DISSOLVED-OXYGEN REGIME

OF THE JORDAN RIVER,

SALT LAKE COUNTY, UTAH

By Doyle W. Stephens

U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS

For readers who prefer to use metric units, conversion factors for units used in this report are listed below:

Multiply inch-pound units	By	To obtain metric units
acre-foot (acre-ft)	0.001233	cubic hectometer
	1233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
foot per mile (ft/mi)	0.1894	meter per kilometer
inch (in.)	25.40	millimeter (mm)
gallon per day (gal/d)	3.785	liter per day
mile (mi)	1.609	kilometer (km)
pound (lb)	0.4536	kilogram (kg)
square mile (mi^2)	2.59	square kilometer

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$^{o}F = 1.8(^{o}C) + 32$$

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

GLOSSARY

BOD_5.--Five-day biochemical-oxygen demand. The quantity of dissolved oxygen required to degrade the carbonaceous-organic matter in a sample at 20°C during a 5-day period.

BOD_u.--Ultimate biochemical-oxygen demand. The total quantity of dissolved oxygen required to degrade the carbonaceous-organic matter in a sample at 20°C.

COD.--Chemical-oxygen demand. The total quantity of dissolved oxygen required to oxidize the chemical and biological material in a sample. The procedure involves refluxing the sample with a strong acid-dichromate solution.

C_v.--Coefficient of variation. The standard deviation of a set of numbers expressed as a percentage of the mean.

DOC.--Dissolved organic carbon. The quantity of organic carbon passing through a 0.45 micrometer silver filter. Determined by combustion to carbon dioxide with quantification by infrared spectrometry.

K_2.--Reaeration coefficient, calculated to log e.

R^2--Coefficient of determination. This is calculated as the square of the correlation coefficient and when multiplied by 100 represents the percent variation of the dependent variable which is explained by the regression equation. It is a "best-fit" test for the population scatter about a curve.

SOC.--Suspended organic carbon. The quantity of organic carbon filtered from a sample by a 0.45 micrometer silver filter. Determined as for dissolved organic carbon.

Water year.--The 12 months beginning on October 1 and ending on September 30 of the year designated.

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ABSTRACT

Concentrations of dissolved oxygen in the Jordan River in Salt Lake County decrease considerably as the river flows northward. Mean concentrations of dissolved oxygen decreased from 8.1 milligrams per liter at the Jordan Narrows to 4.7 milligrams per liter at 500 North Street during April 1981 to September 1982. Coincident with the decrease, the biochemical-oxygen demand increased from 5 to 7 milligrams per liter. About 50 percent of the dissolved-oxygen concentrations and 90 percent of the 5-day biochemical-oxygen demand measured downstream from 1700 South Street exceeded the State intended-use standards. An estimated 6. million pounds of oxygen-demanding substances as measured by 5-day biochemical-oxygen demand were discharged to the Jordan River during 1981 from point sources downstream from 9000 South Street. Seven wastewater-treatment plants contributed 77 percent of this load, nonstorm base flows contributed 22 percent, and storm flows less than 1 percent. The Surplus Canal diversion at 2100 South Street removed about 70 percent of this load, and travel time of about 1 day also decreased the actual effects of the load on the river. Reaeration rates during September and October were quite high (average K_2 at 20° Celsius was about 12 per day) between the Jordan Narrows and 9000 South Street, but they decreased to 2.4 per day in the reach from 1330 South to 1800 North Streets.

INTRODUCTION

The study of the Jordan River in Salt Lake County, Utah, was began to evaluate four water-quality problems, and to discuss each problem in a separate report. The four problems and the reports that have been completed are: dissolved oxygen (this report), toxic substances, turbidity (Weigel, 1984), and sanitary quality (Thompson, 1983). Dissolved-oxygen depletion in the Jordan River was identified as a major problem by two-thirds of the Federal, State, and local agencies responding to a request from the U.S. Geological Survey (July 1980) for comments about the study. Depletion of dissolved-oxygen concentrations to less than 5 to 6 milligrams per liter adversely affects fishery populations, benthic organisms, and the natural oxidation of organic substances within the water. Concentrations of oxygen-demanding substances in the Jordan River as it enters Salt Lake County typically are quite small, and the operation of diversion structures at the Jordan Narrows (fig. 1) provides considerable turbulence of flow which aerates the water to near saturation with respect to dissolved oxygen. As the river flows north through the valley, it receives secondary-treated effluent from eight wastewater-treatment plants, runoff from numerous storm drains, and considerable discharge from nonpoint sources. This effluent and runoff typically contain large quantities of oxygen-demanding substances. Compounding the effects of the effluent and runoff is the decrease in natural reaeration rates north of about 4200 South Street due to decreased channel slope and decreased turbulence.

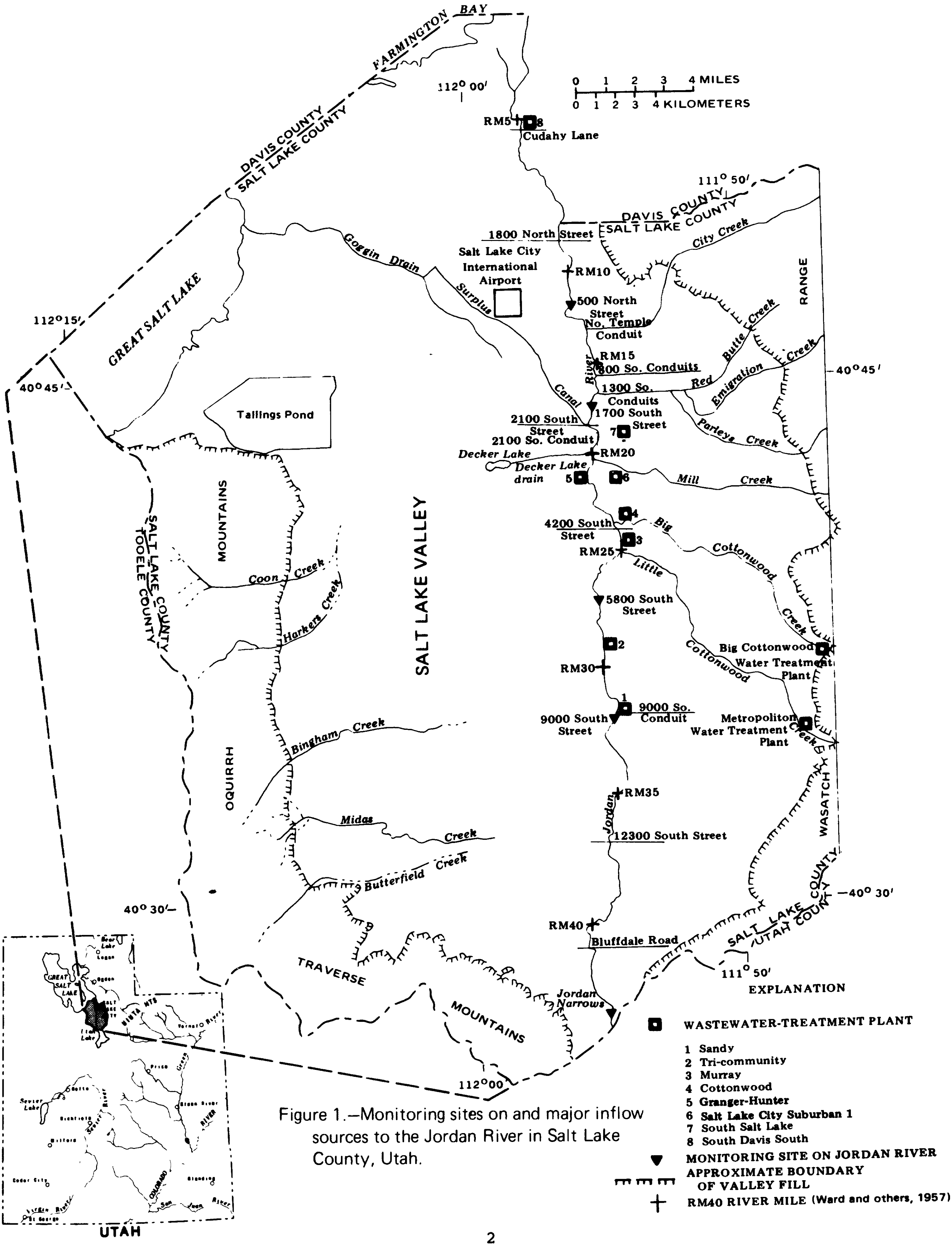

Figure 1.–Monitoring sites on and major inflow sources to the Jordan River in Salt Lake County, Utah.

The intent of the study of dissolved oxygen and of this report is to provide sufficient data and interpretation to understand the dissolved-oxygen regime of the Jordan River. Due to difficulties in measuring or estimating the impact of nonpoint sources, these sources are considered in this report only indirectly by their net effect on the river's oxygen balance.

The study accomplished the following goals: (1) Historical data were tabulated and compared to current data to determine trends; (2) reaeration rates and time-of-travel were determined for the Jordan River from 12300 South to 1800 North Streets; (3) algal productivity and its impact in the downstream part of the river (north of 5800 South Street) was calculated; (4) loads of oxygen-demanding substances from storm runoff and wastewater-treatment plants were determined.

Because dissolved-oxygen depletion is most severe north of 9000 South Street, data collection was concentrated in the reach between 9000 South and 500 North Streets. Data collection began in December 1980 and continued through August 1982, but storm-runoff data were collected only through 1981.

The Jordan River was flowing at relatively high stages throughout most of the study. The total annual discharge at 2100 South Street was 428,000 acre-feet during water year 1981 (see Glossary) and 506,600 acre-feet during water year 1982 compared to an average annual discharge of 362,440 acre-feet, with a standard deviation of 76,179 acre-feet, for water years 1971-80. High river stages usually are associated with significant water turbulence that result in increased rates of reaeration. This indicates that the results of the study may not represent average river conditions.

Physical Setting

The Jordan River originates as outflow from Utah Lake, and it flows north approximately 55 miles before it is diverted into marshlands south of Farmington Bay which is part of Great Salt Lake (fig. 1). Great Salt Lake serves as the terminal receiving body for the Jordan Hydrologic Accounting Unit, a drainage area of 3,825 square miles within the Great Basin Region (U.S. Geological Survey, 1974). Two-thirds of the river miles are within Salt Lake County, the area of this study. All river miles referenced in this report are taken from the map in Ward and others (1957), with the initial reference being the Great Salt Lake at an altitude of 4,202.9 feet.

The Jordan River enters Salt Lake County at the Jordan Narrows, a gap in the Traverse Mountains, 10 miles downstream from Utah Lake (fig. 1). The flow into the river at the lake is controlled by gates or by pumps. The altitude of the river channel decreases from 4,470 feet at the Jordan Narrows to about 4,200 feet at Great Salt Lake. The mean gradient of the Jordan River through Salt Lake County is 6 feet per mile; although the gradient from the Jordan Narrows to 4200 South Street is 11 feet per mile, and from 4200 South Street to Great Salt Lake it is only 1.9 feet per mile.

Salt Lake Valley, through which the river flows, includes a densely-populated urban area. The valley is bordered by mountains on three sides. The Wasatch Range to the east rises to more than 11,000 feet, the Oquirrh Mountains on the west rise to more than 9,000 feet, and the Traverse Mountains on the south rise to more than 6,000 feet. The population of Salt Lake County in July 1981 was estimated to be 641,000 (Marvin Levy, Utah State Health Department, Bureau of Statistical Services, oral commun., 1982), which is 42 percent of the total population of Utah. The Jordan River is the primary drain for most of the urban area; and it receives inflows from various sources, including seven municipal wastewater-treatment plants in Salt Lake County (fig. 1) and one municipal wastewater-treatment plant in Davis County to the north.

The seven major tributaries to the Jordan River in the study area originate in the Wasatch Range. Little Cottonwood Creek flows into the Jordan River at about 4900 South Street (river mile 25.3), Big Cottonwood Creek enters at about 4200 South Street (river mile 24), and Mill Creek enters at 3000 South Street (river mile 20.2). Parleys, Emigration, and Red Butte Creeks are diverted to a storm conduit, which discharges into the Jordan River near 1300 South Street. City Creek is diverted to a storm conduit, which discharges into the Jordan River at North Temple Street. Streams on the west side of the valley are intercepted by canals or in most years they cease flowing before reaching the Jordan River.

During the irrigation season, large quantities of water are diverted from the river at or near the Jordan Narrows into seven large canals. Several canals east of the Jordan River terminate in smaller canals and interchange water with some of the tributaries from the Wasatch Range. Return flows from the canals west of the Jordan River typically reach the Jordan River less directly through nonpoint runoff. The only major diversion north of 9000 South Street is at 2100 South Street where the Surplus Canal, a flood-control structure, is used to divert excess water directly to Great Salt Lake.

Ground-water inflow to the Jordan River averages about 170,000 acre-feet per year (Hely and others, 1971, p. 135). A study by Ward and others (1957, p. 4) during a period of low flow in November 1957 found an average gain of 7.6 cubic feet per second per river mile for the reach from the Jordan Narrows to 6400 South Street (river mile 28.5), an average gain of 6.7 cubic feet per second per river mile from 6400 South to 3300 South Streets (river mile 21.5), and no gain north of 3300 South Street. Summary data reported by Hydroscience, Inc. (1976c, p. 23) indicate a mean gain of 3 cubic feet per second per river mile from 9400 South (river mile 32.6) to 5800 South Streets and 6.3 cubic feet per second per river mile from 5800 South to 2100 South Streets during July through September 1966-68.

The study area ranges from semiarid in parts of Salt Lake Valley to humid in parts of the Wasatch Range. Precipitation during 1981 at the Salt Lake City International Airport was 16.59 inches (National Oceanic and Atmospheric Administration, 1981, p. 4). This was 0.69 inch greater than the 93-year mean of 15.9 inches reported for Salt Lake City by Hely and others (1971, p. 16). Precipitation in the lower parts of the Salt Lake Valley is generally slight and infrequent during the warmer part of the year, so most agriculture is dependent on irrigation.

State Antidegradation Standards for Dissolved Oxygen

The State of Utah has antidegradation standards for all surface waters (Utah Department of Social Services, 1978). The Jordan River from the Jordan Narrows to its confluence with Little Cottonwood Creek is designated as class 3-A, which is use as a cold-water fishery, with a minimum dissolved-oxygen concentration of 6 milligrams per liter. From the Little Cottonwood Creek confluence to North Temple Street, the river is designated as class 3-B, which is use as a warm-water fishery, with a minimum dissolved-oxygen concentration of 5.5 milligrams per liter. Between North Temple Street and the Great Salt Lake, the river is designated as class 2-B, which is use for recreation and esthetics, with a minimum dissolved-oxygen concentration of 5.5 milligrams per liter. The three classes also limit biochemical-oxygen demand (BOD; see Glossary) to 5 milligrams per liter.

Previous Studies

Prior to the early 1970s, dissolved-oxygen measurements were made using the Winkler titration method, which was tedious and subject to interfering substances in the water and analyst error. Under these conditions, few dissolved-oxygen measurements were routinely done. The introduction and popularization of galvanic and polarographic probes in the 1970s allowed dissolved oxygen to be measured easily and greatly increased its use as a water-quality indicator. A water-quality survey done in 1957 and 1958 by Gaufin (1958, p. 5-8) included many dissolved-oxygen measurements at 17 sites on the Jordan River. Values ranged from 0 to 15.3 milligrams per liter (145 percent of saturation) and led the author to conclude that north of 4800 South Street (river mile 25.2), the river was so polluted that the fish population was limited to carp. Concentrations of dissolved oxygen north of 3300 South Street were less than the minimum concentration required to maintain a warm-water fishery during the autumn and winter.

Coburn (1972, p. 26) calculated a mass discharge of BOD for the Jordan River at 2100 South Street of 7,043 pounds per day. This was balanced against a mass discharge of dissolved oxygen of 6,288 pounds per day, giving a dissolved-oxygen deficit of 755 pounds per day. Coburn noted that the deficit was largely eliminated in the 13-mile reach north of 2100 South Street owing to the inflow of oxgenated water from runoff, reaeration, and photosynthesis.

An intensive study during July and August 1972 by the U.S. Environmental Protection Agency (1972) found that the average dissolved oxygen in the Jordan River south of 3300 South Street (river mile 21.5) equaled or exceeded the State minimum standards of 5.5 milligrams per liter for a warm-water fishery and 6 milligrams per liter for a cold-water fishery. North of 2100 South Street, the dissolved oxygen failed to meet fishery standards. Diel measurements of dissolved oxygen indicated significant photosynthetic activity in the water just south of the Jordan Narrows but little activity at Cudahy Lane near Farmington Bay.

Results of a 1-day intensive survey of water quality of the Jordan River were reported by Hydroscience, Inc. (1976a, p. 11-13). Dissolved-oxygen concentrations in the afternoon ranged from 13.7 milligrams per liter (170 percent of saturation) at Bluffdale Road (river mile 40.5) to 4.5 milligrams per liter at Cudahy Lane. Five-day biochemical-oxygen demand (BOD_5; see Glossary) ranged from 8.3 milligrams per liter at North Temple Street (river mile 13.2) to 1.5 milligrams per liter at Bluffdale Road (river mile 40.5). A benthic-oxygen demand of 1.3 grams per square meter was measured at Cudahy Lane. Hydroscience, Inc. (1976c, p. 3) concluded that more than 50 percent of the BOD_5 in the Jordan River north of 2100 South Street was due to discharges from the wastewater-treatment plants.

Application of a numerical model to the dissolved-oxygen regime of the Jordan River (Hydroscience, Inc., 1976b, p. 10) indicated that nonpoint sources were responsible for about 1 milligram per liter of oxygen demand. At typical summer temperatures, only 0.7 milligram per liter of oxygen then would be available to satisfy the point-source demands without decreasing the dissolved oxygen in the river to less than the minimum standard of 6 milligrams per liter. The model projected minimum dissolved-oxygen concentrations of 5 to 5.6 milligrams per liter in the river if advanced secondary treatment of wastewater were used. Without advanced treatment, the dissolved-oxygen concentration would be about 4.1 milligrams per liter for wastewater flows of 48.6 million gallons per day (1975 level) and only 2.6 milligrams per liter for wastewater flows of 77.9 million gallons per day (estimated 1995 level).

In an analysis of the fishery potential of the Jordan River, Way (1977, p. 80) concluded that a minimum of 5.5 milligrams per liter of dissolved oxygen should be provided to maintain a warm-water fishery, and a minimum of 6 milligrams per liter would ensure that all species investigated would be protected. A comparison of data collected from 1976-79 with data from 1979-81 (Gunnell and others, 1982, p. 6, 62) indicated that small concentrations of dissolved oxygen were a problem in the Jordan River from North Temple Street to the Jordan Narrows, with no significant changes in overall dissolved-oxygen concentrations noted between the two data sets.

FACTORS AFFECTING THE DISSOLVED-OXYGEN BALANCE

The concentration of dissolved oxygen in surface water is one of the most important factors affecting the chemical and biological systems in the water. Desirable game-fish communities require fairly large concentrations of dissolved oxygen (minimum of 6 milligrams per liter), and these communities quickly disappear as dissolved-oxygen concentrations decrease. In the absence of any oxygen-demanding substances or photosynthetic-oxygen production, the concentration of dissolved oxygen should be near saturation and be affected only by temperature, atmospheric pressure, and other dissolved substances in the water. As biodegradable-organic matter is added to water, dissolved oxygen is removed by the natural microbial degradation of the organic material. Large organic-waste loads result in large microbial populations, which exhaust the dissolved-oxygen supply in the water faster than it is replaced by diffusion from the atmosphere through the process of reaeration. Aquatic-plant growth, such as periphyton and phytoplankton, also affect the dissolved-oxygen balance in surface water through photosynthesis and respiration. If sufficient dissolved nutrients (primarily nitrogen and phosphorus) are present, considerable plant growth may result in dissolved-oxygen supersaturation of the water during daylight, due to photosynthesis, and severe dissolved-oxygen depletion at night, due to plant respiration.

