WATER-QUALITY CHARACTERISTICS OF URBAN RUNOFF AND ESTIMATES OF ANNUAL LOADS IN THE TAMPA BAY AREA, FLORIDA, 1975-80

By M. A. Lopez and R. F. Giovannelli

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ABBREVIATIONS AND CONVERSION FACTORS

Factors for converting inch-pound units to International System of Units (SI) and abbreviation of units

Multiply	By	To obtain
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
acre	0.4047	hectare (ha)
pound (lb)	0.4536	kilogram (kg)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
degree Fahrenheit (°F)	(°F-32)/1.8	degree Celsius (°C)
micromho per centimeter at 25°C (umho/cm at 25°C)	1.000	microsiemen per centimeter at 25°C (uS/cm at 25°C)

* * * * * * * * * * * * * *

National Geodetic Vertical Datum of 1929 (NGVD of 1929).--A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in the text of this report.

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WATER-QUALITY CHARACTERISTICS OF URBAN RUNOFF AND ESTIMATES OF ANNUAL LOADS IN THE TAMPA BAY AREA, FLORIDA, 1975-80

By M. A. Lopez and R. F. Giovannelli

ABSTRACT

Rainfall, runoff, and water-quality data were collected at nine urban watersheds in the Tampa Bay area of west-central Florida from 1975 to 1980. Watershed drainage area ranged from 0.34 to 3.45 square miles. Land use was mixed. Development ranged from a mostly residential watershed with 19 percent impervious surface to a commercial-residential watershed with 61 percent impervious surface. Average biochemical oxygen demand concentrations of base flow at two sites and of stormwater runoff at five sites exceeded treated sewage effluent standards. Average coliform concentrations of stormwater runoff at all sites were several orders of magnitude greater than standards for Florida Class III receiving water (for recreation or propagation and management of fish and wildlife). Average concentrations of lead and zinc in stormwater runoff were consistantly higher than Class III standards. Generally, turbidity and constituent concentrations were higher for rising stages than for falling stages; the contrast between rising and falling stages was greatest for watersheds with highly developed street drainage and sewer systems.

Stormwater-runoff loads and base-flow concentrations of biochemical oxygen demand, chemical oxygen demand, total nitrogen, total organic nitrogen, total phosphorus, and lead were related to runoff volume, land use, urban development, and antecedent daily rainfall by multiple linear regression. Standard error of estimate for the stormwater-runoff load equation ranged from ±41 percent of the mean for chemical oxygen demand to ±65 percent of the mean for total organic nitrogen. Standard error of estimate for the base-flow concentration equation ranged from ±33 percent for chemical oxygen demand to ±60 percent for biochemical oxygen demand.

Stormwater-runoff volume was related to pervious area, hydraulically connected impervious surfaces, storm rainfall, and soil-infiltration index. The regression equation for volume had an average standard error of ±20 percent and correlation coefficient of 0.93. Base-flow daily discharge was related to drainage area and antecedent daily rainfall; the regression equation has a standard error of ±45 percent and a correlation coefficient of 0.94.

The flow regression equations of this report were used to compute 1979 water-year loads of biochemical oxygen demand, chemical oxygen demand, total nitrogen, total organic nitrogen, total phosphorus, and total lead for the nine Tampa Bay area urban watersheds. The computed loads were compared with loads derived by use of land-use load factors applicable to urban areas in Broward County, Florida. Results obtained by the two methods differed appreciably in most instances, but were of the same order of magnitude. A similar comparison was made of loads computed by use of the screening procedure formulated by the

U.S. Environmental Protection Agency. Annual loads of total nitrogen, biochemical oxygen demand, and total phosphorus were estimated for one of the Tampa Bay area watersheds (St. Louis Street drainage ditch). Loads computed by the screening procedure were about the same as the loads computed by the Tampa Bay area regression equations for total nitrogen, about twice as great for biochemical oxygen demand, and about an order of magnitude smaller for total phorphorus. The Tampa Bay area regression equations presumably reflect the natural high phosphorus content of streamflow in the Tampa Bay area and the fallout from phosphate processing plants on the east shore of Tampa Bay.

INTRODUCTION

Urbanization is the process of constructing roads, houses, and commercial and industrial developments on land that was once in a natural state or rural condition. The major effects of urbanization on water resources are reduced infiltration, increased flood potential, and degradation of the quality of receiving bodies of water. Trash and litter deposited on streets and parking lots, erosion of exposed ground due to construction, lawn and landscape maintenance, domestic pet litter, automobile emissions, and atmospheric deposition from industrial and thermoelectric plants have been identified as sources of urban stormwater loads. These sources of generally distributed substances are grouped together under the classification of nonpoint to distinguish them from the more readily identifiable industrial and domestic sewage plant effluents that are called point sources.

The materials from nonpoint sources are concentrated by stormwater-collection systems and transported to the receiving waterbodies. The extent to which these materials affect the quality of water for various uses generally is appraised by measurement of a suite of water-quality characteristics that describe the condition of the water. Some of the commonly measured characteristics are: temperature, turbidity, specific conductance, biochemical oxygen demand, chemical oxygen demand, coliform count, and concentration of chemical constituents. The substances of primary concern because of their impact on water quality are: (1) material related to suspended solids, (2) oxygen-demanding material, (3) nutrients, (4) bacteria, (5) organics (pesticides and other organic toxics), and (6) trace elements (toxics). The impacts of the first five are the most obvious --turbidity that inhibits light penetration, depletion of dissolved oxygen that can result in fish kills, enrichment that accelerates the growth of nuisance plants, the presence of pathogens that restrict contact sports and harvesting of certain types of shellfish, and fish kills caused by insecticides or herbicides. The impacts of trace elements on receiving waterbodies are not immediately noticed and may not be noticed for years unless these elements are in the dissolved phase.

Assessment of the urban runoff problem requires extensive data collection and analysis of information on land use, rainfall, runoff rates and volumes, and water quality. Late in 1974, the U.S. Geological Survey in cooperation with the Southwest Florida Water Management District, Hillsborough County, Pinellas County, and the cities of Tampa, St. Petersburg, and Clearwater initiated a study to determine the effect of urban development on the quality and quantity of stormwater and base-flow runoff in the Tampa Bay area. The objectives of the study were to: (1) assess the quantity and quality of runoff, and (2) relate quantity and quality of runoff to land use and intensity of development.

A detailed description of the study area, procedures for selection of watersheds, data-collection sites, data-collection techniques, and a tabulation of data processed through September 30, 1976, are included in a report by Lopez and Michaelis (1979).

PURPOSE AND SCOPE

The purpose of this report is to describe the water-quality characteristics of urban runoff in the Tampa Bay area and to provide a method for estimating loads of substances contained in runoff from urbanized watersheds under existing and future conditions. A report by Lopez and Woodham (1982) describes procedures for estimating flood-peak discharges on small urban watersheds in the Tampa Bay area.

From 1975 to 1980, an urban-runoff data-collection program, including streamflow, climatic, physiographic, and water-quality data, was established at nine watersheds ranging from beginning to advanced stages of urban development. Gaging stations were installed to monitor rainfall and runoff for each watershed. Physiographic features that consist of size, shape, and slope of the watershed, type of land use, degree of land use, area of impervious surfaces, type of storm drainage, soil types, and surface area of lakes or detention ponds were compiled from aerial photographs, U.S. Geological Survey topographic maps, planning agency data, and field observations.

Water-quality samples were collected during storms to determine the variation of water quality within and among individual storms and watersheds. Most samples were obtained during the wet-season months of July through September when the frequency of storms was highest. Base-flow samples were collected to provide data for determining loads of various substances transported between periods of stormwater runoff.

AREA DESCRIPTION

The study area, referred to as the Tampa Bay area, includes Hillsborough and Pinellas Counties in west-central Florida (fig. 1). Major cities include Tampa, St. Petersburg, and Clearwater. The land area and population of each county and city are listed below (Thompson, 1977; Florida Department of Commerce, 1980):

Name	Area (mi^2)	Population (1979)
Hillsborough County	1,038	634,469
Pinellas County	265	725,457
City of Tampa	84.5	275,686
City of St. Petersburg	55.4	240,427
City of Clearwater	22.4	82,905

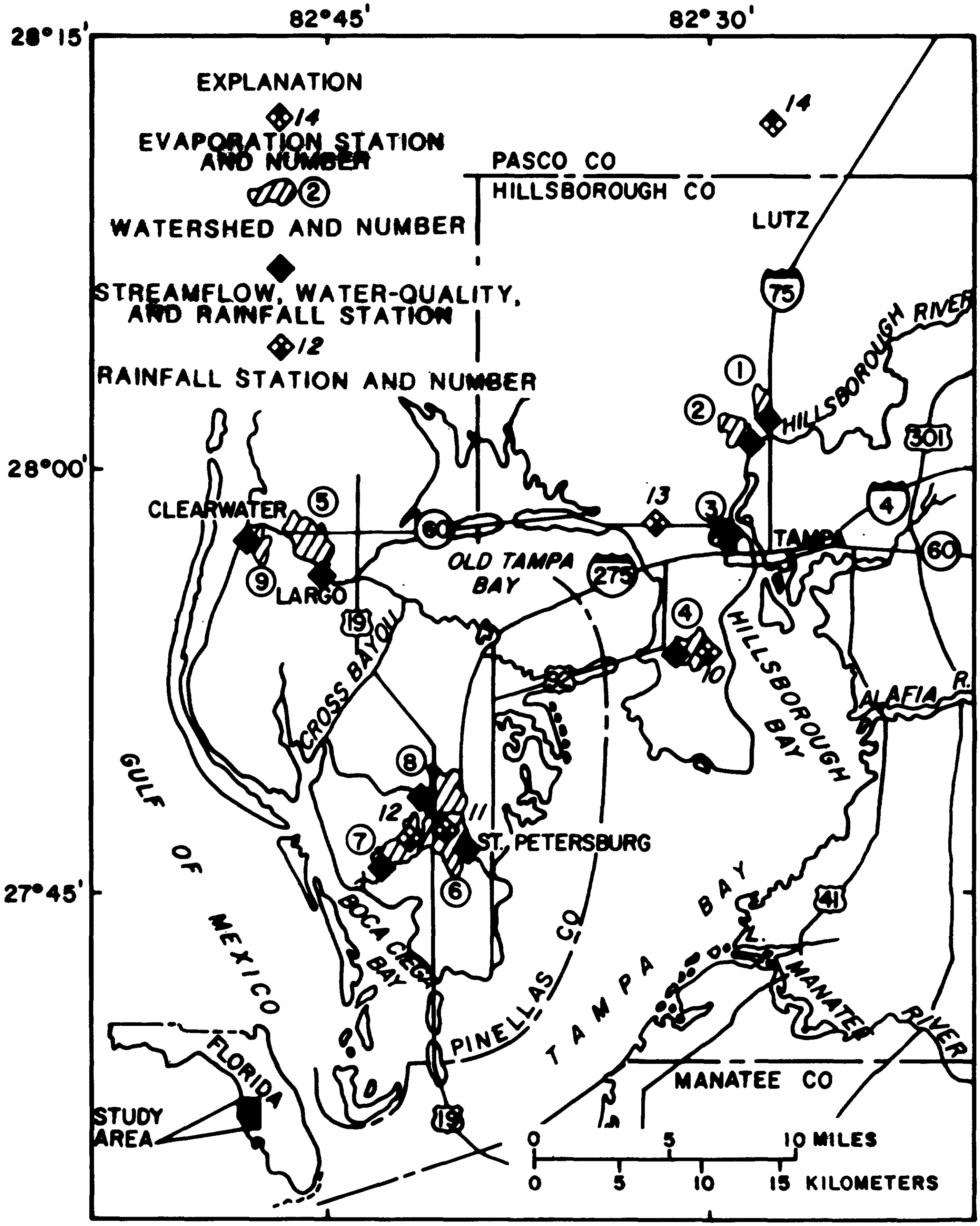

Figure 1.--Location of study area and data-collection sites.

The city of Tampa is the largest city in Hillsborough County and contains nearly 45 percent of the county population while occupying less than 10 percent of the county land area. The cities of Clearwater and St. Petersburg are the two largest cities in Pinellas County and contain approximately 45 percent of the county population.

Parts of Pinellas and Hillsborough Counties, particularly in the cities of Tampa, St. Petersburg, and Clearwater, are heavily urbanized. Urban developments are expanding in many other areas of both counties; expansions are planned for the other areas. The growth rates in the study area are among the highest in Florida and the nation. Land use in Pinellas County and the cities of Tampa, St. Petersburg, and Clearwater is primarily residential and commercial. Major land uses in unincorporated Hillsborough County are residential, agricultural, and strip mining (Tampa Bay Regional Planning Council, 1977). The region's major heavy industrial activity, including several phosphate rock processing and shipping facilities, is centered around the eastern side of Hillsborough Bay. Light industry is scattered throughout both counties. For the most part, large chemical plants, breweries, packing houses, and other industries are confined to zoned industrial areas. The present tendency is for industrial development of the bay shoreline areas.

Land Features

The natural shoreline of the Gulf of Mexico consists of many small bays, inlets, and marshlands drained by tributary streams. Low, narrow barrier islands extend north from the entrance to Tampa Bay and shelter much of the shoreline. Tampa Bay consists of Tampa Bay, Old Tampa Bay, and Hillsborough Bay (fig. 1). The Hillsborough River is the largest stream draining the region and discharges into Hillsborough Bay. There are many smaller streams in Hillsborough and Pinellas Counties that also discharge into Tampa Bay or the Gulf of Mexico.

The main topographic features are broad, coastal lowlands with altitudes ranging from sea level to 20 feet above sea level and inland areas of intermediate relief with altitudes ranging from 20 to 75 feet above sea level (Geraghty and Miller, 1976).

Geology

Hillsborough and Pinellas Counties are underlain by Pleistocene to Holocene sands that comprise the surficial aquifer wherein the water table in most places is 5 to 10 feet below land surface. The structure and composition of the overlying soils differ from place to place and influence the amount of runoff, accordingly. The capacity of soil to receive, store, and transmit water can be expressed by a soil-infiltration index--the maximum infiltration, in inches, that can occur under average soil-moisture conditions. The index can be determined from runoff curve numbers as explained in the National Engineering Handbook, Hydrology, Section 4, page 10.6a (U.S. Department of Agriculture, 1972). A map (from Seijo and others, 1979) showing soil-infiltration index values, modified from an unpublished map compiled by the Soil Conservation Service, is shown in figure 2.

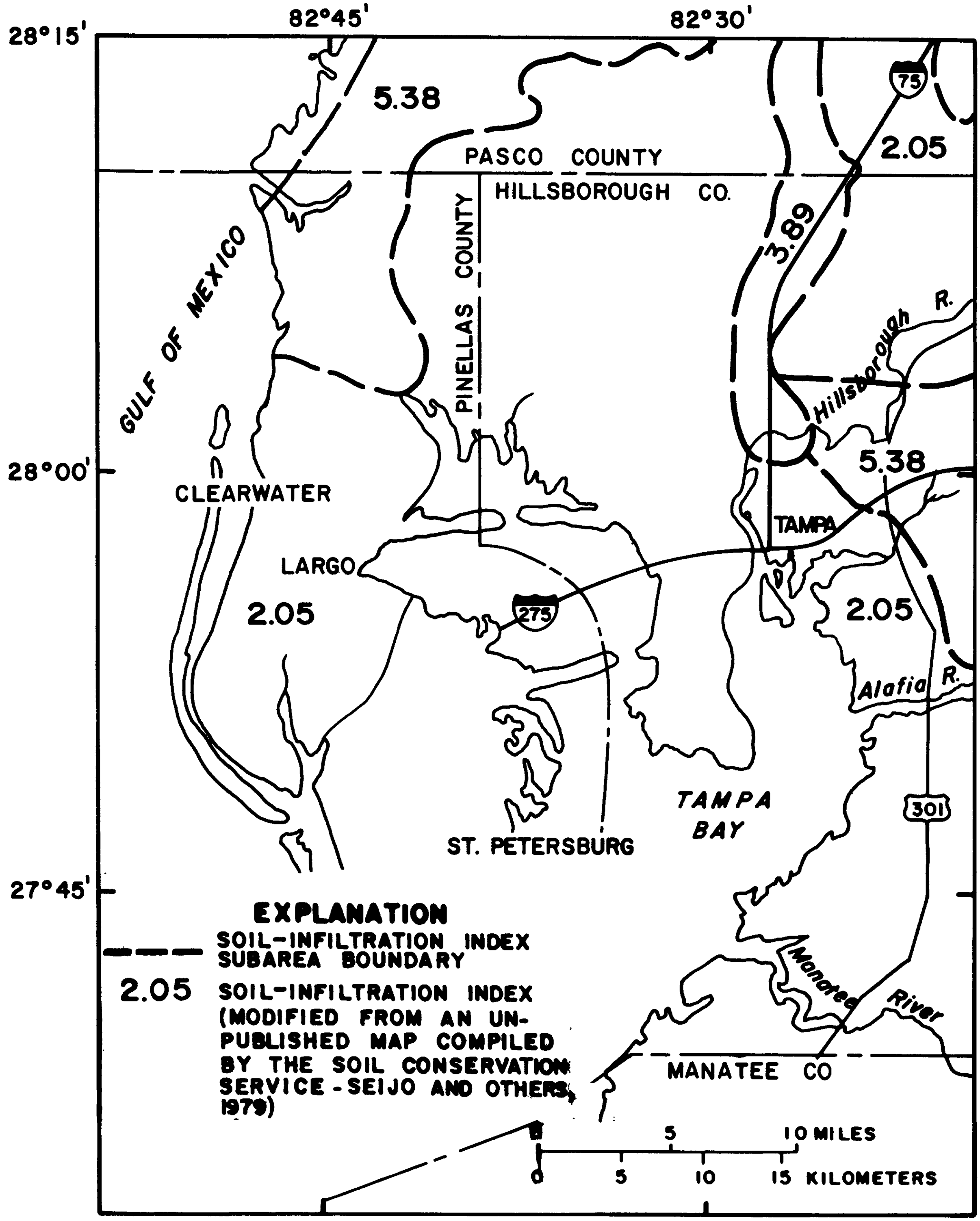

Figure 2.--Soil-infiltration index values for Tampa Bay area.

The overlying soils in areas extending north and east of Tampa are generally fine grained and highly permeable (Florida Department of Administration, 1975). Much of the rainfall in these areas where the indexes are 3.89 and 5.38, respectively, infiltrates rapidly; a large part of surface runoff enters sinkholes or depression areas. In other parts of the study area where the index is 2.05 or less, rocks and soils tend to be less pervious, and surface runoff moves more rapidly from these areas into stream channels or drainage ditches.

Urban Development

Urbanization of Tampa Bay area watersheds includes residential developments with paved streets drained by storm-sewer systems and commercial centers and industrial parks with large paved parking lots. The impervious surfaces in urban watersheds include roads, sidewalks, driveways, roofs, and parking lots. Residential developments have different types of density patterns. Homes in older urban developments are generally smaller and close together, whereas homes in recent suburban developments are larger but are farther apart and thus occupy a smaller percentage of the development. Multifamily residential developments have a high percentage of impervious surface because of parking lots associated with apartment complexes.

As urbanization increases, the area of impervious surface and the volume of stormwater runoff increase, but the time necessary for runoff to occur (time of concentration) decreases due to channel improvements. Generally, residential roofs are not directly connected to the storm-drainage system, and runoff from them flows over pervious areas before reaching the storm-drainage system. Roofs of commercial or industrial buildings usually drain onto paved parking lots that have storm-sewer inlets directly connected to the drainage system. Some of the stormwater runoff from roofs or impervious surfaces that are not directly connected to storm sewers or drainage channels is detained as depression storage. In these cases, considerable infiltration and evaporation may occur before overland flow enters a storm-drainage system. Only a small amount of rain that falls on impervious surfaces that are directly connected to a storm-drainage system is retained for surface wetting and depression storage.

Watershed and drainage-system features also affect quality of runoff. Substances accummulated on paved surfaces that are directly connected to storm-drainage systems wash off easily during initial phases of a storm. This results in high concentrations of these substances in runoff at the beginning of a storm and decreasing concentrations as runoff continues. Substances adsorbed to or attached to particulate matter that are evenly distributed in a watershed that has a relatively small area of directly connected impervious surface tend to wash off and move into the stormwater-drainage system at rates proportional to flow velocity; the highest concentrations generally occurring near peak discharge.

Climate

The climate of the Tampa Bay area is characterized by warm, humid summers and mild winters. Temperatures during the summer range from about 70° to 90°F and winter temperatures range from about 32° to 70°F. The normal annual precipitation as recorded at Tampa is about 51 inches. Annual precipitation fluctuates widely. The lowest yearly total recorded as of 1980 is 28.89 inches, occurring in 1956; the highest is 76.67 inches, occurring in 1959 (Wright, 1974). Most rainfall occurs from June through September as a result of short duration, high intensity, afternoon or evening thundershowers. Rainfall in the fall, winter, and spring generally occurs from less frequent, long duration, frontal-type storms. Hurricanes, tropical storms, and tropical depressions produce heavy rainfall at irregular intervals.

DATA COLLECTION

Nine urban watersheds were selected for the study (fig. 1). Four of these are in the city of Tampa, Hillsborough County, and five are in Pinellas County: three in the city of St. Petersburg, one in the city of Clearwater, and one near the town of Largo, south of Clearwater (fig. 1).

Watershed Features

Land Use

Drainage areas of the selected watersheds range in size from 0.34 to 3.45 mi^2. Drainage areas and land use were field-verified in 1980 and were revised for Kirby Street, Allen Creek, Booker Creek, and Turner Street watersheds. Drainage-area and land-use percentages for these watersheds supercede data published in an earlier data report (Lopez and Michaelis, 1979). Each contains a different mixture of residential, commercial, industrial, and undeveloped areas that is typical of urban development in other parts of the Tampa Bay area. Two of the watersheds (Artic Street storm drain and Kirby Street drainage ditch) have a soil-infiltration index of 3.89 inches. The remaining selected watersheds have a soil-infiltration index of 2.05 inches. Watershed features and land-use characteristics as listed in table 1 are:

Drainage area.--Area, in square miles, planimetered from U.S. Geological Survey 7-1/2-minute series topographic maps. Watershed boundaries were delineated on topographic maps; natural divides were modified to include or exclude areas where storm sewers crossed the natural divides, based on information from city and county agencies.

