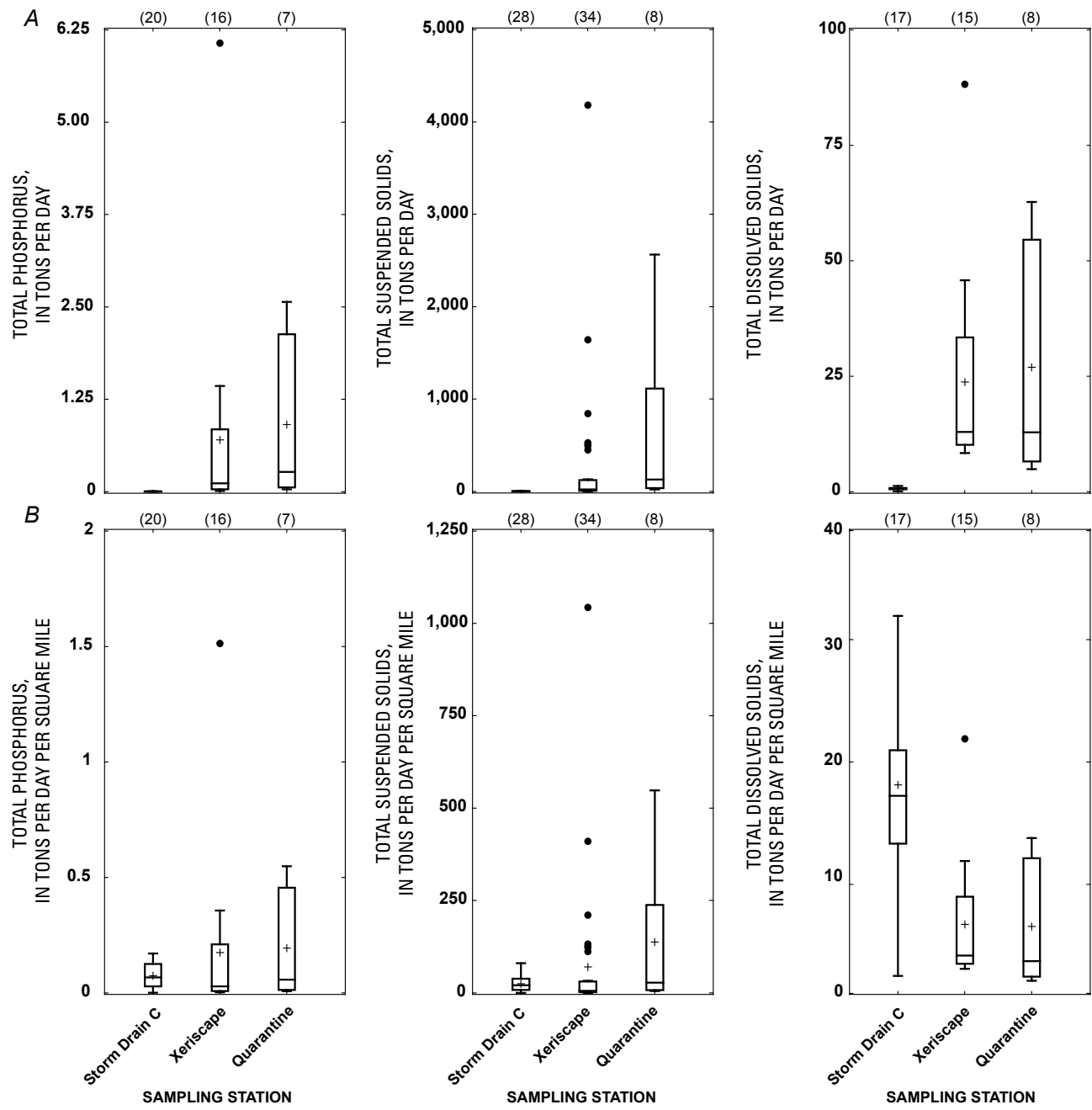
Figure 8. Boxplots of daily loads (*A*) and yields (*B*) for select constituents from composite samples only, collected over the entire period of the study.—Continued.
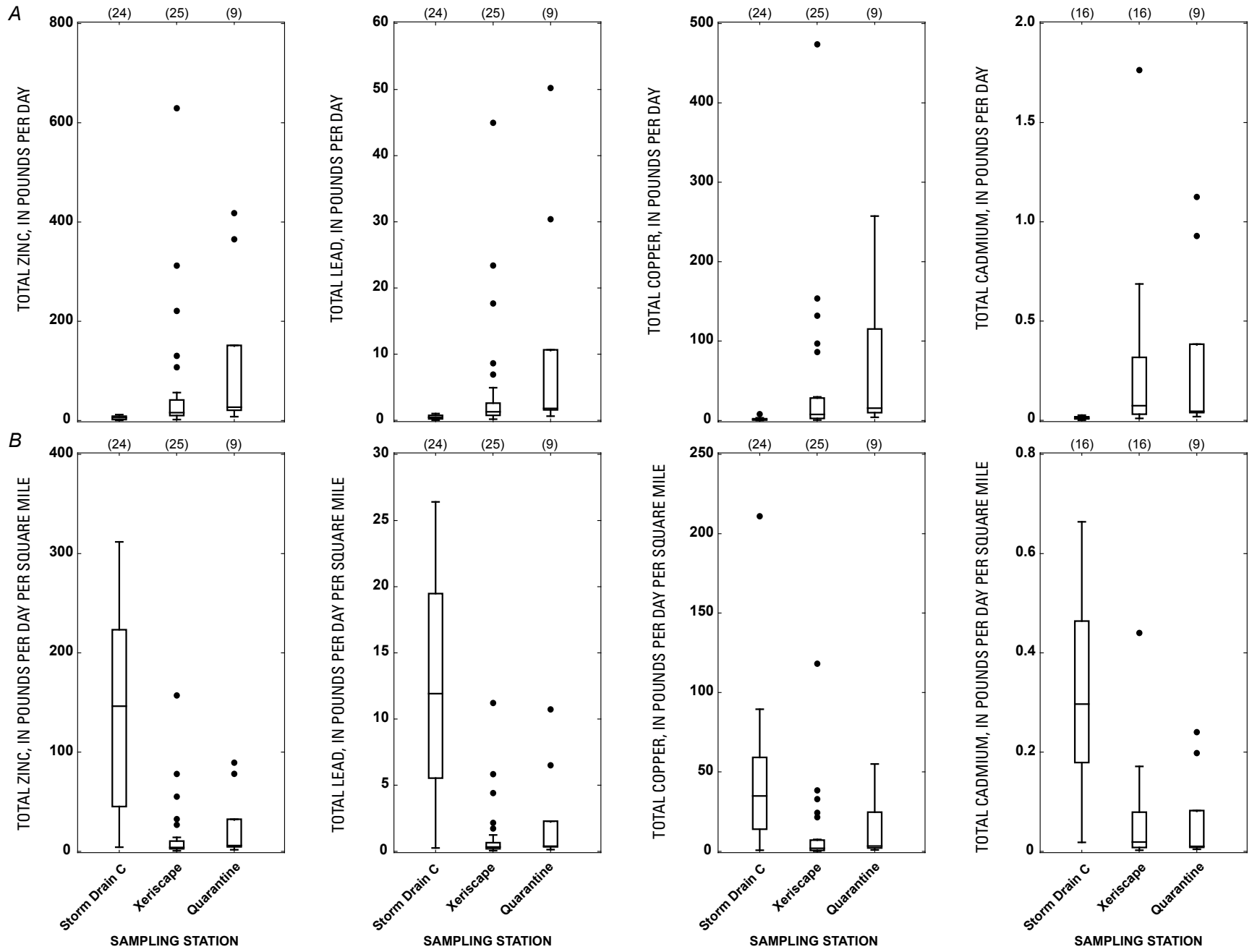
Figure 8. Boxplots of daily loads (*A*) and yields (*B*) for select constituents from composite samples only, collected over the entire period of the study.—Continued.
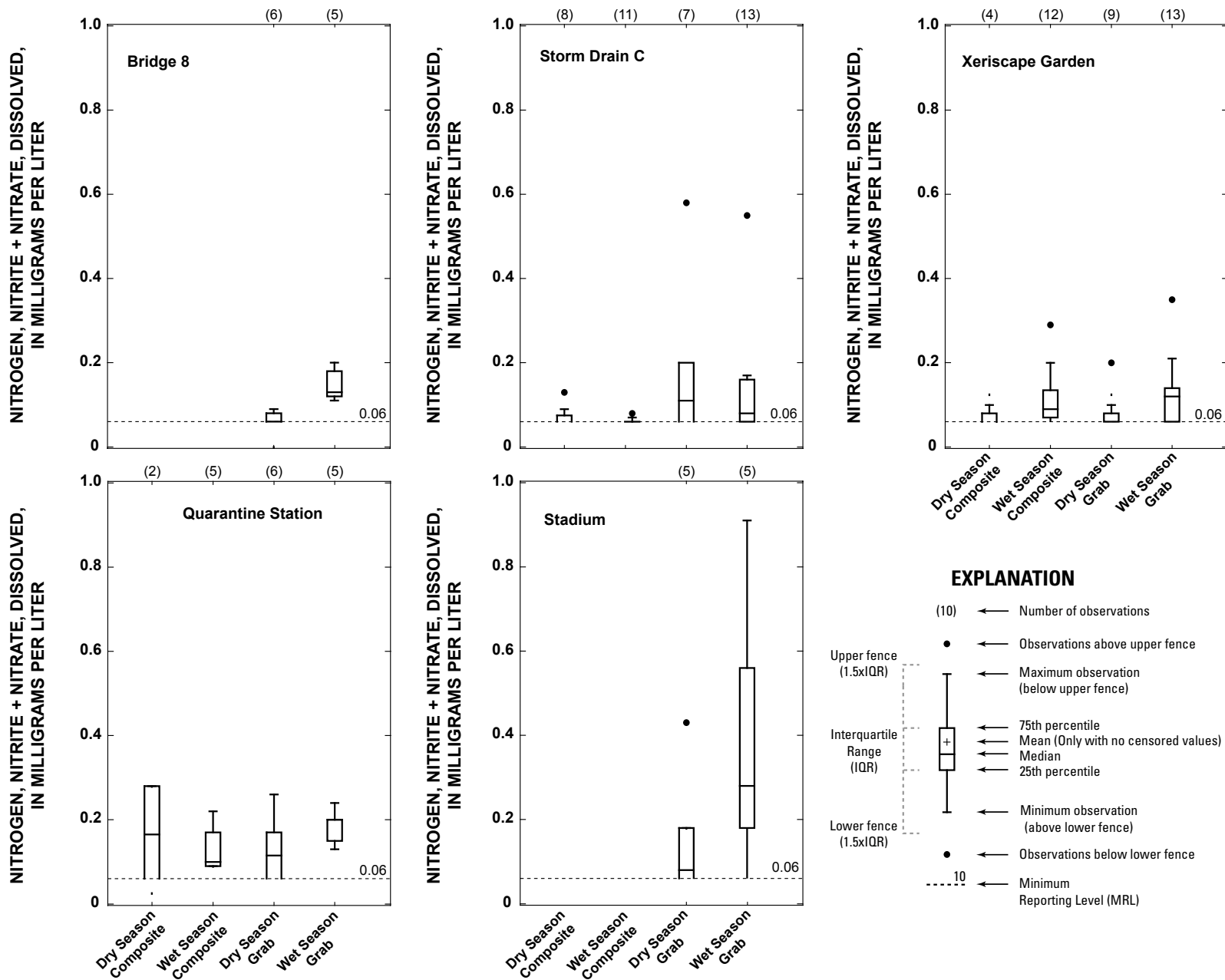
Figure 9. Boxplots of nitrite plus nitrate concentrations, collected over the entire period of the study, compiled by wet and dry seasons.
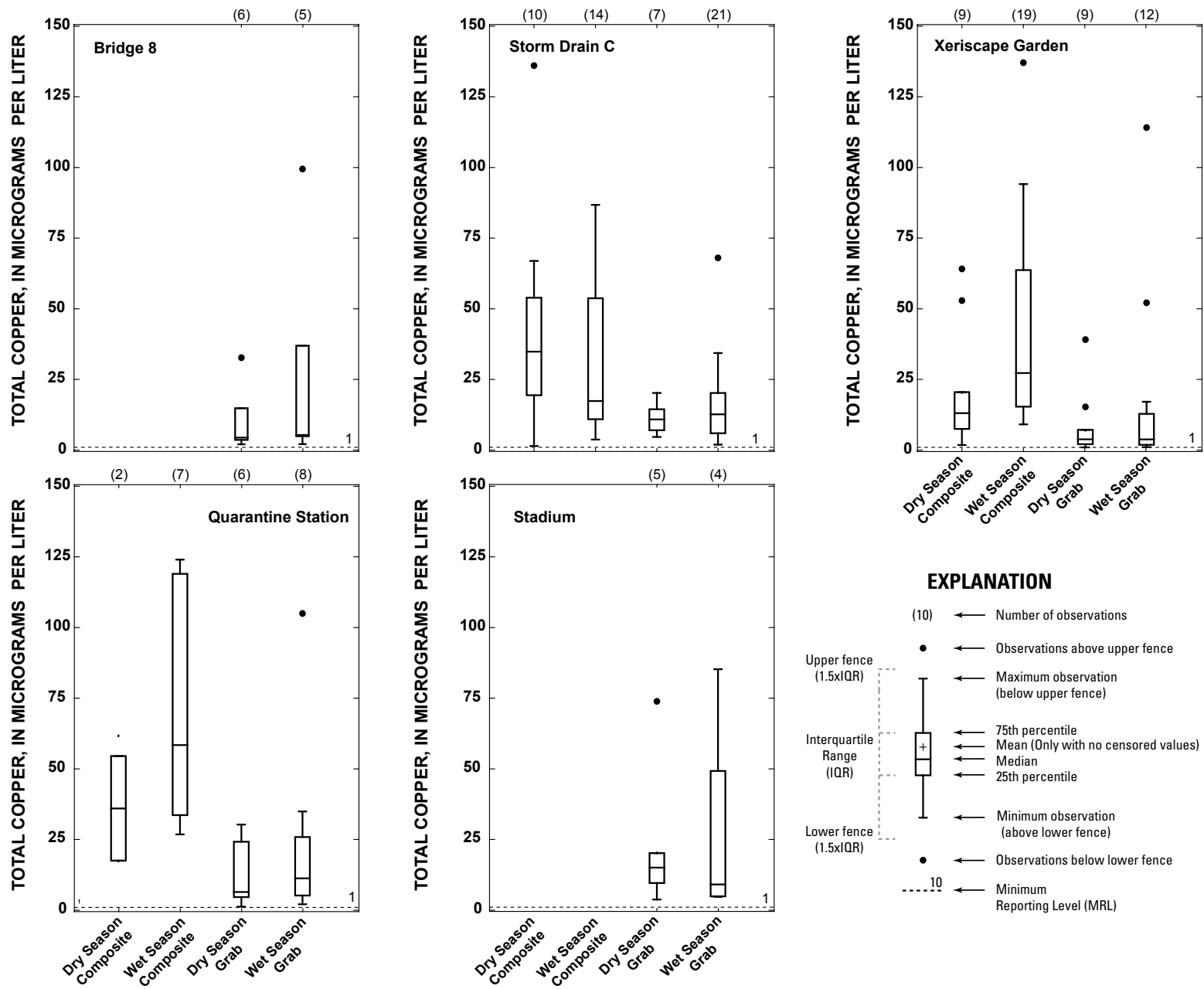
Figure 10. Boxplots of total copper concentrations, collected over the entire period of the study, compiled by wet and dry seasons.

Comparison with State of Hawaii Department of Health Criteria

To determine whether the State of Hawaii water-quality standards (table 5) were exceeded during storms, sample data were compared to the criteria applicable to streams (appendix D) (State of Hawaii Department of Health, 2000). The HDOH water-quality standards were not designed for stormwater sampling. Because the samples in this study were collected exclusively during storms, they are not representative of non-storm conditions, and therefore constituent concentrations are biased. These comparisons are simply meant to provide a point of reference for the stormwater sample results.

The HDOH water-column criteria for streams utilize the geometric means for selected constituents. The geometric mean is an estimate of the median when the logarithms of the data are symmetric and is used to reduce the effects of outliers on the mean value of a dataset. The HDOH water-column criteria for streams also include concentration values that should not be exceeded more than 10 and 2 percent of the time (table 5). These can be compared to the 90th and 98th percentiles of the measured data. Values for the 90th and 98th percentiles were computed by ranking the data from lowest to highest in value and then dividing the rank by the total number of samples (Iman and Conover, 1983). Percentiles were interpolated when necessary. Percentiles were only computed when the number of samples was greater than or equal to five.

Geometric means were calculated using all samples collected during the study period for each season—wet and dry; for each sampling method—grab and composite; and for each water-quality sampling site (appendix D). Censored values were estimated using the robust ROS method before calculating the geometric and arithmetic means. The HDOH water-quality geometric mean standards were exceeded in the majority of the comparisons, as were the 10- and 2-percent-of-the-time exceedence values (appendix D). The State of Hawaii water-quality standards for physical properties—pH, temperature, dissolved oxygen, and specific conductance—are given as numeric values or ranges not to be exceeded, and they consider ambient conditions in the evaluation (table 5). None of the composite samples had physical properties that exceeded the HDOH water-quality standards. There were some exceedances in the grab samples. Two exceedances for pH were in samples collected at Quarantine Station and Stadium during the same storm. One storm sample from Xeriscape Garden had a low value for dissolved oxygen and a high value for specific conductance. This was the only exceedance for dissolved oxygen. Storm Drain C samples only exceeded the criteria for specific conductance on one occasion.

Because most runoff events are relatively short in duration and streamflow in Halawa Stream is intermittent, it may be more appropriate to use criteria based on the effects of acute exposure on aquatic biota rather than long-term or chronic toxicity effects (Driscoll and others, 1990a). For many priority and nonpriority pollutants, the EPA has established a Criteria Maximum Concentration (CMC), which is the maximum constituent concentration to which aquatic biota can be acceptably exposed for brief periods (U.S. Environmental Protection Agency, 2006). The State of Hawaii toxic pollutant standards for the dissolved fraction of trace metals and organic chemical compounds that are applicable to all surface waters, fresh and salt, in the State also consider both acute and chronic conditions (State of Hawaii Department of Health, 2000). Since 2000, the H-3 water-quality samples have only been analyzed for total trace metal concentrations and not for the dissolved fraction, and therefore most of the trace metal data cannot be compared to the HDOH or USEPA water-quality criteria (U.S. Environmental Protection Agency, 2006).

There were only two exceedances of the HDOH fresh-water toxic pollutants standards, both at Storm Drain C. One result for dissolved copper, collected from a grab sample on January 26, 2000, was 8.6 µg/L, higher than the 6.0 µg/L acute and chronic HDOH standard but less than the USEPA CMC of 13 µg/L. For dissolved zinc, a December 1, 1999, grab sample yielded 39 µg/L, higher than the 22 µg/L acute and chronic HDOH standards but well under the USEPA CMC of 120 µg/L. There was one toxic pollutant, hexachlorocyclopentadiene, for which the MRL of 5 µg/L was higher than the HDOH standard of 2 µg/L. Consequently, sample concentrations determined as less than the MRL could still be greater than the HDOH standard. For this reason, exceedances could not be determined.

Comparison with Data Collected Before and During Highway Construction

Water-quality data from before, during, and after H-3 Highway construction were compared at Xeriscape Garden and Stadium stations (fig. 11). Elevated levels of TDS and specific conductance were observed during the construction period, especially at Stadium, with postconstruction levels returning to the preconstruction levels. Small differences in lead and zinc levels were measured among all periods and sites. Concentrations of copper, total phosphorus, and nitrogen (ammonia plus organic and nitrite plus nitrate) were higher after construction, especially at Xeriscape Garden. Similarly, TSS concentrations were much higher after construction at both sites, suggesting that TSS is associated with highway usage.

Comparisons with Other Studies in Hawaii

Fujiwara (1973) investigated urban stormwater pollution at four drainage sites on Oahu that included varying extents of residential, commercial, and industrial land use. A comparison of the compiled data from urban drainages with those of Storm Drain C showed that trace metal, nutrient, and COD concentrations were greater in the urban drainages (fig. 12). Additionally, comparisons with results from the Yamane and Lum (1985) urban runoff study in Mililani also showed greater concentrations in the urban stormwater.

Table 5. State of Hawaii water-quality standards specific for streams.

[mg/L, milligrams per liter; NTU, Nephelometric Turbidity Unit; N, nitrogen; Wet season, November 1 to April 30; Dry season, May 1 to October 31; ambient conditions are conditions that would occur in the receiving waters if these waters were not influenced by the proposed new human activity; source: State of Hawaii Department of Health, 2000]

Property or constituent	Season	Geometric mean not to exceed the given value	Not to exceed the given value more than 10 percent of the time	Not to exceed the given value more than 2 percent of the time
Total nitrogen (mg/L as N)	Wet	0.25	0.52	0.8
	Dry	0.18	0.38	0.6
Nitrogen, nitrite + nitrate (mg/L as N)	Wet	0.07	0.18	0.3
	Dry	0.03	0.09	0.17
Total phosphorus (mg/L as P)	Wet	0.05	0.1	0.15
	Dry	0.03	0.06	0.08
Total suspended solids (mg/L)	Wet	20	50	80
	Dry	10	30	55
Turbidity (NTU)	Wet	5	15	25
	Dry	2	5.5	10
pH	Shall not deviate more than 0.5 units from ambient conditions and shall not be lower than 5.5 nor higher than 8.0			
Oxygen, dissolved	Not less than 80 percent saturation, determined as a function of ambient water temperature and barometric pressure			
Temperature	Shall not vary more than 1 degree Celsius from ambient conditions			
Specific conductance	Not more than 300 micromhos (microsiemens) per centimeter			

Mililani Drain B had a smaller drainage area than Mililani Drain A, with fewer residences and no commercial land use. Mililani Drain-A constituent concentrations were consistently somewhat higher than in the Drain-B samples. Lead and zinc concentrations were highest in the 1973 study, as compared to both the 1985 study and the current study, perhaps as a result of the past use of leaded gasoline, not entirely eliminated in Hawaii until 1989 (Sutherland and Tolosa, 2000; De Carlo and Spencer, 1997). COD and nutrient concentrations in samples from Mililani Drain B and Storm Drain C were similar, whereas the more intensively used areas in the 1973 study and Mililani Drain A had higher concentrations. The bulk of the TSS data were similar among the studies, with some high outlier concentrations measured at Mililani Drain A.

