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SEDIMENT OXYGEN DEMAND AND ITS EFFECT ON DISSOLVED OXYGEN IN A CUTOFF MEANDER OF THE KASKASKIA RIVER

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ABSTRACT

This study was designed to assess the relationship of sediment oxygen demand and dissolved oxygen in a cutoff meander of the Kaskaskia River. The results of the study should be useful to agencies such as Departments of Conservation, Corps of Engineers and the Environmental Protection Agency when assessing the impact of stream channelization on cutoff meanders of channelized streams. Cross-sectional profiles were used to determine area and total water volume in the meander. When stagnant or no-flow conditions prevailed, anoxic conditions created by sediment oxygen demand were observed in a significant part of the water in the meander. When no-flow conditions prevailed during summer months, as much as 25% of the water in the meander became anoxic while 65% fell below 5.0 mg/l. Sediment oxygen demand rates were more closely related to temperature than to sediment consistency or benthic macroinvertebrate numbers. Ambient sediment oxygen demand measured during the summer was almost three times greater than demand measured during the fall. While sediment oxygen demand in the channelized portion of the river was higher than in some stations in the meander, reaeration resulting from flowing water in the channel was sufficient to prevent anoxic conditions from developing.

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KEYWORDS--*sediment oxygen demand/ *cutoffs/ *meanders/ fluvial sediments/ *channel improvement/ *oxbow lakes/ *oxygen demand/ rivers/ sediment load/ lotic environment

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INTRODUCTION

Channelization of streams, which consists of straightening natural meanders, clearing vegetation from the banks, and widening and deepening channels, has been commonplace throughout the United States. Large rivers were originally straightened to provide greater access and safety for steamboats. Later, rivers were channelized to provide more land for agricultural endeavors. Still later, the building of roads, the need for flood control, and an increasing amount of river barge traffic justified more channelization under the Federal Flood Control Acts of 1948 and 1960 and the small watershed program of Public Law 566. The agencies primarily involved in channelization are the United States Corps of Engineers and the Soil Conservation Service.

A significant number of studies have focused on the effects of channelization on fishes and invertebrates, noting changes in populations as related to habitat modification. When a river or stream is channelized, channel modification not only destroys habitat and changes numerous environmental parameters but also alters meanders that have been left behind. When meanders are left behind, modified flow and temperature patterns impose new dissolved oxygen regimes on the system. These factors then become paramount in causing shifts in biological populations to organisms that are more tolerant of extreme environmental conditions.

Numerous studies have documented the decline of biota in rivers and streams following channelization (Tarplee et al., 1971; Trautman and Gartman, 1974; Hansen and Muncy, 1971; Golden and Twilley, 1976; Choate, 1972; Huggins and Moss, 1974). Morris et al. (1968), in a study of the Missouri River in Nebraska, reported that channelization of that river had reduced both the size and variety of aquatic habitats by destroying key productive areas. In a study of the Little Sioux River in Iowa, Hansen and Muncy (1971) found turbidity and water temperature to be higher in channelized reaches but did not report on dissolved oxygen levels. They also reported no difference in benthic organisms in channelized and unchannelized areas although numbers of drift organisms were higher in unchannelized reaches. The unchannelized section of the Little Sioux River had greater numbers of fish species. Groen and Schmulbach (1978) reported that the standing crop of sport fish was considerably greater in the unchannelized reaches of the middle Missouri River, probably as a result of more backwater aquatic habitat and greater habitat diversity in the unchannelized reaches of the river. Huggins and Moss (1974) reported lower biomass and numbers of fishes in channelized stream sections in Kansas. In a study of channelized tributaries on the upper Des Moines River, Zimmer and Bachman (1978) found a decline in habitat variability and invertebrate drift density.

In the Kaskaskia River, initial expectations were that cutoff meanders remaining after channelization would provide nursuries for fishes and other aquatic organisms. Preliminary work by Herricks*, however, indicated that dissolved oxygen was apparently a limiting factor during summer months. In an investigation of normal floodplain pools in the upper Kaskaskia River, Larimore et al. (1973) found that stagnation was experienced during late summer because of high productivity. They also reported that dissolved oxygen content in normal pools could be improved by flushing during floods; but, under static flow conditions coupled with an influx of organic detritus from surrounding woodlands and associated high temperatures, an extensive anoxic zone could be expected to develop during summer.

*E. E. Herricks, 1979; personal communication.

The contribution of sediments in reducing dissolved oxygen in the water column has been termed sediment oxygen demand (SOD). Sediment oxygen demand can be broadly defined as the usage of dissolved oxygen in water overlying benthic sediments as a result of chemical and/or biochemical reactions. Under aerobic conditions, SOD results principally from both micro and macro-organisms exerting a biochemical oxygen demand. The major micro demand is due to bacteria, but diatoms, protozoa, and aquatic fungi can also exert significant demand. Macro demand is caused by aufwuchs communities and burrowing fauna such as worms, insect larvae, nymphs, leeches, and mussels. Aufwuchs communities represent an important source of SOD in some streams, deep clear lakes, and the littoral zones of most lakes and large river pools. Chemical SOD results from reactive, reduced elements and substances such as ferrous iron and sulfides. Generally, chemical demand is exerted in lakes and impoundments exhibiting anoxic conditions in the hypolimnion. High immediate demand often occurs in such bodies of water when benthic material is disturbed and exposed to oxygenated water.

Over the past 15 years, considerable attention has been directed toward the effects of benthic oxygen usage on overlying waters in streams and lakes. Oxygen depletion due to the respiration of bottom dwelling organisms has long been recognized as contributing significantly to the overall environmental quality of a body of water, especially in deep lakes. Until recently, little work had been done to directly quantify oxygen usage rates. Most quantitative and qualitative work in the past has been performed with core samples in the laboratory. Now, however, more emphasis is being placed on *in situ* measurements, and numerous researchers are making significant contributions to the understanding of benthic respiration in a wide range of aquatic habitats, from deep marine environs to sludge lagoons. Bowman and

Delfino (1980) have compiled an excellent review of current methods for measuring SOD in the laboratory and the field. More specifically, Pamatmat and Banse (1969) and Pamatmat (1971) have studied mechanisms influencing oxygen consumption of deep-sea marine sediments. Crook and Bella (1970) and Sturtevant (1977) were interested in estuarine sediments and sediment oxygen demand.

Lake bottom respiration and its effect on deep water columns has received considerable attention in past years. Typical of such studies are those of Hargrave (1969), Snodgrass and Holloran (1977), and Polak and Haffner (1978). In situ SOD studies in flowing waters are not as numerous as lake or still water studies; however, research contributions of significance relative to this subject have been made in the last few years by investigators such as Hunter et al. (1973), Edberg and Hofsten (1973), James (1974), and Kreutzberger et al. (1980). Most of the early research relative to the effects of benthic deposits on dissolved oxygen in streams was oriented toward studying highly polluted sediments and sludge deposits. The early classic works of Baity (1938), Fair et al. (1941), and Velz (1958) are good examples of such research.

Through the years, many bench and in situ studies have been done to evaluate the effects of specific parameters on benthic respiration. Baity (1938), Edwards (1962), McDonnell and Hall (1969), Hargrave (1972), and Fisher and Beeton (1975) examined the relationship between SOD rates and DO concentrations. Duff and Teal (1965), Hanes and White (1968), and Hargrave (1969), are among the many who performed SOD-temperature experiments of various kinds. Fair et al. (1941), Velz (1958), McKeown et al. (1968), Oldaker et al. (1968), and Ogunrombi and Dobbins (1970) considered the effects of sludge (sediment) age and/or sediment depth on demand rates. Crook and Bella (1970), James (1974), and Hall et al. (1979) considered the effects of velocity at the sediment-water interface. Edwards (1962), Cox (1970), Hunter et al. (1973), and Fisher and Beeton (1975) have evaluated to a limited degree the quantitative and qualitative influence of macroinvertebrates on SOD, while Fair et al. (1941) and Ogunrombi and Dobbins (1970) were interested in fitting DO usage and uptake rates into finite mathematical relationships.

Other subjects related to SOD rates which have evoked some limited research are salinity levels (Hanes and White, 1968), benthic gas production (Hayward, 1968), nitrification (Oldaker et al., 1968), phosphorus release (Sonzogni et al., 1977), benthic algae productivity and photosynthesis (Crook and Bella, 1970), and pH levels (McKeown et al., 1968).

The first sediment oxygen demand studies performed in situ in Illinois were by Butts (1974) during the summer of 1973. The study was instituted because a detailed analysis and examination of dissolved oxygen and biochemical oxygen demand (BOD) in the upper Illinois River revealed that dissolved carbonaceous and nitrogeneous BOD was not sufficient to account for the low DO concentrations frequently observed. Subsequent SOD work performed in the state by the Illinois State Water Survey is outlined in reports or papers prepared by Lee et al. (1975), Butts and Sparks (1977), Butts and Evans (1978), Roseboom et al. (1979), and Butts and Evans (1979). These studies include almost all types of surface water which occur in the state, ranging from small intermittent streams to large glacial lakes. Samplers have been designed and developed for use in large streams (Butts, 1974), small streams (Butts and Evans, 1978), and lakes to minimize the effects of gas evolution from benthic sediments (Roseboom et al., 1979). To date, only one other agency has performed SOD measurements within the state; Polls and Spielman (1977) of the Metropolitan Sanitary District of Greater Chicago conducted an

SOD study of deposits in the deep draft waterways of Cook County. With the exception of one case, all these studies were designed to produce gross information on SOD rates.

The objectives of this investigation were to (1) evaluate the effects of channelization on dissolved oxygen and sediment oxygen demand in a cutoff meander of a major river, (2) assess habitat potential for fishes in relationship to dissolved oxygen during summer months, and (3) evaluate and propose, if feasible, an alternative method of connecting cutoff meanders to the main stream of a river in future channelization projects.

The objectives were to be accomplished by (1) quantifying the impact of sediments on dissolved oxygen in the overlying water column by using a sediment oxygen demand sampler, (2) determining organic and inorganic constituents of water and sediments, and (3) developing profiles of dissolved oxygen, temperature, and conductivity in both the meander and main channel. All objectives were met, with the exception of determining organic and inorganic constituents in the water column.

DESCRIPTION OF STUDY AREA

This study was conducted on a cutoff meander of the Kaskaskia River. The Kaskaskia River originates near Champaign, Illinois, at an elevation of 247 km mean sea level and flows 525 km to the southwest, draining a watershed of 14,120 km^2 before entering the Mississippi River (Larimore et al., 1973). It is a turbid, warmwater stream and along its lower reaches, stream gradient is less than 0.6 m per km (Larimore et al., 1973). Two impoundments, Lake Carlyle and Lake Shelbyville, lie upstream of the study area on the main stem of the river. Events affecting the lower Kaskaskia River during the past century along with a review of investigations that have concerned the river's water quality and aquatic habitats has been well documented (Larimore, 1978).

Six stations were selected for study along a 6.5 km cutoff meander (Fig. 1). Dissolved oxygen and temperature profiles were taken at Stations 1 through 5. Sediment oxygen demand was determined at Stations 1 through 5 and Station 2D. The diurnal was conducted at Stations 1, 2D, 3, 4 and 5.

Water depth in the meander varied with rainfall conditions and water levels in the two upstream impoundments. Maximum depth observed during the study was 7.0 meters at Station 3 on April 6, 1979. Cross-sectional areas of each station were measured on October 26, 1979 at a time when water depth at each station varied between 2.5 and 4.0 meters (Figs. 2 and 3).

Channelization of the lower reaches of the river was begun in 1962 to make the lower part of the river navigable from its confluence with the Mississippi River upstream to Fayetteville, Illinois. Approximately 81 km of river were eventually cut to 58 km of canal with a 2.74 m deep, 91.5 m wide channel. In the process, part of the river's main stem was dredged and made a part of the channel; unusable meanders were sealed off from the main stem of the stream at the upper end but were left connected at the lower end. During spring floods, water flows across the plug at the upper end of the meander. The greatest percentage of bottom sediments obtained from the meander were fine-grained, silty materials less than 0.074 mm in diameter (Fig. 4). Sediment samples obtained from the channelized section of the river, however, were coarse-grained sands. Fallen trees, brush piles, and lob jams were present in the meander. Trees and shrubs lined the bank and provided a fair amount of cover. On the other hand, vegetation had been cut back from the channelized section of the river and banks and been riprapped.

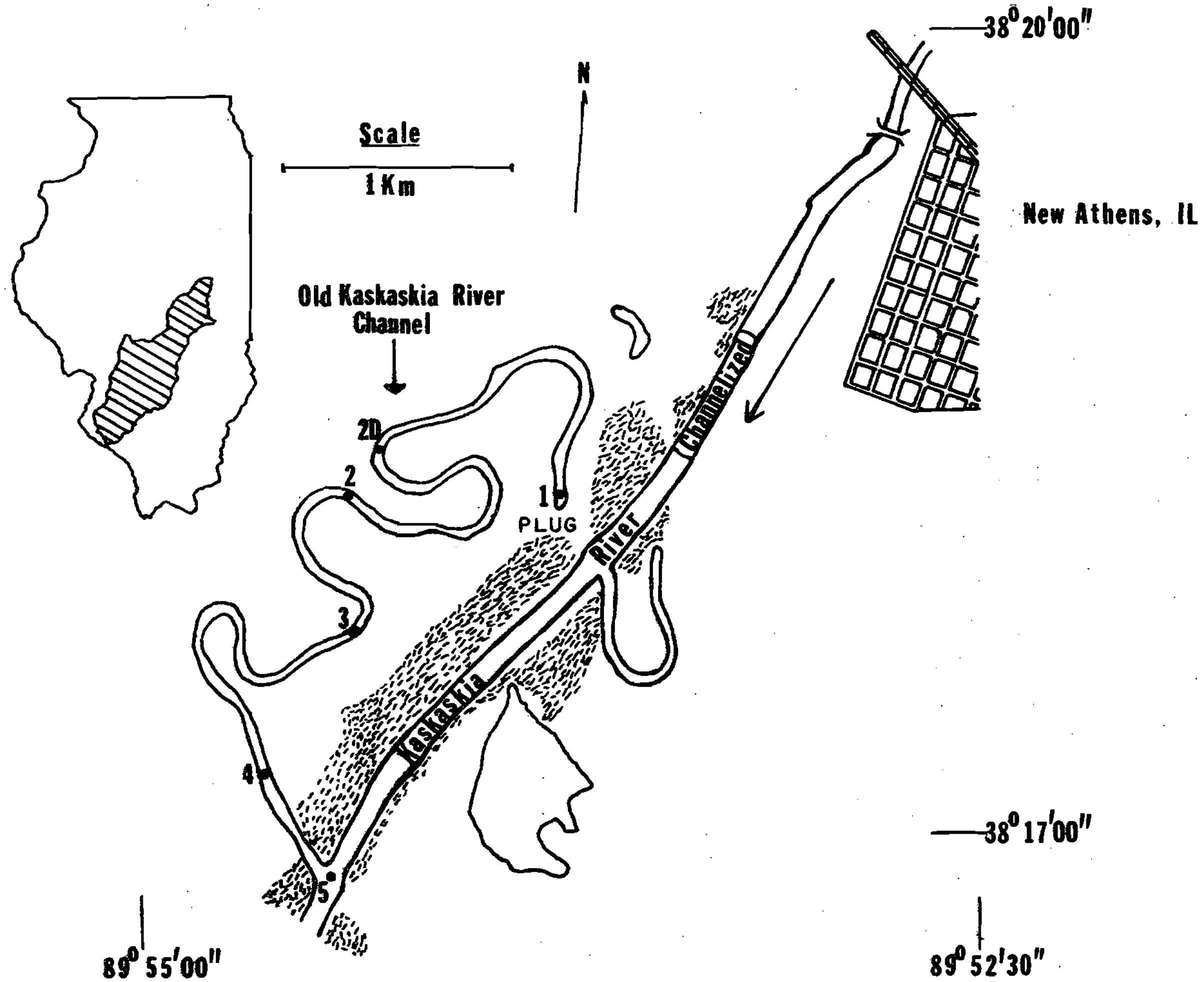

Figure 1. Map of study sites on the Kaskaskia River.

