Relation of Urban Land-Use and Dry-Weather, Storm, and Snowmelt Flow Characteristics to Stream-Water Quality, Shunganunga Creek Basin, Topeka, Kansas

By Larry M. Pope and Hugh E. Bevans

Prepared in cooperation
with the Kansas
Department of Health
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Relation of Urban Land-Use and Dry-Weather, Storm, and Snowmelt Flow Characteristics To Stream-Water Quality, Shunganunga Creek Basin, Topeka, Kansas

By Larry M. Pope *and* Hugh E. Bevans

Abstract

Overland runoff from urban areas can cause concentrations of some water-quality constituents in local receiving streams to increase. The U.S. Geological Survey in cooperation with the Kansas Department of Health and Environment investigated the water-quality characteristics of streams draining Topeka, Kansas, and adjacent parts of the Shunganunga Creek basin from October 1979 through November 1981. The purpose of this investigation was to provide the data and interpretation necessary to determine the effects of runoff from urban areas on the water-quality characteristics of receiving streams.

Water-quality characteristics for three streamflow conditions were determined: (1) dry-weather streamflow—a combination of base flow and point-source contributions, (2) storm streamflow—mainly provided by overland runoff from storms, and (3) snowmelt streamflow—mainly provided by overland runoff from snowmelt.

Median concentrations of trace metals and nutrients were larger in storm streamflow than in dry-weather streamflow. Median concentrations of total lead and zinc were largest in storm streamflow from the more urban basins. Regression equations were developed to estimate median concentrations of total lead and zinc in storm streamflow from the percentage of drainage area in residential plus commercial land-use areas (correlation coefficients were 0.98 for total lead and 0.88 for total zinc); and from street density in lane miles per square mile (correlation coefficients were 0.89 for total lead and 0.84 for total zinc). Median concentrations of dissolved nitrite plus nitrate nitrogen and total phosphorus averaged, respectively, 76-percent and 70-percent larger during storm streamflow than during dry-weather streamflow and were largest in storm streamflow from the more agricultural basins.

Median concentrations of dissolved sodium, chloride, and solids in snowmelt streamflow at all study sites averaged 218-percent larger for dissolved sodium, 296-percent larger for dissolved chloride, and 71-percent larger for dissolved solids relative to median concentrations in dry-weather streamflow. Regression equations also were developed to estimate median concentrations of dissolved sodium, chloride, and solids in snowmelt streamflow from the summation of percentages of the drainage area in residential, commercial, and industrial land-use areas (correlation coefficients were 0.97 for each of the three relationships) and from street density in lane miles per square mile (correlation coefficients were 0.93 for dissolved sodium and 0.94 for both dissolved chloride and dissolved solids).

Multiple-correlation and regression analysis relating storm-runoff volumes and average constituent concentrations to land-use and storm characteristics produced significant relations (0.05 level of significance) for storm-runoff volume (0.81 coefficient of determination), total lead (0.71 coefficient of determination), total zinc (0.50 coefficient of determination), and suspended sediment (0.58 coefficient of determination).

INTRODUCTION

During the past 10–15 years the quality of urban runoff and its effect on local receiving streams have been of increasing concern to State and Federal water-quality agencies. In 1972, Congress passed Public Law 92–500 requiring states to investigate for possible water-quality degradation problems associated with runoff from urban areas. In response, the U.S. Geological Survey entered into a cooperative agreement with the Kansas Department of Health and Environment in 1978 to investigate the quality and effects of urban runoff from Topeka, Kansas. The study area was the Shunganunga Creek basin, an urbanizing part of Shawnee County that includes about one-half of the city of Topeka.

Because little historical water-quality data existed for any part of the study area, the purpose of this investigation was to provide data and interpretation needed to evaluate the physical and chemical characteristics of urban runoff and its effects on the water quality of local receiving streams.

The objectives of this study were essentially two-fold. First, it was necessary to establish a data base of land-use, physiographic, precipitation, streamflow, and water-quality information for selected stream basins of varying sizes and degrees of urbanization. Secondly, the data base was used to (1) determine variability in concentrations of water-quality constituents in streamflow, both at and between sampling sites, (2) develop relationships between land-use characteristics and concentrations of water-quality constituents, and (3) develop equations for estimating storm-runoff volumes and average concentrations of selected water-quality constituents from land-use, physiographic, and storm characteristics.

DESCRIPTION OF STUDY AREA

Drainage Patterns

The study area, shown in figure 1, is in Shawnee County, northeastern Kansas. The 60.3-mi^2 study area is drained by Shunganunga Creek and its three principal tributaries—South Branch Shunganunga, Butcher, and Deer Creeks. A large part of the Shunganunga Creek drainage basin includes the city of Topeka, adjacent suburban areas, and outlying residential or industrial developments.

Flow in Shunganunga Creek is controlled, at least in part, by approximately 320 small ponds (0.5 to 5.0 surface acres) and two major lakes. The small ponds have been built to serve as water supplies for livestock and to control erosion from agricultural areas. The two major lakes, shown on figure 1, were built primarily for flood control. However, both lakes also provide recreational activities, such as fishing, swimming, boating, and water skiing. Sherwood Lake, located on Shunganunga Creek in the western part of the study area, has an approximate surface area of 230 acres and a contributing drainage area of 6.85 mi^2. Lake Shawnee, located on Deer Creek in the eastern part of the study area, has an approximate surface area of 360 acres and a contributing drainage area of 9.12 mi^2. Lake-surface and drainage areas were planimetered from U.S. Geological Survey 7½-minute series topographic maps.

Topography and Geology

The terrain of the study area generally is flat to gently rolling. However, local relief in the southwestern part of the area can be as much as 100 feet. Land-surface altitudes range from 1,205 feet above sea level in the extreme southwestern part to 850 feet at the eastern edge. The total difference in relief is 355 feet.

The geology of the study area is basically the result of sedimentation processes associated with the repeated advance and retreat of the Late Pennsylvanian sea and with glacial deposition from the Kansan glaciation during the Pleistocene age. As explained by Johnson and Adkinson (1967), exposed sedimentary rocks of Late Pennsylvanian age are about 725 feet thick and consist of relatively thick shale formations that alternate with thinner limestone formations in a cyclic pattern of deposition. The shale formations are from nonmarine depositions, and the limestone formations are of marine origin. Unconsolidated sediments found in the area consist of Kansan glacial drift of unstratified and unsorted clay till and more recent deposits of loess and alluvium. Alluvial deposits are found in the valleys of Shunganunga Creek and its major tributaries.

Soils

Soils in the study area are characteristically deep, moderately drained, level to strongly sloping clay loam with silty clay or clay subsoils. Seven major soil associations are identified in the study area: Reading-Wabash, Eudora-Muir, Pawnee-Shelby-Morrill, Ladysmith-Pawnee, Martin-Pawnee-Labette, Martin-Ladysmith, and Gymer-Shelby-Sharpsburg (Abmeyer and Campbell, 1970). Of these seven associations, soils of the Martin-Ladysmith association occur over 51 percent of the study area, an area 2.5 times larger than the next most commonly occurring association, the Martin-Pawnee-Labette (Abmeyer and Campbell, 1970). Nearly all the soils in the study area are classified as hydrologic soil group C or D. These two hydrologic soil groups, as defined by the U.S. Soil Conservation Service (1975), have a slow infiltration rate when thoroughly wet, which impedes the downward movement of water and results in a moderate to high runoff potential.

Climate and Precipitation

The climate of the study area is characteristic of a central plains environment. The climate is controlled by the movement of frontal air masses over the open inland-plains topography, and seasonal temperature and precipitation extremes are common. During the summer months, the weather is dominated by warm, moist air from the Gulf of Mexico or hot, dry air from the desert southwest, and temperatures near or above 100 °F can occur. Winter months are characterized by influxes of cold, dry polar air with temperatures as low as -20 °F. About 70 percent of the average annual precipitation of 34.7 inches falls during the warm growing season, April through September. Only 10 percent of the average annual precipitation falls as rain or snow during the relatively dry winter months of December through February. The average annual snowfall for Topeka is about 20 inches. During the first year of this study, 1980, snowfall was near normal, 22.1 inches, but during 1981, only 6.5 inches were recorded.

Precipitation during the early part of spring and the latter part of fall occurs in association with frontal air masses that produce low-intensity rainfall of regional coverage and relatively lengthy duration. Summer precipitation

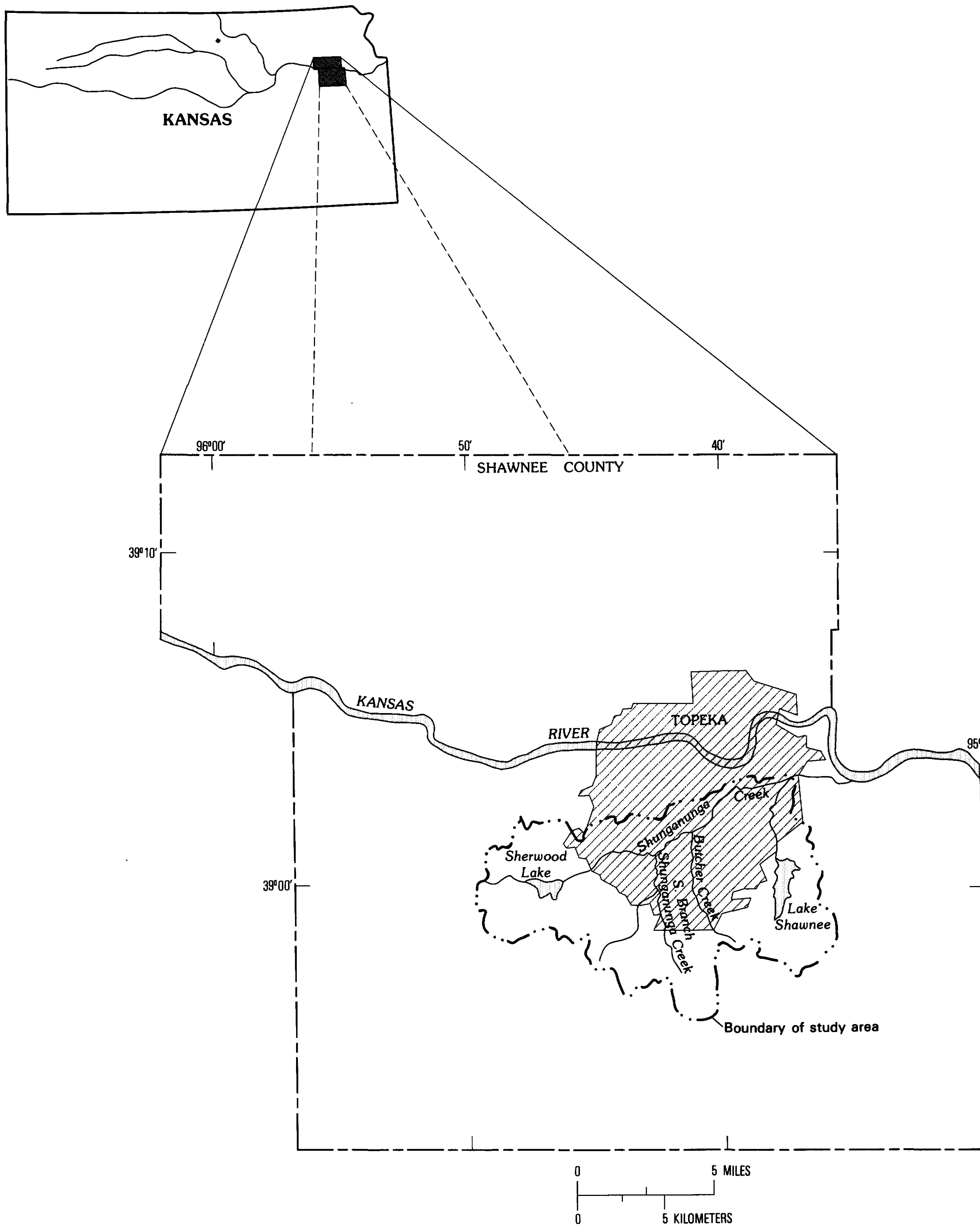

Figure 1. Location of study area.

generally occurs as evening or early morning thundershowers of short duration that can produce large amounts of rainfall. The maximum 24-hour rainfall for Topeka was 8.08 inches on September 6, 1909 (Jennings, 1952).

During the course of this study, several temperature and precipitation extremes were observed. The monthly average temperature and monthly total precipitation recorded by the Topeka National Weather Service during the study, 1980 and 1981, and the monthly average temperature and monthly total precipitation for 1940–70 are compared in figure 2.

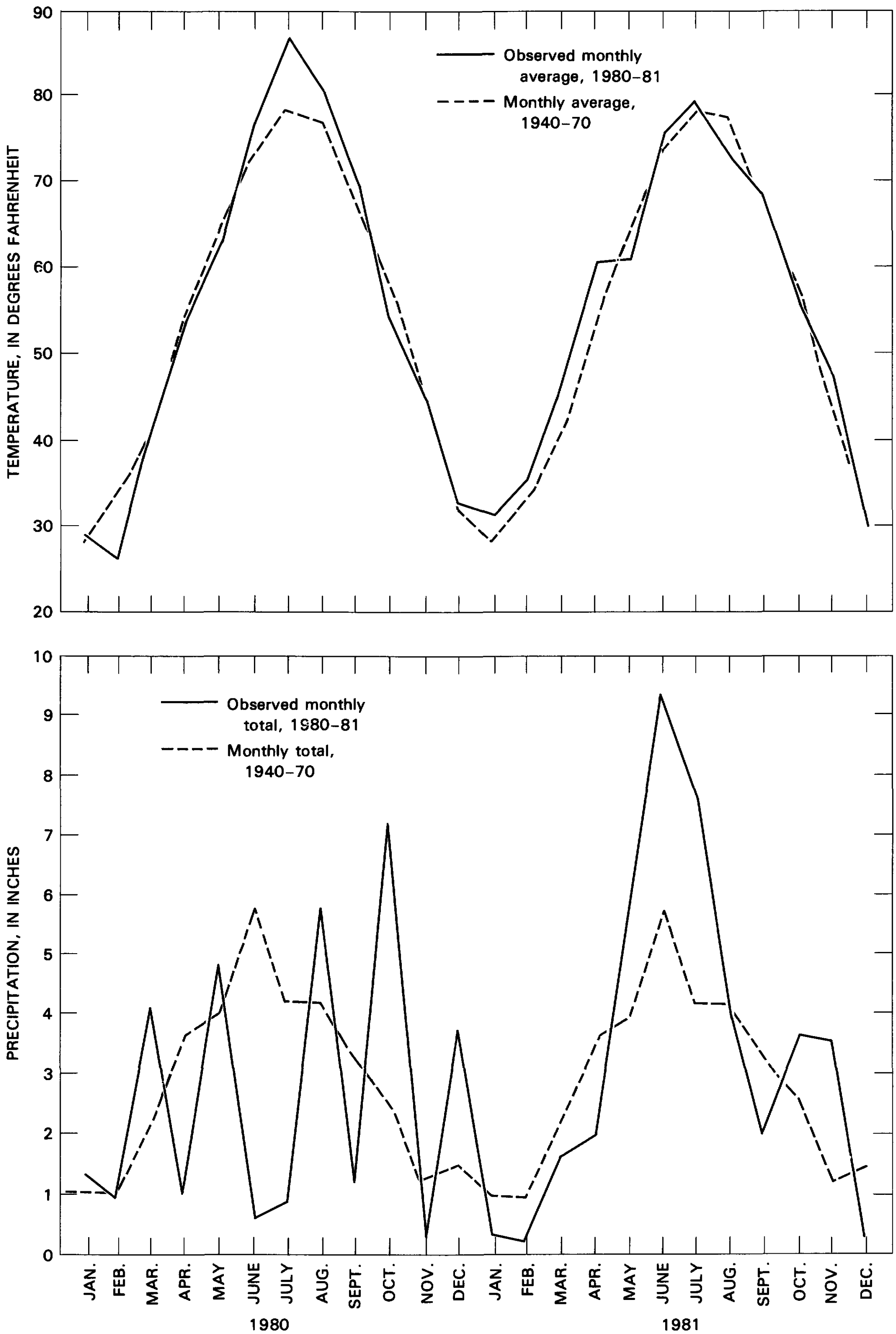

Figure 2. Comparison of monthly average temperature and monthly total precipitation during 1980–81 with monthly average temperature and monthly total precipitation recorded by the National Weather Service at Topeka for 1940–70.

DESCRIPTION OF STUDY SITES

Location of Study Sites

For the purpose of monitoring the effects of urbanization on the water quality of the major receiving streams in the Shunganunga Creek basin, six study sites were established (fig. 3). Study sites were established in the lower reach of each of the three main tributaries of Shunganunga Creek (South Branch Shunganunga, Butcher, and Deer Creeks). Three additional study sites were established on the main branch of Shunganunga Creek. Descriptions of the six sites chosen for this study are presented in table 1. Study site 06889640 receives discharge from study sites 06889580, 06889610, and 06889635, as well as runoff from a 9.88 mi² urban area that includes the southwest quadrant of the city of Topeka. Study site 06889700, the most downstream Shunganunga Creek site, receives discharge from study sites 06889640 and 06889690 and runoff from a 3.88 mi² urban area downstream of Shunganunga Creek site 06889640.

Each study site was selected to meet one or more of the following requirements: (1) to represent changes between major land-use areas, (2) to provide information on tributary streams entering between main-branch sites, (3) to allow the development of a stable, backwater-free, stage-discharge relation, (4) to allow for both the measurement of streamflow and sample collection at high- and low-water stages during all weather conditions, (5) to provide suitable access during all weather conditions, (6) to allow for the installation of an 8-foot by 6-foot instrumentation house, and (7) availability of 220-volt electrical service to power pumps and automatic sampling equipment.

Land-Use and Physiographic Characteristics

Shunganunga Creek originates southwest of Topeka and generally flows in a northeasterly direction until discharging into the Kansas River 2 miles downstream from the eastern boundary of the study area. During its course to the Kansas River, Shunganunga Creek flows through areas with a variety of land uses. After originating in an agricultural area, the stream flows through an area of single- and multifamily housing intermixed with neighborhood commercial developments. Further downstream, after receiving discharge from South Branch Shunganunga and Butcher Creeks, Shunganunga Creek flows through the central downtown commercial area, subsequently through a light-industrial area, and then out of the study area and towards its confluence with the Kansas River.

For the purpose of this study, land use was categorized into six general classifications: (1) agricultural,

Table 1. Description of study sites

Study site	Name and location	Drainage area (square miles)
06889580	Shunganunga Creek at Southwest 29th Street, lat. 39°00′51″ N., long. 95°44′55″ E., in NE¼NW¼NE¼ sec. 16, T. 12 S., R. 15 E.	13.8
06889610	South Branch Shunganunga Creek at Southwest 37th Street, lat. 39° 00′01″ N., long. 95°42′42″ E., in NE¼NW¼NE¼ sec. 23, T. 12 S., R. 15 E.	13.8
06889635	Butcher Creek at Kansas Place, lat. 39°01′01″ N., long. 95°40′49″ E., in SE¼SE¼SW¼ sec. 7, T. 12 S., R. 16 E.	4.65
06889640	Shunganunga Creek at Southeast 15th Street, lat. 39°02′12″ N., long. 95°40′10″ E., in NW¼NW¼SW¼ sec. 5, T. 12 S., R. 16 E.	42.1
06889690	Deer Creek at Southeast 6th Street, lat. 39°02′39″ N., long. 95°37′56″ E., in NE¼NE¼NE¼ sec. 4, T. 12 S., R. 16 E.	14.3
06889700	Shunganunga Creek at Rice Road, lat. 39°03′12″ N., long. 95°37′19″ E., in NW¼SW¼NE¼ sec. 34, T. 11 S., R. 16 E.	60.3

(2) residential, (3) commercial, (4) industrial, (5) urban open space, and (6) lakes. Areal distribution of the six land-use classifications is shown in figure 4. Specific land uses in each classification are as follows:

Agricultural—Cropland, pasture, and rural vacant.

Residential—Single- and multifamily housing and mobile-home parks.

Commercial—Regional shopping malls, neighborhood shopping centers, retail business areas, offices, and other areas with similar public-use patterns, such as schools and hospitals.

Industrial—Manufacturing facilities, storage and warehouse complexes, airports and associated hangar and runway facilities, petroleum storage and pumping facilities, railroad-switching yards, and truck terminals.

Urban open space—All private or public open grassland or undeveloped wooded areas found within the urban part of the study area, such as parks, golf courses, cemeteries, greenbelts along waterways, vacant undeveloped land, and those large, open tracts of land associated with schools and hospitals. This category generally was reserved for areas located in the urban area north of the loop formed by the Kansas Turnpike and U.S. Interstate Highway 470 (fig. 3).