Constituent Concentrations and Storm Characteristics

The relationships among the constituent concentrations measured in storm runoff at Storm Drain C and the characteristics of the sampled storms were investigated. Storm characteristics were calculated from data relevant to the sampled storms, the periods of sample collection, vehicular traffic before and during the sample collection, the preceding dry periods, and characteristics of the preceding storms (fig. 13). The duration of a storm (DUR) was defined as the time between the start of flow greater than 0.10 cfs until the final

recession of flow when flow returned below 0.10 cfs at Storm Drain C. The sampling duration (SDUR) was defined as the time between the start of flow greater than 0.10 cfs until the grab sample or final composite sample was collected at Storm Drain C. The sampling-period variables were included because events that take place after the last sample is collected do not affect the sample. The antecedent dry period (DRY) was defined as the period before the storm, from the last runoff event greater than 0.10 cfs. The preceding storm periods (PDUR) were bounded by the start of flow greater than 0.10 cfs and the start of the dry period.

Confounding Variables

The calculated storm characteristics are not the only factors affecting the constituent concentrations; other factors can affect those concentrations. Data on the timing, frequency, and effectiveness of street sweeping were not available for analysis in this report. Assuming that street sweeping was conducted during dry periods, the net accumulation of material on the highway before the sampled storms would not be strictly related to length of the dry period or the amount of traffic during that period. The amount of material that accumulates on the highway before the sampled storms is also affected by the numerous small runoff events that occur during the antecedent period. These events do not trigger the automatic samplers or provide enough runoff for manual grab samples. The amount of material removed by each of these events was not mea-
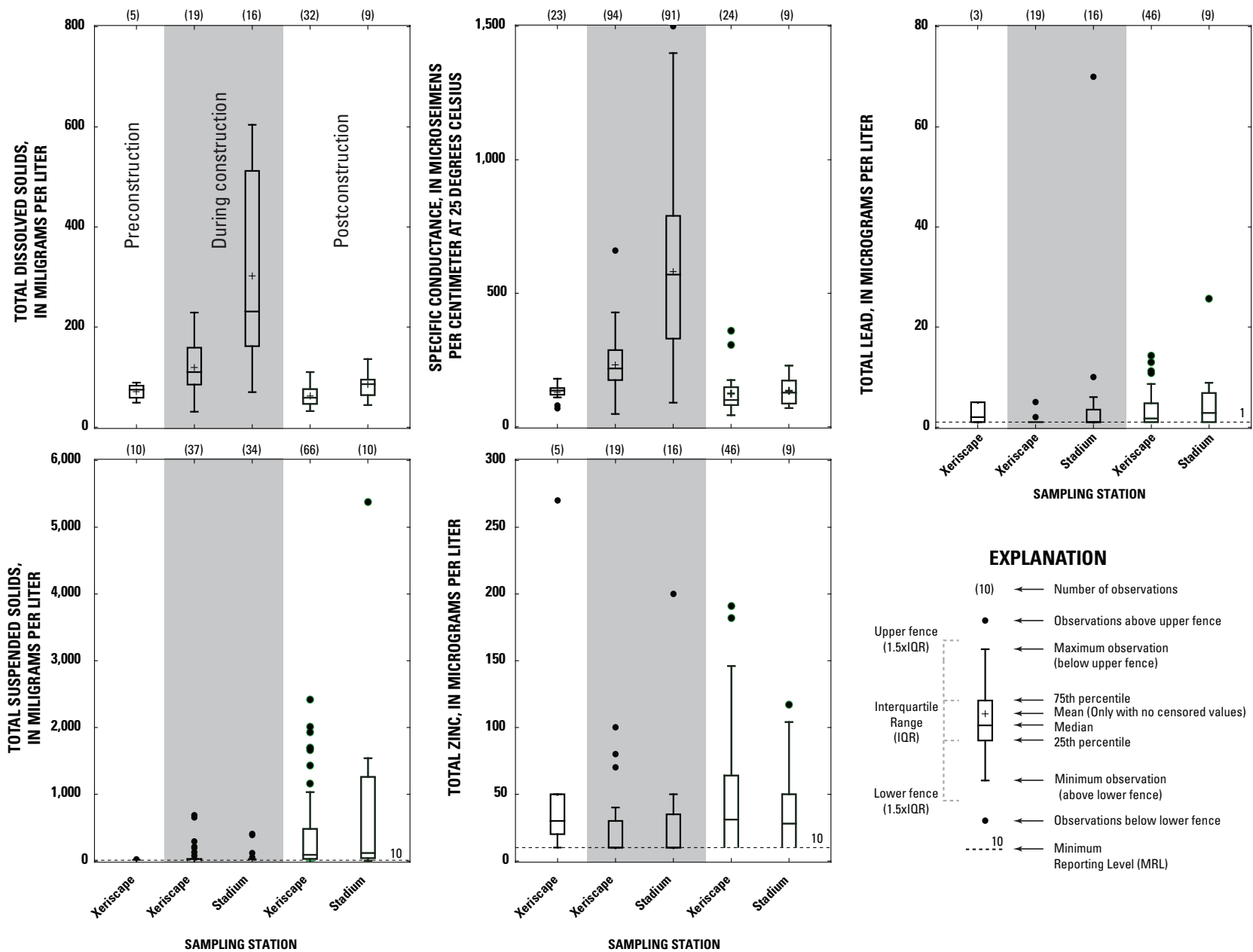
Figure 11. Boxplots comparing select constituent concentrations from Xeriscape Garden and Stadium, collected over the entire period of the study, with data from those sites collected before and during construction of the H-3 Highway.
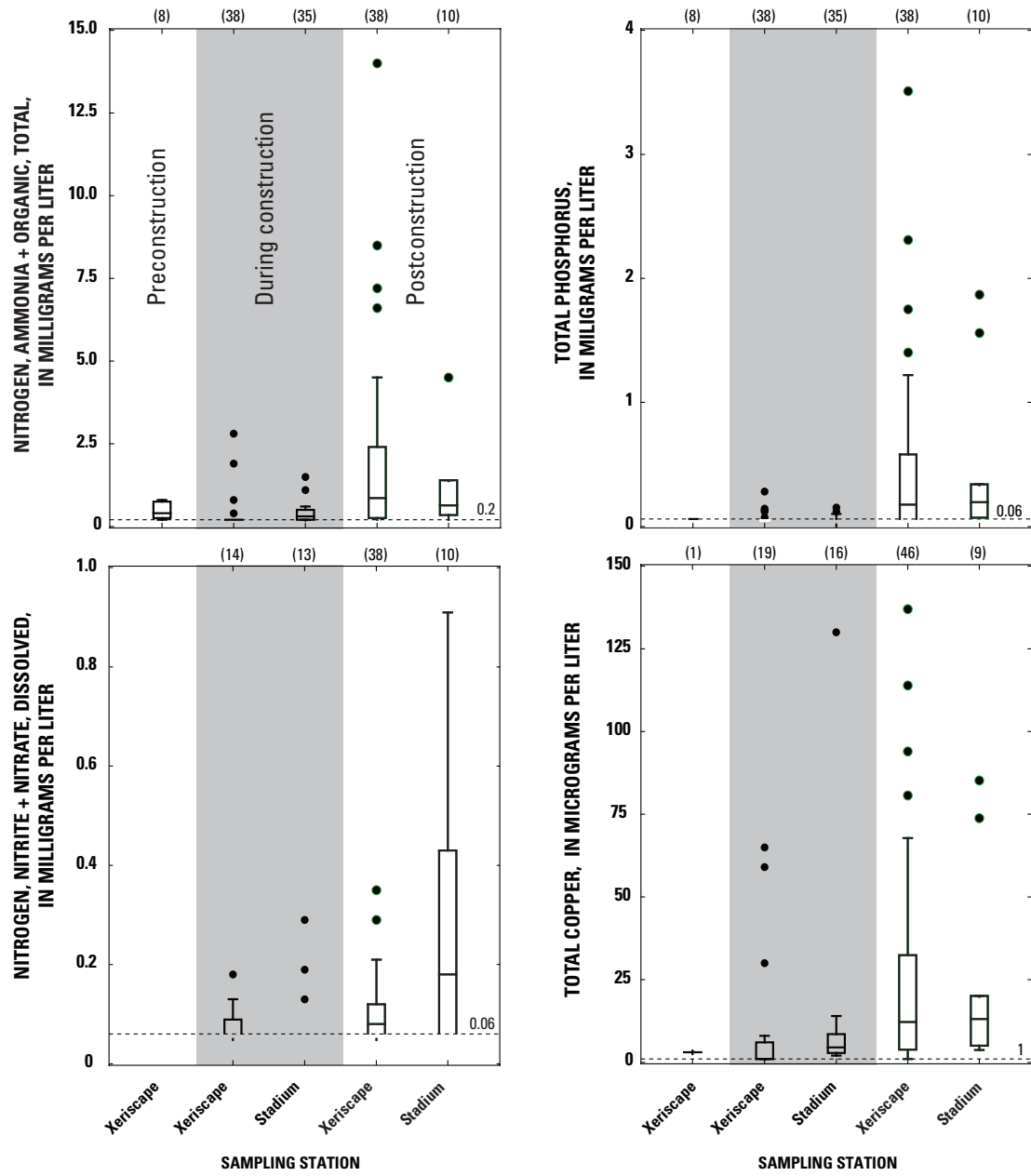
Figure 11. Boxplots comparing select constituent concentrations from Xeriscape Garden and Stadium, collected over the entire period of the study, with data from those sites collected before and during construction of the H-3 Highway—Continued.
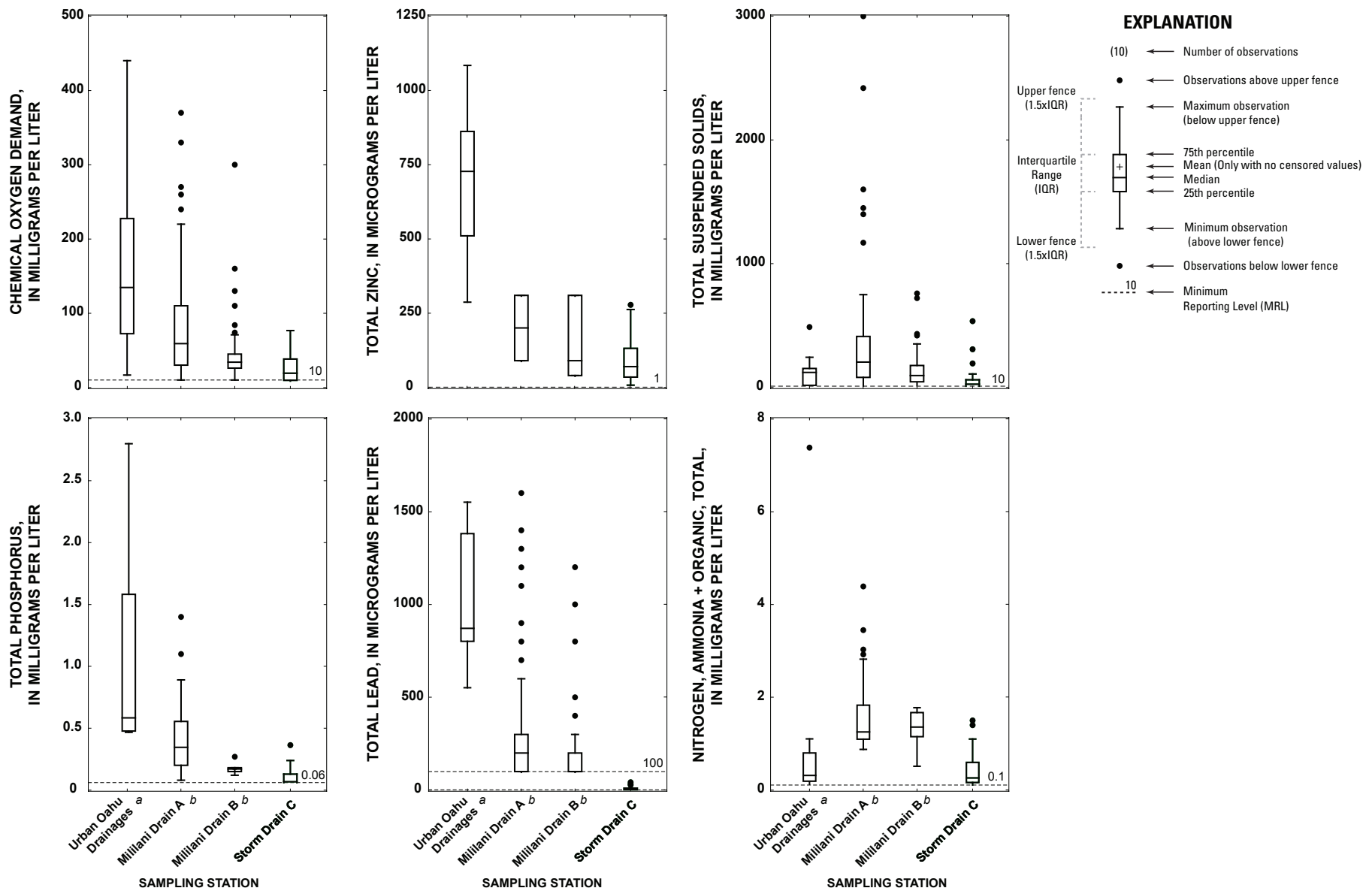
Figure 12. Boxplots comparing select constituent concentrations from Storm Drain C, collected over the entire period of the study, with data from: *a*, Fujiwara (1973) and *b*, Yamane and Lum (1985).
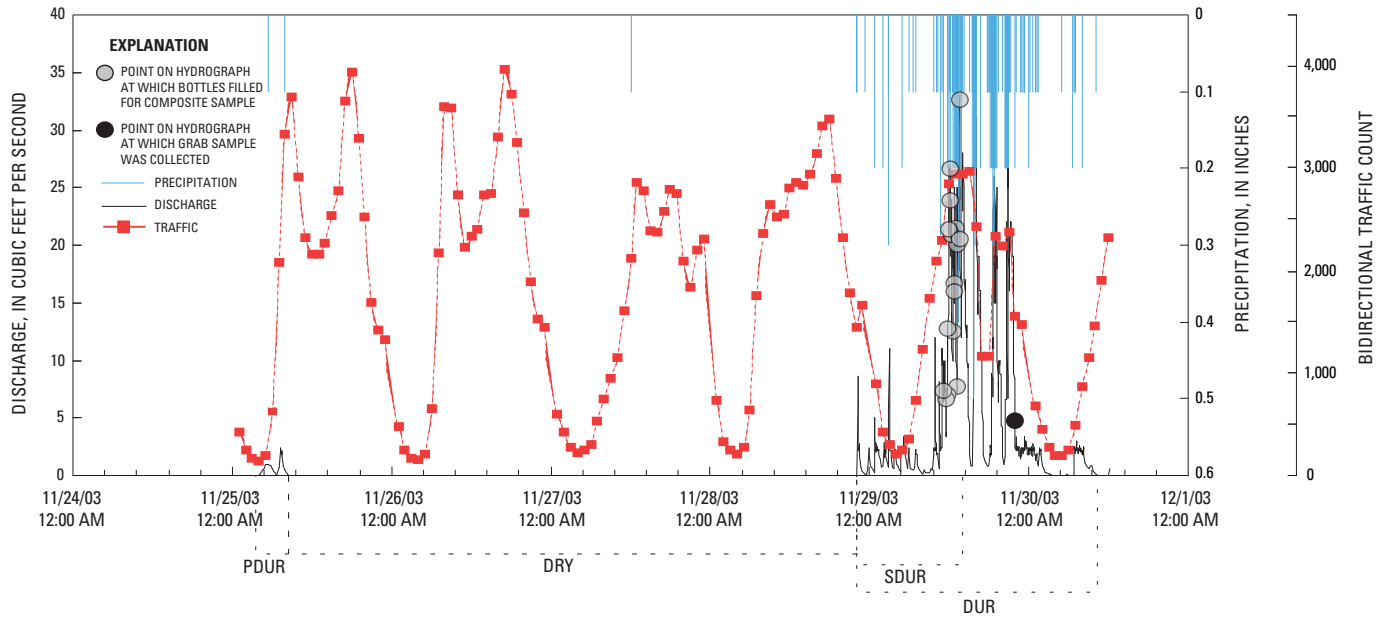
Figure 13. Example of the time-series data for a storm at Storm Drain C. Discharge, precipitation, traffic, and sampling events are shown. Select storm characteristics including the duration of the previous storm (PDUR), the dry period preceding the storm event (DRY), the duration of the sampling event (SDUR), and the duration of the storm event (DUR) are delineated by dotted lines.

sured. Because these smaller events may or may not move large amounts of material, the length of antecedent dry period was defined as the period since the last rainfall greater than or equal to 0.10 inch. Another confounding characteristic of some storms is that the rate of runoff can rise and fall numerous times at the start of a storm at rates that do not trigger the automatic samplers. Not only do these low-intensity runoff events remove an unknown amount of material before the start of sampling, they also cannot be considered part of the antecedent dry period because they are part of the sampled storm.

Storm Characteristics

Storm characteristics are the variables unique to each storm that affect the buildup and washoff of the constituents on the highway. Storm characteristics used in this study were either previously determined in other studies to be significant factors affecting water quality or included because scientific theory suggested their significance (Irish and others, 1995 and 1998). These variables and how they were computed are listed in table 6. The storm characteristics were calculated from time intervals determined by discharge measured at Storm Drain C and rainfall measured at the Tunnel rain gage. These characteristics are summarized in table 7. Because the characteristics of each storm are calculated from the same forces driving the events, there is a lack of independence and therefore a high likelihood of correlations among characteristics within each storm. Spearman rank-correlation analysis was conducted to determine the intensity of the associations among the storm characteristics (appendix E). Because the storm characteristics are generally based on the size and duration of the storm,

many of these characteristics are strongly correlated, as were characteristics of the preceding storm and of the antecedent dry period. For example, storm duration (DUR) was significantly correlated with rain duration (RDUR), with a correlation coefficient (ρ) of 0.98 (p-value < 0.0001; n = 72), simply meaning that the longer it rained the longer the storm lasted (fig. 14). Characteristics of the preceding storms were also analyzed using Spearman rank correlation (appendix E). The two characteristics of the antecedent dry period, the duration of the dry period (DRY) and the number of cars during that period (ADT) were strongly correlated ($\rho = 0.89$; p < 0.0001; n = 72) (fig. 15). Because these variables are so strongly associated with each other, it is difficult to identify which of the variables are the most likely to be factors affecting water quality.

Relations among Constituents at Storm Drain C

Spearman's rank-correlation procedure was used to determine the relationships among the water-quality constituents at Storm Drain C (appendix E). Identifying variables that have similar patterns of behavior can reduce the number of statistical analyses by allowing the use of a single variable that is representative of a larger group. Censored data were recensored to the highest detection limit for each constituent before the correlation analysis. This nonparametric method assigns the average rank to censored values determined as ties (Helsel, 2005).

Two groups of constituents were identified as being correlated—that is, behaving in similar patterns during runoff events at Storm Drain C. The first group (group A) included

Table 6. List of storm characteristics and storm-characteristic acronyms used in this study.

[cf, cubic feet; cfs, cubic feet per second; cfm, cubic feet per minute; nov, number of vehicles; >, greater than]

Storm characteristic acronym	Units	Storm characteristic description
		Storm Event Variables
DUR	minutes	The duration of the storm determined by using flow data from either Storm Drain C or Xeriscape Garden. Measured as the time between the start of flow > 0.10 cfs at Storm Drain C (or 25 cfs at Xeriscape Garden) until the final recession of flow when flow returns below 0.10 cfs at Storm Drain C or 25 cfs at Xeriscape Garden.
RDUR	minutes	The duration of rainfall as measured at the Tunnel rain gage for the storm events identified under DUR.
TOTR	inches	The total rain during the runoff event in inches recorded at the Tunnel rain gage.
Qmax	cfs	Peak flow in DUR.
Qtwa	cfs	Time weighted average discharge over DUR.
OINT	cfm	The overall intensity of the storm determined from the VOL and the DUR.
VOL	cf	The volume of runoff determined from the mean flow rate and runoff event duration
VOLtwa	cf	The time-weighted average volume of runoff determined from the Qtwa and the DUR.
IVOL	cf	The highest intensity of runoff volume during the event determined from Qmax for a 5-minute period.
VDS	nov/DUR	Total number of vehicles during storm determined from hourly traffic data for time period of the runoff duration. Interpolated where necessary between hourly totals.
		Sample Event Variables
SDUR	minutes	The duration of the storm determined by using flow data from either Storm Drain C or Xeriscape Garden. Measured as the time between the start of flow > 0.10 cfs at Storm Drain C (or 25 cfs at Xeriscape Garden) until the grab sample or the last bottle of the composite sample was collected.
SRDUR	minutes	The duration of rainfall as measured at the Tunnel rain gage for the storm events identified under SDUR.
SQMax	cfs	Peak flow in SDUR
SQmaxP	cfs	The maximum instantaneous discharge measured during the storm prior to the collection of the grab sample or first bottle of a composite sample.
SQtwa	cfs	Time weighted average discharge over SDUR.
SampleQtwa	cfs	Time weighted average discharge calculated from time of first composite collection to last composite collection. Instantaneous discharge for grab samples.
SVOLtwa	cf	The volume of runoff determined from SQtwa and SDUR.
SVDS	nov/SDUR	Total number of vehicles counted on the highway during the storm determined from hourly traffic data for time period of the SDUR.
		Preceding Dry Period Variables
DRY	hours	The duration of antecedent dry period since last runoff event with a rainfall greater than or equal to 0.10 inch.
ADT	nov/DRY	The total number of vehicles during the antecedent dry period.
		Previous Runoff Event Variables
PDUR	minutes	The duration of preceding runoff event determined as per DUR.
PTOTR	inches	The total rainfall of preceding runoff event recorded at the Tunnel rain gage.
POINT	cfm	The overall intensity of the preceding runoff event determined as OINT.
PVOL	cf	The volume (VOL) of preceding runoff event.
PIVOL	cf	The highest intensity of volume in the preceding runoff event as determined as IVOL.

Table 7. Descriptive statistics for storm characteristics.

