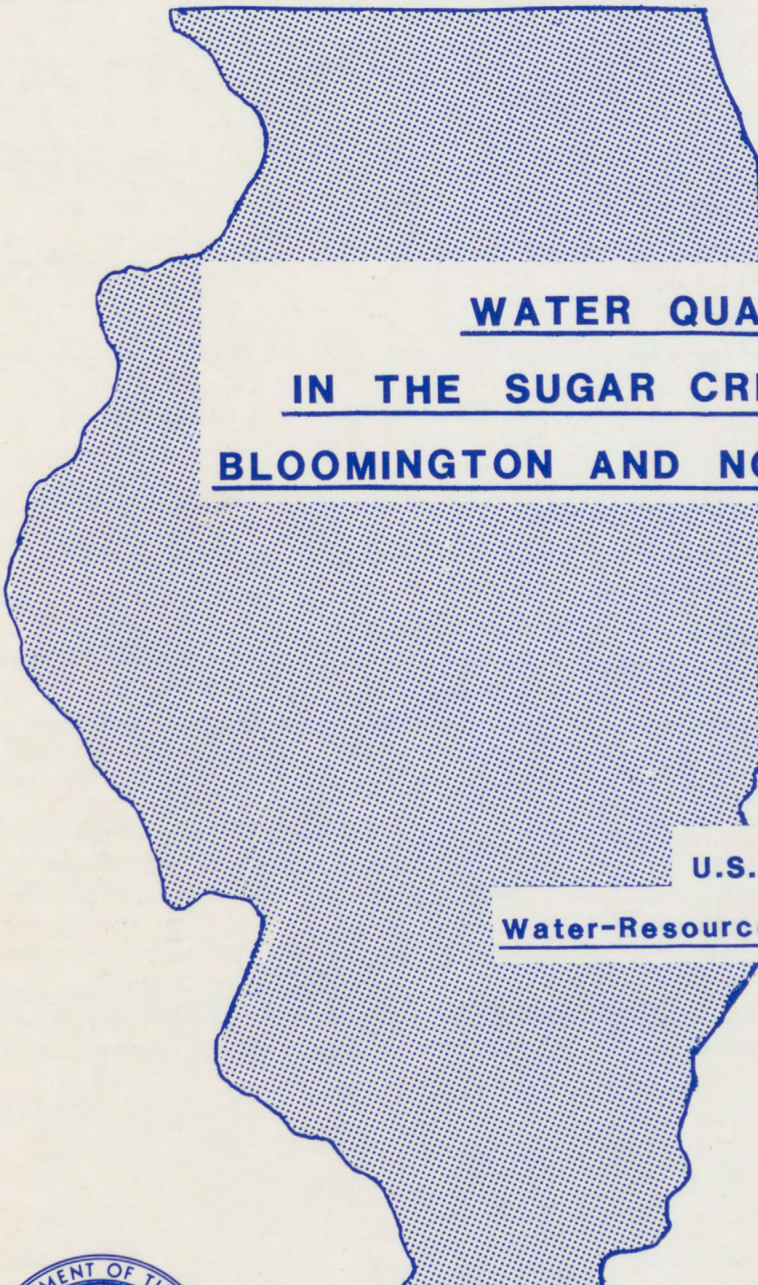

# WATER QUALITY IN THE SUGAR CREEK BASIN, BLOOMINGTON AND NORMAL, ILLINOIS

U.S. GEOLOGICAL SURVEY

Water-Resources Investigation 78-78



Prepared in cooperation with
BLOOMINGTON AND NORMAL
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16. Abstracts

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by Byron J. Prugh, Jr.

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Sanitary District

1978

# UNITED STATES DEPARTMENT OF THE INTERIOR

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## GEOLOGICAL SURVEY

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TABLES



## FACTORS FOR CONVERTING U.S. CUSTOMARY UNITS TO INTERNATIONAL SYSTEM (SI) UNITS

The following factors may be used to convert the U.S. customary units published herein to the International System of Units (SI).

| Multiply U.S. customary units | By | To obtain SI units |
|---|---|---|
| | Length | |
| inches (in) | 25.4 | millimeters (mm). |
| | .0254 | meters (m). |
| feet (ft) | .3048 | meters (m). |
| miles (mi) | 1.609 | kilometers (km). |
| | Area | |
| square miles ($mi^2$) | 2.590 | square kilometers ($km^2$). |

## FACTORS FOR CONVERTING U.S. CUSTOMARY UNITS TO INTERNATIONAL SYSTEM (SI) UNITS––Continued

| Multiply U.S. customary units | By | To obtain SI units |
|---|---|---|
| **Volume** | | |
| gallons (gal) | 3.785 | liters (L). |
| | .003785 | cubic meters ($m^3$). |
| cubic feet ($ft^3$) | .02832 | cubic meters ($m^3$). |
| **Flow** | | |
| cubic feet per second ($ft^3/s$) | 28.32 | liters per second (L/s). |
| | .02832 | cubic meters per second ($m^3/s$). |
| gallons per minute (gal/min) | .06309 | liters per second (L/s). |
| | .00006309 | cubic meters per second ($m^3/s$). |
| million gallons per day (mgal/d) | .04381 | cubic meters per second ($m^3/s$). |
| **Mass and Force** | | |
| pounds (lb) | 453.6 | grams (g). |
| | .4536 | kilogram (kg). |
| tons, short (2,000 lb) | .9072 | metric ton (t) (1,000 kg). |
| **Temperature** | | |
| degrees Fahrenheit (°F) | -32x0.555 | degrees Celsius (°C). |

# WATER QUALITY IN THE SUGAR CREEK BASIN, BLOOMINGTON AND NORMAL, ILLINOIS

By Byron J. Prugh, Jr.

## *ABSTRACT*

*Sugar Creek, within the twin cities of Bloomington and Normal, Illinois, has differences in water quantity and quality as a result of urban runoff and overflows from combined sewers.*

*Water-quality data from five primary and eight secondary locations showed three basic types of responses to climatic and hydrologic stresses. Stream temperatures and concentrations of dissolved oxygen, ammonia nitrogen, total phosphorus, biochemical oxygen demand, and fecal bacteria showed seasonal variations. Conductivity (dissolved solids), pH, chloride, and suspended solids concentrations varied more closely with stream discharges. Total organic carbon, total nitrogen, total phosphorus, biochemical oxygen demand, and fecal coliform and fecal streptococcal bacteria concentrations exhibited variations indicative of initial flushing action during storm runoff.*

*Selected analyses for herbicides, insecticides, and other complex organic compounds in solution and in bed material showed that these constituents were coming from sources other than the municipal sanitary treatment plant effluent. Analyses for 10 common metals: arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, and zinc showed changes in concentrations below the municipal sanitary plant outfall.*

## INTRODUCTION

The Bloomington-Normal urban area is in central Illinois near the headwaters of Sugar Creek (fig. 1) on a series of terminal moraines formed about 20,000 years ago during a recession in the Wisconsinan Stage of Pleistocene glaciation. Soil conditions are typical of many glaciated areas, consisting of some surficial loess underlain by tills composed of intermixed sands, gravels, silts, and clays which vary considerably in thickness and composition from one location to another.

Extensive mining for sand and gravel along the main stem of Sugar Creek, particularly in the area just above its junction with Skunk Creek and below the sewage-treatment plant, attest to the sorting action of glacial melt waters. These sand and gravel deposits facilitate ground-water flow into the creek but, under some conditions, may permit contaminated surface waters to infiltrate into shallow aquifers. The channels of Sugar Creek and the North Branch are concrete lined in the older sections of the urban area, but are unlined in the newly developed upper and lower parts of the basin.

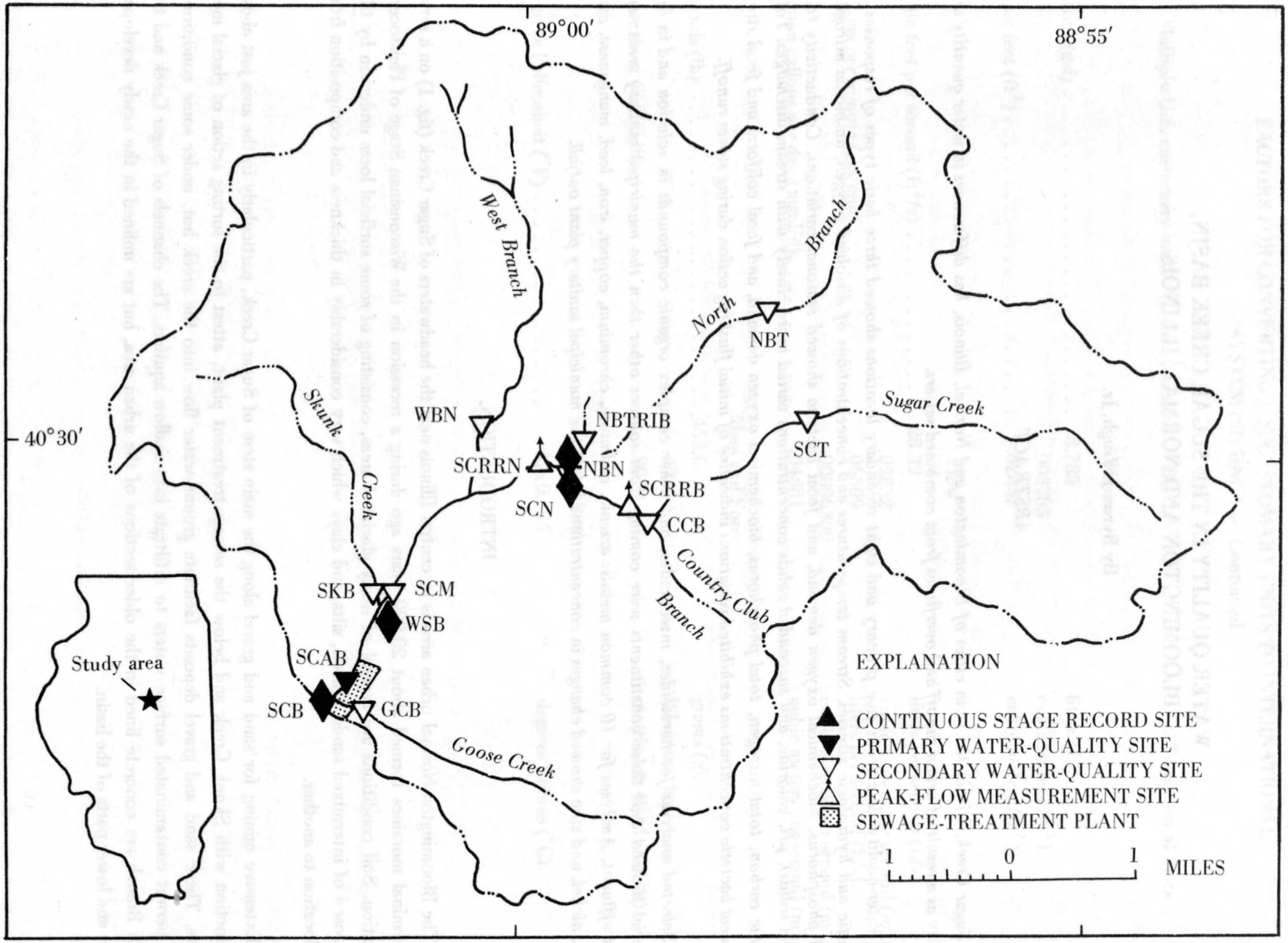


Figure 1.–Location of study area and data-collection sites.

Along most of Sugar Creek, flood-plain management has kept adequate open space adjacent to the channels to prevent flood damage. One area subject to flooding is along a half a mile reach of the creek above its junction with Country Club Branch. Here, uncontrolled vegetation and structural encroachment on the channel restricts flow and creates flooding conditions from backwater. Flooding also occurs along Sugar Creek near its junction with the North Branch, where commercial development has encroached upon the flood plain.

The Bloomington and Normal Sanitary District waste-water treatment plant was completed in 1928. Prior to this date municipal wastes were discharged into Sugar Creek without treatment. The older waste-collection networks in the urban area are combined sewers; but, in systems constructed since 1952, sanitary flows have been separated from stormwater. The Bloomington-Normal area has experienced considerable population growth and urban expansion since the original plant was constructed. The waste-water treatment plant was enlarged in 1965 and is presently being enlarged again to accommodate the increase in waste-water volumes and the more stringent effluent requirements mandated by governmental agencies in recent years.

Currently, conditions of water quality often do not meet Illinois Pollution Control Board standards in most of the urbanized parts of the Sugar Creek basin. The water-quality degradation results from untreated stormwater runoff, combined sewer overflows, and effluent from the municipal sewage treatment plant.

Beginning in September 1974, a 3-year study of the upper Sugar Creek basin was undertaken to assess the water quality in the basin, and to provide data necessary for the design of adequate facilities and procedures to improve the quality of surface waters in the area.

This report is a summary and evaluation of the data collected during the study. Data collected during the study are published in U.S. Geological Survey reports on Water Resources Data for Illinois, 1976, 1977, and 1978.

## ACKNOWLEDGMENTS

The author acknowledges the cooperation and assistance of the Bloomington and Normal Sanitary District staff during the course of this project and in particular, Mr. Howard Sutherland, general plant superintendent, and Mr. Mike Callahan, chief chemist.

## METHODS

Water samples were collected at 13 sites in the basin (table 1 and figs. 1 and 2). Five sites, designated as primary sites for sampling on a monthly basis as well as during storms, included Sugar Creek just downstream (SCB) and upstream (SCAB) from the effluent outfall of the Bloomington-Normal sewage treatment plant, West Slough (WSB)–a major combined sewer overflow site, Sugar Creek just below Franklin Avenue in Normal (SCN), and North Branch Sugar Creek also just below Franklin Avenue in Normal (NBN). Both SCN and NBN receive street and overland runoff. SCN also receives some combined sewer overflows and was selected to provide a comparison with NBN.