Lakes—All lakes with surface areas larger than 5 acres.

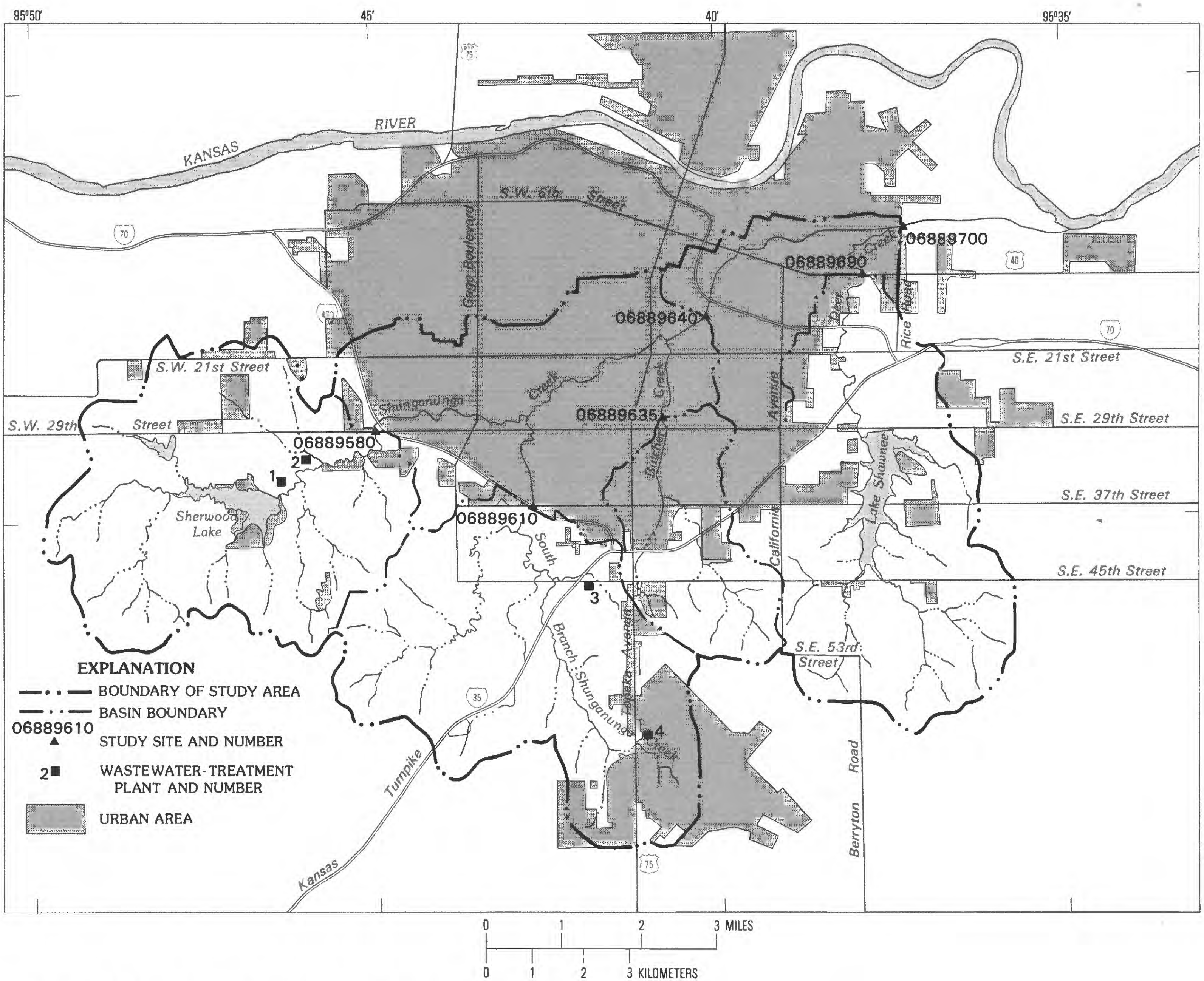

Figure 3. Extent of urbanization and location of study sites and wastewater-treatment plants.

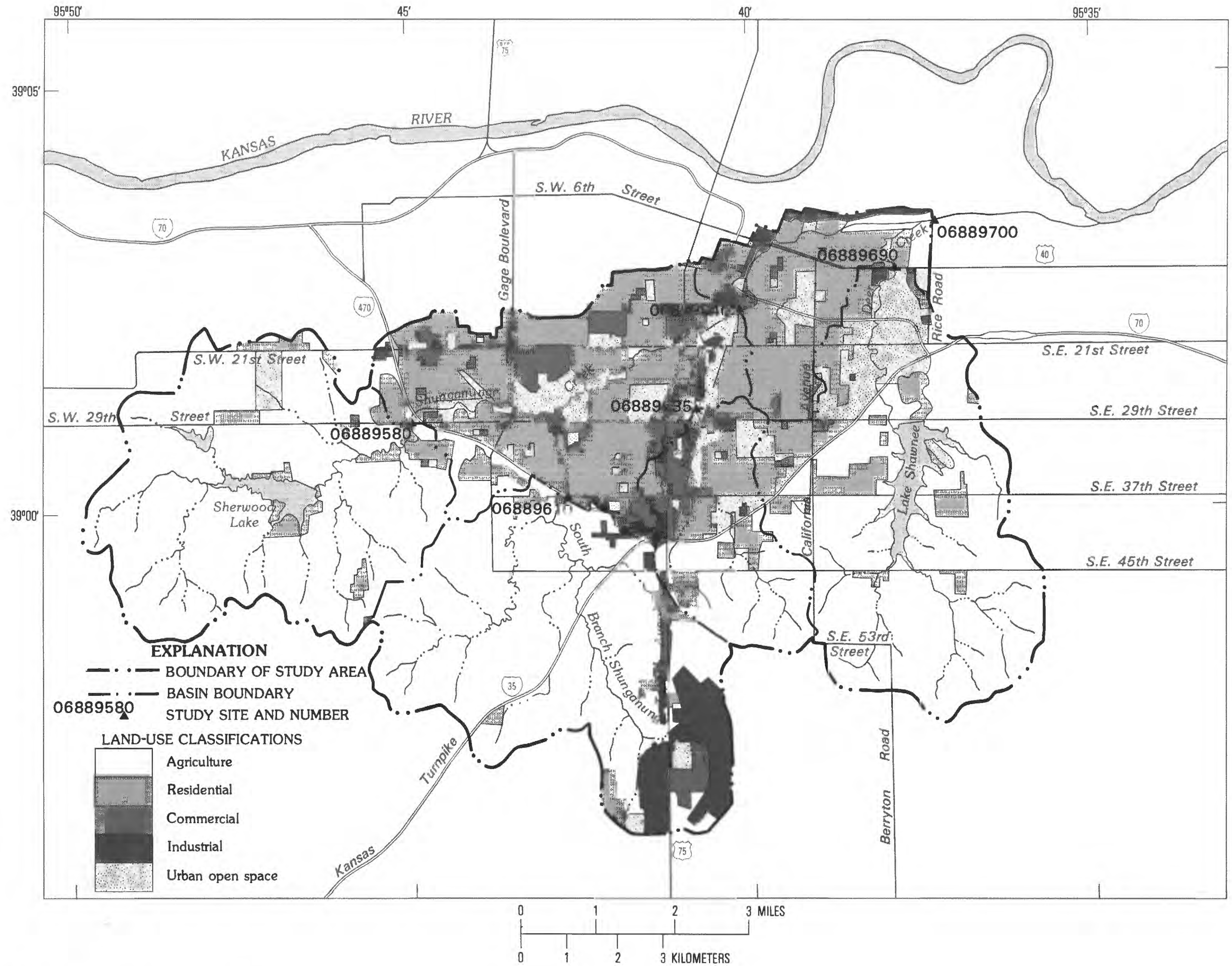

Figure 4. Land use in study area.

Percentages of the drainage area in each land-use classification for each study basin are listed in table 2. Agriculture is the predominant land use in each of the study basins. The percentage of land in agricultural use ranges from 51.1 in the Butcher Creek basin (06889635) to 85.9 in the upper Shunganunga Creek basin (06889580). The percentage of land in residential use, the second most prevalent land use, ranges from 3.1 in the largely agricultural South Branch Shunganunga Creek basin (06889610) to 26.7 in the more urbanized Butcher Creek basin (06889635). In addition to its large percentage of residential area, the Butcher Creek basin contains the largest percentage (11.0) of commercial land use of any of the study basins. This commercial area, which begins just south of study site 06889635 and extends southward to approximately mid-basin, includes a regional shopping mall and surrounding retail-business areas that are associated with Topeka's major north-south street (Topeka Blvd.) and two main east-west routes (29th Street and 37th Street).

The basin with the largest percentage of industrial area (10.2), South Branch Shunganunga Creek (06889610), contains a former U.S. Air Force base (current city airport) as well as a light-industrial warehouse facility. All study basins contain at least a small percentage (range 0.5–11.7 percent) of urban open space; the largest percentage is found in the Deer Creek study basin (06889690). Lakes with surface areas larger than 5 acres are found in two study basins, Shunganunga Creek (06889580) and Deer Creek (06889690). Sherwood Lake on Shunganunga Creek has a watershed equal to 49.6 percent of the drainage area of study site 06889580. Lake Shawnee on Deer Creek, the largest lake in the study area, has a watershed equal to 63.8 percent of the drainage area of study site 06889690.

Land-use percentages, street densities, and slope of main channels, presented in table 2, were computed from latest available U.S. Geological Survey 7½-minute topographic maps that were modified to show current (1983) conditions based on a city of Topeka zoning map updated by onsite observations.

Table 2. Selected land-use classifications and physiographic characteristics of the study basins

Land-use classification or physiographic characteristic	Study basin at site					
	06889580	06889610	06889635	06889640	06889690	06889700
Drainage area, in square miles (acres)	13.8 (8,832)	13.8 (8,832)	4.65 (2,976)	42.1 (26,944)	14.3 (9,152)	60.3 (38,592)
Land use, in percentage of drainage area:						
Agricultural	85.9	83.3	51.1	63.0	70.6	60.7
Residential	7.5	3.1	26.7	20.5	12.3	21.2
Commercial	.2	2.9	11.0	5.6	1.0	4.8
Industrial	0	10.2	.4	3.8	.3	3.3
Urban open space	2.3	.5	10.8	5.8	11.7	8.1
Lakes, larger than 5 surface acres.	4.1	0	0	1.3	4.1	1.9
Drainage basin upstream from lake(s) larger than 5 surface acres, in percentage of drainage area.	49.6	0	0	16.3	63.8	26.5
Impervious area, percentage of drainage area.	5.0	13	22	17	8.0	17
Street density, lane miles per square mile.	5.6	9.5	19	16	10	16
Average slope of main channel, in feet per mile.	30	15	36	11	18	9.2
Hydrologic soil group, in percentage of drainage area:						
Soil group B	0	4	7	4	6	5
Soil group C	83	63	47	66	48	61
Soil group D	17	33	46	30	46	34

Percentages of impervious area (table 2) were estimated by multiplying computed land-use percentages by coefficients of imperviousness for each land use, as listed by the U.S. Soil Conservation Service (1975). Land uses and corresponding coefficients are as follows:

Land use	Coefficient of imperviousness
Residential (0.25-acre lot, average)	0.38
Commercial	.85
Industrial	.72

Additionally, coefficients of imperviousness were estimated for urban open space (0.10) and agricultural areas (0.02). These estimated coefficients were applied in urban open space to account for impervious features such as roads, parking lots, sidewalks, recreational buildings and facilities, and scattered residential areas containing only a few houses (areas too small to be included in the residential category); and in agricultural areas to account for roads, isolated farmhouses and outbuildings, and outcrops of rock. Percentages of drainage area covered by hydrologic soil groups B, C, and D (table 2) were determined from U.S. Soil Conservation Service soils maps (Abmeyer and Campbell, 1970).

DATA COLLECTION AND ANALYSIS

Continuous stream-stage records at the six study sites were collected with either a bubble-gage sensor system or a stilling-well/float combination (Buchanan and Somers, 1978). Stream stage was recorded in 5- or 15-minute increments and was related to periodic current-meter streamflow measurements (Buchanan and Somers, 1976) in order to develop and adjust stage-discharge ratings (Kennedy, 1983) for each study site. Mean daily streamflow for all study sites from October 1979 to September 1981 have been published in "Water-Resources Data for Kansas" (U.S. Geological Survey, 1981; 1982).

In the initial phase of this study, prior to late summer 1980, equipment and methods described in Skougstad and others (1979) were used to manually collect water samples for chemical analysis. Beginning in August 1980, at study site 06889700, and in March 1981, at study sites 06889580, 06889610, 06889635, and 06889640, most of the water-quality samples were collected automatically by the U.S. Geological Survey Urban Hydrology Monitoring System (UHMS). Study site 06889690 was not instrumented with UHMS equipment, and samples there were collected manually throughout this study.

The UHMS consisted of three components: (1) a system control unit that controls sample collection and monitors, stores, and punches onto 16-channel paper tape the date and time of sample collection, stream stage, and accumulated rainfall; (2) a Manning[1] automatic sampler capable of collecting 1 to 24 discrete 3-liter samples based on stage-dependent, programmable time intervals or differential change in stage; and (3) a chest-type freezer that housed the sample containers. The freezer was modified by the addition of an externally regulated thermostatic control that maintained the samples at 39 °F until they could be processed.

Additional instrumentation for this study consisted of Weathertronics Model 6010–99 tipping-bucket rain gages and U.S. Geological Survey minimonitors to record stream-water temperature and specific conductance. A rain gage was installed at each study site equipped with a UHMS. The rain gage was interfaced with the UHMS to record cumulative rainfall at 5- or 15-minute intervals for the duration of a storm. Measurement sensitivity of the Weathertronics rain gage was 0.01 inch. A minimonitor was installed at each of the six study sites to collect continuous records of water temperature and specific conductance at recording intervals of 30 minutes.

Two methods of sampling were used in this study: (1) discrete sampling and (2) composite sampling. The discrete samples were collected individually either manually or by the UHMS. The composite samples consisted of a series of automatically collected discrete samples that were composited into one discharge-weighted sample. Analysis of composite samples produced mean water-quality constituent concentrations for an entire storm, thereby saving analytical cost. The method of computing the discharge-weighted volume of each discrete sample to be included in the composite sample was based on the midinterval method of subdividing (Porterfield, 1977):

$$v_i = \left(\frac{q_i t_i}{\Sigma q_i t_i}\right) V_T \,, \quad (1)$$

where

v_i = volume of discrete sample to be included in the composite sample;

q_i = instantaneous streamflow (cubic feet per second) at the time of discrete-sample collection;

t_i = time interval (minutes)—equal to one-half the time since the previous sample plus one-half the time to the next sample. For the first sample, the time interval is from the beginning of storm runoff to one-half of the time to the second sample. For the last sample, the time interval is from one-half the time since the previous sample to the end of storm runoff; and

V_T = volume of composite sample required by the laboratory.

[1]The use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey nor the Kansas Department of Health and Environment.

Samples for water-quality analysis were collected at each of the six study sites during three streamflow conditions: (1) dry-weather streamflow from natural base flow and from urban point sources, such as sewage-plant effluent, lawn watering, and street or automobile washing, (2) storm streamflow from overland runoff and from storm-sewer systems in combination with components of dry-weather streamflow during precipitation periods, and (3) snowmelt streamflow from snowmelt water that enters local streams by the same routes as storm streamflow in combination with components of dry-weather streamflow.

Chemical analysis of samples collected for this study were made by the Division of Laboratories, Kansas Department of Health and Environment, Topeka, Kansas. Analyses were made in accordance with methods described by the American Public Health Association (1975) or the U.S. Environmental Protection Agency (1979). Concentrations of dissolved chemical constituents presented in this report were determined for water samples that were filtered through 0.45-micron filters. Total concentrations of constituents were determined on unfiltered, acidified samples of the water-sediment mixture. Total concentration represents the amount of a constituent in solution after acid digestion of the readily soluable fraction of the constituent. Complete dissolution of all particulate matter is not achieved. Total concentration, as used in this report, also is known as total recoverable concentration. Determinations made at the time of sample collection or at the U.S. Geological Survey laboratory, Lawrence, Kansas, included specific conductance and suspended-sediment concentrations. Suspended-sediment concentrations were determined by methods described in Guy (1977). Results of water-quality measurements and chemical analyses made during this study have been published (Pope and others, 1983).

WATER-QUALITY CONSTITUENT CONCENTRATIONS

Variations in concentrations of water-quality constituents in streams often are the result of the source of streamflow and the land-use activities in the drainage basin. Results of water-quality analysis for samples collected during three streamflow conditions (dry-weather, storm, and snowmelt) were summarized statistically to determine the variability both at and between the study sites (see table 11 at the back of this report). Median concentrations of constituents were compared for the three streamflow conditions and were used in correlation and regression analysis to develop relations with land use. Graphs showing the relation of water-quality constituent concentrations to streamflow were prepared for periods of storm and snowmelt streamflow to illustrate the concentration variability caused by land-use and storm characteristics. Average storm-runoff constituent concentrations, in pounds per square mile per inch of runoff, were computed and summarized statistically to determine the variability between study sites and storms. Multiple-correlation and regression analysis was used to relate average storm-runoff constituent concentrations to land-use, physiographic, and storm characteristics.

Dry-Weather Streamflow

Mean daily streamflow records for October 1, 1979, to September 30, 1981 (U.S. Geological Survey, 1981; 1982) indicate that streamflow usually was maintained in the study area except during extremely hot or dry periods. Zero flows were never recorded at study sites 06889640 and 06889700, the two most downstream Shunganunga Creek sites. The largest percentage of time that zero flow was recorded (12 percent) was at study site 06889635, which has the smallest drainage area. Most of the zero flow occurred during the summer drought of 1980 (fig. 2).

Determination of constituent concentrations in dry-weather streamflow was necessary to provide a basis for assessing the changes in water quality of local receiving streams that are caused by storm or snowmelt runoff. Total concentrations of trace metals such as chromium, copper, lead, and zinc were small in dry-weather streamflow; in fact, median concentrations of chromium and lead were less than analytical detection limits at most of the study sites (see table 3 for detection limits). Median concentrations of total copper ranged from a low of not detected at study sites 06889580, 06889690, and 06889700 to a high of 10 μg/L (micrograms per liter) at study sites

Table 3. Analytical detection limits of selected water-quality constituents

Constituent	Unit of measurement	Detection limit
Chemical oxygen demand	Milligrams per liter	5.0
Sodium, dissolved	do.	1.0
Chloride, dissolved	do.	2.0
Solids, dissolved	do.	1.0
Nitrite plus nitrate nitrogen, dissolved	do.	.01
Ammonia nitrogen, dissolved	do.	.01
Ammonia plus organic nitrogen, total	do.	.1
Phosphorus, total	do.	.01
Arsenic, total	Micrograms per liter	10
Chromium, total	do.	10
Copper, total	do.	10
Lead, total	do.	10
Mercury, total	do.	.5
Zinc, total	do.	10
Sediment, suspended	Milligrams per liter	1.0

06889635 and 06889640. Median concentrations of total zinc ranged from 10 $\mu g/L$ at study sites 06889580 and 06889610 to 30 $\mu g/L$ at site 06889635. Little variation was observed in total concentrations of trace metals in streams draining the study area during dry-weather streamflow.

Concentrations of dissolved nitrite plus nitrate nitrogen (NO_2+NO_3 as N), dissolved ammonia nitrogen, and total phosphorus in dry-weather streamflow varied more between study sites than did total concentrations of trace metals. Median concentrations of dissolved NO_2+NO_3 as N were largest at the two most upstream study sites, 06889580 (0.85 mg/L, milligrams per liter) and 06889610 (1.10 mg/L), where dry-weather streamflow was sustained by effluent discharged from wastewater-treatment plants (fig. 3). Median concentrations of dissolved NO_2+NO_3 as N were considerably smaller at the two study sites, 06889635 (0.35 mg/L) and 06889690 (0.20 mg/L), that do not receive wastewater-treatment-plant effluent. Also, on the main branch of Shunganunga Creek, there was a decrease in median concentrations of dissolved NO_2+NO_3 as N with increasing distance downstream from study site 06889580, as evidenced by median concentrations of 0.50 mg/L at study site 06889640 and 0.30 mg/L at study site 06889700.

Median concentrations of dissolved ammonia nitrogen did not vary between study sites as much as median concentrations of dissolved NO_2+NO_3 as N (table 11). Median concentrations of dissolved ammonia nitrogen ranged from 0.14 mg/L at study sites 06889640 and 06889690 to 0.27 mg/L at study site 06889635. As with median concentrations of dissolved NO_2+NO_3 as N, median concentrations of dissolved ammonia nitrogen were slightly larger at the two study sites closest to the wastewater-treatment plants. However, unlike dissolved NO_2+NO_3 as N, the largest median concentration of dissolved ammonia nitrogen (0.27 mg/L) occurred at study site 06889635. The source for the relatively large median concentration at study site 06889635 is not known.

