EFFECTS OF IMPOUNDMENTS ON WATER QUALITY OF STREAMS IN THE COTEAU DES PRAIRIES--UPPER MINNESOTA RIVER BASIN

By C. J. Smith, G. A. Payne, and L. H. Tornes

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CONVERSION FACTORS

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	4,047	square meter
square mile (mi^2)	2.590	square kilometer
acre-foot (acre-ft)	1,233	cubic meter
cubic feet per second (ft^3/s)	0.02832	cubic meters per second
ton, short	0.9072	megagrams
degrees Fahrenheit (F°)	5/9 X (°F-32)	degrees Celsius

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

Water-quality and streamflow data were collected in the Coteau des Prairies region of southwestern Minnesota and eastern South Dakota to document the water-quality characteristics of streams and impoundments in the Coteau, and to predict the effect of proposed impoundments on the quality of water in Coteau streams.

Reconnaissance data collection at 66 stream and 24 impoundment sites plus 21 inlets and outlets during 1979, and intensive data collection at 4 stream and 4 impoundment plus 9 inlet and outlet sites during 1980-84, showed that major ions, nutrients, and suspended-sediment concentrations and suspended-sediment discharge differed widely in unimpounded streams, but that maximum and median suspended-sediment concentrations were significantly reduced in impounded streams. Peak daily suspended-sediment discharges were reduced at impoundment outlets relative to the sediment discharge at their inlets. The impoundments were found to have little or no effect on stream temperature and concentrations of dissolved oxygen, dissolved solids, and major ions.

Elevated concentrations of fecal bacteria were found in unimpounded streams throughout the study area and the impoundments did not substantially reduce the number of bacteria transported in the impounded streams. During summer, elevated concentrations of nitrate, ammonia, and phosphorus were present in all the impoundments. Levels of productivity were not significantly related to concentrations of total phosphorus in the euphotic zone. Real levels of productivity differed among the impoundments however, and seemed to be affected by the occurrence and duration of thermal stratification.

Periods of summer stratification and accumulation of late winter snow on pool ice were frequently accompanied by near total depletion of dissolved oxygen. During summer stratification the concentration of ammonia increased with time in the lower part of the water column in some impoundments.

INTRODUCTION

The headwaters for five major tributaries to the Minnesota River--the Redwood, Cottonwood, Lac qui Parle, Yellow Bank, and Yellow Medicine Rivers--lie in the Coteau des Prairies (Coteau) a stepped, upland plateau in southwestern Minnesota and eastern South Dakota (fig. 1). In recent years, flooding, bank erosion, and sediment movement in these river basins have become increasing problems. In December 1975, the Secretaries of Army and Agriculture were directed to make joint investigations and surveys, as provided by Public Law 87-639, of the five river drainage basins named above. The U.S. Army Corps of Engineers (COE) and the U.S. Soil Conservation Service (SCS) initially proposed to construct about 81 reservoirs on streams within the Coteau des Prairies to help alleviate the flooding and erosion and to reduce the movement of sediment.