Table 1.—Data collection sites

| USGS No. | Code | Site | Drainage area (mi$^2$) | Percent rural | Data activity |
|---|---|---|---|---|---|
| 05580730 | SCT | Sugar Creek at Towanda Avenue | 6.20 | 92 | S |
| 05580740 | CCB | Country Club Branch at Emerson Street | 1.45 | 12 | S |
| 05580750 | SCRRB | Sugar Creek below Linden Street | 9.25 | 74 | MQ |
| 05580760 | SCN | Sugar Creek below Franklin Avenue | 9.58 | 62 | GS,RG,P |
| 05580770 | NBT | North Branch Sugar Creek at Towanda Avenue | 2.68 | 90 | S |
| 05580805 | NBTRIB | North Branch Sugar Creek tributary near Church Street | .52 | 0 | S |
| 05580810 | NBN | North Branch Sugar Creek at Franklin Avenue | 5.70 | 60 | GS,P |
| 05580850 | SCRRN | Sugar Creek below Main Street | 16.0 | 60 | MQ |
| 05580880 | WBN | West Branch Sugar Creek at Hovey Avenue | 4.10 | 61 | S |
| 05580910 | SCM | Sugar Creek at Market Street | 21.5 | 54 | S |
| 05580920 | SKB | Skunk Creek at Market Street | 6.42 | 86 | S |
| 05580930 | WSB | West Slough at Caroline Street | 3.26 | 1 | GS,P |
| 05580945 | SCAB | Sugar Creek above Sewage Plant | 32.4 | 55 | P |
| 05580948 | GCB | Goose Creek at Oakland County Road | 2.27 | 66 | S |
| 05580950 | SCB | Sugar Creek below Sewage Plant | 34.6 | 56 | GS,P |

GS = continuous-stage record; RG = precipitation gage; P = primary water-quality site; S = secondary water-quality site; MQ = peak-flow site

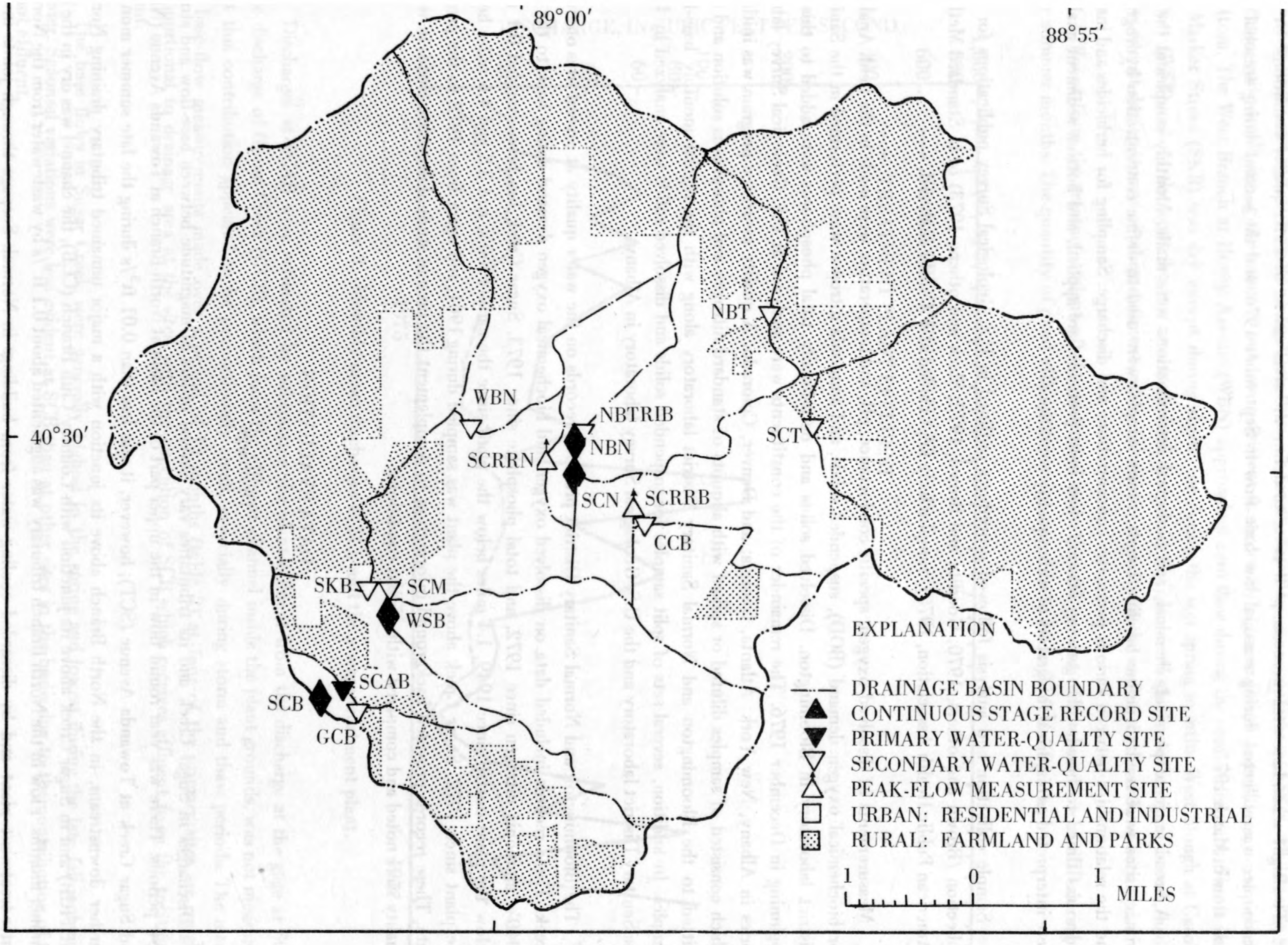


Figure 2.—Subbasins and land-use distribution.

The eight secondary sites were sampled twice to define the areal extent of water-quality conditions. One set of samples was collected during seasonal low base flow in September 1976, and the second during seasonal high base flow in March 1977.

A broad range of physical, chemical, and biological determinations were made. Monthly samples at the five primary sites were used to define baseline trends. Storm samples were used to define concentration hydrographs and the relationships between various parameter concentrations and discharge. Sampling for herbicides and insecticides was timed to bracket the growing season, when most pesticides are applied, and bottom sediment analyses were interpreted as historical integrators of water-quality conditions.

Sample collection and analysis followed procedures outlined in U.S. Geological Survey publications for data collection (Brown and others, 1970; Goerlitz and Brown, 1972; Slack and others, 1973) or in Standard Methods (American Public Health Association, 1975). Samples were kept chilled at 4°C until analyzed.

Measurements of dissolved oxygen, specific conductance, pH, and temperature were made in the field. Analyses for biochemical oxygen demand (BOD), suspended solids, and ammonia nitrogen were performed in the Sanitary District laboratory in Bloomington. Dissolved solids and occasionally total phosphorus were added to this list beginning in December 1976. The remainder of the constituents were analyzed at U.S. Geological Survey laboratories in Albany, New York; Atlanta, Georgia; and Denver, Colorado. A quality assurance program was initiated which consisted of samples diluted or spiked with aliquots of standard nitrogen and phosphorus solution and submitted to the Bloomington and Normal Sanitary District laboratory along with the regular monthly base-flow samples. In addition, several sets of split samples for suspended solids and dissolved solids were analyzed by both the Sanitary District laboratory and the U.S. Geological Survey laboratory in Albany.

The Bloomington and Normal Sanitary District provided records on the water quality at several sites on Sugar Creek. These records included data on dissolved oxygen and biochemical oxygen demand dating back to the late 1940's, ammonia nitrogen since 1972, and total phosphate since 1973. Sugar Creek has been sampled 0.1 mile below the plant outfall since 1949, 1.4 miles below the plant since the early 1960's, and 3.5 and 4.6 miles below the plant since 1972. Sugar Creek above the plant was sampled during 1961, and again from 1972 to the present date. These records provided background information to complement the present study. Long-term trends in water quality were noted and compared with current conditions.

## DATA EVALUATION

### Discharge

Discharges in Sugar Creek and its tributaries vary several orders of magnitude between base-flow and storm-flow periods. There was year round flow in the upper part of the basin at North Branch at Towanda Avenue (NBT) and Sugar Creek at Towanda Avenue (SCT); however, it was less than 0.01 $ft^3/s$ during the late summer months. Farther downstream, in the North Branch above its junction with a major unnamed tributary draining Normal (NBTRIB) and in Sugar Creek above its junction with Country Club Branch (CCB), the channel was dry in the late summer months. Flow in the North Branch tributary was augmented about 0.1 $ft^3/s$ by wastewater from the Normal water-treatment plant and by discarded cooling water from buildings in Normal. Seepage through joints in the concrete lining and inflow from Country Club Branch were the low-flow sources of water at SCN. The flow at SCN became quite small during the summer but was persistent as shown by algae and snail populations on the channel bottom. The West Branch at Hovey Avenue (WBN) approached zero flow during the summer months. Skunk Creek at Market Street (SKB) was dry except during storms or during the wet spring months. West Slough at Caroline Street (WSB), where the contributing area is drained exclusively by combined storm and sanitary sewers, had no flow except during storms or when sediment reduced the sewer capacity to the extent that overflows occurred.

Effluent from the treatment plant often constituted more than 95 percent of the base flow at SCB during the late summer months. The quantity of plant effluent generally ranged from 10 to 25 $ft^3/s$ (fig. 3).

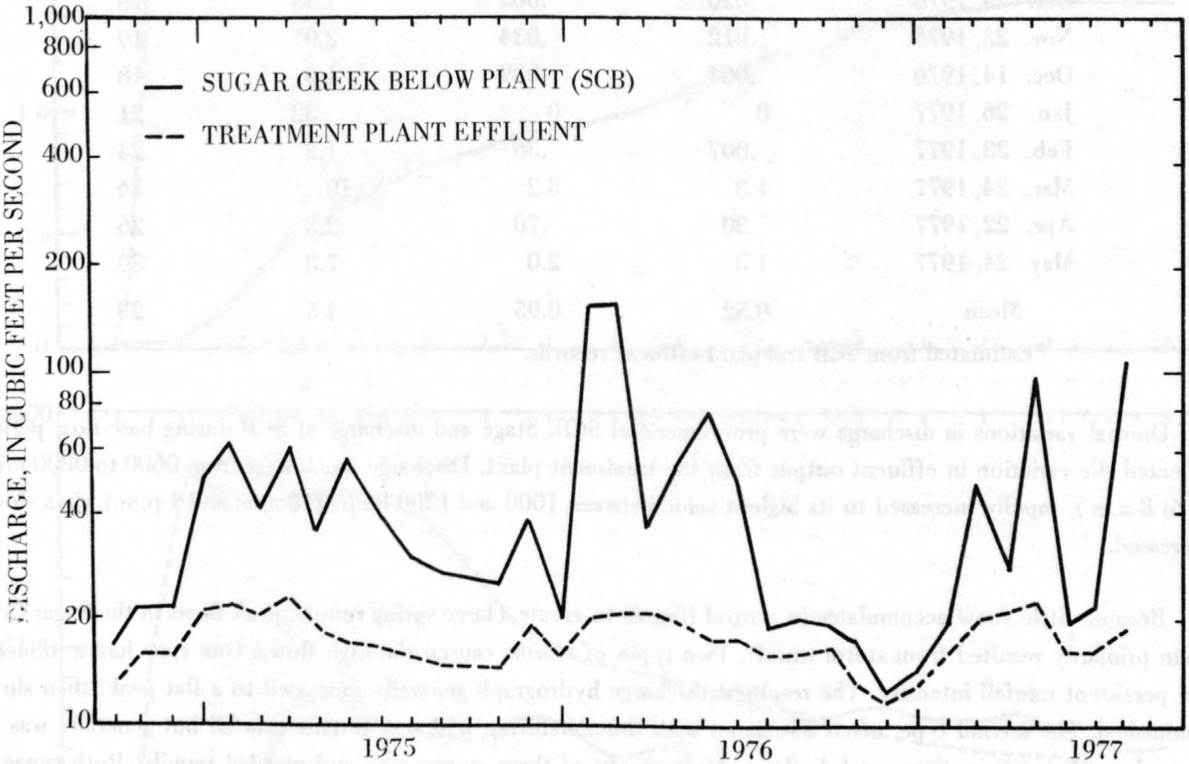


Figure 3.–Monthly mean discharges at SCB and the sewage-treatment plant.

Discharges at SCAB were estimated by subtracting the plant effluent from the discharge at the gage at SCB. The discharge of Goose Creek (GCB), which joins the effluent channel inside the plant grounds, was not measured, but this contribution appeared to be proportionally small, especially during storm and thaw periods. The means of base-flow measurements made over a period of 13 months (table 2) at four of the primary sites are roughly proportional to drainage area at the sites, with the exception of SCB which receives effluent from the treatment plant.

The base flows in Sugar Creek were generally highest in the spring and lowest during the late fall and early winter. Seaonsal variations were less evident at SCB than at other sites in the basin due to the contribution of the plant effluent.

Table 2.—Some selected base-flow measurements

| Date | Discharge, in cubic feet per second NBN | SCN | SCAB | SCB |
|---|---|---|---|---|
| May 25, 1976 | 1.4 | 2.9 | 8.8* | 22 |
| June 25, 1976 | 1.6 | 2.3 | 8.5* | 27 |
| July 30, 1976 | .29 | .72 | 6.8* | 25 |
| Aug. 31, 1976 | .31 | .069 | 9.0* | 25 |
| Sept. 23, 1976 | .19 | .012 | .40* | 10 |
| Oct. 29, 1976 | .020 | .065 | .55 | 18 |
| Nov. 23, 1976 | .012 | .034 | 2.0* | 19 |
| Dec. 14, 1976 | .004 | .039 | .0 | 18 |
| Jan. 26, 1977 | 0 | 0 | .32 | 21 |
| Feb. 28, 1977 | .007 | .36 | 1.2 | 24 |
| Mar. 24, 1977 | 1.3 | 3.2 | 10 | 36 |
| Apr. 22, 1977 | .30 | .70 | 2.3 | 26 |
| May 24, 1977 | 1.3 | 2.0 | 7.3 | 30 |
| Mean | 0.52 | 0.95 | 4.5 | 23 |

*Estimated from SCB and plant effluent records.

Diurnal variations in discharge were pronounced at SCB. Stage and discharge at SCB during base-flow periods reflected the variation in effluent output from the treatment plant. Discharge was lowest from 0600 to 0800 hours (6 to 8 a.m.), rapidly increased to its highest value between 1000 and 1300 hours (10 a.m. and 1 p.m.), then slowly decreased.

Because little snow accumulates in central Illinois to create a large spring runoff, peak flows in the Sugar Creek basin primarily resulted from storm runoff. Two types of storms caused the high flows. One type had a moderate but persistent rainfall intensity. The resultant discharge hydrograph generally increased to a flat peak, then slowly diminished. The second type, often associated with thunderstorms, had very intense rainfall but generally was not of prolonged duration. Stage and discharge hydrographs of these storms rose and receded rapidly. Both types are illustrated in figure 4.

Several major peak flows were documented in the upper Sugar Creek basin. Indirect measurements of peak discharges at several locations, along with two historical measurements, are shown in table 3.

The effects of urbanization on runoff within the Sugar Creek basin may be assessed by comparing Sugar Creek with Money Creek, an adjacent rural stream with similar physiographic and climatic conditions. Money Creek, at a gaging site several miles northeast of Normal near Towanda, has a drainage area of 49.0 $mi^2$, in contrast with 32.4 $mi^2$ for Sugar Creek above the treatment plant.

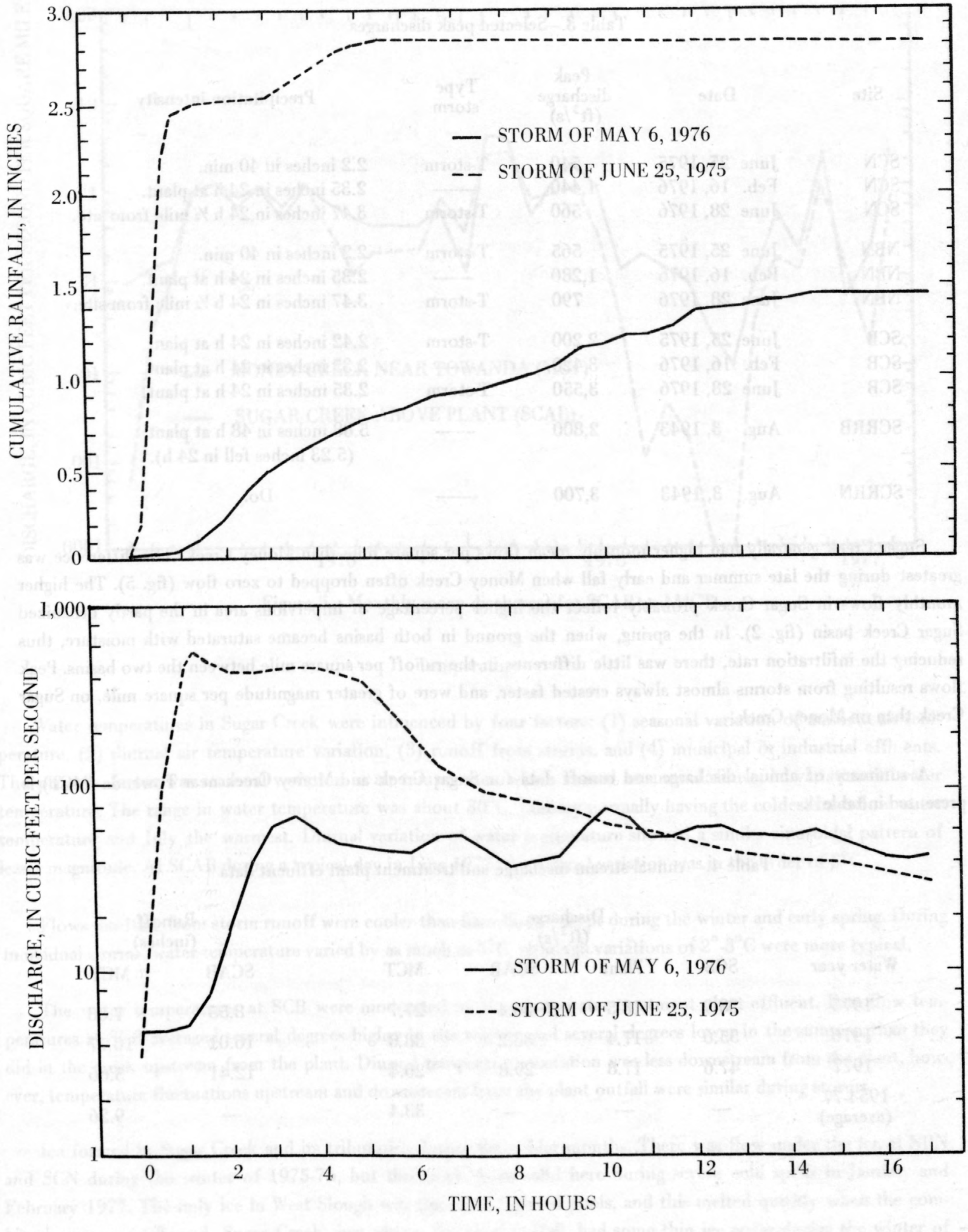


Figure 4.–Rainfall and discharge during two typical storms at SCN.