Population density.--The number of persons per acre computed by dividing the population within the watershed boundary by the watershed area, in acres. Population was estimated for the period of runoff record from 1970 census data.

Land use

Roads.--Percentage of watershed area covered by paved roads;

Single-family residential.--Percentage of watershed area covered by single-family homes;

Multifamily residential.--Percentage of the watershed area covered by multifamily homes or apartments;

Commercial.--Percentage of the watershed area covered by commercial buildings and associated parking lots;

Table 1.--Watershed characteristics

Site no. (fig. 1)	Station number and name	Drainage area, in square miles	Population density, in persons per acre	Land use, in percentage of total area							
				Roads	Single-family residential	Multifamily residential	Commercial	Industrial	Institutional	Recreational	Open space
1	02306002 Artic Street storm drain at Tampa, Fla.	0.34	6.6	14.7	46.2	0	36.5	0	1.5	0	1.1
2	02306006 Kirby Street drainage ditch at Tampa, Fla.	1.40[1]	6.8	4.4	69.0	3.3	4.5	0	2.2	1.0	15.6
3	02306021 St. Louis Street drainage ditch at Tampa, Fla.	.51	8.2	11.8	68.1	0	3.3	0	6.5	2.3	8.0
4	02306071 Gandy Boulevard drainage ditch at Tampa, Fla.	1.29	5.7	8.5	31.6	5.1	21.0	0	3.9	5.6	24.3
5	02307731 Allen Creek near Largo, Fla.	1.79[1]	6.9	10.3	59.0	3.9	7.0	0	7.9	.5	11.4
6	02308193 Booker Creek at St. Petersburg, Fla.	3.45[1]	5.8	12.3	48.8	1.7	18.1	4.4	3.0	2.7	9.0
7	02308773 Bear Creek at St. Petersburg, Fla.	1.89	6.9	12.8	66.1	4.3	5.8	0	5.5	1.0	4.5
8	02308929 Saint Joes Creek at St. Petersburg, Fla.	1.72	5.3	12.0	47.7	.1	16.2	7.7	1.8	1.9	12.6
9	02309160 Turner Street storm at Clearwater, Fla.	.45[1]	6.9	12.7[1]	37.4[1]	1.4[1]	28.0[1]	20.0[1]	.4[1]	0	.1[1]

[1]Revised in 1980.

Industrial.--Percentage of the watershed area covered by industrial buildings and associated parking lots;

Institutional.--Percentage of the watershed area covered by public institutions and surrounding grounds, such as schools, colleges, hospitals, and clinics;

Recreational.--Percentage of the watershed area covered by recreational facilities, such as parks, ball fields, basketball courts, and tennis courts;

Open space.--Percentage of the watershed area covered by unused, undeveloped, or agricultural land.

Urban-Development Characteristics

As land use in a watershed changes from natural or agricultural to urban, the nature of the drainage system and the land surface of the contributing drainage area also change. Channels are altered by realinement or paving and ultimately may be fully enclosed. Realinement often shortens the channel length and increases the channel slope. Paved streets with curb and gutter replace dirt roads and roadside ditches. Depressions, ponds, and lakes are connected to the drainage system to regulate stormwater runoff. Areas taken up by impervious surfaces, such as roads, parking lots, roofs, sidewalks, and driveways, increase as urban development continues.

The average and range in percent of watershed area covered by impervious surfaces for various land-use types in the study area are as follows:

Land-use type	Impervious surface as percentage of watershed area	
	Average	Range
Single-family residential		
Low-density (1/2 to 2 acres per dwelling)	10	3-14
Medium-density (1/8 to 1/3 acre per dwelling)	20	15-22
Multifamily residential	41	30-68
Commercial	64	35-98
Industrial	50	30-65
Institutional	2	0-5.0
Recreational	1	0-3.5
Open space	0	-

Residential developments having different densities or house and lot sizes were evaluated separately. All watersheds studied had at least two different patterns of residential density. The older homes were smaller and closer together, whereas in more recent developments, homes were larger and farther apart. Apartment buildings had the highest percentage of impervious surface for residential land use because paved parking lots were included.

Impervious surfaces for commercial, industrial, and institutional land uses were highly variable and were, therefore, evaluated separately. High schools had large parking lots and, therefore, larger impervious surfaces than elementary and junior high schools.

Urban-development characteristics for each watershed studied are listed in table 2. The drainage-system characteristics (prevalent channel type and prevalent street drainage type) are tabulated for the upper, middle, and lower third of each watershed. The prevalent channel and street drainage types are assigned index numbers as explained in the footnotes to table 2.

Basin-development factor (BDF) is the sum of all street and channel index numbers. Values of BDF can vary from zero to 12. A value of zero does not necessarily mean the watershed is completely natural because watersheds that have all index numbers of zero may have some housing, streets, and other developmental features that create impervious surfaces. BDF was found to be highly significant in previous studies of urban flood-peak discharge (Sauer and others, 1981).

Main channel length, in miles, is measured from the streamflow station to the watershed boundary along the main channel.

Channel slope, in feet per mile, is measured between points 10 and 85 percent of the distance from the streamflow station to the watershed boundary.

Detention storage (DETA) is the surface area of natural lakes or ponds, detention basins, and retention basins measured from aerial photographs or topographic maps and listed as a percentage of the watershed-drainage area.

Total impervious surface (TIA) is the area of all impervious surfaces determined for each watershed and type of land use by measurement of road, sidewalk, driveway, parking lot, and roof surfaces on aerial photographs, expressed as a percentage of watershed-drainage area.

Hydraulically connected impervious surface (HCIA) is the characteristic described by Miller (1979) as the area of hydraulically effective impervious surfaces. The hydraulically connected impervious surface was computed by adding only the area of those roofs, streets, and paved surfaces that are directly connected to a storm drain or a street with curb and gutter drainage leading to a storm drain. The storm drain can be a sewer pipe or drainage ditch. HCIA was determined from aerial photographs and storm-drainage plans. Residential and commercial areas were selectively field verified. The amount of hydraulically connected impervious surface is expressed as a percentage of the watershed-drainage area.

Rainfall and Runoff

Rainfall, stream-stage, and discharge data were collected at each study site from 1975 to 1980. Rainfall and stage data were recorded at 5-minute intervals. Rainfall was recorded to the nearest 0.01 inch. Daily rainfall for periods of missing record was estimated from rainfall records for nearby gages. Stream stages were recorded to the nearest 0.01 foot; discharge was determined from stage-discharge relations based on discharge measurements.

Table 2.--Urban-development characteristics

Site no. (fig. 1)	Prevalent channel type 1/			Prevalent street drainage type 2/			Basin development factor 3/
	Upper third	Middle third	Lower third	Upper third	Middle third	Lower third	
1	3	3	3	1	1	1	12
2	1	1	1	0	0	0	3
3	3	3	3	1	1	1	12
4	3	2	2	0	1	1	9
5	3	1	1	1	1	1	8
6	3	2	3	1	0	1	10
7	3	3	2	1	1	1	11
8	3	3	2	1	1	0	10
9	3	3	3	1	1	1	12

Site no. (fig. 1)	Main channel		Detention storage area, in percentage of drainage area	Impervious surface, in percentage of drainage area	
	Length, in miles	Slope, in feet per mile		Total	Hydraulically connected
1	1.25	12.3	0	61	53
2	2.40	8.1	3.5	19	5.5
3	1.12	10.2	0	27	9.0
4	1.63	4.6	.9	38	28
5	1.40	23.4	.9	36	26
6	3.20	7.1	.9	41	26
7	3.79	12.1	2.6	32	25
8	1.48	5.5	.4	38	26
9	1.06	23.6	.4	48	33

Note: None of the watersheds had natural channels.

1/ Channel type index numbers: 0 = natural; 1 = improved; 2 = paved; 3 = enclosed in box or pipe.

2/ Street drainage type index numbers: 0 = swale or ditch drainage; 1 = curb and gutter drainage.

3/ Basin development factor: equal to sum of channel and street drainage type index numbers for entire basin.

Criteria used in selecting sites for rain gages and stage recorders, types and descriptions of the instrumentation, density of the gages, and the processing and storage of the data are discussed in Lopez and Michaelis (1979).

Water Quality

Water-quality data were collected for a wide range of constituents from July 1975 to May 1980. During the period July to October 1975, all sites were intensively sampled to obtain background data. A less intensified sampling schedule was designed subsequently, using results of background data and recommendations of the Tampa Bay Regional Planning Council (1977) for water-quality characteristics associated with pollution problems in urbanized areas of west-central Florida.

The water-quality sampling program was designed to define temporal and spatial variations in various characteristics, such as variations within and between storms and among watersheds with different levels of development. Samples were also collected during periods of base flow to examine differences in quality between stormwater runoff and base flow. Most samples of stormwater runoff were obtained during the wet season, June through September. The short-duration, high-intensity rainfall associated with thunderstorms during the wet season produced well-defined periods of stormwater runoff. The distinction between stormwater runoff and base flow was less apparent during the fall, winter, and spring when rainfall generally was less intense and of longer duration.

Streamflow samples were collected manually at selected time intervals during periods of stormwater runoff to define variations in water quality. Samples for rising stages were taken at relatively short intervals to define flushing characteristics of the watersheds. Samples for falling stages were obtained at longer time intervals. The samples provided data necessary in determining total stormwater-runoff loads. Collection of samples from base flow to peak flow to base flow was not always possible for all storms because of the unpredictable nature of rainfall from thunderstorms. Surveillance methods, including a local radar weather service, were used in attempts to obtain advance notice of possible storms suitable for sampling (Lopez and Michaelis, 1979).

All samples were analyzed using standard analytical techniques described by Skougstad and others (1979) and Standard Methods for the Examination of Water and Wastewater by the American Public Health Association and others (1976). Two methods were used to determine coliform concentrations, including the multiple-tube fermentation test and the membrane-filter technique. Results of the multiple-tube fermentation tests are expressed as "most probable number" (MPN), an index of the probable number of coliform bacteria per 100 milliliters. This test does not give an actual bacteria count. The membrane-filter technique provides a measure of coliform densities in a given volume of water (colonies per 100 milliliters). In most cases, results of the multiple-tube fermentation test and the membrane-filter technique are similar.

Water-quality characteristics analyzed are listed in table 3 for both water and bottom material samples. Total and dissolved concentrations were obtained for nutrients and most trace elements, and dissolved concentrations only were determined for the major ions.

Table 3.--Water-quality characteristics and number of samples analyzed for each

Water-quality characteristics	Number of samples		
	Water		Bottom material
	Unfiltered	Filtered	
Physical:			
Temperature	80	--	-
Turbidity	118	--	-
Specific conductance	60	--	-
Color	28	--	-
Chemical:			
Biochemical oxygen demand	203	--	-
Chemical oxygen demand	197	--	7
Alkalinity	28	--	-
Bicarbonate	28	--	-
Carbonate	26	--	-
Hardness	28	--	-
Noncarbonate hardness	28	--	-
Carbon:			
Organic carbon	166	5	7
Inorganic carbon	63	--	7
Major nutrients:			
Nitrogen	145	--	-
Organic	214	2	-
Ammonia	178	38	-
Nitrite	177	38	-
Nitrate	178	38	-
Phosphorus	214	38	7
Orthophosphate	178	38	-
Bacteriological:			
Total coliform	116	--	-
Fecal coliform	115	--	-
Fecal streptococci	35	--	-
Miscellaneous organics:			
Phenols	30	--	-
Methylene blue	25	--	-
PCB	25	--	7
Oils and grease	28	--	-
Major ions:			
Calcium	--	28	-
Magnesium	--	28	-
Sodium	--	28	-
Potassium	--	28	-
Chloride	--	28	-
Sulfate	--	28	-
Fluoride	--	28	-
Silica	--	28	-

Table 3.--Water-quality characteristics and number of samples analyzed for each--Continued

Water-quality characteristics	Number of samples: Water, Unfiltered	Number of samples: Water, Filtered	Number of samples: Bottom material
Trace elements:			
Arsenic	140	32	7
Copper	139	33	7
Lead	188	63	7
Zinc	130	33	7
Mercury	140	32	6
Manganese	2	1	7
Iron	2	1	7
Cobalt	1	--	7
Chromium	1	--	7
Cadmium	2	--	7
Insecticides:			
Aldrin	25	--	7
Lindane	25	--	7
Chlordane	25	--	7
DDD	25	--	7
DDT	25	--	7
Dieldrin	25	--	7
Endrin	25	--	7
Toxaphene	25	--	7
Heptachlor	25	--	7
Heptachlor epoxide	25	--	7
Herbicides:			
2,4-D	24	--	7
2,4,5-T	24	--	7
Silvex	24	--	8

Water-quality characteristics listed in table 3 are divided into 10 classes, including physical, chemical, carbon, major nutrients, bacteriological, miscellaneous organics, major ions, trace elements, insecticides, and herbicides. Alkalinity, hardness, miscellaneous organics, major ions, insecticides, and herbicides were sampled only during the period July to October 1975. A single sample of streambottom material was obtained in 1975 at the seven sites in open-channel sections to evaluate accumulation of trace elements, insecticides, herbicides, and other selected characteristics. No sediment deposits were found at the two sites in sewer pipes.

ANALYSIS OF WATER-QUALITY DATA

The average and range in measurements of water-quality characteristics can be compared readily with values published in the literature and with recommended water-quality criteria for various water uses. Variability of constituent concentration with time and discharge is a distinctive characteristic of urban runoff that can be related to watershed land use and drainage system. These two topics are discussed in the following sections.

Average and Range in Streamflow and Water-Quality Characteristics Measurements

The average, minimum, and maximum values of water-quality characteristics and corresponding streamflow data for base flow and stormwater runoff at each streamflow station are listed in tables 4 through 12. These data were evaluated in a comparison with water-quality standards for treated sewage effluent and Class III receiving waters, as described later. The data for all nine stations are summarized in table 13. The water-quality characteristics are divided into six categories: physical, chemical, carbon, major nutrients, bacteriological, and trace elements.

Streamflow rates for the samples varied primarily with drainage-area size and are shown in cubic feet per second per square mile in the tables. Base-flow average for all sites was 0.57 $(ft^3/s)/mi^2$ (table 13). The minimum base flow ranged from 0.12 to 0.58 $(ft^3/s)/mi^2$, and the maximum base flow at a site ranged from 0.22 to 2.0 $(ft^3/s)/mi^2$. Average stormwater-runoff rates at the nine stations were more variable than the base flow, as could be expected. Average stormwater discharge varied from 3.5 to 71 $(ft^3/s)/mi^2$ as a result of the variability in the storms sampled.

Constituent concentrations of biochemical oxygen demand, chemical oxygen demand, total phosphorus, and total nitrogen may be compared with concentrations typically present in untreated domestic sewage and criteria for treated sewage effluent (Florida Department of State, 1979), as shown below.

Constituent	Concentration (mg/L)	
	Typical untreated domestic sewage	Criteria for treated sewage
Biochemical oxygen demand	200	5
Chemical oxygen demand	500	-
Total phosphorus as P	10	1
Total nitrogen as N	40	3

The comparison of sample constituent concentrations with the criteria for treated sewage effluent is a commonly used test of the water quality of urban runoff. Biochemical oxygen demand of some base-flow samples at Bear Creek and Saint Joes Creek exceeded the criteria for treated sewage effluent even though the average concentrations were within the criteria. The chemical oxygen demand for two base-flow samples at Artic Street exceeded the criteria for treated sewage effluent by factors of two and eight. Biochemical oxygen demand concentrations for 75 percent of the stormwater-runoff samples at Artic Street exceeded 5 mg/L although the concentrations were not as high as for the base-flow samples. The biochemical oxygen demand for some of the stormwater-runoff samples at all the sites exceeded the treated sewage-effluent criteria. Flow-weighted average concentrations of biochemical oxygen demand in stormwater runoff at Artic Street, St. Louis Street, Allen Creek, Saint Joes Creek, and Turner Street exceeded 5 mg/L.

Average concentration of total phosphorus in base-flow and stormwater-runoff samples was below the 1-mg/L criteria for treated sewage effluent. One base-flow sample at Artic Street and one or more stormwater-runoff samples at St. Louis Street, Allen Creek, Booker Creek, and Saint Joes Creek had phosphorus concentrations of 1.0 mg/L or greater.

Concentrations of total nitrogen in all base-flow samples were less than 3.0 mg/L except for Kirby Street and Turner Street. Flow-weighted average concentrations ot total nitrogen in stormwater runoff at all sites except St. Louis Street and Saint Joes Creek were less than 3.0 mg/L.

Coliform bacteria carried by urban runoff into the receiving waters, Tampa Bay and the Gulf of Mexico, are of concern to local officials. The receiving waters in Tampa Bay are Class III surface waters for recreation or propagation and management of fish and wildlife. The Florida Department of Environmental Regulation (Florida Department of State, 1979) has set criteria for bacteria concentrations of receiving waters by class and intended use.

The Class III water-quality criteria state that the total coliform bacteria count shall not exceed 2,400 colonies per 100 milliliters (col/100 mL) at any time nor shall the fecal coliform count exceed 800 col/100 mL in any single day in all waters except designated zones of mixing. Concentrations of total and fecal coliforms for two base-flow samples at Kirby Street and St. Louis Street exceeded the Class III water-quality criteria. Average total and fecal coliform concentrations for stormwater-runoff samples at all sites were consistently greater than the specified Class III criteria, generally by several orders of magnitude.

High concentrations of toxic materials, such as the trace elements, can cause fish kills and render receiving waters unfit for human activities or shellfish harvesting. The Florida Deparment of Environmental Regulation has set limits (Florida Department of State, 1979) for trace element concentrations in Class III waters as shown below.

Constituent	Concentration (ug/L)
Arsenic	50 (general)
Mercury	0.1 (marine); 0.2 (fresh)
Copper	15 (marine); 30 (fresh)
Zinc	30 (fresh)
Lead	30 (fresh)

Table 4.--Average, minimum, and maximum values of measurements of streamflow and water-quality characteristics, July 1975 to May 1980, for Artic Street storm drain at Tampa, Florida

Water-quality characteristics and units of measurement	Base flow			
	Number of measurements	Average[1/]	Minimum	Maximum
Streamflow, $(ft^3/s)/mi^2$	-	-	-	-
Physical:				
Turbidity, nephelometric turbidity units	1	72	-	-
Specific conductance, umho/cm at 25°C	-	-	-	-
Chemical:				
Biochemical oxygen demand, mg/L	2	26	10	41
Chemical oxygen demand, mg/L	1	163	-	-
Carbon:				
Total organic carbon as C, mg/L	-	-	-	-
Major nutrients:				
Total phosphorus as P, mg/L	2	.80	.49	1.1
Total orthophosphate as P, mg/L	1	.22	-	-
Total nitrogen as N, mg/L	1	1.6	-	-
Total organic nitrogen as N, mg/L	2	1.9	1.1	2.7
Total ammonia nitrogen as N, mg/L	1	.06	-	-
Total nitrite nitrogen as N, mg/L	1	.07	-	-
Total nitrate nitrogen as N, mg/L	1	.36	-	-
Bacteriological:				
Coliform, multiple-tube method, MPN, col/100 mL	-	-	-	-
Fecal coliform, multiple-tube method, MPN, col/100 mL	-	-	-	-
Coliform, membrane-filter method, col/100 mL	-	-	-	-
Fecal coliform, membrane-filter method, col/100 mL	-	-	-	-
Trace elements:				
Total arsenic as A, ug/L	1	2	-	-
Total copper as Cu, ug/L	1	14	-	-
Total lead as Pb, ug/L	1	320	-	-
Total zinc as Zn, ug/L	1	150	-	-
Total mercury as Hg, ug/L	1	<.5	-	-

[1/] Represents single value where only one measurement was made.

[2/] Median concentration.