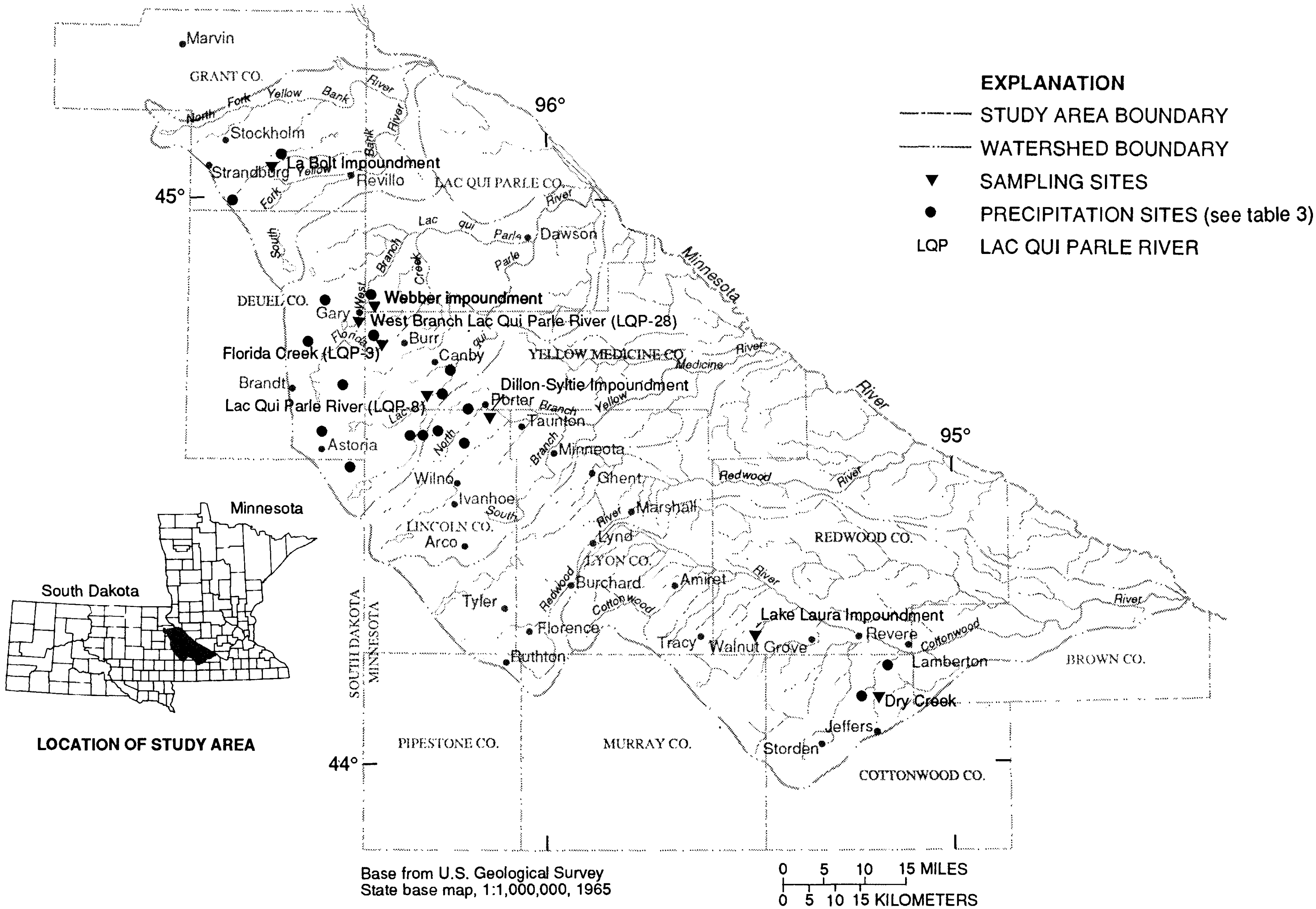


Figure 1.--Study area and data collection at impounded and unimpounded streams.

Little information was available on flow, suspended sediment, nutrients, and other water-quality constituents from streams in the Coteau. As a result, it was difficult to project with any confidence the potential water-quality effects of the many proposed impoundments. A more detailed data base was needed to predict sediment concentration, sediment discharge, chemical quality, and nutrient levels that will occur in and downstream from the proposed impoundments, especially as related to runoff events.

In 1979, the U.S. Geological Survey (USGS) conducted a water-quality reconnaissance of 24 impoundments, 21 inlets and outlets, and streams at 66 proposed impoundment sites as part of the upper Minnesota River subbasins study (Public Law 87-639) of the COE and SCS. Dissolved-oxygen profiles and transparency measurements were made in the impoundments. Temperature, specific conductance, dissolved oxygen concentration, and pH were measured at the proposed sites where streams flowed. From these data and from land-use data, soils data, and topographic maps, representative sites were selected for intensive monitoring. Thirty-four proposed impoundment sites were dropped from consideration by the COE and SCS after this reconnaissance. The data collected in the reconnaissance sampling and during the intensive monitoring are presented in a companion report (Smith and others, 1990).

Intensive monitoring began in March 1980 and involved monitoring of physical, chemical, and biological constituents at four of the impoundments; Dillon-Syltie, La Bolt, Lake Laura, and Webber; and at four natural stream sites on the Lac qui Parle River, West Branch Lac qui Parle River, Florida Creek, and Dry Creek (fig. 1). The monitoring continued until October 1984.

The purpose of this monitoring was to (1) determine the baseline quality of water in streams and impoundments in the Coteau, and (2) determine the effects of the impoundments on quality of water in the impounded streams. The secondary objectives of this monitoring were to (1) determine the characteristics and variability of water quality in impoundments and the relation to quantity and quality of inflow and outflow; (2) evaluate the potential for water-quality problems associated with algae, bacteria, and trace metals in proposed impoundments; (3) determine the quantity and variability of nonpoint-source loadings of sediment and nutrients at impoundment sites; and (4) determine sediment and nutrient retention by impoundments.

Purpose and Scope

This report presents an analysis of the data collected in the reconnaissance sampling in 1979 and during the subsequent intensive monitoring in 1980-84. The report will describe and evaluate the water quality in selected streams and impoundments in the Coteau, and describe the effects of the four studied impoundments on the water quality of their receiving streams.

Description of Study Area

The study area comprises the drainage basins of five tributaries to the Minnesota River: (1) the Yellow Bank River, (2) the Lac qui Parle River, (3) the Yellow Medicine River, (4) the Redwood River, and (5) the Cottonwood River (fig. 1). The study area includes 33 percent of the Minnesota River basin (7,184 square miles) and all or part of nine counties in Minnesota and parts of four counties in South Dakota.

The physiography of the area is characterized by three features: (1) the Coteau des Prairies (Coteau) Outer Part, (2) the Blue Earth Till Plain, and (3) the Minnesota River valley (Wright, 1972, p. 564).

The Coteau des Prairies is a broad regional topographic high that runs from eastern South Dakota to Iowa through the southwestern corner of Minnesota forming the divide between the Minnesota and Big Sioux Rivers. In the study area the Coteau comprises the Coteau upland, a region of glacial moraines, lakes and swamps, and the Coteau escarpment, a long, steep hill sloping toward the northeast that parallels the Minnesota River, 25 to 35 mi (miles) southwest of the river. The escarpment extends from the Minnesota-South Dakota border southeastward to about 30 mi south of New Ulm. The Coteau is formed from several hundred feet of glacial deposits over a postulated bedrock upland of Cretaceous rocks (Wright, 1972, p. 573, Woodward and Anderson, 1986). The Des Moines lobe of the Wisconsin glaciation deposited the Bemis moraine near the crest of the Coteau, and a recessional moraine, the Altamont, along the escarpment of the Coteau. The upland slopes generally to the southeast from an elevation of about 2,000 ft (feet) above sea level near the headwaters of the Yellow Bank and Lac qui Parle Rivers to about 1,750 ft near the headwaters of the Cottonwood river. The escarpment slope is steepest at the northwestern end of the study area where the elevation decreases about 500 ft in about 6 mi. The difference in elevation between the top and the toe of the escarpment over most of the study area is about 250 ft. The escarpment is incised by many ravines, some deep enough to be fed by permanent springs.