Median concentrations of total phosphorus ranged from 0.17 mg/L at study sites 06889635 and 06889690 to 0.76 mg/L at study site 06889610. Generally, the study sites with the largest median concentrations of dissolved NO_2+NO_3 as N also had the largest median concentrations of total phosphorus.

Because median concentrations of nutrients, especially dissolved NO_2+NO_3 as N and total phosphorus, were larger at those study sites closest to the sources of wastewater-treatment-plant effluent, a sample of effluent, collected December 19, 1979, from wastewater-treatment plant number 2 (fig. 3) was analyzed to determine its nutrient content. The effluent, which was discharging at a rate of 0.04 ft^3/s, had a dissolved NO_2+NO_3 as N concentration of 16.0 mg/L, a dissolved ammonia-nitrogen concentration of 0.77 mg/L, and a total phosphorus concentration of 10.0 mg/L. Therefore, wastewater effluents appear to be responsible for the largest concentrations of nutrients observed during dry-weather streamflow.

Storm Streamflow

Quantitative Comparison of Median Concentrations

Comparison of median constituent concentrations during storm streamflow and dry-weather streamflow (table 11) indicates that concentrations of trace metals, dissolved NO_2+NO_3 as N, and total phosphorus were larger during storm streamflow than during dry-weather streamflow. Conversely, median concentrations of dissolved ammonia nitrogen were smaller during storm streamflow than during dry-weather streamflow, except for study site 06889610.

A comparison between median concentrations of total chromium, copper, lead, and zinc in storm and dry-weather streamflow for all study sites is shown in figure 5. Median concentrations of total chromium during storm streamflow, with the exception of study site 06889700, either were less than or equal to the analytical detection limit (10 $\mu g/L$, table 3). Study site 06889700 had a median total chromium concentration during storm streamflow that was twice as large as that of any of the other sites and was the only site with a median concentration above the detection limit during dry-weather streamflow. For most of the study sites, significant concentrations of total chromium were present only during storm streamflow. The larger median concentrations of total chromium at study site 06889700 may be the result of point-source discharges and storm runoff from the industrial area located between study sites 06889640 and 06889700 because the occurrence of chromium in water results mainly from industrial pollution (Hem, 1978, p. 199).

Median concentrations of total copper in storm streamflow generally were larger than those of total chromium. Median concentrations of total copper in storm streamflow were at least twice as large as those in dry-weather streamflow and, with the exception of study site 06889580, were largest at those study sites with the greatest degree of urbanization, as evidenced by land-use percentages in table 2. Copper is a widely used metal in urban areas. The use of copper in pipes, pumps, electrical devices, automotive bushings and brake linings, exterior decorative structures, and rain gutters and flashings on buildings provides a variety of sources from which copper may enter the hydrologic environment in either particulate or dissolved form.

Of the median concentrations shown in figure 5, total lead and total zinc had the greatest at- and between-site variation. With the exception of the 5 $\mu g/L$ median

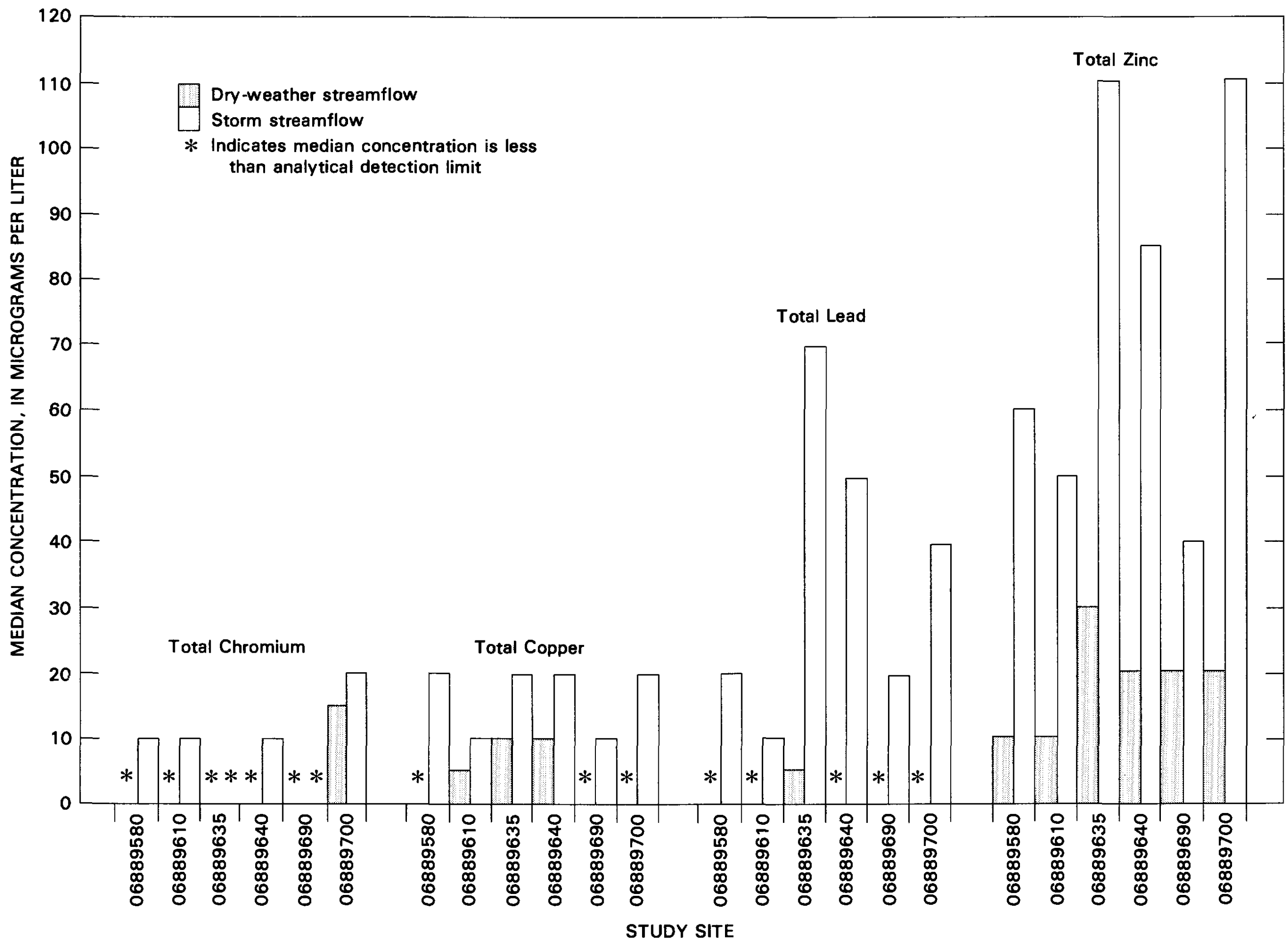

Figure 5. Comparison of median concentrations of total chromium, copper, lead, and zinc in dry-weather and storm streamflows.

(computed from eight samples) dry-weather streamflow concentration at study site 06889635, total lead is basically a constituent transported by storm streamflow, particularly in the more urban basins. The median total lead concentration in storm streamflow at study site 06889635, the most urban study basin, was seven times the median concentration at study site 06889610, the basin with the second largest percentage of agricultural land. The larger median total lead concentrations at study sites with more urban basins probably is due to increased automobile traffic in these areas. The use of lead as a gasoline additive and its subsequent dispersal in automobile exhaust is the primary source of lead in the study area. However, a possible secondary source is the deterioration of exterior-type leaded paints (Linton and others, 1980). Because Federal regulations have required the use of unleaded gasoline in automobiles manufactured since the middle 1970's and prohibited the use of lead in paints due to public health concerns, concentrations of lead in runoff from urban areas may be less in the future than observed during this investigation.

The median concentrations of total zinc in storm streamflow are two to six times larger than those in dry-weather streamflow. Median concentrations of total zinc in storm streamflow ranged from 40 μg/L at study site 06889690, to 110 μg/L at study sites 06889635 and 06889700 (table 11), and were distributed between study sites in an urban-related pattern similar to that of total lead. Zinc, like copper and lead, is a metal commonly found in urban areas. The major use of zinc in urban areas is as a rust-preventative coating on structural steel used in exterior construction or steel used on trucks and automobiles. Also, zinc is a trace component in automobile tire rubber and brake linings (Hopke and others, 1980).

To clarify the extent of variation of concentrations of total lead in storm streamflow, both at and between study sites, cumulative frequency distributions were plotted (fig. 6). A very distinct separation between two groups of curves is evident in figure 6. Concentrations of total lead in storm streamflow from the three most agricultural study basins (06889580, 06889610, and 06889690) are considerably smaller than those in storm streamflow from the three more urban study basins

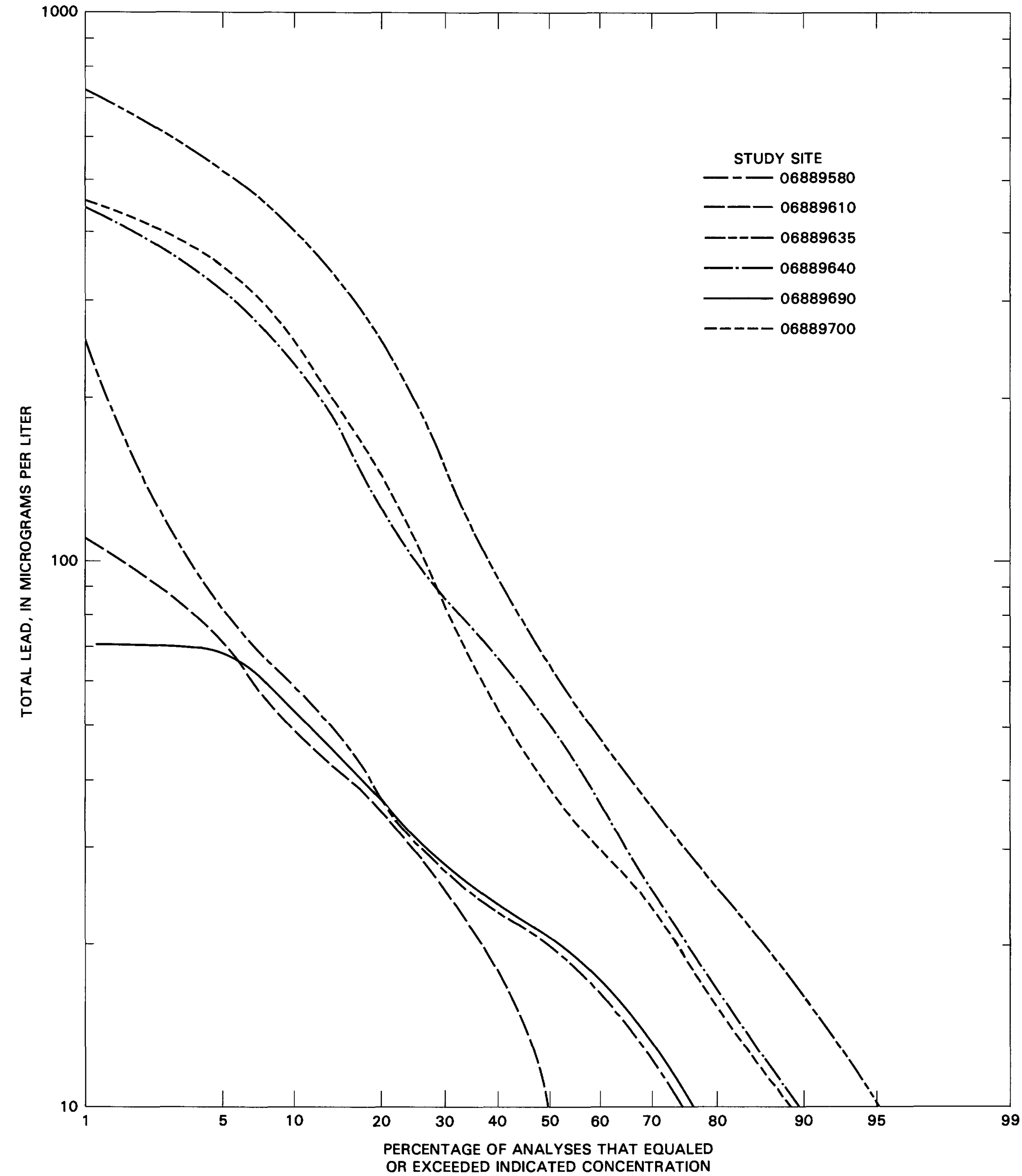

Figure 6. Frequency distribution of total lead concentrations in storm streamflow.

(06889635, 06889640, and 06889700). Figure 6 shows that 50 percent of the observed concentrations of total lead in storm streamflow from the three most agricultural basins were about 20 μg/L or less, whereas concentrations in storm streamflow from the three most urban basins were 40 μg/L or more. An even more striking comparison can be seen at the 10-percent level where storm streamflow from the most agricultural basins had concentrations of 70 μg/L or less whereas concentrations of 230 μg/L or more were observed at the three study sites with the most urban basins. Study site 06889635, the basin with the largest percentage of urban land, had the largest concentrations of total lead throughout the frequency distribution.

Comparisons of median concentrations of dissolved NO_2+NO_3 as N, dissolved ammonia nitrogen, and total phosphorus are shown in figure 7. Median concentrations of dissolved NO_2+NO_3 as N at all study sites averaged 76-percent larger during storm streamflow than during dry-weather streamflow. The largest median concentration of dissolved NO_2+NO_3 as N in storm streamflow occurred at study site 06889610 and was nearly twice that of the next largest median concentration. This relatively large median concentration of dissolved NO_2+NO_3 as N is probably the result of the predominantly agricultural land use (runoff from fertilized cropland and livestock pasture). A previous investigation showed that the mean annual concentration of inorganic nitrogen in streams draining mostly agricultural basins (agricultural land use greater than 75 percent) was 2.5 times larger than the mean annual concentration in streams draining mostly urban basins (urban land use greater than 39 percent) in the eastern United States (Omernik, 1976).

With the exception of study site 06889610, median concentrations of dissolved ammonia nitrogen were larger during dry-weather streamflow than during storm streamflow. The slightly larger median concentration in storm streamflow at study site 06889610 was probably the result of agricultural activities in the study basin. Median concentrations of dissolved ammonia nitrogen in storm streamflow from the other five study basins showed little variation (0.11 to 0.13 mg/L).

Median concentrations of total phosphorus in storm streamflow at all study sites averaged 70-percent larger than median concentrations in dry-weather streamflow. The largest increase was 135 percent at study site 06889690 while the smallest was 5 percent at study site 06889610. The largest median concentrations of total phosphorus in storm streamflow occurred at the two most agricultural study sites, 06889580 and 06889610.

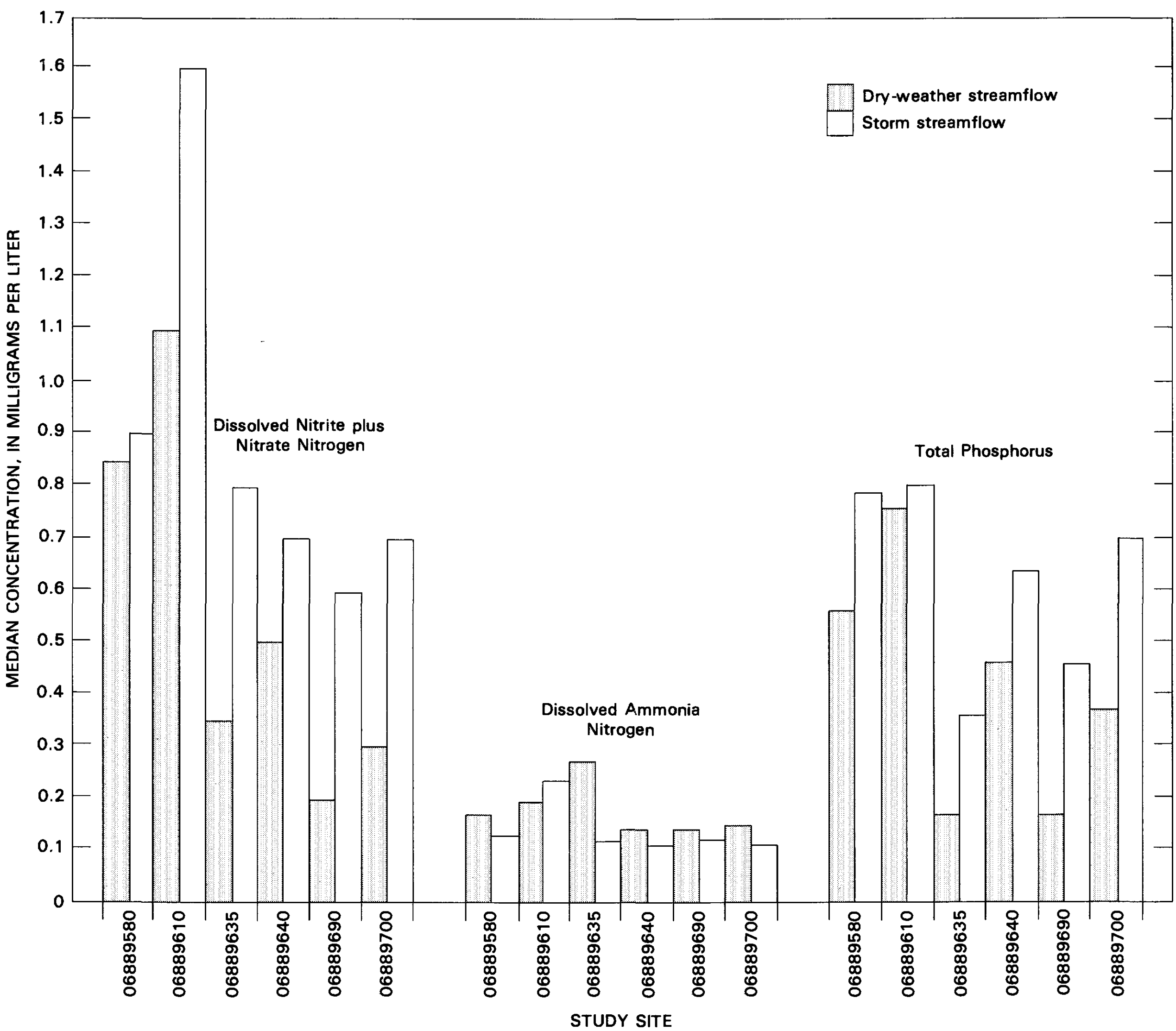

Figure 7. Comparison of median concentrations of dissolved nitrite plus nitrate nitrogen, dissolved ammonia nitrogen, and total phosphorus in dry-weather and storm streamflows.

Relationship of Median Concentrations to Land Use

Linear correlation and regression analysis was used to investigate relationships between median concentrations of total lead and zinc in storm streamflow and selected land-use percentages and street densities in each study basin. The results of this regression analysis are presented in table 4 and figure 8. The best results were obtained with the use of the summation of residential and commercial land-use percentages. The equations presented in table 4 are of the form:

$$Y = a + bx, \qquad (2)$$

where

- Y is the predicted median concentration of total lead or zinc, in micrograms per liter, as computed by the equation;
- a is the y-intercept value, a constant determined by the regression analysis;
- b is the slope of the regression line, a constant determined by the regression analysis; and
- x is the independent variable, either residential plus commercial land use, in percentage of drainage area, or street density, in lane miles per square mile.

In regard to the use of regression equations, the extrapolation of a regression equation beyond the range of the independent variable (x) used in developing the regression equation is discouraged for two reasons. First, as the difference between the mean value of the independent variable and the value used for prediction increases, the confidence intervals about the regression line become wider; second, the relation between the dependent and independent variables (Y and x) may be linear only over the range of x investigated (Haan, 1977, p. 192). Therefore, the equations in table 4 should be used only for basins where the residential and commercial land-use percentages are within the range of those investigated during this study (see table 2). Also, these relations may not be valid if industrial land use comprises a large percentage of the basin. Percentages of industrial land use for the basins in this study ranged from 0 to 10.2 percent.

Table 4. Results of correlation and regression analysis relating median concentrations of total lead (TOTLEAD) and zinc (TOTZINC) in storm streamflow to percentage of residential plus commercial (RES+COM) land uses and street density (STDEN), in lane miles per square mile

[All equations presented are significant at the 0.05 level of significance]

Regression equation	Number of samples	Correlation coefficient	Standard error of estimate (micrograms per liter)
TOTLEAD=1.77 (RES +COM) + 0.52 ...	6	0.98	5.3
TOTZINC=2.14 (RES +COM) + 34.2 ...	6	.88	16
TOTLEAD=3.92 (STDEN) − 15.2 ...	6	.89	11
TOTZINC=4.96 (STDEN) + 12.4 ...	6	.84	19

Correlation coefficients for relationships between median concentrations of total lead and zinc in storm streamflow and percentage of residential plus commercial land uses and street density ranged from 0.84 to 0.98. A relatively good correlation (0.98 correlation coefficient) resulted from the relationship between the median concentration of total lead and the percentage of residential plus commercial land uses. The standard error of estimate for this relationship (5.3 μg/L) is 15 percent of the mean of the median concentrations of total lead in storm streamflow from the six study basins.