Table 4.--Average, minimum, and maximum values of measurements of streamflow and water-quality characteristics, July 1975 to May 1980, for Artic Street storm drain at Tampa, Florida--Continued

Water-quality characteristics and units of measurement	Stormwater runoff			
	Number of measurements	Flow-weighted average	Minimum	Maximum
Streamflow, $(ft^3/s)/mi^2$	17	71	1.8	274
Physical:				
Turbidity, nephelometric turbidity units	12	73	40	150
Specific conductance, umho/cm at 25°C	-	-	-	-
Chemical:				
Biochemical oxygen demand, mg/L	16	6.2	4.4	8.6
Chemical oxygen demand, mg/L	16	57	10	170
Carbon:				
Total organic carbon as C, mg/L	16	13	0	30
Major nutrients:				
Total phosphorus as P, mg/L	17	.28	.12	.61
Total orthophosphate as P, mg/L	17	.14	.09	.31
Total nitrogen as N, mg/L	17	1.7	1.0	2.8
Total organic nitrogen as N, mg/L	17	.94	.54	1.6
Total ammonia nitrogen as N, mg/L	17	.48	.04	2.1
Total nitrite nitrogen as N, mg/L	17	.03	.01	.13
Total nitrate nitrogen as N, mg/L	17	.24	.08	1.3
Bacteriological:				
Coliform, multiple-tube method, MPN, col/100 mL	5	$2.1x10^5$	$1.1x10^5$	$1.1x10^6$
Fecal coliform, multiple-tube method, MPN, col/100 mL	5	$8.0x10^4$	$2.4x10^4$	$1.5x10^5$
Coliform, membrane-filter method, col/100 mL	6	$1.9x10^5$	$1.0x10^5$	$4.9x10^5$
Fecal coliform, membrane-filter method, col/100 mL	6	$1.0x10^5$	$5.0x10^4$	$1.7x10^5$
Trace elements:				
Total arsenic as A, ug/L	12	1	1	2
Total copper as Cu, ug/L	12	16	6	70
Total lead as Pb, ug/L	12	734	43	1,600
Total zinc as Zn, ug/L	12	172	100	310
Total mercury as Hg, ug/L	12	<.5[2/]	<.5	1.4

Table 5.--Average, minimum, and maximum values of measurements of streamflow and water-quality characteristics, July 1975 to May 1980, for Kirby Street drainage ditch at Tampa, Florida

Water-quality characteristics and units of measurement	Base flow			
	Number of measurements	Average[1/]	Minimum	Maximum
Streamflow, $(ft^3/s)/mi^2$	2	0.17	0.12	0.22
Physical:				
Turbidity, nephelometric turbidity units	3	2.3	2.0	3.0
Specific conductance, umho/cm at 25°C	-	-	-	-
Chemical:				
Biochemical oxygen demand, mg/L	4	2.1	.30	4.3
Chemical oxygen demand, mg/L	3	38	27	44
Carbon:				
Total organic carbon as C, mg/L	2	12	10	15
Major nutrients:				
Total phosphorus as P, mg/L	4	.12	.02	.27
Total orthophosphate as P, mg/L	4	.08	.02	.20
Total nitrogen as N, mg/L	3	2.1	1.2	3.2
Total organic nitrogen as N, mg/L	4	1.1	.33	1.6
Total ammonia nitrogen as N, mg/L	4	.32	.04	1.1
Total nitrite nitrogen as N, mg/L	4	.02	.01	.05
Total nitrate nitrogen as N, mg/L	4	.28	.09	.50
Bacteriological:				
Coliform, multiple-tube method, MPN, col/100 mL	-	-	-	-
Fecal coliform, multiple-tube method, MPN, col/100 mL	-	-	-	-
Coliform, membrane-filter method, col/100 mL	2	$6.8x10^4$	$6.5x10^3$	$1.3x10^5$
Fecal coliform, membrane-filter method, col/100 mL	2	$1.4x10^4$	$2.6x10^3$	$2.5x10^4$
Trace elements:				
Total arsenic as A, ug/L	1	1	-	-
Total copper as Cu, ug/L	-	-	-	-
Total lead as Pb, ug/L	2	12	12	12
Total zinc as Zn, ug/L	1	20	-	-
Total mercury as Hg, ug/L	1	<.5	-	-

[1/]Represents single value where only one measurement was made.

[2/]Median concentration.

Table 5.--Average, minimum, and maximum values of measurements of streamflow and water-quality characteristics, July 1975 to May 1980, for Kirby Street drainage ditch at Tampa, Florida--Continued

Water-quality characteristics and units of measurement	Stormwater runoff			
	Number of measurements	Flow-weighted average	Minimum	Maximum
Streamflow, $(ft^3/s)/mi^2$	20	15	3.2	20
Physical:				
Turbidity, nephelometric turbidity units	20	18	3.0	100
Specific conductance, umho/cm at 25°C	-	-	-	-
Chemical:				
Biochemical oxygen demand, mg/L	20	4.5	1.4	8.6
Chemical oxygen demand, mg/L	20	64	5.0	120
Carbon:				
Total organic carbon as C, mg/L	20	20	10	45
Major nutrients:				
Total phosphorus as P, mg/L	20	.25	.08	.50
Total orthophosphate as P, mg/L	20	.12	.04	.27
Total nitrogen as N, mg/L	20	2.2	1.4	4.0
Total organic nitrogen as N, mg/L	20	1.4	.84	2.9
Total ammonia nitrogen as N, mg/L	20	.25	.06	.80
Total nitrite nitrogen as N, mg/L	20	.03	.02	.06
Total nitrate nitrogen as N, mg/L	20	.48	.18	1.7
Bacteriological:				
Coliform, multiple-tube method, MPN, col/100 mL	-	-	-	-
Fecal coliform, multiple-tube method, MPN, col/100 mL	-	-	-	-
Coliform, membrane-filter method, col/100 mL	11	$1.6x10^5$	$3.6x10^4$	$3.1x10^5$
Fecal coliform, membrane-filter method, col/100 mL	10	$9.8x10^4$	$4.7x10^3$	$1.7x10^5$
Trace elements:				
Total arsenic as A, ug/L	-	-	-	-
Total copper as Cu, ug/L	-	-	-	-
Total lead as Pb, ug/L	20	50	5	190
Total zinc as Zn, ug/L	-	-	-	-
Total mercury as Hg, ug/L	-	-	-	-

Table 6.--Average, minimum, and maximum values of measurements of streamflow and water-quality characteristics, July 1975 to May 1980, for St. Louis Street drainage ditch at Tampa, Florida

Water-quality characteristics and units of measurement	Base flow			
	Number of measurements	Average[1/]	Minimum	Maximum
Streamflow, $(ft^3/s)/mi^2$	2	0.20	0.16	0.24
Physical:				
Turbidity, nephelometric turbidity units	1	10	-	-
Specific conductance, umho/cm at 25°C	2	286	285	288
Chemical:				
Biochemical oxygen demand, mg/L	4	3.0	1.3	4.2
Chemical oxygen demand, mg/L	3	44	36	56
Carbon:				
Total organic carbon as C, mg/L	2	25	13	37
Major nutrients:				
Total phosphorus as P, mg/L	4	.14	.06	.24
Total orthophosphate as P, mg/L	4	.08	.02	.15
Total nitrogen as N, mg/L	1	2.5	-	-
Total organic nitrogen as N, mg/L	4	1.0	.71	1.6
Total ammonia nitrogen as N, mg/L	4	1.0	.75	1.2
Total nitrite nitrogen as N, mg/L	4	.06	.03	.11
Total nitrate nitrogen as N, mg/L	4	.14	.04	.40
Bacteriological:				
Coliform, multiple-tube method, MPN, col/100 mL	2	3.5×10^4	2.4×10^4	4.6×10^4
Fecal coliform, multiple-tube method, MPN, col/100 mL	2	8.0×10^3	9.3×10^2	1.5×10^4
Coliform, membrane-filter method, col/100 mL	-	-	-	-
Fecal coliform, membrane-filter method, col/100 mL	-	-	-	-
Trace elements:				
Total arsenic as A, ug/L	3	1	1	1
Total copper as Cu, ug/L	3	12	3	20
Total lead as Pb, ug/L	3	54	29	96
Total zinc as Zn, ug/L	1	50	-	-
Total mercury as Hg, ug/L	3	<.5[2/]	<.5	<.5

1/Represents single value where only one measurement was made.

2/Median concentration.

Table 6.--Average, minimum, and maximum values of measurements of streamflow and water-quality characteristics, July 1975 to May 1980, for St. Louis Street drainage ditch at Tampa, Florida--Continued

Water-quality characteristics and units of measurement	Stormwater runoff			
	Number of measurements	Flow-weighted average	Minimum	Maximum
Streamflow, $(ft^3/s)/mi^2$	41	67	0.82	167
Physical:				
Turbidity, nephelometric turbidity units	21	35	1.0	100
Specific conductance, umho/cm at 25°C	14	232	63	400
Chemical:				
Biochemical oxygen demand, mg/L	40	6.1	2.0	11
Chemical oxygen demand, mg/L	40	55	11	130
Carbon:				
Total organic carbon as C, mg/L	38	10	2.9	20
Major nutrients:				
Total phosphorus as P, mg/L	41	.45	.12	1.7
Total orthophosphate as P, mg/L	24	.14	.10	.23
Total nitrogen as N, mg/L	21	3.0	.59	12
Total organic nitrogen as N, mg/L	40	1.8	.36	12
Total ammonia nitrogen as N, mg/L	24	.55	.03	1.7
Total nitrite nitrogen as N, mg/L	24	.03	.01	.11
Total nitrate nitrogen as N, mg/L	24	.31	0	.57
Bacteriological:				
Coliform, multiple-tube method, MPN, col/100 mL	19	$5.5x10^5$	$4.6x10^3$	$2.4x10^6$
Fecal coliform, multiple-tube method, MPN, col/100 mL	19	$2.1x10^5$	$2.4x10^3$	$2.4x10^6$
Coliform, membrane-filter method, col/100 mL	-	-	-	-
Fecal coliform, membrane-filter method, col/100 mL	-	-	-	-
Trace elements:				
Total arsenic as A, ug/L	25	2	1	8
Total copper as Cu, ug/L	25	16	5	28
Total lead as Pb, ug/L	40	213	24	580
Total zinc as Zn, ug/L	18	133	60	200
Total mercury as Hg, ug/L	25	<.5 2/	<.5	6.0

Table 7.--Average, minimum, and maximum values of measurements of streamflow and water-quality characteristics, July 1975 to May 1980, for Gandy Boulevard drainage ditch at Tampa, Florida

Water-quality characteristics and units of measurement	Base flow			
	Number of measurements	Average[1/]	Minimum	Maximum
Streamflow, $(ft^3/s)/mi^2$	1	0.29	-	-
Physical:				
Turbidity, nephelometric turbidity units	1	1.2	-	-
Specific conductance, umho/cm at 25°C	-	-	-	-
Chemical:				
Biochemical oxygen demand, mg/L	1	4.1	-	-
Chemical oxygen demand, mg/L	1	62	-	-
Carbon:				
Total organic carbon as C, mg/L	-	-	-	-
Major nutrients:				
Total phosphorus as P, mg/L	1	.73	-	-
Total orthophosphate as P, mg/L	1	.21	-	-
Total nitrogen as N, mg/L	1	2.8	-	-
Total organic nitrogen as N, mg/L	1	2.3	-	-
Total ammonia nitrogen as N, mg/L	1	.19	-	-
Total nitrite nitrogen as N, mg/L	1	.04	-	-
Total nitrate nitrogen as N, mg/L	1	.31	-	-
Bacteriological:				
Coliform, multiple-tube method, MPN, col/100 mL	-	-	-	-
Fecal coliform, multiple-tube method, MPN, col/100 mL	-	-	-	-
Coliform, membrane-filter method, col/100 mL	-	-	-	-
Fecal coliform, membrane-filter method, col/100 mL	-	-	-	-
Trace elements:				
Total arsenic as A, ug/L	-	-	-	-
Total copper as Cu, ug/L	-	-	-	-
Total lead as Pb, ug/L	-	-	-	-
Total zinc as Zn, ug/L	-	-	-	-
Total mercury as Hg, ug/L	-	-	-	-

[1/] Represents single value where only one measurement was made.

[2/] Median concentration.

Table 7.--Average, minimum, and maximum values of measurements of streamflow and water-quality characteristics, July 1975 to May 1980, for Gandy Boulevard drainage ditch at Tampa, Florida--Continued

Water-quality characteristics and units of measurement	Stormwater runoff			
	Number of measurements	Flow-weighted average	Minimum	Maximum
Streamflow, $(ft^3/s)/mi^2$	20	40	3.4	74
Physical:				
Turbidity, nephelometric turbidity units	8	17	5.0	25
Specific conductance, umho/cm at 25°C	5	164	108	352
Chemical:				
Biochemical oxygen demand, mg/L	20	5.0	2.0	12
Chemical oxygen demand, mg/L	20	32	14	64
Carbon:				
Total organic carbon as C, mg/L	15	5.9	3.7	12
Major nutrients:				
Total phosphorus as P, mg/L	20	.30	.20	.44
Total orthophosphate as P, mg/L	20	.18	.11	.28
Total nitrogen as N, mg/L	8	.76	.50	1.0
Total organic nitrogen as N, mg/L	20	.66	.21	1.9
Total ammonia nitrogen as N, mg/L	20	.40	.03	.94
Total nitrite nitrogen as N, mg/L	20	.02	.01	.03
Total nitrate nitrogen as N, mg/L	20	.22	.06	.47
Bacteriological:				
Coliform, multiple-tube method, MPN, col/100 mL	12	$3.0x10^5$	$1.1x10^5$	$2.4x10^6$
Fecal coliform, multiple-tube method, MPN, col/100 mL	12	$1.5x10^5$	$1.5x10^4$	$4.6x10^5$
Coliform, membrane-filter method, col/100 mL	-	-	-	-
Fecal coliform, membrane-filter method, col/100 mL	-	-	-	-
Trace elements:				
Total arsenic as A, ug/L	19	2	1	3
Total copper as Cu, ug/L	19	7	2	27
Total lead as Pb, ug/L	19	154	20	590
Total zinc as Zn, ug/L	19	103	50	300
Total mercury as Hg, ug/L	19	<.5[2/]	<.5	5.1

Table 8.--Average, minimum, and maximum values of measurements of streamflow and water-quality characteristics, July 1975 to May 1980, for Allen Creek near Largo, Florida

Water-quality characteristics and units of measurement	Base flow			
	Number of measurements	Average[1/]	Minimum	Maximum
Streamflow, $(ft^3/s)/mi^2$	2	0.48	0.45	0.50
Physical:				
Turbidity, nephelometric turbidity units	2	3.5	3.0	4.0
Specific conductance, umho/cm at 25°C	12	380	210	486
Chemical:				
Biochemical oxygen demand, mg/L	4	1.5	.80	2.8
Chemical oxygen demand, mg/L	2	37	30	44
Carbon:				
Total organic carbon as C, mg/L	1	13	-	-
Major nutrients:				
Total phosphorus as P, mg/L	3	.18	.15	.21
Total orthophosphate as P, mg/L	3	.14	.13	.14
Total nitrogen as N, mg/L	2	1.5	1.4	1.6
Total organic nitrogen as N, mg/L	3	.71	.45	.88
Total ammonia nitrogen as N, mg/L	3	.14	.12	.18
Total nitrite nitrogen as N, mg/L	3	.02	.01	.03
Total nitrate nitrogen as N, mg/L	3	.31	.02	.55
Bacteriological:				
Coliform, multiple-tube method, MPN, col/100 mL	-	-	-	-
Fecal coliform, multiple-tube method, MPN, col/100 mL	-	-	-	-
Coliform, membrane-filter method, col/100 mL	-	-	-	-
Fecal coliform, membrane-filter method, col/100 mL	-	-	-	-
Trace elements:				
Total arsenic as A, ug/L	1	1	-	-
Total copper as Cu, ug/L	1	2	-	-
Total lead as Pb, ug/L	1	17	-	-
Total zinc as Zn, ug/L	1	80	-	-
Total mercury as Hg, ug/L	1	<.5	-	-

1/ Represents single value where only one measurement was made.

2/ Median concentration.

Table 8.--Average, minimum, and maximum values of measurements of streamflow and water-quality characteristics, July 1975 to May 1980, for Allen Creek near Largo, Florida--Continued

Water-quality characteristics and units of measurement	Stormwater runoff			
	Number of measurements	Flow-weighted average	Minimum	Maximum
Streamflow, $(ft^3/s)/mi^2$	40	45	1.5	192
Physical:				
Turbidity, nephelometric turbidity units	7	19	5.0	25
Specific conductance, umho/cm at 25°C	4	135	104	341
Chemical:				
Biochemical oxygen demand, mg/L	34	5.6	.70	11
Chemical oxygen demand, mg/L	29	54	15	130
Carbon:				
Total organic carbon as C, mg/L	19	13	2.0	32
Major nutrients:				
Total phosphorus as P, mg/L	34	.52	.12	1.4
Total orthophosphate as P, mg/L	28	.16	.08	.25
Total nitrogen as N, mg/L	22	2.4	.50	5.6
Total organic nitrogen as N, mg/L	34	1.8	.26	4.3
Total ammonia nitrogen as N, mg/L	28	.22	.05	.50
Total nitrite nitrogen as N, mg/L	28	.05	.01	.13
Total nitrate nitrogen as N, mg/L	28	.36	.06	1.5
Bacteriological:				
Coliform, multiple-tube method, MPN, col/100 mL	12	$4.8x10^5$	$4.6x10^3$	$1.5x10^6$
Fecal coliform, multiple-tube method, MPN, col/100 mL	12	$7.1x10^4$	$2.4x10^3$	$2.4x10^5$
Coliform, membrane-filter method, col/100 mL	6	$1.4x10^5$	$2.0x10^3$	$2.8x10^5$
Fecal coliform, membrane-filter method, col/100 mL	7	$1.1x10^4$	$3.1x10^2$	$1.5x10^4$
Trace elements:				
Total arsenic as A, ug/L	27	2	1	3
Total copper as Cu, ug/L	27	15	3	28
Total lead as Pb, ug/L	34	156	6	300
Total zinc as Zn, ug/L	27	97	20	170
Total mercury as Hg, ug/L	27	<.5[2/]	<.5	<.5

Table 9.--Average, minimum, and maximum values of measurements of streamflow and water-quality characteristics, July 1975 to May 1980, for Booker Creek at St. Petersburg, Florida

Water-quality characteristics and units of measurement	Base flow			
	Number of measurements	Average[1/]	Minimum	Maximum
Streamflow, $(ft^3/s)/mi^2$	4	1.0	0.37	2.0
Physical:				
Turbidity, nephelometric turbidity units	2	140	95	184
Specific conductance, umho/cm at 25°C	3	314	258	385
Chemical:				
Biochemical oxygen demand, mg/L	3	3.3	2.0	4.7
Chemical oxygen demand, mg/L	2	90	69	110
Carbon:				
Total organic carbon as C, mg/L	1	24	-	-
Major nutrients:				
Total phosphorus as P, mg/L	3	.25	.08	.40
Total orthophosphate as P, mg/L	3	.11	.04	.21
Total nitrogen as N, mg/L	2	2.0	1.9	2.2
Total organic nitrogen as N, mg/L	3	1.0	.54	1.4
Total ammonia nitrogen as N, mg/L	3	.14	.05	.30
Total nitrite nitrogen as N, mg/L	2	.05	.05	.05
Total nitrate nitrogen as N, mg/L	3	.54	.31	.70
Bacteriological:				
Coliform, multiple-tube method, MPN, col/100 mL	-	-	-	-
Fecal coliform, multiple-tube method, MPN, col/100 mL	-	-	-	-
Coliform, membrane-filter method, col/100 mL	-	-	-	-
Fecal coliform, membrane-filter method, col/100 mL	-	-	-	-
Trace elements:				
Total arsenic as A, ug/L	1	1	-	-
Total copper as Cu, ug/L	1	2	-	-
Total lead as Pb, ug/L	1	23	-	-
Total zinc as Zn, ug/L	1	50	-	-
Total mercury as Hg, ug/L	1	<.5	-	-

[1/]Represents single value where only one measurement was made.

[2/]Median concentration.

Table 9.--Average, minimum, and maximum values of measurements of streamflow and water-quality characteristics, July 1975 to May 1980, for Booker Creek at St. Petersburg, Florida--Continued

Water-quality characteristics and units of measurement	Stormwater runoff			
	Number of measurements	Flow-weighted average	Minimum	Maximum
Streamflow, $(ft^3/s)/mi^2$	11	38	13	75
Physical:				
Turbidity, nephelometric turbidity units	11	189	50	270
Specific conductance, umho/cm at 25°C	-	-	-	-
Chemical:				
Biochemical oxygen demand, mg/L	11	4.9	3.4	8.3
Chemical oxygen demand, mg/L	11	83	39	160
Carbon:				
Total organic carbon as C, mg/L	11	29	13	50
Major nutrients:				
Total phosphorus as P, mg/L	11	.50	.24	1.0
Total orthophosphate as P, mg/L	11	.21	.10	.32
Total nitrogen as N, mg/L	11	2.4	1.0	6.6
Total organic nitrogen as N, mg/L	11	2.1	.76	6.3
Total ammonia nitrogen as N, mg/L	11	.14	.09	.17
Total nitrite nitrogen as N, mg/L	11	.06	.02	.10
Total nitrate nitrogen as N, mg/L	11	.10	.03	.25
Bacteriological:				
Coliform, multiple-tube method, MPN, col/100 mL	-	-	-	-
Fecal coliform, multiple-tube method, MPN, col/100 mL	-	-	-	-
Coliform, membrane-filter method, col/100 mL	11	$1.3x10^5$	$8.6x10^4$	$1.6x10^5$
Fecal coliform, membrane-filter method, col/100 mL	11	$2.1x10^4$	$1.0x10^4$	$3.9x10^4$
Trace elements:				
Total arsenic as A, ug/L	11	3	1	5
Total copper as Cu, ug/L	11	21	12	38
Total lead as Pb, ug/L	11	219	190	270
Total zinc as Zn, ug/L	11	115	100	150
Total mercury as Hg, ug/L	11	<.5 2/	<.5	<.5

Table 10.--Average, minimum, and maximum values of measurements of streamflow and water-quality characteristics, July 1975 to May 1980, for Bear Creek at St. Petersburg, Florida

Water-quality characteristics and units of measurement	Base flow			
	Number of measurements	Average[1]	Minimum	Maximum
Streamflow, $(ft^3/s)/mi^2$	3	0.64	0.58	0.74
Physical:				
Turbidity, nephelometric turbidity units	2	6.0	5.0	7.0
Specific conductance, umho/cm at 25°C	4	403	294	585
Chemical:				
Biochemical oxygen demand, mg/L	4	4.2	2.1	9.7
Chemical oxygen demand, mg/L	2	50	41	58
Carbon:				
Total organic carbon as C, mg/L	2	24	17	30
Major nutrients:				
Total phosphorus as P, mg/L	3	.11	.08	.16
Total orthophosphate as P, mg/L	3	.04	.03	.06
Total nitrogen as N, mg/L	2	1.5	.52	2.4
Total organic nitrogen as N, mg/L	4	1.0	.18	1.9
Total ammonia nitrogen as N, mg/L	3	.28	.12	.54
Total nitrite nitrogen as N, mg/L	3	.03	.01	.05
Total nitrate nitrogen as N, mg/L	3	.19	.07	.29
Bacteriological:				
Coliform, multiple-tube method, MPN, col/100 mL	-	-	-	-
Fecal coliform, multiple-tube method, MPN, col/100 mL	-	-	-	-
Coliform, membrane-filter method, col/100 mL	1	600	-	-
Fecal coliform, membrane-filter method, col/100 mL	-	-	-	-
Trace elements:				
Total arsenic as A, ug/L	2	3	3	3
Total copper as Cu, ug/L	1	2	-	-
Total lead as Pb, ug/L	2	34	31	37
Total zinc as Zn, ug/L	1	30	-	-
Total mercury as Hg, ug/L	2	<.5[2]	<.5	<.5

1/ Represents single value where only one measurement was made.