[n, number of values; cf, cubic feet; cfs, cubic feet per second; cfm, cubic feet per minute; see table 6 for explanation of acronyms]

Acronym	Units	n	Mean	Standard Deviation	Minimum	Median	Maximum
DUR	minutes	72	969	1,114	65	623	4,890
VOLtwa	cf	72	126,750	159,290	4,848	59,760	621,911
Qtwa	cfs	72	2.2	1.3	0.5	1.8	6.4
QMax	cfs	72	18.1	11.3	2.7	17	42
TOTR	inches	72	3.1	4.1	0.1	1.2	16.3
RDUR	minutes	72	863	1,084	15	443	4,755
VDS	nov/DUR	72	26,730	26,256	280.83	15,796	124,110
IVOL	cf	72	5,418	3,392	810	5,100	12,600
OINT	cfm	72	132.8	76.3	31.8	109.2	385.2
SDUR	minutes	72	415	476	3	234	2,513
SVOLtwa	cf	72	60,911	86,137	100	24,969	393,723
sQtwa	cfs	72	2.7	2	0.1	2.1	8.8
SQMax	cfs	72	15.2	11.5	0.3	12	42
TOTRs	inches	71	1.8	2.3	0.1	0.8	11.5
SRDUR	minutes	70	418	474	15	258	2,505
DRY	hours	72	31	45	0.3	9	211
SVDS	nov/SDUR	72	11,776	12,786	206	7,886	58,786
ADT	nov/DRY	72	50,064	74,792	221	15,185	382,557
PDUR	minutes	72	288	319	15	185	1305
PQtwa	cfs	72	2.1	3.3	0.3	1.1	13.7
PDURSec	seconds	72	17,260	19,152	900	11,100	78,300
PVOLtwa	cf	72	59,587	155,441	648	9,990	636,120
POINT	cfm	72	128	197.3	15	67.2	820.8
PQMax	cfs	72	6.4	8.1	0.8	2.7	30
SQmaxP	cfs	72	10.8	9.7	0.3	7.9	41
PIVOL	cf	72	1,925	2,433	252	810	9,000

the trace metals cadmium, lead, copper, and zinc; the nutrients total nitrogen, total phosphorus, and total ammonia plus organic nitrogen; and the physical properties COD and TSS (appendix E, table E-4). Group B included nitrite plus nitrate, and the physical properties TDS, specific conductance (lab and field), and turbidity (appendix E, table E-5). This would suggest that constituents within each group behave in similar patterns of buildup and washoff on the highway. The source of the group A trace metals is presumably from vehicle emissions and vehicle wear and tear. Group A nutrients most likely come from materials dislodged from tire treads, materials washed off of vehicles, or atmospheric deposition. The group B constituents are more associated with fine sediments, most likely derived from materials dislodged or washed off of vehicles as well.

Relations among Constituents and Storm Characteristics

The relations among the constituents and the storm characteristics described above were examined using Spearman rank-correlation (appendix E). All of the correlation coefficients in appendix E, table E-6 are negative, indicating an inverse relationship between each of the constituents and storm characteristics. This means that constituent concentrations decrease in the highway runoff at Storm Drain C as the storm characteristics, generally associated with the overall size of the storm, increase. As discharge at Storm Drain C increased, the group A constituents plotted in similar patterns like the one shown for TSS (fig. 16), generally decreasing with increased discharge, though with some scatter. However, at the other sampling stations, the group A constituents generally increased with increasing discharge. The group B constituents also plotted in patterns similar to the ones shown for TDS (fig. 17). Group B constituents at Storm Drain C also tended to
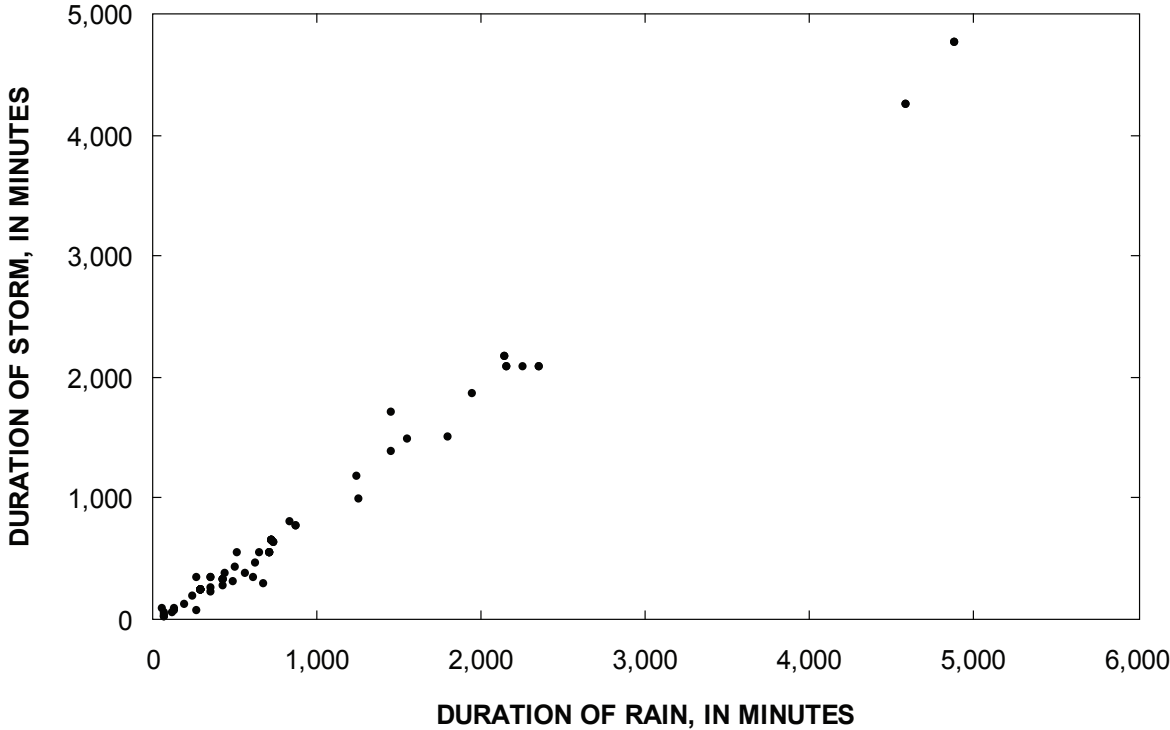
Figure 14. Scatter plot displaying the relationship between the duration of the storms (DUR) as measured by discharge at Storm Drain C and the duration of rainfall (RDUR) as determined at the Tunnel rain gage.
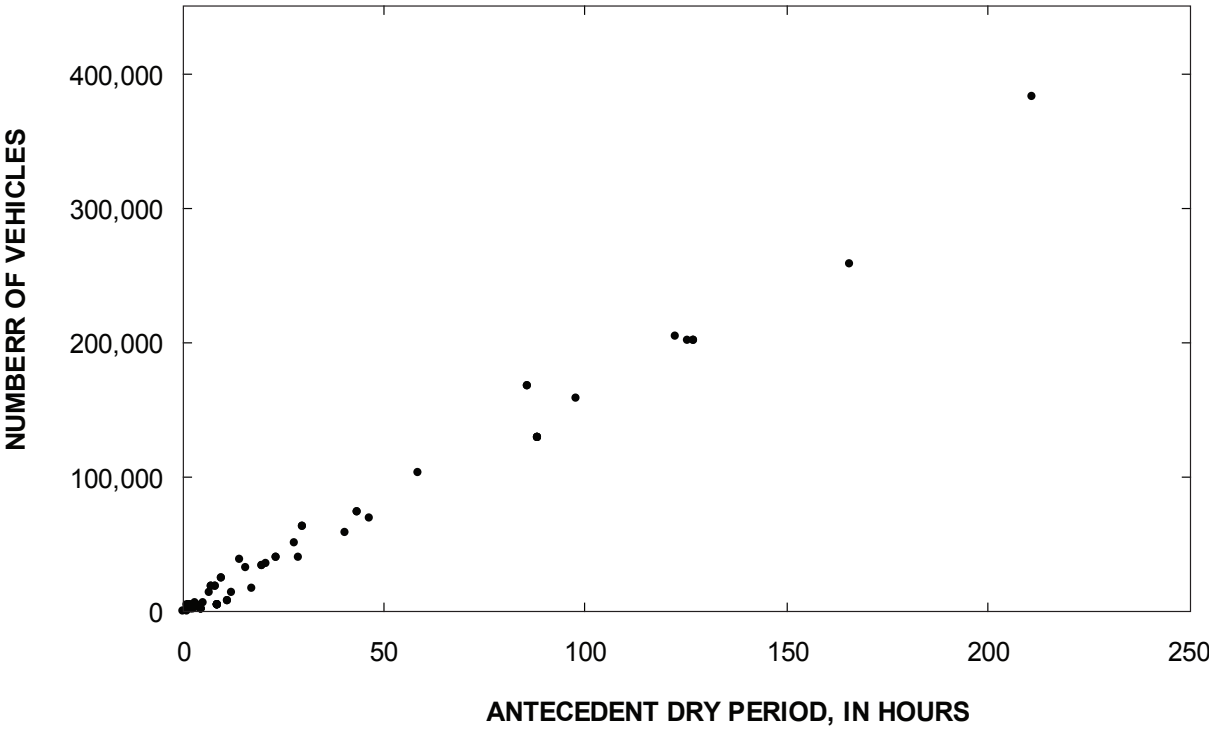
Figure 15. Scatter plot displaying the relationship between the antecedent dry period and the number of vehicles during that period.
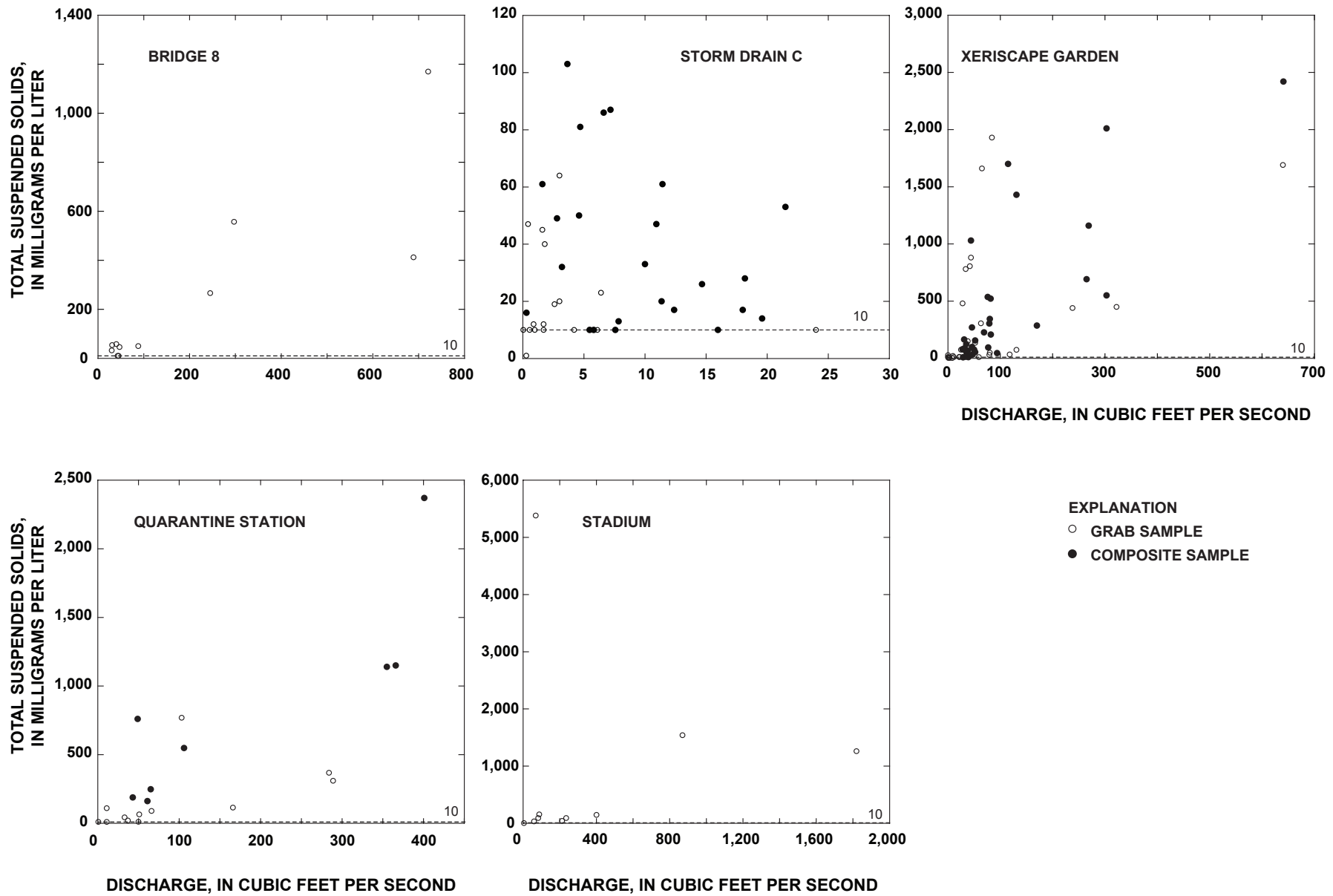
Figure 16. XY scatter plots showing the relation between group A constituent total suspended solids and discharge at each station. Dashed line is the Minimum Reporting Limit of 10 milligrams per liter.
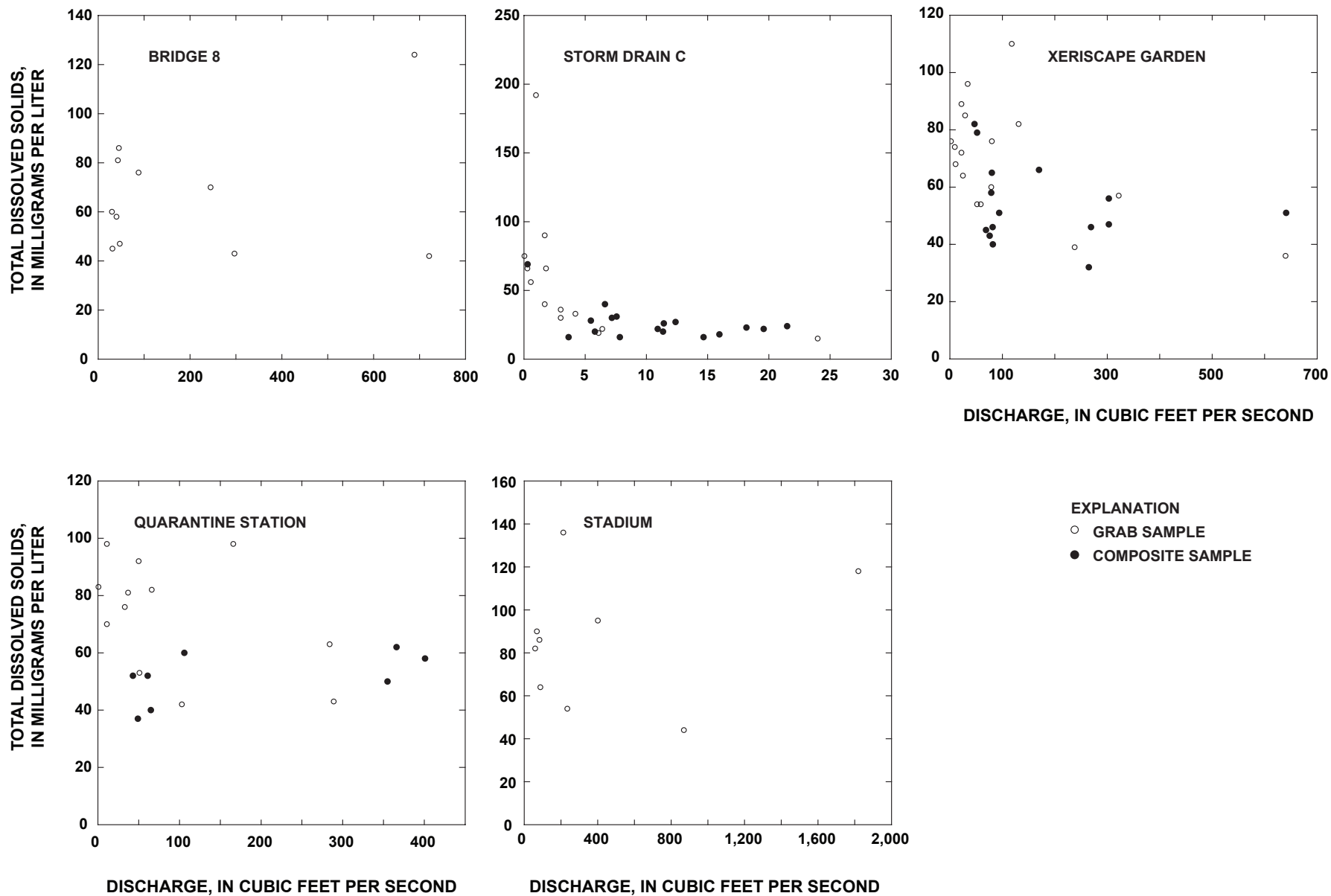
Figure 17. XY scatter plots showing the relation between group B constituent total dissolved solids and discharge at each station.

decrease with an increase in discharge, with less scatter than the group A constituents. Furthermore, group B constituents at the other sampling stations tended to show little change or only slight decreases with increasing discharge. The finite amount of material that builds up and washes off of the highway surface is progressively more diluted as the volume of the storm-driven highway runoff increases. In the stream itself, the group A constituents associated with suspended particulate matter increase in concentration with increasing stormflow because of the increased particulate input caused by an escalation in erosion. The group B constituent concentrations, associated with the dissolved fraction of the stormwater, appear to remain relatively unchanged with an increase in stormwater volume. This is most likely due to the chemical behavior of the constituents, their interactions with other components such as pH or hardness, and their geochemical dissolution processes (Bricker, 1999).

The storm characteristics that were significantly correlated ($p \leq 0.05$) with a majority of the constituents, with correlation coefficients greater than 0.50, were the time-weighted average volume calculated over the duration of the storm (VOLtwa), the time-weighted average volume calculated over the duration of the sampling period (SVOLtwa), the total amount of rain summed over the duration of the storm (TOTR), and the total amount of rain summed over the duration of the sampling period (TOTRs). The volume and rainfall variables, calculated over different time periods, were correlated. The volume variables were significantly correlated, $\rho = 0.75$, $p < 0.0001$, as were the total rain variables, $\rho = 0.81$, $p < 0.0001$ (appendix E, table E1). Also, these variables of the same time period were significantly correlated: VOLtwa and TOTR, $\rho = 0.96$, $p < 0.0001$; SVOLtwa and TOTRs, $\rho = 0.92$, $p < 0.0001$ (appendix E, table E1). The correlations simply mean that these variables are strongly associated; more rain results in greater highway runoff volume. The negative correlations of these storm characteristics with the constituent concentrations suggests that the larger the volume of water (bigger storms) the lower the constituent concentrations at Storm Drain C, as discussed earlier.

Other storm characteristics that were significantly correlated with some of the constituents included (1) the duration of the rainfall (RDUR), which inversely correlated with 5 of the group A constituents; (2) the peak flow during the storm (SQMax), which strongly inversely correlated with the group-B constituents; and (3) the overall intensity of the storm (OINT), which also strongly inversely correlated with the group B constituents. Cadmium was only correlated with the volume of the previous storm, which may just be an artifact and not a true association between the two variables. This analysis shows that there is no single storm characteristic strongly associated with the variability of any one of the constituents in the highway runoff at Storm Drain C.

Of note, two antecedent storm characteristics, the correlated variables DRY and ADT (fig. 15), were not identified as being significantly correlated with any of the constituents in the Spearman rank analysis. It is likely that the buildup of

material during dry periods was offset by street sweeping and that street sweeping was likely to be more frequent the longer the dry period. Other studies also found that the duration of the dry period was not strongly correlated with stormwater quality (Sartor and Boyd, 1972; Driscoll and others, 1990b).

Suggested Modifications to H-3 Highway Monitoring Program

Since 2001, the USGS has collected water-quality, discharge, and rainfall data during a number of storms at stations in the Halawa drainage basin as part of the State of Hawaii Department of Transportation's (HDOT) National Pollutant Discharge Elimination System (NPDES) program. The HDOT has expressed an interest in continuing this program. This section discusses possible modifications to the stormwater monitoring program that is currently being conducted by the HDOT and the USGS.

Grab Sampling

The stormwater sampling protocol currently in use, as described in the HDOT Storm Water Monitoring Plan (State of Hawaii Department of Transportation, 2000), calls for a combination of grab and composite samples. For at least a few storms each year, individual grab samples collected in bottles by the automatic samplers could be analyzed separately instead of combined as a single composite sample. The grab samples provide important information on the water quality at the time of sampling, but because of the logistics involved in getting to the sampling stations during storms, grab samples are usually collected late in the storm, after the peak discharge has occurred. Composite samples span the duration of the storm but provide only one value, the event mean concentration (EMC), for a storm. The EMC is sufficient when the objective is to determine the overall load of the storm, but the discrete constituent concentrations, over the course of the storm, are lost. Additionally, the State of Hawaii Department of Health (HDOH) standards are based on concentrations and not loads.

By analyzing discrete samples from the automatic sampler, it is possible to get a clear profile of the storm, from first flush to the end of storm-related runoff. Additionally, the EMC can be calculated from the discrete samples, but the individual sample concentrations cannot be determined from the composite-sample concentration. Data collection using discrete samples was done by Timperley and others (2005). Harmel and others (2006) point out that discrete sampling can provide an accurate depiction of temporal variability of constituent concentrations during the storm, but it can also increase the uncertainty of the water-quality data, especially in large or lengthy storms if the sampler runs out of sampling bottles. However, the composite sampling they discuss is per-

formed by the automatic sampler itself, continuously adding multiple aliquots to individual bottles to increase the length of sampling period. In the current study, the flow-weighted compositing of the discrete samples is performed in the laboratory and not by the automatic point samplers, but the chance of running out of sampling bottles is the same. The samplers are set to increase the time interval if the storm continues after collecting half of the bottles (State of Hawaii Department of Transportation, 2000). Harmel and others (2006) recommend composite sampling when there is a need to limit the number of samples collected or if the study objective is to determine the storm loadings and not the within-storm variability. As a possible alternative they suggest collecting discrete samples for a period of time to gather data on within-storm constituent behavior and seasonal trends and then switching to composite sampling once this baseline information is acquired.