The drainage basins of study sites 06889580 and 06889690 both contain large surface-water impoundments (Sherwood Lake and Lake Shawnee, respectively) that receive drainage from major parts of their respective study basins. Sherwood Lake receives drainage from 49.6 percent of the total drainage area of study site 06889580, and Lake Shawnee receives drainage from 63.8 percent of the total drainage area of study site 06889690 (table 2). These lakes trap some of the suspended particulate material that originates from the upper part of each basin. However, the lakes may be trapping only a small part of the total lead and zinc load transported from each basin because most of the residential and commercial areas in each basin are located either downstream from the lakes or in areas that drain away from the lakes. For this reason, data from study sites 06889580 and 06889690 were used in the development of the regression equations in table 4 as though the lakes had no trapping effect.

Correlation and regression analysis also was used to investigate relationships between dissolved NO_2+NO_3 as N and total phosphorus and land use. Correlation coefficients for relationships between these two nutrients and selected land-use characteristics are shown in table 5. None of the correlation coefficients shown in table 5 were significant at the 0.05 level of significance; therefore, the resulting regression equations were not shown. Although these relationships are not statistically significant, general trends are indicated. Concentrations of both dissolved NO_2+NO_3 as N and total phosphorus increase with increasing percentage of agricultural land use (as evidenced by the positive correlation coefficients) and decrease with increasing percentage of residential and commercial land uses and street density (as evidenced by the negative correlation coefficients).

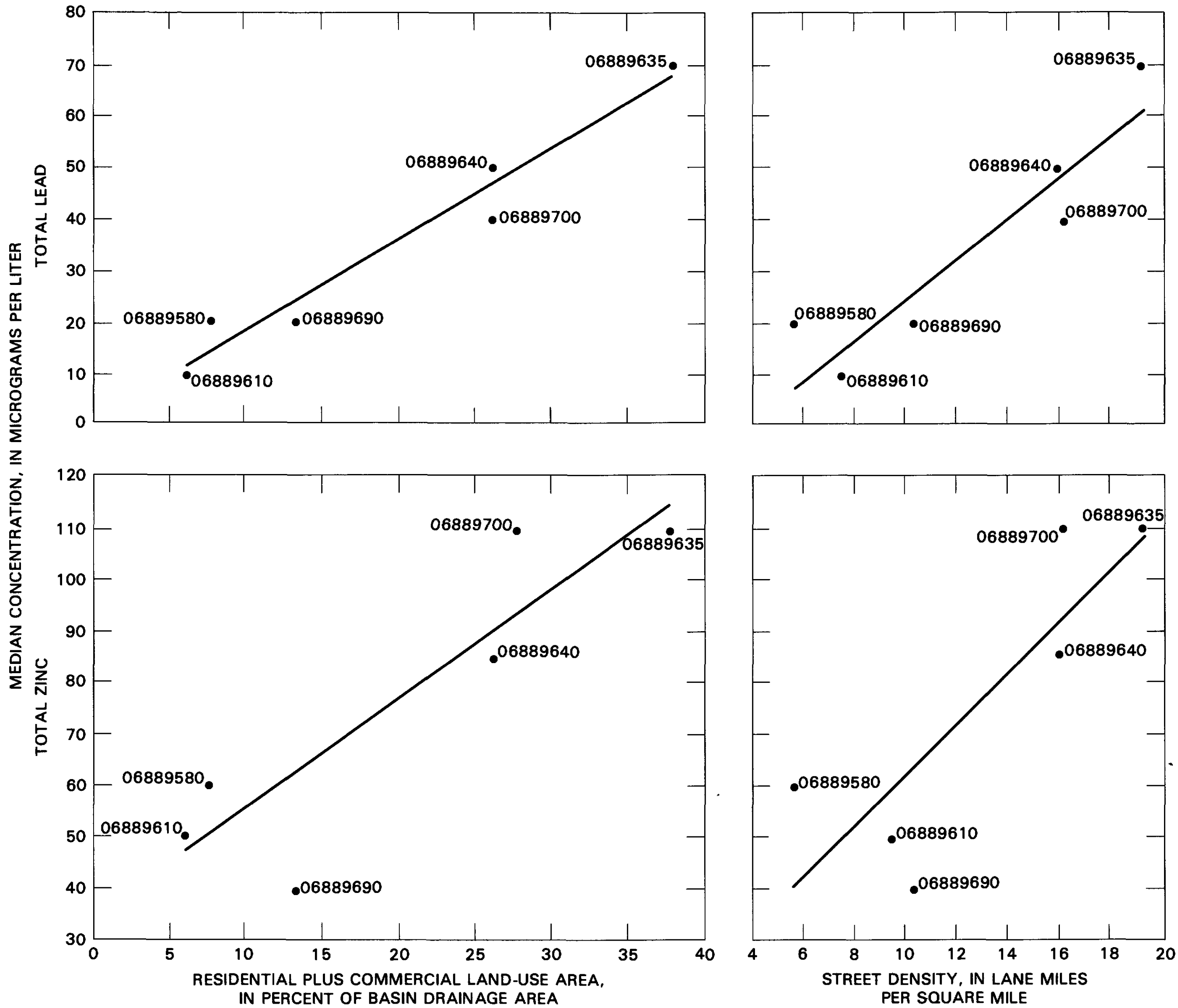

Figure 8. Relations between median concentrations of total lead and zinc in storm streamflow and residential plus commercial land use and street density.

Table 5. Correlations between median concentrations of dissolved nitrite plus nitrate nitrogen and total phosphorus in storm streamflow and selected land uses and street density
[None of the correlation coefficients shown in this table are significant at the 0.05 level]

	Correlation coefficient				
	Agricultural	Residential	Commercial	Residential plus commercial	Street density
Dissolved nitrite plus nitrate nitrogen	0.61	-0.69	-0.19	-0.56	-0.41
Total phosphorus	.74	-.67	-.60	-.67	-.60

Relationship of Concentrations to Storm Streamflow

Concentrations of constituents varied considerably during storm streamflow. The largest concentrations of total lead and suspended sediment occurred while storm streamflow was increasing or was near the peak streamflow and decreased through the storm-streamflow recession as indicated by the graphs of these constituents during the storm of May 9, 1981 (figs. 9 and 10). The plots of total lead are similar to those of suspended sediment because lead is transported absorbed to suspended-sediment particles.

The effects of urbanization on concentrations of these constituents in storm streamflow also are indicated in figures 9 and 10. The maximum concentration of suspended sediment at study site 06889610 (fig. 9), the second most agricultural basin, was much larger (3,000 mg/L) than that at study site 06889635 (fig. 10), the most urban basin, which had a concentration of 1,030 mg/L. Maximum concentrations of suspended sediment occurred near the peak streamflow at both study sites. The maximum concentration of total lead was much larger at study site 06889635, 300 μg/L, than at study site 06889610, 70 μg/L, probably because of the increase in automobile traffic associated with the greater degree of urbanization in the basin of study site 06889635. Also, the maximum concentration of total lead at study site 06889635 occurred much earlier in the storm streamflow than it did at study site 06889610 and appeared to be in response to the maximum rainfall intensity.

Concentrations of total zinc were not determined for the storm of May 9, 1981; however, the distribution of concentrations of total zinc is expected to be similar to that of total lead for three reasons. First, even though zinc is more soluble than lead, most of the zinc in storm streamflow is transported in suspension. For example, at study sites 06889610 and 06889635, median concentrations of total zinc were 5.0 to 5.5 times larger than median concentrations of dissolved zinc. Second, a correlation analysis between concentrations of total lead and zinc produced correlation coefficients of 0.92 at study site 06889610 and 0.78 at study site 06889635, both of which are significant at the 0.05 level of significance. Third, maximum concentrations of total lead and zinc and suspended sediment during the storm of July 18, 1981, occurred at the same time, approximately 15 minutes prior to the peak streamflow (fig. 11).

Rainfall intensity appears to be an important factor affecting concentrations of total lead and zinc and suspended sediment in storm streamflow. The distribution of rainfall, streamflow, and concentrations of total

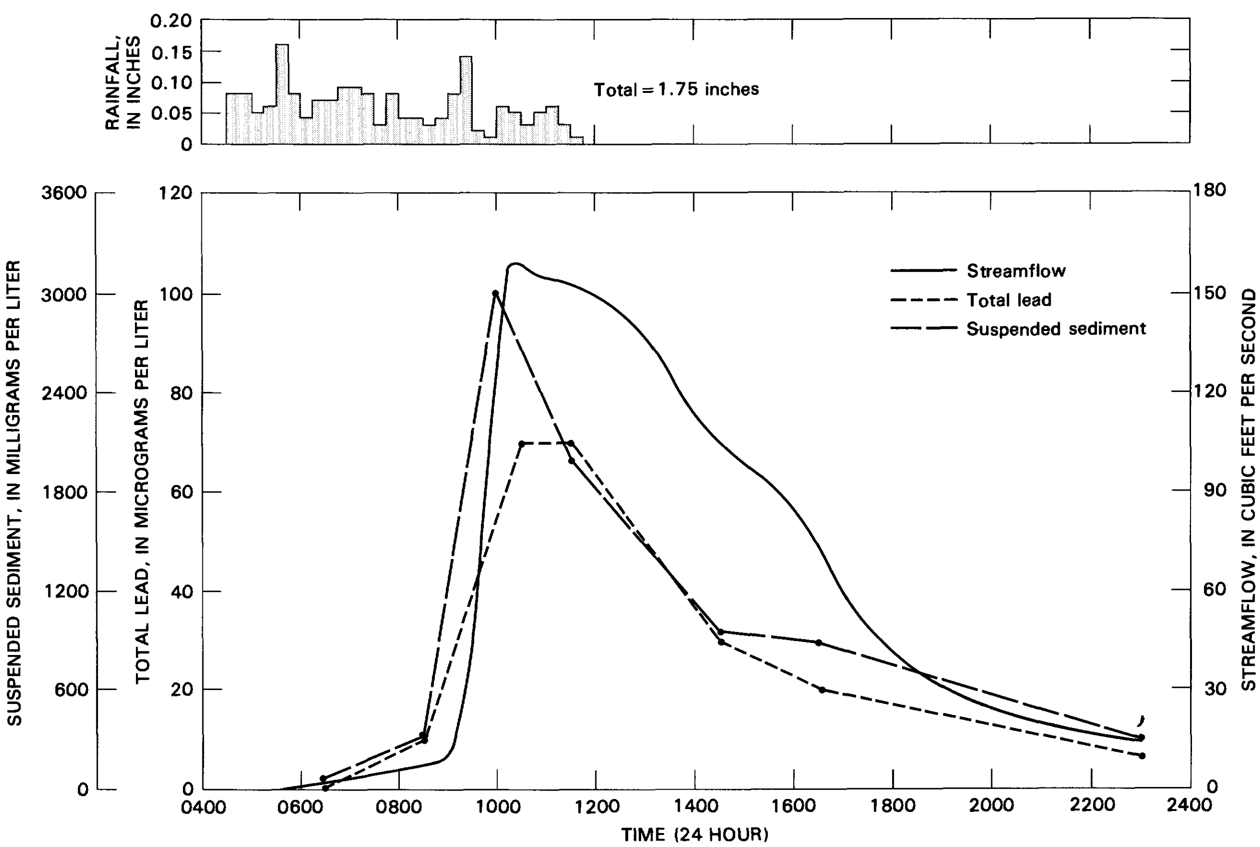

Figure 9. Rainfall, streamflow, and concentrations of total lead and suspended sediment for storm of May 9, 1981, at study site 06889610.

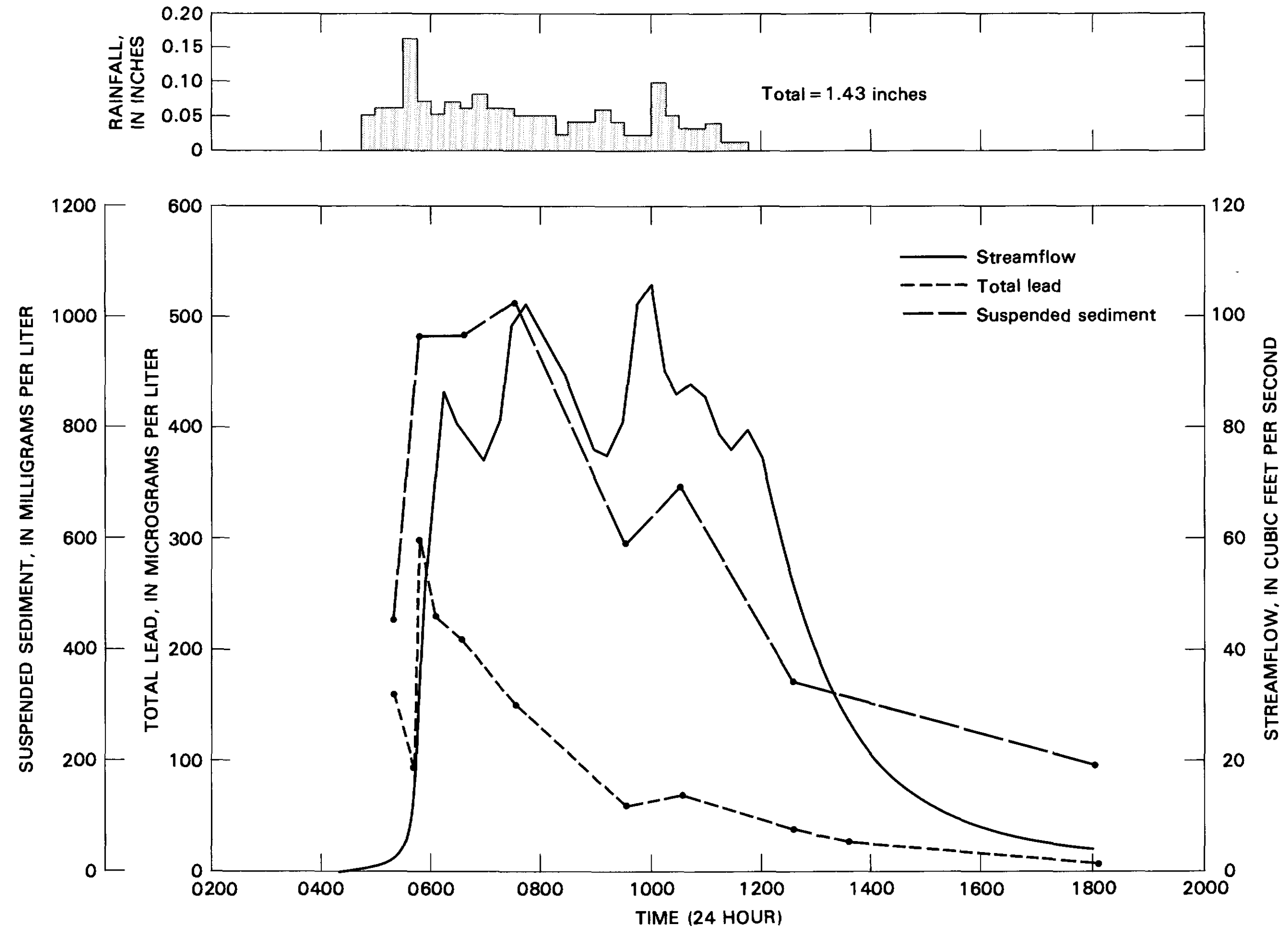

Figure 10. Rainfall, streamflow, and concentrations of total lead and suspended sediment for storm of May 9, 1981, at study site 06889635.

lead and zinc and suspended sediment at study site 06889635 during the storm of July 18, 1981, are shown in figure 11. Although the total rainfall for this storm and the storm represented in figure 10 were about the same (about 1.4 inches), the maximum 5-minute intensity for the storm of July 18 exceeded 4 inches per hour compared to less than 1 inch per hour for the storm in figure 10. The more intense storm produced a much larger volume of storm streamflow and much larger maximum concentrations of total lead and suspended sediment.

Graphs showing concentrations of dissolved NO_2+NO_3 as N and total phosphorus during storm streamflow are shown in figures 12 and 13. Figure 12 represents a predominantly agricultural basin, study site 06889610, during the storm of March 17–18, 1981. Concentrations of dissolved NO_2+NO_3 as N and total phosphorus generally increased through the duration of storm streamflow, and the largest observed concentrations occurred during the storm-streamflow recession, indicating that most of the dissolved NO_2+NO_3 as N was coming from the upstream, more agricultural parts of the basin. In fact, the largest observed concentration of dissolved NO_2+NO_3 as N occurred more than 10 hours after the peak streamflow. Because of questionable analytical results, concentrations of total phosphorus for storm-streamflow samples collected after 0900 hours (9:00 a.m.) were not shown in figure 12. However, available data indicate that maximum concentrations of total phosphorus are contributed by runoff from the upstream, more agricultural parts of the basin.

A graph showing concentrations of dissolved NO_2+NO_3 as N and total phosphorus at study site 06889635 during the storm of September 24, 1981, is presented in figure 13. In contrast to the graph shown in figure 12, a "first-flush" effect is evident in figure 13. The largest observed concentrations of dissolved NO_2+NO_3 as N and total phosphorus occurred during the initial storm streamflow. This first-flush effect is probably the result of runoff from recently fertilized lawns in the lower part of the basin. September is typically a time when homeowners in eastern Kansas fertilize cool-season grasses. Secondary peaks in concentrations of dissolved NO_2+NO_3 as N and total phosphorus occurred about midway during the increasing storm streamflow and were in response to increased rainfall intensity. However, the diluent effect of increased runoff caused

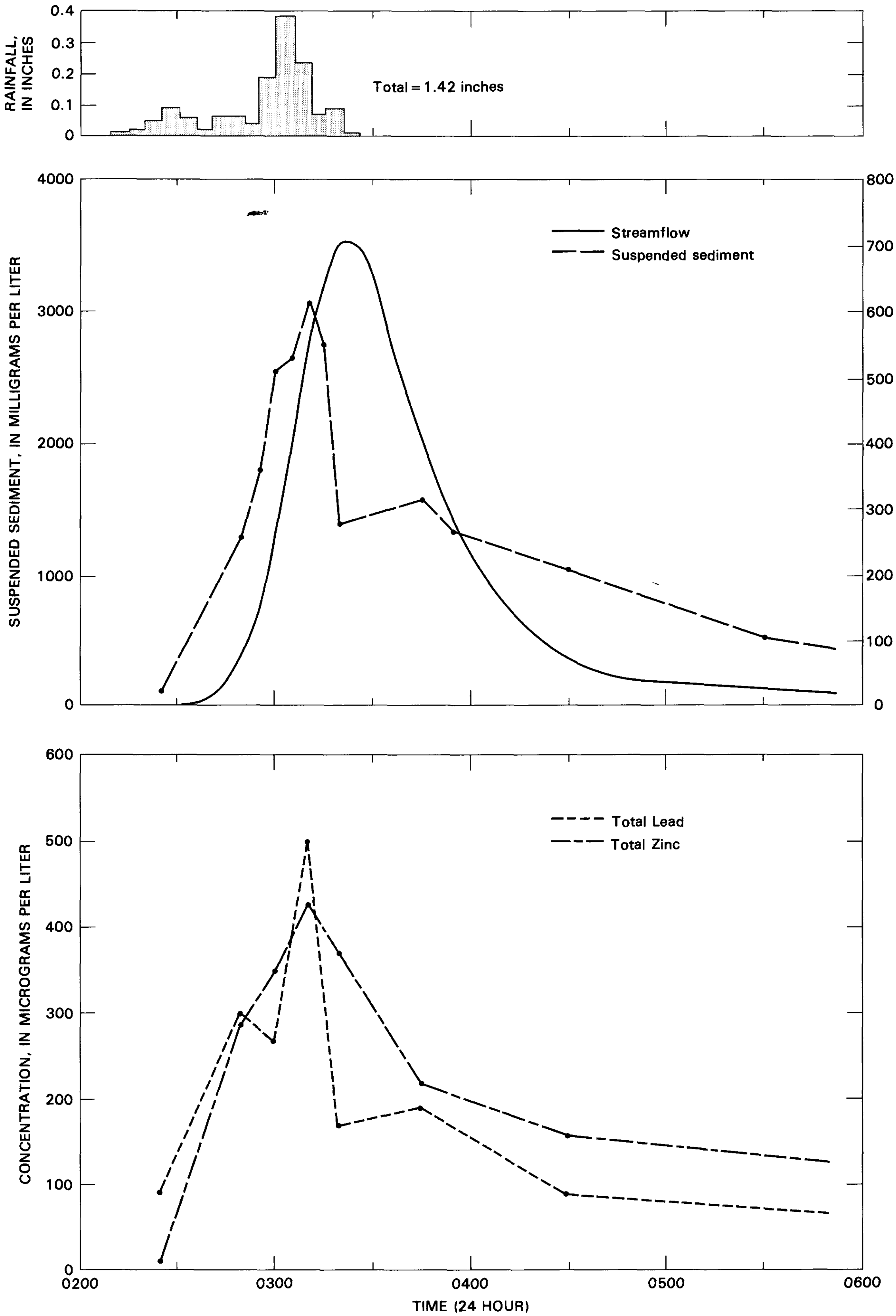

Figure 11. Rainfall, streamflow, and concentrations of total lead and zinc and suspended sediment for storm of July 18, 1981, at study site 06889635.