2/ Median concentration.

Table 10.--Average, minimum, and maximum values of measurements of streamflow and water-quality characteristics, July 1975 to May 1980, for Bear Creek at St. Petersburg, Florida--Continued

Water-quality characteristics and units of measurement	Stormwater runoff			
	Number of measurements	Flow-weighted average	Minimum	Maximum
Streamflow, $(ft^3/s)/mi^2$	21	46	0.90	130
Physical:				
Turbidity, nephelometric turbidity units	11	5.5	4.0	8.0
Specific conductance, umho/cm at 25°C	10	166	87	423
Chemical:				
Biochemical oxygen demand, mg/L	14	4.7	.70	6.0
Chemical oxygen demand, mg/L	18	56	10	210
Carbon:				
Total organic carbon as C, mg/L	20	6.2	2.5	23
Major nutrients:				
Total phosphorus as P, mg/L	21	.20	.06	.30
Total orthophosphate as P, mg/L	15	.08	.03	.10
Total nitrogen as N, mg/L	11	.32	.20	.70
Total organic nitrogen as N, mg/L	21	.42	0	1.0
Total ammonia nitrogen as N, mg/L	15	.21	.09	.40
Total nitrite nitrogen as N, mg/L	15	.02	.01	.05
Total nitrate nitrogen as N, mg/L	15	.09	.03	.30
Bacteriological:				
Coliform, multiple-tube method, MPN, col/100 mL	9	$6.8x10^5$	$7.5x10^4$	$2.4x10^6$
Fecal coliform, multiple-tube method, MPN, col/100 mL	9	$6.6x10^5$	$9.3x10^3$	$2.4x10^6$
Coliform, membrane-filter method, col/100 mL	5	$2.1x10^7$	$6.0x10^3$	$8.2x10^7$
Fecal coliform, membrane-filter method, col/100 mL	5	$5.2x10^3$	$3.4x10^3$	$7.3x10^3$
Trace elements:				
Total arsenic as A, ug/L	21	2	1	5
Total copper as Cu, ug/L	21	9	2	20
Total lead as Pb, ug/L	21	128	15	220
Total zinc as Zn, ug/L	21	83	7	160
Total mercury as Hg, ug/L	21	<.5 2/	<.5	34

Table 11.--Average, minimum, and maximum values of measurements of streamflow and water-quality characteristics, July 1975 to May 1980, for Saint Joes Creek at St. Petersburg, Florida

Water-quality characteristics and units of measurement	Base flow			
	Number of measurements	Average[1/]	Minimum	Maximum
Streamflow, $(ft^3/s)/mi^2$	1	0.57	-	-
Physical:				
Turbidity, nephelometric turbidity units	2	8.5	5.0	12
Specific conductance, umho/cm at 25°C	-	-	-	-
Chemical:				
Biochemical oxygen demand, mg/L	3	3.9	1.0	8.6
Chemical oxygen demand, mg/L	2	46	40	51
Carbon:				
Total organic carbon as C, mg/L	1	25	-	-
Major nutrients:				
Total phosphorus as P, mg/L	3	.10	.05	.16
Total orthophosphate as P, mg/L	3	.04	.03	.04
Total nitrogen as N, mg/L	2	1.6	1.5	1.7
Total organic nitrogen as N, mg/L	3	.76	.43	1.2
Total ammonia nitrogen as N, mg/L	3	.14	.11	.19
Total nitrite nitrogen as N, mg/L	3	.03	.01	.05
Total nitrate nitrogen as N, mg/L	3	.31	0	.63
Bacteriological:				
Coliform, multiple-tube method, MPN, col/100 mL	-	-	-	-
Fecal coliform, multiple-tube method, MPN, col/100 mL	-	-	-	-
Coliform, membrane-filter method, col/100 mL	-	-	-	-
Fecal coliform, membrane-filter method, col/100 mL	-	-	-	-
Trace elements:				
Total arsenic as A, ug/L	1	1	-	-
Total copper as Cu, ug/L	1	8	-	-
Total lead as Pb, ug/L	1	24	-	-
Total zinc as Zn, ug/L	1	300	-	-
Total mercury as Hg, ug/L	1	<.5	-	-

1/ Represents single value where only one measurement was made.

2/ Median concentration.

Table 11.--Average, minimum, and maximum values of measurements of streamflow and water-quality characteristics, July 1975 to May 1980, for Saint Joes Creek at St. Petersburg, Florida--Continued

Water-quality characteristics and units of measurement	Stormwater runoff			
	Number of measurements	Flow-weighted average	Minimum	Maximum
Streamflow, $(ft^3/s)/mi^2$	14	3.5	1.1	7.6
Physical:				
Turbidity, nephelometric turbidity units	7	22	17	45
Specific conductance, umho/cm at 25°C	6	194	105	285
Chemical:				
Biochemical oxygen demand, mg/L	9	8.1	5.2	10
Chemical oxygen demand, mg/L	13	77	38	210
Carbon:				
Total organic carbon as C, mg/L	10	21	11	38
Major nutrients:				
Total phosphorus as P, mg/L	13	.30	.20	1.0
Total orthophosphate as P, mg/L	7	.12	.08	.20
Total nitrogen as N, mg/L	7	3.1	2.8	4.2
Total organic nitrogen as N, mg/L	13	1.0	.55	3.0
Total ammonia nitrogen as N, mg/L	7	.21	.10	.30
Total nitrite nitrogen as N, mg/L	7	.06	.04	.10
Total nitrate nitrogen as N, mg/L	7	1.1	.79	1.3
Bacteriological:				
Coliform, multiple-tube method, MPN, col/100 mL	6	2.0×10^6	7.5×10^4	1.1×10^7
Fecal coliform, multiple-tube method, MPN, col/100 mL	6	1.5×10^6	2.3×10^4	1.1×10^7
Coliform, membrane-filter method, col/100 mL	5	4.3×10^4	9.4×10^3	5.8×10^4
Fecal coliform, membrane-filter method, col/100 mL	5	9.2×10^3	2.0×10^3	1.6×10^4
Trace elements:				
Total arsenic as A, ug/L	6	2	1	3
Total copper as Cu, ug/L	6	51	12	100
Total lead as Pb, ug/L	11	349	72	1,100
Total zinc as Zn, ug/L	6	182	90	300
Total mercury as Hg, ug/L	6	<.5 2/	<.5	<.5

Table 12.--Average, minimum, and maximum values of measurements of streamflow and water-quality characteristics, July 1975 to May 1980, for Turner Street storm drain at Clearwater, Florida

Water-quality characteristics and units of measurement	Base flow			
	Number of measurements	Average[1/]	Minimum	Maximum
Streamflow, $(ft^3/s)/mi^2$	-	-	-	-
Physical:				
Turbidity, nephelometric turbidity units	1	6.0	-	-
Specific conductance, umho/cm at 25°C	-	-	-	-
Chemical:				
Biochemical oxygen demand, mg/L	1	3.4	-	-
Chemical oxygen demand, mg/L	1	40	-	-
Carbon:				
Total organic carbon as C, mg/L	1	18	-	-
Major nutrients:				
Total phosphorus as P, mg/L	1	.15	-	-
Total orthophosphate as P, mg/L	1	.10	-	-
Total nitrogen as N, mg/L	1	3.1	-	-
Total organic nitrogen as N, mg/L	1	1.1	-	-
Total ammonia nitrogen as N, mg/L	1	1.5	-	-
Total nitrite nitrogen as N, mg/L	1	.05	-	-
Total nitrate nitrogen as N, mg/L	1	.42	-	-
Bacteriological:				
Coliform, multiple-tube method, MPN, col/100 mL	-	-	-	-
Fecal coliform, multiple-tube method, MPN, col/100 mL	-	-	-	-
Coliform, membrane-filter method, col/100 mL	-	-	-	-
Fecal coliform, membrane-filter method, col/100 mL	-	-	-	-
Trace elements:				
Total arsenic as A, ug/L	-	-	-	-
Total copper as Cu, ug/L	-	-	-	-
Total lead as Pb, ug/L	-	-	-	-
Total zinc as Zn, ug/L	-	-	-	-
Total mercury as Hg, ug/L	-	-	-	-

[1/] Represents single value where only one measurement was made.

[2/] Median concentration.

Table 12.--Average, minimum, and maximum values of measurements of streamflow and water-quality characteristics, July 1975 to May 1980, for Turner Street storm drain at Clearwater, Florida--Continued

Water-quality characteristics and units of measurement	Stormwater runoff			
	Number of measurements	Flow-weighted average	Minimum	Maximum
Streamflow, $(ft^3/s)/mi^2$	13	24	1.2	64
Physical:				
Turbidity, nephelometric turbidity units	6	24	2.0	35
Specific conductance, umho/cm at 25°C	-	-	-	-
Chemical:				
Biochemical oxygen demand, mg/L	13	10.4	1.4	28
Chemical oxygen demand, mg/L	13	89	25	170
Carbon:				
Total organic carbon as C, mg/L	7	12	3.5	88
Major nutrients:				
Total phosphorus as P, mg/L	13	.52	.13	.97
Total orthophosphate as P, mg/L	13	.19	.10	.35
Total nitrogen as N, mg/L	13	1.5	.53	7.4
Total organic nitrogen as N, mg/L	13	.71	.35	5.9
Total ammonia nitrogen as N, mg/L	13	.23	.03	1.5
Total nitrite nitrogen as N, mg/L	13	.03	.01	.10
Total nitrate nitrogen as N, mg/L	13	.56	.06	1.1
Bacteriological:				
Coliform, multiple-tube method, MPN, col/100 mL	4	$3.8x10^5$	$7.5x10^4$	$1.1x10^7$
Fecal coliform, multiple-tube method, MPN, col/100 mL	4	$1.4x10^4$	$3.9x10^3$	$2.4x10^4$
Coliform, membrane-filter method, col/100 mL	-	-	-	-
Fecal coliform, membrane-filter method, col/100 mL	-	-	-	-
Trace elements:				
Total arsenic as A, ug/L	9	2	1	3
Total copper as Cu, ug/L	9	18	8	69
Total lead as Pb, ug/L	9	405	130	740
Total zinc as Zn, ug/L	9	255	110	400
Total mercury as Hg, ug/L	9	<.5 2/	<.5	.8

Table 13.--Average, minimum, and maximum values of measurements of streamflow and water-quality characteristics, July 1975 to May 1980, for nine urban watersheds in the Tampa Bay area, Florida

Water-quality characteristics and units of measurement	Base flow			
	Number of measurements	Average[1]	Minimum	Maximum
Streamflow, $(ft^3/s)/mi^2$	15	0.57	0.12	2.0
Physical:				
Turbidity, nephelometric turbidity units	15	27	1.2	184
Specific conductance, umho/cm at 25°C	21	366	210	585
Chemical:				
Biochemical oxygen demand, mg/L	26	4.8	.30	41
Chemical oxygen demand, mg/L	17	56	27	160
Carbon:				
Total organic carbon as C, mg/L	10	20	10	37
Major nutrients:				
Total phosphorus as P, mg/L	24	.23	.02	1.1
Total orthophosphate as P, mg/L	23	.09	.02	.22
Total nitrogen as N, mg/L	15	2.0	.52	3.2
Total organic nitrogen as N, mg/L	25	1.1	.18	2.7
Total ammonia nitrogen as N, mg/L	23	.40	.04	1.5
Total nitrite nitrogen as N, mg/L	22	.04	.01	.11
Total nitrate nitrogen as N, mg/L	23	.30	0	.70
Bacteriological:				
Coliform, multiple-tube method, MPN, col/100 mL	2	$3.5x10^4$	$2.4x10^4$	$4.6x10^4$
Fecal coliform, multiple-tube method, MPN, col/100 mL	2	$8.0x10^3$	$9.3x10^2$	$1.5x10^4$
Coliform, membrane-filter method, col/100 mL	3	$4.6x10^4$	$6.0x10^2$	$1.3x10^5$
Fecal coliform, membrane-filter method, col/100 mL	2	$1.4x10^4$	$2.6x10^3$	$2.5x10^4$
Trace elements:				
Total arsenic as A, ug/L	10	2	1	3
Total copper as Cu, ug/L	9	7	2	20
Total lead as Pb, ug/L	11	58	12	320
Total zinc as Zn, ug/L	7	97	20	300
Total mercury as Hg, ug/L	10	<.5[2]	<.5	<.5

1/Represents single value where only one measurement was made.

2/Median concentration.

Table 13.--Average, minimum, and maximum values of measurements of streamflow and water-quality characteristics, July 1975 to May 1980, for nine urban watersheds in the Tampa Bay area, Florida--Continued

Water-quality characteristics and units of measurement	Stormwater runoff			
	Number of measurements	Flow-weighted average	Minimum	Maximum
Streamflow, $(ft^3/s)/mi^2$	197	44	0.82	274
Physical:				
Turbidity, nephelometric turbidity units	103	75	1.0	270
Specific conductance, umho/cm at 25°C	39	173	63	423
Chemical:				
Biochemical oxygen demand, mg/L	177	5.4	.70	28
Chemical oxygen demand, mg/L	180	58	5.0	210
Carbon:				
Total organic carbon as C, mg/L	156	14	0	88
Major nutrients:				
Total phosphorus as P, mg/L	190	.40	.06	1.7
Total orthophosphate as P, mg/L	155	.16	.03	.35
Total nitrogen as N, mg/L	130	2.1	.20	12
Total organic nitrogen as N, mg/L	189	1.4	0	12
Total ammonia nitrogen as N, mg/L	155	.29	.03	2.1
Total nitrite nitrogen as N, mg/L	155	.04	.01	.13
Total nitrate nitrogen as N, mg/L	155	.25	0	1.7
Bacteriological:				
Coliform, multiple-tube method, MPN, col/100 mL	67	$5.2x10^5$	$4.6x10^3$	$1.1x10^7$
Fecal coliform, multiple-tube method, MPN, col/100 mL	67	$2.7x10^5$	$2.4x10^3$	$1.1x10^7$
Coliform, membrane-filter method, col/100 mL	44	$2.9x10^6$	$2.0x10^3$	$8.2x10^7$
Fecal coliform, membrane-filter method, col/100 mL	44	$2.5x10^4$	$3.1x10^2$	$1.7x10^5$
Trace elements:				
Total arsenic as A, ug/L	130	2	1	8
Total copper as Cu, ug/L	130	14	2	100
Total lead as Pb, ug/L	177	179	5	1,600
Total zinc as Zn, ug/L	123	106	7	400
Total mercury as Hg, ug/L	130	<.5 2/	<.5	34

In relation to the trace-element concentration limits set by the Florida Department of Environmental Regulation for Class III water, data for nine urban watersheds of the Tampa Bay area stand as follows:

(1) At all stations sampled, average concentrations of arsenic in both base flow and stormwater runoff were within the limits.

(2) The maximum allowable mercury concentration of 0.2 ug/L may have been exceeded in all samples at all sites. Maximum concentrations of mercury in stormwater runoff exceeded the limit for Class III water at five of the eight stations sampled and may have exceeded the limit at the other three stations, also.

(3) Average concentrations of copper in base-flow samples were within the limit for Class III water for the six watersheds sampled. Average concentrations of copper in stormwater-runoff samples exceeded the limit for Class III water (fresh) at one station.

(4) Average concentrations of zinc exceeded the limit for Class III water at five of seven stations sampled for base flow and at all eight of the stations sampled for stormwater runoff.

(5) Average concentrations of lead in base-flow samples exceeded the limit for Class III water at three of seven stations sampled. Average concentrations of lead in stormwater-runoff samples exceeded the limit for Class III water at all nine stations.

(6) Lead and zinc concentrations of base-flow samples were generally higher from watersheds that had relatively high percentages of commercial development.

Variation of Water-Quality Characteristics with Time and Discharge

Water-quality characteristics of urban runoff can be characterized to some extent by the manner in which they vary. Substances may be transported from a watershed in the initial phase of stormwater runoff in concentrations dependent on the intensity of rainfall, rate of discharge, and physical features of the watershed. Many factors determined the relation between water-quality characteristics and discharge. For example, substances deposited on impervious surfaces, such as roads or paved parking lots, may be rapidly washed into a storm-drainage system and appear in high concentration in the initial phase of stormwater runoff (first flush). Substances deposited on pervious surfaces may be washed off at a rate depending on the volume of stormwater runoff (discharge-related flushing). Other important factors that affect the relation between water-quality parameters and stormwater runoff are the intensity and time distribution of rainfall, the degree to which a basin is sewered, location and amount of impervious surface, and the extent to which impervious surfaces are connected to the storm-drainage system.

Variations in rainfall, discharge, and selected water-quality characteristics are shown as examples in figures 3 through 6 to illustrate differences due to land use and storm-sewer systems. The illustrations represent a different period of stormwater runoff for each of four watersheds. Thus, they also illustrate differences due to storm characteristics.

The trend in concentrations of biochemical oxygen demand, chemical oxygen demand, total organic carbon, total nitrogen, and total phosphorus in samples from the Artic Street (fig. 3) and Bear Creek (fig. 4) watersheds varied simi-

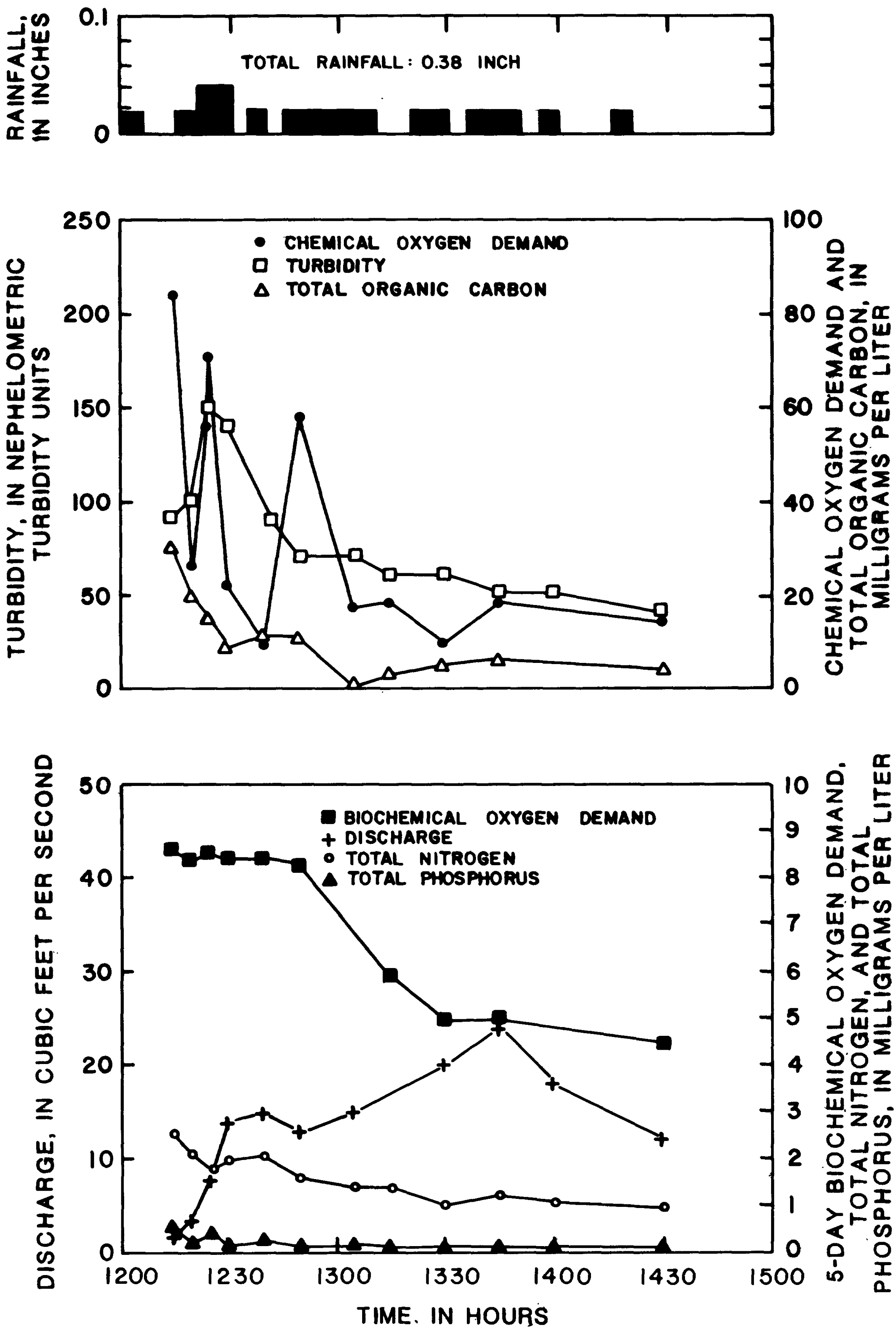

Figure 3.--Rainfall, discharge, and selected water-quality characteristics at Artic Street, 1215 to 1430 hours, August 1, 1978 (site 1, figure 1).