The Blue Earth Till Plain was covered by the interior part of the Des Moines lobe, and is generally featureless (Wright, 1972, p. 574). Wright states the part of the Till Plain in the study area "has a certain linearity that in some cases reflects weak 'lateral' moraines formed during shrinkage of the ice lobe: in other cases the lineations are the channels of former ice-marginal meltwater streams. The courses of the Redwood, Cottonwood, and Watonwan Rivers follow these old channels." Regionally the Till Plain slopes to the southeast in addition to sloping towards the Minnesota River. As a result, streams flow northeast on the escarpment of the Coteau but flow to the east and southeast on the Till Plain. Stream piracy is common on the Coteau and the Till Plain (Matsch, 1972, p. 551, Hall and others, 1911, p. 29-30). The low relief permits cross-basin flooding on the Till Plain.

The Minnesota River valley is incised below the surrounding till plain. The depth of the valley gradually increases from the source of the Minnesota River at Big Stone Lake to a depth of about 200 ft below the adjacent till plains near New Ulm, Minnesota.

The drainage basins of the Yellow Bank, the Lac qui Parle, and the Yellow Medicine Rivers and the headwaters of the Redwood River contain medium-fine- to fine-textured prairie and prairie-border soils of western Minnesota (Arneman, 1963). The lower portion of the Redwood River basin and the Cottonwood River basin contain medium- to fine-textured prairie soils of south-central Minnesota. These fine-textured soils are easily erodible by wind and water if they have been cleared of vegetation. As a result, erosion control and water conservation are important.

The climate of the study area is continental with cold, dry winters and warm, wet summers (Kuehnast and Baker, 1978). The normal annual precipitation is about 25.5 in.; two-thirds falls in the five months from May through September. The normal annual snowfall is about 40 in. The average annual temperature ranges from 6.1 to 7.2 °C (degrees Celsius) (Baker and and others, 1985, p. 46-48). Average monthly temperatures range from -12.5 to -12.1 °C in January to 22 to 23 °C in July.

The major land use in the study area is agricultural. The primary crops are corn, soybeans, small grains and hay (Soil Conservation Service, 1979, p. 40, 1981, p. 75). Other land uses are pasture, woodland, wild life habitat, recreation, and building sites (Soil Conservation Service, 1979, p. 43, 1981, p. 78, 80).

Description of the Impoundments

The primary land use in the impoundment drainage basins is agricultural; row crops are grown on the flatter slopes and pasture is common on steeper slopes and low-lying areas adjacent to streams. Three of the impoundments--La Bolt, Dillon-Syltie and Lake Laura--are used frequently by the public for recreation. The physical characteristics for each impoundment are given in table 1. Land-use data (cropland and pasture) for each drainage basin were provided by the Soil Conservation Service (SCS) (Smith and others, 1990, table 2).

La Bolt impoundment was built by the Work Progress Administration in 1939; it was dredged in 1985 after this study ended. The outlet structure is an earthen dam incorporating a 26.8-ft long concrete ogee weir at the eastern end of the impoundment (fig 2.). At the inlet on the southwestern side there is a small wetland; the land adjacent to the inlet stream is wooded with a part used for pasture. The La Bolt Lake Recreation Area which is sponsored by the city of La Bolt, South Dakota, in cooperation with the South Dakota Department of Game, Fish and Parks, is on the southern edge of the impoundment. On the northern side, the banks slope steeply upward, ranging from 10 to 15 ft in height; corn and soybean fields are on the high ground. During the study, beavers were active in the drainage basin. The major land-uses in the drainage basin are: cropland, 42 percent; pasture, 54 percent; woodland, 1 percent; and other, 3 percent.

Table 1.--*Physical Characteristics of impoundment sites*

[N.A., not available]

Site name	Physical characteristics of impoundments		
	YELLOW BANK RIVER WATERSHED		
La Bolt impoundment near La Bolt, South Dakota	Residual storage volume	36.7	acre-feet
	Surface area at point of zero outflow	6.8	acres
	Depth at sampling point (approximately)	10-12	feet
	Length	1,030	feet
	Width	350	feet
	LAC QUI PARLE RIVER WATERSHED		
Webber impoundment near Gary, South Dakota	[Impoundment water surface elevation was below the minimum outlet elevation during the study]		
	Residual storage volume	N.A.	
	Surface area at point of zero outflow	N.A.	
	Depth at sampling point (approximately)	7.6-18.5	feet
	Length	N.A.	
	Width	N.A.	
	YELLOW MEDICINE RIVER WATERSHED		
Dillon-Syltie impoundment near Porter, Minnesota	Residual storage volume	117	acre-feet
	Surface area at point of zero outflow	15.5	acres
	Depth at sampling point (approximately)	10-14	feet
	Length of shore line	5,300	feet
	Length	1,730	feet
	Width	57	feet
	COTTONWOOD RIVER WATERSHED		
Lake Laura impoundment near Walnut Grove, Minnesota	Residual storage volume	221	acre-feet
	Length of shore line	10,800	feet
	Surface area at point of zero outflow	21.3	acres
	Depth at sampling point (approximately)	20.5-33	feet
	Length	2,480	feet
	Width	550	feet