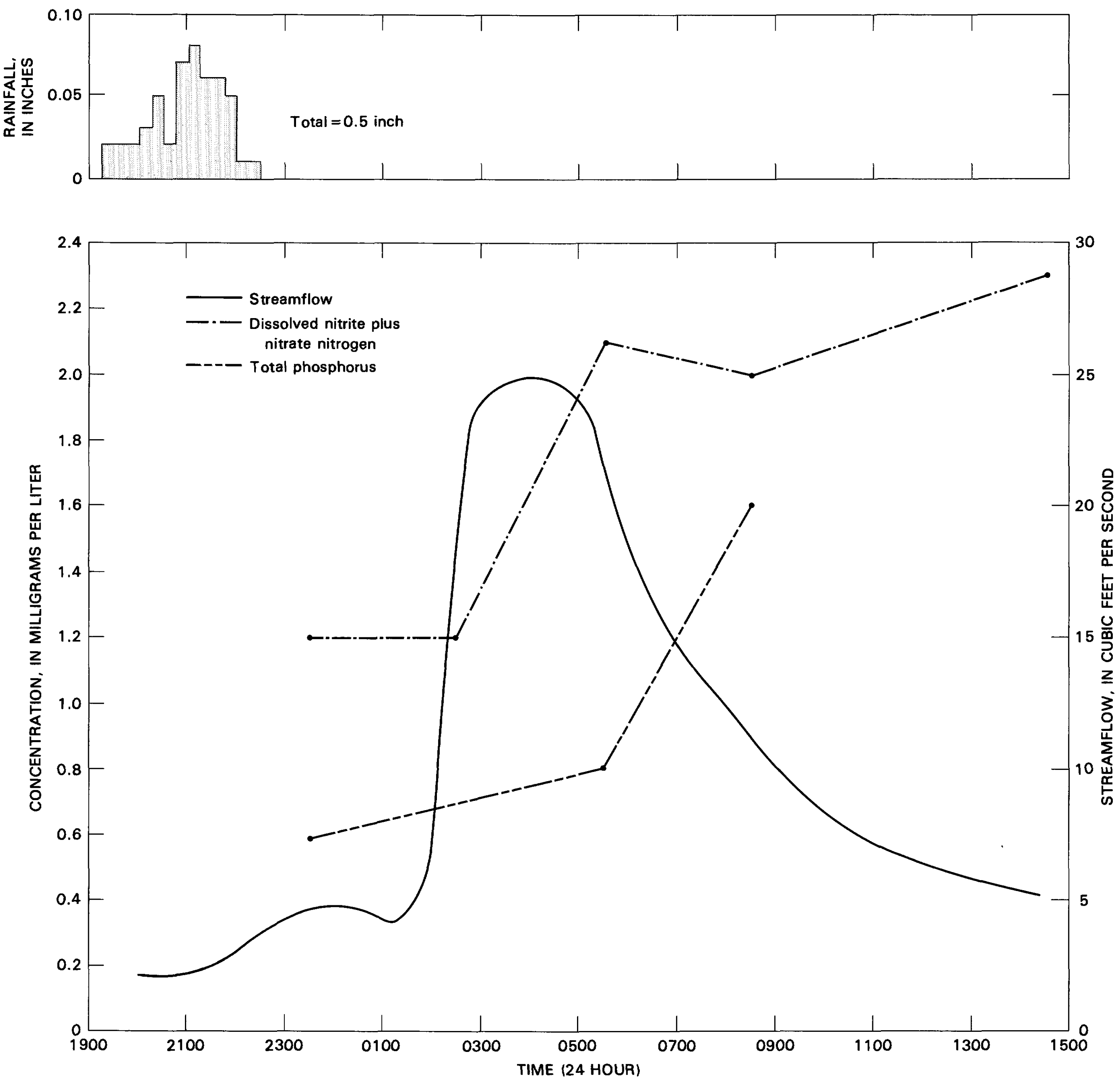

Figure 12. Rainfall, streamflow, and concentrations of dissolved nitrite plus nitrate nitrogen and total phosphorus for storm of March 17–18, 1981, at study site 06889610.

smaller concentrations near the peak storm streamflow. Concentrations of dissolved NO_2+NO_3 as N and total phosphorus increased during the storm-streamflow recession as streamflow from runoff in upstream, more agricultural parts of the basin reached the study site.

Snowmelt Streamflow

Quantitative Comparison of Median Concentrations

Because only 10 percent of the annual precipitation occurs during the winter months of December through February, snowmelt runoff is not a major contributing source of flow to streams in the study area. However, snowmelt runoff from urban areas can cause some significant, temporary changes in the water quality of local receiving streams. A statistical summary of snowmelt streamflow analyses for each study site is presented in table 11 (at the end of this report). Generally, median concentrations of total chromium, copper, lead, and zinc in snowmelt streamflow were equal to or greater than median concentrations observed during dry-weather streamflow but considerably less than those observed in storm streamflow (fig. 14). For example, at study site

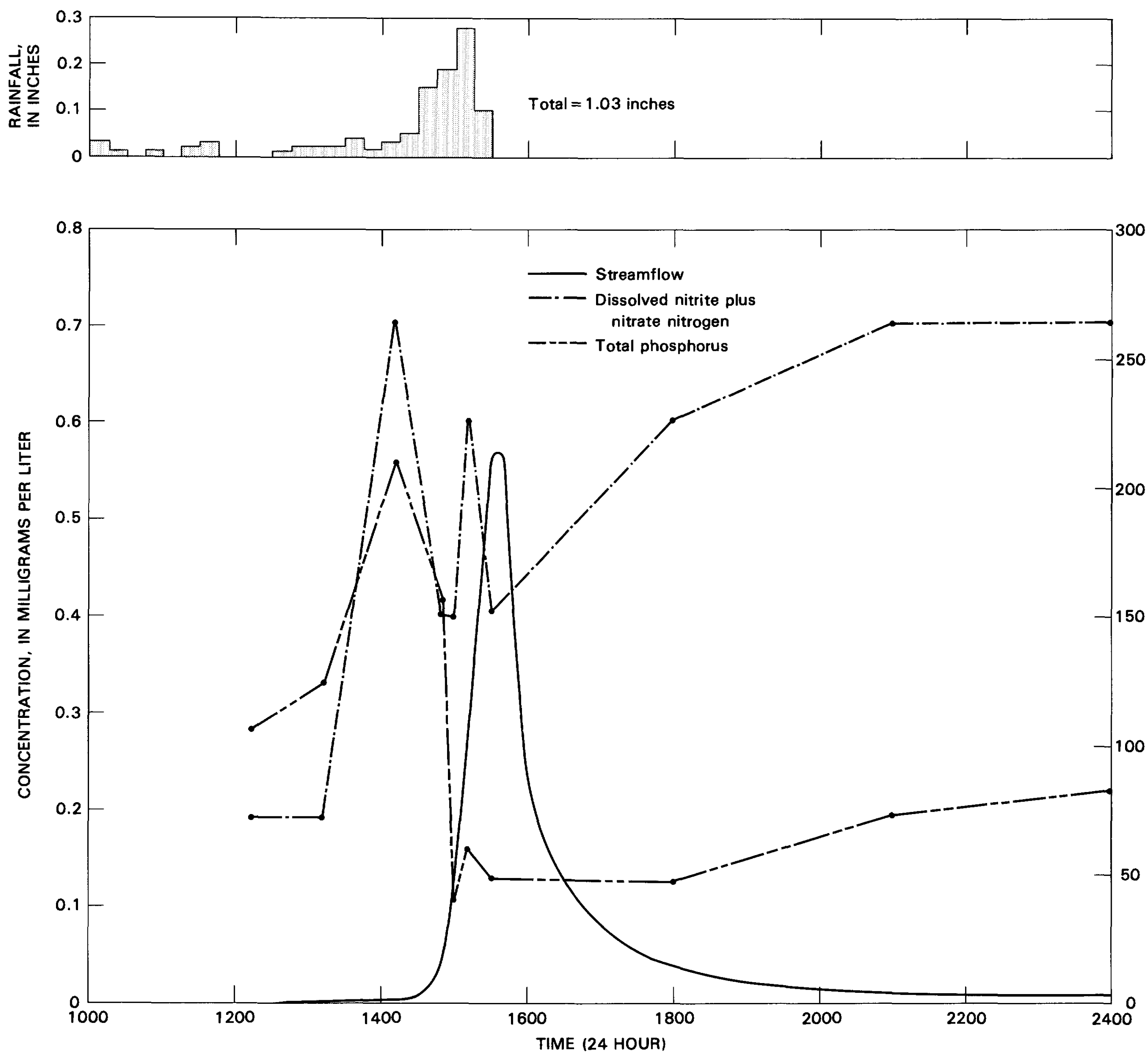

Figure 13. Rainfall, streamflow, and concentrations of dissolved nitrite plus nitrate nitrogen and total phosphorus for storm of September 24, 1981, at study site 06889635.

06889635, the median concentration of total lead in snowmelt streamflow is seven times the median concentration in dry-weather streamflow but is only one-half of the median concentration in storm streamflow. Median concentrations of total lead and zinc in snowmelt streamflow average 26 percent and 38 percent, respectively, of the median concentrations in storm streamflow.

Storm streamflow has much larger concentrations of trace metals than does snowmelt streamflow because of the greater ability of rainfall to dislodge and transport particulate material. This is evident when concentrations of suspended sediment in storm and snowmelt streamflow are compared, as shown in table 11. The largest median concentration of suspended sediment in snowmelt streamflow was 75 mg/L (study site 06889700) while the smallest median concentration of suspended sediment in storm streamflow was 315 mg/L (study site 06889610).

The most significant change observed in the water quality of local receiving streams as a result of snowmelt runoff was increased concentrations of dissolved sodium, chloride, and solids. As shown in figure 15, all study sites with the exception of 06889690 had significant increases in median concentrations of dissolved sodium, chloride, and solids in snowmelt streamflow as compared to median concentrations in dry-weather streamflow. These increased concentrations are the result of applications of deicing material (salt and sand mixture) on local streets and highways during snowfall periods.

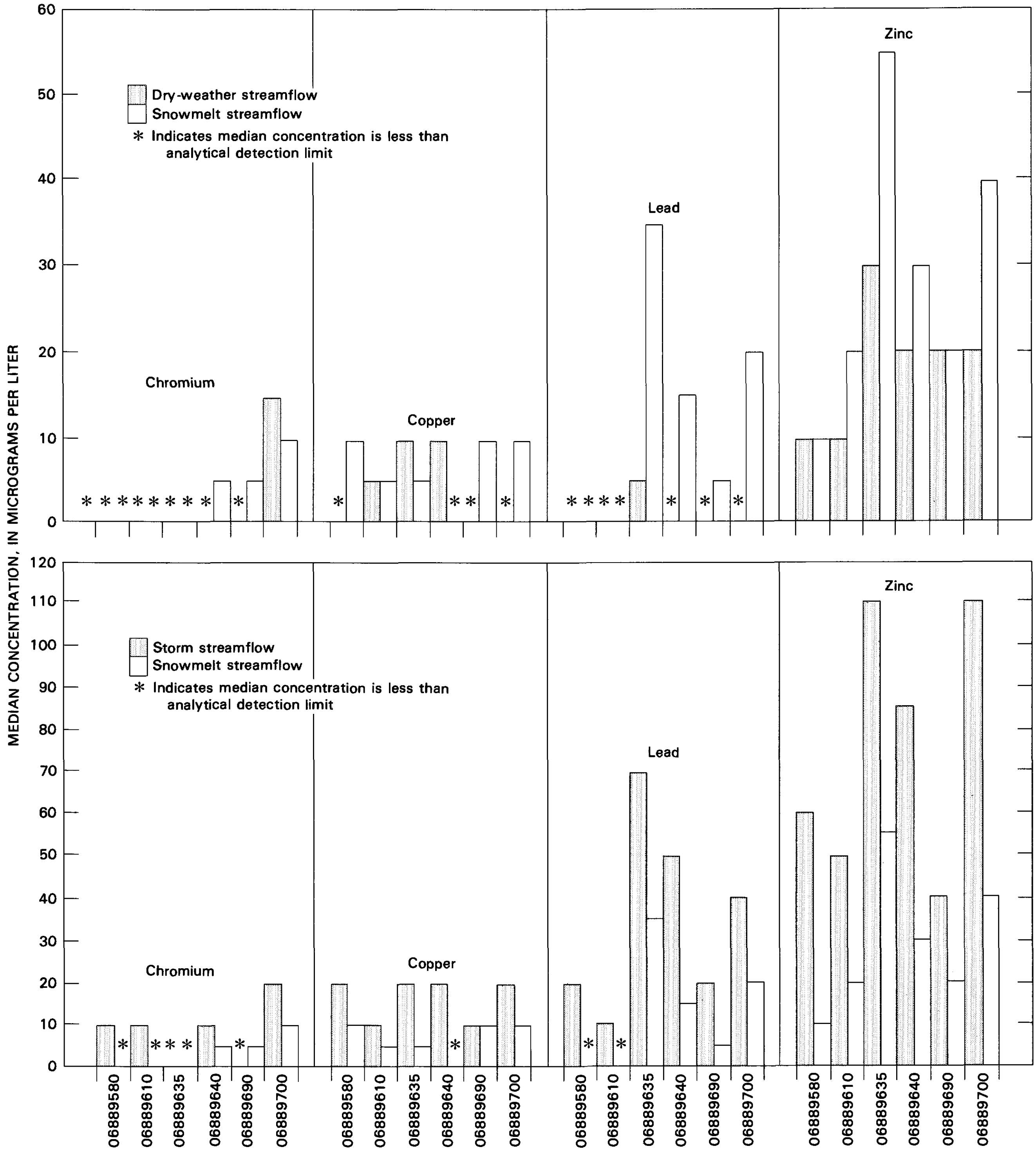

Figure 14. Comparison of median concentrations of total chromium, copper, lead, and zinc in dry-weather, storm, and snowmelt streamflows.

Subsequent snowmelt runoff transports the dissolved salt into local receiving streams. Median concentrations in snowmelt streamflow for all six study sites averaged 218 percent (dissolved sodium), 296 percent (dissolved chloride), and 71 percent (dissolved solids) greater than median concentrations in dry-weather streamflow (table 11).

The largest median concentrations of dissolved sodium, chloride, and solids in snowmelt streamflow occurred at study site 06889635 (fig. 15). Additionally,

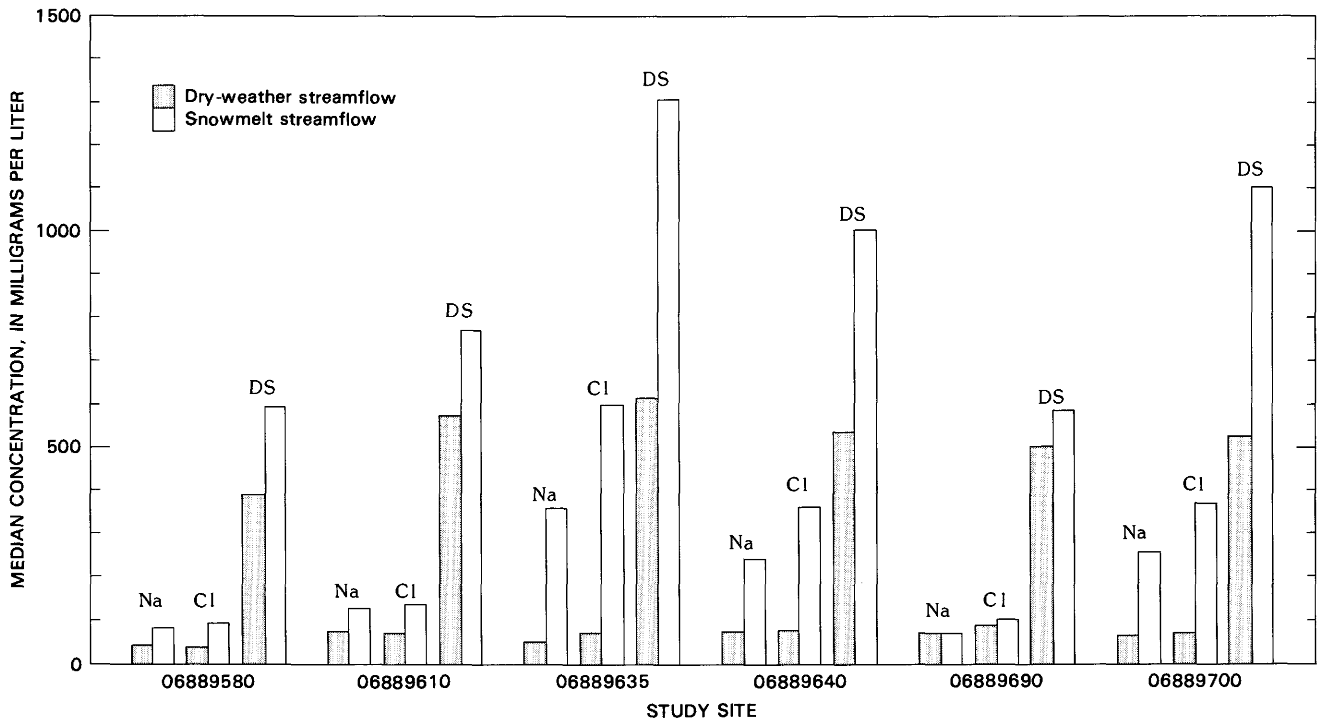

Figure 15. Comparison of median concentrations of dissolved sodium, chloride, and solids in dry-weather and snowmelt streamflows.

study site 06889635 had the largest percentage increases in median concentrations observed during snowmelt streamflow relative to those observed during dry-weather streamflow for all three dissolved constituents. The drainage basin of study site 06889635 contains the largest percentage of residential and commercial land use of any of the six study basins (table 2). It also has the greatest street density because of several major, multiple-lane, cross-town thoroughfares, and the percentage of this basin covered by impervious material is the largest of the six study basins. Therefore, it can be assumed that intense deicing activities occur within this basin. Study site 06889690, on the other hand, had the smallest percentage increase between median concentrations of dissolved sodium, dissolved chloride, and dissolved solids in dry-weather streamflow and snowmelt streamflow. These smaller increases are due to the fact that many of the streets and roads in this study basin are rural (outside city maintenance), less traveled, and, thus, receive fewer deicing treatments than those basins containing a greater percentage of urban, high-traffic streets.

It is emphasized that the comparisons of median concentrations of dissolved constituents in snowmelt and dry-weather streamflows were based on samples of snowmelt streamflow collected during 1980 and 1981, a 2-year period when the annual average snowfall was 14.3 inches (7.8 inches less than the long-term average). Deviations from the annual average snowfall observed during this study could result in significantly different median concentrations of the dissolved constituents in snowmelt streamflow because of one or more of the following reasons: (1) an increase or decrease in deicing applications, (2) changes in frequency and depth of snowfall, (3) varying rates of snowmelt which are dependent upon local weather conditions, such as air temperature and extent and duration of cloud cover, and (4) changing practices of snow removal from streets and highways.