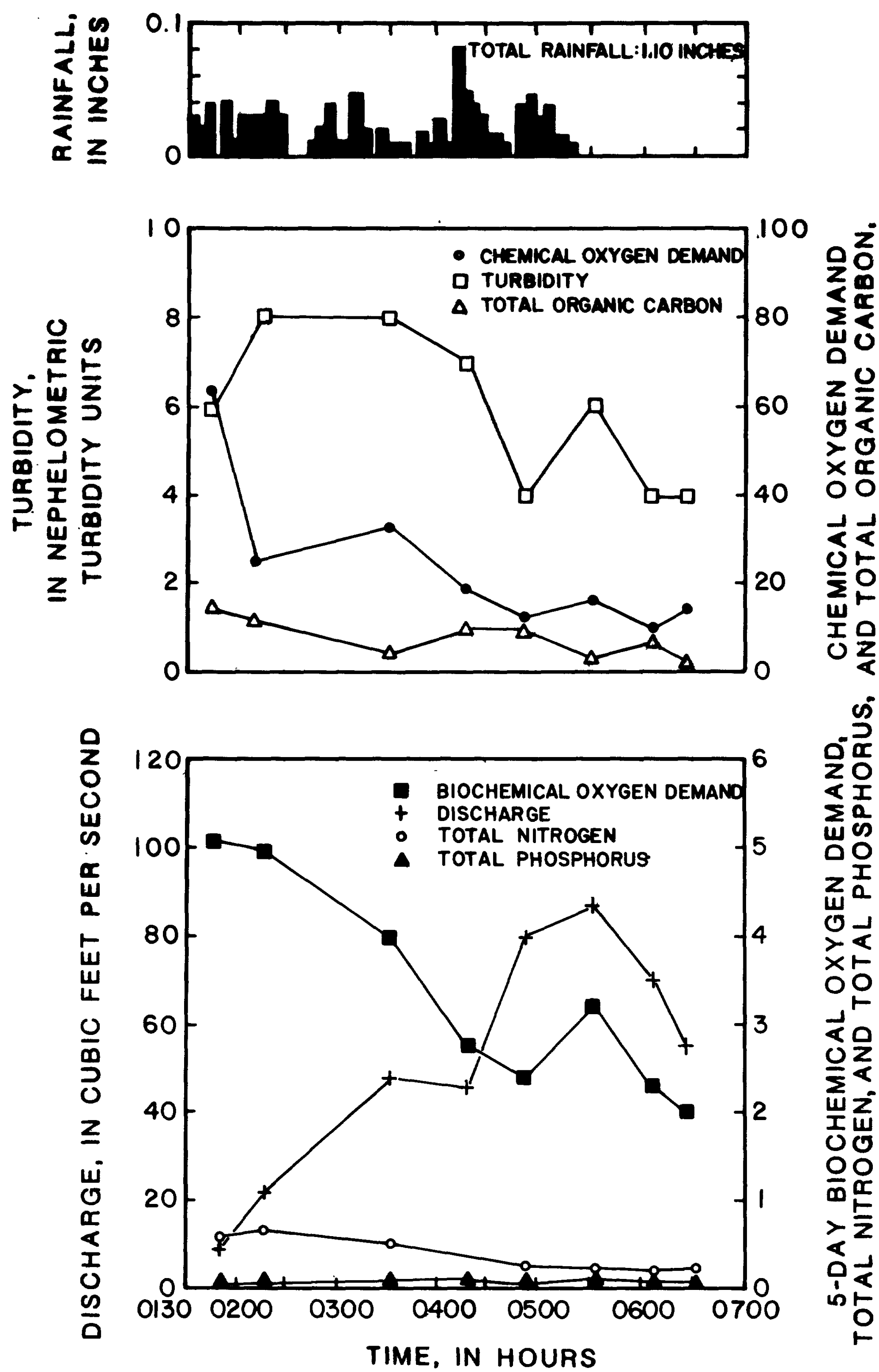

Figure 4.--Rainfall, discharge, and selected water-quality characteristics at Bear Creek, 0145 to 0630 hours, January 12, 1979 (site 8, figure 1).

larly. Generally concentrations of all constituents except total phosphorus decreased with time. Concentrations of total phosphorus varied little with time. The Artic Street watershed is completely sewered and the Bear Creek watershed is sewered to within several hundred yards of the sampling point. Flushing characteristics of these watersheds may be more related to the type of storm-sewer system than to the rainfall and runoff characteristics for individual storms. For example, rainfall intensities were slightly higher near the beginning of stormwater runoff on the Artic Street watershed, but higher intensities occurred near the end of stormwater runoff on the Bear Creek watershed; yet concentrations of all constituents were higher near the start of the stormwater runoff at both stations. Total storm rainfall was different, but the 1-, 2-, 7-, and 14-day antecedent rainfalls were similar: 0.18, 0.31, 0.84, and 2.12 inches at Artic Street and 0.12, 0.15, 0.94, and 2.37 inches at Bear Creek.

In samples collected from these watersheds, constituent concentrations were high at the beginning of the storms and decreased as the storms progressed. Initial concentrations of chemical oxygen demand and total organic carbon were four to five times greater than those occurring near the end of the stormwater runoffs. Initial concentrations of total nitrogen were two to three times greater than those occurring later, whereas the concentrations of total phosphorus did not vary significantly.

Rainfall intensity distributions at Allen Creek (fig. 5) and Booker Creek (fig. 6) were dissimilar, yet all constituent concentrations except for 5-day biochemical oxygen demand, generally increased with stormwater runoff. Antecedent rainfall was also quite different. The 1-, 2-, 7-, and 14-day antecedent rainfalls were 0, 0, 0, and 0.22 inch at Allen Creek and 0, 0.09, 0.11, and 2.62 inches at Booker Creek. Both of these watersheds have open, unlined main channels in the lower section of the storm-sewer system.

Turbidity variations may explain different behavioral patterns of water-quality characteristics in stormwater runoff from different watersheds. Initial runoff tends to flush impervious surfaces connected to a closed drainage system of debris and deposited material and cause turbidities to be high, such as in the Artic Street and Bear Creek watersheds (figs. 3 and 4). As the storm progresses, only material that is washed off the pervious parts of the watershed will contribute to the turbidity of the runoff. In the Allen and Booker Creek watersheds (figs. 5 and 6), as stormwater discharge increases, velocities increase, and materials on the surface are picked up and transported at a proportional rate; thus, peak turbidities occur at high discharges.

Concentrations of the various forms of nitrogen and phosphorus in stormwater runoff from the Artic Street and Allen Creek watersheds are shown in figures 7 and 8. The four forms of nitrogen determined are organic, ammonia, nitrate, and nitrite nitrogen. Organic nitrogen accounted for nearly all of the nitrogen present in runoff, whereas concentrations of ammonia and nitrite nitrogen were negligible. Concentrations of orthophosphate accounted for nearly all of the total phosphorus at the Artic Street station (fig. 7), whereas concentrations of orthophosphate were a much smaller percentage of the total phosphorus at the Allen Creek station (fig. 8). Concentrations of total nitrogen and total phosphorus were lower at the Artic Street station than at the Allen Creek station, which has a higher percentage of residential land use. Fertilizer from lawns and decomposing organic material, such as grass clippings accumulated during a period of low antecedent rainfall, are probably the source of the higher nitrogen and phosphorus concentrations at Allen Creek.

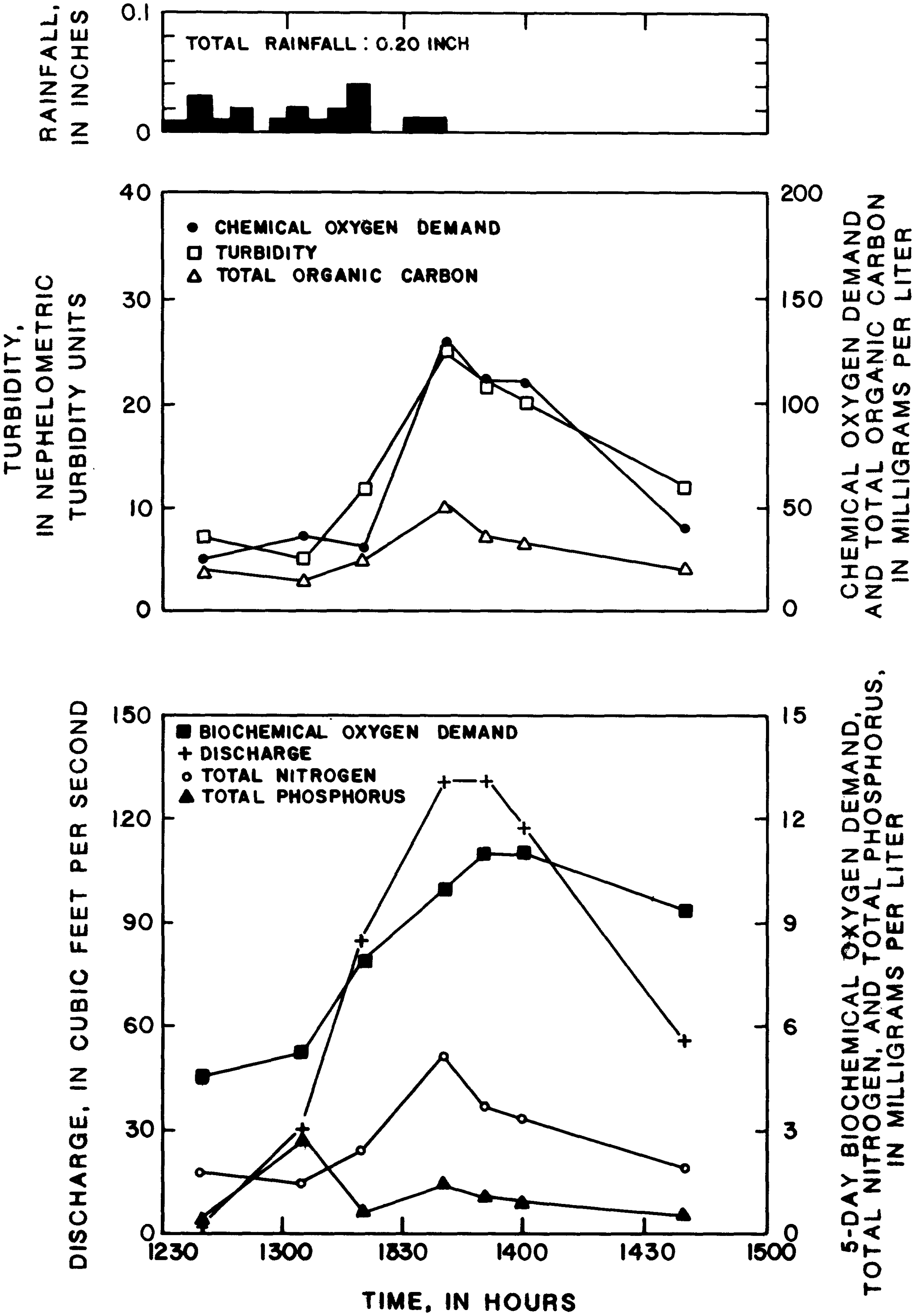

Figure 5.--Rainfall, discharge, and selected water-quality characteristics at Allen Creek, 1240 to 1440 hours, March 13, 1980 (site 5, figure 1).

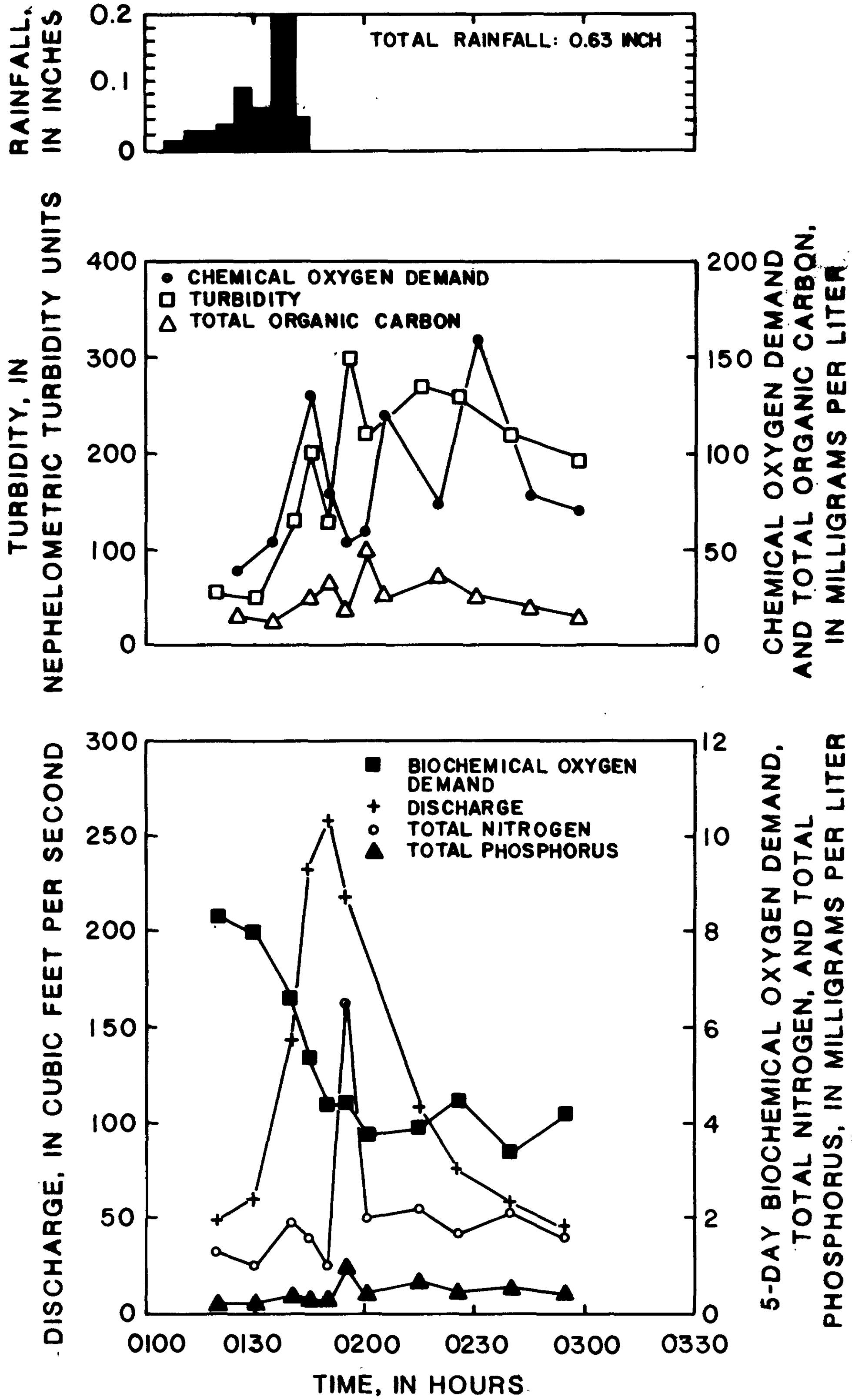

Figure 6.--Rainfall, discharge, and selected water-quality characteristics at Booker Creek, 0120 to 0255 hours, January 24, 1979 (site 6, figure 1).

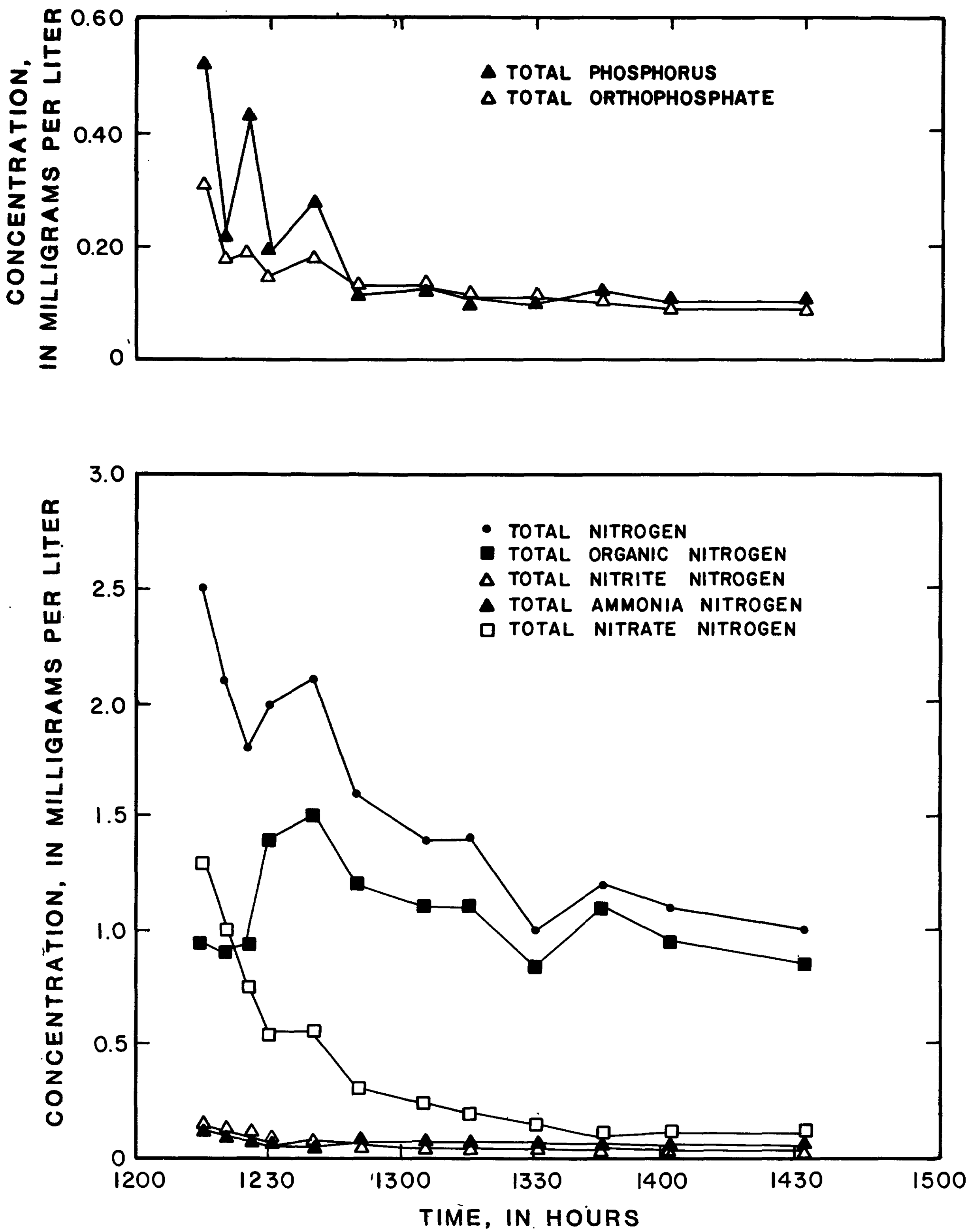

Figure 7.--Concentrations of nitrogen and phosphorus species at Artic Street, 1215 to 1430 hours, August 1, 1978 (site 1, figure 1).

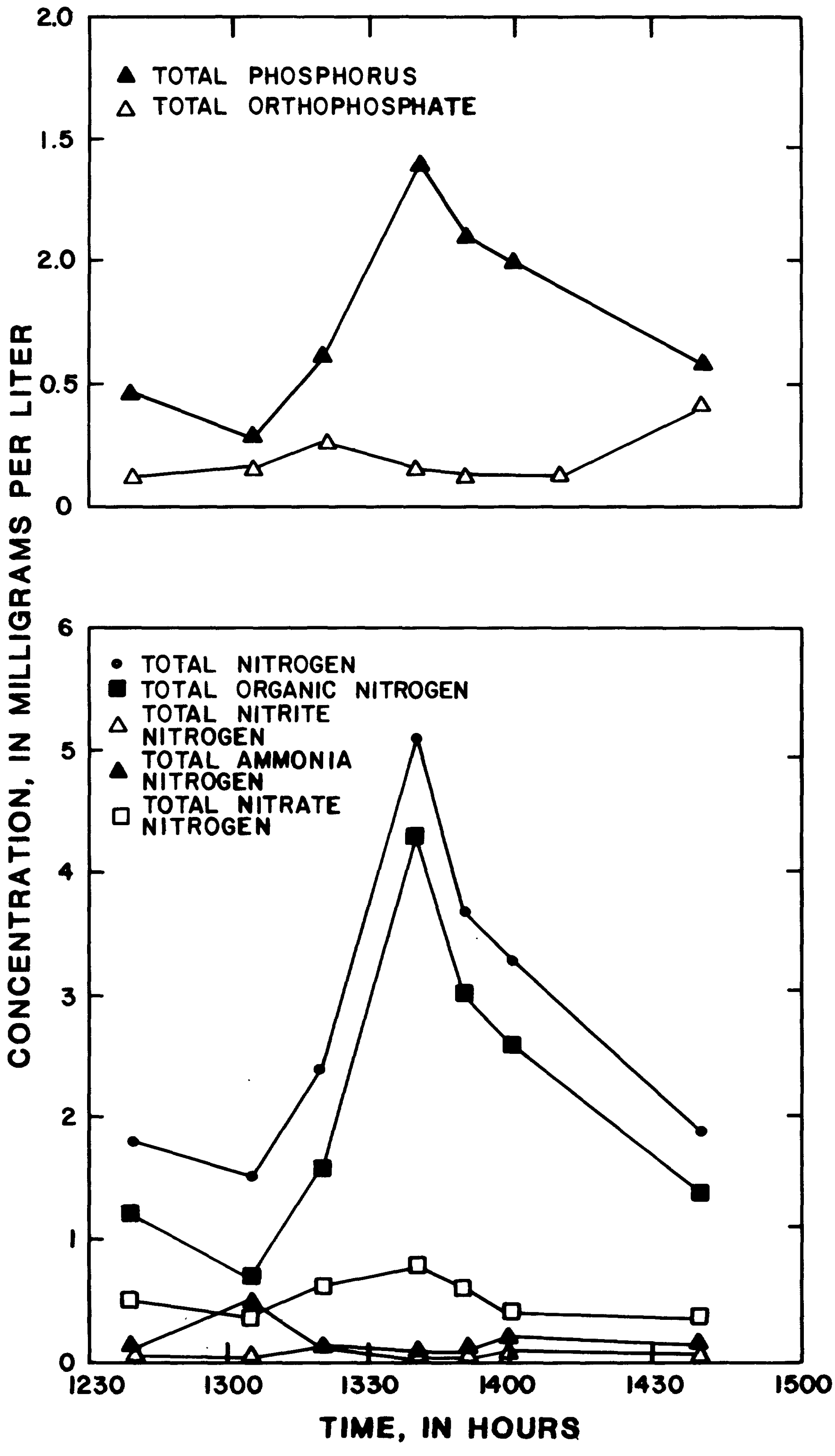

Figure 8.--Concentrations of nitrogen and phosphorus species at Allen Creek, 1240 to 1440 hours, March 13, 1980 (site 5, figure 1).