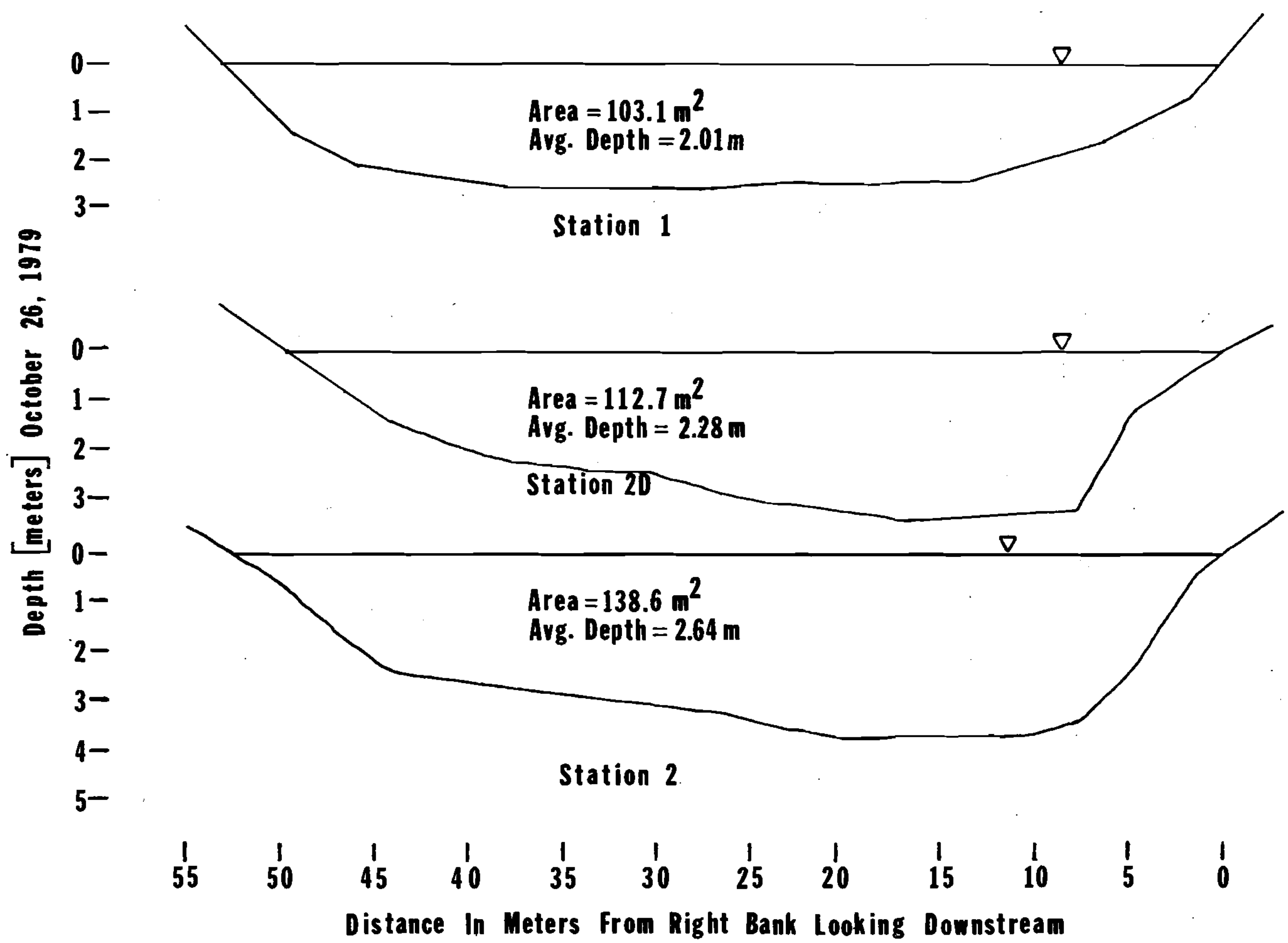

Figure 2. Cross-sectional profile of three upper stations on cutoff meander of Kaskaskia River.

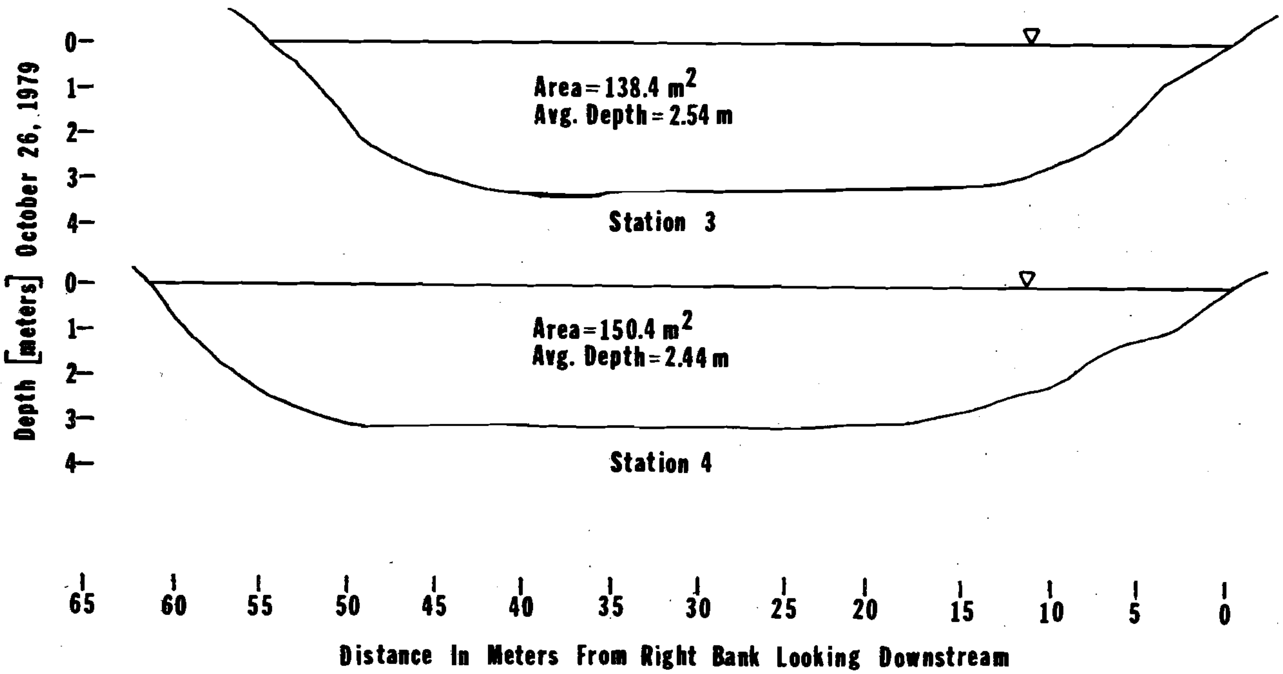

Figure 3. Cross-sectional profile of two lower stations on cutoff meander of Kaskaskia River..

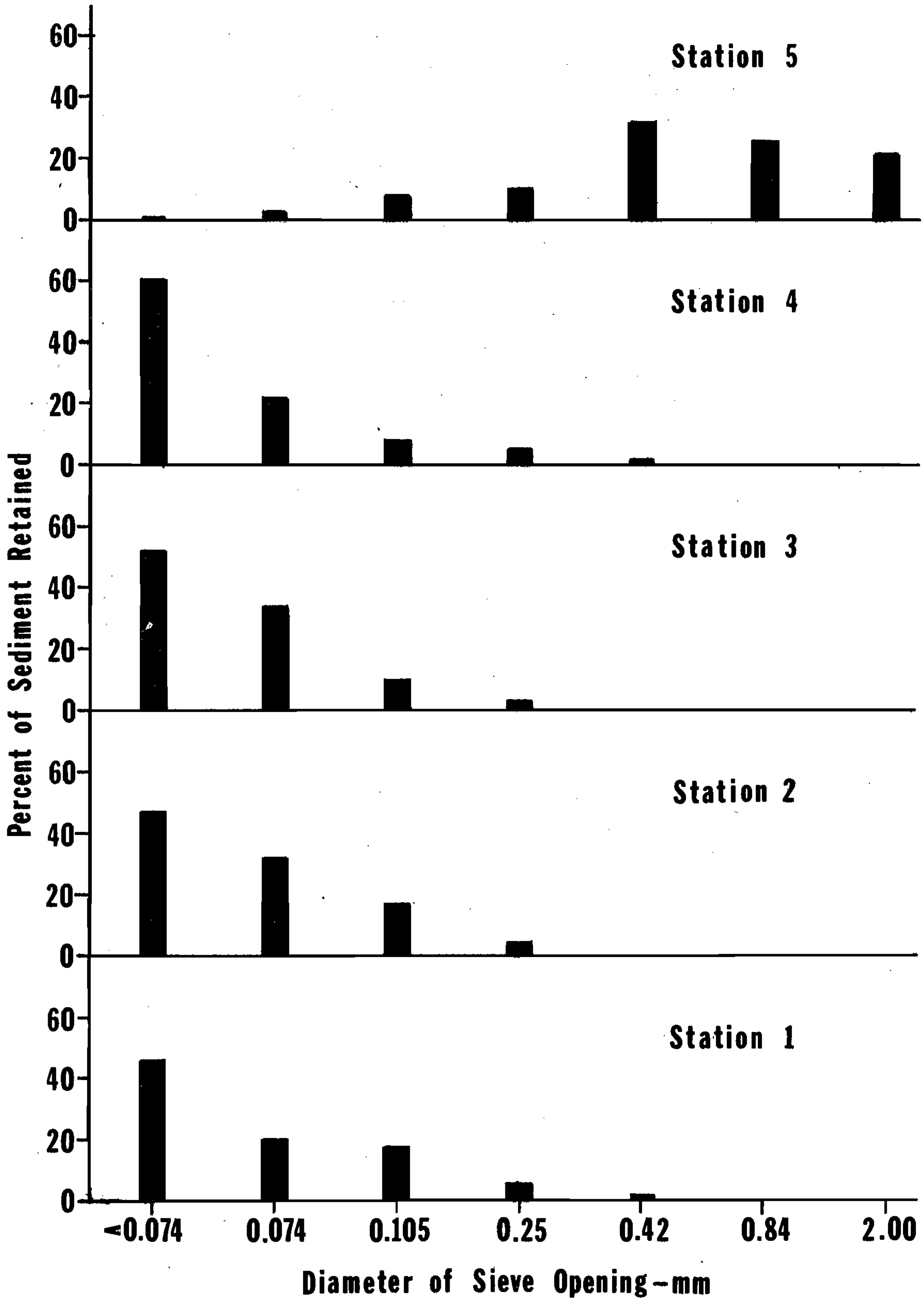

Figure 4. Distribution of sediment particle size.

METHODS AND MATERIALS

Physico-Chemical

Alkalinity was measured in the field according to Standard Methods, while pH was measured colorimetrically with a Hach Field kit or with Hydrion paper. Turbidity was measured in the laboratory with a Model 2100-A Hach Nephelometer. Secchi disc readings were taken with a 23 cm disc.

Sediment samples were collected by using either a core sampler or a Peterson dredge. Volatile constituents in sediments were determined by drying samples at 105°C until a constant weight could be obtained and then ashing at 600°C. Sediment particle size was determined by using standard soil sieves.

Dissolved oxygen was measured by calibrating a YSI Model 54 Oxygen Analyzer by means of the modified Winkler technique. The diurnal oxygen curve method of analysis was used to estimate photosynthesis and respiration rates (Odum, 1956; Odum and Hoskin, 1958; and Odum and Wilson, 1962). Temperature was measured by means of a thermistor attached to the oxygen analyzer. Conductivity was measured in the field by means of a YSI Model 33 conductivity bridge and standardized to 25°C. The depth of the euphotic zone was measured with a G.M. Instruments Mfg. Co. submarine photometer.

Sediment samples were also obtained during SOD runs by using a 22.9 cm Ponar dredge. Approximately 65 to 75 grams of sediment were taken from the top few centimeters and placed in a sealed plastic bag. This sample was returned to the laboratory and analyzed for total and volatile solids.

Benthic organisms were collected by means of a 22.9 cm Ponar dredge and then separated from sediments by means of a Wildco Model 190 No. 30 mesh sieve. Organisms taken from sediments were preserved in large plastic bottles using either ethyl alcohol or a 10 percent formalin solution. Only one benthic sample was taken at each SOD sampling station. The benthic data are used principally to indicate orders of magnitude of bottom degradation.

To estimate the percentage of water in the meander with 0 ppm DO, 4 ppm DO and 5 ppm DO on each sampling trip, cross-sectional profiles developed from soundings taken during low water conditions on October 25 and 26 were used as references for volume adjustments.

Sediment Oxygen Demand

In situ sediment oxygen demand (SOD) measurements were made on two occasions during July and October at six locations to obtain gross measurements of sediment oxygen uptake (Fig. 1). The equipment for SOD measurement and procedures utilized during this study are adaptations and modifications of those originally developed by the Water Quality Section of the Illinois State Water Survey for use in determining the influence of sediments on dissolved oxygen balance along the upper reaches of the Illinois River and small northeastern Illinois streams (Butts, 1974; Butts and Evans, 1978). Figure 5 shows the small boat setup as utilized in this study, and Figure 6 depicts the sampler design.

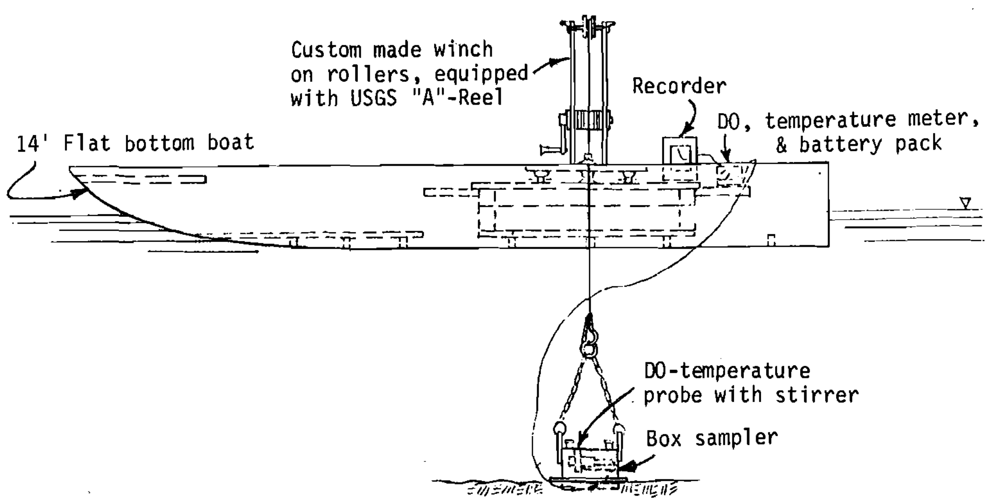

Figure 5. Arrangement of SOD measuring equipment in a small boat.