The diel curve of dissolved oxygen is the outcome of all processes affecting the dissolved-oxygen balance in water, and it is commonly used to estimate the lowest level of aquatic productivity. The dissolved-oxygen balance in water is, therefore, a complex set of interacting variables which may be represented by equation 1:

$$DO = P - R \pm D \pm A \qquad (1)$$

where

- DO is total dissolved oxygen;
- P is photosynthetic-oxygen production;
- R is respiration;
- D is diffusion (reaeration); and
- A is accrual of oxygenated or deoxygenated water.

Determination of the dissolved-oxygen regime in a river involves measuring or estimating the variables in equation 1. A measurement of dissolved oxygen in the water provides an overview or net result of the interaction of all the variables and may be plotted against time to indicate changes in the overall "health" of water. Separating the individual effects of each component in the equation is somewhat difficult. Photosynthesis and respiration may be estimated using measurements of the diel-curve productivity. Reaeration may be estimated with many different and somewhat conflicting equations or measured indirectly using a tracer gas. Accrual of oxygenated or deoxygenated surface water may be measured quite easily, but dissolved-oxygen accrual or dilution due to influent ground water is difficult to measure. Respiration or dissolved-oxygen depletion due to organic loading generally is estimated through measurements of BOD. A related but broader measure of dissolved-oxygen demand is obtained through the test for chemical-oxygen demand (COD; see Glossary), a more vigorous method that measures BOD but also includes dissolved-oxygen demands of substances not measured by BOD.

A principal component of the organic material responsible for BOD loads is organic carbon. As such, it indicates the potential for dissolved-oxygen demands and is a gross indicator of the organic compounds in the water. All the measurements of dissolved-oxygen-demanding substances, such as BOD, COD, and organic carbon, are only indicators of possible but not certain pollution because the biological systems responsible for the degradation also are affected by temperature and toxic substances.

DATA COLLECTION

Five sites on the Jordan River were selected for monitoring continuous flow and water quality during 1980-82 (fig. 1). Two of the sites, 1700 South Street (U.S. Geological Survey station 10171000) and 5800 South Street (10167300) have had water-quality-monitoring stations since 1974, although continuous discharge is available at 5800 South only since 1980. The flow at 500 North Street (10172550) has been monitored since 1975, the flow at 9000 South Street (10167230) since December 1979, and the flow at Jordan Narrows (10161001) has been monitored since 1937.

Water samples were collected monthly from December 1980 through August 1982 at the water-quality stations. Additional samples were collected from the Jordan River, inflowing streams, and conduits during storms as part of the Salt Lake County urban-runoff project (Christensen and others, 1984). Water samples were chilled upon collection, filtered when necessary, and stabilized within 5 hours of collection. Storm samples collected during 1981 were composited using a discharge-weighted method (Christensen and others, 1984). All samples were analyzed using methods given by Skougstad and others (1979).

The hydrologic data used in compiling this report are reported by Pyper and others (1981) and McCormack and others (1983), and storm loads and the interpretive analysis of urban runoff are reported by Christensen and others (1984). Some historical and current data for the Jordan River at 1700 South and 5800 South Streets are reported by the U.S. Geological Survey (1982, and earlier volumes of the same series).

The concentration of dissolved oxygen was measured at the sampling site using a Yellow Springs Instrument (YSI) model 57 dissolved-oxygen meter[1], which was air calibrated using a YSI model 5075 calibration chamber, a barometer, and oxygen-solubility values from Weiss (1970, p. 728-732). Chemical-oxygen demand (COD) was determined by methods given in Skougstad and others (1979). Biochemical-oxygen demand (BOD) was determined for 5 and 20 days using methods given in Skougstad and others (1979). Nitrapyrin was used to inhibit nitrification in all samples, therefore, all BOD values determined by this study represent only carbonaceous BOD. A computer program (Jennings and Bauer, 1976) based on a linear least-squares procedure was used to calculate the process-rate constant for BOD, the 5-day BOD demand (BOD_5), and the ultimate (BOD_u; see Glossary) demand.

Nitrification is the removal of dissolved oxygen from water by bacteria, which oxidize reduced nitrogen forms such as ammonia to oxidized forms such as nitrate. In shallow, swift-flowing reaches of a river receiving ammonia or organic-nitrogenous matter, a considerable population of nitrifying bacteria may occur as a slime on rocky substrates and create a considerable oxygen demand. In some streams, the nitrogenous-oxygen demand may exceed the carbonaceous-oxygen demand (Hines and others, 1977, p. I36). The impact of nitrification in the Jordan River was not investigated because the reach of the Jordan River most impacted by nitrogen loading is characterized by slow-moving water and a silt bottom, conditions that do not favor establishment of large populations of nitrifying bacteria.

Several diel (24-hour) oxygen studies were conducted to calculate the photosynthetic-oxygen production at several sites in the river. Data from these studies were analyzed with a modified Odum approach using a computer program developed by Stephens and Jennings (1976).

Measurements of instream-reaeration rates were made using the modified tracer-gas method of Rathbun (1979). This procedure involves the addition of ethylene or propane to flowing river water with subsequent measurement of the downstream rate of dissolved-gas desorption. There is a well-defined relationship between desorption of the tracer gas and absorption of oxygen by the water which allows the reaeration rate to be calculated (Rathbun and others, 1978, p. 221-226). Data reduction and statistical testing were performed using SAS software (Barr and others, 1979).

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[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.

DISSOLVED-OXYGEN REGIME OF THE JORDAN RIVER

Concentrations of Dissolved Oxygen and Oxygen Demands

April through September is the critical period for dissolved-oxygen concentrations in the Jordan River because temperatures are higher, loads of oxygen-demanding substances are greater, and flow in the river is smaller. Comparison of data collected during August of 1981 and 1982 with similar historical data (fig. 2) illustrates the net decrease in dissolved-oxygen concentrations downstream from river mile 25 (4800 South Street). Dissolved-oxygen concentrations from the 1975 study reported by Hydroscience, Inc. (1976a, p. 11) for river miles 40.5 and 37 were not included because they were unusually large (near 170 percent of saturation) and streamflow was very low (estimated at 20 cubic feet per second), indicating pond-like conditions. Variation of dissolved oxygen during the period of record at the Jordan Narrows is small compared to variation at a downstream site such as 500 North Street. The few quantity of data available indicates a net decrease in dissolved-oxygen concentrations from 1957 and 1975 to 1981 and 1982. The downward trend in the mean dissolved-oxygen concentrations at 5800 South and 1700 South Streets between 1974 and 1982 is shown in figures 3 and 4.

Concentrations of dissolved oxygen may not represent the significance of dissolved oxygen in an aquatic environment quite as well as the percent saturation of dissolved oxygen during the same time period (figs. 5 and 6). Barometric pressures were not recorded for all the 1974 and 1975 data, thus limiting the most useful data to a single point for 1974 and a very small data set of saturation values for 1975. With this limitation, the net decrease in the percent saturation of dissolved oxygen is evident through 1980 at 5800 South and 1700 South Streets. However, an increase in mean percent saturation of about 8 percent has occurred since 1980.

The dissolved-oxygen concentrations for October through March indicate a slightly different trend (figs. 7 and 8). Mean dissolved-oxygen concentrations at both sites had a net decrease from 1974 through 1977 and a net increase from 1977 through 1981. The same pattern was observed for percent saturation of dissolved oxygen from 1974 through 1981.

The mean-daily discharge in the Jordan River at 1700 South Street increased between 1978 and 1982 (figs. 9 and 10). The relationship between discharge and dissolved-oxygen concentration was examined by correlation analysis. Data for the Jordan Narrows were not used due to a lack of variation in dissolved oxygen. A correlation of 0.40 (95-percent-confidence level) was calculated for the data collected during 1981 and 1982. Although it is a weak correlation, it indicates that an increase of discharge does result in an increase of the dissolved-oxygen concentration. The increased discharge most likely acts to dilute oxygen-demanding loads or to increase turbulence and thereby increase reaeration rates.

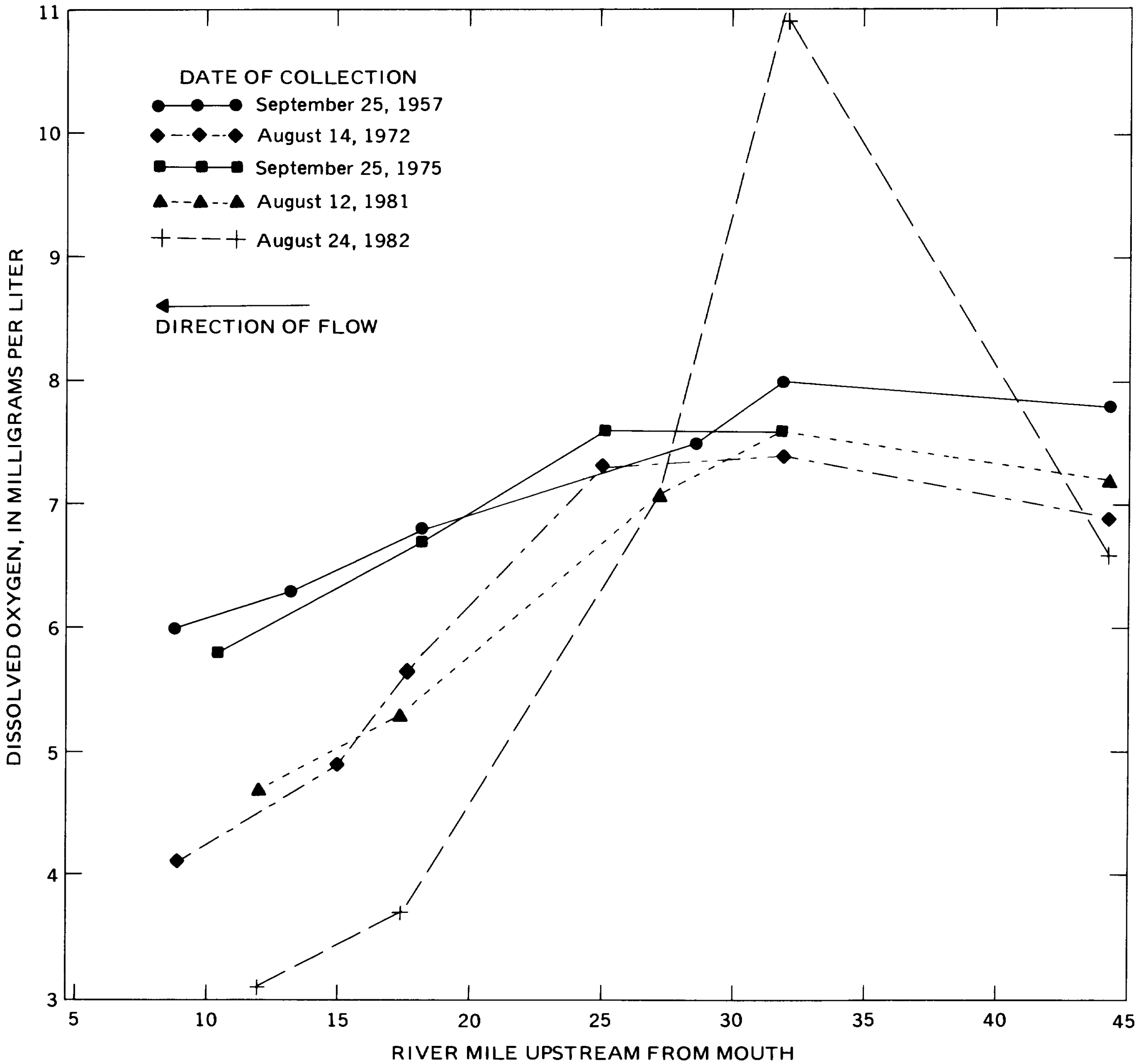

Figure 2.—Variation in dissolved-oxygen concentrations with river mile in the Jordan River during low-flow conditions from 1957 to 1982.

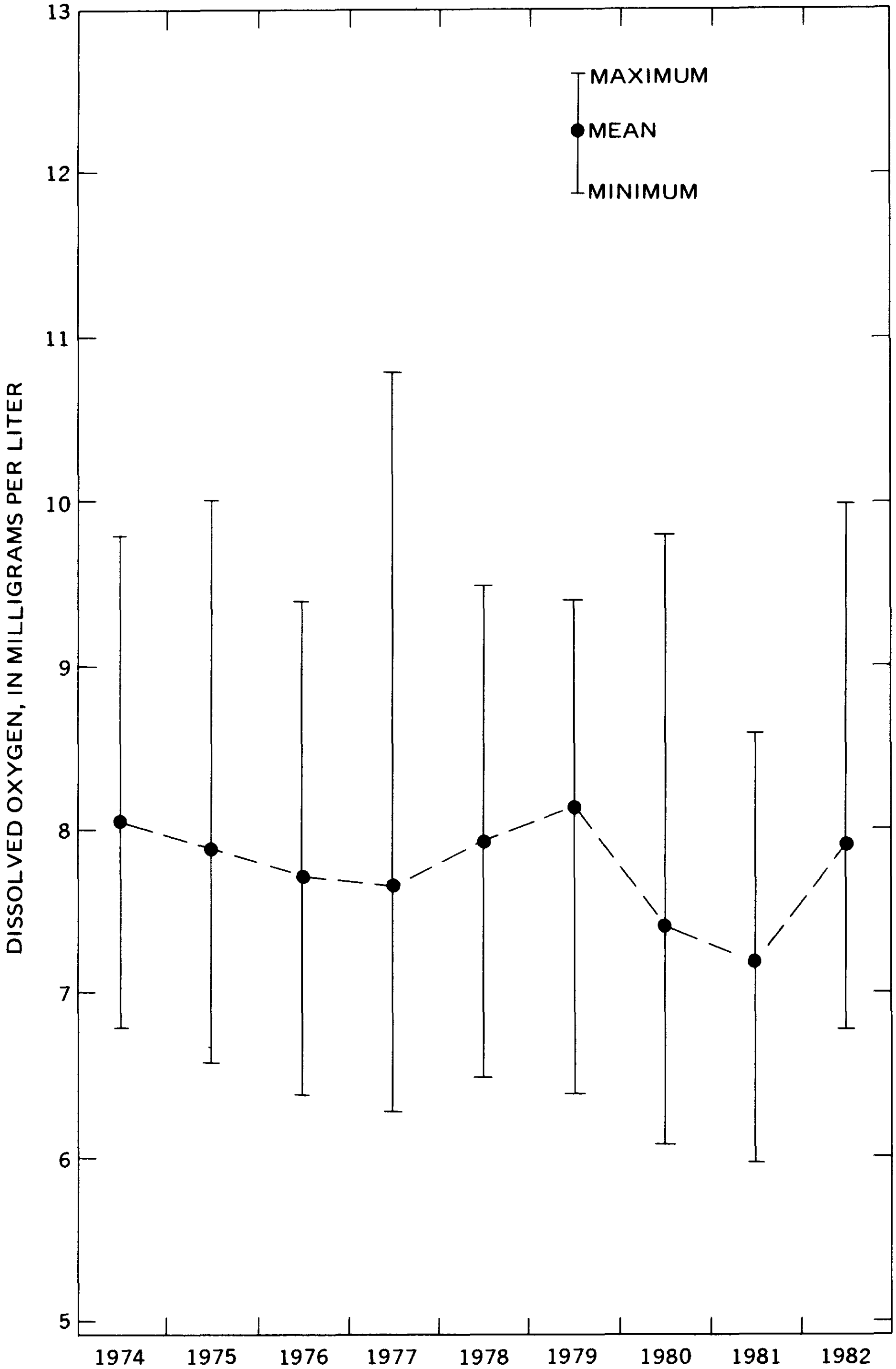

Figure 3.—Variation in dissolved-oxygen concentration during daytime, April-September 1974-82, in the Jordan River at 5800 South Street.

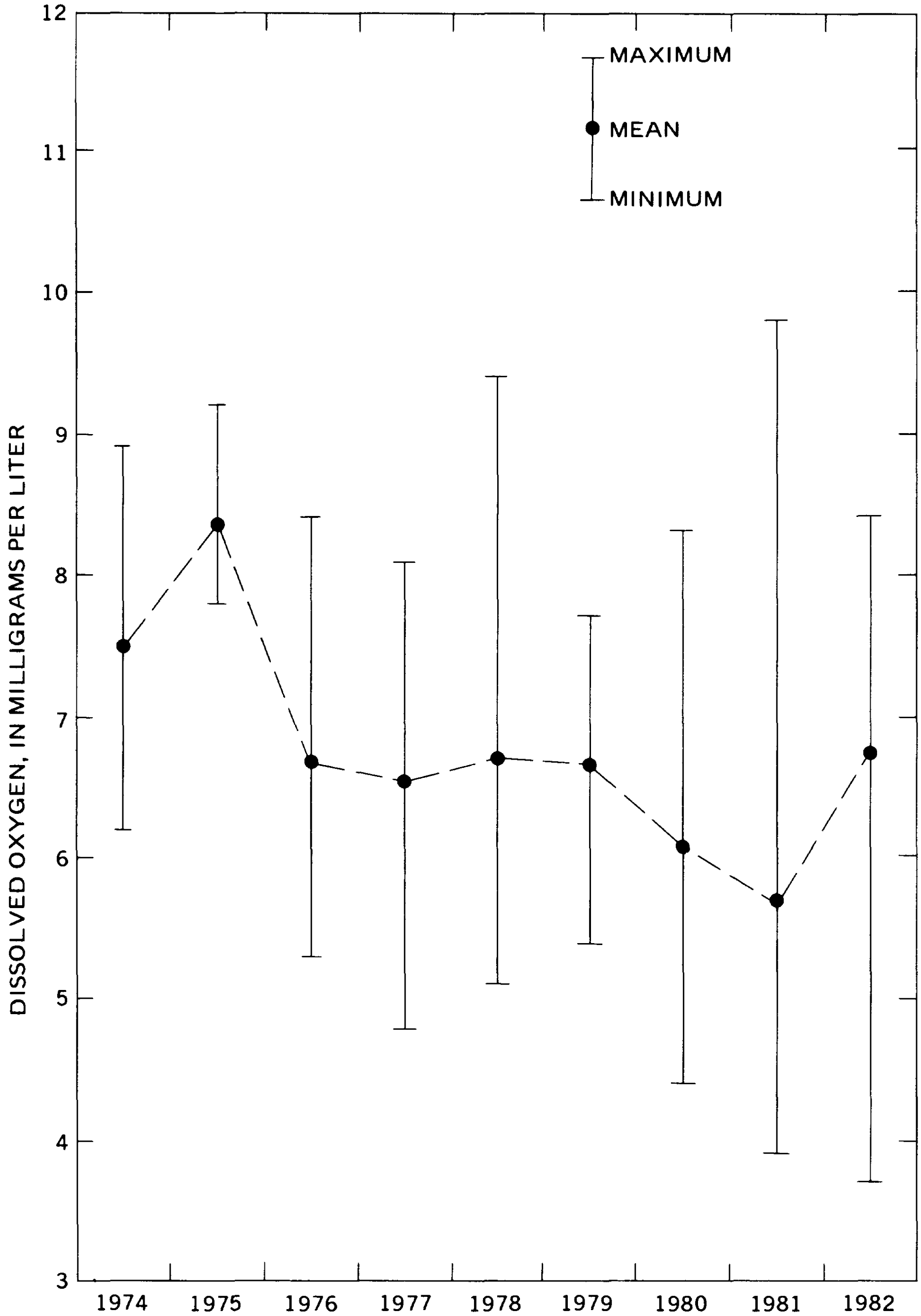

Figure 4.—Variation in dissolved-oxygen concentration during daytime, April-September 1974-82, in the Jordan River at 1700 South Street.