Table 3.–Selected peak discharges

| Site | Date | Peak discharge ($ft^3/s$) | Type storm | Precipitation intensity |
|---|---|---|---|---|
| SCN | June 25, 1975 | 540 | T-storm | 2.2 inches in 40 min. |
| SCN | Feb. 16, 1976 | 1,440 | ------- | 2.35 inches in 24 h at plant. |
| SCN | June 28, 1976 | 560 | T-storm | 3.47 inches in 24 h ½ mile from site. |
| NBN | June 25, 1975 | 565 | T-storm | 2.2 inches in 40 min. |
| NBN | Feb. 16, 1976 | 1,280 | ------- | 2.35 inches in 24 h at plant. |
| NBN | June 28, 1976 | 790 | T-storm | 3.47 inches in 24 h ½ mile from site. |
| SCB | June 25, 1975 | 2,200 | T-storm | 2.42 inches in 24 h at plant. |
| SCB | Feb. 16, 1976 | 3,420 | ------- | 2.35 inches in 24 h at plant. |
| SCB | June 28, 1976 | 3,550 | T-storm | 2.35 inches in 24 h at plant. |
| SCRRB | Aug. 3, 1943 | 2,800 | ------- | 5.88 inches in 48 h at plant (5.23 inches fell in 24 h). |
| SCRRN | Aug. 3, 1943 | 3,700 | ------- | Do. |

Sugar Creek generally had higher monthly mean flows per square mile than Money Creek. The difference was greatest during the late summer and early fall when Money Creek often dropped to zero flow (fig. 5). The higher monthly flows in Sugar Creek probably reflect the higher percentage of impervious area in the partly urbanized Sugar Creek basin (fig. 2). In the spring, when the ground in both basins became saturated with moisture, thus reducing the infiltration rate, there was little difference in the runoff per square mile between the two basins. Peak flows resulting from storms almost always crested faster, and were of greater magnitude per square mile, on Sugar Creek than on Money Creek.

A summary of annual discharge and runoff data for Sugar Creek and Money Creek near Towanda (MCT) is presented in table 4.

Table 4.–Annual stream discharge and treatment plant effluent data

| Water year | Discharge ($ft^3/s$) SCB | Plant | SCAB | MCT | Runoff (inches) SCAB | MCT |
|---|---|---|---|---|---|---|
| 1975 | 38.9 | 18.5 | 20.4 | 27.7 | 8.55 | 7.68 |
| 1976 | 55.6 | 17.4 | 38.2 | 38.8 | 16.01 | 10.77 |
| 1977 | 47.6 | 17.8 | 29.8 | 20.4 | 12.41 | 5.66 |
| 1954-77 (average) | ---- | ---- | ---- | 33.4 | ---- | 9.26 |

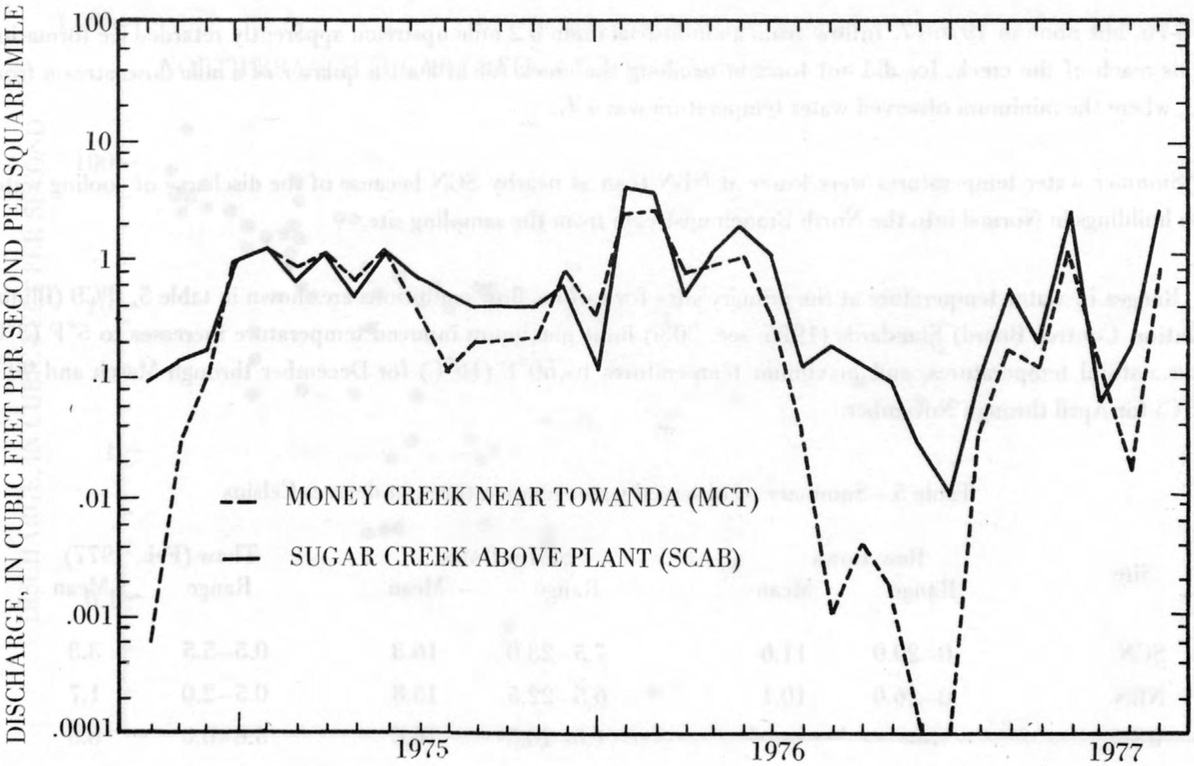


Figure 5.–Monthly mean discharges for SCAB and MCT.

## Temperature

Water temperatures in Sugar Creek were influenced by four factors: (1) seasonal variation of ambient air temperature, (2) diurnal air temperature variation, (3) runoff from storms, and (4) municipal or industrial effluents. The primary factor was seasonal variation in air temperature which caused an annual sinusoidal variation in water temperature. The range in water temperature was about 30°C, January normally having the coldest base-flow water temperature and July the warmest. Diurnal variation of water temperature showed a similar sinusoidal pattern of lesser magnitude. At SCAB during a typical day in June 1977, the diurnal variation was in the order of 5°C.

Flows resulting from storm runoff were cooler than base flows except during the winter and early spring. During individual storms, water temperature varied by as much as 5°C, although variations of 2°-3°C were more typical.

The water temperatures at SCB were moderated by the waste-water treatment plant effluent. Base-flow temperatures at SCB averaged several degrees higher in the winter, and several degrees lower in the summer, than they did in the creek upstream from the plant. Diurnal temperature variation was less downstream from the plant; however, temperature fluctuations upstream and downstream from the plant outfall were similar during storms.

Ice formed in Sugar Creek and its tributaries during the colder months. There was flow under the ice at NBN and SCN during the winter of 1975-76, but the creek froze solid here during severe cold spells in January and February 1977. The only ice in West Slough was found on isolated pools, and this melted quickly when the combined sewers overflowed. Sugar Creek, just above the plant outfall, had some thin ice cover during the winter of

1975-76, but none in 1976-77. Inflow from an industrial drain 0.2 mile upstream apparently retarded ice formation in this reach of the creek. Ice did not form in or along the creek for at least a quarter of a mile downstream from SCB, where the minimum observed water temperature was 4°C.

Summer water temperatures were lower at NBN than at nearby SCN because of the discharge of cooling water from buildings in Normal into the North Branch upstream from the sampling site.

Ranges in water temperature at the primary sites for various flow conditions are shown in table 5. IPCB (Illinois Pollution Control Board) Standards (1976, sec. 203i) limit maximum induced temperature increases to 5°F (3°C) above natural temperatures, and maximum temperatures to 60°F (16°C) for December through March and 90°F (32°C) for April through November.

Table 5.—Summary of observed water temperatures, in degrees Celsius

| Site | Base flows | | Storm flows | | Thaw (Feb. 1977) | |
|---|---|---|---|---|---|---|
| | Range | Mean | Range | Mean | Range | Mean |
| SCN | 0–29.0 | 11.6 | 7.5–23.0 | 16.3 | 0.5–5.5 | 3.3 |
| NBN | 0–26.0 | 10.1 | 6.5–22.5 | 15.8 | 0.5–2.0 | 1.7 |
| WSB | --- | --- | 1.0–23.5 | 16.8 | 5.0–8.0 | 6.0 |
| SCAB | 1.5–32.0 | 17.9 | 13.0–15.5 | 14.3 | 1.5–6.0 | 2.7 |
| SCB | 4.0–28.0 | 14.8 | 10.0–25.0 | 18.2 | 4.5–9.5 | 6.9 |

## Chloride

Chloride is important in water-quality evaluations because high concentrations can be toxic to many types of plants and aquatic life (McKee and Wolf, 1971, p. 159).

Concentrations of chloride were generally inversely proportional to discharge, although sequential samples within a given storm often showed a looped relationship characteristic of channel flushing. The inverse concentration-discharge relationship was best at SCB and poorest at NBN (fig.6). The good relationship at SCB was caused by the more uniform composition of the sewage plant effluent which often composed most of the streamflow at low stages.

Chloride concentrations in base flow varied seasonally, being lowest during the spring and progressively increasing to their highest values during late winter (fig. 7). This pattern is consistent with the inverse concentration-discharge relationship, the normal seasonal decrease in base flows, and the seasonal use of chloride salts for street deicing.

Concentrations of chloride in Sugar Creek during winter were higher when increases in discharges were caused by thawing of ice and snow alone than when the thawing occurred in conjunction with precipitation. Rainwater diluted the chloride in the melting ice and snow. Chloride concentrations, in samples collected in January 1975 during a storm (rain), were considerably lower than the concentrations in samples collected in February 1977 during a thaw (fig. 7).

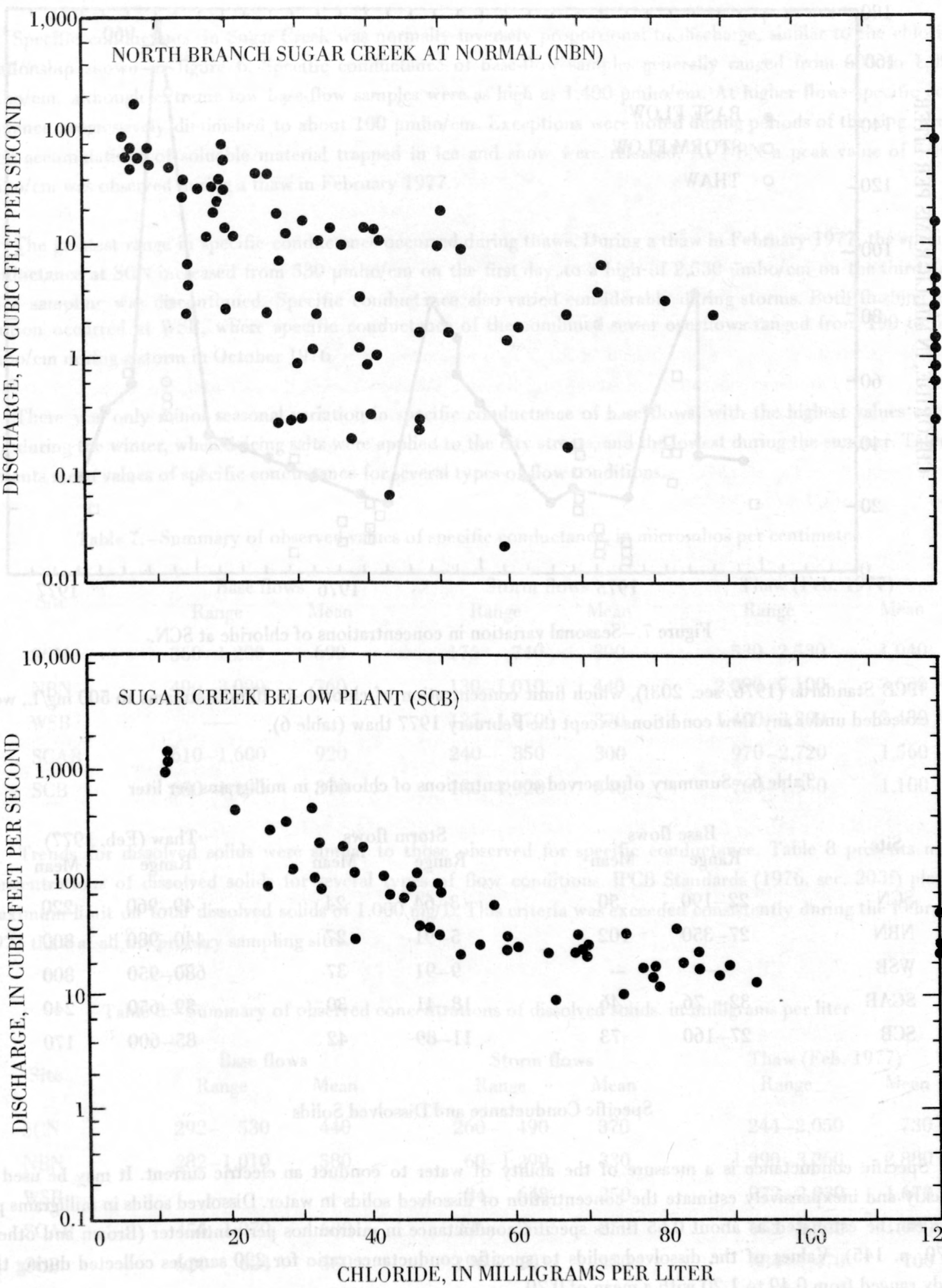


Figure 6.–Discharge versus dissolved chloride at NBN and SCB.