Other Suggestions

If this program continues, the following changes to the current program could be considered:

1. Add dissolved fractions of metals to the sampling plan. The HDOH standards for trace metals are designed for the dissolved fraction. Currently, only the total metals are analyzed. By law (40 CFR 122.45), analysis of whole-water samples is required for monitoring within the NPDES permit. The advantages and disadvantages of whole water versus dissolved (filtered) water sampling are thoroughly discussed in Breault and Granato (2000). Aquatic organisms are more affected by the dissolved fraction of potentially toxic contaminants (Gélinas and others, 1998; DeCarlo and others, 2004). Bricker (1999) presented a complete overview on the major processes driving geochemical interactions and concluded:

   "If the analyses are incomplete for the major dissolved constituents (even though these may not be of interest from the toxics standpoint), it will not be possible to evaluate the behavior of the contaminant species in terms of solubilities, speciation, complexing, sorption, ion exchange, ion pairing, mobilization, and transport—all of the processes that determine toxicity and bioavailability. Analyses of samples only for the total concentrations of selected elements of interest provide, at best, limited information and almost certainly will give a misleading picture about the effects of those elements on the ecosystem."

2. Install an automatic sampler at Bridge 8. This would allow for a more accurate comparison between the highway runoff, measured at Storm Drain C, and the runoff from the surrounding undeveloped basin, measured at Bridge 8. The relations between these sites and the composition of the stormwater runoff passing through them are important to understand. Most of the grab samples collected at Bridge 8 were taken well after the automatic sampler at Storm Drain C had already been triggered. The triggering of the automatic sampler at Storm Drain C alerts the USGS personnel that a sample is being collected. They then must travel to the stations to collect the samples. Storms often occurred late at night, and the grab-sampling collection did not start until early the next morning. More often than not, the Bridge 8 samples are collected well after peak discharge has occurred and discharge is decreasing. These samples are not representative of the constituent concentrations during the critical first flush and rising-discharge flows and can bias the analyses. If a storm is too short in duration, by the time USGS personnel arrive, there may not be adequate runoff to sample at Bridge 8. The installation of an automatic sampler would greatly improve the timeliness of the sampling.

3. Conduct a one-time sampling of soils upstream of Bridge 8. Some of the particulate matter that collects on the elevated highway is most likely being wind-blown into the adjacent forested drainage basin and eventually is being transported by overland runoff into the stream. It is suggested that a series of transects perpendicular to the highway and extending out into the basin be established and that soil samples be collected at points along the transects outward from the highway. These soil samples would be analyzed for certain constituents, such as trace elements, that would most likely have originated from the highway. Sampling at points at a range of distances from the highway would provide information about the constituent concentrations being accumulated and the distances that they travel. This information would help determine the source of these constituents reported in Bridge 8 samples.

4. Collect samples during low-flow conditions. Harmel and others (2006) recommend that low-flow water-quality samples be collected at regular intervals to determine instream concentration variability. Routine low-flow sampling aids in quantifying point source contributions, shallow surface return flow, and constituent release from instream processes (Harmel and others, 2006). North Halawa Stream is intermittent; therefore, low-flow sampling would only occur during those periods between storms while the stream is still flowing. Data from samples collected during low-flow conditions would provide valuable information about the water quality of the stream absent any input from Storm Drain C.

5. Add two metals to the sampling plan—chromium and nickel. This would increase lab analysis cost by a minimal amount. These two metals are relevant to highway runoff and have been sampled in the past. Although previous studies in Hawaii have determined that nickel concentrations in roadway stormwater are not significantly different from naturally occurring levels (De Carlo and Spencer, 1997; Sutherland and others, 2000; De Carlo and Anthony, 2002; De Carlo and others, 2004), it is still

important to monitor nickel concentrations to verify that anthropogenic inputs remain low.

6. Eliminate fecal coliform and biochemical oxygen demand (BOD) analyses from the sampling plan. Because the H-3 Highway is elevated and therefore not exposed to overland runoff, these two constituents, produced from organic input such as livestock or human sewage effluents, would not be expected to impact the highway stormwater runoff.

7. Conduct a study to examine the efficiency of the highway street sweeping. Also, keep a record of the dates and times when street sweeping is conducted on the highway between the Trans-Koolau Tunnels and Storm Drain C.

Summary and Conclusions

Concerns regarding water quality are important issues at the Federal, State, and local levels in all communities. The quality of the Nation's fresh waters can affect the quality of life for the general public. The quality of stormwater runoff that drains into the stream network is of critical importance to managers and regulatory agencies. The U.S. Geological Survey, in cooperation with the State of Hawaii Department of Transportation (HDOT) and the Federal Highway Administration, has been monitoring stormwater quality using a network of five stations in the Halawa Stream basin, on Oahu, Hawaii. This report describes the quality of stormwater sampled from water year 1999 through water year 2004. The network includes four stations on North Halawa Stream known as Bridge 8, Xeriscape Garden, Quarantine Station, and Stadium. The network also includes a station at Storm Drain C, which drains stormwater runoff from the H-3 Highway. Sampling during storms at three stations, Storm Drain C, Xeriscape Garden, and Quarantine Station, was facilitated using automatic point samplers that were used to collect composite samples. Individual grab samples were collected at all five sampling stations and were not composited. Quality-assurance and quality-control samples also were collected to help evaluate potential sources of contamination and inaccurate results.

Selected water-quality data were compared to the State of Hawaii Department of Health (HDOH) water-quality standards to determine the effects of highway storm runoff on the water quality of the affected streams. Because the HDOH criteria were not designed for stormwater sampling, these comparisons are simply meant to provide a point of reference for the stormwater results. The geometric mean and concentrations not to be exceeded 10 percent and 2 percent of the time were used as numeric standards for five water-quality constituents—total nitrogen, nitrite plus nitrate, total phosphorus, total suspended solids, and turbidity. These standards also vary depending on the season, with the wet-season values higher than the dry-season values. The remaining standards consist of a single numeric criterion not to be exceeded, except for water temperature and pH, for which the standards depend

on deviations from ambient conditions. For constituents with data determined to be below the minimum reporting levels, the robust approach to "regression on order statistics" (Robust ROS) was used to determine the numeric values for comparison to the standards. Most of the HDOH standards were exceeded at most sampling stations, most likely because of the bias inevitably introduced by stormwater samples.

The "first flush" phenomenon, in which constituent concentrations are higher at the beginning of storm runoff events and gradually decrease over the course of the storm, was observed at Storm Drain C. An analysis of discrete samples collected by the automatic point sampler at Storm Drain C during the storm of April 20, 2002, showed that concentrations were initially high during the period of increasing discharge, before peak discharge, and decreased over the remainder of the storm for the trace metals cadmium, lead, zinc, and copper, and a similar pattern was shown for specific conductance.

The H-3 Highway is a large source of metals to Halawa Stream relative to the surrounding areas, but it is a small source of nutrients and sediments. The drainage basin for Bridge 8 does not include the H-3 Highway; therefore, water quality at Bridge 8 is unaffected by highway runoff. Higher concentrations and loads of nutrients and dissolved and suspended solids at Bridge 8, relative to Storm Drain C, indicate that the undeveloped drainage basin of Bridge 8 has a larger effect on nutrient and sediment quality in North Halawa Stream than the highway. In contrast, the lower concentrations and loads of metals at Bridge 8, relative to Storm Drain C, indicate that the undeveloped drainage basin of Bridge 8 has a smaller effect on metals in North Halawa Stream than the highway.

Most constituent concentrations and loads in stormwater runoff increase in a downstream direction from Xeriscape Garden to Quarantine station, although results from individual storms may vary. This general trend indicates that the part of the drainage basin of Quarantine station that is downstream of Xeriscape Garden is enriched with nutrients and trace metals. This area contains a light industrial area that may be a source of some of these constituents. The total suspended solids (TSS), total dissolved solids (TDS), and nutrient concentrations at these downstream sites were higher than those in Storm Drain C. Because the discharge at Storm Drain C generally is a small fraction of the total discharge in North Halawa Stream, the stormwater runoff from the H-3 Highway contributes only a small fraction of the total storm loads of TSS, TDS, and nutrients in North Halawa Stream. The storm yields of these constituents from Storm Drain C, however, are comparable to or higher than the yields measured at Xeriscape Garden and Quarantine station. Thus, per unit area, the H-3 Highway contributes comparable amounts of some constituents to North Halawa Stream as the surrounding areas.

Water-quality data presented in this report indicate that the timing of sample collection is an important factor controlling constituent concentrations in stormwater runoff samples. During a storm, constituent concentrations commonly attain peak values during the initial period of increasing discharge,

before peak discharge occurs. This period of increasing discharge can be very short because of the flashy nature of North Halawa Stream. Thus, automatic samplers are needed to best characterize water quality in stormwater runoff. Analyses of grab samples collected during the periods of decreasing discharge provide indications of water quality during the latter parts of storms, but generally underestimate mean constituent concentrations during storms. Flow-weighted composite samples provide better estimates of mean constituent concentrations during storms.

The H-3 Highway may contribute different constituents to stormwater runoff than does the surrounding area. Because suspended sediments in North Halawa Stream mainly are derived from erosion of soils, the primary source areas of suspended sediments are unpaved areas within the valley and not the H-3 Highway. Thus, unpaved areas may represent a main source of some nutrients in stormwater runoff. In contrast, the highway may represent a main source of trace metals, such as cadmium, copper, lead, and zinc, which are commonly associated with tire wear, brake linings, vehicle fluids or lubricants, or emissions.

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Appendix A

Table A1. Results of rinsate blank analyses for trace-element, nutrient, and other determinations for Storm Drain C.

[<, less than value; E, estimated value; M, missing data; -, no analysis performed; values in **bold** exceed minimum reporting level; μS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; N, nitrogen; CaCO₃, calcium carbonate; mg/L, micrograms per liter]

Property or constituent	Units	Sample Dates											
		17-Nov-99	25-Apr-00	3-Oct-00	02-Apr-01[a]	02-Apr-01[b]	21-Aug-01	12-Dec-01	26-Mar-02	13-Nov-02	19-Jun-03	15-Jul-03	4-Feb-04
Temperature, water	degrees C	-	18	-	-	-	-	-	-	-	-	-	-
Specific conductance, field	S/cm at 25°C	-	2	-	-	-	-	-	-	-	-	-	-
Specific conductance, lab	S/cm at 25°C	-	-	-	**3**	**11**	<3	<3	**3**	**E4**	**E3**	**E3**	**E4**
pH, field	standard units	-	6.8	-	-	-	-	-	-	-	-	-	-
pH, lab	standard units	-	-	-	7.4	6.4	7.7	7.2	7.4	8.1	6.7	6.1	E6.9
Total suspended solids	mg/L	-	-	-	-	-	<10	<10	<10	<10	<10	<10	<10
Oil and grease	mg/L	-	-	-	-	-	-	-	-	-	-	-	<7
Nitrogen ammonia dissolved	mg/L as N	-	<0.02	-	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Nitrogen, nitrite, dissolved	mg/L as N	-	<0.01	-	<0.006	<0.006	<0.006	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Nitrogen, ammonia + organic, total	mg/L as N	-	<0.1	-	E0.08	<0.08	<0.08	E0.07	**0.1**	E0.07	<0.1	<0.1	<0.1
Nitrogen, nitrite + nitrate, dissolved	mg/L as N	-	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.06	<0.06	<0.06	**0.62**
Total phosphorus	mg/L	-	<0.05	-	<0.06	<0.06	<0.06	<0.06	<0.06	<0.04	<0.04	<0.04	<0.04
Phosphorus dissolved	mg/L	-	<0.05	-	<0.06	<0.06	<0.06	<0.06	<0.06	<0.04	<0.04	<0.04	<0.04
Carbon, organic, total	mg/L	E0.2	**1.4**	-	-	-	-	-	-	-	-	-	-
Hardness	mg/L as CaCO₃	M	-	-	-	-	-	-	-	-	-	-	-
Calcium, dissolved	mg/L	**0.01**	<0.002	**0.009**	-	-	-	-	-	-	-	-	-
Magnesium, dissolved	mg/L	0.001	<0.001	<0.001	-	-	-	-	-	-	-	-	-
Sodium, dissolved	mg/L	**0.04**	**0.03**	<0.03	-	-	-	-	-	-	-	-	-
Sodium adsorption ratio	ratio	0.1	-	-	-	-	-	-	-	-	-	-	-
Silica, dissolved	mg/L	<0.02	<0.02	<0.02	-	-	-	-	-	-	-	-	-
Barium, dissolved	μg/L	<0.2	<0.2	<0.2	-	-	-	-	-	-	-	-	-
Beryllium, dissolved	μg/L	<0.2	<0.2	<0.2	-	-	-	-	-	-	-	-	-
Cadmium, dissolved	μg/L	<0.3	<0.3	<0.3	-	-	-	-	-	-	-	-	-
Total cadmium	μg/L	-	-	-	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Chromium, dissolved	μg/L	<0.2	<0.2	<0.2	-	-	-	-	-	-	-	-	-
Total chromium	μg/L	-	-	-	-	-	-	-	-	-	-	-	-
Cobalt, dissolved	μg/L	<0.2	<0.2	<0.2	-	-	-	-	-	-	-	-	-
Copper, dissolved	μg/L	<0.2	<0.2	<0.2	-	-	-	-	-	-	-	-	-
Total copper	μg/L	-	-	-	<0.6	<0.6	<0.6	E0.4	<0.6	<0.6	<0.6	<0.6	E0.5
Iron, dissolved	μg/L	<3	<3	**5**	-	-	-	-	-	-	-	-	-
Lead, dissolved	μg/L	**0.4**	<0.3	<0.3	-	-	-	-	-	-	-	-	-
Total lead	μg/L	-	-	-	<1	<1	<1	<1	<1	<0.06	<0.06	<0.06	<0.06
Manganese, dissolved	μg/L	**0.1**	<0.1	<0.1	-	-	-	-	-	-	-	-	-
Molybdenum, dissolved	μg/L	<0.2	<0.2	<0.2	-	-	-	-	-	-	-	-	-
Nickel, dissolved	μg/L	<0.5	<0.5	<0.5	-	-	-	-	-	-	-	-	-
Total nickel	μg/L	-	-	-	-	-	-	-	-	-	-	-	-
Silver, dissolved	μg/L	<0.2	<0.2	<0.2	-	-	-	-	-	-	-	-	-
Strontium, dissolved	μg/L	<0.1	<0.1	<0.1	-	-	-	-	-	-	-	-	-
Zinc, dissolved	μg/L	**3.2**	<0.5	<0.5	-	-	-	-	-	-	-	-	-
Total zinc	μg/L	-	-	-	**8**	**3**	**14**	**8**	**21**	**6**	**4**	**27**	**E2**
Aluminum, dissolved	μg/L	**0.3**	**0.4**	**0.3**	-	-	-	-	-	-	-	-	-
Total dissolved solids	mg/L	-	-	-	-	-	<10	<10	<10	<10	<10	<10	<13

[a] Automatic sampler before cleaning.

[b] Automatic sampler after cleaning.

Table A2.   Results of rinsate blank analyses for semivolatile-compound determinations for Storm Drain C.

[Concentrations are reported as micrograms per liter; <, less than]

Property or constituent	Sample Date 11/17/1999
Acenaphthylene	<2
Acenaphthene	<2
Anthracene	<2
Benzo[b]fluoranthene	<3
Benzo[k]fluoranthene	<3
Benzo[a]pyrene	<3
2-Chloroethylether	<2
2-Chloroethoxymethane	<3
Chloroisopropylether	<2
Butylbenzylphthalate	<4
Chrysene	<3
Diethyl phthalate	<2
Dimethyl phthalate	<2
Fluoranthene	<2
9H-Fluorene	<2
Hexachlorocyclopentadiene	<2
Hexachloroethane	<2
Indenopyrene	<3
Isophorone	<2
Nitrosodipropylamine	<2
Nitrosodiphenylamine	<3
Nitrosodimethylamine	<3
Nitrobenzene	<2
Phenanthrene	<2
Pyrene	<2
Benzo[g,h,i]perylene	<3
Benzo[a]anthracene	<2
1,2-Dichlorobenzene	<2
1,2,4-Trichlorobenzene	<2
Dibenzo[a,h]anthracene	<3
1,3-Dichlorobenzene	<2
1,4-Dichlorobenzene	<2
2-Chloronaphthalene	<2
Di-n-octyl phthalate	<5
2,4-Dinitrotoluene	<3
2,6-Dinitrotoluene	<2
4-Bromophenyl phenyl ether	<2
4-Chlorophenyl phenyl ether	<2
Naphthalene	<2
2-Ethylhexyl phthalate	<5
Dibutyl phthalate	<3
Hexachlorobenzene	<2
Hexachlorobutadiene	<3

Table A3. Results of rinsate blank analyses for trace-element, nutrient, and other determinations for Xeriscape Garden.

[<, less than; E, estimated; M, missing data; –, no analysis performed; values in **bold** exceed minimum reporting level; μS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; N, nitrogen; CaCO₃, calcium carbonate; mg/L, milligrams per liter; μg/L, micrograms per liter]

Property or constituent	Units	Sample Date												
		25-Nov-98	17-Nov-99	3-May-00	3-Oct-00	21-Aug-01[a]	21-Aug-01[b]	21-Aug-01[c]	12-Dec-01	27-Mar-02	13-Nov-02	18-Dec-03	26-May-04	8-Sep-04
Temperature, water	degrees C	-	-	25.5	-	-	-	-	-	-	-	-	-	-
Specific conductance, field	S/cm at 25°C	-	-	2	-	-	-	-	-	-	-	-	-	-
Specific conductance, lab	S/cm at 25°C	-	-	-	-	**3**	<3	<3	**3**	**3**	**E4**	E3	<3	E3
pH, field	standard units	-	-	6.4	-	-	-	-	-	-	-	-	-	-
pH, lab	standard units	-	-	-	-	7.5	7.5	7.6	7.4	7.6	8.3	6.5	E6.6	5.4
Total suspended solids	mg/L	-	-	-	-	<10	-	-	<10	<10	<10	<10	<10	<10
Nitrogen ammonia dissolved	mg/L as N	-	-	<0.02	-	E0.03	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Nitrogen, nitrite, dissolved	mg/L as N	-	-	<0.01	-	<0.006	<0.006	<0.006	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Nitrogen, ammonia + organic, total	mg/L as N	-	-	<0.1	-	<0.08	<0.08	<0.08	<0.1	E0.06	E0.08	<0.1	<0.1	E0.06
Nitrogen, nitrite + nitrate, dissolved	mg/L as N	-	-	<0.05	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.06	<0.06	<0.06	<0.06
Total phosphorus	mg/L	-	-	<0.05	-	<0.06	<0.06	<0.06	<0.06	<0.06	<0.04	<0.04	<0.04	<0.04
Phosphorus dissolved	mg/L	-	-	<0.05	-	<0.06	<0.06	<0.06	<0.06	<0.06	<0.04	<0.04	<0.04	<0.04
Carbon, organic, total	mg/L	-	**0.9**	E0.1	-	-	-	-	-	-	-	-	-	-
Hardness	mg/L as CaCO₃	-	M	M	-	-	-	-	-	-	-	-	-	-
Calcium, dissolved	mg/L	**0.006**	**0.01**	**0.014**	**0.01**	-	-	-	-	-	-	-	-	-
Magnesium, dissolved	mg/L	<0.001	**0.001**	**0.002**	<0.001	-	-	-	-	-	-	-	-	-
Sodium, dissolved	mg/L	<0.03	<0.03	<0.03	<0.03	-	-	-	-	-	-	-	-	-
Silica, dissolved	mg/L	<0.02	<0.02	<0.02	<0.02	-	-	-	-	-	-	-	-	-
Barium, dissolved	μg/L	<0.2	<0.2	<0.2	<0.2	-	-	-	-	-	-	-	-	-
Beryllium, dissolved	μg/L	<0.2	<0.2	<0.2	<0.2	-	-	-	-	-	-	-	-	-
Cadmium, dissolved	μg/L	<0.3	<0.3	<0.3	<0.3	-	-	-	-	-	-	-	-	-
Total cadmium	μg/L	-	-	-	-	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Chromium, dissolved	μg/L	<0.2	<0.2	<0.2	<0.2	-	-	-	-	-	-	-	-	-
Cobalt, dissolved	μg/L	<0.2	<0.2	<0.2	<0.2	-	-	-	-	-	-	-	-	-
Copper, dissolved	μg/L	<0.2	<0.2	<0.2	<0.2	-	-	-	-	-	-	-	-	-
Total copper	μg/L	-	-	-	-	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6
Iron, dissolved	μg/L	<3	<3	<3	<3	-	-	-	-	-	-	-	-	-
Lead, dissolved	μg/L	<0.3	<0.3	<0.3	<0.3	-	-	-	-	-	-	-	-	-
Total lead	μg/L	-	-	-	-	<1	<1	<1	<1	<1	<0.06	<0.06	<0.06	<0.06
Manganese, dissolved	μg/L	<0.1	<0.1	**0.1**	<0.1	-	-	-	-	-	-	-	-	-
Molybdenum, dissolved	μg/L	<0.2	<0.2	<0.2	<0.2	-	-	-	-	-	-	-	-	-
Nickel, dissolved	μg/L	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	-	-	-	-
Silver, dissolved	μg/L	<0.2	<0.2	<0.2	<0.2	-	-	-	-	-	-	-	-	-
Strontium, dissolved	μg/L	<0.1	**0.3**	<0.1	<0.1	-	-	-	-	-	-	-	-	-
Zinc, dissolved	μg/L	<0.5	<0.5	<0.5	<0.5	-	-	-	-	-	-	-	-	-
Total zinc	μg/L	-	-	-	-	**13**	<1	<1	**13**	**7**	**2**	<2	E1	<2
Aluminum, dissolved	μg/L	<0.3	<0.3	<0.3	**0.3**	-	-	-	-	-	-	-	-	-
Total dissolved solids	mg/L	-	-	-	-	<10			<10	<10	<10	<10	<10	<10

[a] Automatic sampler after cleaning.

[b] Teflon bag.

[c] Isokinetic sampler.

Table A4.   Results of rinsate blank analyses for semivolatile-compound determinations for Xeriscape Garden.