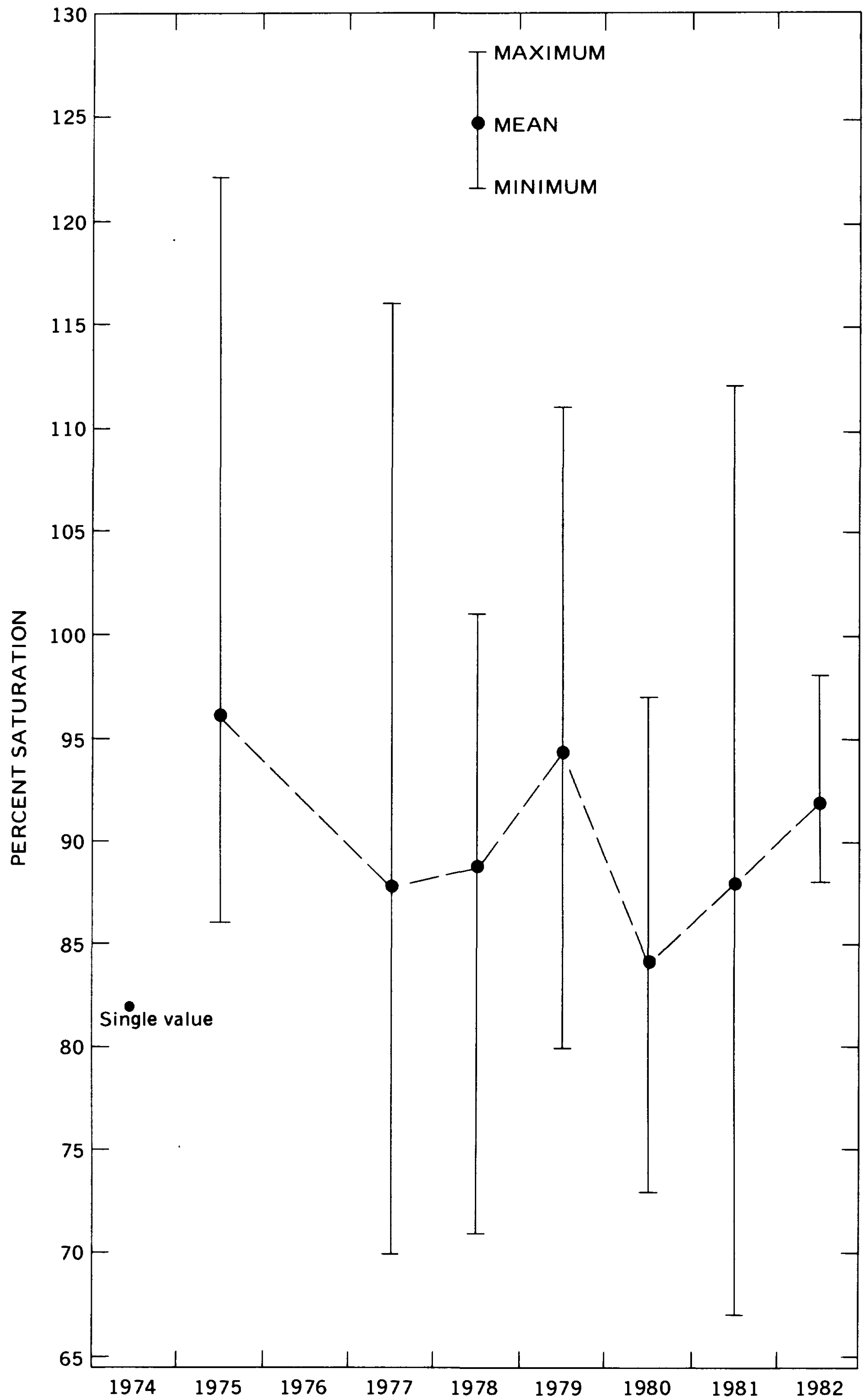

Figure 5.—Variation of percent saturation of dissolved-oxygen during daytime, April-September 1974-82, in the Jordan River at 5800 South Street.

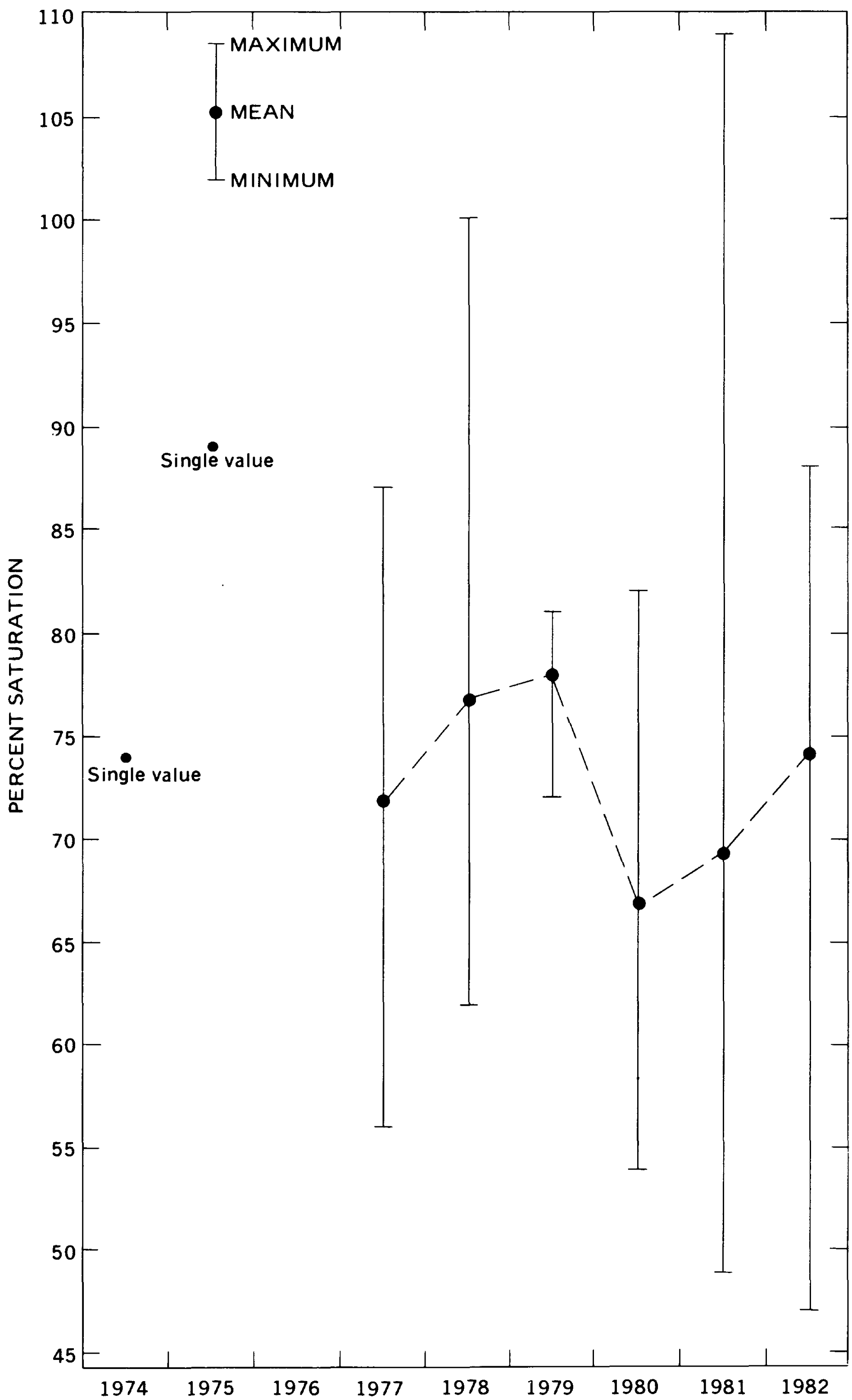

Figure 6.—Variation of percent saturation of dissolved-oxygen during daytime, April-September 1974-82, in the Jordan River at 1700 South Street.

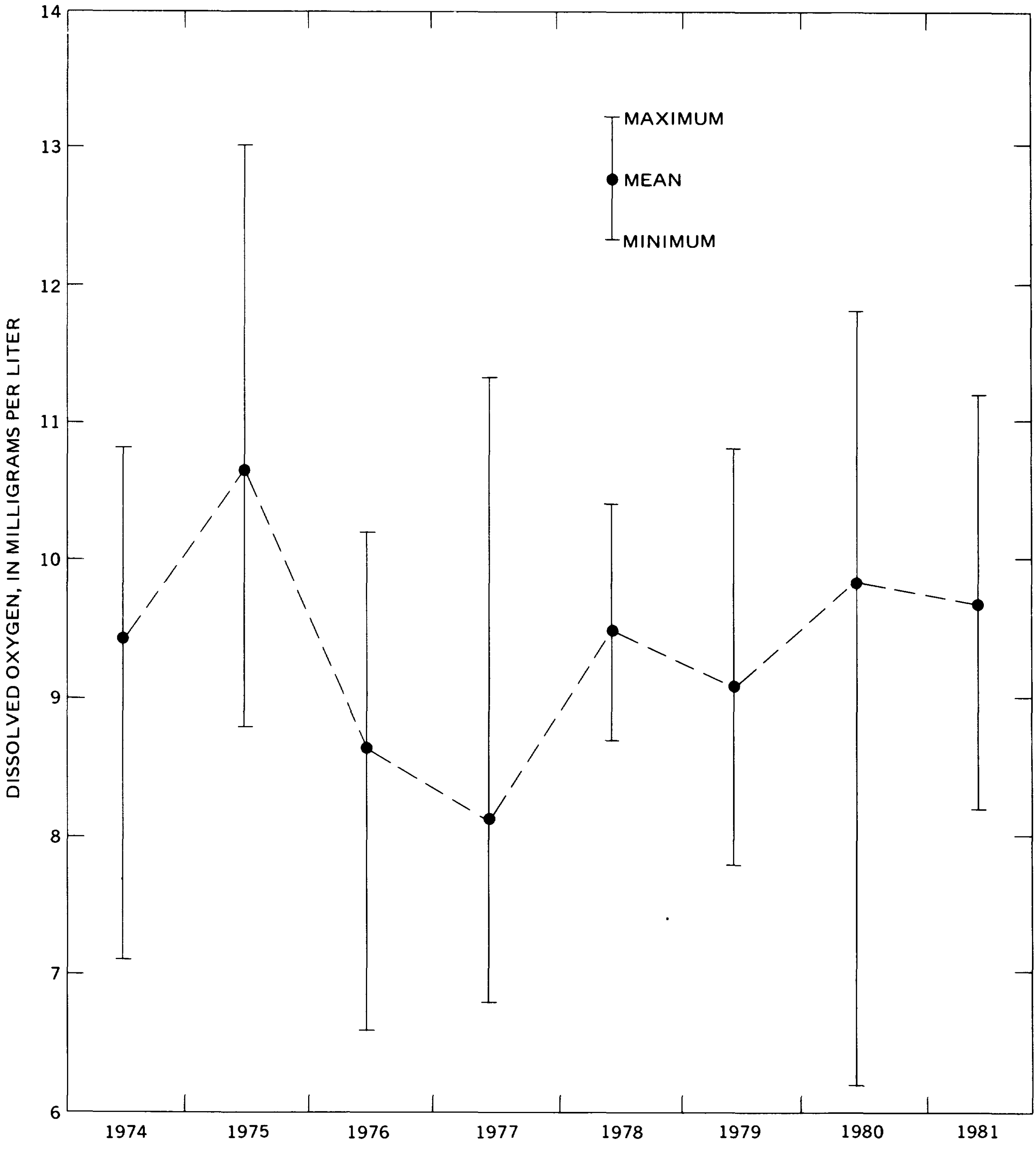

Figure 7.—Variation in dissolved-oxygen concentration during daytime, October-March 1974-81, in the Jordan River at 5800 South Street.

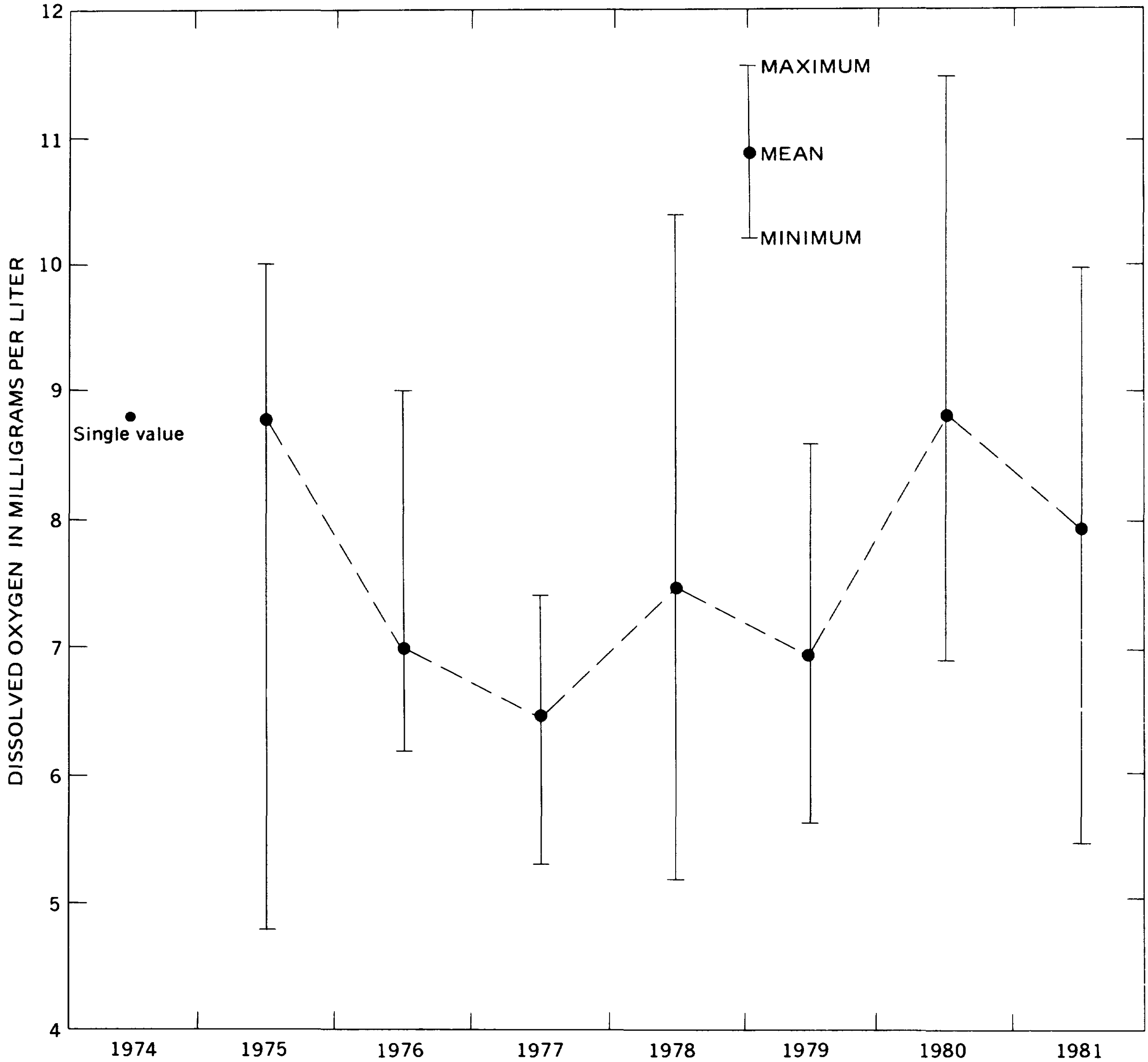

Figure 8.—Variation in dissolved-oxygen concentration during daytime, October-March 1974-81, in the Jordan River at 1700 South Street.

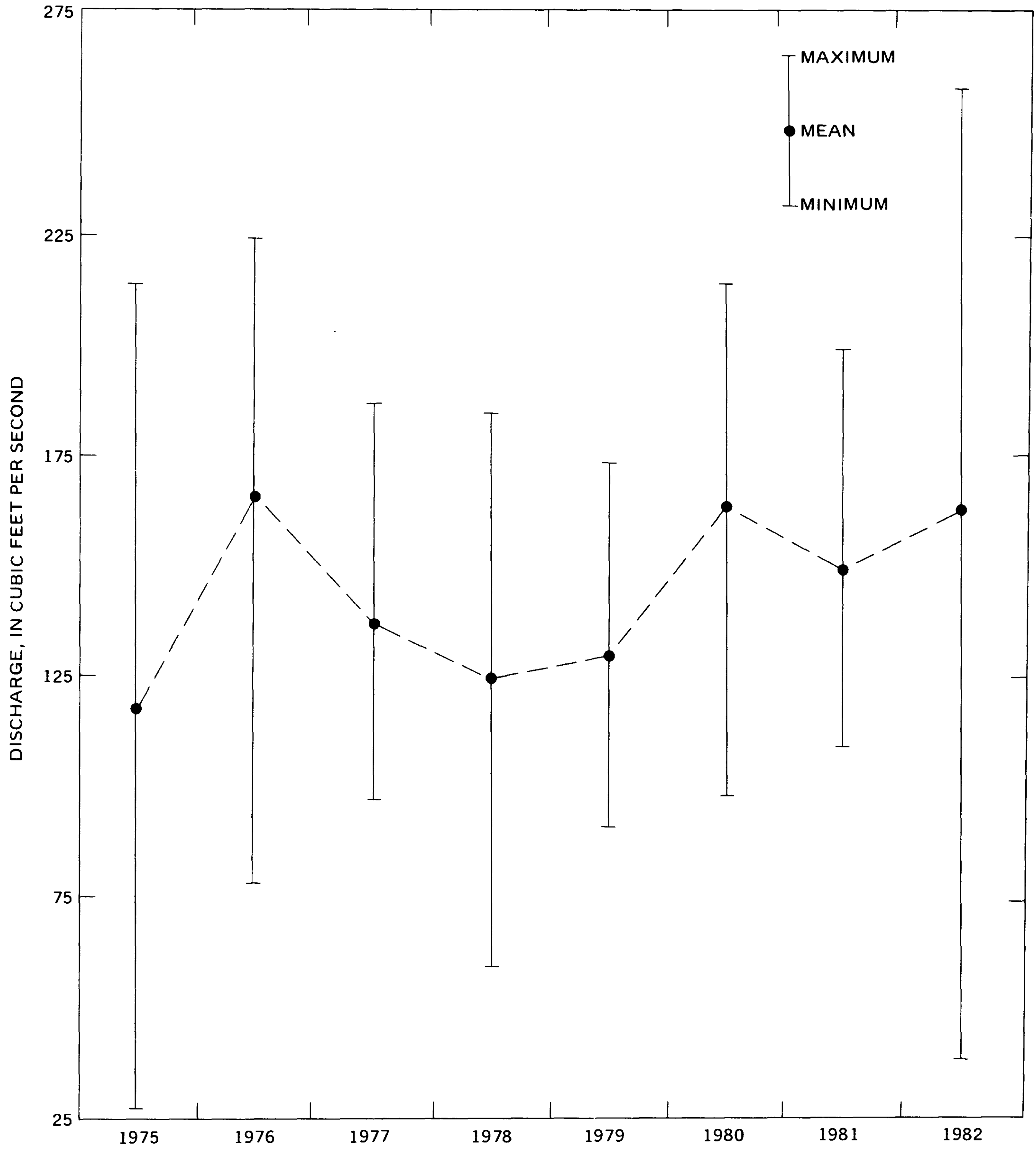

Figure 9.- Variation in mean daily discharge of the Jordan River at 1700 South Street for April-September 1975-82.