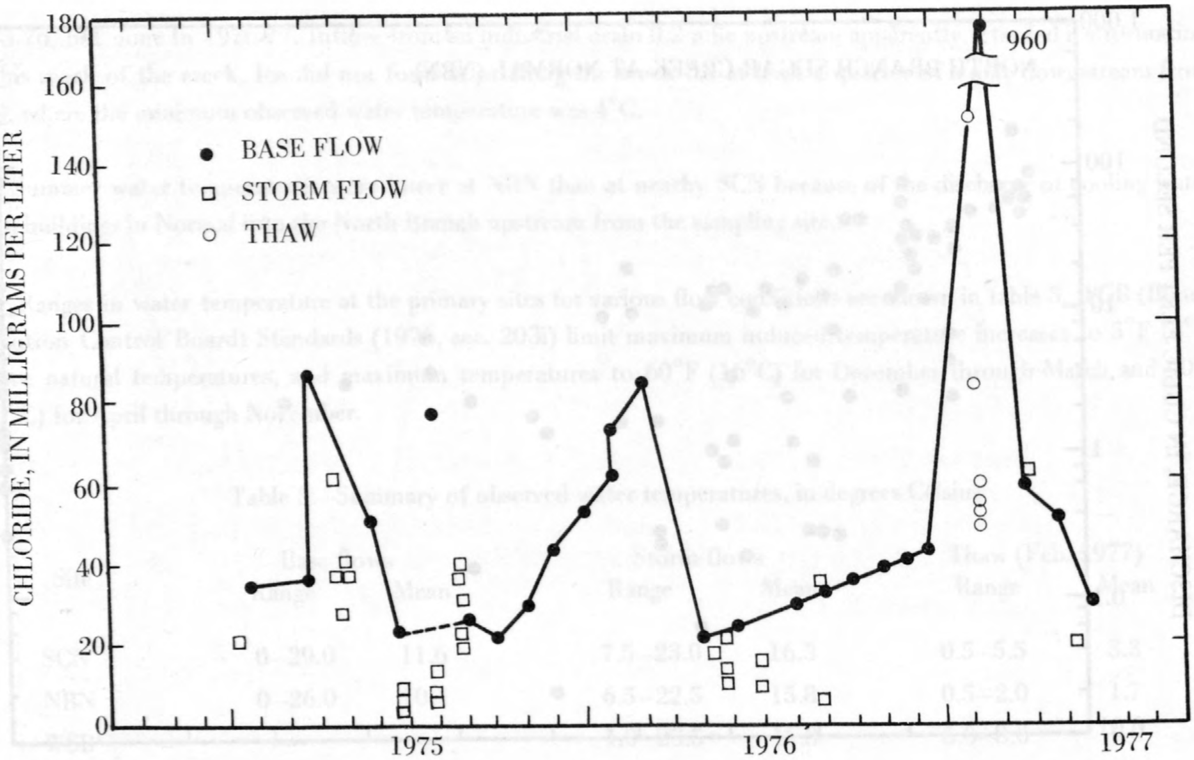


Figure 7.–Seasonal variation in concentrations of chloride at SCN.

IPCB Standards (1976, sec. 203f), which limit concentration of chloride in Illinois streams to 500 mg/L, were not exceeded under any flow conditions except the February 1977 thaw (table 6).

Table 6.–Summary of observed concentrations of chloride, in milligrams per liter

| Site | Base flows | | Storm flows | | Thaw (Feb. 1977) | |
|---|---|---|---|---|---|---|
| | Range | Mean | Range | Mean | Range | Mean |
| SCN | 22–190 | 50 | 3–64 | 24 | 49–960 | 220 |
| NBN | 27–350 | 102 | 5–91 | 27 | 440–980 | 800 |
| WSB | ---- | --- | 9–91 | 37 | 680–950 | 800 |
| SCAB | 32– 76 | 46 | 18–41 | 30 | 39–650 | 240 |
| SCB | 27–160 | 73 | 11–89 | 42 | 85–600 | 170 |

## Specific Conductance and Dissolved Solids

Specific conductance is a measure of the ability of water to conduct an electric current. It may be used to quickly and inexpensively estimate the concentration of dissolved solids in water. Dissolved solids in milligrams per liter can be estimated as about 0.65 times specific conductance in micromhos per centimeter (Brown and others, 1970, p. 145). Values of the dissolved solids to specific conductance ratio for 220 samples collected during this study ranged from 0.49 to 1.20 with a mean of 0.70.

Specific conductance in Sugar Creek was normally inversely proportional to discharge, similar to the chloride relationship shown in figure 6. Specific conductance of base-flow samples generally ranged from 600 to 1,000 μmho/cm, although extreme low base-flow samples were as high as 1,400 μmho/cm. At higher flows specific conductance progressively diminished to about 100 μmho/cm. Exceptions were noted during periods of thawing, when large accumulations of soluable material trapped in ice and snow were released. At NBN a peak value of 5,100 μmho/cm was observed during a thaw in February 1977.

The greatest range in specific conductance occurred during thaws. During a thaw in February 1977, the specific conductance at SCN increased from 530 μmho/cm on the first day, to a high of 2,530 μmho/cm on the third day, when sampling was discontinued. Specific conductance also varied considerably during storms. Both flushing and dilution occurred at WSB, where specific conductance of the combined sewer overflows ranged from 190 to 540 μmho/cm during a storm in October 1976.

There was only minor seasonal variation in specific conductance of base flows, with the highest values occurring during the winter, when deicing salts were applied to the city streets, and the lowest during the summer. Table 7 presents mean values of specific conductance for several types of flow conditions.

Table 7.–Summary of observed values of specific conductance, in micromhos per centimeter

| Site | Base flows | | Storm flows | | Thaw (Feb. 1977) | |
|---|---|---|---|---|---|---|
| | Range | Mean | Range | Mean | Range | Mean |
| SCN | 360–1,200 | 690 | 175– 740 | 390 | 530–2,530 | 1,040 |
| NBN | 490–3,020 | 760 | 130–1,010 | 440 | 2,090–5,100 | 3,630 |
| WSB | ------ | --- | 125–1,070 | 370 | 1,400–3,200 | 2,480 |
| SCAB | 610–1,600 | 920 | 240– 350 | 300 | 970–2,720 | 1,560 |
| SCB | 650–1,190 | 870 | 180–1,920 | 540 | 760–1,950 | 1,100 |

Trends for dissolved solids were similar to those observed for specific conductance. Table 8 presents mean concentrations of dissolved solids for several types of flow conditions. IPCB Standards (1976, sec. 203f) place a maximum limit on total dissolved solids of 1,000 mg/L. This criteria was exceeded consistently during the February 1977 thaw at all the primary sampling sites.

Table 8.–Summary of observed concentrations of dissolved solids, in milligrams per liter

| Site | Base flows | | Storm flows | | Thaw (Feb. 1977) | |
|---|---|---|---|---|---|---|
| | Range | Mean | Range | Mean | Range | Mean |
| SCN | 292– 530 | 440 | 260– 490 | 370 | 244–2,050 | 730 |
| NBN | 282–1,010 | 580 | 60–1,290 | 330 | 1,990–3,260 | 2,880 |
| WSB | ------ | --- | 84– 648 | 250 | 972–2,030 | 1,670 |
| SCAB | 456–1,070 | 680 | 236– 256 | 250 | 652–1,740 | 1,080 |
| SCB | 520– 624 | 550 | 196– 597 | 430 | 384–1,470 | 700 |

NBN received the wash water from the filters of the Normal water-treatment plant and discarded cooling water from buildings in Normal. Both of these uses cause an increase in dissolved solids. Variability in concentrations of dissolved solids in base flow was especially large at this site.

## Suspended Solids

Suspended solids are that part of the whole water sample that is retained on a standard glass fiber filter after filtration. Suspended solids concentrations were generally directly related to discharge. At WSB and SCB this relationship was modified at low flows. When combined sewers began to overflow at WSB, the concentration of suspended solids remained constant at about 100 mg/L until the discharge reached 10 $ft^3/s$. Below 10 $ft^3/s$, the flow was basically of sanitary sewer origin, but above 10 $ft^3/s$ it became more typical of storm runoff at other sites in the basin. At SCB base-flow concentrations of suspended solids were seldom less than 15 mg/L due to the high proportion of sewage plant effluent. The suspended solids-discharge relationship for storms at SCB also became similar to those at upstream sites, as the plant contribution was progressively diluted by stormwater runoff. Peak concentrations during storms at all sites, except WSB, approached 4,000 mg/L. Figure 8 depicts the suspended solids versus discharge relationships for NBN and SCB.

Seasonal variations in concentrations of suspended solids in base flows were not pronounced. At NBN and SCN the lowest values were observed during the summer and the highest in the spring and fall. SCB showed little seasonal trend, although values were usually highest in the late fall and early winter. This rise in concentration at SCB reflects a general decrease in treatment plant effluent quality due to reduced efficiency of the biological processes in the treatment plant brought on by the onset of cooler weather.

The current Illinois Environmental Protection Agency operating permit for the Bloomington and Normal Sanitary District allows a 30-day average of suspended solids for the treatment plant's activated sludge effluent not to exceed 30 mg/L, and the trickling filter effluent not to exceed 50 mg/L. Table 9 presents observed values of suspended solids for various flow conditions at the five primary sites.

Table 9.–Summary of observed concentrations of suspended solids, in milligrams per liter

| Site | Base flows | | Storm flows | | Thaw (Feb. 1977) | |
|---|---|---|---|---|---|---|
| | Range | Mean | Range | Mean | Range | Mean |
| SCN | 3–53 | 18 | 7–3,900 | 610 | 1– 514 | 74 |
| NBN | 2–120 | 20 | 10–3,400 | 430 | 106–3,120 | 830 |
| WSB | ----- | --- | 30– 460 | 190 | 500–1,480 | 1,000 |
| SCAB | 2– 33 | 13 | 620– 690 | 660 | 10– 710 | 145 |
| SCB | 5–128 | 37 | 16–3,900 | 560 | 45–1,270 | 430 |

Sequential samples within a given storm often showed a flat-looped relationship (fig. 8). The shape of the loops varied depending upon antecedent conditions and rainfall intensity for each storm.

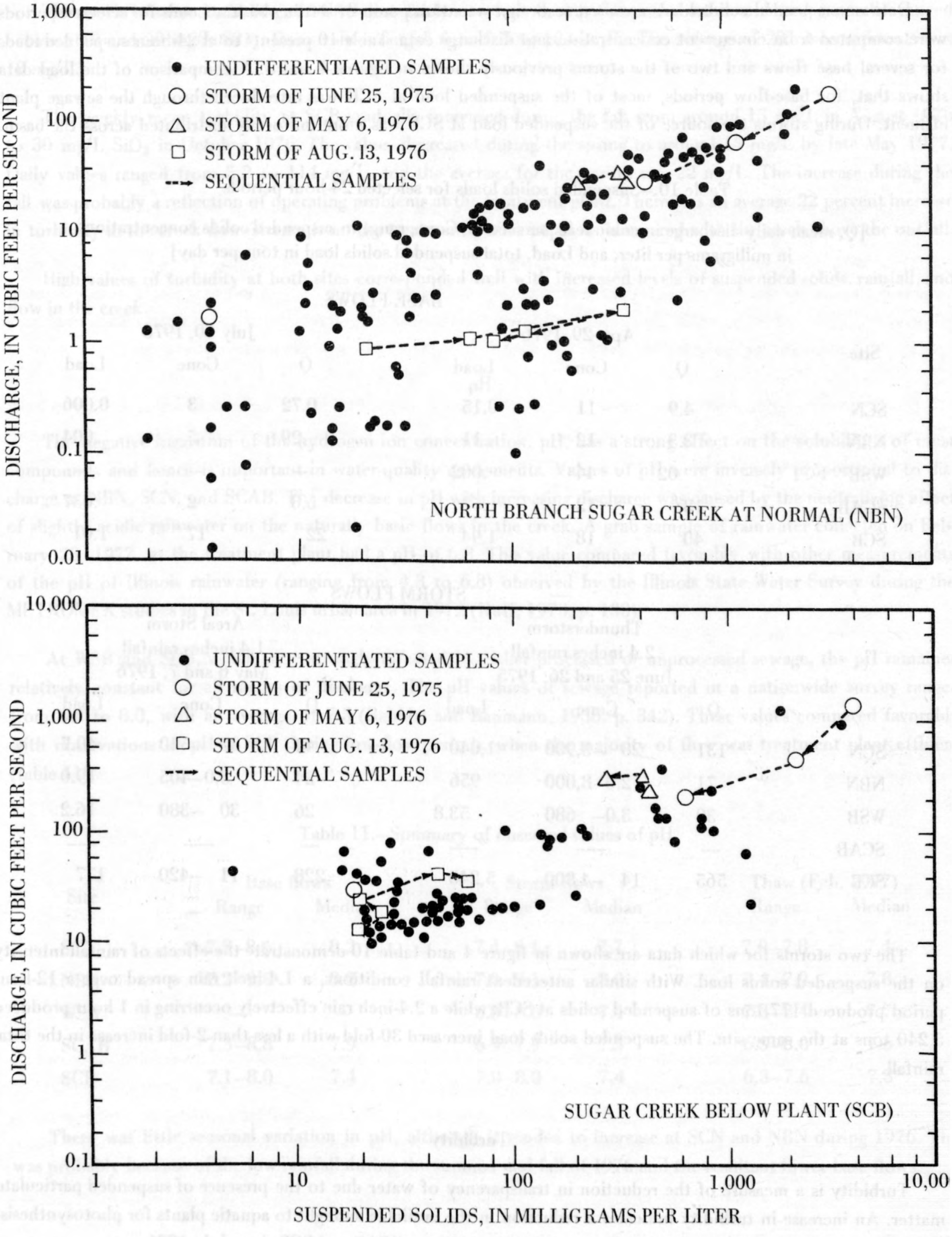


Figure 8.–Discharge versus suspended solids at NBN and SCB.

Data on suspended solids loads are used to design retention ponds or settling basins. Loads for selected periods were computed from concurrent concentration and discharge data. Table 10 presents total 24-hour suspended loads for several base flows and two of the storms previously shown in figures 4 and 8. A comparison of the load data shows that, for base-flow periods, most of the suspended load at SCB was introduced through the sewage plant effluent. During storms the source of the suspended load at SCB was more uniformly distributed across the basin.

Table 10.–Suspended solids loads for selected 24-hour periods

[Q, mean daily discharge in cubic feet per second; Conc, range in suspended solids concentration in milligrams per liter; and Load, total suspended solids load in tons per day]

| Site | Q | Conc | Load | Q | Conc | Load |
|---|---|---|---|---|---|---|
| | BASE FLOWS | | | | | |
| | Apr. 29, 1976 | | | July 30, 1976 | | |
| SCN | 4.9 | 11 | 0.15 | 0.72 | 3 | 0.006 |
| NBN | 3.3 | 12 | .11 | .29 | 5 | .004 |
| WSB | .02 | 44 | .002 | ---- | --- | ---- |
| SCAB | 18 | 12 | .58 | 6.8 | 2 | .037 |
| SCB | 40 | 18 | 1.94 | 22 | 17 | 1.01 |
| | STORM FLOWS | | | | | |
| | Thunderstorm 2.4 inches rainfall June 25 and 26, 1975 | | | Areal Storm 1.4 inches rainfall May 6 and 7, 1976 | | |
| SCN | 131 | 28 –3,900 | 1,040 | 44 | 80 –540 | 40.7 |
| NBN | 71 | 2.0–8,000 | 956 | 24 | 3.0–405 | 19.0 |
| WSB | 39 | 3.0– 680 | 53.8 | 26 | 30 –380 | 16.2 |
| SCAB | ---- | ------ | ------ | ---- | ------ | ------ |
| SCB | 565 | 14 –4,800 | 5,240 | 228 | 11 –420 | 177 |

The two storms for which data are shown in figure 4 and table 10 demonstrate the effects of rainfall intensity on the suspended solids load. With similar antecedent rainfall conditions, a 1.4-inch rain spread over a 12-hour period produced 177 tons of suspended solids at SCB; while a 2.4-inch rain effectvely occurring in 1 hour produced 5,240 tons at the same site. The suspended solids load increased 30-fold with a less than 2-fold increase in the total rainfall.

## Turbidity

Turbidity is a measure of the reduction in transparency of water due to the presence of suspended particulate matter. An increase in turbidity indicates a reduction in the available sunlight to aquatic plants for photosynthesis. The Sanitary District has made daily measurements of turbidity at SCAB and SCB since July 1976.

The weekly mean turbidity at SCAB was fairly constant during the period of record and generally ranged between 10 and 20 mg/L $SiO_2$. Daily values ranged from 3.7 to 103 mg/L. The average of 281 measurements was 18 mg/L.

The weekly mean turbidity at SCB gradually increased during the fall from around 15 mg/L in August 1976 to 30 mg/L $SiO_2$ in October 1976. The values decreased during the spring to around 15 mg/L by late May 1977. Daily values ranged from 5.2 to 114 mg/L, and the average for the period was 22 mg/L. The increase during the fall was probably a reflection of operating problems at the treatment plant. There was an average 22 percent increase in turbidity in the creek downstream from the treatment plant outfall, as compared with the creek above the outfall.