[Concentrations are reported as micrograms per liter; <, less than]

Property or constituent	Sample Dates	
	17-Nov-99	**3-May-00**
Acenaphthylene	<2	<2
Acenaphthene	<2	<2
Anthracene	<2	<2
Benzo[b]fluoranthene	<3	<3
Benzo[k]fluoranthene	<3	<3
Benzo[a]pyrene	<3	<3
2-Chloroethylether	<2	<2
2-Chloroethoxymethane	<3	<3
Chloroisopropylether	<2	<2
Butylbenzylphthalate	<4	<4
Chrysene	<3	<3
Diethyl phthalate	<2	<2
Dimethyl phthalate	<2	<2
Fluoranthene	<2	<2
9H-Fluorene	<2	<2
Hexachlorocyclopentadiene	<2	<2
Hexachloroethane	<2	<2
Indenopyrene	<3	<3
Isophorone	<2	<2
Nitrosodipropylamine	<2	<2
Nitrosodiphenylamine	<3	<3
Nitrosodimethylamine	<3	<3
Nitrobenzene	<2	<2
Phenanthrene	<2	<2
Pyrene	<2	<2
Benzo[g,h,i]perylene	<3	<3
Benzo[a]anthracene	<2	<2
1,2-Dichlorobenzene	<2	<2
1,2,4-Trichlorobenzene	<2	<2
Dibenzo[a,h]anthracene	<3	<3
1,3-Dichlorobenzene	<2	<2
1,4-Dichlorobenzene	<2	<2
2-Chloronaphthalene	<2	<2
Di-n-octyl phthalate	<5	<5
2,4-Dinitrotoluene	<3	<3
2,6-Dinitrotoluene	<2	<2
4-Bromophenyl phenyl ether	<2	<2
4-Chlorophenyl phenyl ether	<2	<2
Naphthalene	<2	<2
2-Ethylhexyl phthalate	<5	<5
Dibutyl phthalate	<3	<3
Hexachlorobenzene	<2	<2
Hexachlorobutadiene	<3	<3

Table A5. Results of rinsate blank analyses for trace-element, nutrient, and other determinations for Quarantine Station.

[<, less than; E, estimated; –, no analysis performed; values in **bold** exceed minimum reporting level; μS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; N, nitrogen; mg/L, milligrams per liter; μg/L, micrograms per liter]

Property or constituent	Units	Sample Date					
		7-Jan-02	27-Mar-02	27-Feb-03[a]	27-Feb-03[b]	27-Feb-03[c]	29-Dec-05
Chemical oxygen demand	mg/L	-	-	-	<10	<10	-
Specific conductance, lab	S/cm at 25°C	<3	**4**	**144**	-	-	**5**
pH, lab	standard units	7.4	7.7	3.5	-	-	8
Total suspended solids	mg/L	<10	<10	<10	-	-	<10
Oil and grease	mg/L	-	-	-	<7	<7	
Nitrogen ammonia dissolved	mg/L as N	E0.02	E0.04	<0.04	-	-	<0.04
Nitrogen, nitrite, dissolved	mg/L as N	<0.008	<0.008	<0.008	-	-	<0.008
Nitrogen, ammonia + organic, total	mg/L as N	E0.07	E0.08	<0.1	-	-	<0.1
Nitrogen, nitrite + nitrate, dissolved	mg/L as N	<0.05	<0.05	<0.06	-	-	<0.06
Total phosphorus	mg/L	<0.06	<0.06	<0.04	-	-	<0.04
Phosphorus dissolved	mg/L	<0.06	<0.06	<0.04	-	-	<0.04
Total cadmium	μg/L	<0.04	<0.04	<0.04	-	-	<0.04
Total chromium	μg/L	-	-	-	-	-	<2
Total copper	μg/L	<0.6	<0.6	<0.6	-	-	**0.9**
Total lead	μg/L	<1	<1	<0.06	-	-	<0.06
Total nickel	μg/L	-	-	-	-	-	<0.16
Total zinc	μg/L	**3**	**11**	<2	-	-	**7**
Total petroleum hydrocarbons	mg/L	-	-	-	<2	<2	-
Total dissolved solids	mg/L	<10	<10	<10	-	-	<10

[a] Automatic sampler after cleaning.

[b] Teflon bag.

[c] Low Density Polyethylene (LDPE) bag.
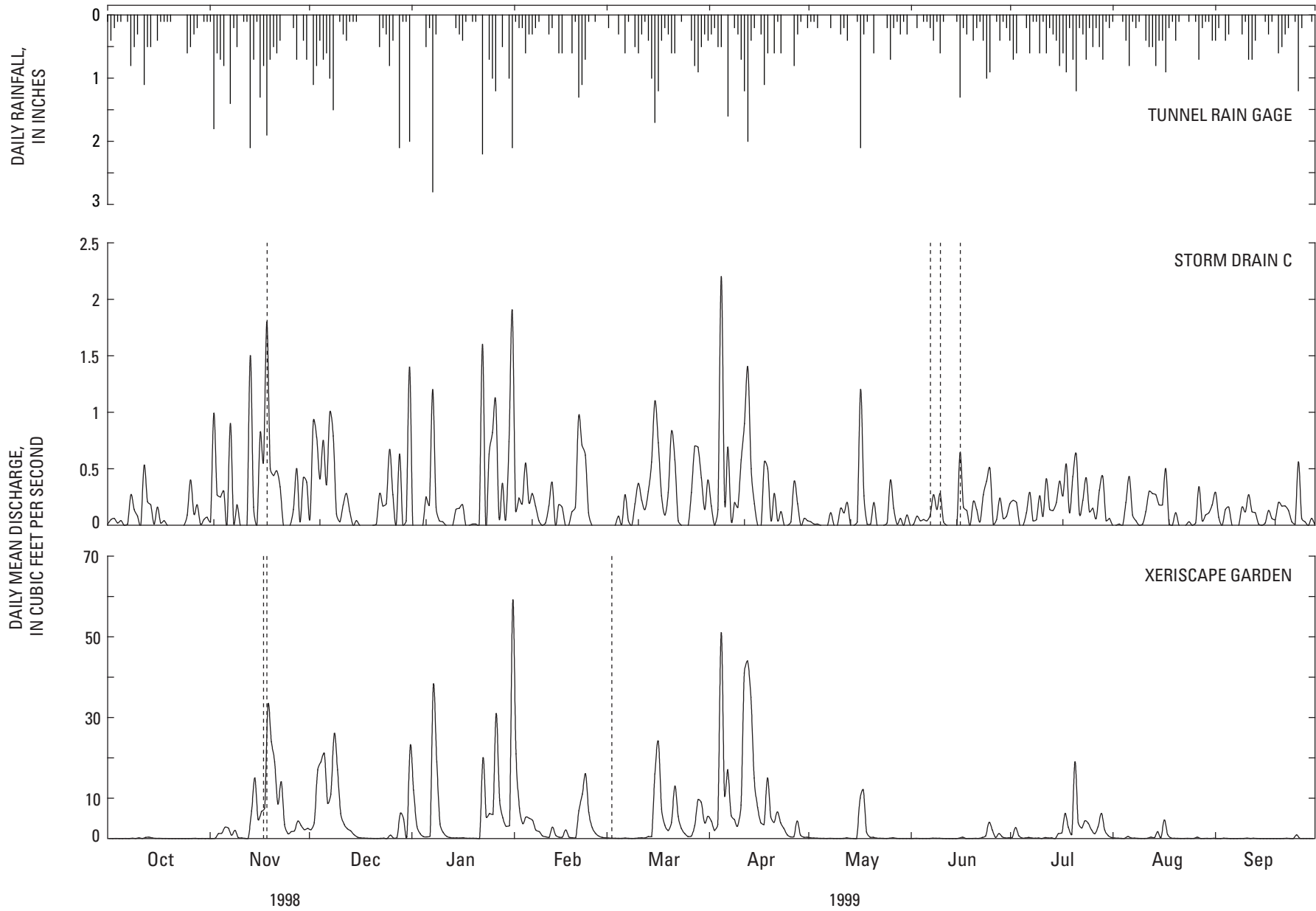
Figure B1.   Daily values for discharge at Storm Drain C and Xeriscape Garden and rainfall at Tunnel rain gage from October 1998 to September 1999. Dashed lines represent days that samples were collected.
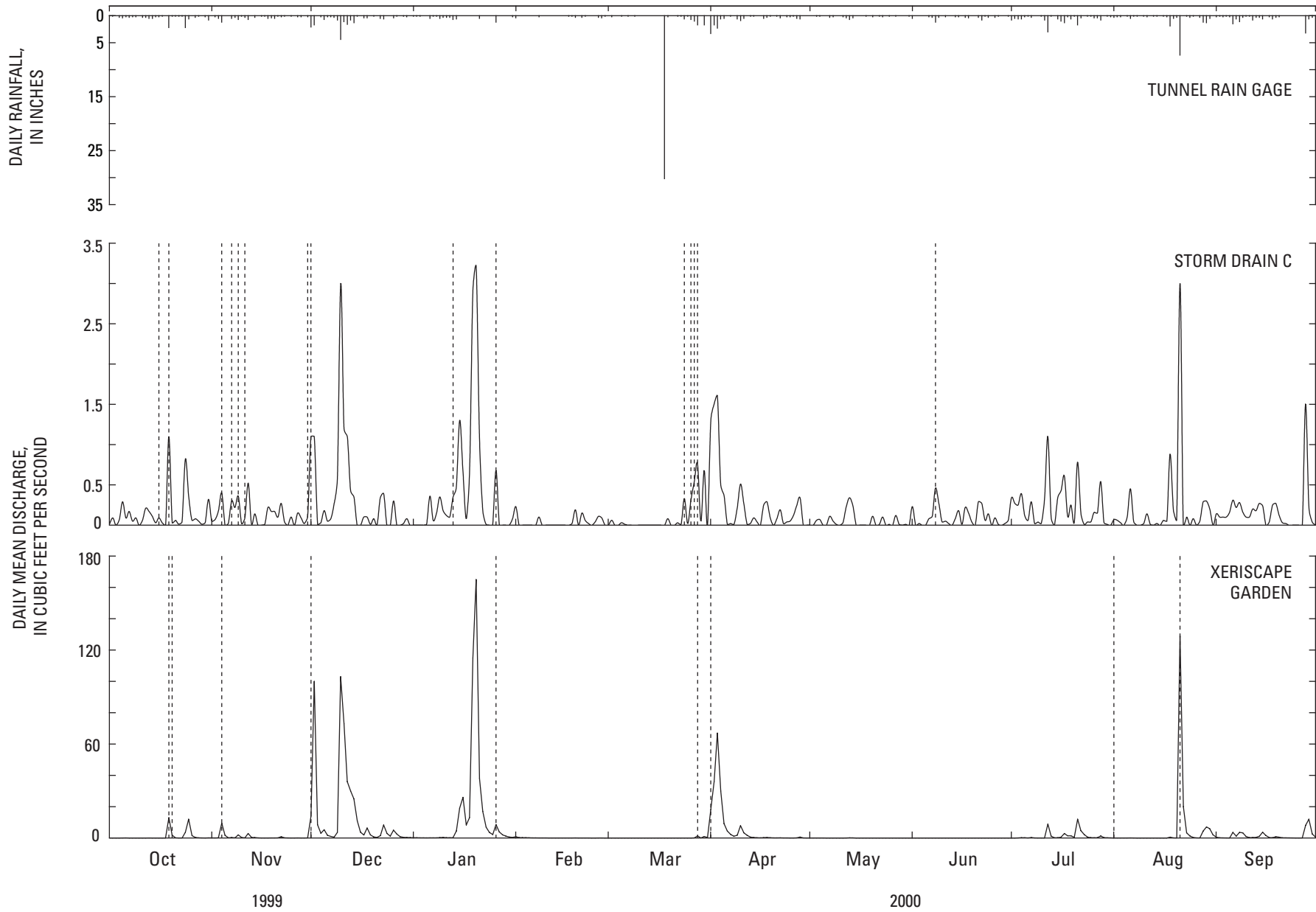
Figure B2.   Daily values for discharge at Storm Drain C and Xeriscape Garden and rainfall at Tunnel rain gage from October 1999 to September 2000. Dashed lines represent days that samples were collected.
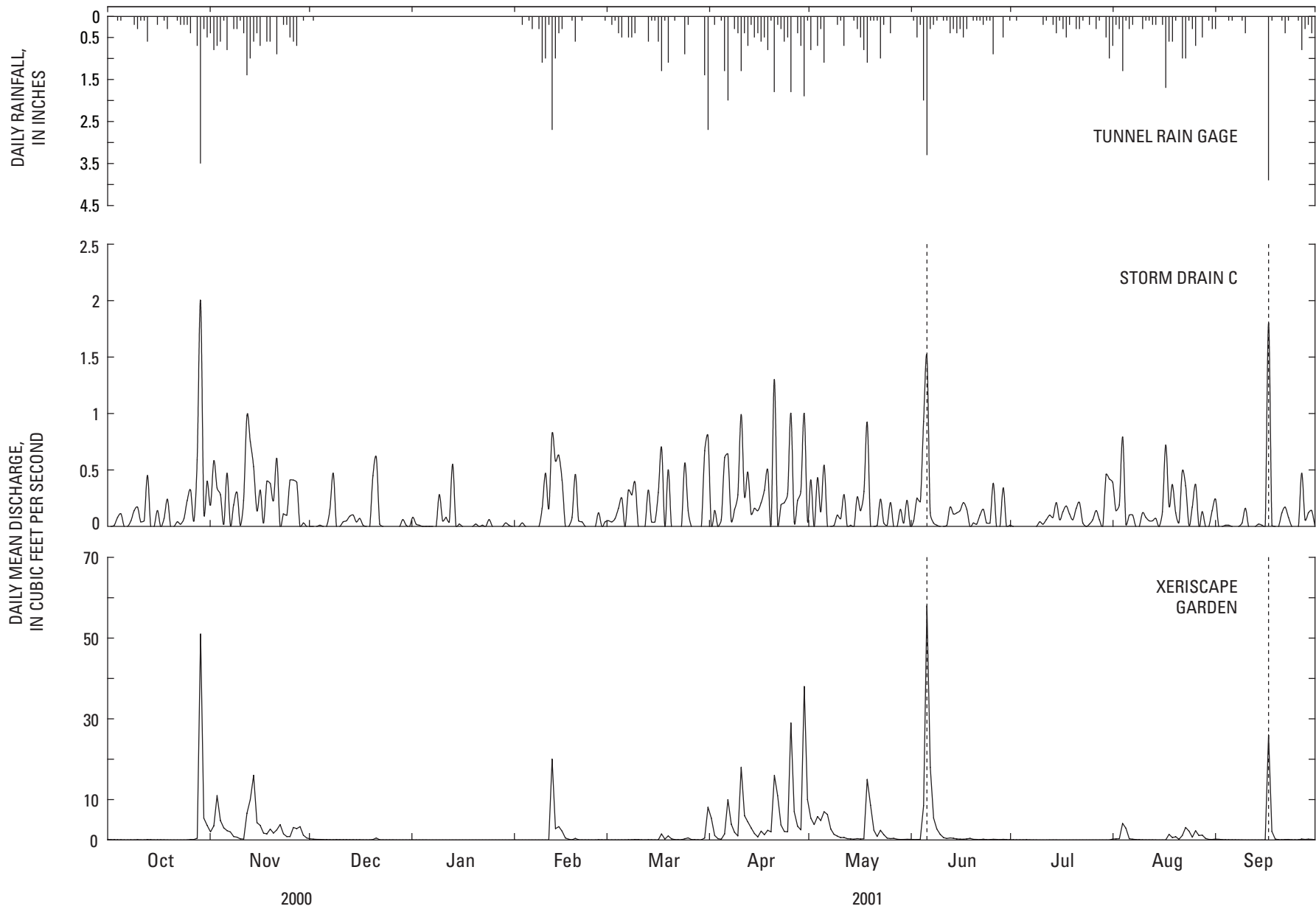
Figure B3. Daily values for discharge at Storm Drain C and Xeriscape Garden and rainfall at Tunnel rain gage from October 2000 to September 2001. Dashed lines represent days that samples were collected.
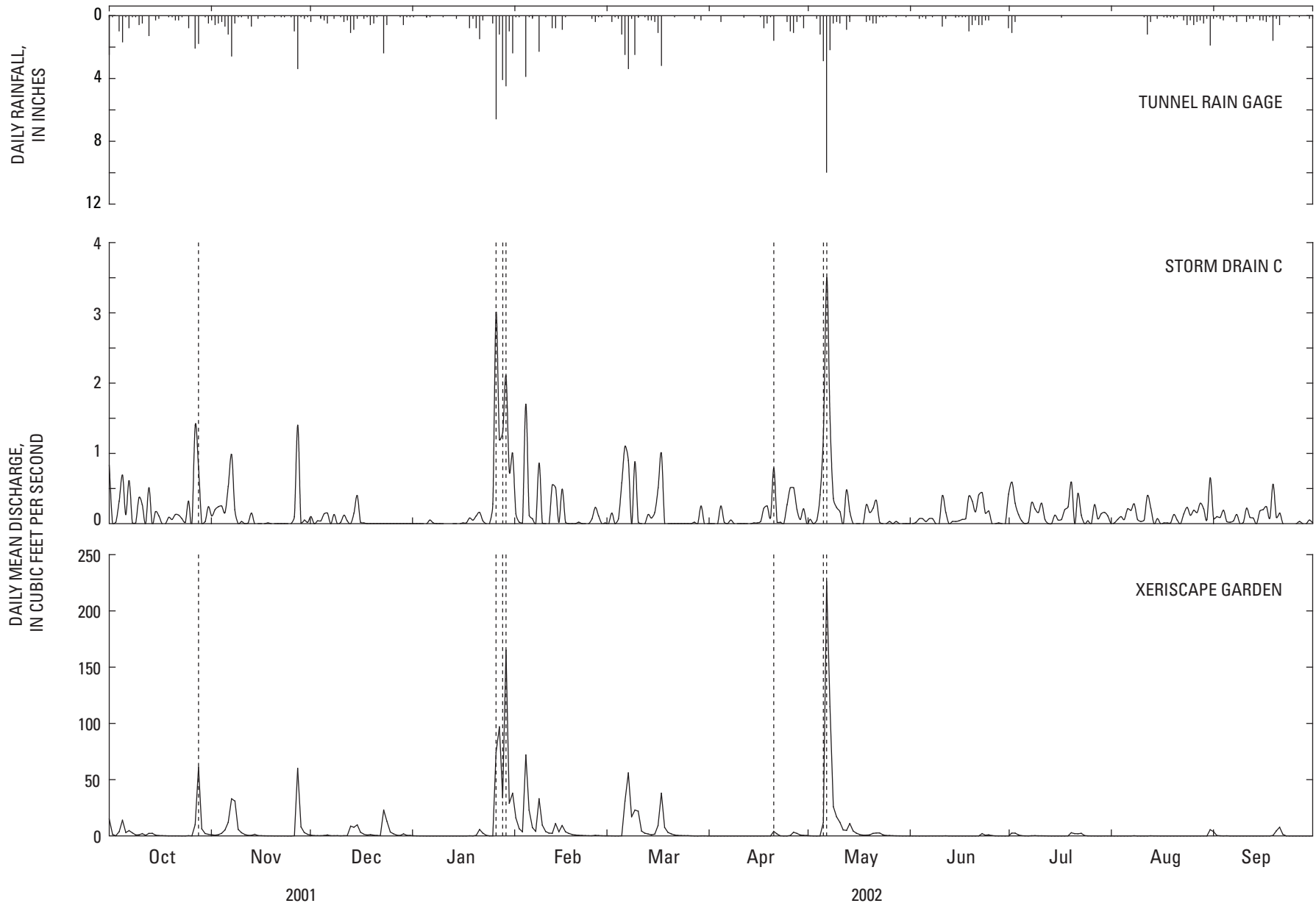
Figure B4.   Daily values for discharge at Storm Drain C and Xeriscape Garden and rainfall at Tunnel rain gage from October 2001 to September 2002. Dashed lines represent days that samples were collected.
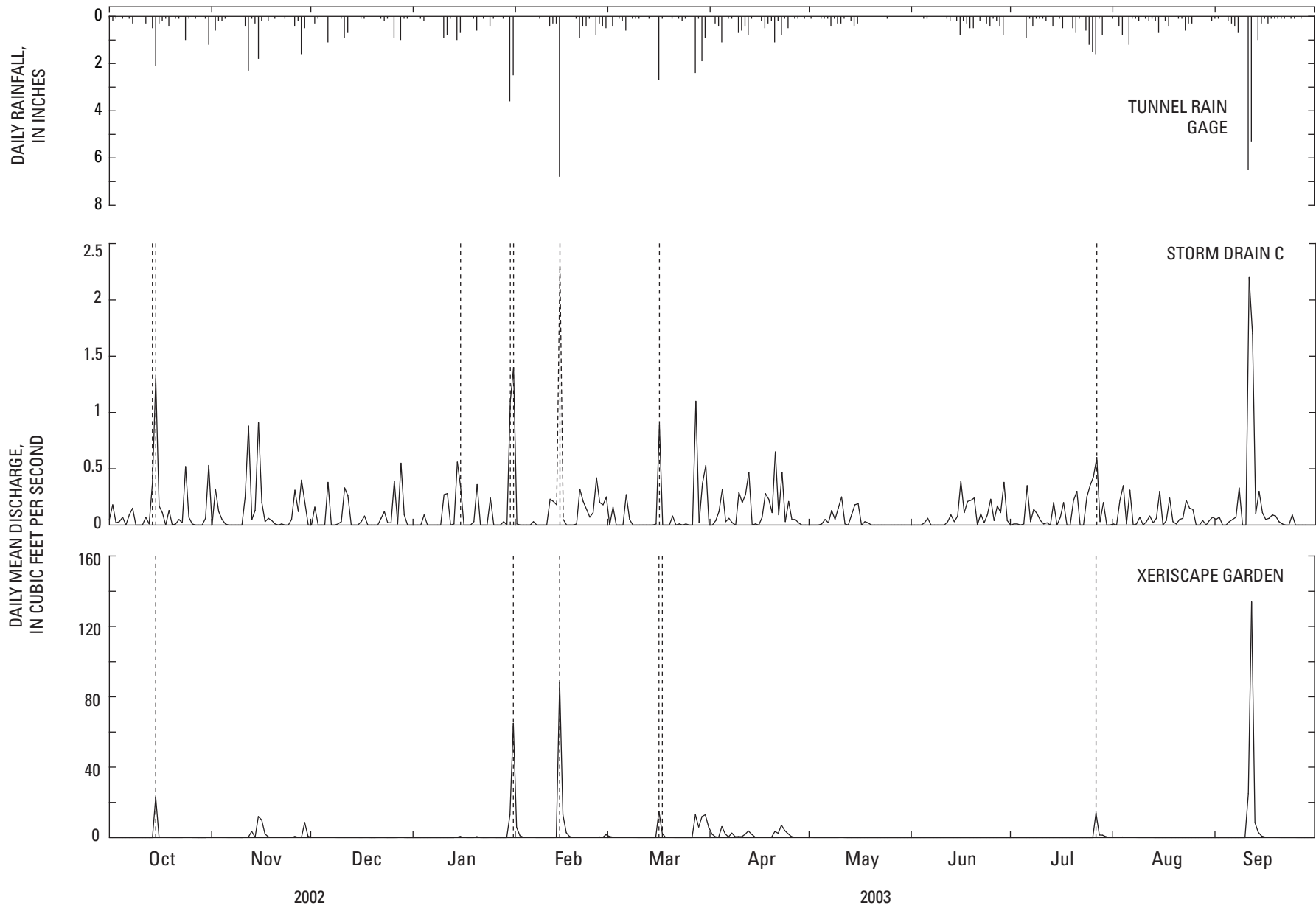
Figure B5. Daily values for discharge at Storm Drain C and Xeriscape Garden and rainfall at Tunnel rain gage from October 2002 to September 2003. Dashed lines represent days that samples were collected.
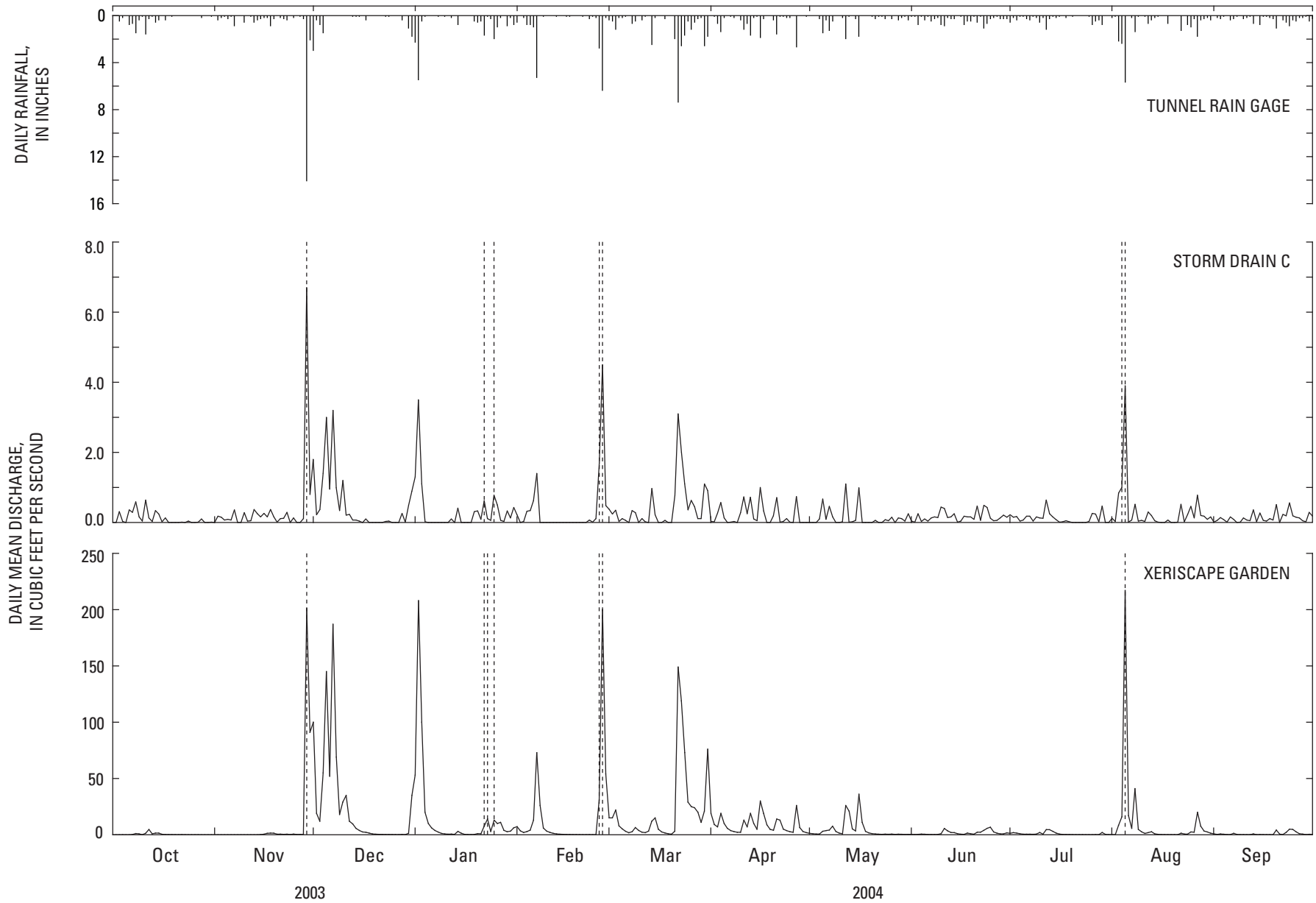
Figure B6.   Daily values for discharge at Storm Drain C and Xeriscape Garden and rainfall at Tunnel rain gage from October 2003 to September 2004. Dashed lines represent days that samples were collected.