Variations in concentrations of total and dissolved lead, zinc, and copper in stormwater runoff at the Artic Street and Bear Creek stations are shown in figures 9 and 10, respectively. Trace elements selected in order of decreasing concentration were lead, zinc, and copper. Variations in the concentrations of trace elements with time were very similar to those of the major nutrients for the same storm (figs. 3 and 4). Artic Street watershed exhibited first-flush characteristics for most constituents. That is, concentrations were generally higher at the beginning of stormwater runoff and decreased with time. The variation of constituent concentration with time was not as pronounced for the Bear Creek watershed.

Lead concentrations in stormwater runoff from the Artic Street watershed (fig. 9) were generally 8 to 10 times greater than those found in the runoff from the Bear Creek watershed (fig. 10). A high traffic-density six-lane road that runs the length of the watershed and two shopping-mall parking lots probably are main sources of higher concentrations of lead at the Artic Street station. Concentrations of copper and zinc were also generally higher at the Artic Street station than at the Bear Creek station. In most cases, dissolved concentrations were about 50 percent or less of the total concentrations of trace elements.

PROCEDURE FOR ESTIMATING LOADS OF SUBSTANCES CONTAINED IN RUNOFF FROM UNGAGED URBAN WATERSHEDS

Regression equations were developed for estimating loads of substances contained in runoff from ungaged urban watersheds in the Tampa Bay area. Equations were developed for selected substances represented by the following water-quality characteristics: biochemical oxygen demand, chemical oxygen demand, total nitrogen, total organic nitrogen, total phosphorus, and total lead. Use of the regression equations requires daily rainfall data representative of the watershed involved.

The regression procedure selected consisted of a variation of the step-forward regression analysis method (Wesolowsky, 1976) for selecting independent variables. The stepwise procedure essentially tests all combinations of independent variables and produces the best one, two, three, and so forth, parameter models. The significant variables are selected as those that induce the greatest improvement of the R^2 statistic (square of the multiple correlation coefficient). For each constituent, choice of a final prediction equation depends on the significance of the independent variables and the degree of improvement in the standard error of estimate.

Stormwater Load

Stormwater load is the quantity of a substance contained in stormwater runoff from a given watershed. Loads are computed as the product of instantaneous values of discharge rates and concentrations of water-quality constituents sampled. Computations include a time factor that converts discharge rates to incremental volumes, the sum of which provides a close approximation of the total volume of stormwater runoff.

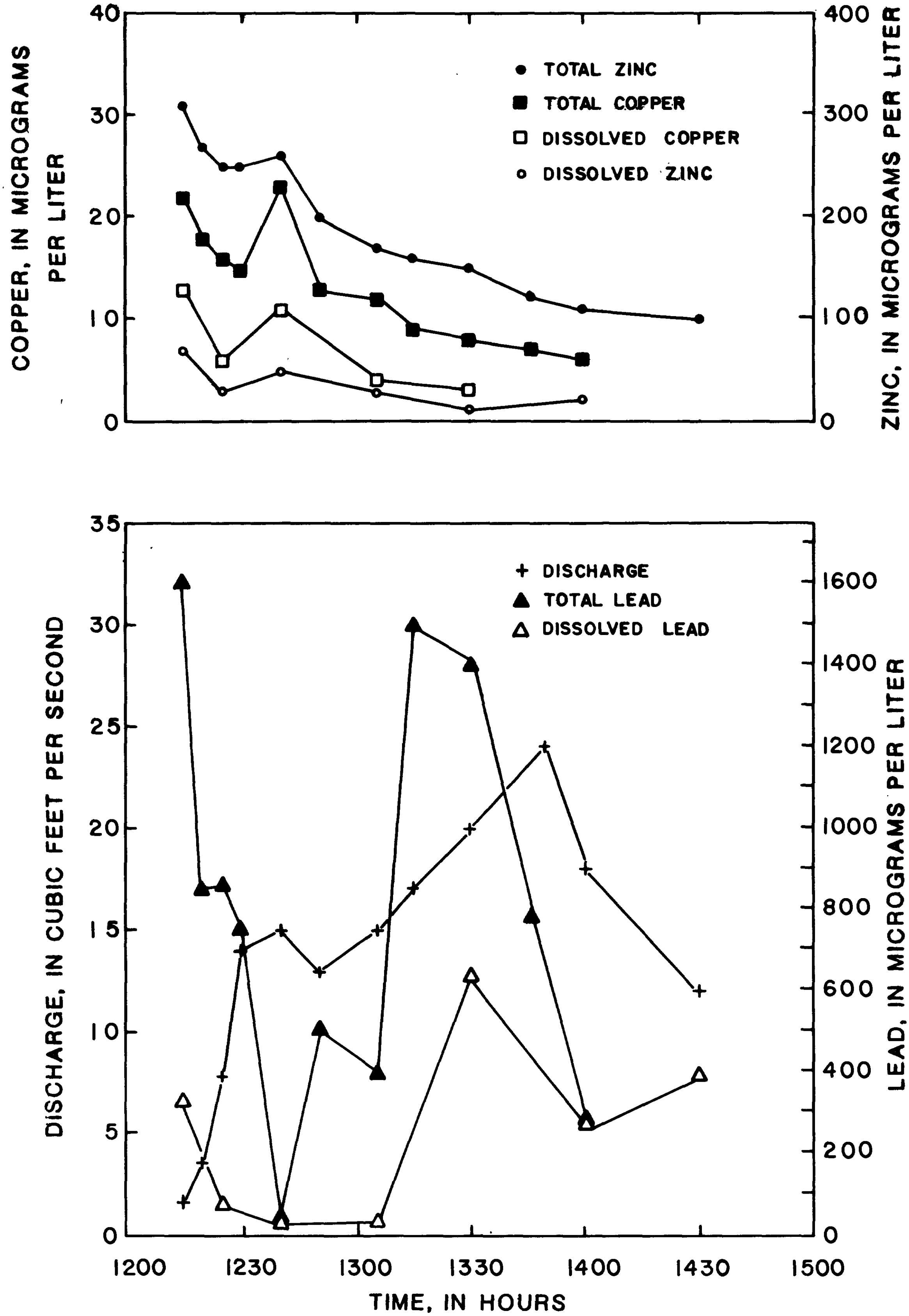

Figure 9.--Concentrations of total and dissolved lead, zinc, and copper at Artic Street, 1215 to 1430 hours, August 1, 1978 (site 1, figure 1).

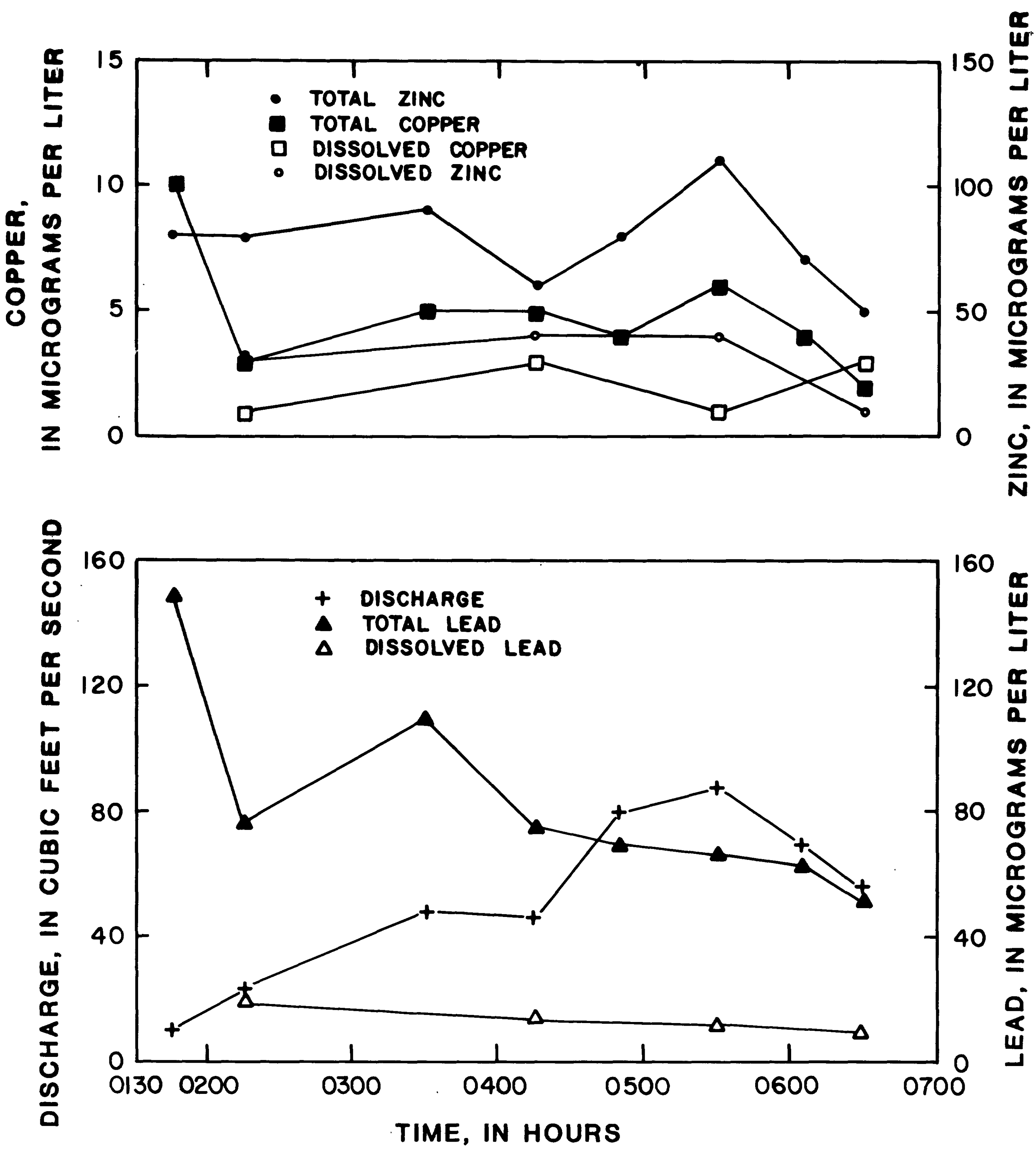

Figure 10.--Concentrations of total and dissolved lead, zinc, and copper at Bear Creek, 0145 to 0630 hours, January 12, 1979 (site 7, figure 1).

Because of the rapidity at which discharge and concentration sometimes change, computations were done for 5-minute intervals. Five-minute concentration values were estimated by linear interpolation between concentrations determined from water samples. If water samples were lacking for the start or end of stormwater runoff, concentrations were estimated by linear interpolation between the nearest available measurement and an assumed starting or ending value equal to the average concentration of the given water-quality parameter as determined from base-flow samples. As an example, the measured and interpolated chemical oxygen demand concentrations at St. Louis Street drainage ditch during the storm of July 31, 1975, are shown in figure 11. The first sample was collected at 1610 before the start of stormwater runoff, and the last sample was collected at 1800 before the end of stormwater runoff. Concentrations were interpolated between samples from 1610 to 1800. From 1805 to end of stormwater runoff at 2100 hours, concentrations were estimated by extrapolation to 44 mg/L on the basis of the average chemical oxygen demand base-flow concentration from table 6. Stormwater loads computed by this method for biochemical oxygen demand, chemical oxygen demand, total nitrogen, total organic nitrogen, total phosphorus, and total lead are listed in table 14.

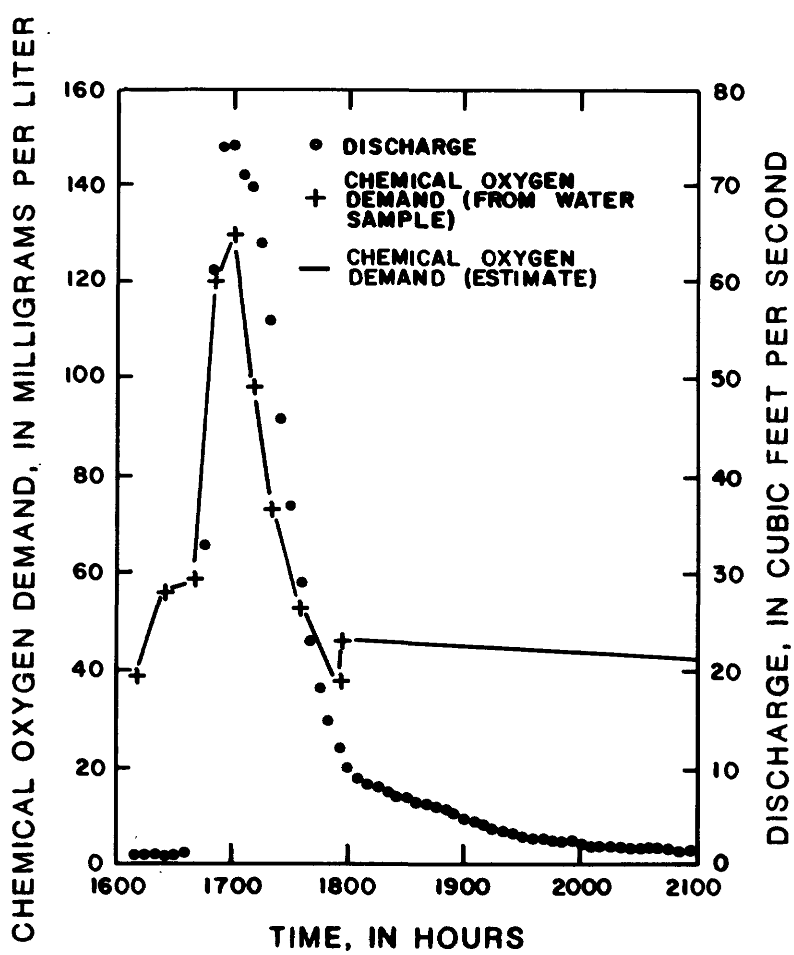

Figure 11.--Discharge and chemical oxygen demand at St. Louis Street, 1600 to 2100 hours, July 31, 1975 (site 3, figure 1).

Table 14.--Water-quality constituent loads for selected storms

Site no. (fig. 1)	Station name	Date	Number of samples	Total runoff volume (acre-ft)	Volume from first to last sample, in percent of total	Load, in pounds					
						Biochemical oxygen demand	Chemical oxygen demand	Total nitrogen	Total organic nitrogen	Total phosphorus	Total lead
1	Artic Street storm drain at Tampa, Fla.	08-09-77	5	4.78	70	65.3	857	18.7	11.0	4.3	-
		08-01-78	12	3.67	82	54.6	184	12.4	10.0	1.4	6.4
2	Kirby Street drainage ditch at Tampa, Fla.	08-02-79	9	10.5	38	180	1,390	67.1	36.9	7.7	1.4
3	St. Louis Street drainage ditch at Tampa, Fla.	07-31-75	11	5.81	80	79.2	1,320	-	25.3	6.0	3.8
		08-20-75	11	3.96	91	71.9	468	-	18.8	3.6	2.8
		01-02-79	6	4.15	100	307	-	25.8	24.5	9.1	2.2
		08-23-79	11	7.12	97	112	924	54.4	37.9	7.2	1.5
		08-27-79	4	4.56	100	80.1	580	21.7	16.1	4.9	2.0
4	Gandy Boulevard drainage ditch at Tampa, Fla.	08-08-75	12	35.8	100	512	3,480	-	56.7	34.3	13.4
		01-02-79	8	16.3	100	126	911	34.4	26.5	11.8	6.6
5	Allen Creek near Largo, Fla.	07-16-75	12	72.0	100	675	7,170	-	251	69.4	22.9
		07-25-77	5	14.2	93	188	-	55.3	38.2	19.8	1.1
		08-01-77	6	8.58	99	31.4	519	13.1	6.9	3.0	0.5
		08-09-77	4	2.19	99	8.2	157	5.1	3.6	0.8	0.1
		03-13-80	7	18.9	95	468	3,500	141	106.9	40.1	7.6

Table 14.--Water-quality constituent loads for selected storms--Continued

Site no. (fig. 1)	Station name	Date	Number of samples	Total runoff volume (acre-ft)	Volume from first to last sample, in percent of total	Load, in pounds					
						Biochemical oxygen demand	Chemical oxygen demand	Total nitrogen	Total organic nitrogen	Total phosphorus	Total lead
6	Booker Creek at St. Petersburg, Fla.	01-24-79	11	32.1	45	397	7,940	162	139	48.7	18.9
7	Bear Creek at St. Petersburg, Fla.	09-11-75	9	28.9	75	-	3,750	-	48.5	21.5	10.1
		01-12-79	8	29.3	71	215	1,330	25.2	2.9	7.3	5.4
8	Saint Joes Creek at St. Petersburg, Fla.	08-29-75	6	13.1	33	12.5	3,750	-	61.1	9.0	12.1
9	Turner Street storm drain at Clearwater, Fla.	08-08-77	4	1.48	55	60.2	570	9.7	4.8	2.1	
		12-27-78	5	2.83	27	24.4	462	4.2	2.8	1.6	3.2

The stormwater loads from table 14 were used in a multiple linear-regression analysis that includes land use, antecedent rainfall, and stormwater-runoff volume as independent variables. The eight land-use classifications listed in table 1 were combined into three major categories (residential, developed, and natural) to combine land uses that have similar influences on runoff volumes and water quality. Residential consisted of single-family and multifamily residential land uses including the roads within the area. Developed consisted of commercial, industrial, and institutional land uses including the roads within the area. Natural consisted of recreational and open space land uses. Combined percentages of land use for these three categories were converted to area in square miles and are listed in table 15. Storm rainfall and variables related to antecedent rainfall are listed in table 16.

Stepwise regression analysis of stormwater loads and various independent variables was performed. Results of the regression analyses are summarized in table 17. All independent variables were significant at the 95 percent level and appear in order of decreasing significance. The number of samples used, multiple correlation coefficient, and average standard error of estimate are also listed in table 17.

The ranges and definitions of input data for the stormwater-load equations are as follows:

Variable	Minimum	Maximum
RVAF	1.48	72
DEVT	.06	1.02
RF14	.07	4.11
RF7	0	2.50
RF2	0	1.32
DRYDAYS	0	16

where RVAF = Stormwater-runoff volume, in acre feet;

DEVT = Developed land area, in square miles;

RF14 = Amount of rainfall during the preceding 14 days, in inches;

RF7 = Amount of rainfall during the preceding 7 days, in inches;

RF2 = Amount of rainfall during the preceding 2 days, in inches;

DRYDAYS = Number of days prior to the storm with less than 0.1 inch of rainfall.

Stormwater-runoff volume (RVAF) was the most significant independent variable in all regression equations. Developed land area (DEVT) was the second most significant variable in the stormwater-load equations for chemical oxygen demand, total nitrogen, total phosphorus, and total lead. This indicates that the loads for these constituents are partly related to the amount of development (commercial, industrial, institutional) in the watershed. Antecedent rainfall (RF2, RF7, and RF14) indicates the amount of rain available during the antecedent period to flush the watershed of pollutants, and the last variable (DRYDAYS) indicates the number of days available for pollutants to accumulate.

Table 15.--Watershed and land-use variables used in regression analyses of loads and concentrations of selected water-quality constituents

Site no. (fig. 1)	Station name	Drainage area, in square miles	Total[1/] residential area, in square miles	Total[2/] developed area, in square miles	Total[3/] natural area, in square miles
1	Artic Street storm drain at Tampa, Fla.	0.34	0.18	0.15	0.01
2	Kirby Street drainage ditch at Tampa, Fla.	1.40	1.06	.10	.24
3	St. Louis Street drainage ditch at Tampa, Fla.	.51	.39	.06	.06
4	Gandy Boulevard drainage ditch at Tampa, Fla.	1.29	.52	.35	.42
5	Allen Creek near Largo, Fla.	1.79	1.25	.30	.24
6	Booker Creek at St. Petersburg, Fla.	3.45	2.01	1.02	.42
7	Bear Creek at St. Petersburg, Fla.	1.89	1.52	.25	.12
8	Saint Joes Creek at St. Petersburg, Fla.	1.72	.94	.50	.28
9	Turner Street storm drain at Clearwater, Fla.	.45	.20	.25	0

[1/] Sum of single-family and multifamily land-use areas including roads (table 1).

[2/] Sum of commercial, industrial, and institutional land-use areas including roads (table 1).

[3/] Sum of open space and recreational land-use areas including roads (table 1).

Table 16.--Rainfall data used in regression analysis of stormwater-runoff loads

Site no. (fig. 1)	Station name	Date	Total storm rainfall, in inches	Antecedent rainfall for indicated number of days, in inches				Number of days prior to storm with less than 0.10 inch of rainfall
				1	2	7	14	
1	Artic Street storm drain at Tampa, Fla.	08-09-77	0.91	0.06	0.08	0.53	2.31	3
		08-01-78	.38	.18	.31	.84	2.12	0
2	Kirby Street drainage ditch at Tampa, Fla.	08-02-79	.33	0	0	0	.07	16
3	St. Louis Street drainage ditch at Tampa, Fla.	07-31-75	1.19	.14	.14	1.22	1.98	0
		08-20-75	.85	0	0	.63	1.98	2
		01-02-79	1.35	0	0	1.69	1.95	4
		08-23-79	.10	0	0	1.19	1.29	3
		08-27-79	.70	0	0	.13	1.32	3
4	Gandy Boulevard drainage ditch at Tampa, Fla.	08-08-75	.70	1.31	1.32	1.56	4.07	0
		01-02-79	1.21	.01	.02	1.90	2.17	4
5	Allen Creek near Largo, Fla.	07-16-75	.70	.02	.03	2.50	2.97	2
		07-25-77	.16	.03	.12	1.22	1.76	1
		08-01-77	.44	0	0	.73	1.95	3
		08-09-77	.11	.25	.25	.62	1.89	0
		03-13-80	.20	0	0	0	.22	11
6	Booker Creek at St. Petersburg, Fla.	01-24-79	.63	.09	.11	.55	2.62	1
7	Bear Creek at St. Petersburg, Fla.	09-11-75	.77	.14	.14	.47	2.56	0
		01-12-79	1.10	.12	.15	.94	2.37	0
8	Saint Joes Creek at St. Petersburg, Fla.	08-29-75	.81	0	0	.09	4.11	7
9	Turner Street storm drain at Clearwater, Fla.	08-08-77	.17	0	0	.30	.41	3
		12-27-78	.71	0	0	.50	.50	2

Table 17.--Regression equations for estimating stormwater-runoff loads for selected water-quality constituents

Number of storms	Regression equation (results in pounds)	Correlation coefficient	Standard error	
			Pounds	Percent of mean
20	Biochemical oxygen demand = 92.4+10.5(RVAF)-32.8(RF14)	0.87	99	±54
19	Chemical oxygen demand = -101+105(RVAF)+4200(DEVT)-812(RF7)	.94	847	±41
15	Total nitrogen = -217+1.70(RVAF)+106(DEVT)+5.36(DRYDAYS)	.87	27	±62
21	Total organic nitrogen = 1.66+3.20(RVAF)-49.4(RF2)	.88	29	±65
21	Total phosphorus = 1.55+0.97(RVAF)+20.4(DEVT)-3.43(RF14)	.92	7.6	±51
19	Total lead = -0.62+0.27(RVAF)+9.82(DEVT)	.91	2.7	±44

RVAF is stormwater-runoff volume, in acre-feet.