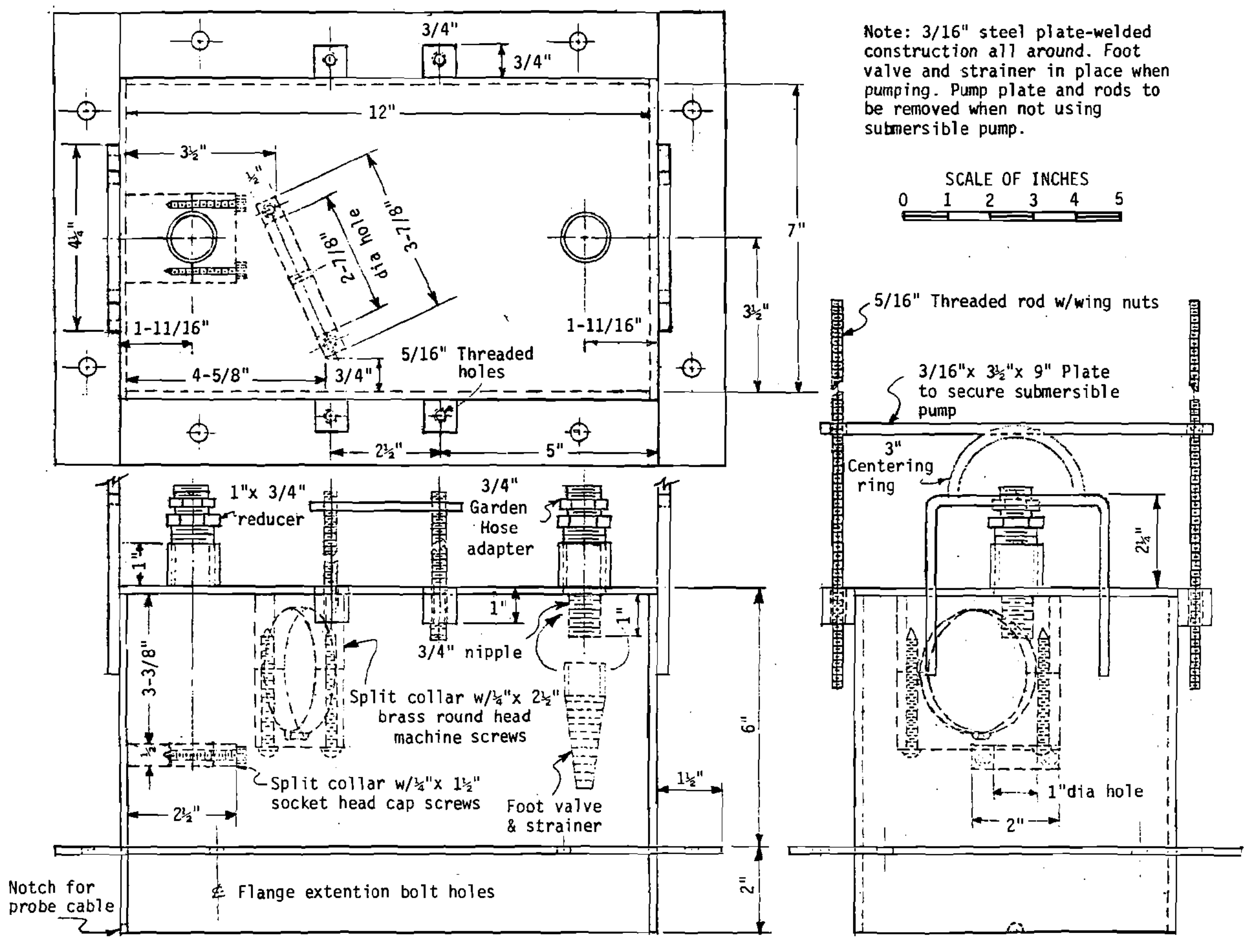

Figure 6. Details of box sampler used in SOD measurements.

The sampler employs what is defined by Bowman and Delfino (1980) as a batch system. Its operation consists essentially of isolating a known volume of water over a given bottom area and measuring dissolved oxygen drop with a galvanic cell oxygen probe that is secured internally. Water velocity across the face of the probe can be maintained by using an internal electrical stirring mechanism or by circulating water externally with a pump located aboard the boat. For this study, internal stirring was employed using a YSI Model 5795 submersible stirrer in conjunction with a YSI Model 57 DO meter attached to a battery operated recorder for a continuous readout for DO. The DO probe is calibrated with ambient river or lake water using the standard Winkler method.

After expelling trapped air from the sampler, it is lowered to the bottom. DO readings are recorded manually every five minutes, and temperature is recorded only at the beginning and end of a run.

During the run interval, two DO bottles were incubated at the bottom to determine if dissolved biochemical oxygen demand is significant. Also, plankton samples were collected and preserved in a 10 percent formalin solution for counting and species identification.

Sediment oxygen demand curves traced by the recorder in the field were used as an aid in analyzing and interpreting specific SOD rates (Appendix A). The interpretation of these curves is somewhat subjective and open to judgement. A number of variables and parameters are either measured or computed to aid in ascertaining causes and effects of SOD rates as described by the curves.

The raw SOD rates recorded in the field are in units of milligrams per liter per minutes (mg/l/min) and must be converted to more applicable units of grams per square meter per day ($g/m^2/day$). The general conversion formula is:

$$SOD_T = (1440SV)/10^3\ A) \quad (1)$$

where:

SOD_T = sediment oxygen demand rate in g/m^2/day at ambient temperature conditions, T^oC

S = slope of some portion of the curve in gm/1/min

V = volume of sampler in liters

A = bottom area of sampler in m^2

Specifically for this study, the formula for the box sampler and stirrer combination when seated up to the flanges in sediment is:

$$SOD = 205.5S \quad (2)$$

The very high initial DO usage rates exhibited by disturbed sediments may be caused by chemical reactions (Wang, 1980). Many SOD curves, especially those generated for polluted sediments, become linear after the effects of initial bottom disturbances have subsided. A trend toward linearity indicates a high bacterial oxygen demand. Baity (1938) found that in the absence of a significant macroinvertebrate population, SOD rates are independent of the DO concentration, especially in sediments which give a linear curve. Others (McDonnell and Hall, 1969; Butts and Sparks, 1977; Edwards and Rolley, 1965; Rolley and Owens, 1967) have shown that, in the presence of a large macroinvertebrate biomass, sediment oxygen uptake is correlated in some degree to the dissolved oxygen concentration at the sediment water interface. Consequently, a curvilinear usage curve indicates that macrofauna may contribute significantly to the SOD. A good semilog fit indicates that the demand is caused principally by macrofauna since such respiration theoretically occurs at a rate in proportion to oxygen concentration. Therefore, as standard practice, the data are routinely subjected to statistical regression curve fitting techniques.

The *in situ* SOD rates measured at ambient water temperatures were corrected to two common temperatures, 20°C and 25°C, for comparative purposes using the modified Arrhenius model. This model is widely used in water quality studies involving the stabilization of organic wastes in aqueous environments. The general form of the model is:

$$R_T = R_R \, \Theta^{T-R} \qquad (3)$$

where:

R_T = biological reaction rate at temperature, T°C

R_R = biological reaction rate at reference temperatures, R°C

Θ = temperature coefficient

A Θ value of 1.047 is widely accepted for use in adjusting dissolved carbonaceous biochemical oxygen demand (BOD) for temperature variations (Kothandaraman, 1968). Velz (1970) suggested that a value of 1.047 is also appropriate for use in adjusting SOD rates. SOD rates published in previous State Water Survey reports dealing with this subject have been adjusted to common temperatures using 1.047. Recent research on SOD rate changes with temperature indicates that a somewhat higher value in the range of 1.085 should be used (Walker and Snodgrass, 1978). The use of a value higher than 1.047 appears justified under some circumstances. Oldaker et al. (1968), for example, found that up to 44 percent of the SOD measured in various kinds of sediments is due to nitrification and that nitrification rate changes in aqueous solutions are more rapid with respect to temperature than is carbonaceous BOD. In a study of secondary sewage effluents, Zanoni (1967) found that a Θ-value for nitrification temperature corrections up to 22°C should be 1.097. Above 22°C, however, the temperature coefficient became variable and dropped off rapidly with temperature increases up to 30°C. Consequently, if similar circumstances can be translated to SOD rates, then those sediments having a large percentage of nitrogenous demand probably exhibit large rate increases with respect to temperature changes up to 22°C, whereupon a sharp drop-off in activity will likely occur. Because a Θ value of 1.085 is the first definitive value derived expressly as the result of SOD work, this figure will be used in this report to adjust the results of this and other studies to the common base temperatures of 20°C and 25°C.

In this study, linear, semilog and log-log fits were made and compared using correlation coefficients and standard error of estimates. Stepwise multiple regression techniques were also used to compare six independent variables with SOD, the dependent variable. The independent parameters were: (1) water temperature, (2) dissolved oxygen concentration in the sampler, (3) logarithms of the total number of macroorganisms, (4) logarithms of the total number of plankton, (5) percent dried solids, and (6) percent volatile solids. This analysis is made routinely to ascertain if relationships exist between readily measured physical, chemical, and biological parameters and SOD. If casual relationships are found to exist, the results can be useful in data interpretation relative to causes and effects.

Oxygen and temperature profiles were plotted following each sampling trip (Appendix B). Water was observed flowing over the plug at the upper end of the meander on April 6, 1979 and May 1, 1979. A flow measurement taken on April 6, 1979 indicated a flow rate of 0.04 m/sec. Water was 1.2 m deep over the plug at that time.

RESULTS AND DISCUSSION

Physico-Chemical

Alkalinity, pH, turbidity and specific conductance readings are summarized in Table 1. Turbidity, as measured in nephelometric turbidity units (NTU), varied with flow and water level. Station 5, however, exhibited a higher average reading than other stations. Secchi disc readings also indicated considerable variability in turbidity, but some of the variability was not significant (Tables 2 and 3).

Table 1

Physico-Chemical Conditions

Station		Alkalinity HCO_3(ppm)	Alkalinity CO_3(ppm)	pH	Turbidity (NTU)	Specific Conductance (μmhos/cm @25°C
1	Mean	167	8.0	8.1	21	343
	Range	135-210	---	7.7-8.6	5-72	203-446
2	Mean	161	30.0	8.3	8	373
	Range	121-187	---	8.0-8.6	2-16	209-800
3	Mean	153	8.5	8.3	14	373
	Range	113-159	7.0-10.0	7.2-8.6	4.52	191-800
4	Mean	158	4.0	8.0	18	380
	Range	137-190	---	7.2-8.6	7.52	210-600
5	Mean	147	7.0	7.9	40	374
	Range	110-198	---	7.2-8.5	15-78	200-632

When water level in the main channel fell below the level of the plug in late spring, the onset of oxygen depletion in lower depths of the meander became evident. All four stations in the meander exhibited severe oxygen de-

Table 2

Secchi Disc Readings in Centimeters

Station	Number of Readings	Mean	Range	Confidence Interval (95%)
1	11	34.6	15.2-71.0	24.4-44.8
2	11	39.8	19.1-66.0	30.3-49.4
3	11	40.9	19.1-55.9	31.7-50.1
4	11	33.5	19.1-48.3	25.6-41.3
5	11	22.5	8.9-33.1	16.7-28.3

Table 3

Tukey Multiple Range Test Comparing Means of Secchi Disc Readings in Centimeters

Station	5	4	1	2	3
Mean	22.5	33.4	34.6	39.8	40.9

Means underlined by the same line are not significantly different at the 0.05 level.

pletion below two meters during summer months. DO was present from surface to bottom in the channelized section at all times, although some stratification was observed late in the summer, especially during the periods of little or no flow. During the final sampling trip in October, DO profiles were essentially vertical with the exception of Station 1.

During summer months, a significant percentage of water in the meander exhibited DO concentrations less than 5.0 ppm. This figure has been adopted by the Illinois Pollution Control Board (IPCB) as a part of its Rules and Regulations for general use waters. The regulation states that dissolved oxygen shall not be less than 6.0 mg/l during at least 16 hours of any 24 hour period, nor less than 5.0 mg/1, at any time (IPCB, 1979). The volume of water in the meander was computed from cross-sectional measurements made on October 26, 1979 and found to be 856,079 cubic meters (Table 4). From these measurements, the percentage of water in the meander at or below Illinois Pollution Control Board minimums was computed (Fig. 7). On May 30th (day 150), for example, fully 25 percent of the water in the meander was anoxic, while 55 percent of the water volume fell below IPCB minimums.

Table 4

Volume of Cutoff Meander by Section
on October 26, 1979

Section	Weighted Length (meters)	Weighted Volume (cubic meters)
1	805	82,958
2D	1368	154,131
2	1287	178,412
3	1609	222,674
4	1449	217,904
Total	6518	856,079

Diurnal Oxygen Curve Analysis

The diurnal changes in DO concentration during hot summer days can be seen in figure 8. With the exception of Station 1, there is a rather sizeable increase in oxygen production during daylight hours. As oxygen concentration in the euphotic zone increased during daylight hours, some DO was recorded just off the bottom for a part of the late afternoon and evening, disappearing sometime around midnight. The effect of flow in keeping DO at lower depths is dramatically illustrated by Station 5. While DO in the cutoff meander on July 11 and 12 fell below 5.0 ppm between 1.5 and 2.0 meters, DO in the channelized stretch was above 5.0 ppm on the bot-

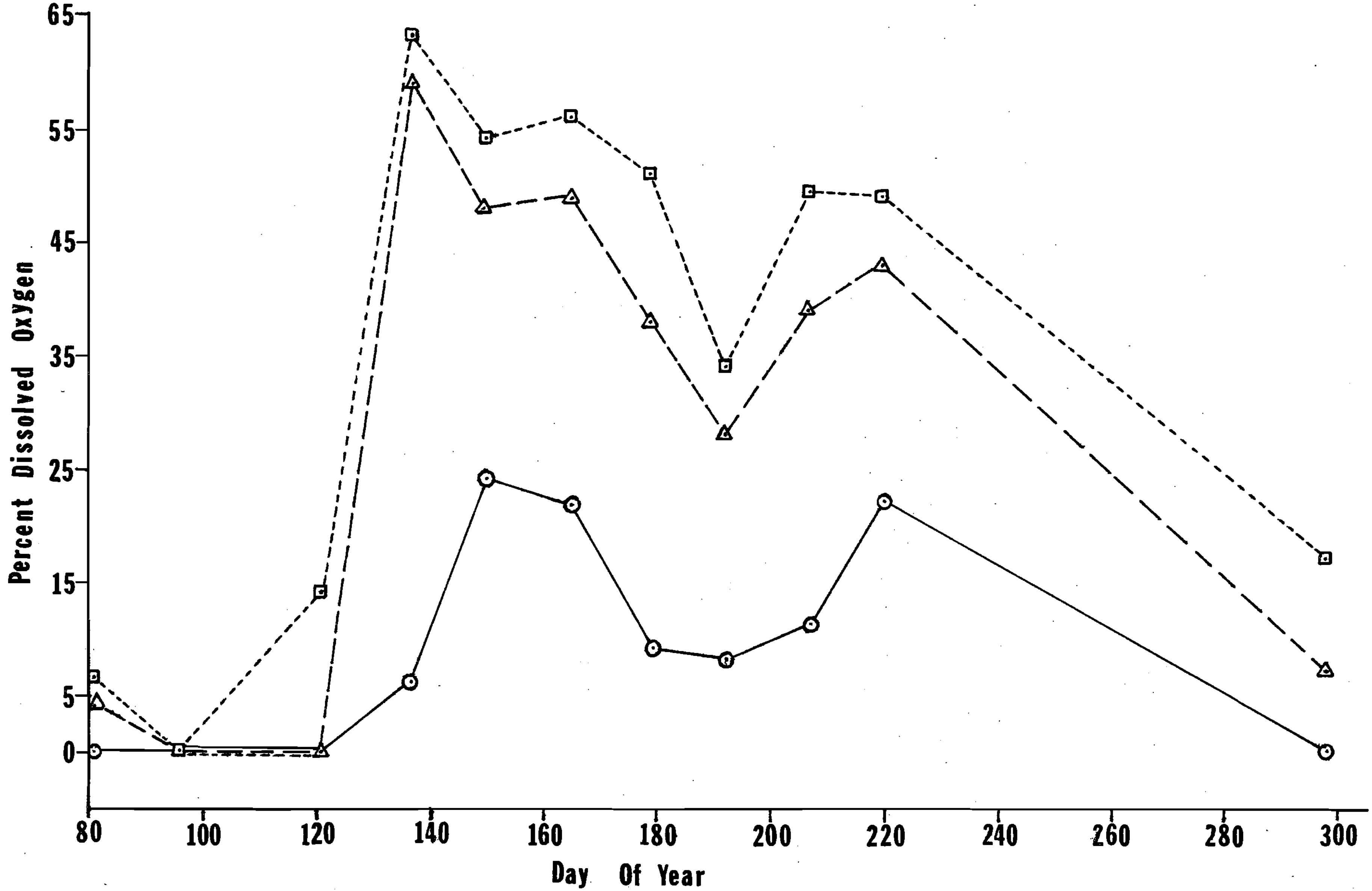

Figure 7. Percent of water volume in Kaskaskia River cutoff meander having dissolved oxygen values at 0 ppm (⊙——⊙), ≤ 4 ppm (△——△), and ≤ 5 ppm (⊡——⊡), during summer of 1979.