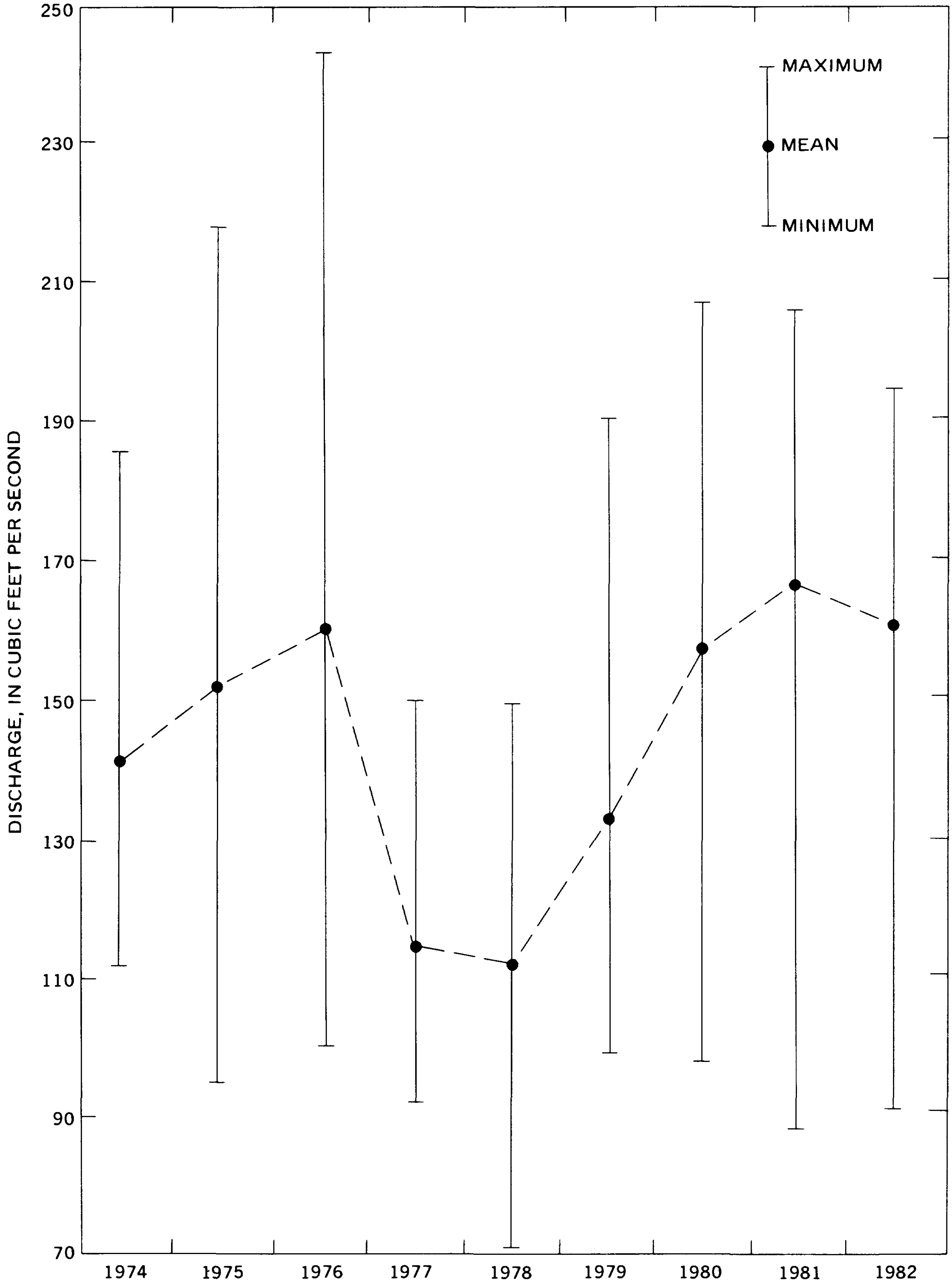

Figure 10.—Variation in mean daily discharge of the Jordan River at 1700 South Street for October-March 1974-82.

The rapid decrease in dissolved-oxygen concentration downstream from 5800 South Street (fig. 2) was accompanied by considerable increases in oxygen-demanding substances during 1980-82 as measured by BOD_5 (fig. 11), BOD_u (fig. 12), and COD (fig. 13). Mean BOD increased about 90 percent between the Jordan Narrows and 500 North Street, but the net rate of increase was greatest downstream from about 5800 South Street. Net mean COD remained relatively constant from the Jordan Narrows to 5800 South Street but then increased about 23 percent downstream to 500 North Street. The means of suspended and dissolved forms of organic carbon did not vary significantly among sites. Mean values of dissolved-organic carbon for October-March generally were 10 to 50 percent larger than means for April-September. There was no correlation between organic carbon and BOD or COD concentrations.

The mean values for dissolved-oxygen-related properties at five monitoring sites for summer (April-September) and winter (October-March) are presented in table 1. Storm samples were excluded because they were not randomly collected. There was little difference, however, between the means of storm- and nonstorm-data sets. Dissolved-oxygen concentrations and percent saturation are always larger during winter months. This is due to the greater solubility of oxygen at lower temperatures and the smaller microbial dissolved-oxygen demands at lower temperatures. BOD during the summer in the downstream reaches of the Jordan River are noticeably smaller than during the winter because the demand is being fulfilled in the stream. Dissolved organic carbon (DOC; see Glossary) has the same pattern with the larger concentrations present in the winter due to decreased microbial action. Suspended organic carbon (SOC; see Glossary) is quite constant with slightly greater concentrations during the summer at three sites. COD generally is larger during the summer, indicating the presence of greater quantities of total oxidizable substances, including algae. This would include any substance exerting a BOD as well as reducing inorganic compounds that are transported with sediment.

The minimal dissolved-oxygen concentrations and excessive oxygen-demanding loads that characterize the downstream reaches of the Jordan River may be summarized by determining the frequency of noncompliance with intended-use standards (table 2). About one-half of the dissolved-oxygen concentrations measured during the 1981-82 study were less than the dissolved-oxygen standard of 5.5 milligrams per liter at 1700 South and 500 North Streets. About 90 percent of the BOD_5 concentrations at these sites exceeded the standard of 5 milligrams per liter. Excess BOD is also a serious problem upstream from 5800 South Street where 40 to 60 percent of the samples exceeded the standard. Dissolved-oxygen concentrations usually are greater than the standard of 6 milligrams per liter upstream from 5800 South Street.

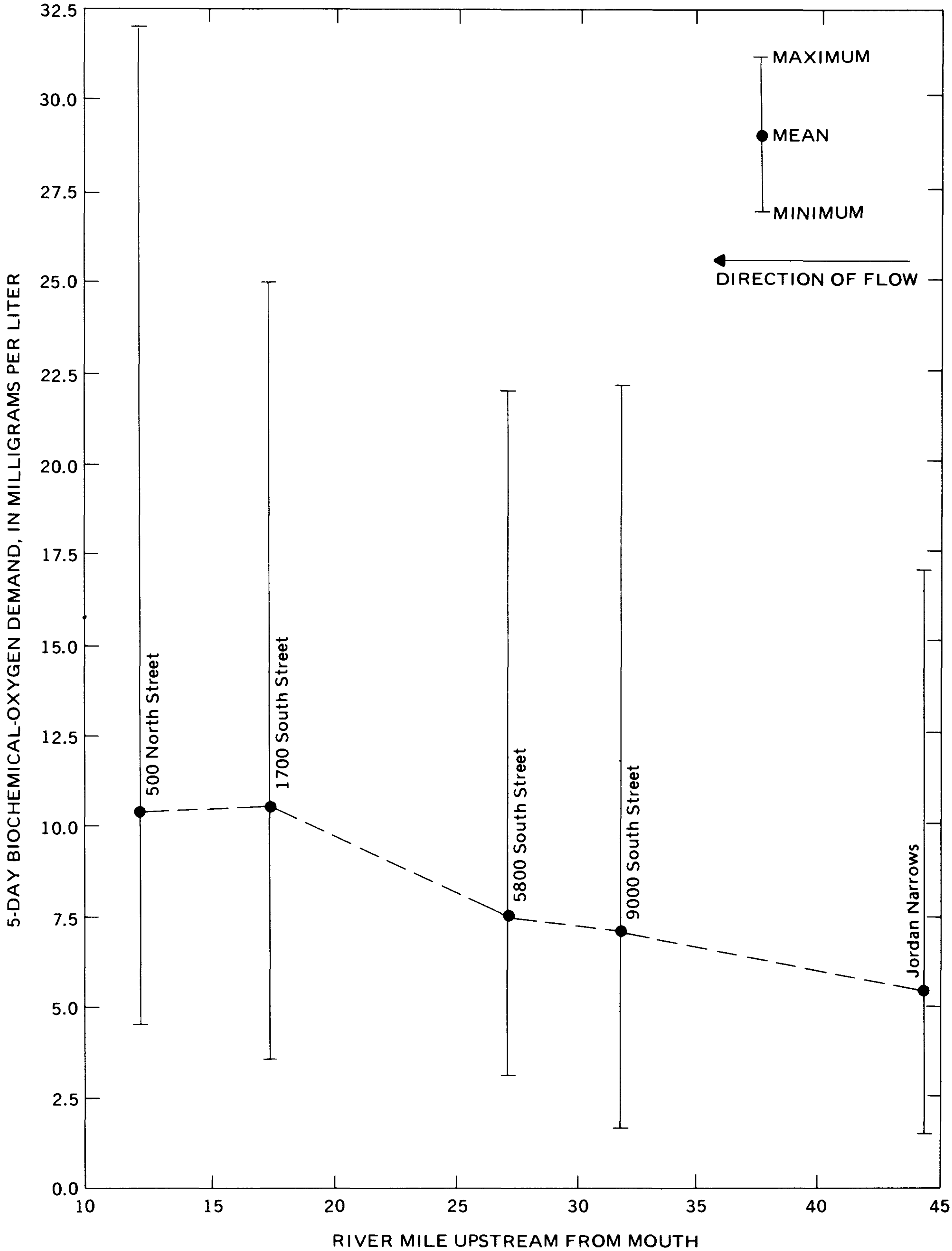

Figure 11.—Variation in 5-day biochemical-oxygen demand in the Jordan River from July 1980 to October 1982.

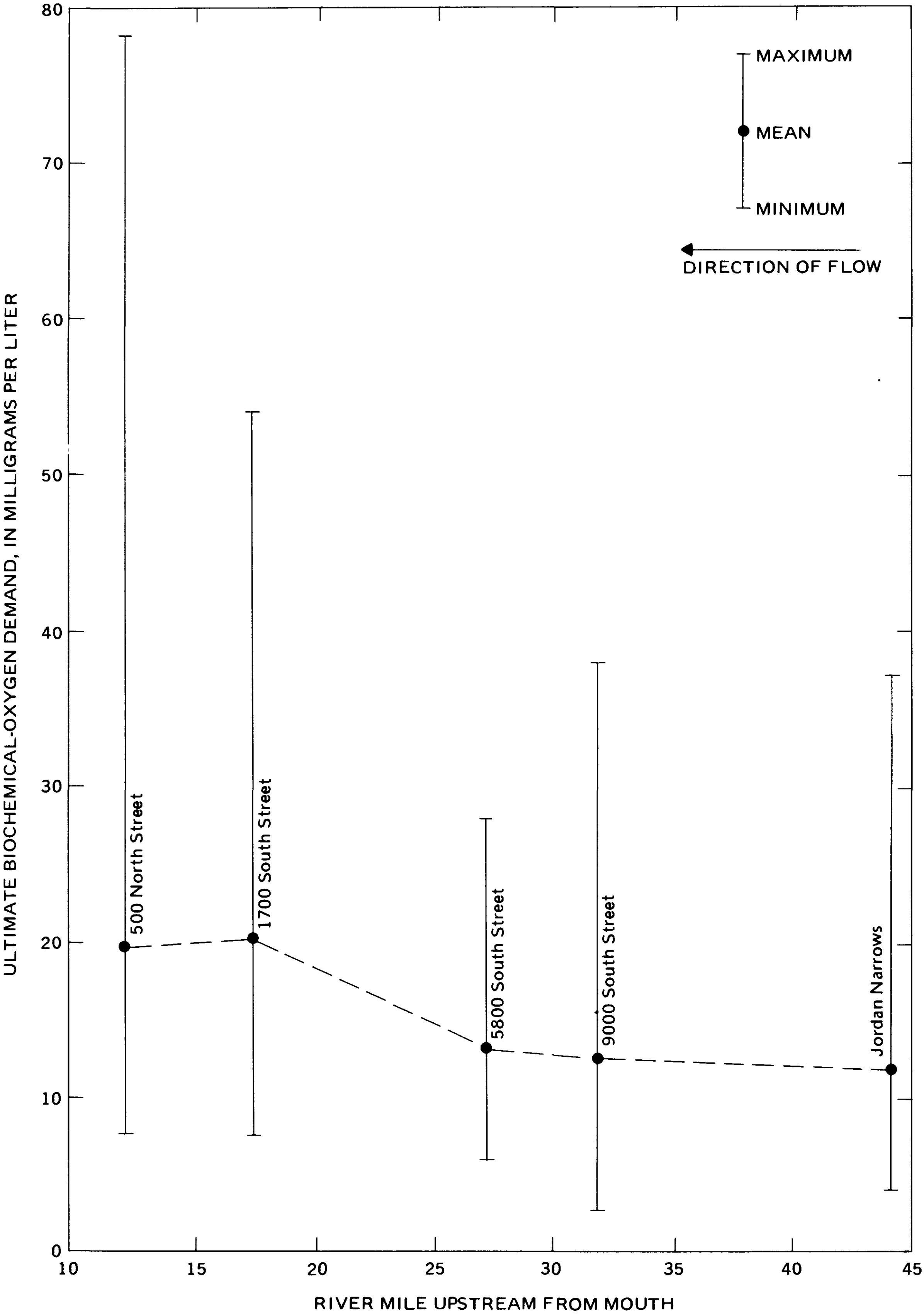

Figure 12.—Variation in ultimate biochemical-oxygen demand in the Jordan River from July 1980 to October 1982.

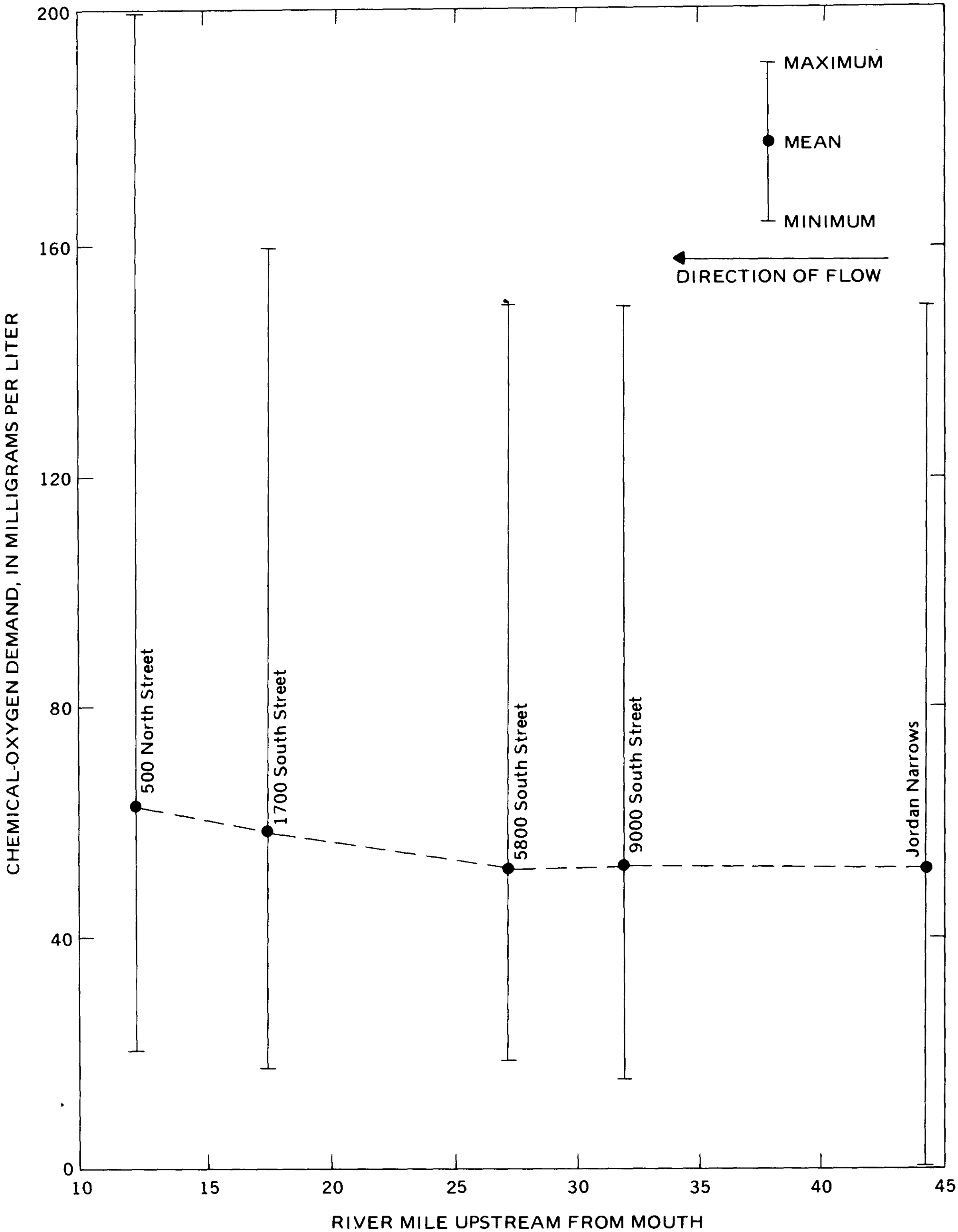

Figure 13.—Variation in chemical-oxygen demand in the Jordan River from July 1980 to October 1982.

Table 1.--Comparison of summer (April-September) and winter (October-March) means for dissolved-oxygen concentration and oxygen-related properties in the Jordan River, July 1980 to October 1982

[Storm samples are excluded; BOD_5, 5-day biochemical-oxygen demand; BOD_u, ultimate biochemical-oxygen demand; COD, chemical-oxygen demand; DOC, dissolved organic carbon; SOC, suspended organic carbon.]