High values of turbidity at both sites corresponded well with increased levels of suspended solids, rainfall, and flow in the creek.

## pH

The negative logarithm of the hydrogen ion concentration, pH, has a strong effect on the solubilities of most compounds and hence is important in water-quality assessments. Values of pH were inversely proportional to discharge at NBN, SCN, and SCAB. The decrease in pH with increasing discharge was caused by the neutralizing affect of slightly acidic rainwater on the naturally basic flows in the creek. A grab sample of rainwater collected on February 23, 1977, at the treatment plant had a pH of 6.8. This value compared favorably with other measurements of the pH of Illinois rainwater (ranging from 4.3 to 6.8) observed by the Illinois State Water Survey during the METROMEX studies in the St. Louis urban area in 1972 (Huff, 1973, p. 130).

At WSB and SCB, which were strongly affected by either processed or unprocessed sewage, the pH remained relatively constant for all ranges of discharge. The pH values of sewage reported in a nationwide survey ranged from 6.8 to 8.0, with an average of 7.3 (Babbitt and Baumann, 1958, p. 342). These values compared favorably with observations of pH at SCB during low-flow periods, when the majority of flow was treatment plant effluent (table 11).

Table 11.—Summary of observed values of pH

| Site | Base flows | | Storm flows | | Thaw (Feb. 1977) | |
|---|---|---|---|---|---|---|
| | Range | Median | Range | Median | Range | Median |
| SCN | 7.3–8.6 | 8.2 | 7.4–8.1 | 7.7 | 7.0–7.8 | 7.4 |
| NBN | 7.2–9.5 | 8.2 | 7.0–9.1 | 8.0 | 7.4–7.9 | 7.8 |
| WSB | ---- | --- | 6.8–8.6 | 7.4 | 7.3–8.4 | 7.7 |
| SCAB | 7.5–8.8 | 7.9 | 6.9–7.9 | 7.5 | 6.5–8.0 | 7.6 |
| SCB | 7.1–8.0 | 7.4 | 7.0–8.0 | 7.4 | 6.3–7.6 | 7.3 |

There was little seasonal variation in pH, although it tended to increase at SCN and NBN during 1976. This was probably because of the low rainfall during the summer and fall of 1976 and the resultant lower base flows.

IPCB Standards (1976, sec. 203b) require that the pH of Illinois streams shall range between 6.5 and 9.0 except for natural causes. Values of pH at NBN sometimes exceeded 9.0 during low-flow periods as a result of lime-rich water flushed into the creek from the water softening treatment at the Normal municipal water plant.

## Total Nitrogen

Total nitrogen is the sum of the organic, ammonia, nitrite and nitrate nitrogen in a sample.

Total nitrogen concentrations in base flow at NBN and SCN ranged from about 3 to 8 mg/L. Concentrations increased to between 15 and 20 mg/L during storms, then decreased to about 1 mg/L as the storm discharge reached its peak. At WSB and SCB, where flows were predominantly raw or treated sewage, nitrogen concentrations started high during storms and progressively diminished to around 5 mg/L as flow was diluted by storm runoff.

Total nitrogen concentrations showed a seasonal variation typical of many organically related constituents. Concentrations reflected the vegetation growing season with low base-flow values during the winter and peak values during the late summer. Table 12 presents observed values of total nitrogen at the five primary sites for various flow conditions.

Table 12.–Summary of observed concentrations of total nitrogen, in milligrams per liter as N

| Site | Base flows | | Storm flows | |
|---|---|---|---|---|
| | Range | Mean | Range | Mean |
| SCN | 1.5–12.6 | 4.6 | 2.5–16.7 | 9.6 |
| NBN | 1.8–12.6 | 5.9 | 1.5–11.8 | 6.2 |
| WSB | ------ | --- | 4.7–88.0 | 17.1 |
| SCAB | 1.0–14.3 | 5.4 | ----- | --- |
| SCB | 6.2–24.3 | 16.6 | 5.9–20.4 | 12.2 |

## Nitrite and Nitrate Nitrogen

Nitrite and nitrate are often grouped together for convenience in analysis. They are usually an indication of the latter stages of decomposition of organic material but can also indicate leaching of fertilizers applied to agricultural land or suburban lawns and gardens.

Nitrite plus nitrate concentrations showed the effects of channel flushing and dilution from stormwater runoff. Concentrations at SCN and NBN typically increased from base-flow values of 2 to 4 mg/L, to around 15 mg/L during the initial rise in discharge, and then diminished to 2 to 4 mg/L at the peak. Maximum concentrations during the initial flushing depended upon the season of the year, antecedent rainfall, and the rainfall intensity of the storm. Nitrite plus nitrate concentrations at SCB responded similarly to storms except that the concentrations in base flows were higher. Nitrite plus nitrate concentrations remained consistently low at WSB (generally less than

1 mg/L) over a range in discharge of from 0.01 to 100 $ft^3/s$. Apparently, the organic material in the combined sewer overflows had not completely decomposed, and even peak concentrations resulting from flushing action during storms seldom exceeded 5 mg/L. Table 13 presents observed concentrations of total nitrite plus nitrate at the five primary sites for base flows and storm flows.

Table 13.–Summary of observed concentrations of total nitrite plus nitrate, in milligrams per liter as N

| Site | Base flows | | Storm flows | |
|---|---|---|---|---|
| | Range | Mean | Range | Mean |
| SCN | 1.1 –12 | 3.6 | 1.6 –15 | 6.8 |
| NBN | .52–12 | 4.0 | 3.1–10 | 4.3 |
| WSB | | | .02– 5.3 | .5 |
| SCAB | .06–11 | 2.7 | ---- | --- |
| SCB | .07–15 | 5.9 | 3.7 –11 | 6.0 |

There are no general criteria for nitrite plus nitrate concentrations in Illinois streams; however, because of the possibility of methemoglobinemia in infants, IPCB Standards (1976, sec. 204b) require that for public drinking water supplies nitrate not exceed 10 mg/L, and nitrite not exceed 1 mg/L.

## Ammonia Nitrogen

Ammonia often is an indication of the decomposition of organic material and because even small concentrations can be toxic to aquatic life, it is of considerable interest in water-quality studies.

At SCN and NBN observed concentrations of ammonia nitrogen were generally less than 1 mg/L during base-flow periods and seldom exceeded 4.5 mg/L during the initial flush resulting from storm runoff. In contrast, concentration levels at WSB began around 20 mg/L, and then progressively declined as stormwater diluted the combined sewer overflows.

Concentrations of ammonia nitrogen at SCAB were similar to sites farther upstream, although base-flow concentrations were slightly higher. Concentrations during storms showed the effects of the combined sewer overflows from West Slough half a mile upstream. Concentrations of ammonia nitrogen at SCB were highly variable, depending upon the loadings in the treatment plant effluent and the flow available in the creek for dilution. Concentrations at SCB ranged from 2 to 20 mg/L in base flows to around 2 mg/L during the latter stages of storms.

Maximum ammonia nitrogen concentrations occurred in the fall and minimums in the spring. The seasonal variation was more pronounced at SCB than at SCAB. Seasonal variation at both SCAB and SCB was superimposed upon a trend of gradually increasing ammonia nitrogen concentrations noted since 1973 (fig. 9). The annual mean concentration of ammonia nitrogen during this period increased from 0.65 to 1.3 mg/L at SCAB and from 1.85 to 4.6 mg/L at SCB. This increase was more pronounced at SCB than at SCAB and was concurrent with an increase in biochemical oxygen demand and a decrease in dissolved oxygen values at these sites.

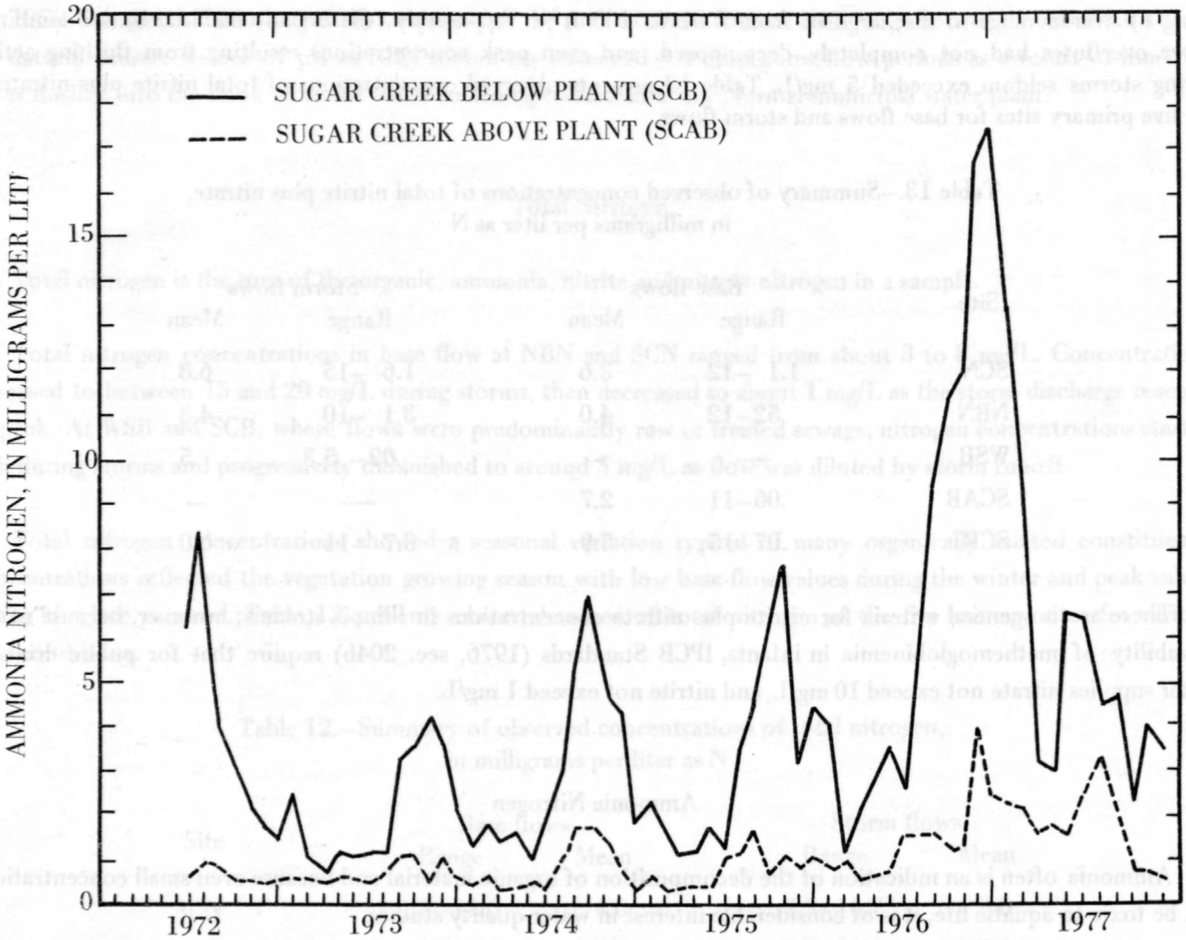


Figure 9.–Monthly mean values of ammonia nitrogen at SCB and SCAB.

Table 14 presents observed values of ammonia nitrogen at the five primary sites.

Table 14.–Summary of observed concentrations of ammonia nitrogen, in milligrams per liter

| Site | Base flows Range | Base flows Mean | Storm flows Range | Storm flows Mean | Thaw (Feb. 1977) Range | Thaw (Feb. 1977) Mean |
|---|---|---|---|---|---|---|
| SCN | 0.08– 3.8 | 0.47 | 0.50– 4.5 | 1.8 | 0.30– 9.4 | 3.6 |
| NBN | .03– 1.8 | .60 | .50–11 | 2.4 | 4.6 –26 | 12.5 |
| WSB | ----- | ---- | 1.0 –16 | 6.7 | 9.2 –21 | 15.8 |
| SCAB | .38– 6.6 | 2.3 | 1.7 – 6.7 | 4.2 | .93–33 | 9.9 |
| SCB | 1.2 –21 | 7.4 | 1.9 – 7.8 | 3.5 | 14 –62 | 23.0 |

Because of the toxic effects which ammonia nitrogen may have on certain species of fish, IPCB Standards (1976, sec. 203f) require that ammonia nitrogen levels do not exceed 1.5 mg/L, or that the addition of any effluent raise ambient levels above this limit (1976, sec. 404f). Concentrations of ammonia nitrogen at both SCAB and SCB were consistently above the maximum levels defined in the State's water-quality criteria.

## Phosphorus

Phosphorus, an essential ingredient in aquatic life metabolism, may get into surface waters from leaching of fertilizers, decomposition of plant and animal remains, sewage, or industrial effluents.

The concentration-discharge relationships for total phosphorus at the five primary sites were similar to those shown by ammonia nitrogen. At NBN and SCN total phosphorus concentrations seldom exceeded 0.6 mg/L although a brief increase in concentrations was observed during the first flush resulting from stormwater runoff at these sites.

In contrast, concentrations at SCB were as high as 8 mg/L during base-flow periods but decreased during storms to around 1 mg/L. A peak concentration value of 18.2 mg/L was observed in February 1977 when a sedimentation basin at the sanitary treatment plant was flushed during a thaw that followed 6 weeks of sub-zero temperatures. At WSB total phosphorus concentrations in the combined sewer overflows reached about 4 mg/L before dilution from stormwater runoff occurred.

There was a slight increase in total phosphorus concentrations 1.4 miles below the plant during base-flow periods. This site was near the low point on the dissolved oxygen sag curve created by the discharge of the treatment plant effluent into Sugar Creek. The low levels of dissolved oxygen in this reach of the stream probably encouraged phosphorus in bottom sediments to re-enter the water (Kothandaraman and others, 1977, p. 199). Total phosphorus concentrations at sites 3.5 and 4.6 miles downstream were progressively smaller as phosphorus was slowly utilized by aquatic life, reincorporated into bottom sediments, or diluted by additional inflows.

There was a three to five-fold increase in total phosphorus concentrations between SCAB and SCB apparently due to the addition of treatment plant effluent. Both sites showed strong seasonal variations in total phosphorus concentrations at base flows, with lowest seasonal concentrations occurring during the spring and the highest during the late fall. Base-flow concentrations were lower at SCN and NBN than at SCAB or SCB but followed the same seasonal variation pattern.

Average monthly phosphorus concentrations at SCAB and SCB showed a declining trend from 1973 to 1976 (fig. 10). The trend may reflect a reduction in fertilizer use in the basin, as well as a reduction of phosphate compounds in household detergents. The exceptionally high values of phosphorus shown in figure 10 for SCB during the summer and fall of 1976 were due to operating problems with the sewage treatment plant during this period.

Water-quality criteria for phosphorus in Illinois waters were established to minimize eutrophication in ponded water and are not applicable to Sugar Creek in the study area. IPCB Standards (1976, sec. 203c) require that phosphorus concentrations not exceed 0.05 mg/L on a stream at the point where it enters a lake or reservoir. Table 15 presents observed phosphorus concentrations at the five primary sites for various flow conditions.