RF14 is rainfall in previous 14 days, in inches.

DEVT is area of watershed in commercial, industrial, and institutional land use, in square miles (table 15).

RF7 is rainfall in previous 7 days, in inches.

RF2 is rainfall in previous 2 days, in inches.

DRYDAYS is number of days prior to storm with less than 0.10 inch of rainfall.

Stormwater-Runoff Volumes

A nonlinear regression was used to relate runoff volume to storm rainfall. The model was formulated to represent storm runoff in inches, RUNIN, in terms of storm rainfall in inches, TSTMRF. Base-10 log transforms were used in the following equation at each gage:

$$\log \text{RUNIN} = \log \text{B1} + \text{B3} \cdot \log (\text{TSTMRF} - \text{B2}) \tag{1}$$

where B1, B2, B3 = Regression coefficients;
RUNIN = Storm runoff, in inches;
TSTMRF = Storm rainfall that caused the runoff (RUNIN), in inches.

Data for 141 storms on the nine watersheds were used in the analysis (table 18). Estimates of B1, B2, and B3 for each watershed were determined iteratively by the multivariate secant or false position method. The best-fit model estimates of these variables are listed in table 19. The results of the comparison between the estimated and observed runoff are also shown in table 19. An intercept of zero and a slope of one indicates a perfect fit.

To estimate runoff volume from ungaged watersheds, the nonlinear-regression coefficients were related to urban development characteristics (table 2) and the soil-infiltration index (fig. 2) by multiple linear regression. The regression estimates of the nonlinear-equation coefficients are:

$$\text{B1} = 0.0510 + 0.00652 \cdot \text{HCIA} \tag{2}$$

$$\text{B2} = 0.0808\ (\text{DETA}+1)^{0.479} \cdot \text{PERSOIL}^{0.261} \tag{3}$$

$$\text{B3} = 1.97 \cdot \text{HCIA}^{-0.145} \tag{4}$$

where HCIA = Hydraulically connected impervious surface, in percent of drainage area;
DETA = Percentage of drainage area surface in lakes, ponds, or detention basins;
PERSOIL = Product of (100 - TIA)/100 (table 2) and the soil-infiltration index, SOIL (fig. 2), in inches.

The average square of the multiple correlation coefficient of the comparison of regional estimate and observed runoff volume is 0.93. The standard error of estimate is ±20 percent and ranges from ±14 to ±26 percent (table 20). The ranges of input data were as follows:

Variable	Minimum	Maximum	Units of measurement
RUNIN	0.04	1.60	inches
TSTMRF	.25	5.07	inches
HCIA	5.5	53	percent
TIA	19	61	percent
SOIL	2.05	3.89	inches
DETA	0	3.5	percent

Table 18.--Rainfall and runoff volumes for selected storms

Site no. (fig. 1)	Station name	Date	Rainfall (inches)	Runoff (inches)
1	Artic Street storm drain at Tampa, Fla.	10-18-75	0.84	0.28
		08-02-76	.50	.12
		08-09-77	.91	.27
		09-15-77	.32	.07
		01-19-78	.87	.41
		06-19-78	.62	.20
		08-10-78	.67	.26
		08-15-78	.47	.10
		01-12-79	.96	.41
2	Kirby Street drainage ditch at Tampa, Fla.	07-19-75	2.58	.27
		05-15-76	3.95	.74
		06-18-76	2.58	.40
		07-28-77	2.00	.21
		09-18-77	2.63	.28
		05-04-78	1.40	.09
3	St. Louis Street drainage ditch at Tampa, Fla.	06-08-75	1.49	.23
		06-18-75	2.54	.57
		07-15-75	1.01	.11
		07-31-75	1.19	.19
		06-18-76	2.27	.37
		06-20-76	.76	.06
		07-04-77	1.07	.12
		10-12-77	1.03	.14
		12-01-77	.46	.04
		04-13-78	.69	.06
		08-15-78	.95	.12
		12-01-78	.51	.04
		05-14-79	.50	.05
		05-24-79	2.27	.40
		06-21-79	.92	.11
		06-28-79	2.27	.35
		07-23-79	2.69	.61
4	Gandy Boulevard drainage ditch at Tampa, Fla.	08-25-77	.51	.10
		09-02-77	.66	.13
		09-12-77	1.25	.25
		09-15-77	.56	.09
		09-17-77	.88	.14
		09-18-77	.70	.17
		09-23-77	.47	.12
		11-23-77	.67	.17
		01-13-78	.72	.11
		02-16-78	.90	.15

Table 18.--Rainfall and runoff volumes for selected storms--Continued

Site no. (fig. 1)	Station name	Date	Rainfall (inches)	Runoff (inches)
4	Gandy Boulevard drainage ditch at Tampa, Fla.	02-18-78	1.75	0.39
		03-03-78	1.03	.18
		04-13-78	.37	.05
		05-04-78	1.50	.28
		07-16-78	1.98	.43
		08-01-78	1.47	.33
		08-09-78	2.29	.73
		08-30-78	1.46	.35
		01-23-79	1.06	.23
5	Allen Creek near Largo, Fla.	06-08-75	.86	.27
		08-16-76	.94	.33
		08-12-77	.47	.14
		08-22-77	1.30	.44
		09-02-77	.36	.08
		09-03-77	.68	.19
		12-09-77	.71	.14
		01-08-78	.30	.07
		01-19-78	.34	.11
		02-16-78	.63	.15
		03-09-78	.66	.18
		08-09-78	.45	.09
		09-11-78	.41	.07
		09-24-78	.83	.18
		12-05-78	.42	.08
		08-11-79	.83	.18
		08-12-79	.55	.12
6	Booker Creek at St. Petersburg, Fla.	05-26-75	1.86	.28
		08-29-75	.55	.08
		09-05-76	.39	.06
		07-03-77	.75	.11
		08-01-77	1.18	.17
		05-04-78	1.94	.36
		07-14-79	2.14	.48
		07-29-79	.66	.16
		08-22-79	1.37	.23
		08-30-79	1.92	.49
7	Bear Creek at St. Petersburg, Fla.	05-15-75	1.03	.29
		05-26-75	2.28	.93
		05-27-75	1.01	.26
		06-21-75	1.56	.42
		07-17-75	1.13	.34

Table 18.--Rainfall and runoff volumes for selected storms--Continued

Site no. (fig. 1)	Station name	Date	Rainfall (inches)	Runoff (inches)
7	Bear Creek at St. Petersburg, Fla.	07-21-76	0.96	0.32
		07-22-76	.97	.34
		07-03-77	2.00	.83
		07-11-77	1.51	.41
		08-01-77	1.66	.55
		08-03-77	.61	.13
		08-04-77	.45	.09
		08-11-77	1.34	.34
		08-30-77	.53	.12
		09-22-77	.71	.19
		07-04-79	1.05	.35
		07-07-79	.83	.31
		08-11-79	1.64	.67
		08-12-79	1.06	.42
		08-24-79	1.97	.76
		09-25-79	1.78	.63
8	Saint Joes Creek at St. Petersburg, Fla.	06-18-75	1.65	.50
		07-13-75	5.07	1.60
		07-16-75	1.85	.35
		07-31-75	.71	.16
		03-05-76	.57	.14
		07-22-76	1.57	.53
		08-17-76	2.62	.66
		05-31-77	3.24	.77
		07-04-77	.25	.08
		08-01-77	.43	.12
		09-03-77	2.54	.67
		08-06-78	.96	.18
9	Turner Street storm drain at Clearwater, Fla.	08-10-77	.96	.14
		08-11-77	1.42	.20
		08-12-77	1.89	.26
		11-23-77	.94	.10
		12-25-77	.44	.07
		12-30-77	.52	.06
		01-08-78	.62	.08
		01-13-78	.79	.12
		01-17-78	.69	.09
		01-19-78	1.31	.15
		02-08-78	.93	.13
		02-16-78	1.24	.18
		07-16-78	.81	.13
		07-18-78	1.26	.23
		08-03-78	1.43	.26

Table 18.--Rainfall and runoff volumes for selected storms--Continued

Site no. (fig. 1)	Station name	Date	Rainfall (inches)	Runoff (inches)
9	Turner Street storm drain at Clearwater, Fla.	08-08-78	1.86	0.23
		08-09-78	.47	.07
		09-23-78	1.80	.26
		10-12-78	.97	.14
		10-14-78	1.83	.35
		02-24-79	.48	.07
		05-24-79	.87	.13
		08-02-79	2.26	.41
		08-08-79	1.53	.33
		08-11-79	1.82	.31
		08-29-79	1.99	.27
		08-30-79	1.56	.20
		08-31-79	1.47	.23
		09-13-79	.94	.15
		09-29-79	1.84	.29

Table 19.--Nonlinear-regression equation variables for estimating storm runoff volume at nine urban watersheds in the Tampa Bay area, Florida

Site no. (fig. 1)	Nonlinear-regression variables			Comparison of estimated and observed runoff volume		
	B1	B2	B3	Intercept	Slope	Standard error, in percent
1	0.40	0.10	1.20	-0.044	0.94	±18
2	.071	.20	1.50	- .027	.95	±16
3	.10	.10	1.50	.019	1.03	±14
4	.20	.10	1.20	- .017	1.00	±21
5	.20	.10	1.20	- .035	.98	±22
6	.20	.10	1.20	- .008	1.13	±21
7	.30	.20	1.20	- .028	.94	±16
8	.20	.10	1.20	.005	1.03	±21
9	.10	.10	1.20	- .040	1.10	±23

Table 20.--Comparison of regional estimate and observed storm runoff volume at nine urban watersheds in the Tampa Bay area, Florida

Site no. (fig. 1)	Regional estimate of variables			Comparison of regional estimate versus observed runoff volume		
	B1	B2	B3	Intercept	Slope	Standard error, in percent
1	0.40	0.12	1.11	-0.17	0.75	±15
2	.087	.22	1.54	- .082	.82	±14
3	.11	.090	1.43	- .10	1.01	±15
4	.23	.085	1.21	.034	1.08	±23
5	.22	.085	1.23	- .20	1.05	±26
6	.22	.085	1.23	.11	1.04	±22
7	.21	.070	1.23	- .22	1.04	±17
8	.22	.058	1.23	.001	1.13	±23
9	.27	.058	1.19	.18	.98	±22

Base-Flow Load

Base flow makes up a significant part of the total annual discharge of urban storm-drainage systems in the Tampa Bay area. Consequently, urban-runoff loads should include loads of substances contained in base flow. Base-flow loads can be determined for specific water-quality characteristics if the constituent concentration and the daily discharge are known or can be estimated.

Data for the nine watersheds of the Tampa Bay area were used to develop regression equations for estimating base-flow discharge and concentrations of selected water-quality characteristics. These equations provide the basis for estimating base-flow loads of substances from ungaged watersheds in the Tampa Bay area.

Base-Flow Concentrations

Water-quality data collected during periods of base flow were related to indices of urban development, land use, soil-infiltration index, antecedent rainfall, and base-flow daily discharge per square mile of drainage area by multiple linear-regression techniques. Regression equations were developed for biochemical oxygen damand, chemical oxygen demand, total nitrogen, total organic nitrogen, total phosphorus, and total lead. The equations, summarized in table 21, provide daily concentrations of each constituent in milligrams per liter.

Table 21.--Regression equations for estimating base-flow concentrations of selected water-quality constituents

Number of samples	Concentration, in milligrams per liter	Correlation coefficient, R	Standard error, in percent
26	Biochemical oxygen demand = $0.0094 \cdot BDF^{1.88} \cdot SOIL^{2.82} \cdot (DRYDAYS+1)^{-0.426}$	0.84	±60
17	Chemical oxygen demand = $0.334 \cdot BDF^{1.36} \cdot SOIL^{2.01} \cdot (NATT+1)^{0.276} \cdot (RF7+1)^{-0.482}$	.81	±33
15	Total nitrogen = $0.284 \cdot (DRYDAYS+1)^{-0.665} \cdot ROADS^{-1.59} \cdot TIA^{1.76}$	.72	±37
25	Total organic nitrogen = $46.1 \cdot (REST+1)^{-0.990} \cdot SOIL^{0.640} \cdot (DRYDAYS+1)^{-0.196}$	.53	±58
24	Total phosphorus = $0.273 \cdot (DRYDAYS+1)^{-0.495} \cdot (DEVT+1)^{0.589} \cdot (NATT+1)^{0.310}$	.77	±58
11	Total lead = $22.5 \cdot CFSM^{-0.393} \cdot HCIA^{0.627} \cdot (DRYDAYS+1)^{-0.550}$	.88	±57

BDF is basin development factor (table 2).
SOIL is soil-infiltration index (figure 2).
NATT is total natural area, in square miles (table 15).
DRYDAYS is number of consecutive days when antecedent rainfall was less than 0.1 inch.
RF7 is total rainfall in preceding 7 days, in inches.
ROADS is percentage of drainage area covered by roads (table 1).
TIA is percentage of drainage area covered by impervious surfaces (table 2).
REST is total area of residential land use, in square miles (table 15).
DEVT is total area of commercial, industrial, and institutional land use, in square miles (table 15).
CFSM is base-flow daily discharge, in cubic feet per second, divided by drainage area, in square miles (table 15).
HCIA is percentage of drainage area covered by hydraulically connected impervious surfaces (table 2).

Concentrations of biochemical oxygen demand and chemical oxygen demand are mainly influenced by the basin development factor (BDF). High values of BDF are associated with closed storm-sewer systems that reduce air circulation over the water thereby inhibiting oxidation processes. Concentrations of the other constituents in base flow are less related to the storm-drainage system characteristics. The concentrations seem to vary directly with factors that influence the source of material carried into the drainage system and inversely by factors that influence base flow. Antecedent rainfall expressed as (RF7 + 1) or (DRYDAYS + 1) is inversely related to concentration in each of the equations.

Although some land-use categories and measures of impervious area are interrelated, the combined effect on either the source of the constituents or base-flow rate explains their use in the equation. For instance, total impervious area (TIA) is directly related to total organic nitrogen, whereas ROADS, one of the land uses that is impervious, is inversely related. TIA is always greater than ROADS, and as the ratio $\frac{\text{TIA}}{\text{ROADS}}$ increases, the volume of runoff increases, thereby carrying more material into the storm-drainage system. During base flow, this material is available as the source of the constituents.

Base-Flow Discharge

Discharge measurements of base flow were made on days when rainfall was zero or negligible. Flow measurements were related to watershed-drainage area and antecedent rainfall (table 22) by multiple linear-regression techniques. The resulting regression equation, which provides estimates of base-flow daily discharge, is as follows:

$$\text{BASEQ} = 0.19\ \text{DAREA}^{1.67} \cdot (\text{RF14} + 1)^{0.66} \qquad (5)$$

where BASEQ = Base-flow daily discharge, in cubic feet per second;
DAREA = Drainage area, in square miles;
RF14 = 14-day antecedent rainfall, in inches.

The multiple correlation coefficient for this equation is 0.94 and the average standard error of estimate is ±45 percent. The ranges of input data were as follows:

Variable	Minimum	Maximum
BASEQ	0.08	6.92
DAREA	.51	3.45
RF14	.02	7.43

Accuracy of Load Estimates

Some precautionary measures are required for valid use of the regression equations for computing runoff volumes and water-quality constituent loads. Until otherwise shown, they are applicable only to urban watersheds in the Tampa Bay area. Further, the equations are empirically derived and, as is true for all empirical relations, are strictly applicable only in instances where values of the independent variables involved fall within the range of values used in their formulation.

Table 22.--Data used in regression analysis of base-flow daily discharge

Site no. (fig. 1)	Station name	Date	Drainage area, in square miles	Daily rainfall, in inches	Antecedent rainfall for 14 days, in inches	Discharge, in cubic feet per second
2	Kirby Street drainage ditch at Tampa, Fla.	11-16-76	1.40	0	1.83	0.31
		10-26-78		0	.44	.17
3	St. Louis Street drainage ditch at Tampa, Fla.	11-16-76	0.51	0	1.47	.12
		10-26-78		.01	.34	.08
4	Gandy Boulevard drainage ditch at Tampa, Fla.	10-26-78	1.29	0	.17	.37
5	Allen Creek near Largo, Fla.	11-17-76	1.79	.01	.44	.81
		10-24-78		0	.90	.89
6	Booker Creek at St. Petersburg, Fla.	10-01-74	3.45	.01	3.80	4.36
		07-19-75		0	7.43	6.92
		11-17-76		0	.02	1.26
		11-26-78		.05	.27	1.29
7	Bear Creek at St. Petersburg, Fla.	08-26-75	1.89	.02	1.87	1.39
		11-17-76		0	.28	1.14
		10-25-78		.01	1.55	1.10
8	Saint Joes Creek at St. Petersburg, Fla.	10-25-78	1.72	.01	.39	.98

At an ungaged site, an estimate of storm-runoff volume will be computed by equation 1, and this estimate will have an error associated with it. To evaluate the possible magnitude of this error in the computation of storm load, the regression estimate for runoff volume (equation 1) was used in the multiple linear regression instead of the observed volume. The standard errors were as follows:

Constituent load	Standard error, in percent of the mean
Biochemical oxygen demand	±99
Chemical oxygen demand	±82
Total nitrogen	±69
Total organic nitrogen	±137
Total phosphorus	±109
Total lead	±79

Except for error for total nitrogen, these standard errors are greater than the sum of the runoff-volume estimate (±20 percent) and the constituent load estimates (table 17). The reason for this may be that the rainfall recorded during the storms that were sampled were not representative of the rainfall over the watershed. Only 2 of the storms for which storm loads were computed (table 14) were in the 141 storms used for the runoff-volume regressions (table 18). The regression estimates for constituent loads and runoff volume are applied to ungaged watersheds assuming uniform rainfall over the area. Therefore, the regression estimates for storm loads from ungaged watersheds probably have errors less than those listed above.

Similarly, at an ungaged site, the base-flow discharge will be estimated by equation 5, and this estimate will have an error. The estimated base-flow load error will be some combination of the constituent concentration error (table 21) and discharge error (±45 percent), but not necessarily the sum. For the modeled constituents, except total lead, the load estimate would tend to vary as the estimated discharge. The errors in the load estimate of total lead would tend to offset each other because, as discharge increases, concentration decreases.

Annual Loads

The annual load of substances contained in urban runoff is the sum of the stormwater and base-flow loads for a year. The regression equations of tables 17 and 21 were used with streamflows estimated by use of equations 1 and 5 to determine daily stormwater and base-flow loads that were summed for the 1979 water year (October 1, 1978, to September 30, 1979). Computations were performed for six water-quality constituents for each of the nine Tampa Bay area watersheds. Annual totals are shown in table 23.

Although rainfall differed appreciably among the nine watersheds, the same daily rainfall data--that of St. Louis Street drainage ditch station--were used in computations of runoff and annual loads for all watersheds. Consequently, the differences in the computed runoff from the various watersheds shown in table 23 are due to differences in land use and watershed characteristics. The differences in runoff are reflected in the magnitude of the computed basin loads of the various substances involved because runoff volume enters directly into the load computations. It follows, generally, that the higher the ratio of base flow to annual runoff, the higher the ratio of base-flow load to annual load.

Table 23.--Estimated loads* of selected substances in runoff from urban watersheds in the Tampa Bay area, 1979 water year

Station	Water-quality characteristic	Load, in pounds per acre per year			
		Based on Tampa Bay area regression equations			Based on Broward County land-use factors[1/]
		Storm-water	Base flow	Total	Total
Artic street storm drain at Tampa, Fla.	Total nitrogen	8.19	1.21	9.40	5.14
	Total organic nitrogen	3.75	.77	4.52	-
	Total phosphorus	1.25	.10	1.35	.54
	Biochemical oxygen demand	21.6	12.7	34.3	-
	Chemical oxygen demand	164	77.4	241	318
	Total lead	.57	.13	.70	1.71
	Runoff, in inches	16.49	2.32	18.81	-
Kirby Street drainage ditch at Tampa, Fla.	Total nitrogen	1.53	2.87	4.40	.78
	Total organic nitrogen	1.12	1.43	2.55	-
	Total phosphorus	.32	.16	.48	.14
	Biochemical oxygen demand	5.65	2.55	8.20	-
	Chemical oxygen demand	38.2	42.6	80.8	20.9
	Total lead	.12	.06	.18	.10
	Runoff, in inches	4.14	5.99	10.13	-
St. Louis Street drainage ditch at Tampa, Fla.	Total nitrogen	3.94	.52	4.46	2.58
	Total organic nitrogen	1.41	.45	1.86	-
	Total phosphorus	.37	.09	.46	.48
	Biochemical oxygen demand	10.7	2.68	13.4	-
	Chemical oxygen demand	42.6	38.2	80.8	53.0
	Total lead	.13	.05	.18	.22
	Runoff, in inches	5.59	3.05	8.64	-

*Rainfall from St. Louis Street drainage ditch station.