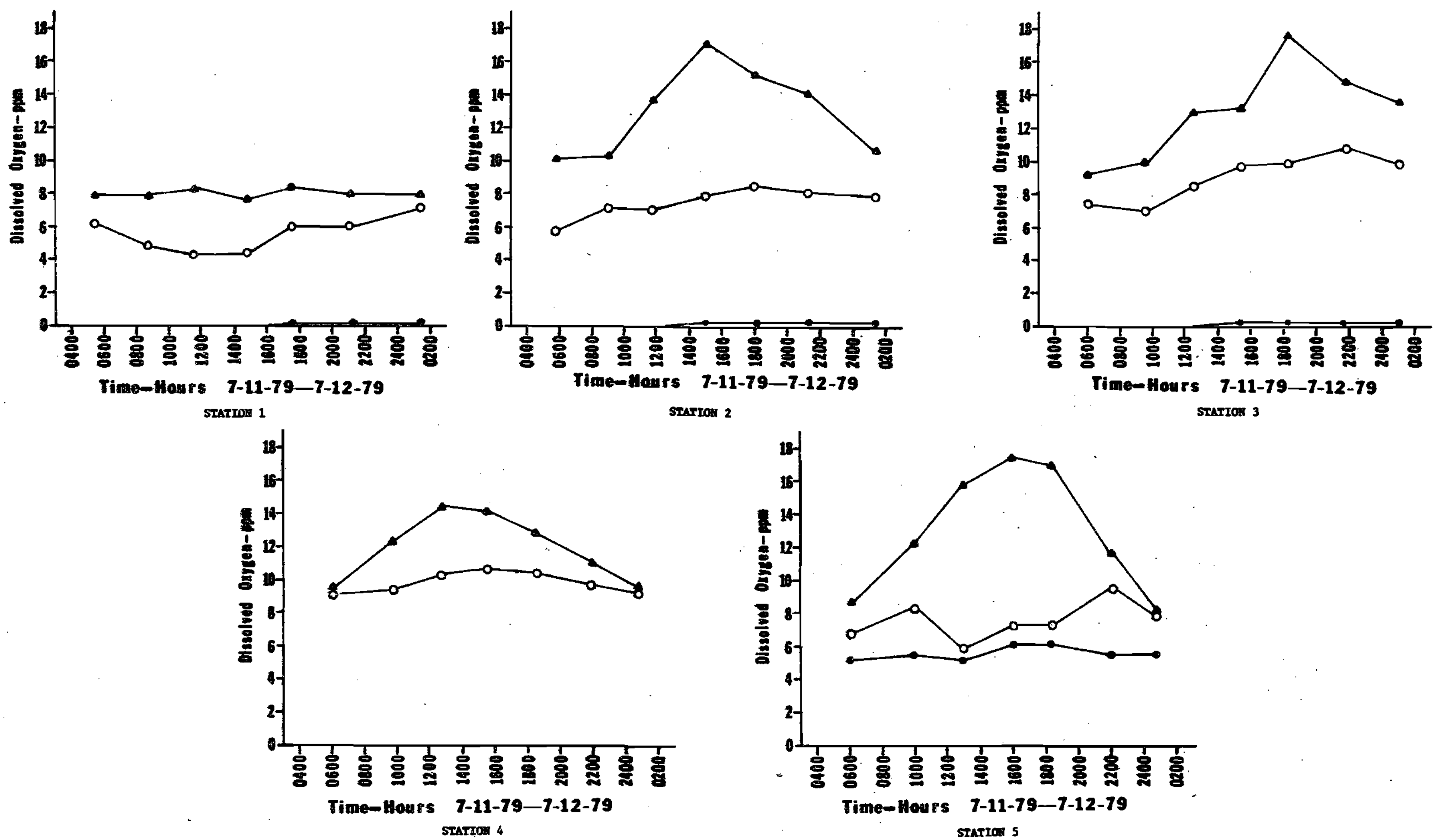

Figure 8. Diurnal changes in dissolved oxygen on July 11-12, 1979. (▲—▲) = surface; (○—○) = 1.2 meters; (●—●) = bottom.

tom. Maximum water depth in the meander on this date varied from 2.8 meters at Station 1 to 3.7 meters at Station 2, while water depth at Station 5 was 4.5 meters.

The diurnal oxygen curve analysis of photosynthesis and respiration rates revealed autotrophic conditions (P/R ≥1) at all diurnal sampling stations (Table 5). The lack of an extensive overlying canopy, coupled with a rather deep euphotic zone (depth to which one percent of incident light penetrates) apparently contributed to this condition.

Table 5

Results of the Diurnal Oxygen Curve of July 11-12, 1979

Station	Photosynthesis (P) $g/O_2/m^2/day$	Respiration (R) $g/O_2/m^2/day$	P/R	Depth of Euphotic Zone (meters)
1	1.1	1.1	1.00	0.60
2D	8.1	7.9	1.03	0.96
3	15.8	13.9	1.14	1.00
4	8.0	6.2	1.30	0.96
5	12.0	10.8	1.11	0.81

Water temperatures at stations in the meander were similar to those in the channelized section of the study area near the surface. At greater depths, however, lower temperatures were observed in the meander, especially during summer. Maximum surface temperature observed during the study was 29°C at Stations 2 and 5. Other stations had maximum temperatures within 1°C of this. Gelroth and Marzolf (1978), in a study of a small (second order) Kansas streams, reported P/R ratios of less than one in an unchannelized stretch but greater than one in the channelized portion. In that study, however, water temperatures varied from 26.3°C in the natural area to 31.2°C in the channelized stretch.

Sediment Oxygen Demand

SOD runs were completed at six stations during July and October of 1979. Run times averaged approximately 70 minutes. Respiration from suspended algae in the sampler appears to have had minimal influence on the results, as incubated DO bottles showed no significant change in dissolved oxygen over the course of a run. Also, plankton counts were relatively low (< 1,800/ml) when compared to those encountered during an algal influenced, warm weather SOD run made on Horseshoe Lake where counts exceeded 100,000 per ml (Butts and Evans, 1979).

The SOD curves traced by the field recorder and presented in Appendix A were also manually recorded and are presented in Appendix C. These data were used to compute ambient SOD rates. The results, including the estimated 20°C and 25°C rates, are presented in Table 6. The last or underlined value listed for each specific station represents the linear or the most stable portion of each curve, and, as a consequence, these values have been used to evaluate water quality conditions relative to DO depletion.

Volatile solids in sediments were measured at each station to ascertain the role they play in producing SOD. Station 5 exhibited the lowest mean percentage of volatile solids while Station 3 exhibited the highest value (Table 7). The variability in volatile solids between stations was significant as indicated in Table 8. When the means were compared with the Tukey Multiple Range Test, Station 5 was the only station that was significantly different from all others at the 0.05 level of significance (Table 9). Volatile solids were not highly correlated with SOD in this study, which corresponds with the findings of similar studies conducted by Butts (1974), Butts and Evans (1978), Butts and Evans (1979), Hunter et al. (1973) and James (1980).

Table 6

Ambient and Temperature-Corrected SOD Rates

Date	Station	Temperature T(^{o}C)	Time Frame (minutes)	SOD (g/m^2/day) T^{o}C	20^{o}C	25^{o}C
7/10/79	1	26.8-26.8	0-2	20.55	11.80	17.74
		26.8-26.5	2-10	3.85	2.24	3.37
		26.5-25.0	10-70	1.80	1.12	1.69
	2D	25.8-25.8	0-3	10.28	6.40	9.63
		25.8-25.3	3-12	3.42	2.18	3.27
		24.8-24.8	12-67	2.24	1.52	2.28
	2	25.5-25.2	0-13	9.48	6.13	9.22
		25.2-24.8	13-33	5.14	3.42	5.14
		24.8-24.0	33-68	3.52	2.46	3.70
	3	25.2-25.2	0-5	10.28	6.72	10.11
		25.2-23.2	5-70	4.43	3.14	4.72
	4	26.8-26.8	0-3	34.25	19.67	29.57
		26.8-23.8	3-68	4.11	2.67	4.01
	5	26.0-25.8	0-68	2.57	1.59	2.39
10/25/79	1	16.2-15.8	0-22	0	0	0
		15.8-14.9	22-72	1.64	2.40	3.61
	2D	14.9-14.9	0-5	6.17	9.35	14.05
		14.9-14.8	5-20	3.42	5.21	7.83
		14.8-14.5	20-65	0.68	1.06	1.59
	2	14.5-14.5	0-3	13.07	21.46	32.27
		14.5-14.5	3-13	2.06	3.22	4.83
		14.5-14.4	13-53	1.03	1.62	2.43
	3	14.7-13.9	0-62	0.99	1.58	2.38
	4	14.1-14.1	0-23	3.13	5.06	7.61
		14.1-14.2	23-60	0.83	1.34	2.02
	5	13.8-13.8	0-20	2.06	3.41	5.12
		13.8-13.8	20-60	1.80	2.98	4.48

Table 7

Percent Volatile Solids in Sediments

Station	Number of Samples	Mean %	Range %	Confidence Interval (95%)
1	10	2.96	1.65-4.79	2.30-3.62
2	12	3.70	1.79-7.13	2.68-4.71
3	10	5.37	4.40-7.50	4.68-6.00
4	10	4.32	2.89-5.58	3.73-4.92
5	10	1.48	0.24-2.88	0.85-2.10

Table 8

Summary Table for ANOVA-Percent Volatile Solids in Bottom Sediments

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F
Between Groups	4	85.97	21.49	17.78*
Within Groups	47	56.81	1.21	
Total	51	142.78		

*Significant at $\alpha = 0.001$

Table 9

Tukey Multiple Range Test Comparing Percent Means of Volatile Constituents in Sediments

Station	5	1	2	4	3
Mean	1.48	2.96	3.70	4.32	5.37

Means underlined by the same line are not significantly different at the 0.05 level.

Three-way Regression Curves

The results of the regression curves using data from Appendix C are summarized in Table 10. In general, the curves tend to be linear or log-log indicating that oxygen usage is primarily bacterial or is greatly influenced by bacteriological activity. An exception is the data from Station 3 where the semilog model fits slightly better; however, good linear and log-log fits are indicated also. Station 3 also had the highest benthic macroinvertebrate count of any of the six sampling stations during October (Table 11). *Chaoborus* sp. and turbificid annelids were the most abundant forms collected. The numbers in which they were observed do not appear to significantly affect DO depletion at the sediment-water interface, however. The paucity of benthic macrofauna, the shape of the SOD curve, and the magnitude of the values presented in Tables 5 and 6 are reflective of conditions which have been observed for much deeper lakes and impoundments in Illinois.

Based on the low number of benthic organisms and the linear nature of the stabilized portion of the curve, the conclusion that oxygen usage is principally one of bacterial origin appears justified. However, a significant portion of the early oxygen uptake may be the result of chemical reactions, especially during the summer when bottom sediments are anoxic for long periods. Exposing the sediments to oxygenated water after disturbing them slightly with the sampler may release reduced chemical compounds or elements. This disturbance would account for the high immediate uptakes given in Table 6.

Relationship of Variables

SOD curves presented in Appendix A indicate that respiration rates, as measured in the box sampler, are variable throughout the meander. Table 12

Table 10

Three-Way Regression Analysis Curve Fitting Correlations*

Date	Station	Correlation Coefficient Linear	Semilog	Log-Log
July 10-11, 1979	1	.984	.898	.991
	2D	.995	.933	.996
	2	.984	.868	.982
	3	.998	.971	.993
	4	.972	.791	.939
	5	.998	.929	.997
Oct. 25-26, 1979	1	.969	.864	.948
	2D	.933	.883	.976
	2	.991	.964	.994
	3	.933	.996	.937
	4	.971	.917	.993
	5	.996	.958	.999

*DO used, mg/l versus time (minutes)

Table 11

Number of Benthic Macroinvertebrates Per M^2

Taxa	1	2D	2	3	4	5
July 11-12, 1979						
Sphaerium sp.						153
Hexagenia limbata						325
Chaoborus sp.	2794	1014	3004	4057	38	
Chironomidae	19	77				115
Tubificidae	153	325	96	96	440	
Totals	2996	1416	3100	4153	478	593
October 25-26, 1979						
Stenonema sp.						19
Sphaerium sp.						19
Ceratopogonidae					19	
Hexagenia limbata						1799
Chaoborus sp.	1971	574	804	2354	249	29
Chironomidae	38			57	77	125
Tubificidae	230	19	19	19	115	
Totals	2239	593	861	2430	460	1991

presents SOD rates in rank order for the two seasonal sets of data. This ordering reveals several facts: (1) within seasons, considerably variability exists between stations, (2) seasonal differences are great, and (3) rank orders of the stations are somewhat reversed from summer to fall.

Table 12

Ranked SOD Rates at Ambient Temperatures (T^oC)

July 10-11, 1979		October 25-26, 1979	
Station	SOD @ T^oC ($g/m^2/day$)	Station	SOD @ T^oC ($g/m^2/day$)
1	1.80	2D	0.68
2D	2.24	4	0.83
5	2.57	3	0.99
2	3.52	2	1.03
4	4.11	1	1.64
3	4.43	5	1.80
Mean	3.11		1.16

Stepwise regression techniques were used to isolate the principal parameters causing this variability and to formulate them into an empirical but usable predictive equation. The data used for this analysis are presented in Appendix D, and simple correlation coefficients generated between all the variables during the statistical manipulation of the data are presented as a matrix in Table 13. Although sample size is small, it is still of sufficient size to reveal some statistically significant trends and interrelationships between parameters. Not surprising is the fact that temperature is the variable most highly correlated with SOD. The correlation coefficient relating these two variables was 0.80. Also, as would be expected, dissolved oxygen concentrations and populations of macroorganisms and plankton exhibited highly significant correlations with temperature.