Relationship of Median Concentrations to Land Use

An examination of figure 15 shows wide variations in median concentrations of dissolved sodium, chloride, and solids between study sites during snowmelt streamflow. Correlation and regression analysis was used to determine if these variations could be explained by differences in land use and street density. Results of this analysis are shown in figure 16. All the regression equations presented in table 6 were statistically significant at the 0.05 level. Correlation coefficients for all six relations were 0.93 or larger. The largest correlation coefficients and the smallest standard error of estimates were achieved when using the summation of residential, commercial, and industrial land-use percentages as the independent variable. The relationships of dissolved sodium, chloride, and solids to urban land use and street density show the effect that deicing of streets can have on the water quality of local streams. Using land-use percentages or street densities as independent variables in regression analysis

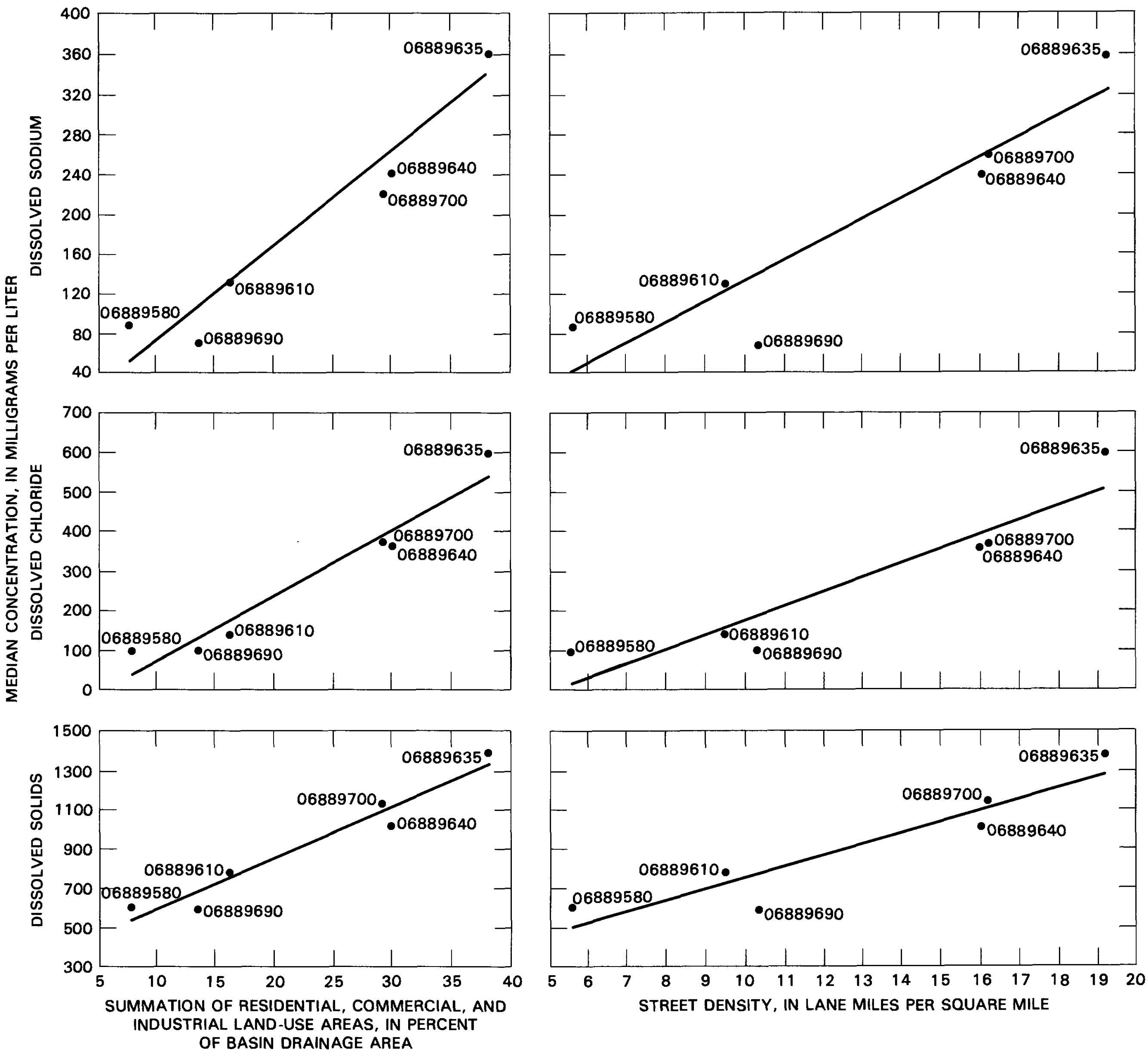

Figure 16. Relations between median concentrations of dissolved sodium, chloride, and solids in snowmelt streamflow and a summation of residential, commercial, and industrial land-use percentages and street density.

is an indirect method of measuring the true cause-and-effect relationship; that is, the amount of deicing material distributed within a basin (cause) is related to the median concentration of one of the three aforementioned dissolved constituents in snowmelt streamflow (effect). However, information on the amount of deicing material applied within the boundaries of a particular basin for any given snowfall or time period would be difficult to ascertain.

Relationship of Concentrations to Snowmelt Streamflow

It has been shown that median concentrations of dissolved solids were considerably larger in snowmelt streamflow than in dry-weather streamflow due, in large part, to increases in dissolved sodium and dissolved chloride. A graph of concentrations of dissolved solids during snowmelt streamflow would be similar to the distribution of specific conductance shown in figure 17. Because specific conductance measures the ability of water to conduct an electric current and is directly related to the concentrations of ions in solution (Na and Cl, among others), the larger the concentration of dissolved solids, the greater the specific conductance. As the deicing material enters local streams in snowmelt runoff, dissolved-solids concentrations increase and cause a corresponding increase in specific conductance, as observed during the snowmelt period shown in figure 17.

Table 6. Results of correlation and regression analysis relating median concentrations of dissolved sodium (Na), chloride (Cl), and solids (DS) in snowmelt streamflow to a summation of residential, commercial, and industrial land-use percentages (RES+COM+IND) and street density (STDEN), in lane miles per square mile

[All equations presented are significant at the 0.05 level of significance]

Regression equation	Number of samples	Correlation coefficient	Standard error of estimate (milligrams) per liter)
Na=9.52(RES+COM +IND) − 22.9	6	0.97	30
Cl=16.7(RES+COM +IND) − 97.2	6	.97	55
DS=26.3(RES+COM +IND) + 318	6	.97	83
Na=20.8(STDEN) − 74.9	6	.93	46
Cl=36.7(STDEN) − 192	6	.94	78
DS=57.7(STDEN) + 171	6	.94	124

Storm-Runoff Volume and Average Constituent Concentrations

Water-quality constituents transported by streams draining urban areas during non-winter periods are contributed by dry-weather streamflow and storm runoff. To determine streamflow volume and average constituent concentrations, in pounds per square mile per inch of runoff, provided by storm runoff, streamflow volumes, in inches, and loads of constituents, in pounds, provided by dry-weather streamflow were subtracted from storm-streamflow volumes and average concentrations of constituents. The resultant average storm-runoff constituent concentrations then were divided by basin drainage area, in square miles, and storm-runoff volume, in inches. In this form, average storm-runoff constituent concentrations from different study basins and storms could be compared.

Storm-runoff volumes and average constituent concentrations were summarized statistically to determine ranges and variability within the study basins and for comparison between study basins. Multiple-correlation and regression analysis was used to develop relationships between storm-runoff volumes and average constituent concentrations and land-use and storm characteristics.

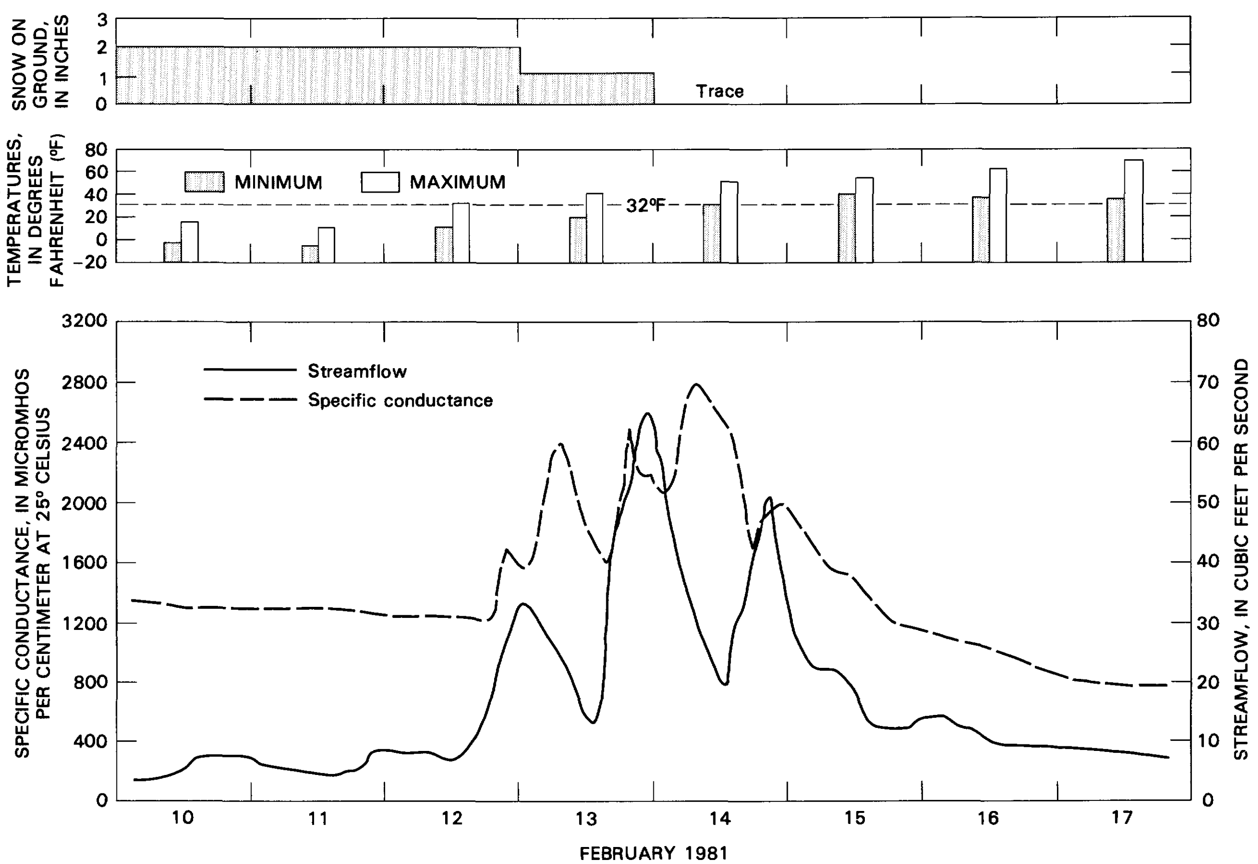

Figure 17. Effects of snowmelt runoff on streamflow and specific conductance at study site 06889640, February 10–17, 1981.

Computations

In order to compute average storm-runoff constituent concentrations, the streamflow hydrograph, recorded during the storm, was separated into dry-weather streamflow and storm runoff. Dry-weather streamflow, in this instance, is a combination of base flow and point-source contributions. Point-source contributions were assumed to remain constant throughout the storm. The storm-runoff part of the storm-streamflow hydrograph was separated by drawing a line from the point on the hydrograph where the streamflow began to increase to the point on the recession side of the hydrograph where the rate of decrease in streamflow approached a straight line. The time between the beginning and end of storm runoff is referred to as the storm-runoff duration.

Dry-weather-streamflow volume was computed by multiplying the average of the streamflow prior to storm runoff and the streamflow when storm runoff ceased by the storm-runoff duration. Dry-weather-streamflow volume then was subtracted from the total storm-streamflow volume to compute the volume of storm runoff. Storm-runoff durations determined for this investigation have been published by Pope and others (1983).

Average dry-weather-streamflow constituent loads were computed by multiplying the median concentrations of water-quality constituents in discrete dry-weather-streamflow water samples (table 11) by the dry-weather-streamflow volume determined for the duration of the storm. Total storm-streamflow constituent loads were computed by multiplying the total storm-streamflow volume by concentrations of constituents determined from a discharge-weighted composite sample of discrete samples collected during the duration of the storm streamflow. The methodology of developing a discharge-weighted composite sample from discrete samples is explained in the "Data Collection and Analysis" section of this report. Total storm-streamflow volumes and loads of constituents in composite samples for the durations of storm-streamflow periods sampled during this investigation also have been published by Pope and others (1983). Average storm-runoff constituent loads were computed by subtracting average dry-weather-streamflow constituent loads, in pounds, from total storm-streamflow constituent loads, in pounds, and then dividing by drainage area, in square miles, and storm-runoff volume, in inches.

Statistical Summary

Average storm-runoff constituent concentrations, in pounds per square mile per inch of storm runoff, were summarized statistically to determine ranges and variability within and between the study basins. A statistical summary is not available for study site 06889690 because this study site was not instrumented for the collection of composite samples. Examination of these summaries (table 7) with respect to land-use characteristics (table 2) leads to the following general observations:

Storm runoff ranged from 0.003 to 0.991 inch for all storms sampled during this investigation. Median volumes of storm runoff ranged from 0.025 inch at study site 06889580, which not only has the largest percentage of land in agricultural use but also has Sherwood Lake in its drainage basin, to 0.060 inch at study site 06889635, the most urban basin.

Average storm-runoff concentrations of *chemical oxygen demand* ranged from 3,000 to 18,800 $(lb/mi^2)/in.$ for all storms sampled. Median concentrations ranged from 9,190 $(lb/mi^2)/in.$ at study site 06889635, the most urban basin, to 13,400 $(lb/mi^2)/in.$ at study site 06889580, the most agricultural basin.

Average storm-runoff concentrations of *dissolved nitrite plus nitrate nitrogen* ranged from zero to 2,590 $(lb/mi^2)/in.$ for all storms sampled. The maximum concentration, which was observed at study site 06889610, was nearly an order of magnitude larger than the maximum at any other study site and five times larger than the next largest concentration, 494 $(lb/mi^2)/in.$, observed at that study site. However, the second, third, fourth, and fifth largest concentrations also were observed at study site 06889610. Median concentrations ranged from 72.3 $(lb/mi^2)/in.$ at study site 06889635, the most urban basin, to 239 $(lb/mi^2)/in.$ at study site 06889610, the second most agricultural basin.

Average storm-runoff concentrations of *dissolved ammonia nitrogen* ranged from zero to 139 $(lb/mi^2)/in.$ for all storms sampled. Median concentrations ranged from 3.43 $(lb/mi^2)/in.$ at study site 06889700, based on only two samples, and 6.07 $(lb/mi^2)/in.$ at study site 06889580, to 24.1 $(lb/mi^2)/in.$ at study site 06889640, and 29.6 $(lb/mi^2)/in.$ at study site 06889610. There appears to be no relationship between land use and average storm-runoff concentrations of dissolved ammonia nitrogen.

Average storm-runoff concentrations of *total ammonia plus organic nitrogen* ranged from 95 to 1,170 $(lb/mi^2)/in.$ for all storms sampled. Median concentrations ranged from 273 $(lb/mi^2)/in.$ at study site 06889635, the most urban basin, to 517 $(lb/mi^2)/in.$ at study site 06889610, which had the second largest percentage of agricultural land use.

Average storm-runoff concentrations of *total phosphorus* ranged from zero to 446 $(lb/mi^2)/in.$ for all storms sampled. Median concentrations ranged from 18.0 $(lb/mi^2)/in.$ at study site 06889700, based on four storms, and 57.4 $(lb/mi^2)/in.$ at study site 06889640, the second most urban basin, to 155 $(lb/mi^2)/in.$ at study site 06889580, the most agricultural basin.

Table 7. Statistical summary of storm-runoff volumes and average constituent concentrations
[Storm runoff is in inches, and constituent concentrations are in pounds per square mile per inch of storm runoff]

Runoff or constituent	Number of samples	Mean	Median	Maximum	Minimum	Standard deviation
		Study site 06889580				
Storm runoff	12	0.095	0.025	0.390	0.007	0.125
Chemical oxygen demand	6	14,300	13,400	18,800	9,540	3,800
Nitrite plus nitrate nitrogen, dissolved	11	123	147	175	0	51.2
Ammonia nitrogen, dissolved	7	8.17	6.07	24.3	0	8.72
Ammonia plus organic nitrogen, total	7	432	396	1,110	95.3	356
Phosphorus, total	8	181	155	446	0	146
Arsenic, total	12	1.09	0	4.38	0	1.65
Chromium, total	12	2.18	1.45	5.80	0	1.80
Copper, total	12	3.74	2.93	7.25	1.38	2.19
Lead, total	12	4.59	3.67	10.1	0	3.21
Mercury, total	6	.229	.070	1.16	0	.458
Zinc, total	12	13.7	13.6	24.1	5.02	6.56
Sediment, suspended	12	238,000	144,000	559,000	26,100	187,000
		Study site 06889610				
Storm runoff	22	0.123	0.038	0.991	0.004	0.224
Chemical oxygen demand	10	8,820	10,100	14,100	3,110	4,440
Nitrite plus nitrate nitrogen, dissolved	20	352	239	2,590	0	538
Ammonia nitrogen, dissolved	12	38.9	29.6	117	9.01	34.0
Ammonia plus organic nitrogen, total	17	516	517	1,170	139	292
Phosphorus, total	10	116	83.6	308	.309	92.1
Arsenic, total	22	1.38	1.44	5.80	0	1.30
Chromium, total	22	1.91	1.46	5.82	0	1.51
Copper, total	22	3.15	2.54	11.0	0	2.66
Lead, total	22	2.77	2.19	7.26	0	2.09
Mercury, total	13	.124	0	.723	0	.244
Zinc, total	21	11.2	9.93	22.2	1.44	6.15
Sediment, suspended	21	122,000	122,000	272,000	4,040	84,000
		Study site 06889635				
Storm runoff	26	0.103	0.060	0.444	0.006	0.112
Chemical oxygen demand	9	9,460	9,190	14,900	5,450	3,070
Nitrite plus nitrate nitrogen, dissolved	22	74.1	72.3	206	0	51.9
Ammonia nitrogen, dissolved	15	13.1	11.1	48.2	0	13.6
Ammonia plus organic nitrogen, total	18	271	273	460	95.0	113
Phosphorus, total	17	85.4	63.0	298	5.63	79.0
Arsenic, total	25	.521	0	1.46	0	.709
Chromium, total	26	1.06	0	5.77	0	1.55
Copper, total	25	3.72	3.10	10.4	0	2.76
Lead, total	26	14.3	10.7	44.8	1.47	10.3
Mercury, total	13	.183	0	1.00	0	.346
Zinc, total	23	17.6	13.5	52.2	6.02	11.2
Sediment, suspended	26	95,300	56,800	499,000	3,930	115,000

Table 7. Continued.

Runoff or constituent	Number of samples	Mean	Median	Maximum	Minimum	Standard deviation
		Study site 06889640				
Storm runoff	14	0.067	0.036	0.235	0.003	0.067
Chemical oxygen demand	4	10,200	10,300	13,000	7,440	2,270
Nitrite plus nitrate nitrogen, dissolved	13	126	104	281	24.4	75.4
Ammonia nitrogen, dissolved	12	31.6	24.1	139	0	35.7
Ammonia plus organic nitrogen, total	10	346	277	623	182	144
Phosphorus, total	11	82.9	57.4	176	0	66.0
Arsenic, total	14	.720	0	2.89	0	.938
Chromium, total	14	1.75	1.44	5.78	0	1.52
Copper, total	14	4.72	4.54	7.96	1.43	2.16
Lead, total	14	13.0	13.7	28.6	2.89	7.39
Mercury, total	6	.076	0	.291	0	.124
Zinc, total	13	18.7	20.7	32.2	7.82	7.87
Sediment, suspended	14	140,000	152,000	228,000	29,600	62,800
		Study site 06889700				
Storm runoff	10	0.098	0.053	0.253	0.019	0.087
Chemical oxygen demand	4	8,740	10,100	11,700	3,000	3,950
Nitrite plus nitrate nitrogen, dissolved	8	107	111	152	59.3	30.3
Ammonia nitrogen, dissolved	2	3.43	3.43	6.96	.095	4.99
Ammonia plus organic nitrogen, total	8	338	390	544	141	147
Phosphorus, total	4	32.8	18.0	86.7	8.64	36.3
Arsenic, total	10	1.14	1.44	2.90	0	.914
Chromium, total	10	2.14	1.33	9.13	0	2.63
Copper, total	10	5.17	4.35	11.6	0	3.72
Lead, total	10	9.88	10.1	24.5	1.45	6.81
Mercury, total	5	.029	0	.146	0	.065
Zinc, total	9	15.5	14.2	37.0	2.94	9.60
Sediment, suspended	10	131,000	90,100	353,000	2,250	99,200

Average storm-runoff concentrations of *total arsenic* ranged from zero to 5.80 (lb/mi^2)/in. for all storms sampled. Median concentrations ranged from zero at study sites 06889580, 06889635, and 06889640, to 1.44 (lb/mi^2)/in. at study sites 06889610 and 06889700. There appears to be no relationship between land use and average storm-runoff concentrations of total arsenic.

Average storm-runoff concentrations of *total chromium* ranged from zero to 9.13 (lb/mi^2)/in. for all storms sampled. Median concentrations ranged from zero at study site 06889635 to between 1.33 and 1.46 (lb/mi^2)/in. at the rest of the study sites. There appears to be no relationship between land use and average storm-runoff concentrations of total chromium.