Site	Season	Dissolved oxygen (milligrams per liter)	Saturation (percent)	Other properties (milligrams per liter)				
				BOD_5	BOD_u	COD	DOC	SOC
Jordan Narrows	summer	8.1	100	5	11	66	9	2.4
	winter	10.9	106	7	13	36	12	1.4
9000 South Street	summer	8.2	97	5	11	55	11	1.3
	winter	10.5	101	13	19	42	9	1.4
5800 South Street	summer	7.1	87	7	13	50	10	1.7
	winter	9.8	94	9	14	37	9	1.6
1700 South Street	summer	5.8	69	12	28	63	8	2.1
	winter	8.5	80	18	31	47	11	1.9
500 North Street	summer	4.7	58	7	14	57	9	1.7
	winter	7.9	77	17	32	75	13	1.8

Table 2.--Frequency of noncompliance with water-quality standards for intended use in the Jordan River, 1981-82

[Standard for dissolved oxygen is 6 milligrams per liter at Jordan Narrows and 9000 South and 5800 South Streets, and 5.5 milligrams per liter at all other sites; standard for 5-day biochemical-oxygen demand is 5 milligrams per liter at all sites.]

Site	Dissolved oxygen		5-day biochemical-oxygen demand	
	Total number of measurements	Noncompliance frequency (percent)	Total number of measurements	Noncompliance frequency (percent)
Jordan Narrows	29	3	27	44
9000 South Street	32	0	23	39
5800 South Street	51	10	26	58
1700 South Street	61	46	23	87
500 North Street	62	52	25	92

Relationship of Dissolved Oxygen to Other Variables

The decreases in dissolved-oxygen concentration and percent saturation and the increases in oxygen-demanding substances observed during 1981 and 1982 indicated a cause-effect situation that could be evaluated statistically. Stepwise-multiple-regression analysis was used with dissolved-oxygen concentration and percent saturation as dependent variables and with BOD_5, BOD_u, COD, SOC, DOC, chlorophyll a, water temperature, and river discharge as independent variables. The primary objective of the analysis was to evaluate the degree of relationship among the variables, but not to produce predictive regression equations. Data from all sites except the Jordan Narrows were pooled and regressions were run. The Jordan Narrows was excluded because water there typically is saturated with dissolved oxygen most of the year. The analysis failed to identify any single parameter equations that explained 50 percent or greater ($R^2 \geq 0.50$; see Glossary) of the variation in the dependent variables. Separating the data into winter and summer groups did not indicate significantly better relationships. Using the same data but limiting the analysis to individual sample sites produced several equations that were statistically significant at the 95-percent-confidence level (table 3).

Water temperature is important in all dissolved-oxygen equations being inversely correlated. This reflects the inverse relationship between oxygen solubility and temperature and the decreased reaction rates of oxygen-demanding processes at lower temperatures. Discharge appears to be positively correlated with the oxygen variables in three equations. This may represent reaeration rates associated with larger discharges and increased turbulence or dilution of organic loads due to overall larger flows.

Table 3.—Equations showing the relation of dissolved oxygen and percent saturation to discharge and measures of water quality

[Equation: DO, dissolved oxygen; PS, percent saturation; Q, river discharge; SOC, suspended organic carbon; DOC, dissolved organic carbon; BOD_5, 5-day biochemical-oxygen demand; CHL, chlorophyll a; T, water temperature.]

Site	Number of observations	R^2	Equation
9000 South Street	8	0.95	DO = 14.36 + 0.015Q - 1.15SOC - 0.37T
	8	.80	PS = 110.24 - 38.02SOC + 1.15CHL + 0.10Q
5800 South Street	10	.86	DO = 6.17 + 0.11DOC + 1.19SOC - 0.10T
	10	.80	PS = 95.20 - 0.39BOD_5 + 0.75DOC - 0.41CHL
500 North Street	10	.85	DO = 7.09 - 0.54SOC - 0.25T + 0.02Q

The appearance of BOD_5 in only one equation is surprising because BOD_5 and BOD_u are direct measures of oxygen demands in water; however, variation in BOD was near 100 percent for the combined data, which would decrease the correlation potential in any relationship. As BOD in a stream is affected directly by temperature, the winter- and summer-data sets also were analyzed separately. For all sites this greatly decreased the available data and did not improve the relationship of dissolved oxygen to BOD. Chlorophyll a was significant in two equations indicating that large algal populations upstream from 9000 South Street were associated with increased daytime dissolved-oxygen saturations at 9000 South Street and were associated with decreased saturations at 5800 South. This may be due to the association of large phytoplankton populations from Utah Lake with well-oxygenated water in the river from the Jordan Narrows to 9000 South Street. As the river flows north, the phytoplankton exert a larger oxygen demand through respiration and decay than is fulfilled through reaeration and photosynthetic-oxygen production.

A regression analysis was performed to determine the relationship between chlorophyll a and direct measures of organic-oxygen demands (BOD, DOC, SOC, COD) at each site. There was a positive relationship at the Jordan Narrows between chlorophyll a and BOD_5 (R^2 = 0.66), which was statistically significant at the 95-percent-confidence level with 10 observations. This indicates that phytoplankton from Utah Lake and conditions in the reach of the Jordan River from Utah Lake to the Jordan Narrows may be responsible for some of the summer BOD exerted on the river near and downstream from the Jordan Narrows. As indicated later in the section on "Photosynthetic-oxygen production and respiration," algal populations contribute significantly to the daytime dissolved-oxygen concentrations in the upstream reaches of the Jordan River, hence the positive relationship at 9000 South Street with percent saturation. The algae, however, also are responsible for much of the nighttime dissolved-oxygen demand placed on the system downstream from 9000 South Street.

The inverse relationship between measured dissolved-oxygen concentrations and organic-carbon concentrations at 9000 South and 500 North Streets is realistic, but plots of organic carbon at 5800 South Street show a considerable scatter, which probably is responsible for the spurious positive correlations of DOC and SOC at this site. Regression analyses of long-term but scanty data collected at 5800 South and 1700 South Streets prior to 1981 failed to produce any significant relationships between the two oxygen properties and properties affecting the dissolved-oxygen balance.

Reaeration Rate and Time-of-Travel

Reaeration is the principal physical process by which oxygen enters or leaves water. The quantity of oxygen that actually passes through the water surface is dependent on the degree of dissolved-oxygen saturation in the water as well as on the reaeration coefficient. This quantity can be determined by equation 2.

$$\frac{\Delta C}{\Delta T} = K_2 \ (C_s - C) \tag{2}$$

where

- ΔC is the change in concentration of oxygen;
- ΔT is the change in time;
- K_2 is the reaeration rate coefficient, calculated to log base e and expressed as per day;
- C_s is the oxygen saturation at the measured temperature and atmospheric pressure;
- C is the measured dissolved-oxygen concentration in the water.

K_2 is difficult to measure, therefore it generally is calculated using a variety of equations (reviewed in Bennett and Rathbun, 1972) that have been developed for specific rivers and which may not be applicable to the Jordan River. Prior to this study, no measurements of reaeration had been done on the Jordan River. A calculated reaeration rate of 14.5 day^{-1} was reported by Hydroscience, Inc. (1976c, p. 47) for September the 1975 study of the Jordan River. Reaeration rates, however, vary considerably within different reaches of a river due to differences in discharge rates, turbulence, and channel slope and depth. Because of these differences, measurements of the rates for short reaches of uniform flow result in more accurate characterization of the dissolved-oxygen balance.

Measurement of reaeration rates under the low-flow conditions of September and October 1981, 1982 was done using the hydrocarbon-tracer method of Rathbun (1979). The tracer method is based on the concept that the ratio of the rate coefficient for a tracer gas desorbing from water to the rate coefficient for oxygen absorption by the water is a constant, regardless of mixing conditions. The procedure consists of injecting a tracer gas into the river, determining the desorption coefficient of the gas from the river at various downstream points, and converting that desorption coefficient to an oxygen-reaeration coefficient by means of a constant determined in the laboratory. A tracer dye (Rhodamine-WT) is used to correct for dispersion and dilution and also to provide data on time-of-travel. The method requires that the entire dye cloud passing through the measurement section be sampled, producing a skewed curve with a truncated leading edge and a trailing edge, as in figure 14. Only the peak concentration of tracer gas is needed to calculate the desorption rate, although many samples are collected and analyzed to identify the gas peak (fig. 15).

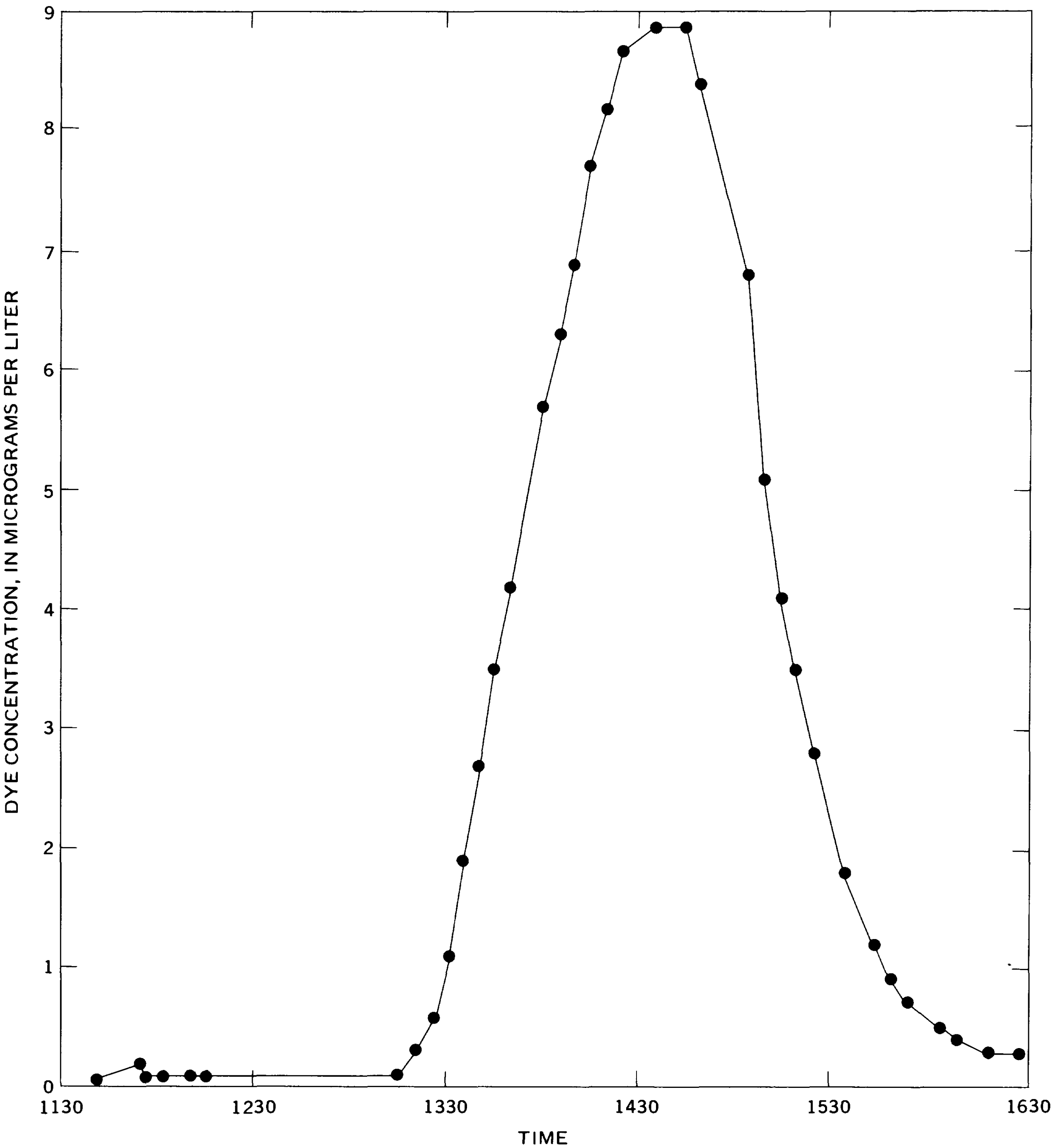

Figure 14.—Time distribution of Rhodamine-WT concentrations in the Jordan River at 3300 South Street, October 6, 1981.

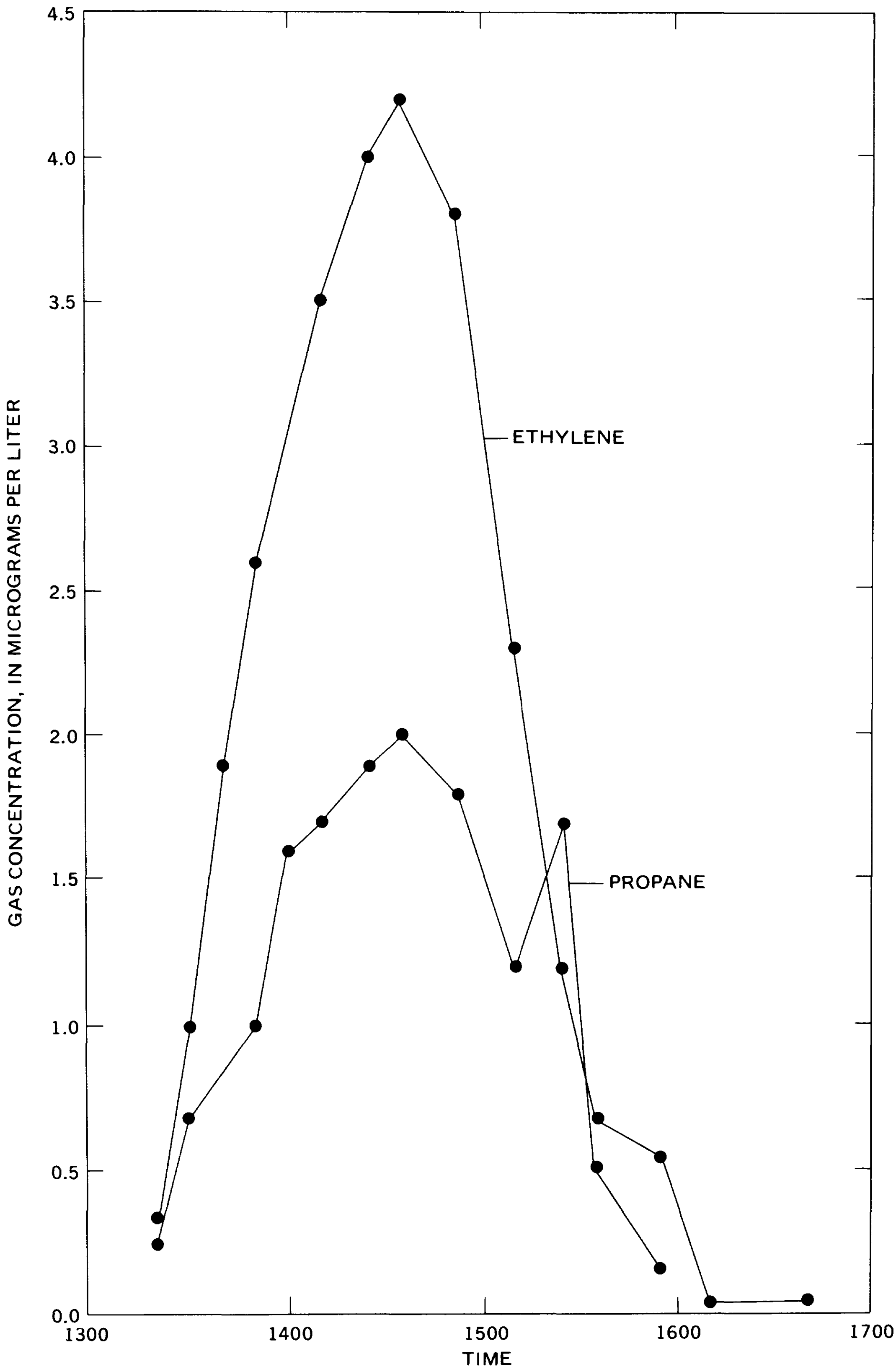

Figure 15.—Time distribution of hydrocarbon-tracer gases in the Jordan River at 3300 South Street, October 6, 1981.

The time-of-travel and reaeration measurements made during September and October of 1981 and 1982 are summarized in table 4. The value given for K_2 is corrected to 20°C, and it is the mean of reaeration rates determined with both ethylene and propane tracer gases.

Reaeration coefficients increase as water temperatures increase, but they typically are presented at a standard temperature of 20°C. They need to be corrected to actual stream temperatures before application using the following equation (Rathbun and others, 1975, p. 27).

$$K_{2_T} = K_{2_{20}} (1.0241)^{(T-20)} \quad (3)$$

where

K_{2_T} is the reaeration coefficient at temperature T; and

$K_{2_{20}}$ is the reported reaeration coefficient at 20°C.

The general trend for K_2 in the Jordan River is to decrease in a downstream direction (table 4). The trend is partly in response to decreased channel slope, which decreases the stream velocity and turbulence. The relatively large K_2 values for the reach between 4800 South (river mile 25.2) and 3300 South Streets (river mile 21.5) and the unusually slow rate for the reach between 3300 South and 2100 South Streets do not fit the trend and currently are unexplained. With the exception of these points, the decrease in K_2 is quite similar to the decrease in slope of the channel profile (fig. 16) with considerable decreases in K_2 downstream from 4800 South Street near the confluence of the Jordan River and Little Cottonwood Creek.

The time-of-travel varies considerably with river discharge and channel slope; and it may be estimated by several equations using these variables (Boning, 1974), or it may be measured using a tracer dye. Under the flow conditions of September and October 1981 and 1982, the total time-of-travel from 12300 South to 1800 North Streets was about 26 hours for peak-to-peak dye concentrations. Although the travel times presented in table 4 are accurate for the measured discharges, extrapolation to other flow conditions needs to be done with discretion.

Photosynthetic-Oxygen Production and Respiration

Diel variation in the free dissolved-oxygen concentration of aquatic systems has been used extensively to estimate rates of oxygen production and respiration (Odum, 1956; Hoskin, 1959; Edwards and Owens, 1962; O'Connell and Thomas, 1965). All procedures for defining the diel-oxygen relationship use dissolved-oxygen measurements to solve the dissolved-oxygen balance in equation (1) given earlier. Knowledge of the photosynthetic production of oxygen is useful, as it may be a major source of dissolved oxygen for microbial decomposition of organic matter during daylight. Nighttime respiration by the algal community also will exert considerable oxygen demand on the aquatic system. The summation of these two processes during 24 hours represents the net available dissolved oxygen for further use by the biological community in a river. Often, as in the Jordan River, there is no significant net production of dissolved oxygen, only an increased dissolved-oxygen deficit during the 24 hours. Biological communities of rivers typically are regarded as heterotrophic or are greater consumers than producers. Standing-water communities (such as ponds) typically are autotrophic, with greater production of substances (such as oxygen) than consumption.

Table 4.--Summary of reaeration coefficients (K_2), time-of-travel, channel slope, and discharge for the Jordan River

[Time: Time to reach the peak concentration of tracer dye.]

Jordan River reach	Mean discharge (cubic feet per second)	Channel slope (feet per 1,000 feet)	Time (hours)	K_2 at 20°Celsius (day^{-1})
12300 South to 10600 South Streets	84	2.42	2.5	12.51
10600 South to 9000 South Streets	134	1.39	2.7	11.38
9000 South to 5800 South Streets	203	1.37	4.0	7.73
5800 South to 4800 South Streets	173	1.33	1.3	6.49
4800 South to 3300 South Streets	244	.69	2.8	12.09
3300 South to 2100 South Streets	364	.29	2.3	.15
2100 South to 1700 South Streets	[1]168	.24	.7	—
1700 South to 1330 South Streets	169	.16	2.0	—
1330 South to 700 South Streets	184	.27	1.7	3.47
700 South to 500 North Streets	202	.41	2.6	3.17
500 North to 1800 North Streets	201	.30	3.3	.53

[1] Discharge is for 1700 South Street.