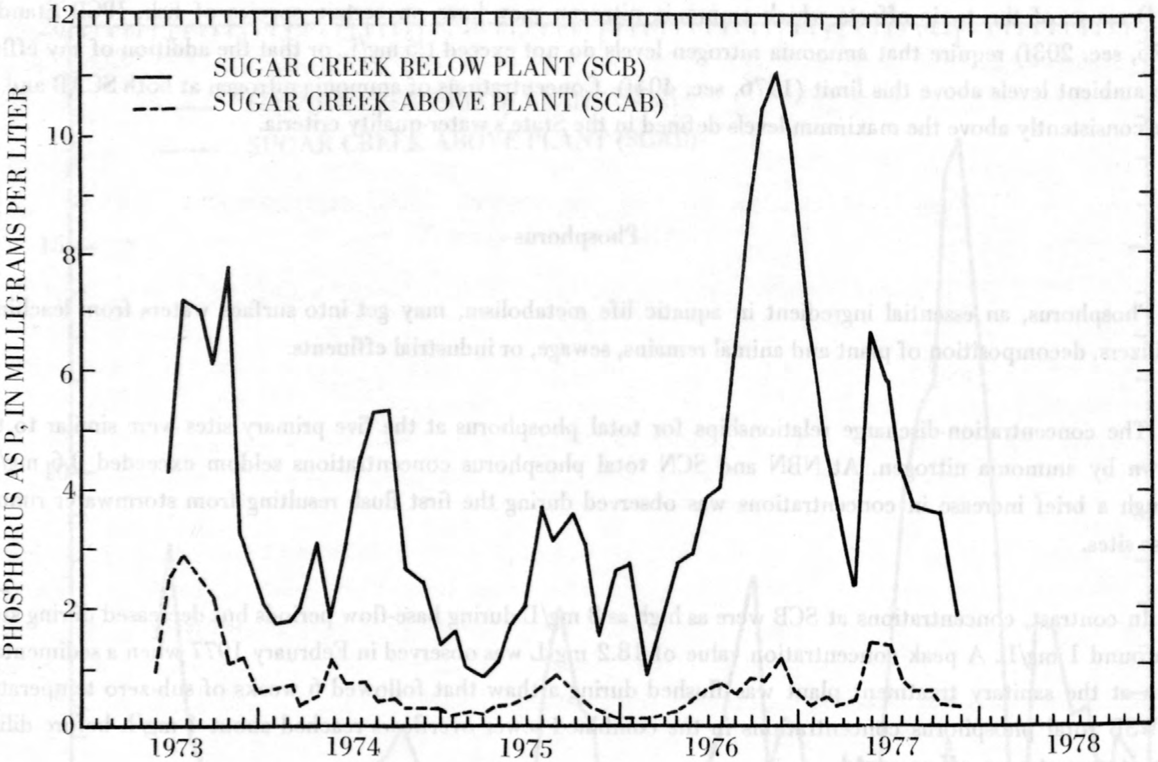


Figure 10.—Monthly mean values of total phosphorus at SCB and SCAB.

Table 15.—Summary of observed concentrations of total phosphorus, in milligrams per liter as P

| Site | Base flows | | Storm flows | | Thaw (Feb. 1977) | |
|---|---|---|---|---|---|---|
| | Range | Mean | Range | Mean | Range | Mean |
| SCN | 0.04–1.4 | 0.25 | 0.07– 1.5 | 0.29 | 0.14– 2.6 | 1.1 |
| NBN | .05– .91 | .25 | .13– 4.2 | .56 | .21– .82 | .52 |
| WSB | ------ | --- | .73–13 | 4.0 | 3.5 – 8.4 | 6.8 |
| SCAB | .13–3.2 | .90 | 1.4 – 2.2 | 1.8 | .13– 5.2 | 2.2 |
| SCB | 2.9 –7.6 | 4.7 | .72– 8.5 | 3.3 | 5.1 –18 | 8.2 |

## Dissolved Oxygen

Dissolved oxygen is important in assessing water-quality conditions because oxygen is required for basic metabolism by most aquatic life.

Concentration of dissolved oxygen (DO) varied seasonally because of differences in solubility of gaseous oxygen at various temperatures and because of aquatic chemical and biological processes. Biological action can either increase or decrease the oxygen concentration in water through photosynthesis, respiration, or decomposition. Temperature variation was the dominant factor in controlling levels of dissolved oxygen in Sugar Creek where maximum values of DO were observed during the winter and minimum values during the late summer.

The relationships between dissolved oxygen concentrations and discharge at the primary sites were poorly defined, especially at base flows. At higher discharges, when the flow was mainly from storm-water runoff, the relationships were better, and DO concentrations of 8 to 9 mg/L were typical.

Long-term records at SCB showed that annual mean DO concentrations declined from 1950 until 1956, when filters at the treatment plant were improved. After 1956 the annual DO values increased slightly until 1959, when the downward trend resumed and continued through 1966. At that time activated sludge treatment facilities were added. DO values increased sharply after 1966, and then held fairly constant through 1973, when a new declining trend began. DO concentrations at SCAB have followed the same general trend as SCB since 1971 but average 0.5 mg/L higher (fig. 11).

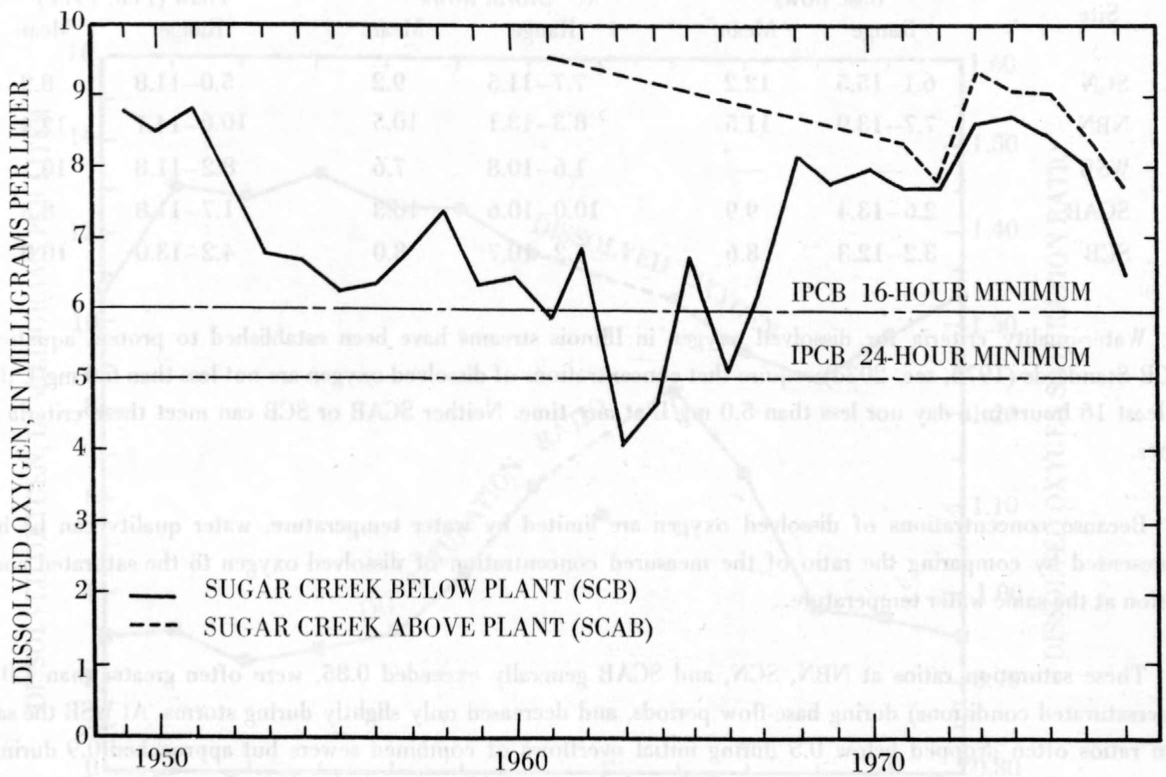


Figure 11.—Annual mean values of dissolved oxygen at SCB and SCAB.

The monthly mean and annual mean DO concentrations at sites 1.4, 3.5 and 4.6 miles below the treatment plant showed similar declines since 1973. The site 1.4 miles downstream appeared to be near the low point of the dissolved oxygen sag curve.

Diurnal variations in DO concentrations were pronounced, especially during the summer. Samples collected at 0700 hours (7 a.m.) often showed concentrations of DO at SCAB to be less than at SCB, although samples collected in the early afternoon showed the opposite. At SCAB diurnal variation in DO concentrations exceeded 6 mg/L on occasion. Diurnal variations under base-flow conditions were less at SCB due to the high proportion of treatment plant effluent in the total flow. Samples collected over a period of 24 hours at SCAB and SCB in June 1977 (see fig. 15) indicated that mid-morning values approximated the daily mean values. Most base-flow samples at SCN and NBN were collected during the morning hours and should approximate daily mean values. Concentrations of DO at SCB, even though measured in the early afternoon, should also approximate daily mean values because of the stabilizing effect of the treatment plant effluent. Mean values for base-flow samples collected at SCAB may be slightly higher than true mean values because of the early afternoon sampling time.

Table 16 presents dissolved oxygen concentrations at the five primary sites for different flow conditions.

Table 16.—Summary of observed concentrations of dissolved oxygen, in milligrams per liter

| Site | Base flows | | Storm flows | | Thaw (Feb. 1977) | |
|---|---|---|---|---|---|---|
| | Range | Mean | Range | Mean | Range | Mean |
| SCN | 6.1–15.5 | 12.2 | 7.7–11.5 | 9.2 | 5.0–11.8 | 8.9 |
| NBN | 7.7–13.9 | 11.5 | 8.3–13.1 | 10.5 | 10.6–14.1 | 12.4 |
| WSB | ------ | ---- | 1.6–10.8 | 7.6 | 8.2–11.8 | 10.1 |
| SCAB | 2.6–13.4 | 9.9 | 10.0–10.6 | 10.3 | 1.7–11.8 | 8.3 |
| SCB | 3.2–12.3 | 8.6 | 5.2–10.7 | 8.0 | 4.2–13.0 | 10.0 |

Water-quality criteria for dissolved oxygen in Illinois streams have been established to protect aquatic life. IPCB Standards (1976, sec. 203d) require that concentrations of dissolved oxygen are not less than 6.0 mg/L during at least 16 hours in a day nor less than 5.0 mg/L at any time. Neither SCAB or SCB can meet these criteria at all times.

Because concentrations of dissolved oxygen are limited by water temperature, water quality can be better represented by comparing the ratio of the measured concentration of dissolved oxygen to the saturated concentration at the same water temperature.

These saturation ratios at NBN, SCN, and SCAB generally exceeded 0.85, were often greater than 1.0 (i.e., supersaturated conditions) during base-flow periods, and decreased only slightly during storms. At WSB the saturation ratios often dropped below 0.5 during initial overflows of combined sewers but approached 0.9 during the latter part of storms. Saturation ratios at SCB varied over a wide range during base flows, depending upon the quality of the treatment plant effluent; however, during storm flows ratios were near 0.9. Table 17 presents observed DO saturation conditions at the five primary sites.

Oxygen saturation ratios varied seasonally, with maximum values occurring at NBN, SCN, and SCAB during the summer. No seasonal variation was observed at SCB. Saturation ratios greater than 1.0 represent the effect of biologically induced oxygen inputs. The annual saturation ratio cycle was out of phase with the dissolved oxygen concentration cycle, which was more influenced by seasonal temperatures (fig. 12).

Table 17.—Ratios of observed dissolved oxygen to saturated dissolved oxygen

| Site | Base flows | | Storm flows | | Thaw (Feb. 1977) | |
|---|---|---|---|---|---|---|
| | Range | Mean | Range | Mean | Range | Mean |
| SCN | 0.78–1.58 | 1.12 | 0.85–1.20 | 0.97 | 0.39–0.89 | 0.68 |
| NBN | .89–1.34 | 1.03 | .84–1.29 | .98 | .79–1.05 | .93 |
| WSB | ------ | ---- | .38–1.06 | .81 | .72–1.01 | .84 |
| SCAB | .30–1.52 | .91 | 1.03–1.04 | 1.04 | .13–.93 | .65 |
| SCB | .37–1.09 | .76 | .65–1.14 | .89 | .38–1.18 | .86 |

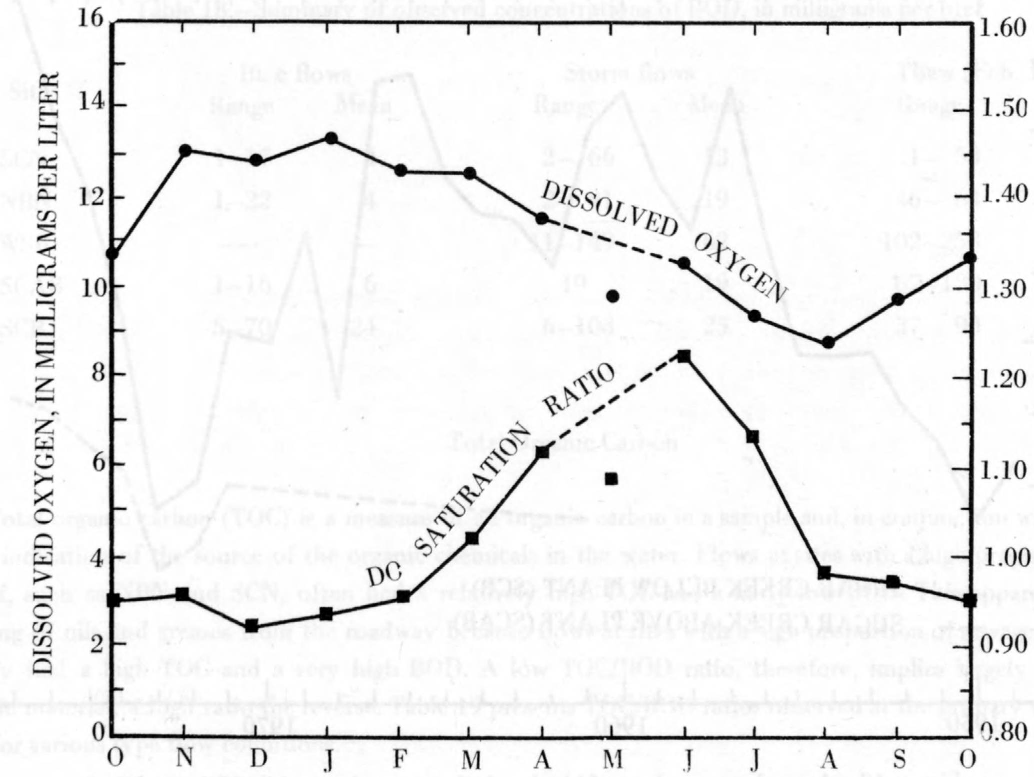


Figure 12.—Mean monthly values of dissolved oxygen and dissolved oxygen saturation ratios at NBN.

## Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) can be defined as the oxygen required by biological action to meet the demands generated by the decomposition of organic solids under aerobic conditions for a standard time and temperature (Babbitt and Baumann, 1958, p. 345). BOD values may not always reflect the total oxygen demand; nevertheless, it is a practical tool for evaluating potential sewage treatment because it reflects that part of the total organic load that can be removed through simple biological treatment.

At NBN, SCN, and SCAB low values of BOD occurred in the spring and high values during the early fall, whereas at SCB the high values usually occurred in early winter. This slight time lag at SCB probably reflected the reduced effectiveness in the biological processing at the treatment plant, as the composition of flora and fauna changed at the onset of cold weather.

Annual mean BOD values have been increasing since 1973 at both SCB and SCAB in a long-term trend similar to those exhibited by dissolved oxygen and ammonia nitrogen (fig. 13). The adjustments to the treatment plant filters in 1956, which produced an increase in dissolved oxygen concentrations, apparently also increased the BOD levels in the stream, and it was not until after the plant enlargement in 1966 that BOD levels showed any significant reduction. (See figures 11 and 13.)