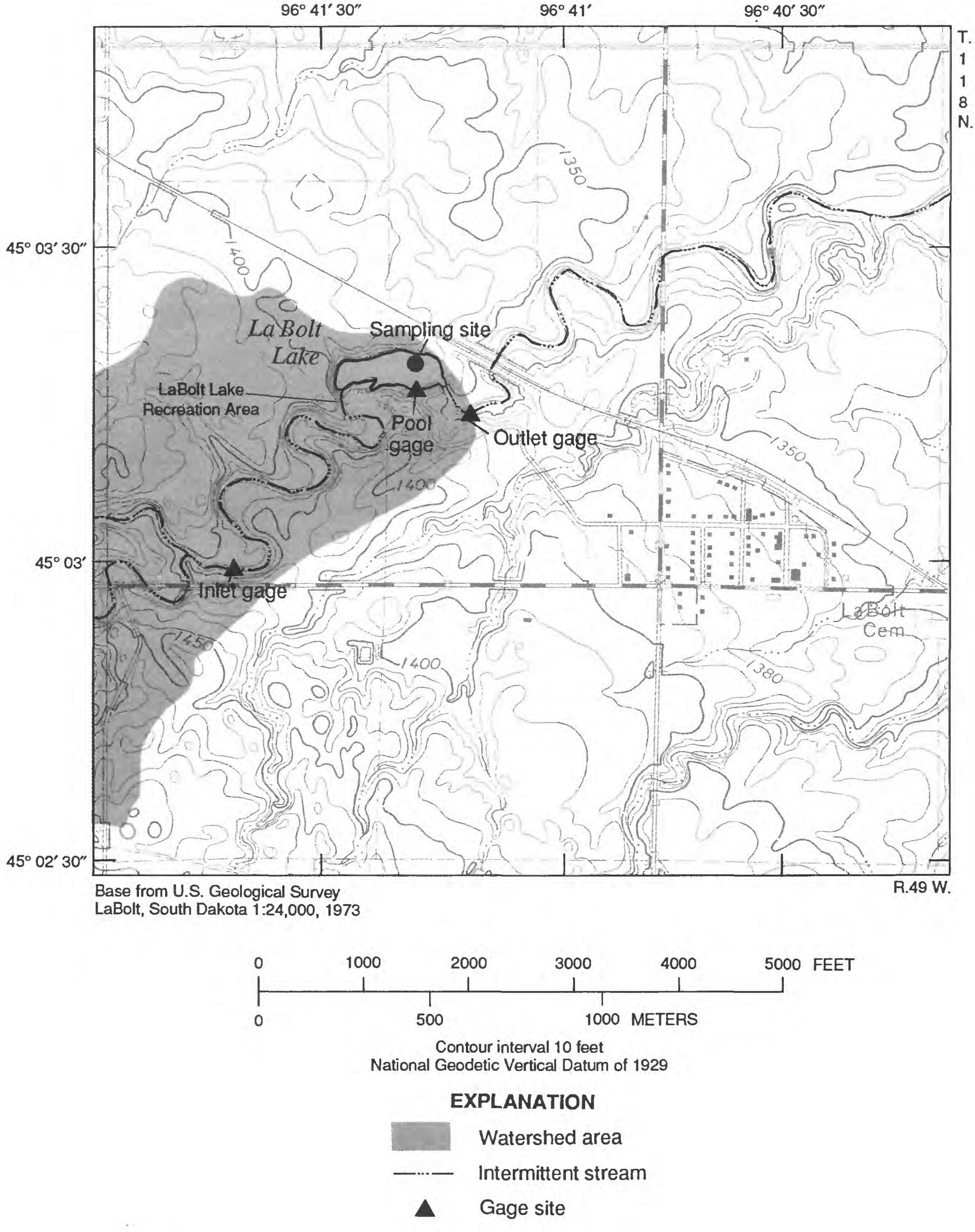


Figure 2.--Data collection sites at LaBolt impoundment.

Webber impoundment was built in 1974 by the landowner in cooperation with the SCS. The outlet structure on the east side is a corrugated metal culvert through an earthen dam (fig. 3). No inlet structure is attached to the culvert. The banks around the impoundment slope steeply upward to higher levels where fields of corn, soybeans, and hay are grown. The embankment slopes are periodically used for pasture. The impoundment is drawn down for irrigation if sufficient water is in storage. Land-use data for the drainage basin were not compiled and no soundings were made to determine the volume of the impounded waters.

The Dillon-Syltie impoundment was built in 1974 as a flood control and recreational structure by the Yellow Medicine Watershed District in cooperation with the SCS and the U.S. Agricultural Stabilization and Conservation Service. The outlet structure at the northeastern side of the impoundment is a box-shaped weir around the entrance to a metal culvert in an earthen dam (fig. 4). A grass-covered emergency spillway is located at the southern end of the dam. Some bank erosion from wave action occurred at the water line of the dam during the study. The inlet is on the southwestern side of the impoundment. During the study beavers were active in the swampy land between the inlet gage and the impoundment and livestock were grazed on the low ground along the inlet stream. Corn and soybeans were grown on the high ground around the impoundment. The land adjacent to the impoundment is open for public-recreational use such as fishing and picnicking. Land uses in the drainage basin are cropland, 85 percent; pasture, 7 percent; woodland, 3 percent; and other uses, 5 percent.

The Lake Laura impoundment was built in 1978 by Area 2 Minnesota River Basin Project, Inc. in cooperation with the SCS. The outlet structure, a tower with a drop inlet, is at the earthen dam at the eastern side of the pool (fig. 5). There are two inlets to the impoundment at the northwestern and southwestern sides. The lower land along the borders of the inlet streams is used for grazing of livestock; a small feed lot is upstream from the north inlet. The impoundment is located in the northwestern corner of a large county park. The Redwood County Park contains picnicking and camping areas; a swimming beach is located at the impoundment. The northern and western sides of the impoundment are adjacent to corn and soybean fields. The major land-uses in the drainage basin are cropland, 79 percent; pasture, 2 percent; woodland, 6 percent; and other uses, 13 percent.

Description of the Stream Sites

The sampling site on the West Branch of the Lac qui Parle River was upstream from the bridge on a Deuel County road going west on the southwestern corner of Gary, South Dakota, 6 mi downstream from Briggs Lake (fig. 1). A residential area is on the northern side of the stream near the bridge. The land adjacent to stream was occasionally used for pasture during the study. The major land uses in the drainage basin are cropland, 51 percent; pasture, 45 percent; wooded, 1 percent; and other uses, 3 percent.