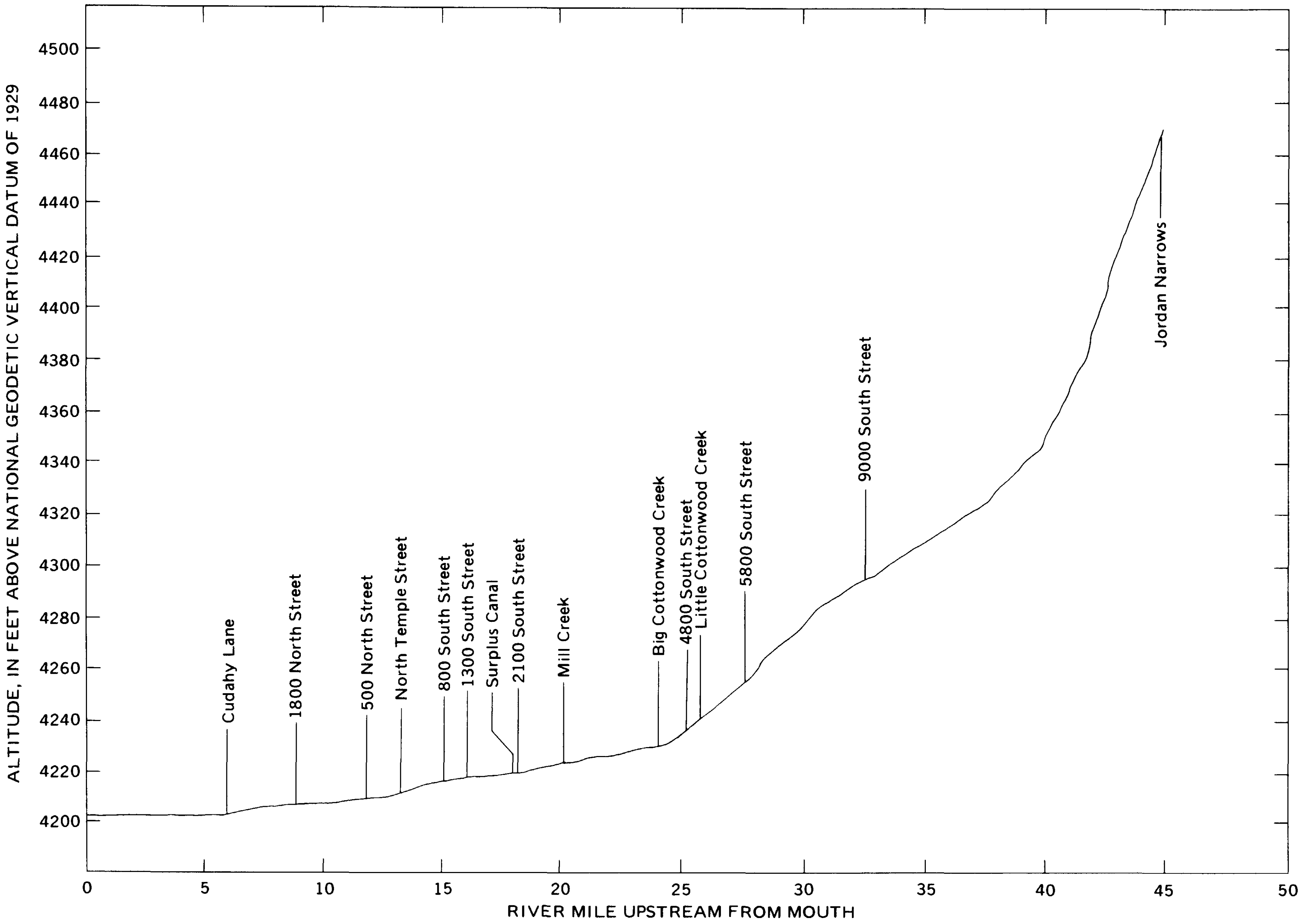

Figure 16.—Profile of the Jordan River channel through Salt Lake Valley with selected landmarks.

The computer program used to analyze algal-oxygen production and respiration (Stephens and Jennings, 1976) uses reaeration rates to correct the measured dissolved-oxygen concentration for diffusion into or from the system. Under the flow conditions of 1981 and 1982, diffusion rates may have been larger than during more typical years. With decreased flows, the oxygen-diffusion rate into or from the system would be decreased and light penetration into the shallower water column would be extended, factors that would increase photosynthetic-oxygen production and algal respiration.

An estimate of the impact of photosynthetic production and respiration of oxygen at several of the sites sampled by Gaufin (1958, p. 50-54) on September 15-16, 1957, was obtained using the computer program of Stephens and Jennings (1976). Only four dissolved-oxygen measurements were available, which limited the accuracy of the determination but provided an approximate indicator of the trend. During the day, no net production of dissolved oxygen was measured in excess of the dissolved oxygen consumed at any site downstream from 12400 South Street. At this site, dissolved-oxygen production during the daytime totaled 6.4 milligrams per liter, but this was expended during the night, giving a 24-hour deficit of 10.7 milligrams per liter. During the 24 hours, total deficits were 12.6 milligrams per liter at 2100 South, 15.8 milligrams per liter at 6400 South, and 12.8 milligrams per liter at 9000 South Streets.

The same computer program was used to analyze the diel-oxygen data collected on August 21, 1972, during the study by the U.S. Environmental Protection Agency (1972, p. 62). Twelve data points were available which improved the accuracy of the method. A net gain of 1.8 milligrams per liter per day was observed at the Lehi-Fairfield Road, 6 miles south of the Jordan Narrows. The Jordan River at this site is slow-moving and resembles a pond. Considerable algal material is present, and dissolved-oxygen concentrations usually were in excess of saturation. At Cudahy Lane (fig. 1), a dissolved-oxygen deficit of 3.4 milligrams per liter per day was placed on the system during the 24 hours by community metabolism.

Several diel studies conducted during 1981-82 are summarized in table 5. The daytime dissolved-oxygen deficit at 5800 South Street is quite small relative to the nighttime deficit due to considerable algal production of oxygen in the sunny, open reaches upstream from this site. The oxygen produced by photosynthesis is expended for respiration of the large algal community at night, which results in a considerable net deficit for the 24 hours. Production and respiration at the three sites downstream from 5800 South Street were quite uniform in July. Dissolved oxygen also was monitored continuously at 1700 South Street for several weeks in September 1981 and January 1982. Considerable 24-hour dissolved-oxygen demands were evident for both time periods. Low temperatures should have greatly decreased algal activity during January, however, the daytime deficits are about one-half of those in September, indicating that there is some algal production (and respiration) of oxygen even during the winter.

Table 5.--Effects of photosynthesis and respiration on the dissolved-oxygen balance in the Jordan River

[Data from diel-curve analyses were corrected using reaeration rates presented in table 4.]

Date	Site	Water temperature (degrees Celsius)	Photosynthesis during day	Respiration during night	24-hour net
			(milligrams of dissolved oxygen per liter)		
7-28-81	5800 South Street	20	-0.9	-20.9	-21.8
7-28-81	1700 South Street	21	-5.3	-5.5	-10.8
7-28-81	700 South Street	20	-6.2	-6.0	-12.2
7-28-81	500 North Street	20	-6.6	-6.0	-12.6
9- 1-81	1700 South Street	20	-2.9	-12.7	-15.6
9- 7-81	1700 South Street	18	-3.6	-11.8	-15.4
9-16-81	1700 South Street	15	-4.2	-11.8	-16.0
1-23-82	1700 South Street	2	-1.5	-13.7	-15.2
1-26-82	1700 South Street	4	-2.1	-14.1	-16.2

Supersaturation of dissolved oxygen measured during the summer in the upstream reaches of the Jordan River indicates considerable algal-oxygen production during the day. This production also was noted by Hydroscience, Inc. (1976c, p. 47). Although not directly measured, that study resulted in an estimate of algal-oxygen production of 27 milligrams per liter per day for the reach from the Jordan Narrows to about 9000 South Street. The total load of additional dissolved oxygen does not persist in the river downstream due to diversion of about one-half of the river flow into the North Jordan canal near 9400 South Street (river mile 32.6) during the summer. Additionally, chlorophyll-a concentrations due to phytoplankton (suspended algae) decrease considerably with distance downstream (fig. 17). This decrease is due to death of the cells and dilution by relatively plankton-free water entering the river from tributary streams. Periphyton (attached algae) could produce considerable oxygen in the downstream reaches of the river if turbidity were decreased sufficiently to allow for increased light penetration, although specific data on periphyton were not collected in this study.

Effects of Storm Runoff from Urban Areas

A summary report (Keefer and others, 1979, p. 10) on the nationwide effect of storm runoff from urban areas on receiving streams concluded that in streams where concentrations of dissolved oxygen are already marginal (5 to 7 milligrams per liter), storm drainage can further decrease the dissolved-oxygen concentrations to 4 to 5 milligrams per liter for several days. The concentrations occasionally may even decrease to less than the critical-fishery limit of 2 milligrams per liter for a 4-hour period. These conclusions were regarded as conservative because most oxygen monitoring is done too near the urban source to detect the maximum dissolved-oxygen depletion which occurs farther downstream.

Analysis of storm-runoff data collected from the Jordan River during 1981 and 1982 indicates that the mean concentrations of oxygen-demanding substances present in storm runoff from urban areas are larger than the means for nonstorm samples (table 6). Application of Students t-test at the 95-percent-confidence level, however, indicates that only the means for organic carbon are significantly different. The addition of these oxygen-demanding substances results in decreases in the mean-concentration and percent-saturation values of dissolved oxygen in the Jordan River when data for all sites are combined (table 7). Variability in the data, as measured by the coefficient of variation (C_v; see Glossary), is generally smaller for the storm samples because the storm data set is smaller. When analyzed on a site basis, all sites show decreases in concentrations and percent saturation of dissolved oxygen during storms except 500 North Street. At this site, both concentrations and percent saturation of dissolved oxygen increase during storms, most likely due to increased runoff of oxygenated water from mountain streams, which enters through storm conduits at 1300 South and at North Temple Streets. Results of the t-test on the grouped means for dissolved oxygen indicate that there is no significant difference in storm and nonstorm means at the 95-percent-confidence level, but a significant difference is present at the 90-percent level. Means of percent saturation for the grouped data are significantly different at the 95-percent level. It should be noted that the data base for dissolved-oxygen samples during storms is quite small at all sites except 500 North Street.

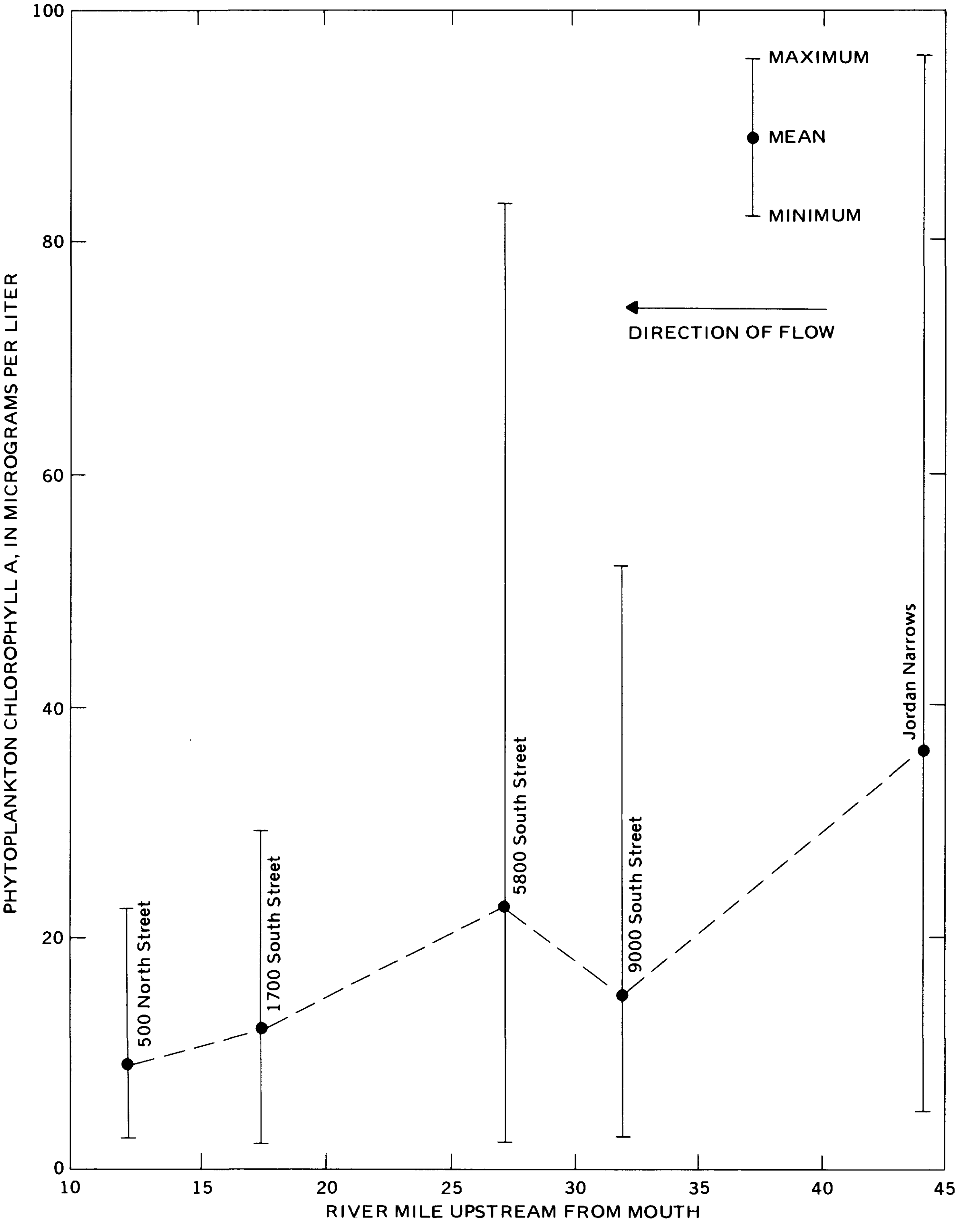

Figure 17.—Decrease in concentrations of phytoplankton chlorophyll a in the Jordan River during the summers of 1981 and 1982.

Table 6.--Comparison of mean concentrations of constituents or processes reflecting oxygen demands in storm runoff from urban areas with concentrations present under nonstorm conditions, 1981-82

Constituent	Storm samples		Nonstorm samples	
	Number	Mean concentration (mg/L)	Number	Mean concentration (mg/L)
Biochemical-oxygen demand (5-day)	91	9	44	5
Chemical-oxygen demand	237	81	73	70
Suspended organic carbon	209	3.4	66	1.6
Dissolved organic carbon	246	15	73	9

Considerable data were collected from the major storm conduits and creeks draining to the Jordan River during four storms in 1981 which covered most of Salt Lake Valley (March 26, May 10, May 20, September 5). The total load (base flow plus runoff from urban areas) of oxygen-demanding substances was computed and a mean load for all the storms was calculated (figs. 18, 19, 20, 21). Data for the three storm conduits at 800 South Street were combined, as were data for the two storm conduits at 1300 South Street. Loads of oxygen-demanding substances as measured by BOD for Big Cottonwood Creek (fig. 18) include the effluent from the Cottonwood wastewater-treatment plant, which averaged 2,300 pounds as measured by BOD_5 load per storm for the four storms sampled during 1981. Loads of BOD_5 for the 2100 South Conduit include an average load of 170 pounds per storm from the South Salt Lake wastwater-treatment plant. Data for constituent concentrations in treatment-plant effluents were available only for BOD_5, thus prohibiting the separation of the treatment-plant loads from the total loads for other constituents. It is evident from these figures that a large quantity of oxygen-demanding substances enters the Jordan River downstream from 9000 South Street in storm runoff.

Table 7.--Statistical summary of dissolved-oxygen concentration and percent saturation for the Jordan River from July 1980 through September 1982 for storm and nonstorm data

[Values for nighttime samples (1900 hours to 0700 hours) deleted; C_v, coefficient of variation.]

Site	Storm samples			Nonstorm samples		
	Number	C_v	Mean	Number	C_v	Mean
	Concentration (milligrams per liter)					
All sites	28	16	6.9	388	48	8.0
Jordan Narrows	4	9	8.6	23	26	9.1
9000 South Street	5	5	7.7	23	17	9.1
5800 South Street	4	8	6.9	182	56	8.9
1700 South Street	4	8	6.4	127	26	7.1
500 North Street	11	15	6.1	33	39	5.6
	Percent saturation					
All sites	25	17	77	287	21	84
Jordan Narrows	4	2	95	23	8	103
9000 South Street	5	6	88	23	7	99
5800 South Street	4	8	77	118	14	90
1700 South Street	1	--	73	90	17	73
500 North Street	11	9	66	33	26	64

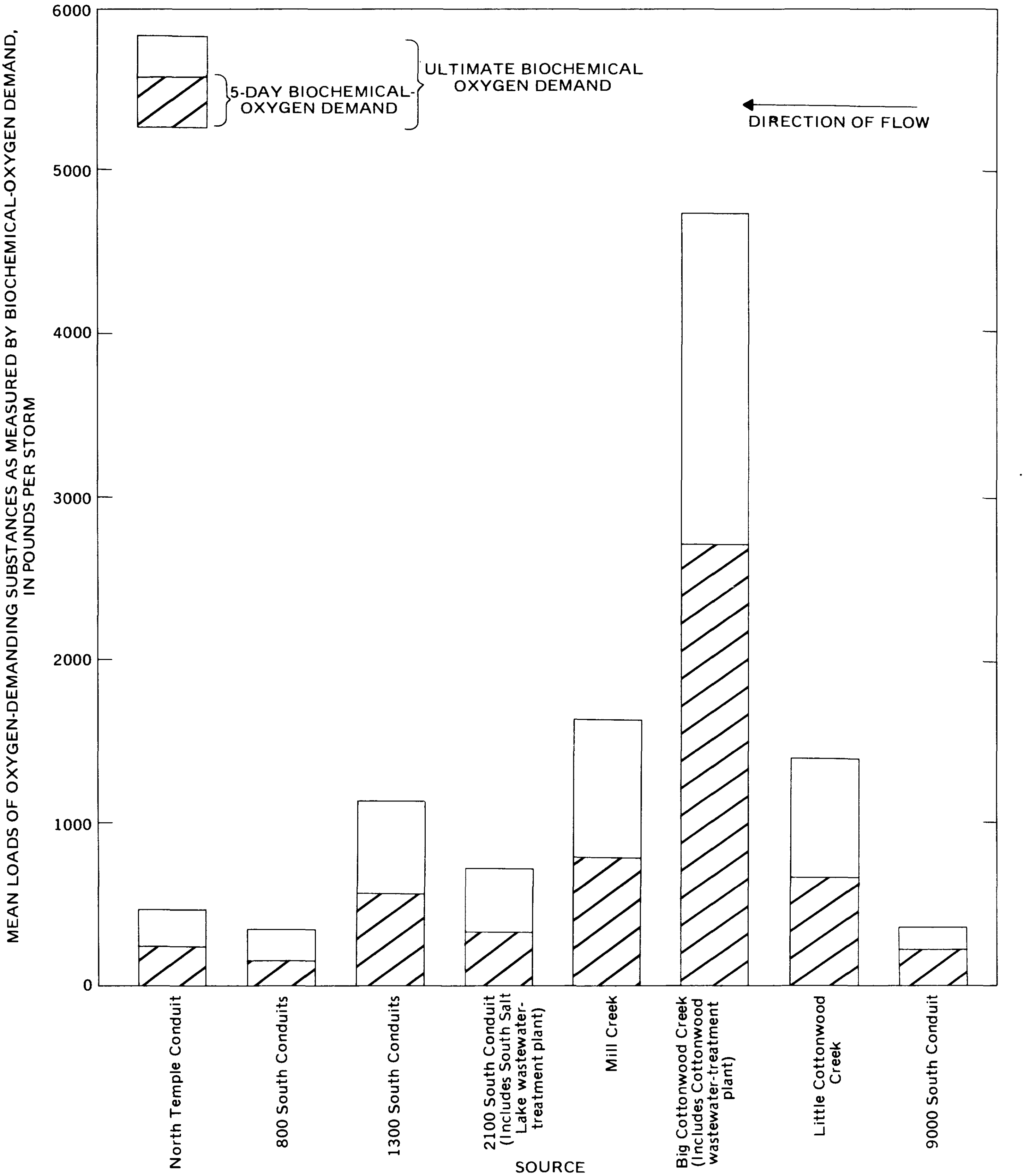

Figure 18.—Mean storm loads of oxygen-demanding substances as measured by biochemical-oxygen demand entering the Jordan River during 1981 from point sources.