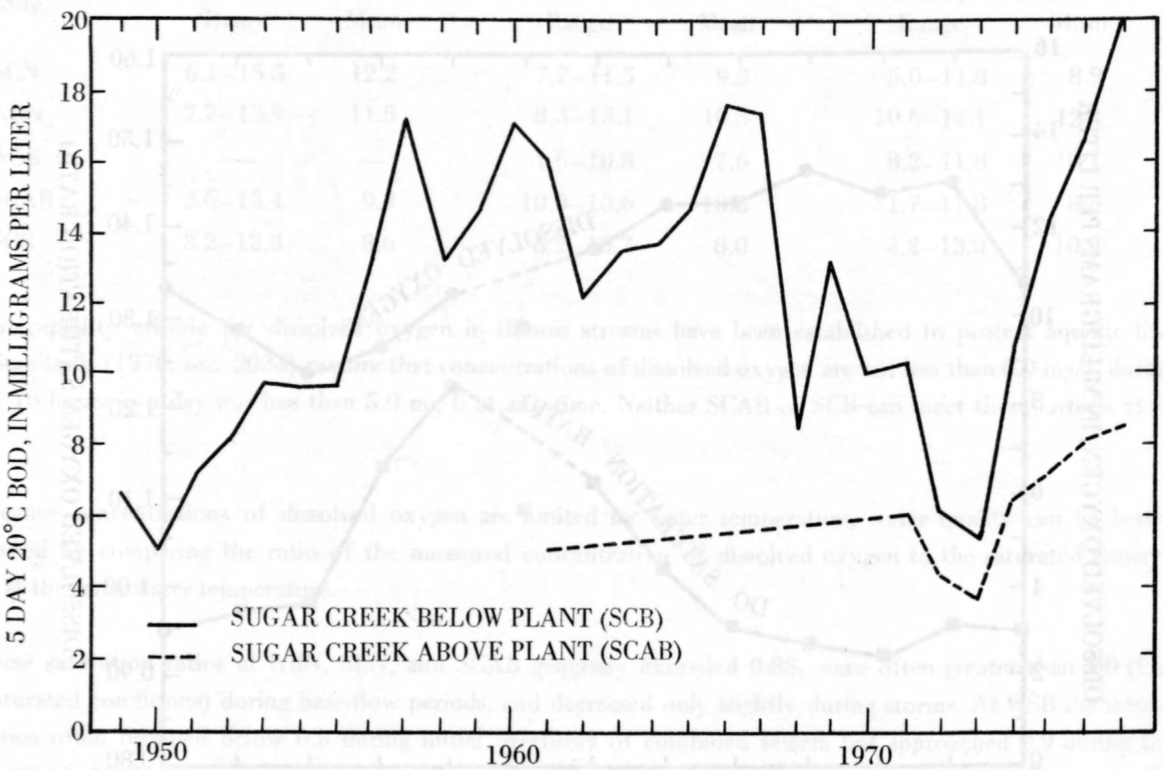


Figure 13.—Annual mean values of biochemical oxygen demand at SCB and SCAB.

At SCN, NBN, and SCAB, BOD concentrations were generally less than 10 mg/L for all discharges except during the initial flushing from storm runoff or during spring thaws. The relationships between BOD concentration and discharge for different storms were similar, with the maximum concentration of the first flush determined by antecedent conditions and rainfall intensity.

At SCB, BOD concentrations in base flows were highly variable because of the influence of the treatment plant effluent. BOD values generally ranged from 10 to 30 mg/L, although on occasion they exceeded 60 mg/L. Concentrations diminished to around 10 mg/L during peak flows associated with storm runoff. BOD concentrations at WSB were higher than at SCB, but they also diminished at higher flows, similar to the trend in concentrations of ammonia nitrogen.

Limits are placed upon BOD concentrations in effluents discharged into Illinois streams to help preserve and maintain desired levels of aquatic life. The IEPA operating permit for the Bloomington-Normal sewage treatment plant currently places as a limit a 30-day BOD average of 25 mg/L for the activated sludge effluent and 35 mg/L for the trickling filter effluent. Table 18 presents observed values of BOD for samples obtained at the five primary sites during this study.

Table 18.—Summary of observed concentrations of BOD, in milligrams per liter

| Site | Base flows | | Storm flows | | Thaw (Feb. 1977) | |
|---|---|---|---|---|---|---|
| | Range | Mean | Range | Mean | Range | Mean |
| SCN | 1–17 | 4 | 2– 66 | 13 | 1– 50 | 18 |
| NBN | 1–22 | 4 | 2– 91 | 19 | 46– 64 | 54 |
| WSB | ----- | --- | 11–149 | 62 | 102–253 | 180 |
| SCAB | 1–16 | 6 | 19 | 19 | 67–130 | 57 |
| SCB | 5–70 | 24 | 6–103 | 25 | 37– 90 | 55 |

## Total Organic Carbon

Total organic carbon (TOC) is a measure of all organic carbon in a sample and, in conjunction with BOD, gives some indication of the source of the organic chemicals in the water. Flows at sites with a high proportion of street runoff, such as NBN and SCN, often had a relatively high TOC and a fairly low BOD. This apparently indicates flushing of oils and greases from the roadway because flows at sites with a high proportion of sewage, such as WSB, usually had a high TOC and a very high BOD. A low TOC/BOD ratio, therefore, implies largely biodegradable organic material, a high ratio the reverse. Table 19 presents TOC/BOD ratios observed at the primary data collection sites for various type flow conditions.

Table 19.—Summary of observed TOC/BOD ratios

| Site | Base flows | | Storm flows | | Thaw (Feb. 1977) | |
|---|---|---|---|---|---|---|
| | Range | Mean | Range | Mean | Range | Mean |
| SCN | 0.16–42 | 5.71 | 0.35–31 | 6.06 | 1.3 –3.6 | 2.13 |
| NBN | .09–13 | 3.38 | .69–26 | 4.00 | 1.1 –2.1 | 1.65 |
| WSB | ----- | ---- | .21– 3.4 | 1.39 | .51– .87 | .74 |
| SCAB | .65– 2.8 | 1.60 | ----- | ---- | .52–7.0 | 1.77 |
| SCB | .26– 4.5 | 1.38 | .39–16 | 2.22 | .43–1.7 | 1.11 |

TOC concentrations showed a looped concentration to discharge relationship during storms. Different storms had similar relationships, but maximum values were influenced by antecedent conditions and precipitation intensity. Base-flow TOC concentrations were high at SCB, apparently because of the treatment plant effluent which enters upstream from the site. Table 20 presents observed TOC concentrations at the five primary sites for different flow conditions.

Table 20.—Summary of observed concentrations of TOC, in milligrams per liter

| Site | Base flows | | Storm flows | | Thaw (Feb. 1977) | |
|---|---|---|---|---|---|---|
| | Range | Mean | Range | Mean | Range | Mean |
| SCN | 2.3–46 | 9.7 | 4.4–220 | 31 | 4– 70 | 24 |
| NBN | 1.9–13 | 7.3 | 4.8–130 | 36 | 62–120 | 102 |
| WSB | ------ | ---- | 9.0–330 | 65 | 72–170 | 126 |
| SCAB | 3.5–14 | 8.5 | ------ | --- | 7–110 | 48 |
| SCB | 3.9–51 | 22 | 9.5– 81 | 35 | 22–170 | 63 |

## Fecal Bacteria

Large numbers of fecal coliform and fecal streptococcal bacteria indicate that animal or human wastes are entering a stream. In general, fecal streptococcal bacteria were more numerous in Sugar Creek than fecal coliform except where sewage overflows occurred; however, both fecal coliform and fecal streptococcal concentrations were highly variable under all flow conditions. Concentrations during storms increased sharply at all sites during the first flushing, then were diluted at higher flows. Highest concentrations of bacteria occurred at WSB and SCB where sewage overflowed.

At NBN and SCN seasonal variations in base-flow bacteria concentrations of several orders of magnitude occurred, with the highest values appearing during the winter and lowest during the summer. Bacteria concentrations in base flows at SCB were generally lower than those at SCAB due to the toxic effects of residual chlorine in the treatment plant effluent.

Tables 21 and 22 present bacteria concentrations at the five primary sites for both base-flow and storm-flow periods.

Because fecal coliform bacteria are used as an indicator of potential health hazards, IPCB Standards (1976, sec. 405) currently limit fecal coliform concentrations in effluents to less than 400 per 100 ml. Secondary and indigenous aquatic life standards limit 30-day fecal coliform geometric means to 1,000 per 100 ml, with no more than 10 percent of the samples exceeding 2,000 per 100 ml (1976, sec. 205d).

Ratios of fecal coliform to fecal streptococcal bacteria of less than 0.7 generally indicate an animal source for the bacteria, while ratios greater than 4.0 indicate a human source, such as sewage or septic tank drainage (Kittrell, 1969, p. 98). Ratios at NBN and SCN were usually less than 0.7 and only rarely exceeded 3.0. Values at SCAB were

Table 21.–Summary of observed fecal streptococcal concentrations, in number of colonies per 100 milliliters

| Site | Base flows Range | Base flows Geometric mean | Storm flows Range | Storm flows Geometric mean |
|---|---|---|---|---|
| SCN | 8.0– 7,200 | 460 | 1,300– 330,000 | 25,000 |
| NBN | 1.0– 20,000 | 300 | 630– 950,000 | 27,000 |
| WSB | ------- | ----- | 67,000–2,500,000 | 340,000 |
| SCAB | 23 – 37,000 | 1,700 | | |
| SCB | 2.0–140,000 | 660* | 320– 620,000 | 24,000* |

* Flow includes chlorinated plant effluent.

Table 22.–Summary of observed fecal coliform concentrations, in number of colonies per 100 milliliters

| Site | Base flows Range | Base flows Geometric mean | Storm flows Range | Storm flows Geometric mean |
|---|---|---|---|---|
| SCN | 1.0– 13,000 | 260 | 1,500– 90,000 | 7,800 |
| NBN | 1.0– 22,000 | 92 | 150– 35,000 | 3,900 |
| WSB | ------ | ---- | 150,000–5,700,000 | 600,000 |
| SCAB | 300 –180,000 | 4,100 | ------- | ----- |
| SCB | 10 –270,000 | 440* | 230– 710,000 | 44,000* |

* Flow includes chlorinated plant effluent.

erratic during base-flow periods, ranging from 0.10 to more than 10. This suggests some intermittent sources of human waste contamination above the site. At the combined sewer overflow site at WSB, values generally exceeded 0.7. Table 23 presents fecal coliform/fecal streptococcal ratios at the five primary sites for base flows and storm flows.

Table 23.–Summary of observed fecal coliform/fecal streptococcal ratios

| Site | Base flows Range | Base flows Mean | Storm flows Range | Storm flows Mean |
|---|---|---|---|---|
| SCN | 0.01– 4.5 | 0.99 | 0.02– 2.3 | 0.58 |
| NBN | .01– 4.4 | .64 | .01– 1.6 | .25 |
| WSB | ------ | ---- | .46– 8.8 | 2.8 |
| SCAB | .10–13.3 | 3.8 | ---- | ---- |
| SCB | .02–15 | 2.1* | .25–28 | 3.1 |

*Flow includes chlorinated plant effluent.

## Insecticides, Herbicides, and Industrial Compounds

Analyses for 13 organochlorine insecticides and industrial compounds were made on four samples collected at SCB. Chlordane, DDT, and Dieldrin were detected in the water and Chlordane, DDD, DDE, DDT, Dieldrin, Heptachlor epoxide, polychlorinated biphenyls (PCB's), and polychlorinated napthalenes (PCN's) were detected in the bottom sediments. Chlordane, Dieldrin, and Heptachlor epoxide were detected consistently in all the samples of bottom material. Aldrin, Endrin, Heptachlor, Lindane, and Toxaphene were analyzed for but not detected in any samples. (See table 24.)

Table 24.—Observed concentrations of organochlorine insecticides and industrial compounds at SCB

| Date | Total PCB (μg/L) | PCB in bottom material (μg/kg) | Total PCN (μg/L) | PCN in bottom material (μg/L) | Total Chlordane (μg/L) | Chlordane in bottom material (μg/kg) | Total DDD (μg/L) | DDD in bottom material (μg/kg) |
|---|---|---|---|---|---|---|---|---|
| Dec. 18, 1974 | 0.0 | ---- | 0.0 | ---- | 0.3 | ---- | 0.00 | ---- |
| Mar. 19, 1975 | .0 | 0 | .0 | 0 | .2 | 190 | .00 | 5.1 |
| Dec. 30, 1975 | .0 | 190 | .0 | 0 | .1 | 74 | .00 | 8.9 |
| July 30, 1976 | .0 | 0 | .0 | 190 | .4 | 0 | .00 | .00 |

| Date | Total DDE (μg/L) | DDE in bottom material (μg/kg) | Total DDT (μg/L) | DDT in bottom material (μg/kg) | Total Dieldrin (μg/L) | Dieldrin in bottom material (μg/kg) | Total Heptachlor Epoxide (μg/L) | Heptachlor Epoxide in bottom material (μg/kg) |
|---|---|---|---|---|---|---|---|---|
| Dec. 18, 1974 | 0.00 | ---- | 0.00 | ---- | 0.01 | ---- | 0.00 | ---- |
| Mar. 19, 1975 | .00 | 0.0 | .01 | 4.5 | .01 | 19 | .00 | 5.0 |
| Dec. 30, 1975 | .00 | 7.8 | .00 | .0 | .00 | 36 | .00 | 11 |
| July 30, 1976 | .00 | .0 | .00 | .0 | .00 | 5.4 | .00 | 1.5 |

Samples collected in March and December 1975 at SCB were analyzed for three chorophenoxy acid herbicides: 2,4-dichlorophenoxyacetic acid (2,4-D); 2,4,5-trichlorophenoxyacetic acid (2,4,5-T); and 2-(2,4,5-trichlorophenoxy) propionic acid (Silvex), but none were detected.

Three samples from SCB were analyzed for seven phosphorothioate insecticides: Diazinon, Ethion, Malathion, Parathion, Methyl parathion, Trithion, and Methyl trithion. Only Diazinon was detected (table 25).

In July 1976 surface water samples from NBN, SCN, SCAB, and SCB were examined for 13 organochlorine compounds to ascertain whether the source of these chemicals was above or below the treatment plant outfall. In addition bottom sediment samples were also collected from the creek both above and below the plant outfall. In the water analyses only Chlordane and DDE at SCAB and SCB, and Dieldrin at SCN and NBN were detected.

Table 25.—Observed concentrations of Diazinon at SCB

| Date | Total Diazinon (µg/L) | Diazinon in bottom material (µg/kg) |
|---|---|---|
| Dec. 18, 1974 | 0.30 | ---- |
| Mar. 19, 1975 | .10 | 0.0 |
| Dec. 30, 1975 | .02 | .0 |

In the bottom sediments the amount of Dieldrin and Heptachlor epoxide was about the same above and below the plant outfall. PCB and PCN concentrations were inconsistent; PCB's were detected at SCAB and not at SCB while PCN's were detected at SCB and not at SCAB. The occurrence of Dieldrin in the surface water as far upstream as NBN and SCN and in the sediments both above and below the plant indicated a source other than the treatment plant effluent for this chemical. The inconsistent concentrations of PCB's and PCN's in the bottom sediments were not helpful in defining their source.

## Dissolved Metals

Analyses for 26 dissolved metals were made on filtered water samples collected at SCB in December 1974 and March 1975. Additional analyses for 10 of these metals were made on samples collected in December 1975, June, September, and December 1976 (table 26).

Concentrations of these metals were less than the Illinois Pollution Control Board Water Quality Standards (1976, sec. 203f) for all except two samples: one in December 1974 for copper and lead and the other in June 1976 for mercury.

In September and December 1976, samples were collected both above and below the treatment plant outfall to determine the effects of plant effluent on the metal concentrations in the creek (table 27). The addition of treatment plant effluent to Sugar Creek apparently decreased the concentration of manganese and increased the concentrations of nickel, iron, zinc, lead, cadmium, and chromium. Arsenic, copper, and mercury concentrations were unchanged. With the exception of chromium, manganese, and nickel, all the differences noted were small and additional samples would be required to confirm the apparent differences.

Changes in the concentrations of metals in the sediments were different from changes in concentrations of the dissolved metals. Cadmium, chromium, iron, lead, and nickel concentrations were all less in sediments below the plant than above. Manganese and mercury levels were higher while arsenic, copper, and zinc remained about the same.

An average of 0.32 mg/L of boron was observed at SCB compared with an average value for Illinois streams of about 0.07 mg/L (Nienkerk and Flemal, 1976, p. 16). The observed concentrations at SCB suggest sources such as detergents or laundry aids and are thus indicative of sewage wastes.