[1/]Land-use factors from Mattraw and Miller, 1981.

Table 23.--Estimated loads* of selected substances in runoff from urban watersheds in the Tampa Bay area, 1979 water year--Continued

Station	Water-quality characteristic	Load, in pounds per acre per year			
		Based on Tampa Bay area regression equations			Based on Broward County land-use factors[1/]
		Storm-water	Base flow	Total	Total
Gandy Boulevard drainage ditch at Tampa, Fla.	Total nitrogen	4.75	3.00	7.75	2.81
	Total organic nitrogen	2.55	1.57	4.12	-
	Total phosphorus	1.05	.36	1.41	.34
	Biochemical oxygen demand	11.8	2.90	14.7	-
	Chemical oxygen demand	143	62.6	206	152
	Total lead	.45	.14	.59	.82
	Runoff, in inches	10.37	5.67	16.04	-
Allen Creek near Largo, Fla.	Total nitrogen	3.62	2.50	6.12	3.49
	Total organic nitrogen	2.61	1.13	3.74	-
	Total phosphorus	.95	.26	1.21	.58
	Biochemical oxygen demand	11.0	2.90	13.9	-
	Chemical oxygen demand	121	52.0	173	108
	Total lead	.37	.15	.52	.52
	Runoff, in inches	10.01	7.07	17.08	-
Booker Creek at St. Petersburg, Fla.	Total nitrogen	4.78	3.68	8.46	2.92
	Total organic nitrogen	2.94	2.11	5.05	-
	Total phosphorus	1.36	.54	1.90	.38
	Biochemical oxygen demand	11.0	6.85	17.8	-
	Chemical oxygen demand	191	107	298	141
	Total lead	.52	.20	.72	.74
	Runoff, in inches	10.01	10.97	20.98	-

Table 23.--Estimated loads* of selected substances in runoff from urban watersheds in the Tampa Bay area, 1979 water year--Continued

Station	Water-quality characteristic	Load, in pounds per acre per year			
		Based on Tampa Bay area regression equations			Based on Broward County land-use factors[1/]
		Storm-water	Base flow	Total	Total
Bear Creek at St. Petersburg, Fla.	Total nitrogen	3.20	1.46	4.66	3.69
	Total organic nitrogen	2.56	1.02	3.58	-
	Total phosphorus	.89	.19	1.08	.65
	Biochemical oxygen demand	10.8	5.39	16.2	-
	Chemical oxygen demand	108	70.8	179	92.6
	Total lead	.34	.15	.49	.42
	Runoff, in inches	9.74	7.33	17.07	-
Saint Joes Creek at St. Petersburg, Fla.	Total nitrogen	5.25	2.01	7.26	2.88
	Total organic nitrogen	2.70	1.35	4.05	-
	Total phosphorus	1.21	.35	1.56	.40
	Biochemical oxygen demand	11.7	4.13	15.8	-
	Chemical oxygen demand	173	70.2	243	127
	Total lead	.52	.15	.67	.28
	Runoff, in inches	10.37	6.88	17.25	-
Turner Street storm drain at Clearwater, Fla.	Total nitrogen	9.58	1.13	10.7	3.14
	Total organic nitrogen	2.92	.68	3.60	-
	Total phosphorus	1.31	.09	1.40	.32
	Biochemical oxygen demand	18.4	2.37	20.8	-
	Chemical oxygen demand	204	16.8	221	200
	Total lead	.72	.10	.82	1.08
	Runoff, in inches	12.48	2.80	15.28	-

The ratio of base-flow runoff to annual runoff ranged from 12 percent at Artic Street storm drain to 59 percent at Kirby Street drainage ditch. For the various constituents involved, the ratio of base-flow load to annual load at the Artic Street storm drain ranged from 7 percent (total phosphorus) to 37 percent (biochemical oxygen demand) and at Kirby Street drainage ditch ranged from 31 percent (biochemical oxygen demand) to 65 percent (total nitrogen). At St. Louis Street drainage ditch, base-flow runoff made up 35 percent of the annual runoff. The ratio of base-flow load to annual load ranged from 12 percent (total nitrogen) to 47 percent (chemical oxygen demand). Because the 47.52-inch rainfall of the 1979 water year was only slightly less than the 51-inch average annual (calendar year) rainfall for Tampa, the estimated loads of table 23 may be representative of average conditions in the Tampa Bay area.

The monthly distribution of the annual load is demonstrated in figure 12, using biochemical oxygen demand as the water-quality constituent and St. Louis Street drainage ditch as the watershed site. Monthly base-flow loads of biochemical oxygen demand ranged from about 27 pounds in November to about 117 pounds in July. Monthly stormwater loads ranged from zero in November (no stormwater runoff) to about 730 pounds in May. The variation in monthly stormwater load corresponds generally to the variation of the monthly rainfall.

COMPARISON OF ANNUAL LOADS COMPUTED BY PROCEDURES DEVELOPED FOR DIFFERENT REGIONS

Studies of the water quality of urban runoff in other regions provide a basis for comparison of results obtained by use of the Tampa Bay area regression equations. Because of differences in physical conditions, sampling techniques, sampling frequency, and analytical procedures involved in the various studies, results of such a comparison should be deemed significant only insofar as the area of agreement or disagreement is viewed in terms of orders of magnitude. The regression equations developed for the Tampa Bay area are empirical and, as such, inherently account for effects of conditions peculiar to that locality. The equations presumably provide the most reliable results presently obtainable from data available for that area.

Mattraw and Miller (1981, p. 51) provide land-use load factors applicable in parts of Broward County on the east coast in south Florida. Specifically, the Broward County land-use load factors give the average daily load of selected water-quality constituents in runoff from hydraulically connected impervious surfaces in areas classed as residential, highway, and commercial. For the purpose at hand, use of these factors required that the land-use data of the nine Tampa Bay area watersheds be reevaluated and fitted as best possible into these three categories; and, further, that the amount of hydraulically connected impervious surface be determined for each category and watershed. The Broward County land-use load factors were used to compute annual loads of total nitrogen, total phosphorus, chemical oxygen demand, and total lead for each of the nine Tampa Bay area watersheds. Results of the computations are shown in table 23.

The annual loads computed by use of the Tampa Bay area regression equations (Tampa Bay loads) and the Broward County land-use load factors (Broward County loads) are of the same order of magnitude. In general, the Tampa Bay loads of total nitrogen and total phosphorus were two to five times greater than the

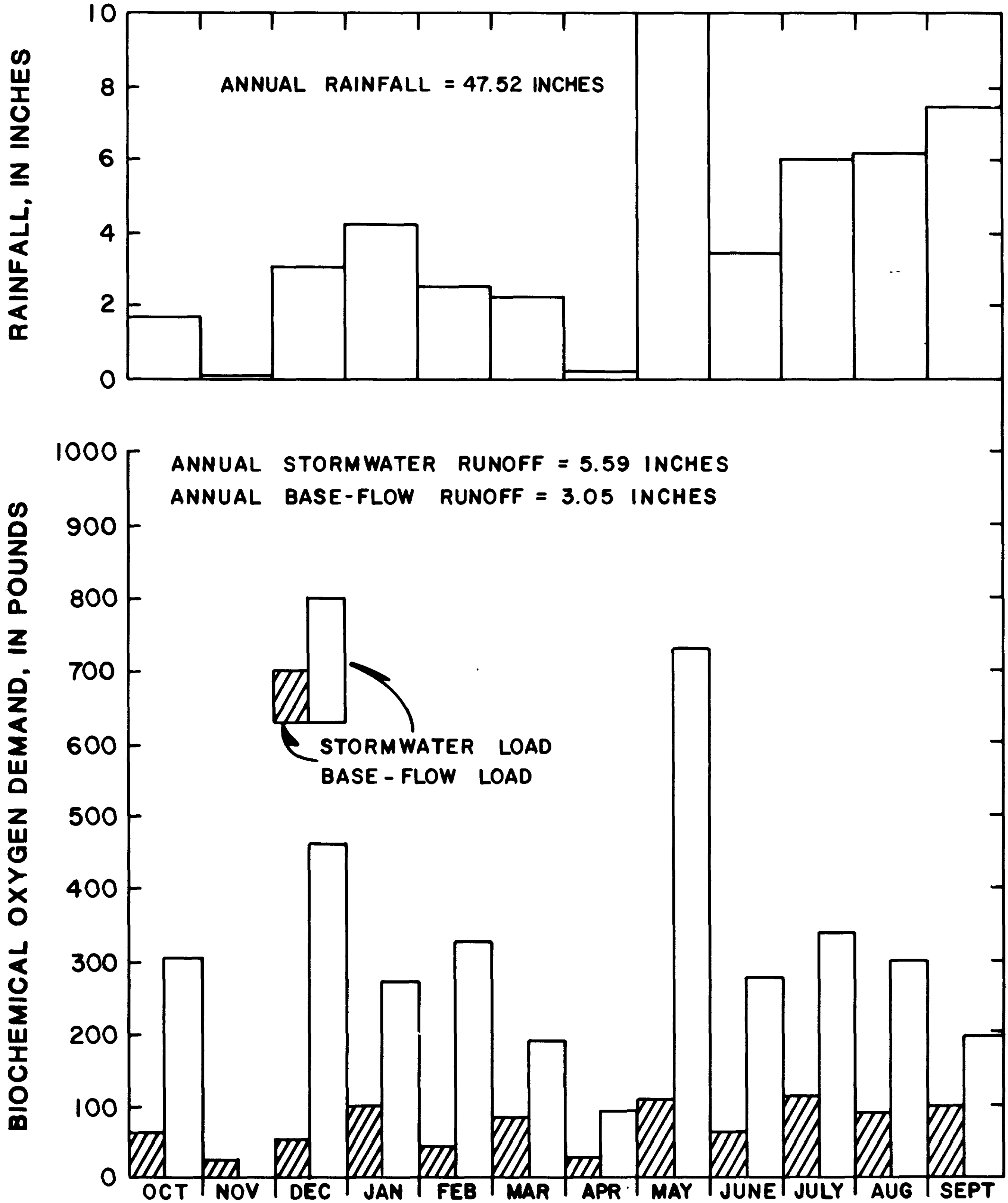

Figure 12.--Monthly load of biochemical oxygen demand of runoff at St. Louis Street drainage ditch station, 1979 water year.

Broward County loads except at the St. Louis Street drainage ditch. Tampa Bay loads of chemical oxygen demand were greater at all sites except Artic Street and Turner Street. Estimates of total lead loads had the closest agreement.

Another procedure for computing loads of water-quality constituents is the U.S. Environmental Protection Agency screening procedure described by Heaney and others (1976, p. 17). This procedure employs loading coefficients and pollutant loading factors that are applicable to the land-use data of the Tampa Bay area watersheds. One of the factors pertains to the frequency of street sweeping, N_s, which was determined to be once in every 6 weeks for the St. Louis Street drainage ditch watershed (L. Moreda, oral commun., 1981). Consequently, the factor for N_s>20 days was used in conjunction with other relevant coefficients and factors to compute 1979 water-year loads of selected water-quality constituents for the St. Louis Street drainage ditch station with results as follows:

Water-quality constituent	Annual load, in pounds per acre
Biochemical oxygen demand	25
Total nitrogen	4.1
Total phosphorus	.03

Corresponding loads, as determined by use of the Tampa Bay area regression equations, are shown in table 23.

In relation to the annual loads computed by use of the Tampa Bay area regression equations, loads computed by the procedure of Heaney and others (1976) were about twice as great for biochemical oxygen demand; were about the same for total nitrogen; and were smaller by an order of magnitude for total phosphorus. The difference in phosphorous loads might be due to the high natural content of phosphorus of streamflow in the Tampa Bay area and to fall-out from phosphate processing plants along the east shore of Tampa Bay, both of which would be better reflected in the Tampa Bay area regression equations.

EVALUATING EFFECT OF INCREASED DEVELOPMENT OF URBAN WATERSHEDS

The regression equations previously described (equations 1 and 5, tables 17 and 21) can be used to appraise the effects of increased urbanization of Tampa Bay area watersheds simply by changing the values of the independent variables involved. As an example, the annual runoff and water-quality constituent loads were recomputed for the St. Louis Street drainage ditch site using different values for the land-use percentages. DEVT was increased from 12 percent to 44 percent (0.06 mi^2 to 0.22 mi^2), HCIA from 9 percent to 53 percent, and TIA from 27 percent to 61 percent. The higher percentages are those of the same variables for the more highly developed Artic Street storm drain site (tables 2 and 15). The increase in DEVT was offset by decreasing NATT from 0.06 mi^2 to 0 mi^2 and REST from 0.39 mi^2 to 0.29 mi^2. The resulting increase in computed annual runoff was 126 percent, as shown in figure 13. The increase in computed annual loads of the various water-quality constituents ranged from 64 percent for biochemical oxygen demand to 327 percent for total lead.

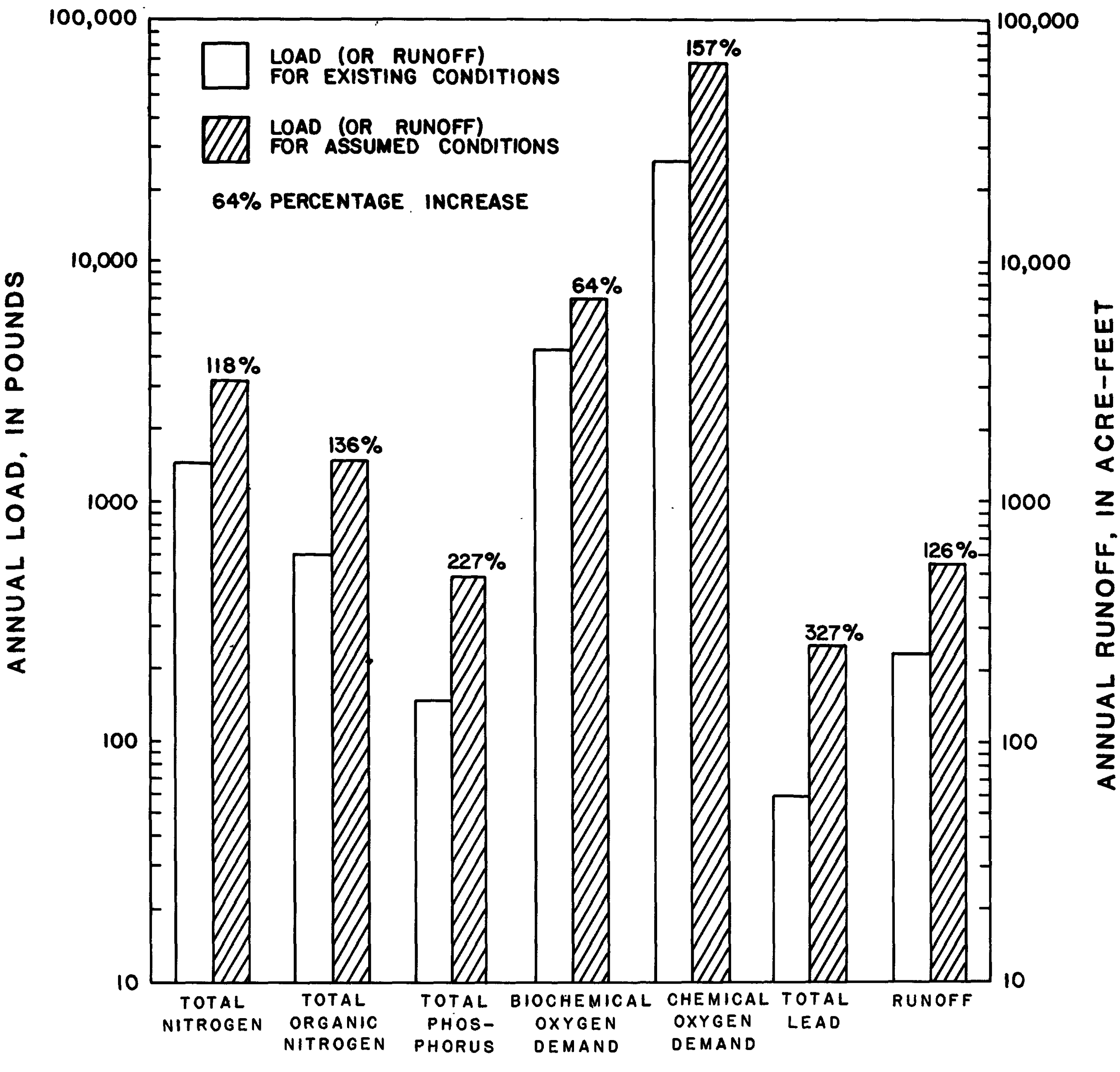

Figure 13.--Comparison of annual loads of selected substances and runoff for present and assumed degrees of basin development, St. Louis Street drainage ditch station, based on rainfall for 1979 water year.

SUMMARY AND CONCLUSIONS

Runoff from urban watersheds in the Tampa Bay area contains chemical and other substances that impact receiving-water bodies, such as the Hillsborough River, Tampa Bay, and the Gulf of Mexico. As part of an effort to quantify the constituent loads entering receiving waters, rainfall and streamflow data were collected from 1975 to 1980 to evaluate the quantity and quality of runoff from nine urban watersheds in the Tampa Bay area. Residential, commercial, industrial, institutional, recreational, and open-space land uses were identified and measured. Impervious surfaces, such as roofs, paved roads, and parking lots, were measured; separate tabulations were made of impervious surfaces that were directly connected to sewer systems (hydraulically connected impervious surfaces). The land-use mixture of the various watersheds differed appreciably, as did the degree of development, which ranged from a sparsely populated watershed having 19 percent impervious surface to a commercial-residential watershed having 61 percent impervious surface. Many of the urbanized watersheds in the Tampa Bay area fall within the range in size and land-use mixture of the nine selected watersheds.

Streamflow and water-quality data were collected during periods of stormwater runoff and base flow. Average biochemical oxygen demand concentration for base flow at one site and the flow-weighted average of stormwater-runoff samples at four sites exceeded treated sewage effluent standards. Average concentrations of total nitrogen and phosphorus in both base-flow and stormwater-runoff samples were within treated sewage effluent standards at all sites. Average concentrations of coliform in stormwater-runoff samples were generally several orders of magnitude greater than limits set by the Florida Department of Environmental Regulation for Class III water (that used for recreation or propagation and management of fish and wildlife). Average concentrations of lead and zinc in stormwater-runoff samples were consistently higher than limits for Class III water at all sites sampled. Average concentrations of lead and zinc also exceeded limits for Class III water in base-flow samples from watersheds having large percentages of commercial development.

Time variations in rainfall, discharge, and water-quality constituent concentrations were determined for selected sites. In watersheds that have a high percentage of hydraulically connected impervious surface, high concentrations occurred during rising stream stages. Concentrations of chemical oxygen demand, total organic carbon, nitrogen, and total phosphorus were generally several times higher at the start of stormwater runoff than at the end.

Regression equations were developed for estimating stormwater-runoff loads from ungaged watersheds for water-quality constituents as follows: biochemical oxygen demand, chemical oxygen demand, total nitrogen, total organic nitrogen, total phosphorus, and total lead. Multiple linear-regression techniques were used to relate stormwater-runoff loads to runoff volume, land use, and antecedent rainfall. Standard errors of estimate ranged from ±41 percent of the mean for chemical oxygen demand to ±65 percent of the mean for total nitrogen. Stormwater-runoff volume was estimated by use of a separate regression equation that relates runoff volume to pervious area multiplied by soil-infiltration index, hydraulically connected impervious surface, and rainfall. The average standard of error of estimate for this equation was ±20 percent; correlation coefficient, 0.93.

Regression equations also were developed to compute base-flow concentrations for the same suite of water-quality constituents. Base-flow constituent concentrations were related to daily discharge, rainfall, watershed, and land-use variables. Standard error of estimates ranged from ±33 percent for chemical oxygen demand to ±60 percent for biochemical oxygen demand. Base-flow daily discharge was estimated by use of a separate regression equation that related discharge to drainage area and antecedent rainfall. This equation has an average standard error of ±45 percent and a multiple correlation coefficient of 0.94.

The regression equations were used to compute base-flow, stormwater, and annual runoff volumes and loads of selected water-quality constituents for the nine urban watersheds of the Tampa Bay area. Base-flow volume made up from 12 to 59 percent of the annual runoff volume from the various watersheds. The ratio of base-flow load to annual load of water-quality constituents differed in like manner, ranging from as little as 7 percent for total phosphorus at Artic Street storm drain to as much as 65 percent for total nitrogen at Kirby Street drainage ditch.

Comparison was made of loads of selected water-quality constituents as computed by use of the Tampa Bay area regression equations and as computed by methods devised for other parts of the country. The annual loads computed by use of the Tampa Bay area regression equations (Tampa Bay loads) and the Broward County land-use load factors (Broward County loads) are of the same order of magnitude. In general, the Tampa Bay loads of total nitrogen and total phosphorus were two to five times greater than the Broward County loads except at the St. Louis Street drainage ditch. Tampa Bay loads of chemical oxygen demand were greater at all sites except Artic Street and Turner Street. Estimates of total lead loads had the closest agreement. A second comparison was made by application of the U.S. Environmental Protection Agency screening procedure (Heaney and others, 1976) to land-use data at the St. Louis Street drainage ditch site. As determined by use of the Tampa Bay area regression equations, the annual load of nitrogen was about the same, biochemical oxygen demand was about one-half as great, and total phosphorus was about one order of magnitude greater than loads estimated by the screening procedure. The Tampa Bay area regression equations, because of their empirical nature, presumably reflect the high natural phosphorous content of bay area streamflow and fallout from local phosphate processing plants.

The regression equations developed in this report for estimating volume of stormwater runoff, base-flow daily discharge, stormwater-runoff loads, and base-flow concentrations of the various water-quality constituents may be applicable to other urban watersheds of the Tampa Bay area provided the independent variables involved fall within the range defined by data for the nine selected watersheds.

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