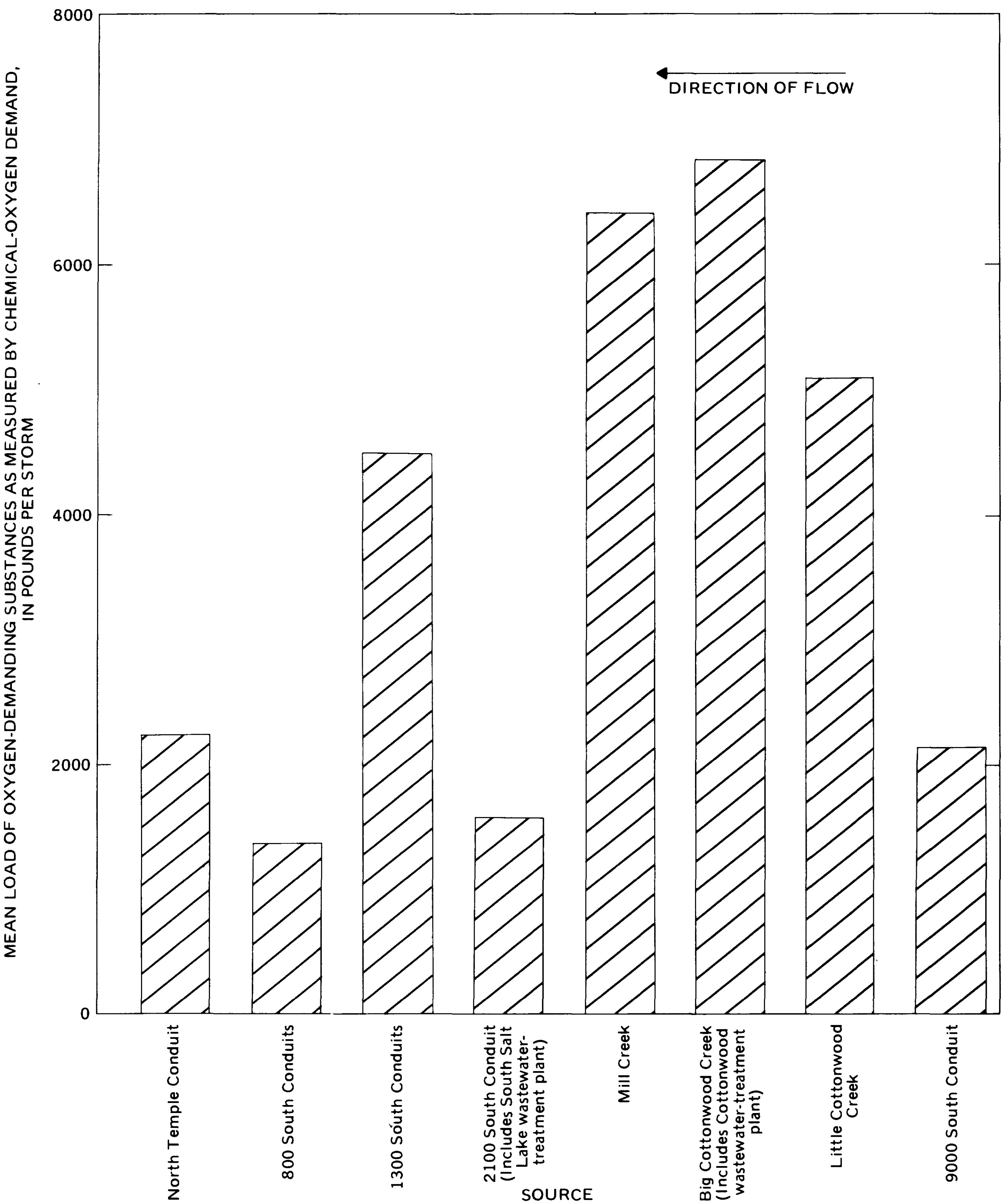

Figure 19.—Mean storm loads of oxygen-demanding substances as measured by chemical-oxygen demand entering the Jordan River during 1981 from point sources.

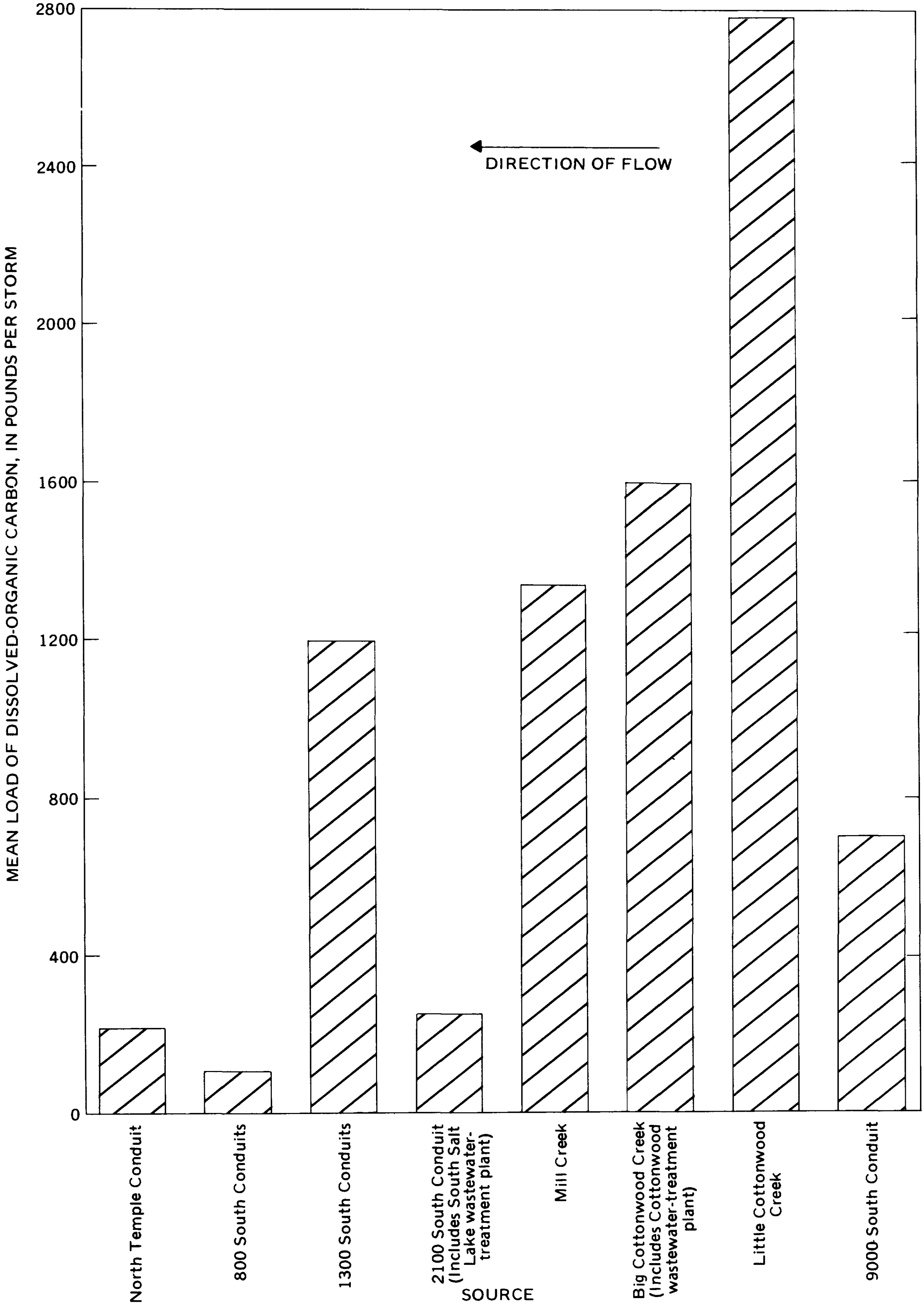

Figure 20.—Mean storm loads of dissolved-organic carbon entering the Jordan River during 1981 from point sources.

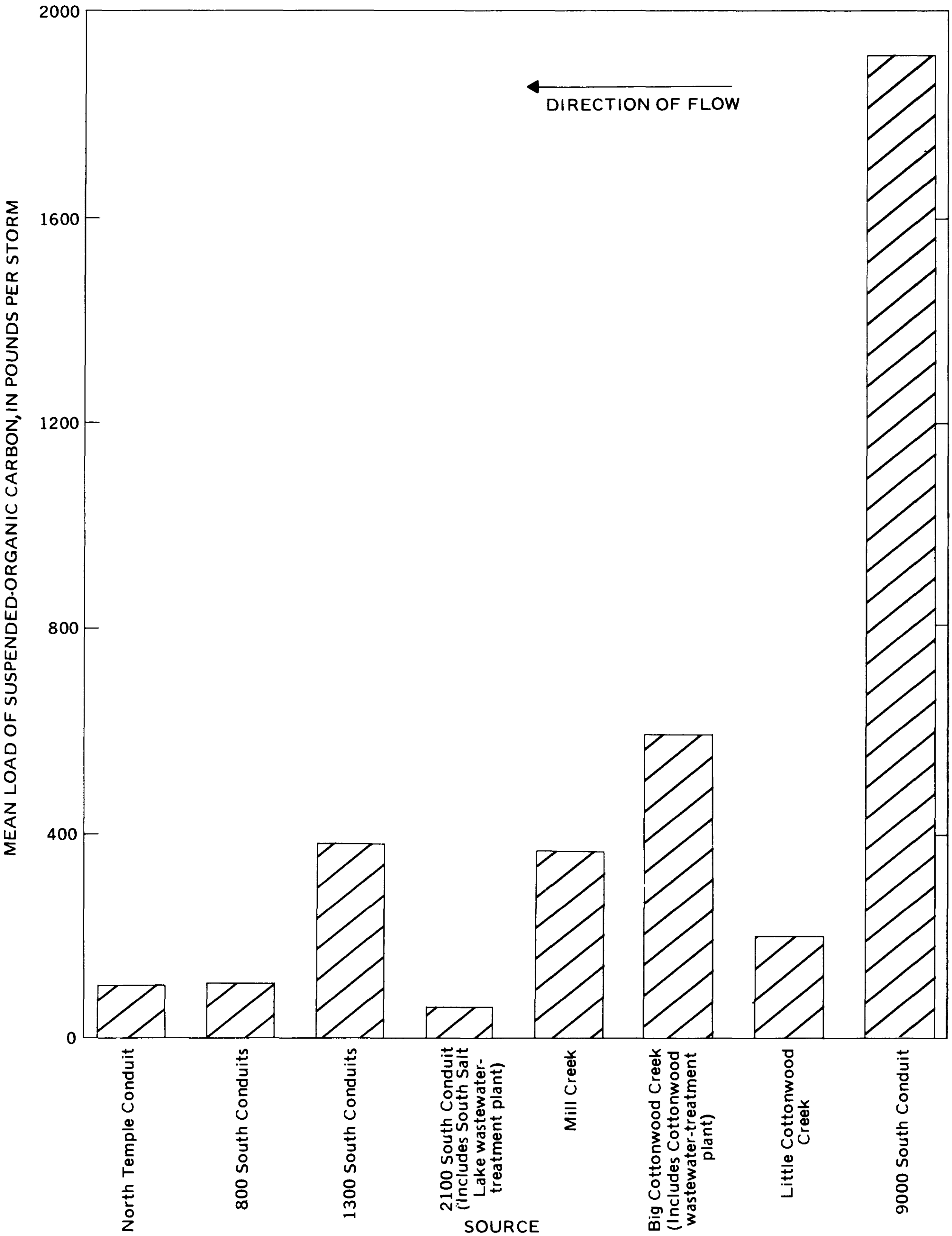

Figure 21.—Mean storm loads of suspended-organic carbon entering the Jordan River during 1981 from point sources.

The mean per storm load of oxygen-demanding substances as measured by BOD_u entering the river was calculated to be 11,000 pounds. This is considerably less than the total load as measured by BOD_u of 474,000 pounds per day for a typical summer storm, as estimated by Hydroscience, Inc. (1977, p. 89) and used in their STREM2 model. Concentration estimates used by Hydroscience, Inc. were approximations and were based only on categories of urban- or nonurban-land use and estimated storm flows. The water-quality model also diverted all storm loads entering the river south of 2100 South Street into the Surplus Canal, which effectively decreases the load in the downstream reach of the Jordan River. Even with this assumed diversion, the model projected a minimum dissolved-oxygen concentration of 0.0 to 2.7 milligrams per liter in the river due only to loads as measured by BOD in storm water. The model clearly indicated that storm runoff has an adverse effect on the dissolved-oxygen balance in the Jordan River. During 1981, there were at least 10 storms of sufficient duration to result in considerable runoff to the river. This number is a conservative estimate formed by examination of the storm characteristics of the following drainage basins: North Temple Conduit, 1300 South Conduit, and Big Cottonwood Creek (Christensen and others, 1984). Using the mean load for each variable from figures 18 to 21, a total annual storm load from the major point sources may be estimated (table 8). These represent "end of pipe" storm loads, with effluents from base flow and wastewater-treatment plants included.

Effects of Effluent from Wastewater-Treatment Plants

Seven wastewater-treatment plants in Salt Lake County and one in Davis County discharge secondary-treated effluent directly or indirectly to the Jordan River. All these plants, except the South Salt Lake City plant, are hydraulically overloaded (Gunnell and others, 1982, p. 61). The monthly average discharge from the Salt Lake County plants during 1981 ranged from 2.2 million gallons per day for the South Salt Lake City plant to 14.7 million gallons per day from the Salt Lake Suburban No. 1 plant (Jay Pitkin, State of Utah Division of Environmental Health, written commun., 1982). Monthly average flows from the plants were combined with the average monthly or bimonthly BOD_5 values (Frank Nabrotsky, Salt Lake City-County Health Dept., written commun., 1981, 1982) to calculate a mean load of oxygen-demanding substances as measured by BOD_5 discharged from each treatment plant (table 9 and fig. 22). Eighty-five percent (11,000 pounds) of the daily load as measured by BOD_5 from the treatment plants enters the river downstream from river mile 25 in a reach characterized by small reaeration rates and slight assimilative capacity for oxygen-demanding loads. Projection of the mean daily load for each plant to an annual load also is presented in table 9. It should be noted that these loads were measured using BOD_5, with the nitrification process uninhibited. This gives a slightly greater load than the storm loads measured by nitrification-inhibited BOD_5 calculated for this study. Additionally, loads measured by BOD_u would be about twice the loads as measured by BOD_5.

Table 8.--Estimated total loads, in pounds of oxygen-demanding substances, in annual-storm runoff entering the Jordan River from the major tributary creeks and storm conduits during 1981

[BOD_5, 5-day biochemical-oxygen demand; BOD_u, ultimate biochemical-oxygen demand; COD, chemical-oxygen demand; DOC, dissolved organic carbon; SOC, suspended organic carbon; values in parentheses represent that part of the load as measured by BOD_5 contributed by wastewater-treatment plants discharging to the 2100 South Conduit and Big Cottonwood Creek during the 10 storms.]

Site	BOD_5	BOD_u	COD	DOC	SOC
North Temple Conduit	2,500	4,800	22,300	2,200	1,000
800 South Conduits	1,800	3,600	13,700	1,100	1,100
1300 South Conduits	5,500	11,300	44,900	12,200	3,800
2100 South Conduit	3,400 (1,700)	7,300	15,600	2,600	600
Mill Creek	8,000	16,500	64,000	13,500	3,600
Big Cottonwood Creek	27,200 (23,000)	47,600	68,200	16,000	5,900
Little Cottonwood Creek	6,800	15,700	51,000	27,900	2,000
9000 South Conduit	2,300	3,600	21,100	7,000	19,300
Totals	57,500 (24,700)	110,400	300,800	82,500	37,300

Table 9.--Calculated loads of oxygen-demanding substances as measured by 5-day biochemical-oxygen demand discharged to the Jordan River by wastewater-treatment plants in Salt Lake County during 1981

Wastewater-treatment plant	River mile	Mean daily load (pounds)	Annual load (pounds x 1,000)
Sandy	31.7	757	276
Tri-Community	29.0	1,066	389
Murray	24.7	473	173
Cottonwood	24.0	4,343	1,585
Granger-Hunter	20.6	2,485	907
Salt Lake City Suburban No.1	20.5	3,45[illegible]	1,261
South Salt Lake	18.0	249	91
Totals		12,829	4,682

Annual Load of Oxygen-Demanding Substances

An annual point-source load of 6 million pounds of oxygen-demanding substances as measured by BOD_5 (table 10, fig. 23) was estimated using loads from storms and wastewater-treatment plants (tables 8 and 9) and loads at base-flow conditions in the major tributaries to the Jordan River (fig. 24). These tributaries are Little Cottonwood Creek; Big Cottonwood Creek; Mill Creek; Emigration, Parleys, and Red Butte Creeks (discharging from the 1300 South Conduit); and City Creek (discharging from the the North Temple Conduit). The base-flow loads were calculated using the mean load as measured by BOD_5 for nonstorm samples and the mean daily-flow rates from McCormack and others (1983).

The total loads as measured by BOD_5 contributed by the wastewater-treatment plants are 77 percent of the total load and constitute the largest point source of oxygen demand placed on the river. Base flows from the major tributaries contribute 22 percent and storm runoff less than 1 percent. The storm loads may be underestimated, but even if they were increased several fold, they would still be relatively insignificant compared to the loads from the wastewater-treatment plants. These loads would be reduced by a proposed regionalization of wastewater-treatment plants. Under such regionalization, the minimum dissolved-oxygen concentrations would be in the range of 5 to 6 milligrams per liter (Way, 1977, p. 11).