Table 26.—Average concentrations of dissolved metals at SCB

[Results in micrograms per liter; <, less than; >, greater than]

| | Aluminum | Arsenic | Barium | Beryllium | Bismuth |
|---|---|---|---|---|---|
| Mean | 65 | 1 | 32 | < 2 | < 6 |
| IPCB* | ----- | < 1,000 | < 5,000 | ---- | |
| | **Boron** | **Cadmium** | **Chromium** | **Cobalt** | **Copper** |
| Mean | 320 | 4 | 150 | < 6 | 16 |
| IPCB* | < 1,000 | < 50 | < 1,000 | ----- | < 20 |
| | **Gallium** | **Germanium** | **Iron** | **Lead** | **Lithium** |
| Mean | < 2 | < 8 | 140 | 60 | 15 |
| IPCB* | ----- | ----- | < 1,000 | < 100 | ----- |
| | **Manganese** | **Mercury** | **Molybdenum** | **Nickel** | **Silver** |
| Mean | 65 | < 0.5 | 8 | 140 | < 1 |
| IPCB* | < 1,000 | < 0.5 | ----- | < 1,000 | < 5 |
| | **Strontium** | **Tin** | **Titanium** | **Vanadium** | **Zinc** |
| Mean | 165 | < 7 | < 5 | < 6 | 155 |
| IPCB* | ----- | ----- | ----- | ----- | < 1,000 |
| | **Zirconium** | | | | |
| Mean | < 10 | | | | |
| IPCB* | | | | | |

* Illinois Pollution Control Board Standard, 1976

Table 27.–Concentrations of 10 common metals at SCAB and SCB

| Metal | Concentration in surface waters, in micrograms per liter* | | Concentration in bottom sediments, in micrograms per gram** | |
|---|---|---|---|---|
| | SCAB | SCB | SCAB | SCB |
| Arsenic | 1 | 1 | 8 | 5 |
| Cadmium | 1 | 2 | 10 | 0 |
| Chromium | 10 | 235 | 130 | 20 |
| Copper | 10 | 10 | 20 | 20 |
| Iron | 80 | 90 | 9,600 | 5,700 |
| Lead | 1 | 2 | 170 | 50 |
| Manganese | 285 | 60 | 200 | 370 |
| Mercury | .5 | .5 | .10 | .50 |
| Nickel | 60 | 170 | 60 | 20 |
| Zinc | 35 | 50 | 100 | 100 |

* Average of samples collected on Sept. 23, 1976, and Dec. 14, 1976.
** Samples collected on Dec. 14, 1976.

## SPECIAL STUDIES

### Basinwide Reconnaissance

Eight sites in addition to the five basic data sites were sampled in September 1976 and March 1977. Samples taken progressively downstream along the main stem of Sugar Creek had a general trend toward increased concentrations of ammonia nitrogen, phosphorus, suspended solids, conductivity (dissolved solids), and lower values of pH (fig. 14).

### Diurnal Study

Samples were collected at SCB and SCAB every 2 hours for 26 hours during a base-flow period on June 16-17, 1977, to ascertain the dirunal variation in water-quality parameters.

The more pronounced variations were in temperature and dissolved oxygen (fig. 15). The range in temperatures at SCB (21.0°-22.0°C) was considerably less than at SCAB (21.5°-27.0°C). Dissolved oxygen concentrations at SCB ranged from 3.2 to 6.0 mg/L, whereas at SCAB they ranged from 2.6 to 8.3 mg/L with means of 5.4 and 5.2 mg/L, respectively. Although both sites had essentially the same mean dissolved oxygen concentrations, the saturation ratios ranged from 0.30 to 1.05 at SCAB and from 0.37 to 0.70 at SCB.

Dissolved solids concentrations and pH showed no discernable trends at either site. BOD, ammonia nitrogen, and suspended solids remained essentially constant at SCAB but slowly decreased at SCB after some operational problems at the treatment plant were corrected during the morning of June 16.

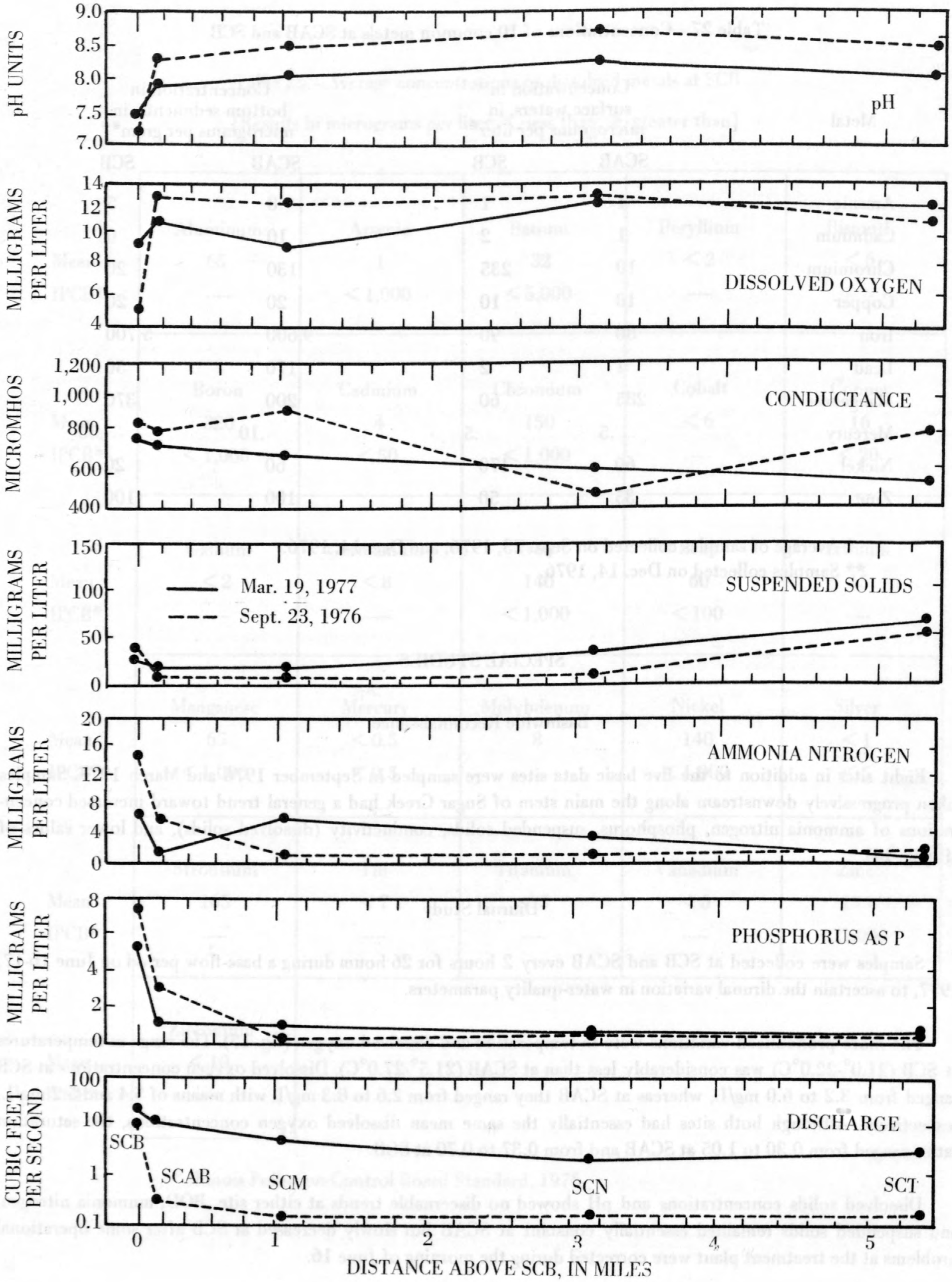


Figure 14.—Water quality versus distance above SCB.

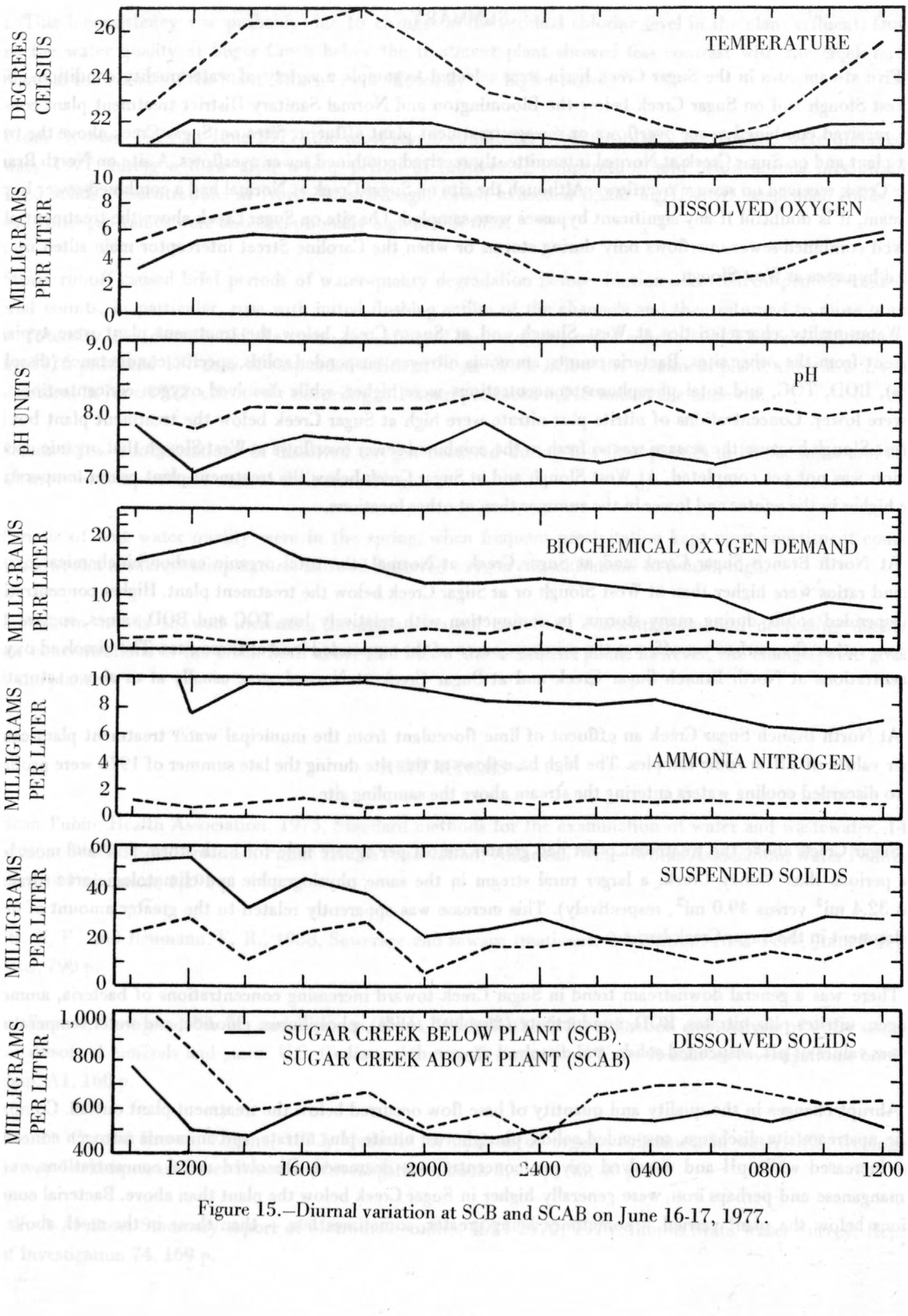


Figure 15.—Diurnal variation at SCB and SCAB on June 16-17, 1977.

## SUMMARY

Five stream sites in the Sugar Creek basin were selected to sample a variety of water-quality conditions. Sites on West Slough and on Sugar Creek below the Bloomington and Normal Sanitary District treatment plant consistently received combined sewer overflows or sewage treatment plant effluent. Sites on Sugar Creek above the treatment plant and on Sugar Creek at Normal intermittently received combined sewer overflows. A site on North Branch Sugar Creek received no sewage overflows. Although the site on Sugar Creek at Normal had a combined-sewer bypass upstream, it is doubtful if any significant bypasses were sampled. The site on Sugar Creek above the treatment plant received combined-sewer overflows only during storms or when the Caroline Street interceptor main silted up and caused bypasses at West Slough.

Water-quality characteristics at West Slough and at Sugar Creek below the treatment plant were typically different from the other sites. Bacteria counts, ammonia nitrogen, suspended solids, specific conductance (dissolved solids), BOD, TOC, and total phosphorus concentrations were higher, while dissolved oxygen concentrations and pH were lower. Concentrations of nitrite plus nitrate were high at Sugar Creek below the treatment plant but low at West Slough because the sewage was so fresh in the combined sewer overflows at West Slough that organic decomposition was not yet completed. At West Slough and at Sugar Creek below the treatment plant, water temperatures were higher in the winter and lower in the summer than at other locations.

At North Branch Sugar Creek and at Sugar Creek at Normal, the total organic carbon/biochemical oxygen demand ratios were higher than at West Slough or at Sugar Creek below the treatment plant. Higher concentrations of suspended solids during many storms, in conjunction with relatively low TOC and BOD values, suggest that erosion, rather than urban runoff, was the primary source of the suspended load at these sites. The dissolved oxygen concentrations at North Branch Sugar Creek and at Sugar Creek at Normal were usually at or above saturation.

At North Branch Sugar Creek an effluent of lime flocculant from the municipal water treatment plant caused higher values of pH in some samples. The high base flows at this site during the late summer of 1976 were probably due to discarded cooling waters entering the stream above the sampling site.

Sugar Creek above the treatment plant had greater runoff per square mile for both storm-flow and most base-flow periods than Money Creek, a larger rural stream in the same physiographic and climatologic area (drainage areas 32.4 $mi^2$ versus 49.0 $mi^2$, respectively). This increase was apparently related to the greater amount of urban development in the Sugar Creek basin.

There was a general downstream trend in Sugar Creek toward increasing concentrations of bacteria, ammonia nitrogen, nitrites plus nitrates, BOD, conductivity (dissolved solids), phosphorus, chloride, and water temperatures, whereas values of pH, suspended solids, and dissolved oxygen decreased.

Abrupt changes in the quality and quantity of base flow occurred below the treatment plant outfall. Compared to the upstream site discharge, suspended solids, phosphorus, nitrite plus nitrate, and ammonia nitrogen concentrations increased while pH and dissolved oxygen concentrations decreased. Dissolved metal concentrations, except for manganese and perhaps iron, were generally higher in Sugar Creek below the plant than above. Bacterial concentrations below the plant varried – sometimes being greater, sometimes less – than those in the creek above the plant. This inconsistency was probably due to changes in the residual chlorine level in the plant effluent. During storms the water quality at Sugar Creek below the treatment plant showed less contrast with the creek farther upstream, as the effects of the plant effluent were diluted by the higher flows.

From October 1974 to June 1977, the most severe conditions of water-quality degradation were observed in February 1977 during a thaw after a long period of subfreezing temperatures and below-normal precipitation. Dissolved solids concentrations at North Branch Sugar Creek exceeded 3,200 mg/L. BOD, suspended solids, and ammonia nitrogen values were also exceptionally high at this time.

Storm runoff caused brief periods of water-quality degradation before dilution occurred. Suspended solids and bacterial counts, in particular, rose with initial flushing action of the channels and then returned to more normal values. Intensity and duration of the storm also affected the total suspended solids load. A 1.4-inch, 12-hour rain in May 1976 produced 177 tons of suspended solids at Sugar Creek below the treatment plant, whereas a 2.4-inch thunderstorm in June 1975, effectively occurring in 1 hour, produced 5,240 tons at the same site.

Seasonal low concentrations of dissolved oxygen occurred during low-flow periods in late summer and early fall, when water temperatures were at their annual highs.

Periods of best water quality were in the spring, when frequent precipitation kept most constituent concentrations low, and moderate temperatures allowed dissolved oxygen concentrations to remain high.

Long-term trends showed increasing ammonia nitrogen and BOD concentrations and decreasing dissolved oxygen concentrations in the creek both above and below the treatment plant; however, the changes were greater below the plant.

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