Average storm-runoff concentrations of *total copper* ranged from zero to 11.6 (lb/mi^2)/in. for all storms sampled. Median concentrations ranged from 2.54 (lb/mi^2)/in. at study site 06889610, the second most agricultural basin, to 4.54 (lb/mi^2)/in. at study site 06889640, the second most urban basin.

Average storm-runoff concentrations of *total lead* ranged from zero to 44.8 (lb/mi^2)/in. for all storms sampled. Median concentrations ranged from 2.19 (lb/mi^2)/in. at study site 06889610, the second most agricultural basin, to 13.7 (lb/mi^2)/in. at study site 06889640, the second most urban basin.

Average storm-runoff concentrations of *total mercury* ranged from zero to 1.16 (lb/mi^2)/in. for all storms sampled. Median concentrations of mercury were zero at all study sites except study site 06889580, which had a median concentration of 0.070 (lb/mi^2)/in. There does not appear to be any relationship between land use and average storm-runoff concentrations of total mercury.

Average storm-runoff concentrations of *total zinc* ranged from 1.44 to 52.2 (lb/mi^2)/in. for all storms sampled. Median concentrations ranged from 9.93 (lb/mi^2)/in. at study site 06889610, the second most agricultural basin, to 20.7 (lb/mi^2)/in. at study site 06889640, the second most urban basin.

Average storm-runoff concentrations of *suspended sediment* ranged from 2,250 to 559,000 (lb/mi^2)/in. for all storms sampled. Median concentrations ranged from 56,800 (lb/mi^2)/in. at study site 06889635, the most urban basin, to 152,000 (lb/mi^2)/in. at study site 06889640, the second most urban basin. However, with the exception of study site 06889640, the more agricultural basins yielded larger median concentrations of suspended sediment.

Based on the statistical summary of average storm-runoff constituent concentrations observed during this investigation it appears that urbanization increases storm-runoff volumes and average storm-runoff concentrations of total copper, lead, and zinc; decreases average storm-runoff concentrations of chemical oxygen demand, dissolved nitrite plus nitrate nitrogen, total ammonia plus organic nitrogen, total phosphorus, and suspended sediment; and has no discernible effect on average storm-runoff concentrations of dissolved ammonia nitrogen, and total arsenic, chromium, and mercury, relative to average storm-runoff concentrations produced by agricultural land use.

Relationship to Land-Use, Physiographic, and Storm Characteristics

Multiple-correlation and regression analysis was used to determine if storm-runoff volumes and average constituent concentrations could be estimated by land-use, physiographic, and storm characteristics. The best results were obtained when the variables were converted to logarithmic equivalents prior to analyses. The resultant regression equations are of the form:

$$Y = a\, X_1^{b_1} X_2^{b_2} \cdots X_n^{b_n}\,, \tag{3}$$

where Y is the storm-runoff volume or constituent concentration estimated by the regression equation;

a is a constant determined by the regression analysis;

$X_{1\text{-}n}$ are the land-use, physiographic, and storm characterstics;

$b_{1\text{-}n}$ are the exponents determined by the regression analysis.

Land-use, physiographic, and storm characteristics used as independent variables in the correlation and regression analysis are listed in table 8. Values of land-use and physiographic characteristics for the five study basins used in this analysis are shown in table 2. Values of storm characteristics for storms sampled during this investigation, shown in table 9, were computed from rainfall data collected at study sites 06889580, 06889610, 06889635, 06889640, and 06889700. The Theissen polygon method of computing rainfall was used for study sites 06889640 and 06889700 to take advantage of the several rain gages within their drainage basins (Wisler and Brater, 1951, p. 86). Storm-runoff volumes and average constituent concentrations used as dependent variables in the correlation and regression analysis are not shown for individual storms, but statistical summaries of these data are shown in table 7.

A stepwise procedure (Haan, 1977, p. 211) was used to develop the multiple-regression equations relating storm-runoff volumes and average constituent concentrations to land-use, physiographic, and storm characteristics. The regression equation was developed by first entering the independent variable that had the best simple correlation with the dependent variable. Independent variables then were added in order of the amount of variation in the dependent variable they explain that had not been explained by previously entered independent variables. After each variable was entered, all independent variables were tested with an F-test to see if they were significant at a previously selected level (0.05 level of significance in this study). If an independent variable was not significant, it was deleted from the equation. The process continued until all independent variables not in the equation were found to be insignificant and those remaining in the equation were significant. Additionally, the correlation coefficient for the equation was tested with an F-test to see if it was significant at a previously selected level (0.05 level of significance for this study). The stepwise procedure is an excellent method of developing a multiple-regression equation. However, care should be taken to assure that the resulting equation is conceptually valid.

The stepwise procedure developed equations with partial- and multiple-correlation coefficients that were significant at the 0.05 level and rationally estimated storm-runoff volumes and average constituent concentrations of total lead, zinc, and suspended sediment (table 10). These were the only equations developed that explained 50 percent or more of the variance in the dependent variable (that is, had coefficients of determination greater than 0.50). The independent variables in the equations are listed in order of decreasing significance, as calculated by an F-test.

Storm-runoff volume, in inches, is related directly to (1) the storm rainfall, in inches, (2) the percentage of

Table 8. Land-use, physiographic, and storm characteristics used as independent variables in correlation and regression analysis with storm-runoff volumes and average constituent concentrations

Land-use, physiographic, or storm characteristic	Variable name
Percentage of basin in:	
Agricultural land use	AGR
Residential land use	RES
Commercial land use	COM
Residential and commercial land use	RES+COM
Industrial land use	IND
Urban open space	URBOP
Upstream from lakes larger than 5 acres	LAKEDA
Impervious to rainfall infiltration	IMPER
Street density, in lane miles per square mile	STDEN
Drainage area, in square miles	DA
Average slope of main stream channel, in feet per mile	CHSLOPE
Percentage of basin covered by:	
Hydrologic soil group B	HSOILB
Hydrologic soil group C	HSOILC
Hydrologic soil group D	HSOILD
Storm rainfall, in inches	RAIN
Duration of storm rainfall, in minutes	RAINDUR
Time from start of storm rainfall to maximum streamflow, in minutes	MINTOPEAK
Maximum 15-minute storm rainfall intensity, in inches per hour	MAX15MIN
Maximum 1-hour storm rainfall intensity, in inches per hour	MAX1HR
Time since previous rainfall greater than:	
0.25 inch, in days	DSRGT.25
0.50 inch, in days	DSRGT.50
1.0 inch, in days	DSRGT1.0
Total rainfall in previous 3 days, in inches	RPRE3D
Total rainfall in previous 14 days, in inches	RPRE14D

the drainage area covered by impervious material because of the lack of infiltration in these areas, (3) the total rainfall in the 3 days prior to the storm; and (4) the total rainfall in the 14 days prior to the storm, indicating that wet antecedent conditions produce more runoff.

Average storm-runoff concentrations of *total lead*, in pounds per square mile per inch of storm runoff, is related directly to (1) the percentage of the drainage area in residential and commercial land use, probably reflecting the large traffic volume in these areas; (2) the maximum 15-minute rainfall intensity during the storm, in inches per hour, indicating that intense rains dislodge and transport more lead; and (3) the number of days prior to the storm since a rainfall of 1 inch or more, indicating that lead accumulates during the time between significant rainfalls.

Average storm-runoff concentration of *total zinc*, in pounds per square mile per inch of storm runoff, is related directly to (1) the maximum 15-minute rainfall intensity during the storm, in inches per hour, indicating that intense rains dislodge and transport more zinc, (2) the percentage of the drainage area in residential and commercial land use, probably reflecting the large quantities of galvanized steel in these areas; (3) the number of days prior to the storm since a rainfall of 1 inch or more, indicating that zinc accumulates during the time between significant rainfalls; and (4) the storm rainfall, in inches.

Average storm-runoff concentration of *suspended sediment*, in pounds per square mile per inch of storm runoff, is related directly to (1) the maximum 15-minute rainfall intensity during the storm, in inches per hour, indicating that intense rains dislodge and transport more suspended sediment; (2) total storm rainfall, in inches; (3) and total rainfall in the 3 days prior to the storm, indicating that wet antecedent conditions produce more runoff, which erodes and transports more suspended sediment.

It is of interest to note that of the four equations shown in table 10 only land-use and storm characteristics were significant independent variables. None of the physiographic characteristics shown in table 8 (drainage area, average slope of main channel, and hydrologic soil groups B, C, and D) were significant.

SUMMARY

The Shunganunga Creek study basin is a 60.3-mi^2 area that includes about one-half of the area of the city of Topeka and consists of a mixture of agricultural, residential, commercial, and industrial land uses. The data-collection network consisted of six sites that were established in 1979 to monitor the water-quality characteristics of streams draining urban areas. Streamflows

Table 9. Values of storm characteristics used as independent variables in the correlation and regression analysis with storm-runoff volumes and average constituent concentrations

Study site	Storm date (1981)	Storm rainfall (inches)	Runoff (inches)	Duration of storm rainfall (minutes)	Time from start of storm rainfall to maximum streamflow (minutes)	Maximum 15-minute storm rainfall intensity (inches per hour)	Maximum[1] 1-hour storm rainfall intensity (inches per hour)	Time since previous rainfall greater than 0.25 inch (days)	Time since previous rainfall greater than 0.50 inch (days)	Time since previous rainfall greater than 1.0 inch (days)	Total rainfall previous 3 days (inches)	Total rainfall previous 14 days (inches)
06889580	Mar. 28–29	0.62	0.014	185	190	1.60	2.00	2	2	111	0.63	1.15
	May 9	1.63	.022	350	380	.44	.30	26	42	153	.08	.25
	17–18	1.36	.027	535	475	.64	.34	3	3	8	.12	2.53
	22–23	.36	.007	150	175	.48	.21	4	4	4	.00	5.61
	June 11–12	3.36	.390	675	610	2.40	1.40	8	24	24	.00	.65
	21–22	1.40	.250	260	375	2.64	.89	2	6	10	.15	4.39
	27	.99	.031	330	315	.48	.24	6	6	6	.14	2.57
	July 18	1.80	.022	190	95	2.00	1.59	14	21	21	.03	.05
	24–25	.97	.023	45	70	3.16	1.29	6	6	6	.03	2.11
	26	.48	.013	340	135	.52	.32	2	2	6	.97	3.08
	Oct. 13–14	2.45	.131	770	665	.88	.69	1	10	20	.43	1.09
	Nov. 4	.93	.210	505	335	.36	.31	3	3	3	1.56	2.57
06889610	Mar. 25–26	.84	.074	465	600	.32	.25	8	8	108	.09	.59
	28–29	.43	.026	165	450	.72	.31	3	3	111	.83	1.43
	Apr. 3–4	.37	.022	25	385	1.74	.89	10	10	117	.00	1.36
	11	.44	.020	65	415	.84	.23	17	17	124	.00	.80
	13–14	.26	.008	30	480	.36	.52	2	19	126	.44	.81
	18–19	.60	.022	450	320	1.44	.45	5	24	130	.01	.71
	May 9–10	1.75	.165	870	810	.64	.35	5	21	151	.07	.34
	13–14	.57	.037	1,095	600	.16	.14	4	4	4	.03	2.16
	17–18	1.00	.104	1,155	1,365	.52	.30	4	4	8	.18	2.89
	28–29	.33	.012	225	510	.24	.15	6	6	11	.00	3.50
	June 27–28	.85	.122	345	375	.28	.26	6	6	6	.13	1.62
	29–30	.43	.027	130	340	.72	.25	2	2	18	.93	2.47
	July 18–19	1.71	.061	140	420	2.20	1.54	15	21	37	.06	.06
	24–25	1.11	.040	30	330	3.76	2.22	6	6	6	.07	2.08
	Aug. 25–26	1.00	.073	285	510	1.56	.57	23	23	29	.00	.18
	Sept. 24–26	1.26	.077	330	600	1.32	.94	30	30	59	.00	.00
	Oct. 1	.19	.004	45	825	.16	.25	7	7	7	.00	1.62
	3–4	.56	.018	510	765	.52	.25	8	9	9	.00	1.81
	12–13	.37	.013	705	930	.36	.11	9	9	18	.00	.75
	13–14	1.84	.466	855	750	.64	.60	1	10	19	.38	1.13
	31–Nov 2	2.48	.991	975	1,095	.52	.37	18	18	18	.00	.20
	Nov. 4	.86	.323	600	390	.32	.26	3	3	3	1.50	2.68
06889635	Mar. 28–29	.34	.041	160	170	.72	.25	3	3	111	.58	1.19
	Apr. 11	.44	.049	55	70	.80	.48	8	8	125	.00	.91
	13–14	.35	.035	40	70	.88	.52	2	10	127	.44	1.01
	18–19	.51	.080	25	30	1.72	1.22	5	15	132	.00	.79
	May 4	.22	.008	170	110	.24	.12	16	16	148	.00	.00
	9	1.45	.219	420	235	.64	.35	21	21	153	.06	.29
	13–14	.59	.064	1,105	915	.16	.14	4	4	4	.02	1.77
	16–17	.21	.013	185	220	.36	.13	3	3	6	.60	2.37
	17–18	.94	.166	235	470	.36	.22	4	4	7	.22	2.58
	22–23	.63	.298	170	190	.72	.28	4	4	13	.00	2.79
	28	.23	.015	185	190	.16	.10	6	6	19	.00	3.55

Table 9. Continued.

Study site	Storm date (1981)		Storm rainfall (inches)	Runoff (inches)	Duration of storm rainfall (minutes)	Time from start of storm rainfall to maximum streamflow (minutes)	Maximum 15-minute storm rainfall intensity (inches per hour)	Maximum[1] 1-hour storm rainfall intensity (inches per hour)	Time since previous rainfall greater than 0.25 inch (days)	Time since previous rainfall greater than 0.50 inch (days)	Time since previous rainfall greater than 1.0 inch (days)	Total rainfall previous 3 days (inches)	Total rainfall previous 14 days (inches)
06889635 (cont.)	June	27	0.97	0.120	355	170	0.44	0.20	6	6	6	0.13	1.82
		29-30	.51	.056	115	55	.96	.42	2	2	8	1.10	2.79
	July	17-18	1.80	.222	685	460	3.28	1.43	14	19	26	.00	.02
	Aug.	5	.54	.044	150	170	.44	.28	3	3	9	.00	5.26
		25	1.00	.084	285	305	1.72	.66	20	20	29	.00	.12
		31	.54	.076	125	155	.32	.35	6	6	35	.01	1.01
	Sept.	7	.56	.052	255	40	1.08	.30	7	7	7	.07	2.88
		24	1.03	.087	450	355	1.24	.73	17	17	24	.00	.00
		30-Oct. 1	—	.010	—	75	—	—	—	—	—	—	—
	Oct.	3	.44	.037	985	285	.64	.21	9	9	9	.00	1.43
		12	.34	.015	755	375	.36	.11	9	18	18	.00	.55
		13-14	1.82	.444	655	490	.76	.59	1	19	19	.36	.91
		25	.19	.006	290	190	.08	.07	12	12	12	.00	2.17
	Nov.	4	.74	.318	515	245	.28	.22	3	3	3	1.42	2.59
		30	.89	.127	945	430	.28	.21	22	22	29	.00	.00
06889640	Mar.	28-29	.49	.035	165	345	.60	.27	3	113	113	.70	1.26
	Apr.	3-4	.26	.019	25	85	1.68	.62	6	119	119	.00	1.46
		11	.42	.025	60	135	.60	.33	8	8	127	.00	.76
		13-14	.34	.028	60	195	1.96	.69	2	10	129	.42	.69
		18-19	.54	.032	510	90	.68	.25	5	5	134	.00	.77
	May	9-10	1.64	.159	450	465	.40	.33	5	26	155	.08	.30
		13-14	.54	.039	1,170	495	.24	.14	4	4	4	.03	2.00
		16-17	.15	.003	180	345	.28	.12	3	3	7	.54	2.54
		17-18	1.14	.113	465	480	.56	.30	4	4	8	.16	2.69
	June	27-28	.94	.127	--	--	--	--	6	6	6	.13	2.07
		29-30	.49	.016	300	270	1.56	.49	2	2	2	1.07	3.01
	Aug.	25-26	1.01	.038	300	345	1.40	.74	52	58	67	.00	.14
		31	.61	.071	120	210	.64	.41	6	6	6	.08	1.48
	Nov.	4-5	.88	.235	720	480	.28	.26	3	3	3	1.51	2.60
06889700	Mar.	25-26	.63	.048	240	570	.12	.12	7	109	109	.08	.56
		28-29	.45	.033	180	375	.64	.23	3	112	112	.63	1.20
	Apr.	3-4	.34	.019	30	165	.88	.68	6	118	118	.00	1.30
	June	27-28	1.01	.154	360	360	2.24	1.06	6	6	6	.13	2.10
		29-30	.54	.055	300	75	2.20	.90	2	2	2	1.14	3.11
	July	18-19	1.70	.115	285	300	1.12	.89	14	20	22	.04	.09
	Aug.	25-26	1.06	.051	285	360	1.72	.85	23	23	29	.00	.14
	Oct.	12-13	.38	.019	690	855	.08	.12	7	7	18	.00	.67
		13-14	2.01	.253	720	630	.52	.44	1	8	19	.38	1.05
	Nov.	4-5	.85	.232	765	495	.24	.20	22	22	22	1.49	2.57

[1]For storms of less than 1-hour duration, the value shown represents the average intensity.

Table 10. Multiple-regression equations for estimating storm-runoff volume (in inches) and average concentrations of total lead, zinc, and suspended sediment (in pounds per square mile per inch of storm runoff)

[All equations and independent variables are significant at the 0.05 level. Independent-variable names are identified in table 8]

Multiple-regression equation	Number of samples	Coefficient of determination	Standard error of estimate, in percent of estimated value: Above regression line	Below regression line
Storm-runoff volume $= 0.003(\mathrm{RAIN})^{1.7581} (\mathrm{IMPER})^{1.1522} (\mathrm{RPE3D}^{2})^{0.7692} (\mathrm{RPRE14D}^{2})^{0.4753}$	81	0.81	6.25	5.88
Lead[1] $= 0.584(\mathrm{RES+COM})^{0.7943} (\mathrm{MAX15MIN})^{0.4311} (\mathrm{DSRGT1.0}^{2})^{0.1578}$	81	.71	5.22	4.96
Zinc $= 4.34(\mathrm{MAX15MIN})^{0.3372} (\mathrm{RES+COM})^{0.3296} (\mathrm{DSRGT1.0}^{2})^{0.1298} (\mathrm{RAIN})^{0.1715}$	75	.50	4.75	4.53
Suspended sediment $= 124{,}000(\mathrm{MAX15MIN})^{0.6947} (\mathrm{RAIN})^{0.5901} (\mathrm{RPRE3D}^{2})^{0.8581}$	81	.58	12.5	11.1

[1]To avoid taking the log of zero, 1.0 pound per square mile per inch of runoff was added to all average concentrations of lead before they were converted to logarithms for the regression analysis. Therefore, 1.0 must be subtracted from the average lead concentration computed by using this equation.

[2]To avoid taking the log of zero, 1.0 was added to these independent variables before they were converted to logarithms for the regression analysis. Therefore, 1.0 must be added to these variables when applying the equations.

from three sources were sampled: (1) Dry-weather streamflow, a combination of base flow and point-source contributions, (2) storm streamflow, mainly provided by overland runoff from storms, and (3) snowmelt streamflow, mainly provided by overland runoff from snowmelt. Data pertaining to the physical and chemical characteristics of the three types of streamflow were collected and summarized statistically for each study site.

Median concentrations of total chromium, copper, lead, and zinc in dry-weather streamflow were either small or less than analytical detection limits at all study sites. Median concentrations of dissolved nitrite plus nitrate nitrogen and total phosphorus in dry-weather streamflow were largest at study sites closest to upstream wastewater-treatment plants. Median concentrations of dissolved ammonia did not vary significantly between study sites.

Median concentrations of trace metals, dissolved nitrite plus nitrate nitrogen, and total phosphorus were larger during storm streamflow than during dry-weather streamflow and varied considerably between study sites. Median concentrations of total lead in storm streamflow ranged from 10 to 70 μg/L, and median concentrations of total zinc ranged from 40 to 110 μg/L. The largest median concentrations of total lead and zinc occurred at study sites with the largest percentage of urban land use. Correlation and regression analysis relating median concentrations of total lead and zinc to percentage of residential plus commercial land uses and to street density produced relationships with correlation coefficients of 0.84 to 0.98 and were significant at the 0.05 level of significance. Median concentrations of dissolved nitrite plus nitrate nitrogen and total phosphorus averaged, respectively, 76-percent and 70-percent larger during storm streamflow than during dry-weather streamflow. The largest median concentrations were observed at the study sites with the most agricultural basins. Although median concentrations of dissolved nitrite plus nitrate nitrogen and total phosphorus in storm streamflow were not significantly related to land-use characteristics (at the 0.05 level of significance), the results generally indicate that larger median concentrations are associated with increases in agricultural land use.