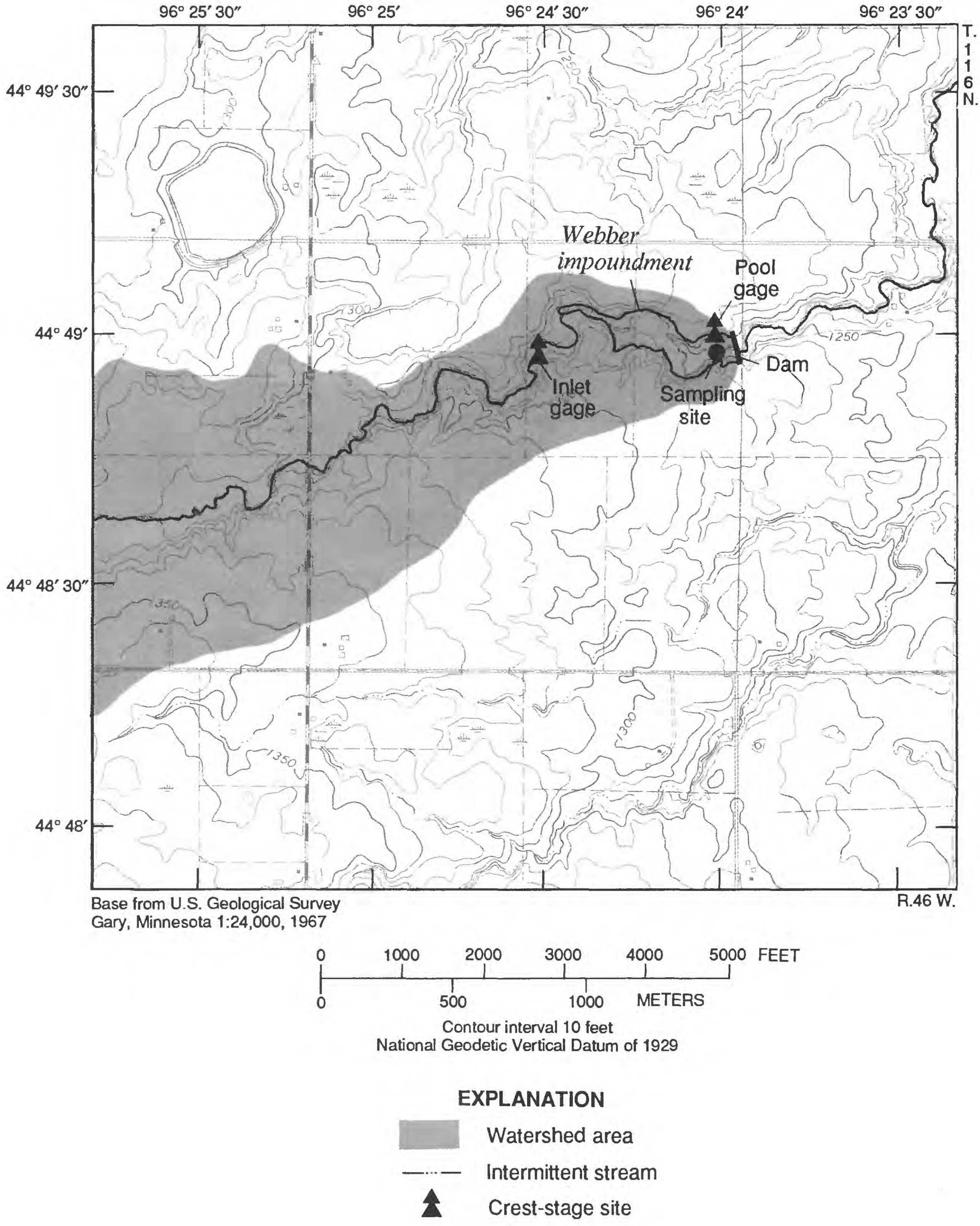
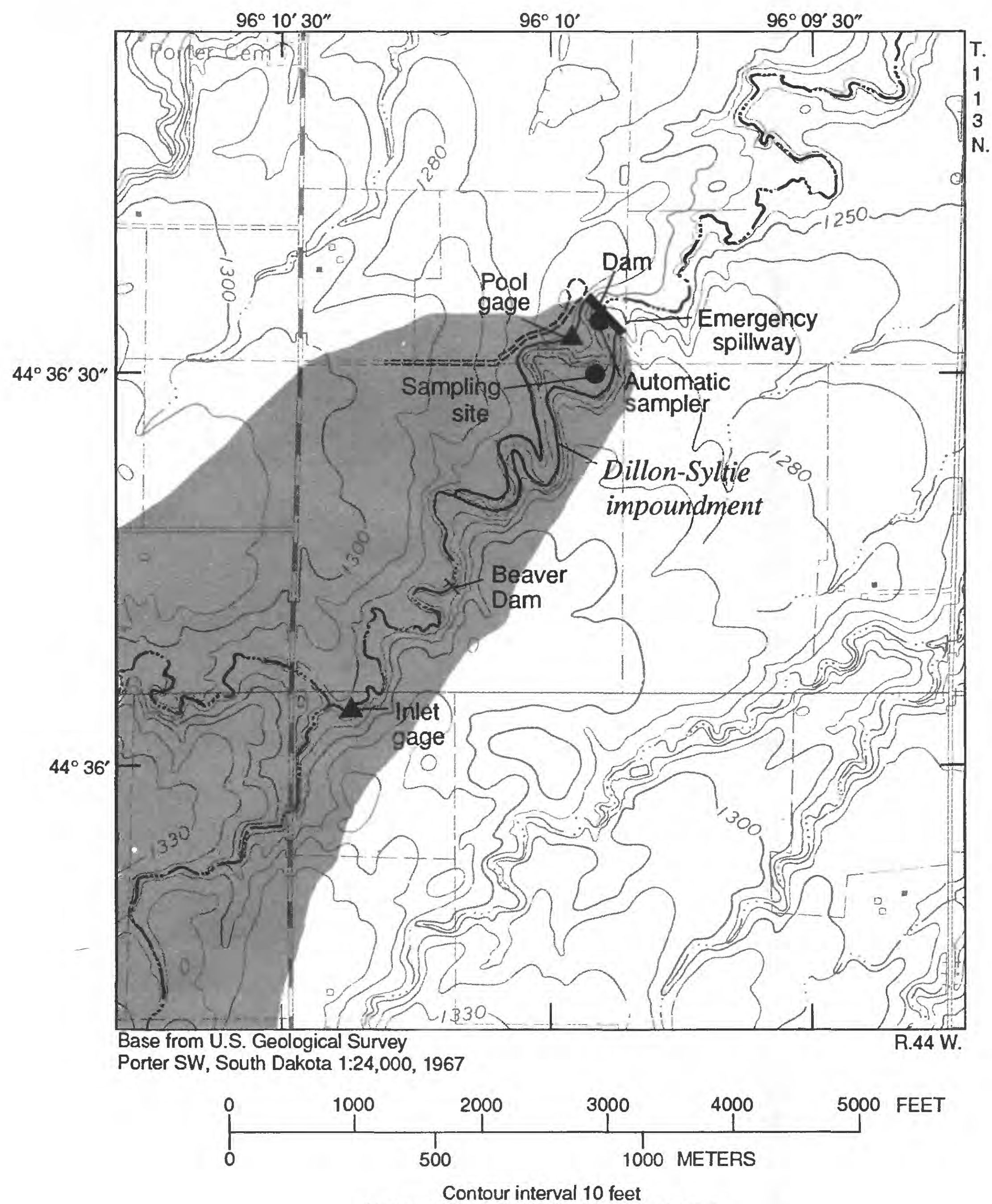