Table 13

Simple Correlation Coefficient Matrix

	Temp.	DO	Log. No. Macroorg.	Log No. Plankton	Percent Dried Solids	Percent Volatile Solids	SOD
Temperature	x	.79	.75	.95	.63	.53	.80
Initial DO		x	.69	.77	.60	.70	.65
Log No. Macroorganisms			x	.68	.74	.76	.50
Log No. Plankton				x	.56	.55	.75
Percent Dried Solids					x	.29	.23
Percent Volatile Solids						x	.51
SOD							x

Multiple correlation coefficients were also obtained in order to determine if casual relationships exist between the dependent variable and one or more independent variables (Table 14). This analysis revealed that temperature is the principal factor for SOD variability in the meander, accounting for 63.3 percent (coefficient of determination x 100), while percent dried solids accounted for an additional 12.6 percent for a total of 75.9 percent in combination with temperature. The remaining four independent variables

Table 14

Multiple Correlation Coefficients for Stepwise Variable Additions Relative to Sediment Oxygen Demand

Sequential Parameter Addition	Multiple Correlation R	Coefficient of Determination R^2
Temperature	.795	0.633
Percent Dried Solids	.871	0.759
Initial	.879	0.773
Log No. of Plankton	.883	0.780
Percent Volatile Solids	.884	0.782
Log No. Macroorganisms	.885	0.782

together accounted for only 2.3 percent of the variance, an insignificant contribution. Consequently, sediment oxygen usage can be roughly estimated at a given water temperature if the consistency of the bottom is known. The prediction equation relating these two factors to oxygen usage in the sampler is:

$$SOD = 0.196T - .038P + .177 \qquad (4)$$

where:

SOD = oxygen usage in $g/m^2/day$

T = water temperature in ^{o}C

P = percent dried solids

Such a stochastic formulation can aid in predicting generalized conditions expected to occur when input data approximate that for which the equation was derived. For Equation 4, T ranged from 13.8°C to 25.9°C while P ranged from 37.7 percent to 62.8 percent. By retaining observed P values and utilizing a winter water temperature of 0°C to 4°C, an estimated two months of snow-covered ice would be needed to totally deplete DO in the meander.

SOD rates measured by the State Water Survey at various lakes and impoundments within Illinois are similar to those observed for the Kaskaskia River (Table 15). Except for Pistakee Bay, one of the highly eutrophic Fox River Chain of Lakes, water bodies listed in Table 15 have depths ranging from 0.6 to 3.7 meters. Pistakee Bay is approximately 9.1 meters deep and is included to show the extremes to which SOD values can reach in a highly eutrophic environment.

Sediments in the Kaskaskia cutoff meander appear to be more solid and less organic than in most areas that have been investigated. This is partially due to the relatively high percentage of sand in the meander. An interesting comparison can be made with Lake Ellyn (Table 15), a small, shallow lake in the Chicago metropolitan area which receives storm sewer runoff. Sediments in the lake are very liquid and highly organic. By contrast, the Kaskaskia cutoff meander is a relatively isolated rural body of water with a much more solidified bottom and less organic material. Nevertheless, SOD levels fell within the range of those observed for Lake Ellyn.

Table 15

SOD Rates Measured in Illinois Lakes and Impoundments Corrected to 25°C (Θ=1.085)

Lake or Impoundment	Percent Dried Solids	Percent Volatile Solids	SOD Rate @ 25°C ($g/m^2/day$) Disturbed	Stabilized
Lake DePue	---	---	5.45	3.04
Lake Meredosia, Sta. 4	23.7	8.8	14.76	4.86
Lake Meredosia, Sta. 5	23.7	9.8	88.41	3.74
Lake Meredosia, Sta. 9	30.6	9.8	66.31	2.76
Fox Lake	37.8	9.2	6.78	4.05
Nippersink Lake	20.8	20.6	61.37	10.28
Pistakee Bay	24.7	15.3	207.86	37.06
Keokuk Pool, Sta. 5	49.7	6.4	9.59	1.39
Keokuk Pool, Sta. 9	53.1	4.9	8.59	2.75
Keokuk Pool, Sta. 6	64.7	3.7	6.02	5.25
*Horseshoe Lake, Sta. 7	26.4	10.0	4.85	4.10
*Horseshoe Lake, Sta. 8	37.6	7.5	3.19	2.92
Lake Ellyn, Sta. 1	32.8	20.6	15.26	6.73
Lake Ellyn, Sta. 2	22.8	15.5	14.01	4.50
Lake Ellyn, Sta. 3	20.3	14.9	4.75	2.74
**Kaskaskia River, Sta. 1	52.3	4.3	8.87	2.65
**Kaskaskia River, Sta. 2D	64.0	2.2	11.84	1.94
**Kaskaskia River, Sta. 2	53.3	3.5	20.75	3.07
**Kaskaskia River, Sta. 3	39.4	5.9	5.06	3.55
**Kaskaskia River, Sta. 4	51.4	4.6	18.59	3.02
**Kaskaskia River, Sta. 5	57.9	2.8	2.56	3.44

* Average of three seasonal values
**Average of two seasonal values

SUMMARY AND CONCLUSIONS

Sediment oxygen demand (SOD) in the meander is sufficiently high to cause severe oxygen depletion while stagnant conditions persist. Absolute SOD values, compared to those known to exist in other aquatic environments in the state, are not exceptionally high.

SOD appears to result principally from microbial activity. Benthic macroinvertebrate biomass was small and did not contribute significantly to oxygen demand. High immediate demand observed inside the sampler may have been caused by chemical oxygen demand created during persistent periods of anoxic conditions near the bottom.

SOD rates appear to be governed principally by temperature and to a lesser degree by sediment consistency. Ambient SOD rates measured during summer were almost three times as great as those measured during fall. SOD rates were found to be inversely related to the percent of solid composition of the sediments.

It is apparent that cutoff meanders exhibit water quality degradation due to sediment oxygen demand and summer temperatures. Even though super-saturated dissolved oxygen was observed in the euphotic zone, it had minimal influence on dissolved oxygen at lower depths. While SOD in the channelized portion of the Kaskaskia River was higher than some stations in the meander, reaeration resulting from flowing water in the channel was sufficient to prevent persistently low dissolved oxygen levels from developing.

SOD rates do not appear to be sufficient to cause severe DO depletion in the winter under normal Southern Illinois weather conditions. Using equation 4, an estimated two months of snow covered ice would be needed to totally deplete DO in the meander.

The potential for an excellent fishery resource in cutoff meanders of the Kaskaskia River is questionable. With radically changed flow conditions after channelization, depressed dissolved oxygen levels in a significant portion of the total volume of water during summer months becomes a severe limiting factor. Preliminary engineering evaluations using hydrologic and hydraulic information indicate that routing flow from the main channel through the meander will improve DO levels over ambient conditions but will not necessarily prevent stressful conditions from developing during low flow and/or high temperature conditions.

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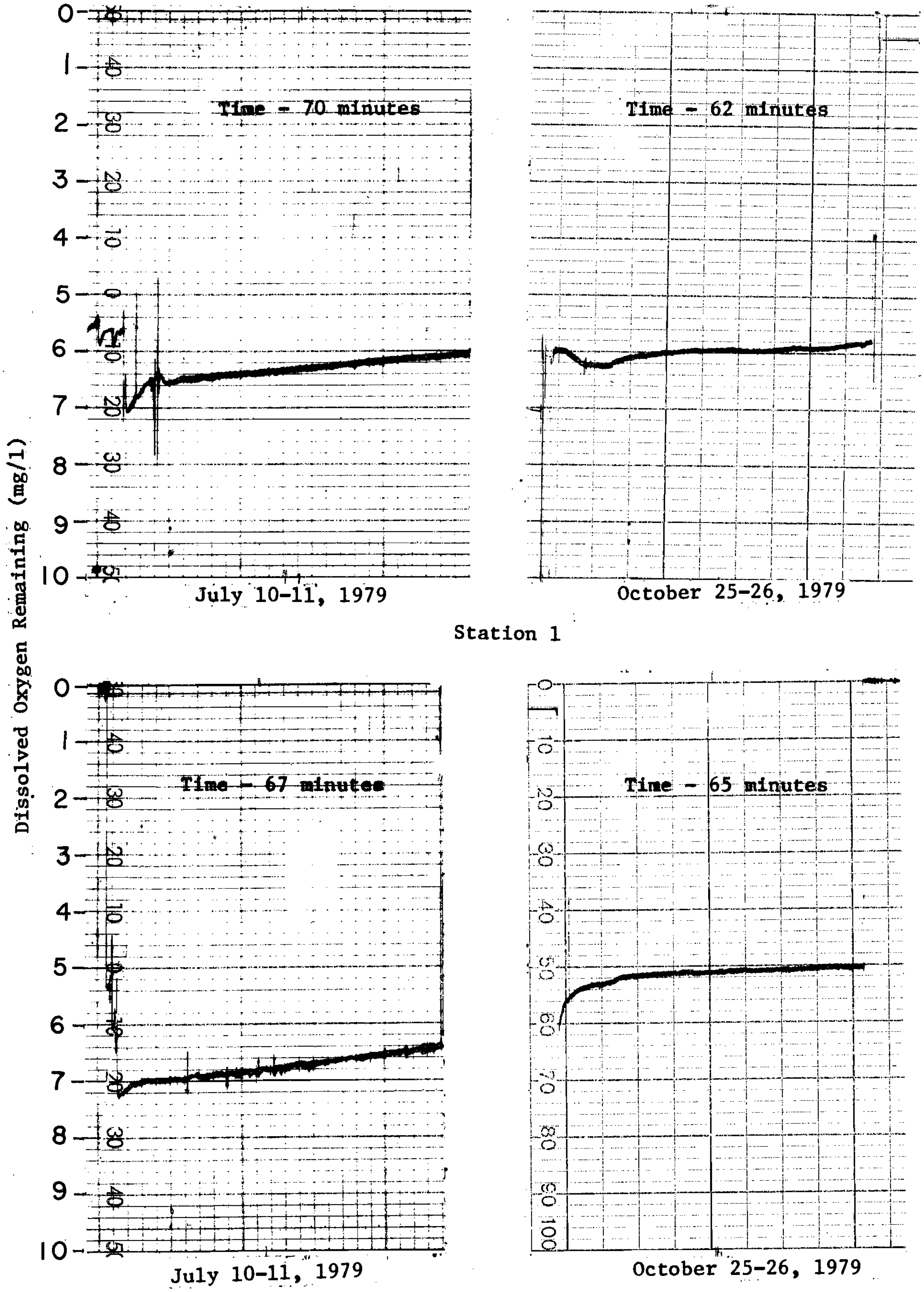
APPENDICES

APPENDIX A

Field traced sediment oxygen demand curves.

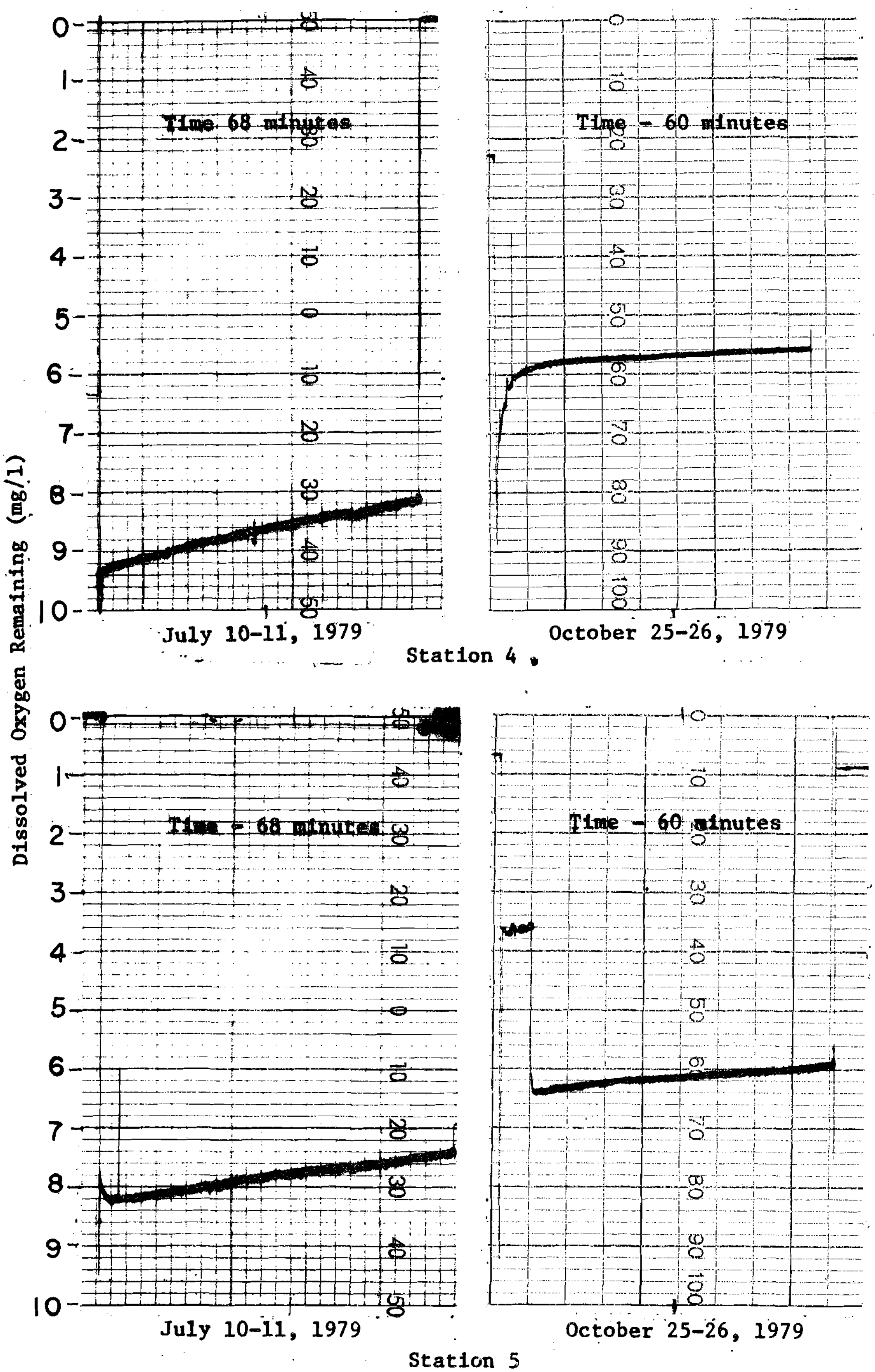
APPENDIX A

Field-Traced Sediment Oxygen Demand Curves

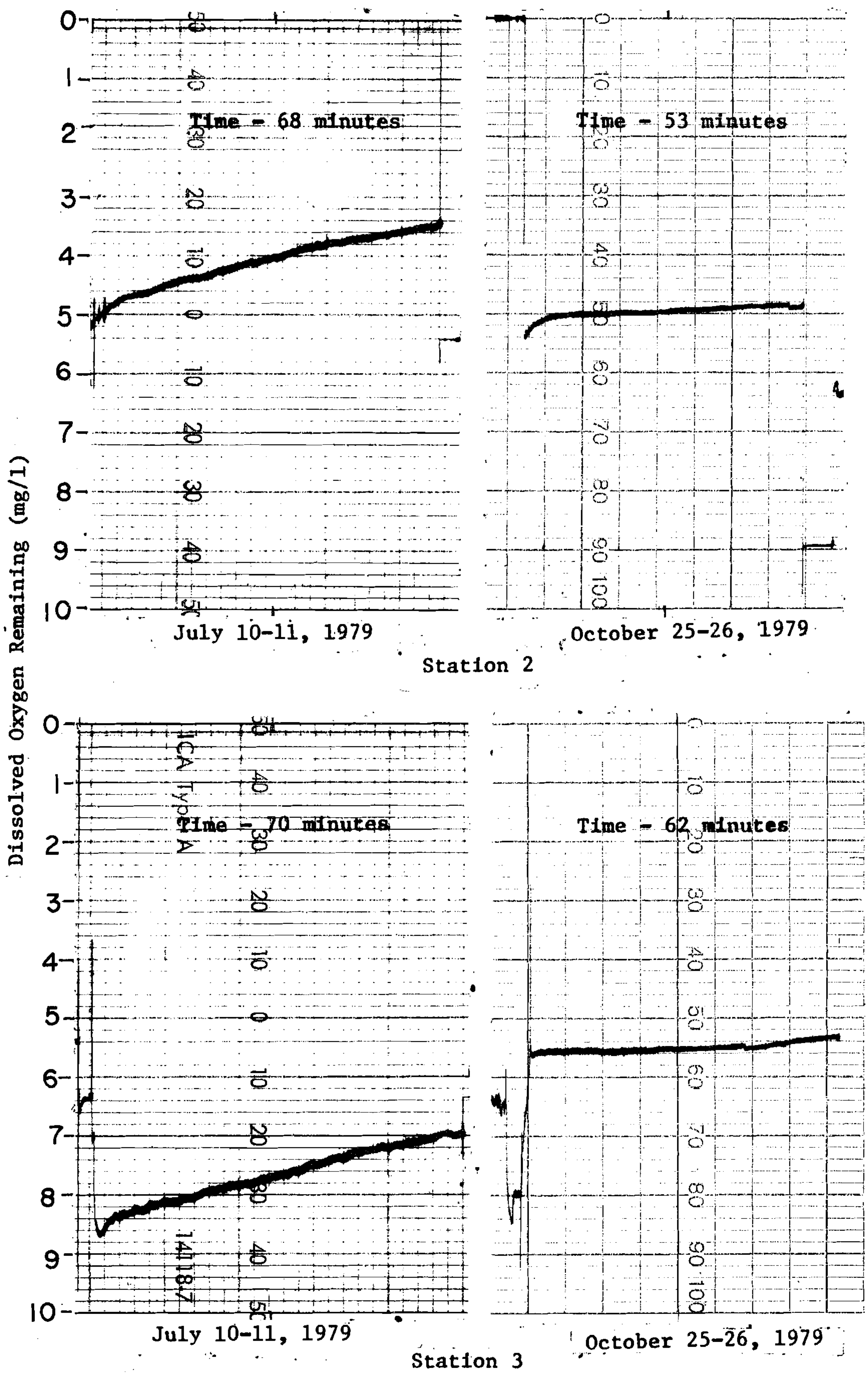


Station 2D

APPENDIX A (Continued)