Appendix C

Table C1. Statistical summary of detections and values for selected physical properties and constituents measured in grab samples collected at Bridge 8.

[The five-digit USGS parameter code is used to uniquely identify a specific constituent or property; μS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter; μg/L, microgram per liter; –, no data or not computed; E, estimated value; N, nitrogen; NO_2, nitrite; cfs, cubic feet per second]

| USGS parameter code | Property or constituent | Units | Grab Samples | | | | | |
| | | | Number Of | | | Detected Values | | |
			Samples	Non-Detects	Detects	Min.	Median	Max.
00010	Temperature, water	degrees Celsius	11	–	11	17.9	20.5	23
00061	Discharge, instantaneous	cfs	11	–	11	30	47	721
00065	Gage height	feet	9	–	9	96.52	97.4	100.3
00095	Specific conductance, field	μS/cm at 25°C	9	–	9	59	95	146
90095	Specific conductance, lab	μS/cm at 25°C	11	–	11	E68	82	152
00340	Chemical oxygen demand	mg/L	11	2	9	10	20	190
00400	pH, field	standard units	9	–	9	5.8	6.5	7.4
00403	pH, lab	standard units	11	–	11	6.9	7.4	7.9
00530	Total suspended solids	mg/L	11	2	9	32	58	1170
00556	Oil and grease	mg/L	11	11	–	–	–	–
00600	Total nitrogen	mg/L	11	–	11	0.25	0.6	6.3
00608	Nitrogen, ammonia, dissolved	mg/L as N	11	11	–	–	–	–
00613	Nitrogen, nitrite, dissolved	mg/L as N	11	9	2	E0.004	–	0.007
71856	Nitrite, dissolved	mg/L as NO_2	1	–	1	–	0.023	–
00625	Nitrogen, ammonia + organic, total	mg/L as N	11	–	11	0.2	0.51	6.2
00631	Nitrogen, nitrite + nitrate, dissolved	mg/L as N	11	1	10	0.05	0.1	0.2
00665	Total phosphorus	mg/L	11	–	11	E0.03	0.1	1.77
00666	Phosphorus, dissolved	mg/L	11	10	1	–	E0.03	–
01027	Total cadmium	μg/L	11	5	6	E0.02	0.08	0.4
01042	Total copper	μg/L	11	–	11	2	4.9	99.4
01051	Total lead	μg/L	11	4	7	0.07	0.79	7.95
01092	Total zinc	μg/L	11	–	11	2	7	129
45501	Total petroleum hydrocarbons	mg/L	11	9	2	2	–	3
70300	Total dissolved solids	mg/L	11	–	11	42	60	124

Table C2. Statistical summary of detections and values for selected physical properties and constituents measured in grab samples collected at Storm Drain C.

[The five-digit USGS parameter code is used to uniquely identify a specific constituent or property; μS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter; μg/L, microgram per liter; –, no data or not computed; na, not applicable; E, estimated value; %, percent; N, nitrogen; NO_2, nitrite; NO_3, nitrate; NH_4, ammonia; $CaCO_3$, calcium carbonate; mm of Hg, millimeters of mercury; NTU, nephelometric turbidity unit; cfs, cubic feet per second]

| USGS parameter code | Property or constituent | Units | Grab Samples | | | | | |
| | | | Number Of | | | Detected Values | | |
			Samples	Non-Detects	Detects	Min.	Median	Max.
00010	Temperature, water	degrees Celsius	15	–	15	18	22	24
00020	Temperature, air	degrees Celsius	6	–	6	21	21.75	24
00025	Air pressure	mm of Hg	5	–	5	751	756	761
00060	Discharge	cfs	1	–	1	–	6.6	–
00061	Discharge, instantaneous	cfs	45	–	45	0.01	3	24
00065	Gage height	feet	45	–	45	1.22	1.7	3.63
00076	Turbidity	NTU	20	–	20	1.3	3.75	22
00095	Specific conductance, field	μS/cm at 25°C	18	–	18	25	91	314
90095	Specific conductance, lab	μS/cm at 25°C	29	–	29	28	68	327
00300	Oxygen dissolved	mg/L	3	–	3	8.1	8.3	10.5
00301	Oxygen dissolved	% of saturation	3	–	3	96	97	121
00340	Chemical oxygen demand	mg/L	18	6	12	10	30	60
00400	pH, field	standard units	19	–	19	6	7.4	8
00403	pH, lab	standard units	29	–	29	6.8	7.6	8.2
00405	Carbon dioxide	mg/L	1	–	1	–	1.6	–
00530	Total suspended solids	mg/L	38	10	28	1	43	560
00556	Oil and grease	mg/L	16	8	8	1	4.5	8
00600	Total nitrogen	mg/L	20	–	20	0.16	0.425	1.6
00605	Organic nitrogen	mg/L	2	–	2	0.19	–	0.55
00608	Nitrogen ammonia dissolved	mg/L as N	20	14	6	0.02	0.035	0.06
00613	Nitrogen, nitrite, dissolved	mg/L as N	18	8	10	E0.004	0.009	0.035
00618	Nitrogen, nitrate, dissolved	mg/L as N	5	–	5	0.07	0.09	0.15
00625	Nitrogen, total organic + ammonia	mg/L as N	20	–	20	0.12	0.235	1.5
00631	Nitrogen, nitrite + nitrate dissolved	mg/L as N	20	2	18	E0.03	0.115	0.58
71846	Ammonia, dissolved	mg/L as NH_4	2	–	2	0.05	–	0.08
71851	Nitrate, dissolved	mg/L as NO_3	5	–	5	0.288	0.416	0.677
71856	Nitrite, dissolved	mg/L as NO_2	5	–	5	0.033	0.046	0.115
00665	Total phosphorus	mg/L	20	1	19	E0.03	0.07	0.24
00666	Phosphorus dissolved	mg/L	18	13	5	E0.02	0.03	0.08
00680	Carbon, organic, total	mg/L	4	–	4	7.5	8.4	9.9
00900	Hardness	mg/L as $CaCO_3$	1	–	1	–	35	35
00915	Calcium, dissolved	mg/L	1	–	1	–	12.2	–
00925	Magnesium, dissolved	mg/L	1	–	1	–	0.934	–
00930	Sodium, dissolved	mg/L	1	–	1	–	8.93	–
00931	Sodium adsorption ratio	ratio	1	–	1	–	0.7	–
00932	Sodium, equivalents of major cations	percent	1	–	1	–	35	–
00935	Potassium, dissolved	mg/L	1	–	1	–	1.05	–
00940	Chloride, dissolved	mg/L	6	–	6	1.69	4.55	9.22
00945	Sulfate, dissolved	mg/L	6	–	6	1.3	3.65	6.2
00950	Fluoride, dissolved	mg/L	1	1	–	–	–	–
00955	Silica, dissolved	mg/L	1	–	1	–	4.21	–
01005	Barium, dissolved	μg/L	1	–	1	–	7.6	–
01027	Total cadmium	μg/L	23	1	22	0.02	0.1	0.61
01030	Chromium, dissolved	μg/L	6	–	6	2	2.9	4.7
01034	Total chromium	μg/L	5	–	5	5	6	9.8
01035	Cobalt, dissolved	μg/L	1	1	–	–	–	–
01040	Copper, dissolved	μg/L	6	–	6	1.5	3.05	8.6
01042	Total copper	μg/L	28	–	28	1.9	11.7	68
01045	Total iron	μg/L	1	–	1	–	1130	–
01046	Iron, dissolved	μg/L	1	–	1	–	E8	–
01049	Lead, dissolved	μg/L	6	6	–	–	–	–
01051	Total lead	μg/L	28	3	25	0.49	4.37	20.2
01056	Manganese, dissolved	μg/L	1	1	–	–	–	–
01060	Molybdenum, dissolved	μg/L	1	1	–	–	–	–
01065	Nickel, dissolved	μg/L	6	6	–	–	–	–
01067	Total nickel	μg/L	5	–	5	2.4	4.1	8.2
01075	Silver, dissolved	μg/L	1	1	–	–	–	–
01080	Strontium, dissolved	μg/L	1	–	1	–	72.4	–
01085	Vanadium, dissolved	μg/L	1	1	–	–	–	–
01090	Zinc, dissolved	μg/L	6	2	4	E11	18	39
01092	Total zinc	μg/L	28	–	28	8	57.5	274
01105	Total aluminum	μg/L	1	–	1	–	930	–
01106	Aluminum, dissolved	μg/L	1	–	1	–	90	–
01130	Lithium, dissolved	μg/L	1	1	–	–	–	–
01145	Selenium, dissolved	μg/L	1	1	–	–	–	–
45501	Total petroleum hydrocarbons	mg/L	12	9	3	2	3	3
70300	Total dissolved solids	mg/L	16	–	16	15	48	192
70301	Residue, sum of constituents	mg/L	1	–	1	–	56	–
70302	Residue	tons/day	1	–	1	–	0.05	–
70303	Residue	tons/acre-feet	1	–	1	–	0.09	–
90410	Acid neutralizing capacity	mg/L as $CaCO_3$	1	–	1	–	34	–

Table C3.   Statistical summary of detections and values for selected physical properties and constituents measured in composite samples collected at Storm Drain C.

[The five-digit USGS parameter code is used to uniquely identify a specific constituent or property; μS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter; μg/L, microgram per liter; –, no data or not computed; NTU, nephelometric turbidity unit; E, estimated value; N, nitrogen; NO_2, nitrite; NO_3, nitrate; NH_4, ammonia; $CaCO_3$, calcium carbonate; mm of Hg, millimeters of mercury; cfs, cubic feet per second]

| USGS parameter code | Property or constituent | Units | Composite Samples | | | | | |
| | | | Number Of | | | Detected Values | | |
			Samples	Non-Detects	Detects	Min.	Median	Max.
00010	Temperature, water	degrees Celsius	1	–	1	–	17.2	–
00025	Air pressure	mm of Hg	3	–	3	756	756	757
00060	Discharge	cfs	14	–	14	6.5	11	20
00061	Discharge, instantaneous	cfs	13	–	13	0.3	4.7	18
00065	Gage height	feet	12	–	12	1.3	1.845	2.37
00076	Turbidity	NTU	10	–	10	1.4	4.1	14
00095	Specific conductance, field	μS/cm at 25°C	8	–	8	37	45	65
90095	Specific conductance, lab	μS/cm at 25°C	24	–	24	36	52.5	114
00300	Oxygen dissolved	mg/L	1	–	1	–	8.3	–
00340	Chemical oxygen demand	mg/L	20	5	15	10	30	80
00400	pH, field	standard units	7	–	7	6.6	7.3	8
00403	pH, lab	standard units	24	–	24	7	7.5	8.1
00530	Total suspended solids	mg/L	28	4	24	13	48	103
00556	Oil and grease	mg/L	6	1	5	2	3	E5
00600	Total nitrogen	mg/L	19	–	19	0.075	0.295	1.46
00605	Organic nitrogen	mg/L	5	–	5	0.25	0.63	1.4
00608	Nitrogen ammonia dissolved	mg/L as N	19	9	10	0.02	0.03	0.05
00613	Nitrogen, nitrite, dissolved	mg/L as N	17	13	4	E0.004	0.011	0.024
00618	Nitrogen, nitrate, dissolved	mg/L as N	2	–	2	0.05	0.085	0.12
00625	Nitrogen, total organic + ammonia	mg/L as N	20	1	19	E0.09	0.35	1.4
00631	Nitrogen, nitrite + nitrate dissolved	mg/L as N	19	8	11	E0.03	0.05	0.13
71846	Ammonia, dissolved	mg/L as NH_4	5	–	5	0.03	0.05	0.07
71851	Nitrate, dissolved	mg/L as NO_3	2	–	2	0.23	–	0.522
71856	Nitrite, dissolved	mg/L as NO_2	3	–	3	0.026	0.046	0.079
00665	Total phosphorus	mg/L	20	2	18	E0.02	0.09	0.38
00666	Phosphorus dissolved	mg/L	17	15	2	E0.03	0.03	0.03
00680	Carbon, organic, total	mg/L	6	–	6	5.6	6.7	11
00900	Hardness	mg/L as $CaCO_3$	1	–	1	–	36	–
00915	Calcium, dissolved	mg/L	1	–	1	–	12.8	–
00925	Magnesium, dissolved	mg/L	1	–	1	–	0.963	–
00930	Sodium, dissolved	mg/L	1	–	1	–	7.43	–
00931	Sodium adsorption ratio	ratio	1	–	1	–	0.5	–
00932	Sodium, equivalents of major cations	percent	1	–	1	–	30	–
00935	Potassium, dissolved	mg/L	1	–	1	–	1.02	–
00940	Chloride, dissolved	mg/L	7	–	7	0.71	3	10.2
00945	Sulfate, dissolved	mg/L	7	–	7	0.9	1.3	41.8
00950	Fluoride, dissolved	mg/L	1	1	–	–	–	–
00955	Silica, dissolved	mg/L	1	–	1	–	4.85	–
01005	Barium, dissolved	ug/L	1	–	1	–	8.1	–
01027	Total cadmium	μg/L	16	–	16	E0.02	0.165	0.53
01030	Chromium, dissolved	μg/L	8	–	8	E0.7	2.85	3.6
01034	Total chromium	μg/L	8	–	8	5	10.55	16.5
01035	Cobalt, dissolved	μg/L	1	1	–	–	–	–
01040	Copper, dissolved	μg/L	8	–	8	1.9	2.4	5.4
01042	Total copper	μg/L	24	–	24	1.4	26.3	136
01045	Total iron	μg/L	1	–	1	–	1510	–
01046	Iron, dissolved	μg/L	1	–	1	–	21	–
01049	Lead, dissolved	μg/L	8	8	–	–	–	–
01051	Total lead	μg/L	24	1	23	0.92	9.5	44.4
01056	Manganese, dissolved	μg/L	1	1	–	–	–	–
01060	Molybdenum, dissolved	μg/L	1	1	–	–	–	–
01065	Nickel, dissolved	μg/L	8	6	2	E0.7	–	0.9
01067	Total nickel	μg/L	8	–	8	4.6	8.95	20.8
01075	Silver, dissolved	μg/L	1	1	–	–	–	–
01080	Strontium, dissolved	μg/L	1	–	1	–	78.3	–
01085	Vanadium, dissolved	μg/L	1	1	–	–	–	–
01090	Zinc, dissolved	μg/L	8	4	4	6.5	17	21
01092	Total zinc	μg/L	24	–	24	12	105.5	290
01105	Total aluminum	μg/L	1	–	1	–	1220	–
01106	Aluminum, dissolved	μg/L	1	–	1	–	80	–
01130	Lithium, dissolved	μg/L	1	1	–	–	–	–
01145	Selenium, dissolved	μg/L	1	1	–	–	–	–
45501	Total petroleum hydrocarbons	mg/L	2	–	2	3	–	4
70300	Total dissolved solids	mg/L	17	–	17	16	23	69
70301	Residue, sum of constituents	mg/L	1	–	1	–	102	–
70302	Residue	tons/day	1	–	1	–	0.06	–
70303	Residue	tons/acre-feet	1	–	1	–	0.09	–
90410	Acid neutralizing capacity	mg/L as $CaCO_3$	1	–	1	–	37	–

Table C4. Statistical summary of detections and values for selected physical properties and constituents measured in grab samples collected at Xeriscape Garden.