Figure 3.--Data collection sites at Webber impoundment.



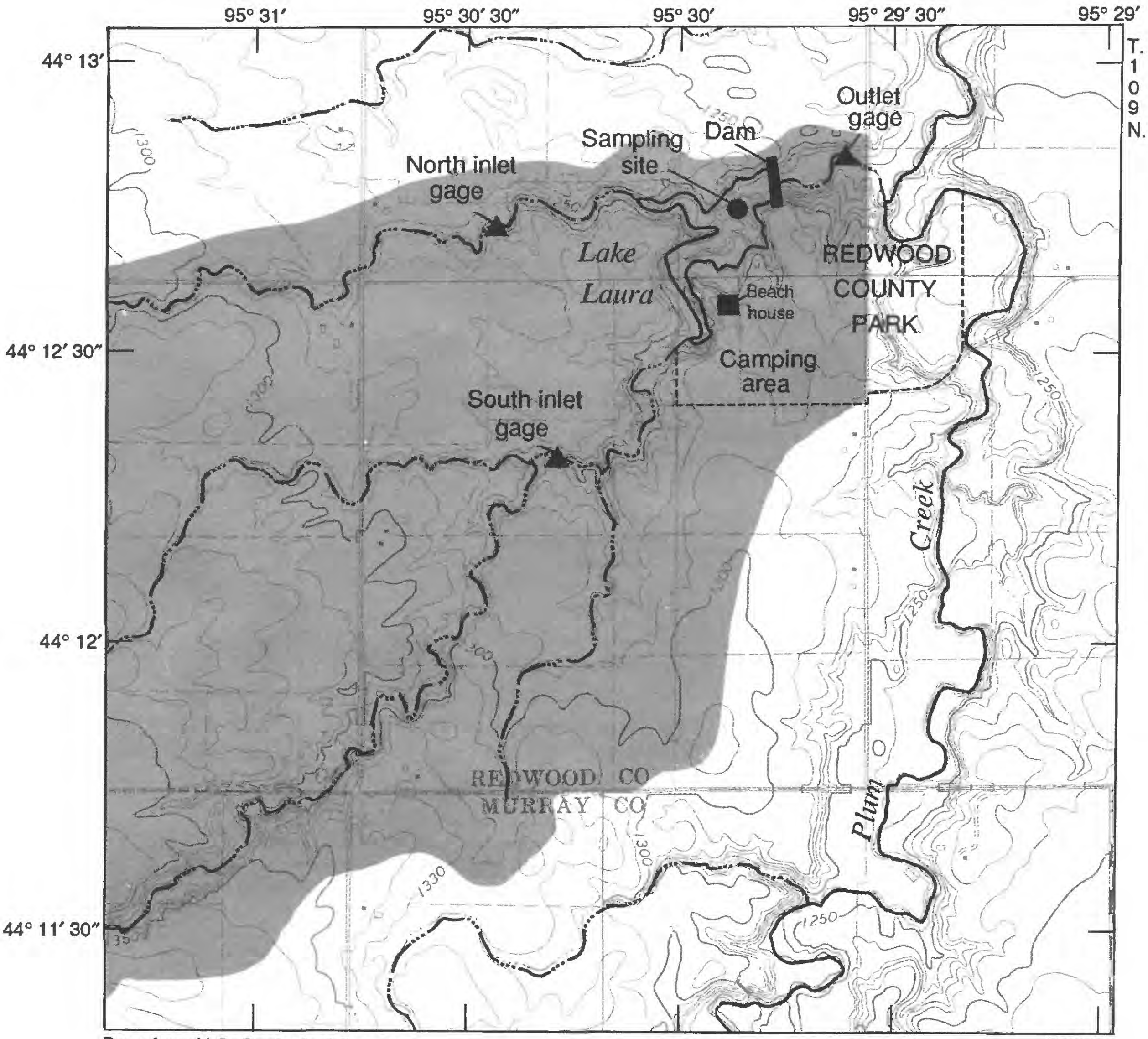
EXPLANATION

Watershed area

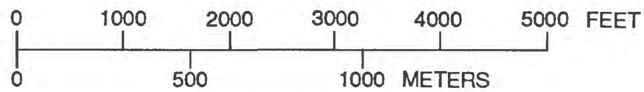
Intermittent stream

Gage site

Figure 4.--Data collection sites at Dillon-Syltie impoundment.



Base from U.S. Geological Survey
Tracy East and Walnut Grove, Minnesota
1:24,000, 1967



Contour interval 10 feet
National Geodetic Vertical Datum of 1929

EXPLANATION

Watershed area
Intermittent stream
Gage site

Figure 5.--Data collection sites at Lake Laura impoundment.

The sampling site on the Lac qui Parle River was 1 mi downstream from the confluence of streams draining Steep Bank Lake and Fish Lake and immediately upstream from the bridge on a Norman township road 4 mi southwest of Canby, Minnesota. The low lands near the sampling site were used for pasture during the study. The major land uses in the drainage basin are cropland, 75 percent; pasture, 20 percent; woodland, 1 percent; and other uses, 4 percent.

The sampling site on Florida Creek was just upstream from a 20-ft-diameter corrugated-metal culvert on County Highway 15. The site was 1.5 mi downstream from South Dakota-Minnesota border. In South Dakota, the stream is named Cobb Creek. The low lands near the sampling site were used as pasture. The major land uses in the drainage basin are cropland, 67 percent; pasture, 29 percent; woodland, 1 percent; and other uses, 3 percent.

The sampling site on Dry Creek was just upstream from a concrete box culvert on County Road 10. The major land uses in the drainage basin are cropland, 90 percent; pasture, 5 percent; woodland, 1 percent; and other uses, 4 percent

Data Collection

Collection of physical, chemical, and biological data began in March 1980 and ended in September 1984. Data were collected at four impoundments, five impoundment inlets, four impoundment outlets, and four stream sites (table 2). A list of sampling sites, drainage areas, and periods of record are shown on figures 1-5. Table 3 contains a general description of data collected at each site.

Starting in March 1980, water-quality data were collected monthly at Dillon-Syltie, La Bolt, and Webber impoundments and at their inlets and outlets through September

In February 1981, the three impoundments and flow at their inlets and outlets were sampled during a period of ice cover. Data collection was then discontinued until March, 1982 at the La Bolt and Webber impoundments. Data collection continued monthly at the Dillon-Syltie impoundment and at its inlet and outlet through September.

During the 1982 water year, data collection resumed at the sampling sites for the La Bolt and Webber impoundments in March. Water-quality data were collected in March and biweekly from May through September at the sampling sites for the three impoundments. Data were collected monthly at three stream sites (Florida Creek, West Branch Lac qui Parle River, and Lac qui Parle River) and from three impoundment inlets and two outlets, March through September.