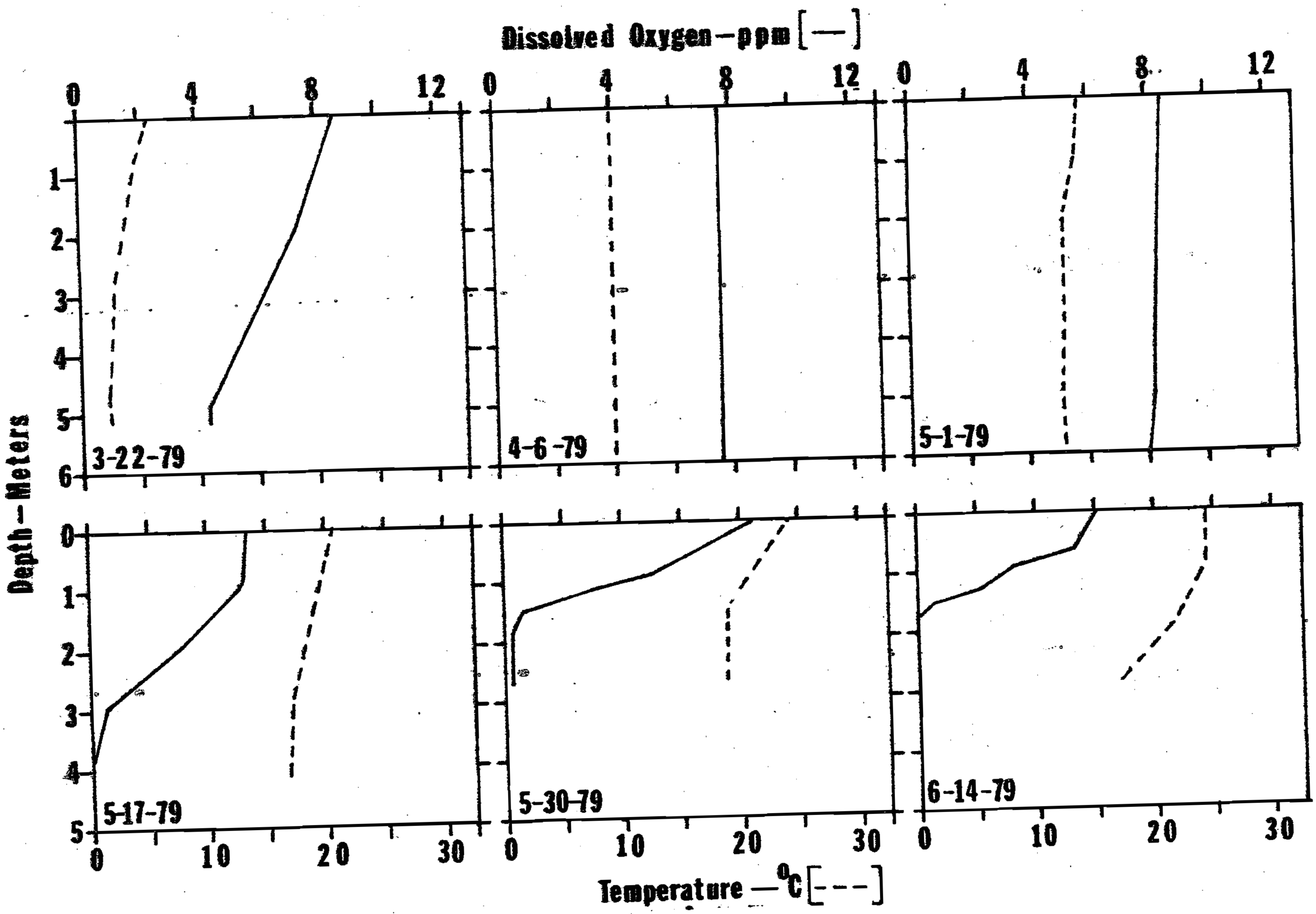


APPENDIX A (Continued)

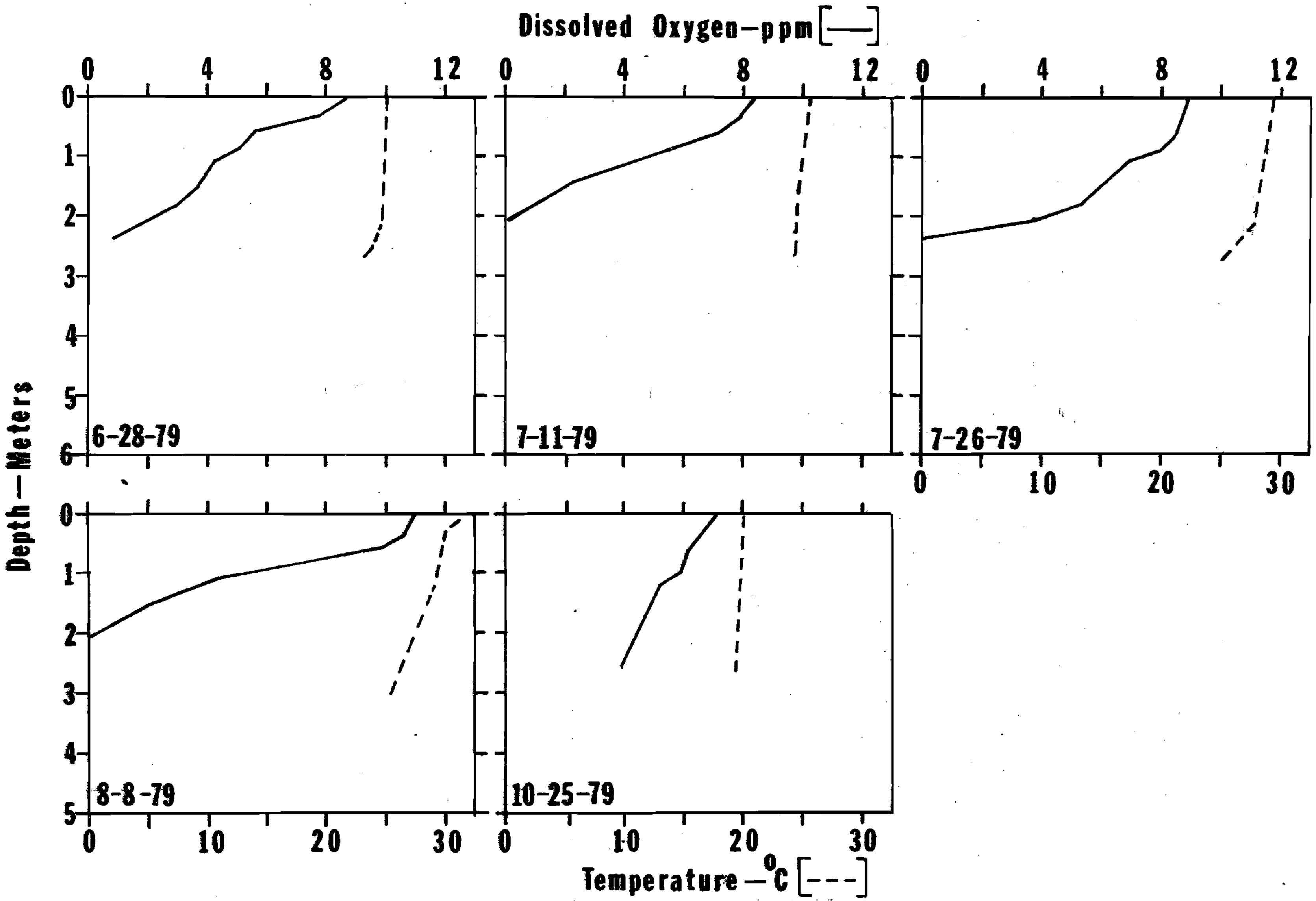


Appendix B

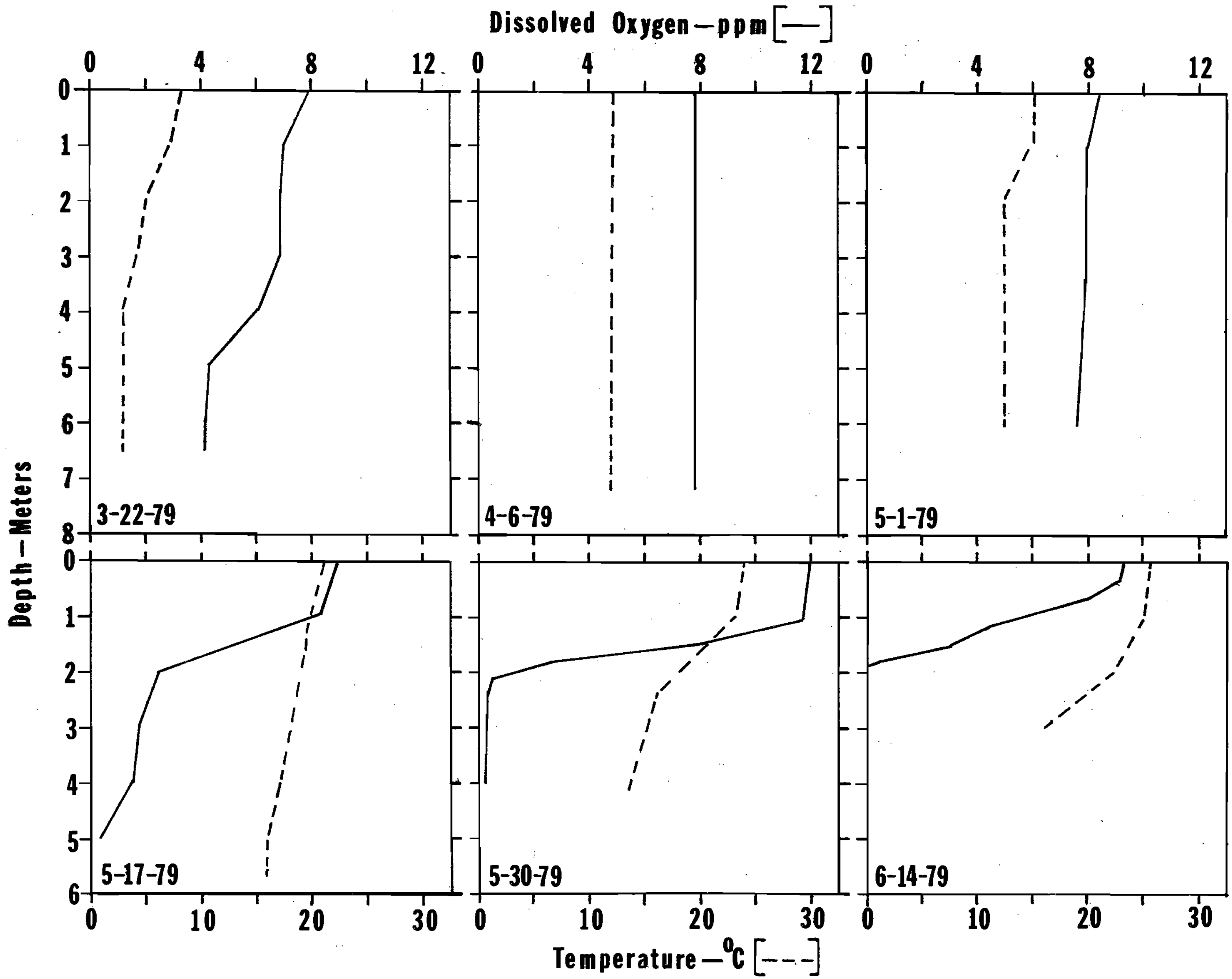
Dissolved oxygen and temperature profiles in a cutoff meander (Stations 1-4) and main channel (Station 5) of the Kaskaskia River during spring, summer and fall of 1979.