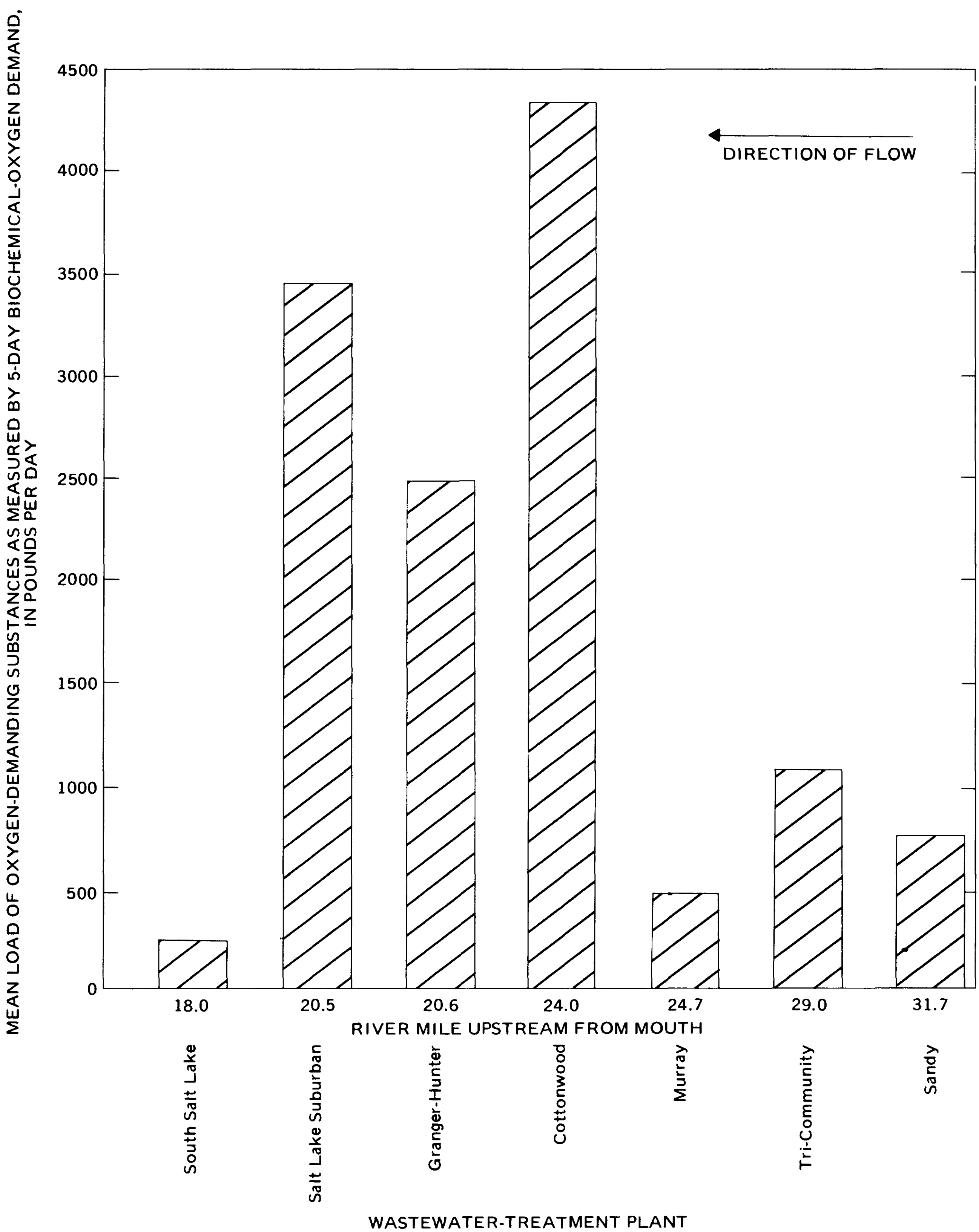

Figure 22.—Daily mean loads of oxygen-demanding substances as measured by 5-day biochemical-oxygen demand discharged to the Jordan River by wastewater-treatment plants during 1981.

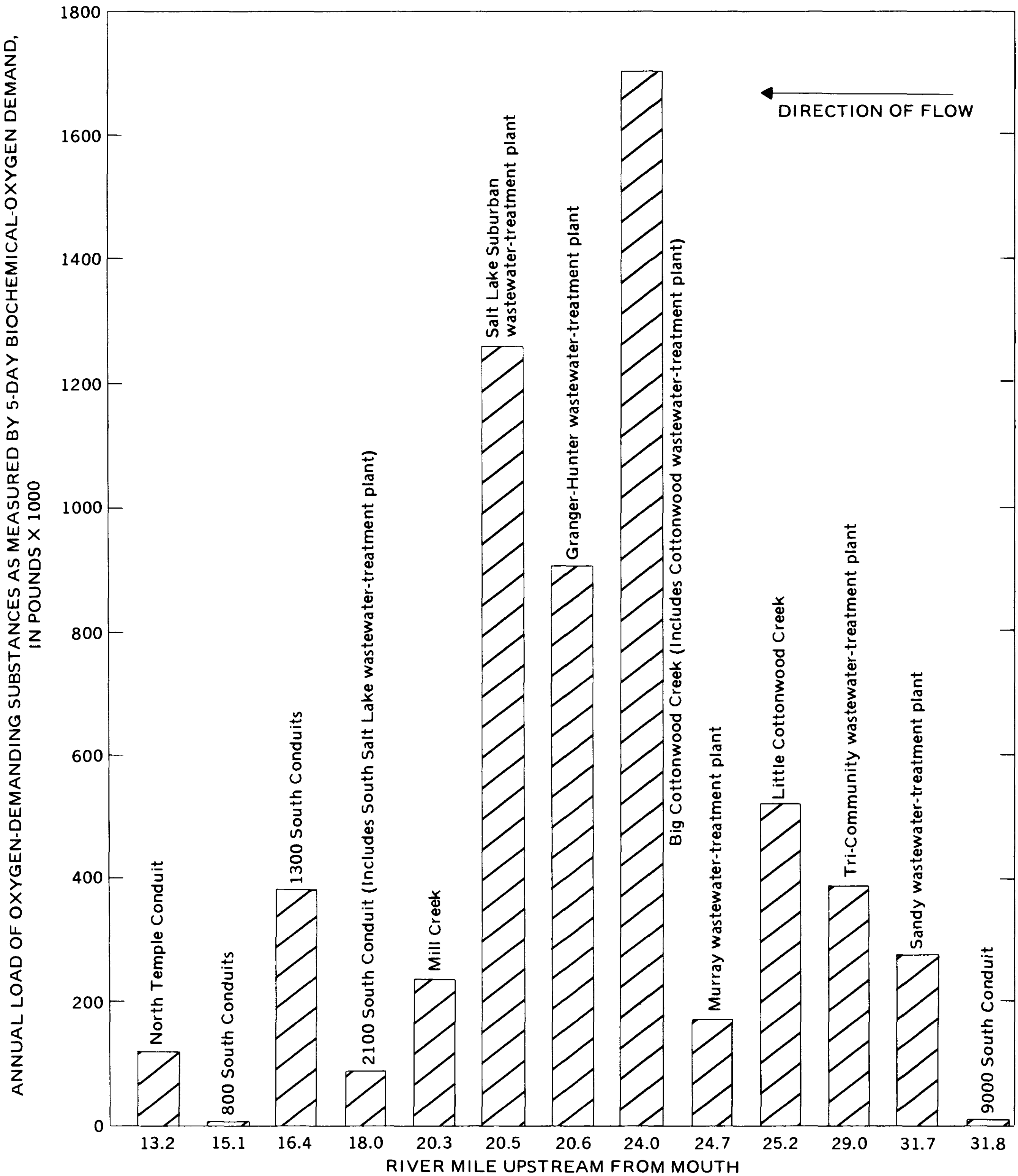

Figure 23.—Total annual loads of oxygen-demanding substances as measured by 5-day biochemical-oxygen demand discharged to the Jordan River during 1981 from point sources.

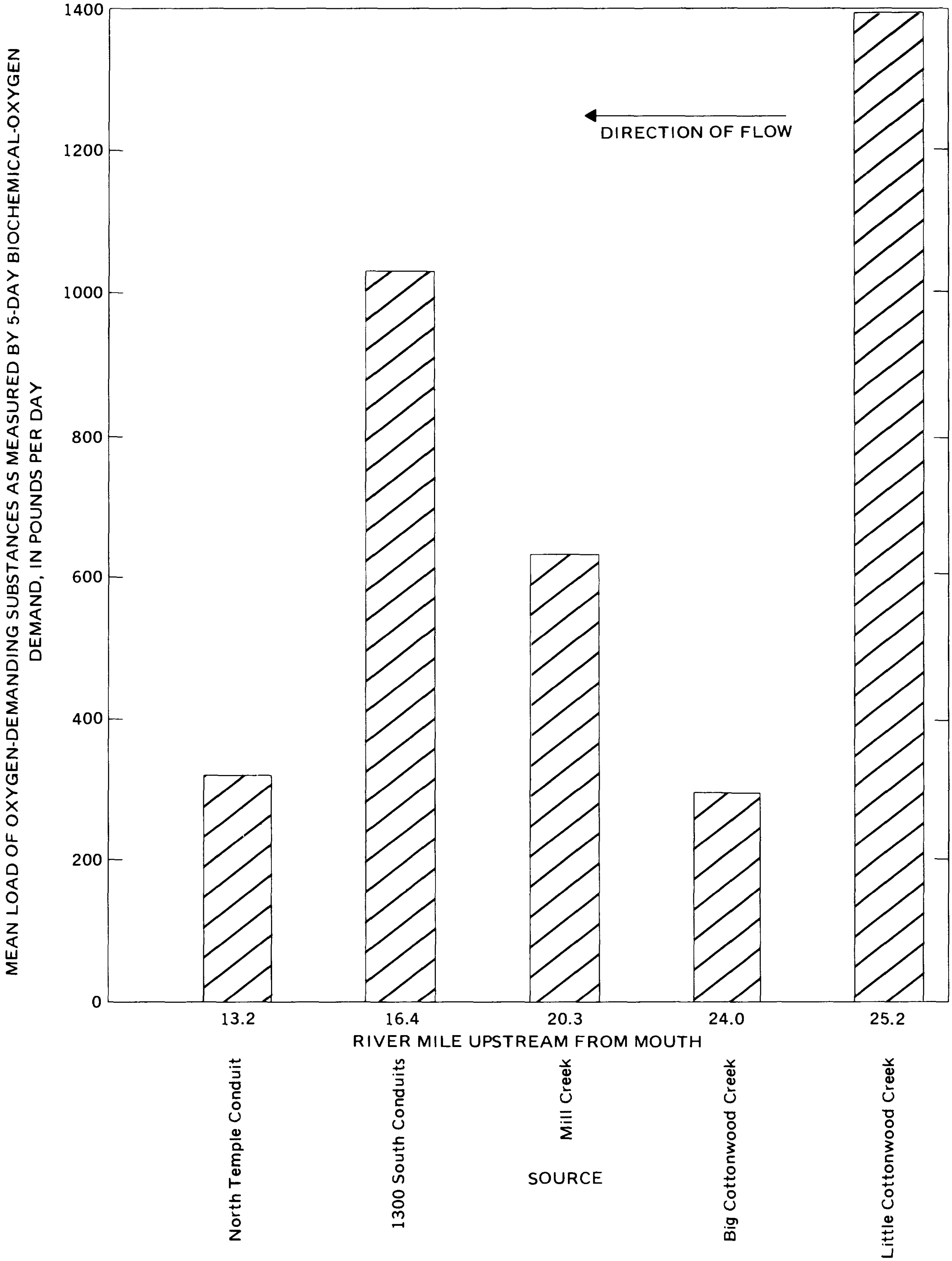

Figure 24.—Mean daily-nonstorm loads of oxygen-demanding substances as measured by 5-day biochemical-oxygen demand discharged to the Jordan River from Little Cottonwood, Big Cottonwood, and Mill Creeks, and conduits at 1300 South and North Temple Streets.

Table 10.—Summary of point-source loads of oxygen-demanding substances as measured by 5-day biochemical-oxygen demand to the Jordan River in Salt Lake County for 1981, in pounds

[Values in parentheses do not include loads from wastewater-treatment plants (WWTP) discharged to the 2100 South Conduit or to Big Cottonwood Creek during storms.]

Source	River mile	Base flow	Storms	Wastewater-treatment plants	Totals
9000 South Conduit	31.8	—	2,300	—	2,300
Sandy WWTP	31.7	—	—	276,300	276,300
Tri-Community WWTP	29.0	—	—	389,000	389,000
Little Cottonwood Creek	25.2	516,500	6,800	—	523,300
Murray WWTP	24.7	—	—	172,600	172,600
Big Cottonwood Creek, Cottonwood WWTP	24.0	108,400	(4,200)	1,585,200	1,697,800
Granger-Hunter WWTP	20.6	—	—	907,000	907,000
Salt Lake City, Sub. 1 WWTP	20.5	—	—	1,261,400	1,261,400
Mill Creek	20.3	231,000	8,000	—	239,000
2100 South Conduit, South Salt Lake WWTP	18.0	—	(1,700)	90,900	92,600
1300 South Conduit	16.4	376,700	5,500	—	382,200
800 South Conduit	15.1	—	1,800	—	1,800
North Temple Conduit	13.2	118,600	2,500	—	121,100
Totals		1.4×10^6	0.03×10^6	4.7×10^6	6.1×10^6

The actual effect of the loads as measured by BOD_5 probably is less than the values indicate. The implication of BOD_5 is that a specified quantity of oxygen will be used to degrade the oxygen-demanding substances at 20°C during 5 days. Although the temperature of 20°C is a reasonable approximation for the Jordan River during summer, 5 days is considerably longer than the typical time-of-travel of about 1 day for water to flow from 12300 South to 500 North Streets. If all the BOD_5 present in the river were completely dissolved and standing water and ponding were eliminated, only a fraction of the total load as measured by BOD_5 would be oxidized within the boundaries of Salt Lake County. The greatest actual demand on the aquatic system would be (and is) exerted in Farmington Bay. In practice, however, some of the load is in the form of suspended substances and organic material which forms aggregates and settles to the river bottom. In this form, the oxygen demands accumulate and persist and rapidly deplete oxygen in the overlying water.

Although the total load of oxygen-demanding substances, such as measured by BOD_5, that discharges to the Jordan River appears very large, not all this load actually remains in the river. The Surplus Canal at 2100 South Street diverts a large quantity of water (and its constituent load). During the 1981 water year, the total diversion to the Surplus Canal was 309,800 acre-feet, which was 72 percent of the flow in the Jordan River. Downstream from the diversion, the river had a total flow of 118,200 acre-feet during 1981. Ninety percent of the total load as measured by BOD_5 is discharged from point sources between 9000 South and 2100 South Streets. This is about 5.5 million pounds, of which only 28 percent (1.5 million pounds) is actually transported in the Jordan River downstream from the diversion to the Surplus Canal. Combining this load with the 600,000 pounds contributed downstream from 2100 South Street yields an actual annual load of about 2.1 million pounds in the river between 2100 South and 500 North Streets.

SUMMARY AND CONCLUSIONS

1. Comparison of historical data for the Jordan River at 1700 South and 5800 South Streets shows that mean dissolved-oxygen concentrations generally decreased from 1974 to 1981 but have increased slightly at both sites since 1981. Mean dissolved-oxygen concentrations during April to September of 1981 and 1982 ranged from 8.1 milligrams per liter at the Jordan Narrows to 4.7 milligrams per liter at 500 North Street. Means during October-March of 1981 and 1982 were 10.9 to 7.9 milligrams per liter. About one-half of all measurements of dissolved oxygen at 1700 South and 500 North Streets were in noncompliance with the State intended-use standard of 5.5 milligrams per liter.

2. Mean concentrations of oxygen-demanding substances as measured by chemical-oxygen demand and biochemical-oxygen demand increased over 200 percent as the Jordan River flowed through the Salt Lake Valley during October-March. Mean summer concentrations of BOD_5 ranged from 5 to 12 milligrams per liter between the Jordan Narrows and 500 North Street and mean winter concentrations from 7 to 18 milligrams per liter. About 40 percent of the samples collected upstream from 5800 South Street had BOD_5 concentrations that exceeded the State standard of 5 milligrams per liter, but nearly 90 percent of the BOD_5 concentrations downstream from 1700 South Street exceeded the standard.

3. Regression analyses identified water temperature and discharge as significant variables affecting dissolved-oxygen concentrations at three sites. Concentrations of suspended-organic carbon were inversely related to dissolved-oxygen concentrations at two sites. Nearly 100-percent variability in BOD concentrations obscured the expected inverse relationships of oxygen demand to dissolved-oxygen concentrations.

4. Reaeration rates (K_2 at 20°C) were large between 12300 South and 9000 South Streets, averaging nearly 12 per day during late summer flow conditions. Between 9000 South and 2100 South Streets, rates decreased to an average of 6.6 per day and were only 2.4 per day in the reach from 1330 South to 1800 North Streets. Reaeration was closely related to channel slope, showing marked decreases downstream from 4800 South Street where the channel slope decreases markedly. During low-flow conditions in September and October, travel time was 26 hours between 12300 South and 1800 North Streets.

5. Concentrations of phytoplankton chlorophyll a decreased from a mean of 36 micrograms per liter at the Jordan Narrows to 9 micrograms per liter at 500 North Street due to death of the algal cells and dilution by inflowing streams. Production of oxygen by photosyntheses did not result in a net gain of oxygen in 24 hours in the Jordan River downstream from 5800 South Street. Deficits of dissolved oxygen for a diel study in July 1981 ranged from 21.8 to 10.8 milligrams per liter in the reach from 5800 South to 500 North Streets. Examination of historical diel studies indicates that there was no net daytime gain in dissolved oxygen downstream from 12400 South Street in 1957, and only a modest gain of 1.8 milligrams per liter occurred in the Jordan River at the Lehi-Fairfield Road in 1972.

6. Concentrations of dissolved oxygen in the Jordan River during periods of storm runoff averaged 6.9 milligrams per liter and were significantly smaller (90-percent-confidence level) than the mean concentration of 8 milligrams per liter measured during nonstorm periods. Mean concentrations of oxygen-demanding substances measured by BOD and COD, and organic carbon appeared greater in storm runoff than in base-flow samples, although most of the differences were not statistically significant. The annual storm load as measured by BOD_5 (excluding discharge from wastewater-treatment plants) was estimated at 33,000 pounds.

7. Oxygen-demanding wastes discharged from wastewater-treatment plants constituted the greatest single-point source of BOD loading to the Jordan River. Total loads as measured by BOD_5 ranged from 0.09 million pounds for the South Salt Lake treatment plant to 1.59 million pounds for the Cottonwood plant during 1981. The total annual load from all plants was estimated at 4.7 million pounds. Eighty-five percent of this load was discharged to the river in the downstream reaches where the reaeration rates are the least.

The population of Salt Lake County is projected to increase and additional loads placed on already overburdened wastewater facilities will inundate them. A proposed regionalization of wastewater-treatment plants that will provide increased removal efficiency for oxygen-demanding waste is projected to result in minimum dissolved-oxygen concentrations of 5 to 6 milligrams per liter in the Jordan River.

8. The total oxygen-demanding load as measured by BOD_5 of 6 million pounds that was discharged to the Jordan River from point sources in 1981 consisted of 4.7 million pounds from wastewater-treatment plants, 1.4 million pounds from nonstorm streamflow, and 33,000 pounds from storm runoff. Diversion of nearly three-quarters of the discharge of the Jordan River to the Surplus Canal effectively decreased the total point-source load in the Jordan River downstream from 2100 South Street to 2.1 million pounds. Only a part of this demand is actually exerted in the Jordan River because maximum travel times through the Salt Lake Valley are less than 48 hours. Suspended and settleable fractions of the load, however, could result in the accumulation of considerable quantities of oxygen-demanding sediments on the river bottom.

9. Additional understanding of the dissolved-oxygen regime of the Jordan River could be obtained from the following studies:

A. Reareation measurements downstream from 4200 South Street under a variety of flow conditions;

B. Time-of-travel studies under much smaller velocities than were present during 1981-82;

C. Determination of oxygen demands exerted by river sediments and the effect of dredging on oxygen demand of sediment in the Jordan River; and

D. Mathematical modeling of the dissolved-oxygen balance using measured, rather than estimated, values for reaeration and oxygen demands of sediment.

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