In the 1983 water year, water-quality data were collected in October and November 1982, and from March through September with the same frequency as in the 1982 water year at the sampling sites for the three impoundments. Beginning in May water-quality data were collected from the Lake Laura impoundment, its two inlets, and its outlet. Data were collected biweekly from the four impoundments from May through September. In September, data collection was discontinued at Webber impoundment, La Bolt impoundment, and the La Bolt impoundment outlet but continued in the 1984 water year at the La Bolt-impoundment inlet on a reduced schedule. During 1983 water year, data were collected monthly at the three stream sites and at the five inlets and three outlets, October 1982, and from March through September.

In the 1984 water year, data were collected monthly at the sampling sites for Dillon-Syltie and Lake Laura impoundments and at the La bolt impoundment inlet during October and November 1983 and from March through September 1984. Beginning in March water-quality data were collected monthly at a new stream site on Dry Creek and monthly samples were collected at the other three stream sites. Sampling was discontinued at all impoundment and stream sites in September, 1984.

During scheduled visits to the streams and impoundments water-quality data were collected (pH, specific conductance, water temperature, and dissolved oxygen concentration). Streamflows were measured, and sediment samples were collected in the streams, other water-quality samples were collected during periods of runoff using automatic samplers. Transparencies were measured and total phosphorus samples were collected in the impoundments. Other water-quality data were collected in the impoundments on a monthly, bimonthly, or yearly basis.

Water-quality discrete and composite samples were collected using techniques discussed by Smith and others (1990). For each stream site, a flow-weighted composite sample of water was analyzed and a mean concentration was determined for each constituent for the individual sample period during runoff. Runoff samples were collected manually or with an automatic sampler and composited to reduce the cost of sample analysis. In the impoundments, vertical composite samples were collected from the euphotic zone[1] in 1980-81 with a horizontal Van Dorn Sampler and in 1982-84 with a 2-inch diameter plastic pipe (4-four foot sections) lowered vertically into the pool, capped and withdrawn. The types of water-quality data collected during 1980-84 are given in table 4. Chemical constituents were analyzed at the U.S. Geological Survey Central Laboratories in Atlanta Georgia. Chemical data was analyzed using the P-Stat Statistical Software Package[2] (P-STAT, Inc., 1989).