Dissolved Oxygen—ppm [—]
0 4 8 12
Depth—Meters
0 1 2 3 4 5 6
3-22-79
4-6-79
5-1-79
5-17-79
5-30-79
6-14-79
0 10 20 30
Temperature —°C [---]

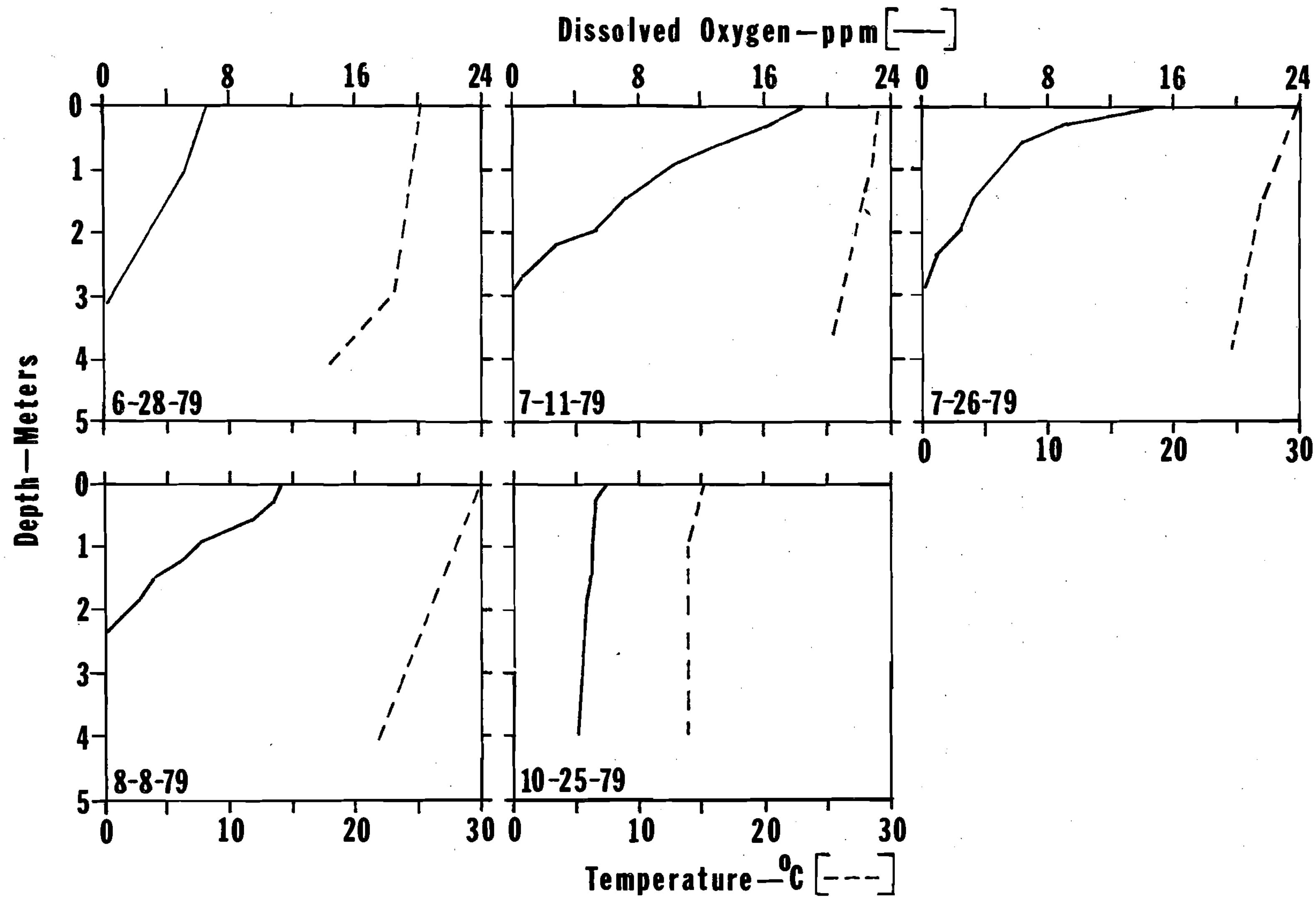
Station 1



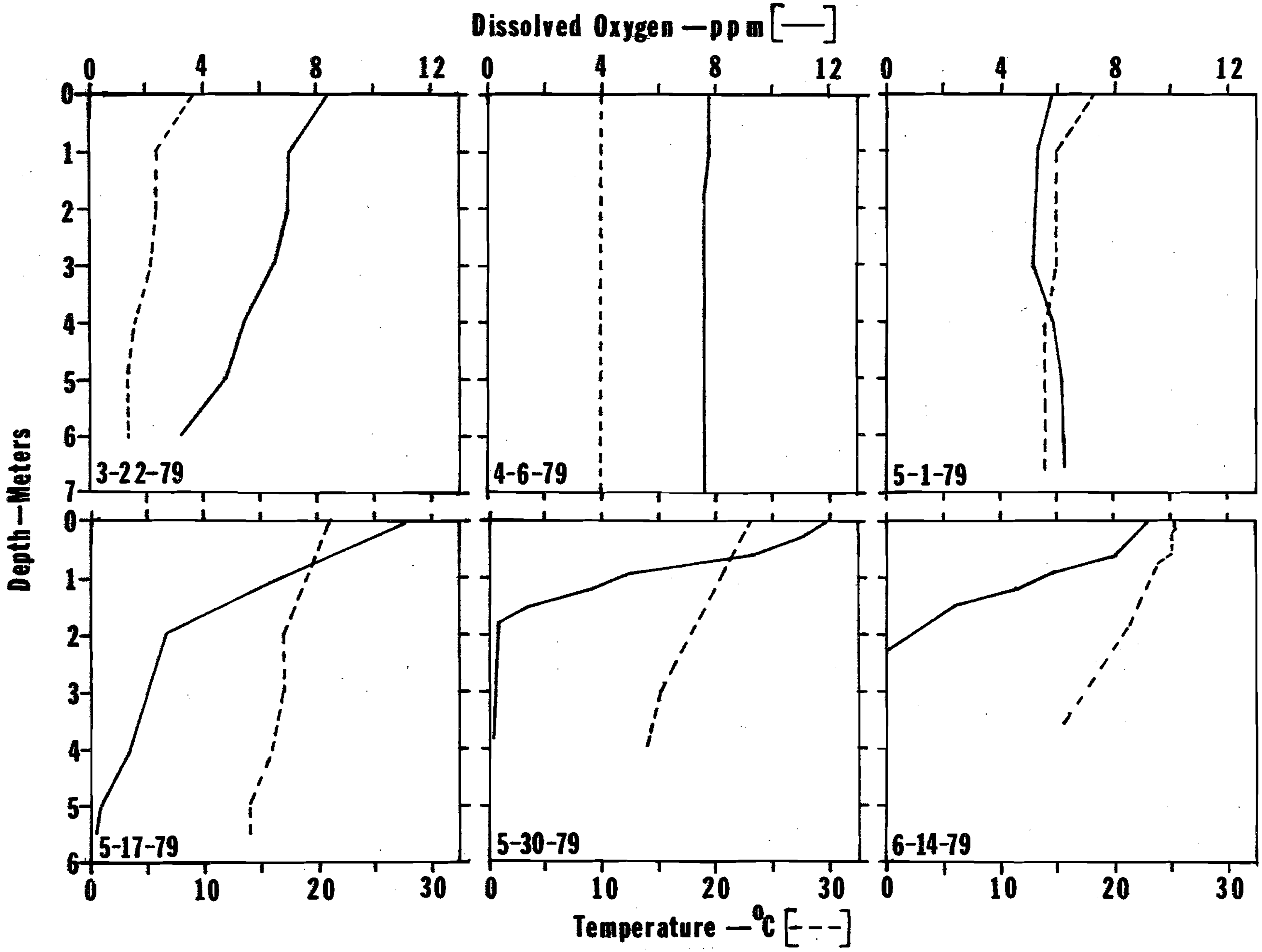
Station 1 (continued)


Dissolved Oxygen—ppm [—]
Depth—Meters
3-22-79
4-6-79
5-1-79
5-17-79
5-30-79
6-14-79
Temperature—°C [- - -]

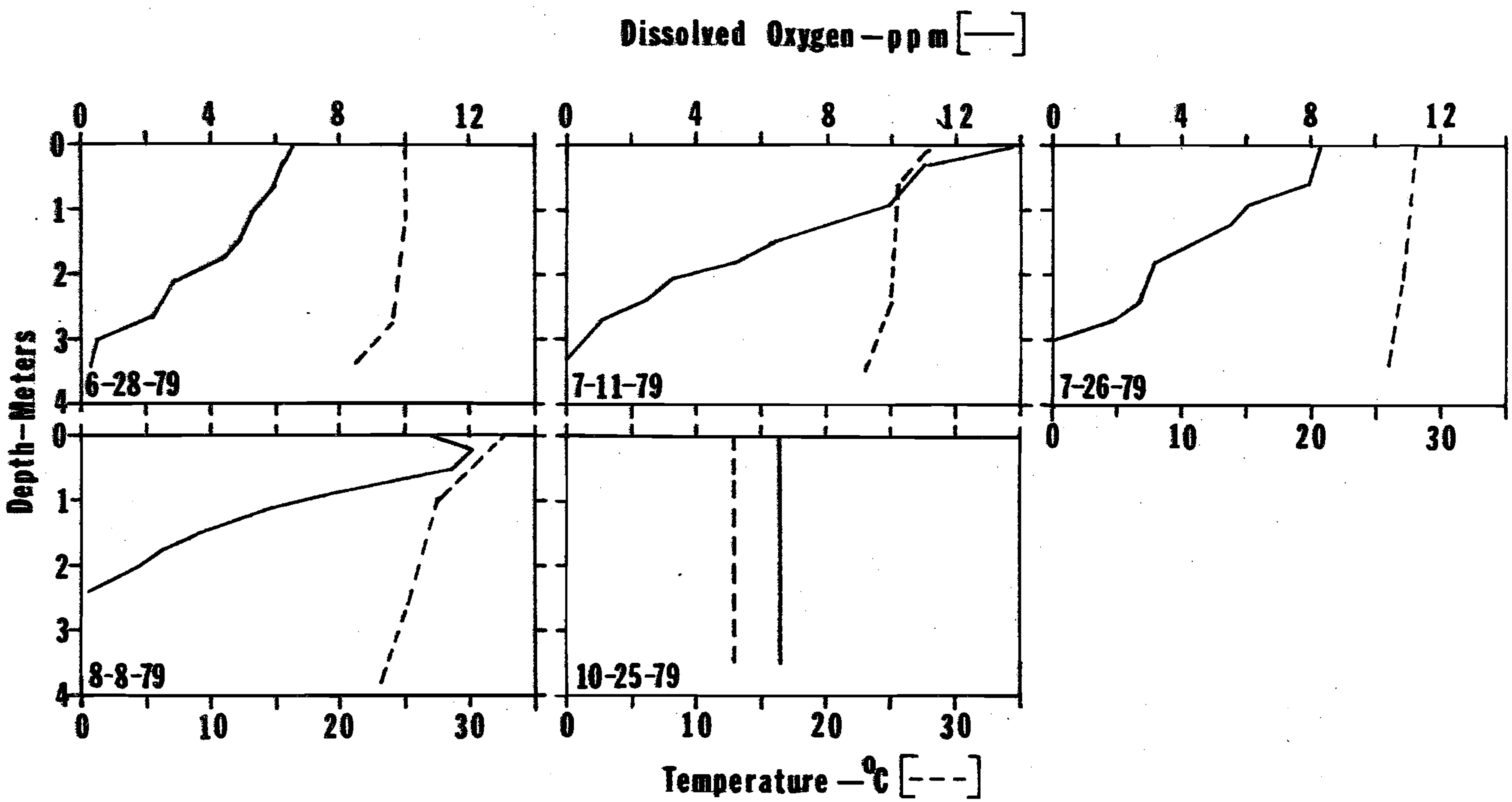
Station 2



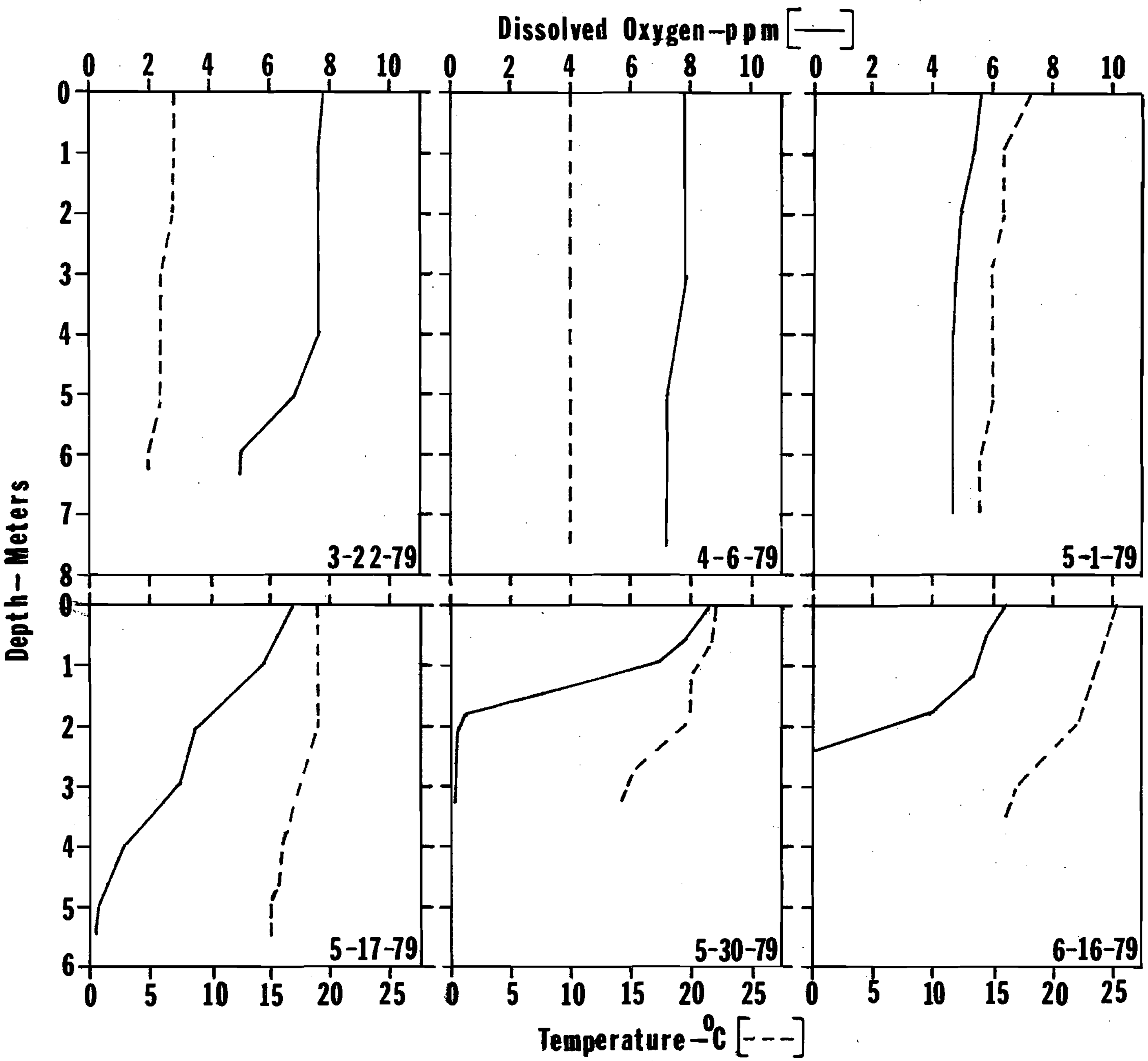
Station 2 (continued)

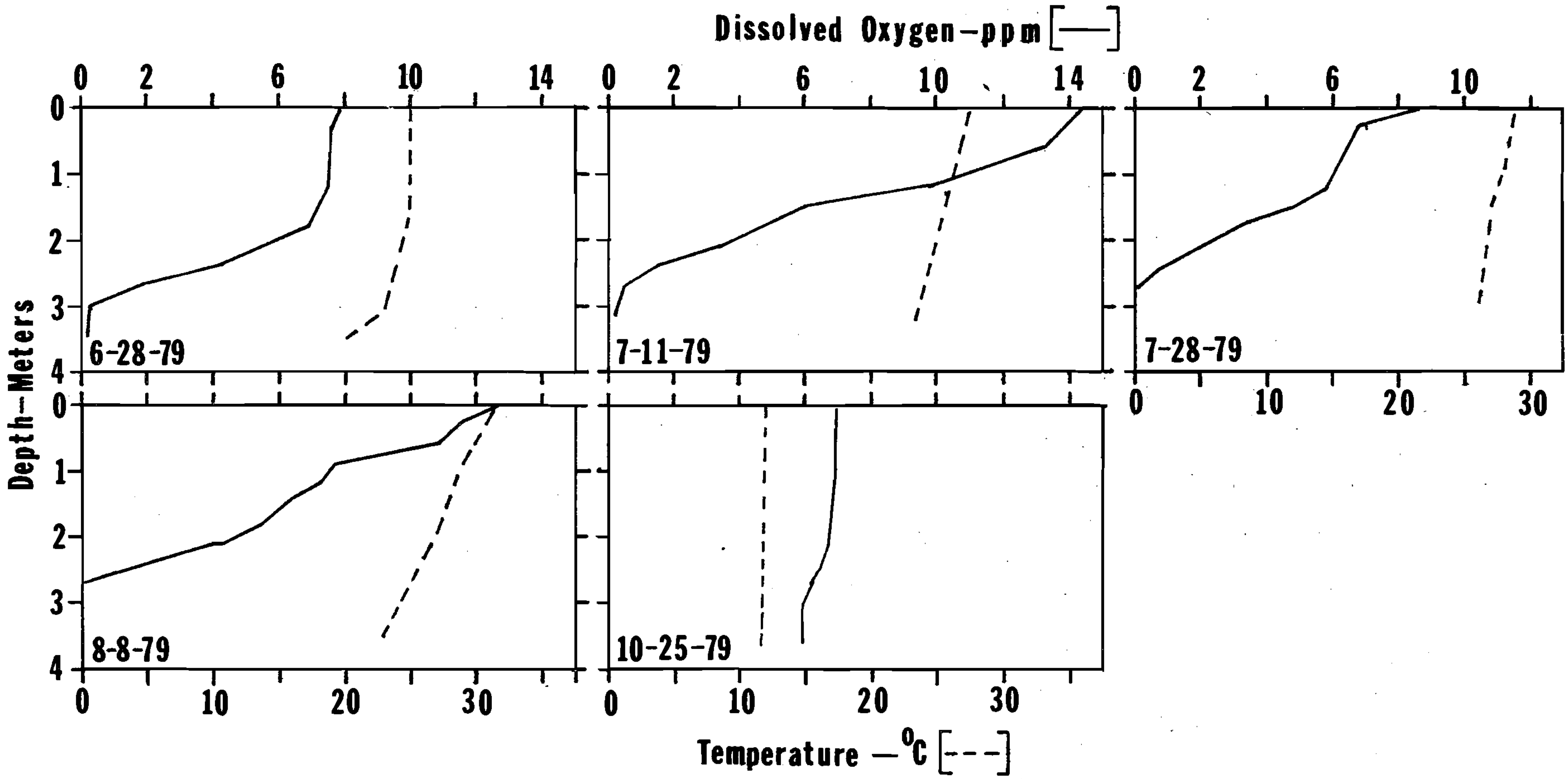

Dissolved Oxygen — ppm [—]
Depth — Meters
3-22-79
4-6-79
5-1-79
5-17-79
5-30-79
6-14-79
Temperature — °C [- - -]