[The five-digit USGS parameter code is used to uniquely identify a specific constituent or property; μS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter; μg/L, microgram per liter; –, no data or not computed; %, percent; NTU, nephelometric turbidity unit; E, estimated value; N, nitrogen; NH_4, ammonia; $CaCO_3$, calcium carbonate; mm of Hg, millimeters of mercury; cfs, cubic feet per second]

| USGS parameter code | Property or constituent | Units | Grab Samples | | | | | |
| | | | Number Of | | | Detected Values | | |
			Samples	Non-Detects	Detects	Min.	Median	Max.
00010	Temperature, water	degrees Celsius	18	–	18	18.3	21.5	25.5
00020	Temperature, air	degrees Celsius	7	–	7	20	22.5	28.5
00025	Air pressure	mm of Hg	7	–	7	757	761	764
00061	Discharge, instantaneous	cfs	33	–	33	0.03	35	640
00065	Gage height	feet	32	–	32	5.89	7.195	10.1
00076	Turbidity	NTU	16	–	16	0.58	32	380
00095	Specific conductance, field	μS/cm at 25°C	19	–	19	57	107	359
90095	Specific conductance, lab	μS/cm at 25°C	23	–	23	61	118	352
00300	Oxygen dissolved	mg/L	6	–	6	5.9	8.55	9.4
00301	Oxygen dissolved	% of saturation	6	–	6	73	96	101
00340	Chemical oxygen demand	mg/L	21	8	13	10	20	200
00400	pH, field	standard units	19	–	19	6.7	7.1	8.3
00403	pH, lab	standard units	23	–	23	6.9	7.5	8.1
00405	Carbon dioxide	mg/L	2	–	2	6.9	–	9.3
00530	Total suspended solids	mg/L	32	6	26	3	79	1930
00556	Oil and grease	mg/L	23	21	2	2	–	E4
00600	Total nitrogen	mg/L	21	–	21	0.075	0.44	6.7
00605	Organic nitrogen	mg/L	1	–	1	–	0.08	–
00608	Nitrogen ammonia dissolved	mg/L as N	22	21	1	–	0.03	–
00613	Nitrogen, nitrite, dissolved	mg/L as N	18	16	2	0.003	–	E0.004
00625	Nitrogen, total organic + ammonia	mg/L as N	22	–	22	E0.05	0.3	6.6
00631	Nitrogen, nitrite + nitrate dissolved	mg/L as N	22	6	16	0.05	0.11	0.35
71846	Ammonia, dissolved	mg/L as NH_4	1	–	1	–	0.03	–
00665	Total phosphorus	mg/L	22	6	16	E0.03	0.1	2.31
00666	Phosphorus dissolved	mg/L	18	14	4	E0.02	0.025	E0.04
00680	Carbon, organic, total	mg/L	8	–	8	1.4	2.8	13.9
00900	Hardness	μS/cm at 25°C	2	–	2	27	–	39
00915	Calcium, dissolved	mg/L	2	–	2	5.72	–	7.69
00925	Magnesium, dissolved	mg/L	2	–	2	3.04	–	4.86
00930	Sodium, dissolved	mg/L	2	–	2	8.42	–	11
00931	Sodium adsorption ratio	ratio	2	–	2	0.7	–	0.8
00932	Sodium, equivalents of major cations	percent	2	–	2	37	–	39
00935	Potassium, dissolved	mg/L	2	–	2	1	–	1.71
00940	Chloride, dissolved	mg/L	7	–	7	11.2	16.3	39.5
00945	Sulfate, dissolved	mg/L	7	–	7	3	4.3	9.8
00950	Fluoride, dissolved	mg/L	2	2	–	–	–	–
00955	Silica, dissolved	mg/L	2	–	2	7.53	–	12.8
01005	Barium, dissolved	μg/L	2	–	2	E1	–	1.3
01027	Total cadmium	μg/L	15	7	8	E0.02	0.085	0.41
01030	Chromium, dissolved	μg/L	8	5	3	E0.5	0.8	2.1
01034	Total chromium	μg/L	6	3	3	1	2.6	6
01035	Cobalt, dissolved	μg/L	2	2	–	–	–	–
01040	Copper, dissolved	μg/L	8	2	6	1	1.35	2
01042	Total copper	μg/L	21	1	20	1	3.85	114
01045	Total iron	μg/L	2	–	2	410	–	1810
01046	Iron, dissolved	μg/L	2	–	2	29	–	142
01049	Lead, dissolved	μg/L	8	8	–	–	–	–
01051	Total lead	μg/L	21	7	14	0.09	0.85	8.64
01056	Manganese, dissolved	μg/L	2	–	2	3.5	–	7.3
01060	Molybdenum, dissolved	μg/L	2	2	–	–	–	–
01065	Nickel, dissolved	μg/L	8	8	–	–	–	–
01067	Total nickel	μg/L	6	3	3	1.1	1.31	5
01075	Silver, dissolved	μg/L	2	2	–	–	–	–
01080	Strontium, dissolved	μg/L	2	–	2	35.1	–	45.6
01085	Vanadium, dissolved	μg/L	2	2	–	–	–	–
01090	Zinc, dissolved	μg/L	8	7	1	–	E10	–
01092	Total zinc	μg/L	21	6	15	1	9	146
01105	Total aluminum	μg/L	2	–	2	530	–	2020
01106	Aluminum, dissolved	μg/L	2	–	2	20	–	180
01130	Lithium, dissolved	μg/L	2	2	–	–	–	–
01145	Selenium, dissolved	μg/L	2	2	–	–	–	–
45501	Total petroleum hydrocarbons	mg/L	14	14	–	–	–	–
70300	Total dissolved solids	mg/L	17	–	17	36	72	110
70301	Residue, sum of constituents	mg/L	2	–	2	60	–	82
70302	Residue	tons/day	2	–	2	4.32	–	5.29
70303	Residue	tons/acre-feet	2	–	2	0.09	–	0.12
90410	Acid neutralizing capacity	mg/L as $CaCO_3$	2	–	2	24	–	36

Table C5.   Statistical summary of detections and values for selected physical properties and constituents measured in composite samples collected at Xeriscape Garden.

[The five-digit USGS parameter code is used to uniquely identify a specific constituent or property; μS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter; μg/L, microgram per liter; –, no data or not computed; NTU, nephelometric turbidity unit; E, estimated value; N, nitrogen; cfs, cubic feet per second]

USGS parameter code	Property or constituent	Units	Composite Samples					
			Number Of			Detected Values		
			Samples	Non-Detects	Detects	Min.	Median	Max.
00010	Temperature, water	degrees Celsius	2	–	2	20.3	–	21.2
00060	Discharge	cfs	15	–	15	41	82	641
00061	Discharge, instantaneous	cfs	19	–	19	28	39	131
00065	Gage height	feet	19	–	19	7.04	7.28	8.2
00076	Turbidity	NTU	15	–	15	15	27	390
00095	Specific conductance, field	μS/cm at 25°C	5	–	5	43	61	128
90095	Specific conductance, lab	μS/cm at 25°C	25	–	25	50	85	145
00340	Chemical oxygen demand	mg/L	17	–	17	10	90	410
00400	pH, field	standard units	6	–	6	6.3	7.15	7.6
00403	pH, lab	standard units	25	–	25	6.6	7.3	7.8
00530	Total suspended solids	mg/L	34	1	33	9	165	2420
00556	Oil and grease	mg/L	5	4	1	–	1	–
00600	Total nitrogen	mg/L	16	–	16	0.565	2.45	14
00608	Nitrogen ammonia dissolved	mg/L as N	16	15	1	–	0.03	–
00613	Nitrogen, nitrite, dissolved	mg/L as N	16	15	1	–	E0.004	–
00625	Nitrogen, total organic + ammonia	mg/L as N	16	–	16	0.54	2.3	14
00631	Nitrogen, nitrite + nitrate dissolved	mg/L as N	16	3	13	0.05	0.09	0.29
00665	Total phosphorus	mg/L	16	–	16	0.07	0.575	3.51
00666	Phosphorus dissolved	mg/L	16	13	3	E0.02	E0.02	E0.03
00680	Carbon, organic, total	mg/L	5	–	5	16.2	24.7	27.1
00940	Chloride, dissolved	mg/L	9	–	9	6.75	9.25	15.7
00945	Sulfate, dissolved	mg/L	9	–	9	2.3	2.8	3.2
01027	Total cadmium	μg/L	16	2	14	0.06	0.155	0.51
01030	Chromium, dissolved	μg/L	9	–	9	0.9	1.4	1.7
01034	Total chromium	μg/L	9	–	9	4.2	8.1	36.8
01040	Copper, dissolved	μg/L	9	–	9	1.6	2.1	3.2
01042	Total copper	μg/L	25	–	25	1.7	20.5	137
01049	Lead, dissolved	μg/L	9	9	–	–	–	–
01051	Total lead	μg/L	25	3	22	1.3	4.73	14.3
01065	Nickel, dissolved	μg/L	9	9	–	–	–	–
01067	Total nickel	μg/L	9	–	9	2.06	6.1	20.5
01090	Zinc, dissolved	μg/L	9	5	4	1.7	3.15	10.5
01092	Total zinc	μg/L	25	1	24	8	58.5	191
70300	Total dissolved solids	mg/L	15	–	15	32	51	82

Table C6. Statistical summary of detections and values for selected physical properties and constituents measured in grab samples collected at Quarantine Station.

[The five-digit USGS parameter code is used to uniquely identify a specific constituent or property; μS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter; μg/L, microgram per liter; –, no data or not computed; E, estimated value; N, nitrogen; NH_4, ammonia]

USGS parameter code	Property or constituent	Units	Grab Samples					
			Number Of			Detected Values		
			Samples	Non-Detects	Detects	Min.	Median	Max.
00010	Temperature, water	degrees Celsius	11	–	11	18.3	21.8	24
00061	Discharge, instantaneous	cfs	15	–	15	0.78	50	289
00065	Gage height	feet	13	–	13	3.43	4.92	6.56
00095	Specific conductance, field	μS/cm at 25°C	11	–	11	68	102	173
90095	Specific conductance, lab	μS/cm at 25°C	14	–	14	E70	111	163
00340	Chemical oxygen demand	mg/L	11	2	9	10	20	130
00400	pH, field	standard units	11	–	11	6.5	7.4	8.3
00403	pH, lab	standard units	14	–	14	6.7	7.5	7.8
00530	Total suspended solids	mg/L	12	2	10	11	100	769
00556	Oil and grease	mg/L	13	11	2	3	–	6
00600	Total nitrogen	mg/L	11	–	11	0.27	0.7	4.3
00605	Organic nitrogen	mg/L	1	–	1	–	1.5	–
00608	Nitrogen ammonia dissolved	mg/L as N	11	10	1	–	0.08	–
00613	Nitrogen, nitrite, dissolved	mg/L as N	11	7	4	E0.004	E0.005	E0.007
00625	Nitrogen, total organic + ammonia	mg/L as N	11	–	11	0.23	0.51	4.1
00631	Nitrogen, nitrite + nitrate dissolved	mg/L as N	11	1	10	E0.04	0.165	0.26
00665	Total phosphorus	mg/L	11	–	11	E0.04	0.15	2.06
00666	Phosphorus dissolved	mg/L	11	7	4	E0.02	0.025	0.12
71846	Ammonia, dissolved	mg/L as NH_4	1	–	1	–	0.1	–
01027	Total cadmium	μg/L	14	3	11	E0.03	0.07	0.38
01042	Total copper	μg/L	14	–	14	1.2	8.95	105
01051	Total lead	μg/L	14	2	12	0.09	1.365	9.14
01092	Total zinc	μg/L	14	1	13	2	14	135
45501	Total petroleum hydrocarbons	mg/L	12	11	1	–	E4	–
70300	Total dissolved solids	mg/L	12	–	12	42	78.5	98

Table C7. Statistical summary of detections and values for selected physical properties and constituents measured in composite samples collected at Quarantine Station.

[The five-digit USGS parameter code is used to uniquely identify a specific constituent or property; μS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter; μg/L, microgram per liter; –, no data or not computed; E, estimated value; N, nitrogen; NO_2, nitrite; NO_3, nitrate; cfs, cubic feet per second]

USGS parameter code	Property or constituent	Units	Composite Samples					
			Number Of			Detected Values		
			Samples	Non-Detects	Detects	Min.	Median	Max.
00010	Temperature, water	degrees Celsius	2	–	2	19.7	–	21.7
00060	Discharge	cfs	9	–	9	34	65	401
00095	Specific conductance, field	μS/cm at 25°C	2	–	2	72	–	90
90095	Specific conductance, lab	μS/cm at 25°C	9	–	9	55	86	118
00340	Chemical oxygen demand	mg/L	6	–	6	40	125	380
00400	pH, field	standard units	3	–	3	6.9	7.1	7.3
00403	pH, lab	standard units	9	–	9	6.9	7.3	7.7
00530	Total suspended solids	mg/L	8	–	8	162	654	2370
00600	Total nitrogen	mg/L	7	–	7	1.325	3.8	9.9
00608	Nitrogen ammonia dissolved	mg/L as N	7	7	–	–	–	–
00613	Nitrogen, nitrite, dissolved	mg/L as N	7	5	2	E0.004	–	0.016
00618	Nitrogen, nitrate, dissolved	mg/L as N	1	–	1	–	0.26	–
00625	Nitrogen, total organic + ammonia	mg/L as N	7	–	7	1.3	3.7	9.7
00631	Nitrogen, nitrite + nitrate dissolved	mg/L as N	7	1	6	0.09	0.135	0.28
71851	Nitrate, dissolved	mg/L as NO_3	1	–	1	–	1.15	–
71856	Nitrite, dissolved	mg/L as NO_2	1	–	1	–	0.053	–
00665	Total phosphorus	mg/L	7	–	7	0.28	1.07	2.6
00666	Phosphorus dissolved	mg/L	7	5	2	E0.03	–	E0.04
01027	Total cadmium	μg/L	9	–	9	0.08	0.2	0.52
01042	Total copper	μg/L	9	–	9	17.5	54.4	124
01051	Total lead	μg/L	9	–	9	2.65	5.59	23.2
01092	Total zinc	μg/L	9	–	9	33	85	193
70300	Total dissolved solids	mg/L	8	–	8	37	52	62

Table C8. Statistical summary of detections and values for selected physical properties and constituents measured in grab samples collected at Stadium.

[The five-digit USGS parameter code is used to uniquely identify a specific constituent or property; μS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligram per liter; μg/L, microgram per liter; –, no data or not computed; E, estimated value; %, percent; NTU, nephelometric turbidity unit; N, nitrogen; NO_2, nitrite; NO_3, nitrate; NH_4, ammonia; mm of Hg, millimeters of mercury; cfs, cubic feet per second]

| USGS parameter code | Property or constituent | Units | Grab Samples | | | | | |
| | | | Number Of | | | Detected Values | | |
			Samples	Non-Detects	Detects	Min.	Median	Max.
00010	Temperature, water	degrees Celsius	9	–	9	19.5	21.6	27.5
00020	Temperature, air	degrees Celsius	1	–	1	–	26.5	–
00025	Air pressure	mm of Hg	1	–	1	–	762	–
00061	Discharge, instant.	cfs	10	–	10	4.8	150.5	1820
00065	Gage height	feet	9	–	9	1.08	1.92	18.91
00076	Turbidity	NTU	1	–	1	–	1.9	–
00095	Specific conductance	μS/cm at 25°C	9	–	9	70	128	229
90095	Specific conductance, lab	μS/cm at 25°C	9	–	9	78	127	232
00300	Oxygen dissolved	mg/L	1	–	1	–	10	–
00301	Oxygen dissolved	% of saturation	1	–	1	–	127	–
00340	Chemical oxygen demand	mg/L	10	1	9	10	20	150
00400	pH, field	standard units	9	–	9	5.9	7.4	9.1
00403	pH, lab	standard units	9	–	9	7.2	7.5	7.9
00530	Total suspended solids	mg/L	10	–	10	4	119.5	5380
00556	Oil and grease	mg/L	10	8	2	E5	–	E5
00600	Total nitrogen	mg/L	10	–	10	0.175	0.85	5.4
00605	Organic nitrogen	mg/L	1	–	1	–	0.13	–
00608	Nitrogen ammonia dissolved	mg/L as N	10	9	1	–	0.03	–
00613	Nitrogen, nitrite, dissolved	mg/L as N	9	4	5	E0.005	E0.007	0.009
00618	Nitrogen, nitrate, dissolved	mg/L as N	1	–	1	–	0.17	–
00625	Nitrogen, total organic + ammonia	mg/L as N	10	–	10	0.15	0.635	4.5
00631	Nitrogen, nitrite + nitrate dissolved	mg/L as N	10	2	8	E0.04	0.23	0.91
71846	Ammonia, dissolved	mg/L as NH_4	1	–	1	–	0.03	–
71851	Nitrate, dissolved	mg/L as NO_3	1	–	1	–	0.753	–
71856	Nitrite, dissolved	mg/L as NO_2	2	–	2	0.02	–	0.03
00665	Total phosphorus	mg/L	10	1	9	0.04	0.2	1.87
00666	Phosphorus dissolved	mg/L	9	3	6	E0.02	0.04	0.07
00680	Carbon, organic, total	mg/L	1	–	1	–	2.9	–
00940	Chloride, dissolved	mg/L	1	–	1	–	17.4	–
00945	Sulfate, dissolved	mg/L	1	–	1	–	5.8	–
01027	Total cadmium	μg/L	9	4	5	0.05	0.12	0.35
01042	Total copper	μg/L	9	–	9	3.7	13.1	85.2
01051	Total lead	μg/L	9	2	7	0.54	3.42	25.7
01092	Total zinc	μg/L	9	–	9	6	28	117
45501	Total petroleum hydrocarbons	mg/L	9	7	2	2	–	3
70300	Total dissolved solids	mg/L	9	–	9	44	86	136

Appendix D

Table D1. Geometric means and Hawaii Department of Health criteria for nutrients and total suspended solids in grab samples at Bridge 8.

[Values in **bold** exceed State of Hawaii Department of Health criteria; n, number of samples; Wet Season, November 1 through April 30; Dry Season, May 1 through October 31; all concentrations are in milligrams per liter]

Property or constituent	Season	n	Geometric Mean Concentration		90th Percentile Concentration		98th Percentile Concentration		Sample Date Range
			HDOH Criteria	Value	HDOH Criteria	Value	HDOH Criteria	Value	
Grab Samples									
Nitrogen, nitrite + nitrate, dissolved	Dry	6	0.03	**0.058**	0.09	0.09	0.17	0.09	06/05/01 – 08/04/04
	Wet	5	0.07	**0.144**	0.18	**0.2**	0.3	0.2	01/29/02 – 02/27/04
Total nitrogen	Dry	6	0.18	**0.631**	0.38	**1.4**	0.6	**1.4**	06/05/01 – 08/04/04
	Wet	5	0.25	**1.033**	0.52	**6.3**	0.8	**6.3**	01/29/02 – 02/27/04
Total phosphorus	Dry	6	0.03	**0.125**	0.06	**0.67**	0.08	**0.67**	06/05/01 – 08/04/04
	Wet	5	0.05	**0.208**	0.1	**1.77**	0.15	**1.77**	01/29/02 – 02/27/04
Total suspended solids	Dry	6	10	**70.54**	30	**557**	55	**557**	06/05/01 – 08/04/04
	Wet	5	20	**84.92**	50	**1,170**	80	**1,170**	01/29/02 – 02/27/04

Table D2. Geometric means and Hawaii Department of Health criteria for select nutrients, total suspended solids, and turbidity at Storm Drain C.

[Values in **bold** exceed State of Hawaii Department of Health standards; n, number of samples; Wet Season, November 1 through April 30; Dry Season, May 1 through October 31; all values are in milligrams per liter except Turbidity in Nephelometric Turbidity Units]

Property or constituent	Season	n	Geometric Mean Concentration		90th Percentile Concentration		98th Percentile Concentration		Sample Date Range
			HDOH Criteria	Value	HDOH Criteria	Value	HDOH Criteria	Value	
Grab Samples									
Nitrogen, nitrite + nitrate, dissolved	Dry	7	0.03	**0.1**	0.09	**0.58**	0.17	**0.58**	10/19/99 - 08/04/04
	Wet	13	0.07	**0.09**	0.18	0.17	0.3	**0.55**	11/18/98 - 02/27/04
Total nitrogen	Dry	7	0.18	**0.38**	0.38	**0.7**	0.6	**0.7**	10/19/99 - 08/04/04
	Wet	13	0.25	**0.46**	0.52	**0.95**	0.8	**1.6**	11/18/98 - 02/27/04
Total phosphorus	Dry	7	0.03	**0.06**	0.06	**0.09**	0.08	**0.09**	10/19/99 - 08/04/04
	Wet	13	0.05	**0.07**	0.1	**0.18**	0.15	**0.24**	11/18/98 - 02/27/04
Total suspended solids	Dry	12	10	**12.66**	30	**58**	55	**203**	06/06/99 - 08/04/04
	Wet	26	20	**24.89**	50	**113**	80	**560**	11/18/98 - 02/27/04
Turbidity	Dry	6	2	**4.38**	5.5	**18**	10	**18**	06/06/99 - 10/19/99
	Wet	14	5	**5.24**	15	**21**	25	22	11/18/98 - 01/26/00
Composite Samples									
Nitrogen, nitrite + nitrate, dissolved	Dry	8	0.03	**0.04**	0.09	**0.13**	0.17	0.13	06/15/99 - 08/03/04
	Wet	11	0.07	0.04	0.18	0.07	0.3	0.08	11/04/99 - 02/26/04
Total nitrogen	Dry	8	0.18	**0.42**	0.38	**1.2**	0.6	**1.2**	06/15/99 - 08/03/04
	Wet	11	0.25	**0.33**	0.52	**0.84**	0.8	**1.46**	11/04/99 - 02/26/04
Total phosphorus	Dry	9	0.03	**0.12**	0.06	**0.25**	0.08	**0.25**	06/15/99 - 08/03/04
	Wet	11	0.05	**0.07**	0.1	**0.24**	0.15	**0.38**	11/04/99 - 02/26/04
Total suspended solids	Dry	11	10	**34.96**	30	**86**	55	**103**	06/15/99 - 08/03/04
	Wet	17	20	**27.85**	50	**95**	80	**96**	11/04/99 - 02/26/04
Turbidity	Dry	5	2	**2.81**	5.5	4.9	10	4.9	06/15/99 - 06/07/00
	Wet	5	0.5	**5.53**	15	14	25	14	11/04/99 - 03/26/00

Table D3. Geometric means and Hawaii Department of Health criteria for select nutrients, total suspended solids, and turbidity at Xeriscape Garden.