Concentrations of total lead, total zinc, suspended sediment, dissolved nitrite plus nitrate nitrogen, and total phosphorus in storm streamflow varied considerably both during storms and with land use. The largest concentrations of total lead, total zinc, and suspended sediment occurred while storm streamflow was increasing or was near the peak streamflow and decreased through the storm-streamflow recession. When comparisons were made for the same storm, concentrations of total lead were larger at the study sites with the most urban basins. Conversely, concentrations of suspended sediment were larger at the study sites with the most agricultural basins. In addition to land-use related variation, concentrations of total lead, total zinc, and suspended sediment were larger for storms with greater rainfall intensity. Concentrations of dissolved nitrite plus nitrate nitrogen and total phosphorus gradually increased through the duration of storm streamflow at the study site with the second most agricultural land basin, while a "first flush" effect was observed at the study site with the most urban basin. In both study basins some of the largest concentrations of dissolved nitrite plus nitrate nitrogen and, to a lesser degree, total phosphorus, occurred during the storm-streamflow recession when runoff water from the upstream more agricultural parts of the basins reached the study sites.

Median concentrations of total chromium, copper, lead, and zinc in snowmelt streamflow were equal to or greater than those observed in dry-weather streamflow but were considerably less than those observed in storm streamflow. For example, the median concentration of total lead in snowmelt streamflow at the study site with the most urban basin was seven times greater than the median concentration in dry-weather streamflow but only one-half of the median concentration in storm streamflow. Additionally, median concentrations of total lead and zinc in snowmelt streamflow averaged only 26 percent and 38 percent, respectively, of the median concentrations in storm streamflow.

The most significant change in the water quality of streams in the study area observed during snowmelt streamflow was caused by the application and subsequent transport in snowmelt runoff of deicing material (salt and sand) from streets and highways. Median concentrations of dissolved sodium, chloride, and solids in snowmelt streamflow at all six study sites, averaged 218-percent greater for dissolved sodium, 296-percent greater for dissolved chloride, and 71-percent greater for dissolved solids relative to median concentrations in dry-weather streamflow. The largest median concentrations of dissolved sodium, chloride, and solids occurred in the more urban study basins. Correlation and regression analysis relating median concentrations of dissolved sodium, chloride, and solids to the summation of residential, commercial, and industrial land-use percentages and to street density produced significant (0.05 level of significance), direct relations with correlation coefficients of 0.93 or larger.

Storm-runoff volumes, in inches, and average constituent concentrations, in pounds per square mile per inch of runoff, were computed for storms with composite samples of storm streamflow. Statistical summaries of storm-runoff volumes and average concentrations of suspended sediment and selected chemical constituents were computed. Based on the statistical summaries, it appears that urbanization increases storm-runoff volumes and average concentrations of total copper, lead, and zinc, decreases average storm-runoff concentrations of chemical oxygen demand, dissolved nitrite plus nitrate nitrogen, total ammonia plus organic nitrogen, total phosphorus, and suspended sediment, and has no apparent effect on average storm-runoff concentrations of dissolved ammonia nitrogen and total arsenic, chromium, and mercury, relative to average storm-runoff concentrations produced by agricultural land use.

Multiple-correlation and regression analysis relating storm-runoff volumes and average constituent concentrations to land-use, physiographic, and storm characteristics produced significant relations (0.05 level of significance) for storm-runoff volume (0.81 coefficient of determination), total lead (0.71 coefficient of determination), total zinc (0.50 coefficient of determination), and suspended sediment (0.58 coefficient of determination). The percentage of residential plus commercial land uses was a significant independent variable in predicting average storm-runoff concentrations of total lead and zinc. Impervious area was a significant independent variable in predicting storm-runoff volume. Maximum 15-minute rainfall intensity was significant in the equations for predicting average storm-runoff concentrations of total lead, total zinc, and suspended sediment. Storm rainfall was a significant independent variable in predicting storm-runoff volume and average concentrations of total zinc and suspended sediment. The number of days since rainfall greater than 1.00 inch was significant in the equations for predicting average storm-runoff concentrations of total lead and zinc, and rainfall in the previous 3 days was significant in the equations predicting storm-runoff volume and average concentrations of suspended sediment. No physiographic characteristics were significant in any of the predictive equations.

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Table 11. Statistical summary of water-quality measurements and concentrations of selected chemical constituents for water samples collected during dry-weather, storm, and snowmelt streamflows at the study sites

[ND indicates not detected. See table 3 for analytical detection limits]

Water-quality measurement or chemical constituent	Dry-weather streamflow					Storm streamflow					Snowmelt streamflow				
	Number of samples	Mean	Median	Minimum	Maximum	Number of samples	Mean	Median	Minimum	Maximum	Number of samples	Mean	Median	Minimum	Maximum
Shunganunga Creek at S.W. 29th Street (study site 06889580)															
Streamflow, instantaneous (ft^3/s)[1]	21	1.9	0.52	0.05	18.0	190	84	22	0.31	1,090	4	0.95	0.83	0.74	1.4
Specific conductance (μmho/cm at 25 °C)[2]	20	690	702	270	1,100	184	368	320	120	1,060	4	1,050	926	906	1,430
Chemical oxygen demand (mg/L)[3]	6	23	19	16	44	33	60	40	15	210	2	19	19	15	23
Sodium, dissolved (mg/L)	10	50	42	23	110	38	36	24	7.7	99	4	100	86	77	160
Chloride, dissolved (mg/L)	11	45	40	21	110	38	36	25	7.0	100	4	120	97	82	190
Solids, dissolved (mg/L)	10	426	393	291	651	32	284	232	136	614	4	644	592	530	864
Nitrite plus nitrate nitrogen, dissolved (mg/L)	10	--	.85	ND	7.0	62	1.0	.90	.20	3.4	4	3.8	3.8	2.5	5.0
Ammonia nitrogen, dissolved (mg/L)	11	--	.17	ND	.94	48	--	.13	ND	.98	4	.20	.18	.04	.39
Ammonia plus organic nitrogen, total (mg/L)	2	1.8	1.8	1.7	2.0	4	2.0	1.8	1.5	2.9	1	1.5	1.5	1.5	1.5
Phosphorus, total (mg/L)	12	--	.56	.17	2.5	81	1.0	.79	.13	4.4	4	2.3	2.0	.28	5.0
Arsenic, total (μg/L)[4]	9	--	ND	ND	10	110	--	ND	ND	200	4	--	ND	ND	10
Chromium, total (μg/L)	9	--	ND	ND	20	83	--	10	ND	60	4	ND	ND	ND	ND
Copper, total (μg/L)	8	--	ND	ND	10	107	--	20	ND	80	4	--	10	ND	20
Lead, total (μg/L)	8	--	ND	ND	10	120	--	20	ND	290	4	ND	ND	ND	ND
Mercury, total (μg/L)	8	--	ND	ND	15	42	--	ND	ND	12	4	ND	ND	ND	ND
Zinc, total (μg/L)	10	26	10	10	120	64	73	60	10	200	4	12	10	10	20
Sediment, suspended (mg/L)	18	102	14	4	1,360	175	1,270	671	7	10,200	2	10	10	5	14
South Branch Shunganunga Creek at S.W. 37th Street (study site 06889610)															
Streamflow, instantaneous (ft^3/s)[1]	19	2.4	1.7	0.18	9.2	210	72	17	0.9	1,080	4	2.5	2.7	1.3	3.2
Specific conductance (μmho/cm at 25 °C)[2]	18	886	887	466	1,400	203	591	520	127	1,270	4	1,250	1,250	1,030	1,470
Chemical oxygen demand (mg/L)[3]	5	20	19	10	28	18	52	24	14	400	2	20	20	17	23
Sodium, dissolved (mg/L)	10	81	75	35	150	29	57	47	9.3	190	4	130	130	95	180
Chloride, dissolved (mg/L)	11	83	73	38	180	28	67	53	12	230	4	160	140	100	240
Solids, dissolved (mg/L)	9	521	573	272	684	24	379	372	150	774	4	762	770	638	869
Nitrite plus nitrate nitrogen, dissolved (mg/L)	10	--	1.1	ND	1.7	41	1.7	1.6	.10	3.9	4	2.1	1.9	1.9	2.6
Ammonia nitrogen, dissolved (mg/L)	11	.33	.19	.03	1.1	41	--	.23	ND	.81	4	1.2	1.1	.89	1.5
Ammonia plus organic nitrogen, total (mg/L)	1	1.4	1.4	1.4	1.4	6	1.8	1.6	.40	4.0	1	2.0	2.0	2.0	2.0
Phosphorus, total (mg/L)	12	.94	.76	.37	1.9	57	1.2	.80	.13	11	4	1.3	1.2	1.0	2.0
Arsenic, total (μg/L)[4]	9	--	ND	ND	10	127	--	ND	ND	30	4	--	ND	ND	10
Chromium, total (μg/L)	9	--	ND	ND	30	94	--	10	ND	70	4	--	ND	ND	10
Copper, total (μg/L)	8	--	5.0	ND	20	143	--	ND	ND	190	4	--	5.0	ND	10
Lead, total (μg/L)	8	--	ND	ND	10	153	--	10	ND	120	4	--	ND	ND	20
Mercury, total (μg/L)	8	--	ND	ND	13	46	--	ND	ND	16	4	ND	ND	ND	ND
Zinc, total (μg/L)	9	16	10	10	40	69	71	50	10	350	4	18	20	10	20
Sediment, suspended (mg/L)	15	22	10	4	160	201	999	315	10	10,100	2	10.5	10.5	8	13

See notes at end of table.

Table 11. Continued.

Water-quality measurement or chemical constituent	Dry-weather streamflow					Storm streamflow					Snowmelt streamflow				
	Number of samples	Mean	Median	Minimum	Maximum	Number of samples	Mean	Median	Minimum	Maximum	Number of samples	Mean	Median	Minimum	Maximum
Butcher Creek at Kansas Place (study site 06889635)															
Streamflow, instantaneous (ft^3/s)[1]	17	0.14	0.06	0.02	1.1	305	65	15	0.07	724	4	0.17	0.16	0.10	0.25
Specific conductance (μmho/cm at 25 °C)[2]	16	871	998	252	1,220	293	413	361	76	1,380	4	2,420	2,560	1,570	2,990
Chemical oxygen demand (mg/L)[3]	6	19	18	13	24	36	62	46	16	160	2	34	34	30	38
Sodium, dissolved (mg/L)	10	48	52	12	87	38	32	23	7.2	180	4	320	360	150	440
Chloride, dissolved (mg/L)	11	65	72	17	130	39	44	28	9	290	4	560	600	260	770
Solids, dissolved (mg/L)	9	541	616	152	795	34	285	232	3	708	4	1,330	1,380	949	1,610
Nitrite plus nitrate nitrogen, dissolved (mg/L)	10	--	.35	ND	.70	72	1.0	.70	.10	4.2	4	1.1	1.0	.70	1.6
Ammonia nitrogen, dissolved (mg/L)	10	--	.27	ND	1.2	58	--	.12	ND	3.8	4	.62	.68	.04	1.1
Ammonia plus organic nitrogen, total (mg/L)	1	1.0	1.0	1.0	1.0	7	2.4	2.1	1.3	4.5	1	1.8	1.8	1.8	1.8
Phosphorus, total (mg/L)	11	.30	.17	.06	1.5	87	.47	.36	.01	2.1	4	.14	.14	.04	.21
Arsenic, total (μg/L)[4]	8	--	ND	ND	10	188	--	ND	ND	30	4	--	5.0	ND	10
Chromium, total (μg/L)	9	--	ND	ND	20	132	--	ND	ND	40	4	ND	ND	ND	ND
Copper, total (μg/L)	8	--	10	ND	20	209	--	20	ND	190	4	--	5	ND	20
Lead, total (μg/L)	8	--	5	ND	60	235	--	70	ND	800	4	--	35	ND	60
Mercury, total (μg/L)	8	--	ND	ND	3.0	69	--	ND	ND	150	4	ND	ND	ND	ND
Zinc, total (μg/L)	9	38	30	10	80	72	140	110	7	520	4	52	55	20	80
Sediment, suspended (mg/L)	13	32	27	9	76	284	798	362	37	8,250	2	27	27	19	35
Shunganunga Creek at S.E. 15th Street (study site 06889640)															
Streamflow, instantaneous (ft^3/s)[1]	23	5.5	3.4	0.21	29	200	242	66	5.1	2,940	4	6.0	5.6	2.4	10
Specific conductance (μmho/cm at 25 °C)[2]	22	820	838	381	1,310	200	486	442	155	1,130	4	1,880	1,810	1,670	2,250
Chemical oxygen demand (mg/L)[3]	6	24	23	15	39	33	46	42	8	82	2	26	26	23	29
Sodium, dissolved (mg/L)	13	69	73	35	100	35	41	28	8.4	110	4	240	240	210	290
Chloride, dissolved (mg/L)	14	76	76	46	120	35	49	30	9.0	140	4	360	360	280	430
Solids, dissolved (mg/L)	12	489	538	224	693	29	328	317	149	660	4	1,070	1,010	1,000	1,260
Nitrite plus nitrate nitrogen, dissolved (mg/L)	13	--	.50	ND	1.1	56	--	.60	ND	3.6	1	2.0	2.0	2.0	2.0
Ammonia nitrogen, dissolved (mg/L)	14	--	.14	ND	.29	47	--	.11	ND	1.2	4	.84	.72	.50	1.4
Ammonia plus organic nitrogen, total (mg/L)	2	1.6	1.6	1.6	1.7	5	2.0	2.4	.26	2.7	4	1.4	1.8	.10	2.0
Phosphorus, total (mg/L)	15	.51	.46	.25	1.1	61	.82	.64	.02	5.8	4	1.2	.95	.84	2.1
Arsenic, total (μg/L)[4]	12	--	ND	ND	10	134	--	ND	ND	20	4	--	5.0	ND	10
Chromium, total (μg/L)	11	--	ND	ND	60	82	--	10	ND	60	4	--	5.0	ND	10
Copper, total (μg/L)	11	--	10	ND	10	150	--	20	ND	170	4	--	ND	ND	10
Lead, total (μg/L)	11	--	ND	ND	30	155	--	50	ND	440	4	25	15	10	60
Mercury, total (μg/L)	10	--	ND	ND	2.0	43	--	ND	ND	14	4	ND	ND	ND	ND
Zinc, total (μg/L)	13	19	20	10	60	64	100	85	10	300	4	28	30	10	40
Sediment, suspended (mg/L)	18	35	14	9	155	188	1,060	584	23	6,420	2	24	24	20	27

See notes at end of table.

Table 11. Continued.

Water-quality measurement or chemical constituent	Dry-weather streamflow					Storm streamflow					Snowmelt streamflow				
	Number of samples	Mean	Median	Minimum	Maximum	Number of samples	Mean	Median	Minimum	Maximum	Number of samples	Mean	Median	Minimum	Maximum
Deer Creek at S.E. 6th Street (study site 06889690)															
Streamflow, instantaneous (ft^3/s)[1]	9	1.5	0.32	0.01	7.6	29	138	15	0.22	1,740	4	0.24	0.12	0.10	0.60
Specific conductance (μmho/cm at 25 °C)[2]	9	762	700	521	1,140	29	392	300	135	1,000	4	919	841	625	1,370
Chemical oxygen demand (mg/L)[3]	5	21	15	13	44	12	55	30	16	196	2	16	16	14	17
Sodium, dissolved (mg/L)	6	69	68	39	100	18	41	20	6.5	140	4	78	69	42	130
Chloride, dissolved (mg/L)	7	90	87	43	160	16	59	31	9	180	4	120	100	54	220
Solids, dissolved (mg/L)	6	515	499	398	678	11	317	290	109	601	3	584	586	394	773
Nitrite plus nitrate nitrogen, dissolved (mg/L)	7	.25	.20	.10	.50	17	.60	.5	.10	1.5	4	1.1	.80	.50	2.3
Ammonia nitrogen, dissolved (mg/L)	6	.34	.14	.01	1.0	.14	--	.1	ND	.53	4	--	.70	ND	2.5
Ammonia plus organic nitrogen, total (mg/L)	0	--	--	--	--	5	1.6	1.6	1.5	1.8	1	1.5	1.5	1.5	1.5
Phosphorus, total (mg/L)	7	.37	.17	.07	.88	20	.69	.4	.16	3.0	4	.17	.14	.05	.35
Arsenic, total (μg/L)[4]	5	--	ND	ND	10	22	--	ND	ND	10	4	--	ND	ND	10
Chromium, total (μg/L)	5	ND	ND	ND	ND	22	--	ND	ND	40	4	--	5.0	ND	10
Copper, total (μg/L)	5	--	ND	ND	10	22	--	10	ND	30	4	--	10	ND	10
Lead, total (μg/L)	5	--	ND	ND	10	23	--	20	ND	70	4	--	5.0	ND	10
Mercury, total (μg/L)	5	--	ND	ND	2	15	--	ND	ND	2	4	ND	ND	ND	ND
Zinc, total (μg/L)	6	17	20	10	20	23	48	40	10	120	4	--	20	ND	50
Sediment, suspended (mg/L)	6	35	30	26	62	28	800	330	24	4,160	2	15	15	14	16
Shunganunga Creek at Rice Road (study site 06889700)															
Streamflow, instantaneous (ft^3/s)[1]	18	4.9	3.9	0.45	15	315	310	100	2.0	4,830	3	38	8.5	4.2	100
Specific conductance (μmho/cm at 25 °C)[2]	17	847	818	598	1,190	308	447	396	117	1,200	3	2,070	1,940	1,800	2,480
Chemical oxygen demand (mg/L)[3]	4	23	24	16	28	73	66	53	8	300	1	23	23	23	23
Sodium, dissolved (mg/L)	11	64	64	33	100	44	53	46	12	130	3	280	260	220	370
Chloride, dissolved (mg/L)	12	75	71	40	130	47	64	53	12	150	3	440	370	350	590
Solids, dissolved (mg/L)	10	500	525	278	698	31	363	320	111	709	3	1,180	1,120	1,030	1,380
Nitrite plus nitrate nitrogen, dissolved (mg/L)	11	--	.30	ND	1.0	106	--	.7	ND	2.1	3	2.4	2.1	1.9	3.3
Ammonia nitrogen, dissolved (mg/L)	12	.43	.15	.01	2.1	82	--	.1	ND	1.5	3	.88	.93	.20	1.5
Ammonia plus organic nitrogen, total (mg/L)	1	1.2	1.2	1.2	1.2	23	2.3	2.3	1.2	4.3	1	1.7	1.7	1.7	1.7
Phosphorus, total (mg/L)	13	.57	.37	.22	2.0	144	--	.7	ND	13	3	.77	.75	.60	.97
Arsenic, total (μg/L)[4]	9	--	ND	ND	10	233	--	10	ND	50	3	--	10	ND	10
Chromium, total (μg/L)	10	--	15	ND	140	164	--	20	ND	440	3	--	10	ND	80
Copper, total (μg/L)	9	--	ND	ND	10	237	--	20	ND	200	3	13	10	10	20
Lead, total (μg/L)	10	--	ND	ND	10	239	--	40	ND	470	3	43	20	20	90
Mercury, total (μg/L)	10	--	ND	ND	2	120	--	ND	ND	59	3	ND	ND	ND	ND
Zinc, total (μg/L)	11	20	20	10	60	153	140	110	10	490	3	43	40	30	60
Sediment, suspended (mg/L)	12	16	14	9	29	288	1,240	636	14	7,120	2	75	75	40	110

[1]Cubic feet per second.
[2]Micromhos per centimeter at 25 °Celsius.
[3]Milligrams per liter.
[4]Micrograms per liter.

Conversion Factors

Inch-pound units of measurements used in this report can be converted to the International System of Units (SI) using the following conversion factors:

Multiply inch-pound units	*By*	*To obtain SI units*
inch	2.54	centimeter
foot	0.3048	meter
mile	1.609	kilometer
inch per hour	2.54	centimeter per hour
foot per mile (ft/mi)	0.1894	meter per kilometer
mile per square mile	0.62	kilometer per square kilometer
square mile (mi^2)	2.590	square kilometer
acre	0.4047	hectare
gallon	3.785	liter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
pound (lb)	0.4536	kilogram (kg)
pound per square mile per inch [(lb/mi^2)/in.]	0.0690	kilogram per square kilometer per centimeter
micromho per centimeter at 25 °Celsius (μmho/cm at 25 °C)	1.000	microsiemens per centimeter at 25 °Celsius
degree Fahrenheit (°F)	(1)	degree Celsius (°C)

[1]Temp °C = (temp °F −32)/1.8.

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