Station 3

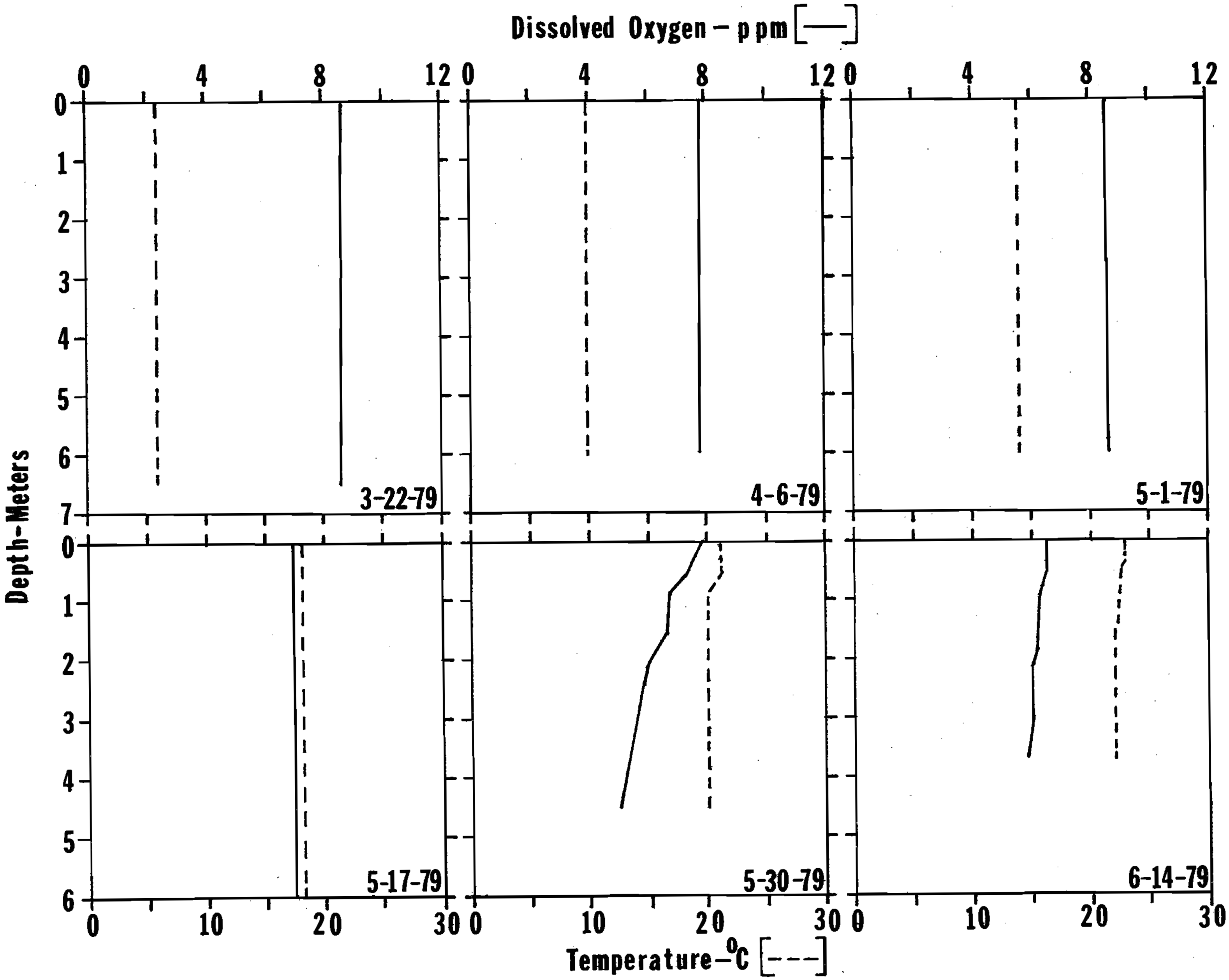


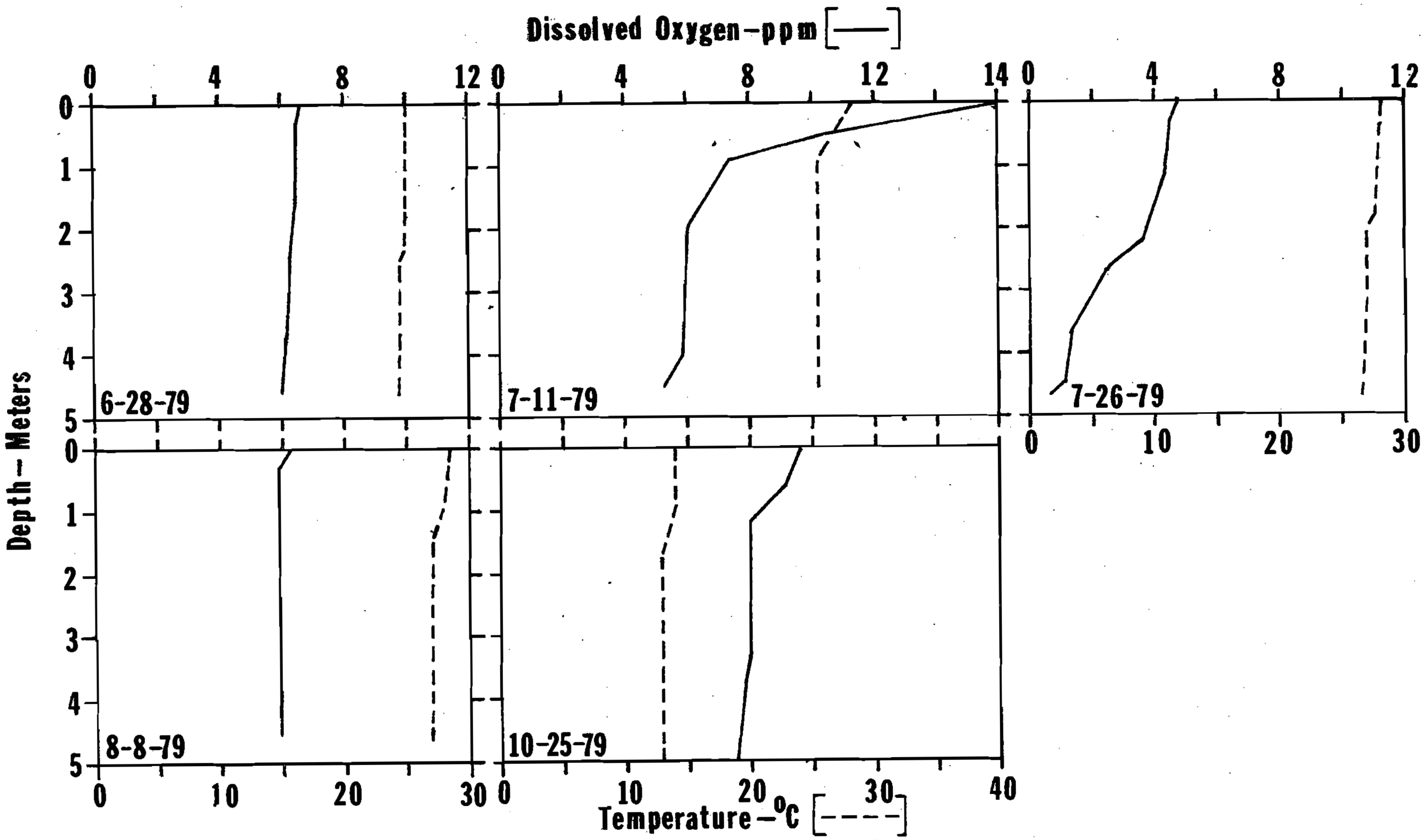
Station 3 (continued)


Dissolved Oxygen—ppm [——]
Depth—Meters
Temperature—°C [- - -]
3-22-79
4-6-79
5-1-79
5-17-79
5-30-79
6-16-79
Station 4



Station 4 (continued)


Dissolved Oxygen – ppm [——]
Depth-Meters
3-22-79
4-6-79
5-1-79
5-17-79
5-30-79
6-14-79
Temperature–°C [- - -]
Station 5



Station 5 (continued)

Appendix C

Field-recorded dissolved oxygen usage in sediments of Kaskaskia River cutoff meander.

Appendix C

Field-Recorded Dissolved Oxygen Usage in Sediments of Kaskaskia River Cutoff Meanders

July 10-11, 1979

Station 1			Station 2D			Station 2		
ΣT	ΣDO (ppm)	Temp. °C	ΣT	ΣDO (ppm)	Temp. °C	ΣT	ΣDO (ppm)	Temp. °C
0	0	22.8*	0	0	25.8*	0	0	25.5*
1	0.10		2	0.10		2	0.15	
2	0.20		3	0.15		3	0.10	
7	0.25		7	0.20		8	0.40	
10	0.35		12	0.30		13	0.60	
20	0.45		17	0.35		18	0.70	
25	0.50		22	0.40		23	0.80	
30	0.55		27	0.45		28	0.90	
35	0.60		32	0.50		33	1.10	
40	0.65		37	0.55		38	1.20	
45	0.70		42	0.60		43	1.30	
50	0.75		47	0.65		48	1.40	
55	0.80		52	0.70		53	1.45	
60	0.82		57	0.75		58	1.50	
65	0.85		62	0.80		63	1.60	
70	0.87	25.0**	67	0.90	24.8**	68	1.70	24.0**
Station 3			Station 4			Station 5		
0	0	25.0*	0	0	26.8*	0	0	26.0*
5	0.25		1	0.10		3	0.05	
10	0.35		2	0.50		8	0.10	
15	0.45		5	0.60		13	0.20	
20	0.60		8	0.70		18	0.25	
25	0.65		13	0.80		23	0.30	
30	0.75		18	0.90		28	0.35	
35	0.85		23	1.00		33	0.40	
40	0.95		28	1.10		38	0.45	
45	1.05		33	1.20		43	0.55	
50	1.15		38	1.30		48	0.60	
55	1.25		43	1.40		53	0.65	
60	1.35		48	1.50		58	0.75	
65	1.50		53	1.55		63	0.80	
70	1.65	23.2**	58	1.60		68	0.85	25.8**
			63	1.70				
			68	1.80	23.8**			

Appendix C (Continued)

October 25-26, 1979

Station 1			Station 2D			Station 2		
ΣT	ΣDO (ppm)	Temp. ^oC	ΣT	ΣDO (ppm)	Temp. ^oC	ΣT	ΣDO (ppm)	Temp. ^oC
0	0	16.2*	0	0	14.9*	0	0	14.5*
2	0		5	0.15		3	0.20	
12	0.05		10	0.20		13	0.30	
17	0.15		20	0.40		23	--	
27	0.25		30	0.42		33	0.40	
32	0.30		40	0.47		43	0.45	
42	0.35		50	0.50		48	0.47	
47	0.40		55	0.52		53	0.50	14.4**
57	0.42		60	0.52				
62	0.45	14.9**	65	0.55	14.5**			

Station 3			Station 4			Station 5		
0	0	14.7*	0	0	14.1*	0	0	13.8*
7	0.02		3	0.15		10	0.10	
22	0.05		8	0.25		20	0.20	
32	0.07		23	0.35		30	0.30	
42	0.10		33	0.37		40	0.40	
57	0.25		38	0.40		50	0.50	
62	0.30	13.9**	48	0.45		60	0.55	--
			60	0.50	14.2**			

* Beginning Temperature
**Ending Temperature

Appendix D

Data input for stepwise regression analysis.

Appendix D

Data Input for Stepwise Regression Analysis

Station	Parameter	7/10-11/79	10/25-26/79
1	Temperature, °C	25.8	15.4
	Initial DO, mg/l	6.5	6.2
	Macroorganisms, no./m^2	2,966	2,239
	Plankton, no./ml	1,729	84
	Percent Solids	49.6	55.0
	Percent Volatile Solids	4.6	4.0
	SOD, g/m^2/day @ T°C	1.80	1.64
	SOD, g/m^2/day @ 25°C	1.69	3.61
2D	Temperature, °C	24.8	14.7
	Initial DO, mg/l	7.0	5.1
	Macroorganisms, no./m^2	1,416	593
	Plankton, no./ml	1,304	15
	Percent Solids	62.8	65.2
	Percent Volatile Solids	2.3	2.0
	SOD, g/m^2/day @ T°C	2.24	0.68
	SOD, g/m^2/day @ 25°C	2.28	1.59
2	Temperature, °C	24.4	14.5
	Initial DO, mg/l	4.0	5.0
	Macroorganisms, no./m^2	3,100	861
	Plankton, no./ml	838	34
	Percent Solids	51.2	55.3
	Percent Volatile Solids	3.7	3.3
	SOD, g/m^2/day @ T°C	3.52	1.03
	SOD, g/m^2/day @ 25°C	3.70	2.43

Appendix D (Continued)

Station	Parameter	7/10-11/79	10/25-26/79
3	Temperature, °C	24.2	14.3
	Initial DO, mg/l	8.3	6.6
	Macroorganisms, no./m^2	4,153	2,430
	Plankton, no./ml	642	38
	Percent Solids	37.7	41.0
	Percent Volatile Solids	5.9	5.9
	SOD, g/m^2/day @ T°C	4.43	0.99
	SOD, g/m^2/day @ 25°C	4.72	2.38
4	Temperature, °C	25.3	14.2
	Initial DO, mg/l	9.4	5.8
	Macroorganisms, no./m^2	478	460
	Plankton, no./ml	1,431	311
	Percent Solids	51.0	51.7
	Percent Volatile Solids	4.7	4.4
	SOD, g/m^2/day @ T°C	4.11	0.83
	SOD, g/m^2/day @ 25°C	4.01	2.02
5	Temperature, °C	25.9	13.8
	Initial DO, mg/l	8.2	6.3
	Macroorganisms, no./m^2	593	1,990
	Plankton, no./ml	1,029	181
	Percent Solids	56.1	59.6
	Percent Volatile Solids	3.2	2.3
	SOD, g/m^2/day @ T°C	2.57	1.80
	SOD, g/m^2/day @ 25°C	2.39	4.48