[Values in **bold** exceed State of Hawaii Department of Health standards; n, number of samples; Wet Season, November 1 through April 30; Dry Season, May 1 through October 31; all values are in milligrams per liter except Turbidity in Nephelometric Turbidity Units; –, not calculated because of small sample size]

Property or constituent	Season	n	Geometric Mean Concentration		90th Percentile Concentration		98th Percentile Concentration		
			HDOH Criteria	Value	HDOH Criteria	Value	HDOH Criteria	Value	Sample Date Range
Grab Samples									
Nitrogen, nitrite + nitrate, dissolved	Dry	9	0.03	**0.057**	0.09	**0.2**	0.17	**0.2**	10/20/99 – 08/04/04
	Wet	13	0.07	**0.094**	0.18	**0.21**	0.3	**0.35**	11/17/98 – 02/27/04
Total nitrogen	Dry	8	0.18	**0.428**	0.38	**1.3**	0.6	**1.3**	07/31/00 – 08/04/04
	Wet	13	0.25	**0.543**	0.52	**2.8**	0.8	**6.7**	11/17/98 – 02/27/04
Total phosphorus	Dry	9	0.03	**0.069**	0.06	**0.5**	0.08	**0.5**	10/20/99 – 08/04/04
	Wet	13	0.05	**0.09**	0.1	**1.02**	0.15	**2.31**	11/17/98 – 02/27/04
Total suspended solids	Dry	12	10	**36**	30	**306**	55	**440**	10/19/99 – 08/04/04
	Wet	20	20	**74**	50	**1,675**	80	**1,930**	11/17/98 – 02/27/04
Turbidity	Dry	5	2	**10**	5.5	**62**	10	**62**	10/19/99 – 07/31/00
	Wet	11	5	**50**	15	**320**	25	**380**	11/17/98 – 01/26/00
Composite Samples									
Nitrogen, nitrite + nitrate, dissolved	Dry	4	0.03	–	0.09	–	0.17	–	09/16/01 – 10/15/02
	Wet	12	0.07	**0.1**	0.18	**0.2**	0.3	0.29	12/01/99 – 02/26/04
Total nitrogen	Dry	4	0.18	–	0.38	–	0.6	–	09/16/01 – 10/15/02
	Wet	12	0.25	**2.97**	0.52	**8.6**	0.8	**14**	12/01/99 – 02/26/04
Total phosphorus	Dry	4	0.03	–	0.06	–	0.08	–	09/16/01 – 10/15/02
	Wet	12	0.05	**0.62**	0.1	**1.75**	0.15	**3.51**	12/01/99 – 02/26/04
Total suspended solids	Dry	9	10	**91**	30	**536**	55	**536**	10/19/99 – 10/15/02
	Wet	25	20	**219**	50	**1,700**	80	**2,420**	11/18/98 – 02/26/04
Turbidity	Dry	5	2	**21.7**	5.5	**27**	10	**27**	10/19/99 – 08/20/00
	Wet	10	5	**67.42**	15	**325**	25	**390**	11/18/98 – 12/01/99

Table D4. Geometric means and Hawaii Department of Health criteria for select nutrients and total suspended solids at Quarantine Station.

[Values in **bold** exceed State of Hawaii Department of Health standards; n, number of samples; Wet Season, November 1 through April 30; Dry Season, May 1 through October 31; all values are in milligrams per liter; –, not calculated because of small sample size]

Property or constituent	Season	n	Geometric Mean Concentration		90th Percentile Concentration		98th Percentile Concentration		Sample Date Range
			HDOH Criteria	Value	HDOH Criteria	Value	HDOH Criteria	Value	
Grab Samples									
Nitrogen, nitrite + nitrate, dissolved	Dry	6	0.03	**0.102**	0.09	**0.26**	0.17	**0.26**	06/05/01 – 08/04/04
	Wet	5	0.07	**0.18**	0.18	**0.24**	0.3	0.24	01/29/02 – 02/27/04
Total nitrogen	Dry	6	0.18	**0.68**	0.38	**1.5**	0.6	**1.5**	06/05/01 – 08/04/04
	Wet	5	0.25	**1.108**	0.52	**4.3**	0.8	**4.3**	01/29/02 – 02/27/04
Total phosphorus	Dry	6	0.03	**0.142**	0.06	**0.53**	0.08	**0.53**	06/05/01 – 08/04/04
	Wet	5	0.05	**0.265**	0.1	**2.06**	0.15	**2.06**	01/29/02 – 02/27/04
Total suspended solids	Dry	6	10	**59.581**	30	**368**	55	**368**	06/05/01 – 08/04/04
	Wet	6	20	**62.921**	50	**769**	80	**769**	01/29/02 – 02/27/04
Composite Samples									
Nitrogen, nitrite + nitrate, dissolved	Dry	2	0.03	–	0.09	–	0.17	–	05/05/02 – 10/15/02
	Wet	5	0.07	**0.125**	0.18	**0.22**	0.3	0.22	01/26/02 – 11/29/03
Total nitrogen	Dry	2	0.18	–	0.38	–	0.6	–	05/05/02 – 10/15/02
	Wet	5	0.25	**4.447**	0.52	**9.9**	0.8	**9.9**	01/26/02 – 11/29/03
Total phosphorus	Dry	2	0.03	–	0.06	–	0.08	–	05/05/02 – 10/15/02
	Wet	5	0.05	**1.185**	0.1	**2.6**	0.15	**2.6**	01/26/02 – 11/29/03
Total suspended solids	Dry	2	10	–	30	–	55	–	05/05/02 – 10/15/02
	Wet	6	20	**675.339**	50	**2,370**	80	**2,370**	01/26/02 – 11/29/03

Table D5. Geometric means and Hawaii Department of Health criteria for select nutrients and total suspended solids at Stadium.

[Values in **bold** exceed State of Hawaii Department of Health standards; n, number of samples; Wet Season, November 1 through April 30; Dry Season, May 1 through October 31; all values are in milligrams per liter]

Property or constituent	Season	n	Geometric Mean Concentration		90th Percentile Concentration		98th Percentile Concentration		Date Range
			HDOH Criteria	Value	HDOH Criteria	Value	HDOH Criteria	Value	
Grab Samples									
Nitrogen, nitrite + nitrate, dissolved	Dry	5	0.03	**0.092**	0.09	**0.43**	0.17	**0.43**	06/05/01 – 08/04/04
	Wet	5	0.07	**0.264**	0.18	**0.91**	0.3	**0.91**	11/17/98 – 02/27/04
Total nitrogen	Dry	5	0.18	**1.147**	0.38	**4.6**	0.6	**4.6**	06/05/01 – 08/04/04
	Wet	5	0.25	**0.879**	0.52	**5.4**	0.8	**5.4**	11/17/98 – 02/27/04
Total phosphorus	Dry	5	0.03	**0.256**	0.06	**1.56**	0.08	**1.56**	06/05/01 – 08/04/04
	Wet	5	0.05	**0.142**	0.1	**1.87**	0.15	**1.87**	11/17/98 – 02/27/04
Total suspended solids	Dry	5	10	**444.578**	30	**5,380**	55	**5,380**	06/05/01 – 08/04/04
	Wet	5	20	**57.63**	50	**1,260**	80	**1,260**	11/17/98 – 02/27/04

Appendix E

Table E1.   Spearman correlation coefficients and associated significance probabilities for storm characteristics at Storm Drain C.

[Upper number is the Spearman correlation coefficient (ρ), lower number is the probability that the null hypothesis of no correlation is true (p); numbers in **bold** have Spearman correlation coefficients greater than 0.5 and significance probabilities less than or equal to 0.05; Spearman correlation coefficients with significance probabilities (p) greater than 0.05 are not shown; significance probabilities less than 0.005 are reported as 0.00; See table 6 for explanation of abbreviated terms]

	VOLtwa	Qtwa	QMax	TOTR	RDUR	VDS	IVOL	OINT	SDUR	SVOLt-wa	sQtwa	SQMax	TOTRs	SRDUR	SVDS
DUR	**0.76**		0.32	**0.78**	**0.98**	**0.9**	0.32		**0.79**	**0.6**	-0.24		**0.65**	**0.78**	**0.72**
	0.00		0.01	0.00	0.00	0.00	0.01		0.00	0.00	0.04		0.00	0.00	0.00
VOLtwa		**0.53**	**0.78**	**0.96**	**0.78**	**0.76**	**0.78**	**0.53**	**0.57**	**0.75**	0.3	**0.57**	**0.79**	**0.61**	**0.57**
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Qtwa			**0.81**	0.47			**0.81**	**1**		0.37	**0.77**	**0.72**	0.35		
			0.00	0.00			0.00	0.00		0.00	0.00	0.00	0.00		
QMax				**0.75**	0.36	0.38	**1**	**0.81**	0.23	**0.62**	**0.61**	**0.81**	**0.58**		0.32
				0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00		0.01
TOTR					**0.81**	**0.78**	**0.75**	0.47	**0.6**	**0.77**	0.29	**0.56**	**0.81**	**0.61**	**0.59**
					0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
RDUR						**0.93**	0.36		**0.77**	**0.62**			**0.67**	**0.79**	**0.75**
						0.00	0.00		0.00	0.00			0.00	0.00	0.00
VDS							0.38		**0.72**	**0.61**			**0.66**	**0.75**	**0.8**
							0.00		0.00	0.00			0.00	0.00	0.00
IVOL								**0.81**	0.23	**0.62**	**0.61**	**0.81**	**0.58**		0.32
								0.00	0.05	0.00	0.00	0.00	0.00		0.01
OINT									0.37	**0.77**	**0.72**	0.35			
									0.00	0.00	0.00	0.00			
SDUR										**0.8**		0.31	**0.77**	**0.93**	**0.9**
										0.00		0.01	0.00	0.00	0.00
SVOLtwa											0.39	**0.74**	**0.92**	**0.76**	**0.75**
											0.00	0.00	0.00	0.00	0.00
sQtwa												**0.75**	0.3		
												0.00	0.01		
SQMax													**0.66**	0.29	0.37
													0.00	0.01	0.00
TOTRs														**0.831**	**0.737**
														0.00	0.00
SRDUR															**0.86**
															0.00

Table E2. Spearman correlation coefficients and associated significance probabilities for the preceding-storm characteristics at Storm Drain C.

[Upper number is the Spearman correlation coefficient (ρ), lower number is the probability that the null hypothesis of no correlation is true (p); numbers in **bold** have Spearman correlation coefficients greater than 0.5 and significance probabilities less than or equal to 0.05; significance probabilities (p) less than 0.005 are reported as 0.00; see table 6 for explanation of abbreviated terms]

	PQtwa	PVOLtwa	POINT	PQMax	PIVOL
PDUR	0.02	**0.87**	0.02	0.45	0.44
	0.88	0.00	0.88	0.00	0.00
PQtwa		0.38	**1**	**0.77**	**0.77**
		0.00	0.00	0.00	0.00
PVOLtwa			0.38	**0.69**	**0.69**
			0.00	0.00	<0.00
POINT				**0.77**	**0.77**
				0.00	0.00
PQMax					**1**
					0.00

Table E3. Simple statistics for constituents used in Spearman Rank Correlation from Storm Drain C.

[n, number of samples; Std Dev, Standard deviation; ROS, regression on statistics; µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; NTU, nephelometric turbidity unit]

Property or constituent	Units	n	Mean	Std Dev	Number of ROS estimated values	Minimum Detected	Median	Maximum Detected
Chemical oxygen demand	mg/L	35	24.2	18.8	10	10	20	80
Nitrogen, nitrite + nitrate, dissolved	mg/L	36	0.1	0.1	10	0.06	0.1	0.55
Nitrogen, ammonia + organic, total	mg/L	37	0.4	0.4	1	0.1	0.3	1.5
Specific conductance	µS/cm at 25°C	25	82.2	57.7	0	25	66	314
Specific conductance, lab	µS/cm at 25°C	50	71.8	44.8	0	28	61	327
Total cadmium	µg/L	36	0.2	0.2	1	0.04	0.1	0.61
Total copper	µg/L	49	25.7	26.9	0	1.4	16.1	136
Total dissolved solids	mg/L	30	39.6	35.1	0	15	27.5	192
Total lead	µg/L	49	8.2	9.1	3	1	5.4	44.4
Total nitrogen	mg/L	36	0.5	0.4	0	0.08	0.4	1.6
Total phosphorus	mg/L	37	0.1	0.1	3	0.06	0.1	0.38
Total suspended solids	mg/L	63	52.7	83	13	10	30	560
Total zinc	µg/L	49	94.1	72.1	0	12	74	290
Turbidity	NTU	30	6.4	5.9	0	1.3	3.8	22

Table E4. Spearman rank correlation coefficients and associated significance probabilities for group A constituents from Storm Drain C.

[The upper number is the Spearman rank correlation coefficients (ρ), the middle number is the probability that the null hypothesis of no correlation is true (p), and the number in parenthesis () is the number of samples used in the calculation; significance probabilities (p) less than 0.005 are reported as 0.00; correlation coefficients in **bold** indicate significance probabilities less than or equal to 0.05]

Property or constituent	Total suspended solids	Total nitrogen	Nitrogen, ammonia + organic, total	Total phosphorus	Total cadmium	Total copper	Total lead	Total zinc
Chemical oxygen demand	**0.66**	**0.64**	**0.72**	**0.67**	**0.68**	**0.68**	**0.69**	**0.77**
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	(35)	(34)	(35)	(35)	(25)	(34)	(34)	(34)
Total suspended solids		**0.72**	**0.82**	**0.79**	**0.88**	**0.88**	**0.84**	**0.86**
		0.00	0.00	0.00	0.00	0.00	0.00	0.00
		(36)	(37)	(37)	(41)	(41)	(41)	(41)
Total nitrogen			**0.89**	**0.79**	**0.58**	**0.73**	**0.74**	**0.77**
			0.00	0.00	0.00	0.00	0.00	0.00
			(36)	(36)	(25)	(35)	(35)	(35)
Nitrogen, ammonia + organic, total				**0.84**	**0.74**	**0.87**	**0.88**	**0.88**
				0.00	0.00	0.00	0.00	0.00
				(37)	(25)	(35)	(35)	(35)
Total phosphorus					**0.88**	**0.88**	**0.9**	**0.85**
					0.00	0.00	0.00	0.00
					(35)	(35)	(35)	(35)
Total cadmium						**0.87**	**0.86**	**0.8**
						0.00	0.00	0.00
						(36)	(36)	(36)
Total copper							**0.97**	**0.91**
							0.00	0.00
							(49)	(49)
Total lead								**0.9**
								0.00
								(49)

Table E5.   Spearman rank correlation coefficients and associated significance probabilities for group B constituents from Storm Drain C.

[The upper number is the Spearman rank correlation coefficient (ρ), the middle number is the probability that the null hypothesis of no correlation is true (p), and the number in parenthesis () is the number of samples used in the calculation; significance probabilities (p) less than 0.005 are reported as 0.00; correlation coefficients in **bold** indicate significance probabilities less than or equal to 0.05; –, not calculated]

Property or constituent	Specific conductance, field	Specific conductance, lab	Total dissolved solids	Turbidity
Nitrogen, nitrite + nitrate, dissolved	**0.82**	**0.79**	**0.77**	0.23
	0.00	0.00	0.00	0.53
	(22)	(36)	(27)	(10)
Specific conductance		**0.98**	**0.96**	**0.67**
		0.00	0.00	0.05
		(23)	(16)	(9)
Specific conductance, lab			**0.92**	**0.63**
			0.00	0.02
			(30)	(13)
Total dissolved solids				–
				–
				(2)

Table E6.   Spearman rank correlation coefficients and associated significance probabilities for composite sample constituents and storm characteristics from Storm Drain C.
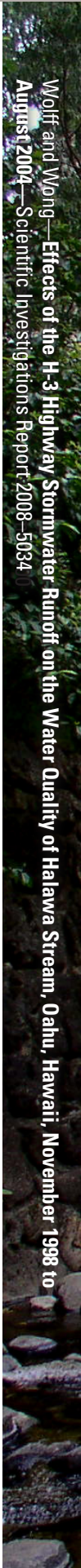
[The upper number is the Spearman rank correlation coefficients (ρ), the middle number is the probability that the null hypothesis of no correlation is true (p), and the number in parenthesis () is the number of samples used in the calculation; significance probabilities (p) less than 0.005 are reported as 0.00; only correlation coefficients with significance probabilities less than or equal to 0.05 are shown; values in **bold** indicate correlation coefficients greater than or equal to 0.50; negative correlation coefficients indicate inverse relationships; see table 6 for explanation of abbreviated terms]

	COD	Specific conductance, (Lab)	Specific conductance, (field)	Total Nitrogen	Nitrogen, ammonia + organic, total	Nitrogen, nitrite + nitrate, dissolved	Total Phosphorus	TSS	TDS	Cu	Pb	Zn	Cd
DUR	–	-0.43	–	–	–	**-0.53**	–	-0.43	**-0.55**	-0.47	-0.49	-0.41	–
	–	0.03	–	–	–	0.02	–	0.04	0.02	0.02	0.01	0.04	–
	–	(24)	–	–	–	(19)	–	(24)	(17)	(24)	(24)	(24)	–
VOLtwa	-0.48	**-0.76**	**-0.85**	-0.49	**-0.51**	**-0.71**	**-0.61**	**-0.54**	**-0.71**	**-0.57**	**-0.67**	**-0.65**	–
	0.04	0.00	0.01	0.03	0.02	0.00	0.01	0.01	0.00	0.00	0.00	0.00	–
	(19)	(24)	(8)	(19)	(19)	(19)	(19)	(24)	(17)	(24)	(24)	(24)	–
Qtwa	–	**-0.63**	**-0.73**	–	–	–	–	–	–	–	–	–	–
	–	0.00	0.04	–	–	–	–	–	–	–	–	–	–
	–	(24)	(8)	–	–	–	–	–	–	–	–	–	–
QMax	–	**-0.79**	**-0.83**	–	–	**-0.5**	–	–	**-0.6**	–	**-0.5**	-0.47	–
	–	0.00	0.01	–	–	0.03	–	–	0.01	–	0.01	0.02	–
	–	(24)	(8)	–	–	(19)	–	–	(17)	–	(24)	(24)	–
TOTR	–	**-0.76**	**-0.9**	-0.49	**-0.51**	**-0.64**	**-0.65**	**-0.55**	**-0.72**	**-0.63**	**-0.72**	**-0.66**	–
	–	0.00	0.00	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	–
	–	(24)	(8)	(19)	(19)	(19)	(19)	(24)	(17)	(24)	(24)	(24)	–
RDUR	–	**-0.5**	–	–	–	–	**-0.56**	-0.49	–	**-0.56**	**-0.57**	-0.49	–
	–	0.01	–	–	–	–	0.01	0.02	–	0.00	0.00	0.01	–
	–	(24)	–	–	–	–	(19)	(24)	–	(24)	(24)	(24)	–
VDS	–	–	–	–	–	–	–	–	–	-0.44	-0.43	–	–
	–	–	–	–	–	–	–	–	–	0.03	0.04	–	–
	–	–	–	–	–	–	–	–	–	(24)	(24)	–	–
IVOL	–	**-0.79**	**-0.83**	–	–	**-0.5**	–	–	**-0.6**	–	**-0.5**	-0.46	–
	–	0.00	0.01	–	–	0.03	–	–	0.01	–	0.01	0.02	–
	–	(24)	(8)	–	–	(19)	–	–	(17)	–	(24)	(24)	–
OINT	–	**-0.63**	**-0.73**	–	–	–	–	–	–	–	–	–	–
	–	0.00	0.04	–	–	–	–	–	–	–	–	–	–
	–	(24)	(8)	–	–	–	–	–	–	–	–	–	–
SDUR	**-0.54**	-0.48	–	–	–	**-0.67**	**-0.56**	-0.41	**-0.59**		–	-0.47	**-0.5**	–
	0.02	0.02	–	–	–	0.00	0.01	0.04	0.01		0.02	0.01	–
	(19)	(24)	–	–	–	(19)	(19)	(24)	(17)		(24)	(24)	–
SVOLtwa	**-0.64**	**-0.78**	**-0.83**	**-0.56**	**-0.58**	**-0.64**	**-0.71**	**-0.56**	**-0.64**	**-0.51**	**-0.65**	**-0.67**	–
	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.00	–
	(19)	(24)	(8)	(19)	(19)	(19)	(19)	(24)	(17)	(24)	(24)	(24)	–
sQtwa	–	**-0.6**	–	–	–	–	–	–	–	–	-0.45	-0.41	–
	–	0.00	–	–	–	–	–	–	–	–	0.03	0.05	–
	–	(24)	–	–	–	–	–	–	–	–	(24)	(24)	–
SQMax	-0.48	**-0.78**	**-0.87**	–	–	**-0.53**	**-0.54**	–	**-0.6**	–	**-0.53**	-0.48	–
	0.04	0.00	0.00	–	–	0.02	0.02	–	0.01	–	0.01	0.02	–
	(19)	(24)	(8)	–	–	(19)	(19)	–	(17)	–	(24)	(24)	–
TOTRs	**-0.54**	**-0.77**	**-0.85**	–	–	**-0.52**	**-0.61**	**-0.56**	**-0.58**	**-0.5**	**-0.64**	**-0.61**	–
	0.02	0.00	0.01	–	–	0.03	0.01	0.00	0.02	0.01	0.00	0.00	–
	(18)	(23)	(8)	–	–	(18)	(18)	(23)	(16)	(16)	(23)	(23)	–
RsDUR	–	-0.42	–	–	–	**-0.68**	–	–	**-0.53**	–	–	-0.47	–
	–	0.04	–	–	–	0.00	–	–	0.04	–	–	0.02	–
	–	(23)	–	–	–	(18)	–	–	(16)	–	–	(23)	–
SVDS	–	-0.43	–	–	–	**-0.51**	-0.45	–	–	–	–	–	–
	–	0.03	–	–	–	0.03	0.05	–	–	–	–	–	–
	–	(24)	–	–	–	(19)	(19)	–	–	–	–	–	–

Table E6. Spearman rank correlation coefficients and associated significance probabilities for composite sample constituents and storm characteristics from Storm Drain C—Continued.

[The upper number is the Spearman rank correlation coefficients (ρ), the middle number is the probability that the null hypothesis of no correlation is true (p), and the number in parenthesis () is the number of samples used in the calculation; significance probabilities (p) less than 0.005 are reported as 0.00; only correlation coefficients with significance probabilities less than or equal to 0.05 are shown; values in **bold** indicate correlation coefficients greater than or equal to 0.50; negative correlation coefficients indicate inverse relationships; see table 6 for explanation of abbreviated terms]

	COD	Specific conductance, (Lab)	Specific conductance, (field)	Total Nitrogen	Nitrogen, ammonia + organic, total	Nitrogen, nitrite + nitrate, dissolved	Total Phosphorus	TSS	TDS	Cu	Pb	Zn	Cd
PDUR	**-0.59**	–	–	–	–	–	–	-0.44	–	–	–	-0.43	–
	0.01	–	–	–	–	–	–	0.03	–	–	–	0.03	–
	(19)	–	–	–	–	–	–	–	–	–	–	(24)	–
PVOLtwa	**-0.56**	–	–	–	–	–	–	-0.42	–	–	–	–	**-0.53**
	0.01	–	–	–	–	–	–	0.04	–	–	–	–	0.03
	(19)	–	–	–	–	–	–	–	–	–	–	–	(16)
SQmaxP	-0.46	–	–	–	–	**-0.65**	–	–	–	–	–	–	–
	0.04	–	–	–	–	0.00	–	–	–	–	–	–	–
	(19)	–	–	–	–	(19)	–	–	–	–	–	–	–