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[1]One and half times the transparency depth was used as a guide to location of the euphotic zone of sample collection.
[2]The use of trade names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Table 2.--*Sampling site, period of record, and drainage area*

[USGS, U.S. Geological Survey; COE, U.S. Army Corps of Engineers; mi^2, square miles]

USGS station identification number	COE site number	County	Site name	Period of record	Drainage area (mi^2)
		YELLOW BANK RIVER WATERSHED			
450317096412100		Grant	La Bolt impoundment near La Bolt, So. Dak.	June 1979, Mar. 1980- Sept. 1980, [1]Mar. 1982- Sept. 1984	17.4
450317096412102		Grant	La Bolt inlet near La Bolt, So. Dak.	[2]Mar. 1980- Sept. 1980, [3]Mar. 1982- Aug. 1984	17.1
450317096412104		Grant	La Bolt outlet near La Bolt, So. Dak.	[3]Mar. 1982- Sept. 1983 [2]Mar. 1984- Aug. 1984	17.4
		LAC QUI PARLE RIVER WATERSHED			
444900096240000		Lac qui Parle	Webber impoundment near Gary, So. Dak.	June 1979, Mar. 1980- Sept. 1980, Mar. 1982- Sept. 1983	1.4
444900096240002		Lac qui Parle	Webber inlet near Gary, So. Dak.	[2]Mar. 1982- Sept. 1983	1.4
444900096240004		Lac qui Parle	Webber outlet near Gary, So. Dak.	no outflow	1.4
444726096274201	LQP-28	Deuel	West Branch Lac qui Parle River near Gary, So. Dak.	[2]Mar. 1982- Sept. 1984	28
444410096251001	LQP-3	Yellow Medicine	Florida Creek near Burr, Minn.	[2]Mar. 1982- Sept. 1982, [3]Oct. 1982- Sept. 1984	50
443916096174801	LQP-8	Yellow Medicine	Lac qui Parle River near Canby, Minn.	[3]Mar. 1982- Sept. 1984	186

Table 2.--*Sampling site, period of record, and drainage area*--Continued

USGS station identification number	COE site number	County	Site name	Period of record	Drainage area (mi^2)
			YELLOW MEDICINE RIVER WATERSHED		
443636096095400	YM-23	Lincoln	Dillon-Syltie impoundment near Porter, Minn.	[1]Mar. 1980-Sept. 1984	4.8
443636096095402		Lincoln	Dillon-Syltie inlet near Porter,Minn.	[3]Mar. 1980-Sept. 1984	4.78
443636096095404		Lincoln	Dillon-Syltie outlet near Porter, Minn.	[3]Mar. 1980-Sept. 1984	4.8
			COTTONWOOD RIVER WATERSHED		
441246095294800	CW-27	Redwood	Lake Laura impoundment near Walnut Grove, Minn.	[1]May 1983-Sept. 1984	6.83
441246095294801		Redwood	Lake Laura south inlet near Walnut Grove, Minn.	[3]May 1983-Sept. 1984	5.0
441246095294802		Redwood	Lake Laura north inlet near Walnut Grove, Minn.	[2]May-Oct. 1983-[3]Sept.-Mar. 1984	1.12
441246095294804		Redwood	Lake Laura outlet near Walnut Grove Minn.	[3]May 1983-Sept. 1984	6.83
			LOWER COTTONWOOD RIVER		
05316900	LCW-21	Cotton-wood	Dry Creek near Jeffers, Minn.	[4]June 1982-Sept. 1984	3.13

[1]Lake stage data available, water-quality data available.

[2]Miscellaneous high-flow site, water-quality data available.

[3]Daily discharge record available, water-quality data available.

[4]Daily discharge record available, water-quality data available for 1984 only.

Table 3.--*Method and frequency of data collection*

[No stage or discharge available during winter months. Sample type: manual--instantaneous samples collected by hydrographer; automatic--instantaneous samples collected at predetermined intervals by automatic pumping sampler; composite--instantaneous samples collected during runoff and combined into one sample; observer--instantaneous samples collected by observer at predetermined intervals]

Site	Stage-recorder interval	Water-quality samples	Suspended-sediment samples
		YELLOW BANK RIVER WATERSHED	
La Bolt pool	15 minute	manual composite	
La Bolt inlet	15 minute	manual composite automatic	manual automatic observer
La Bolt outlet	15 minute	manual composite	manual automatic
		LAC QUI PARLE RIVER WATERSHED	
Webber pool		manual composite	
Webber inlet		manual	manual
Webber outlet			
West Branch Lac qui Parle River	Instanteous peak stage only	manual composite	manual
Florida Creek	15 minute	manual automatic composite	manual automatic observer
Lac qui Parle River	15 minute	manual automatic composite	manual automatic observer
		YELLOW MEDICINE RIVER WATERSHED	
Dillon-Syltie pool	15 minute	manual composite	
Dillon-Syltie inlet	15 minute	manual automatic composite	manual automatic
Dillon-Syltie outlet		manual automatic composite	manual automatic
		COTTONWOOD RIVER WATERSHED	
Lake Laura pool	Observer	manual composite	
Lake Laura south inlet	15 minute	manual automatic composite	manual automatic observer
Lake Laura north inlet	15 minute	manual automatic composite	manual automatic observer
Lake Laura outlet	15 minute	manual composite observer	manual observer
Dry Creek	15 minute	manual automatic composite	manual automatic observer

Table 4.--*Types of data collected, 1980-84*

[S indicates stream site; P indicates pool site; "dissolved" indicates a filtered sample; "total" indicates an unfiltered sample; ---, indicate data not available; water year, period from October 1, through September 30]

	Water Years				
	1980	1981	1982	1983	1984
Streamflow	S	S	S	S	S
Stage	PS	PS	PS	PS	PS
Air temperature	PS	PS	PS	PS	PS
Barometric	---	---	PS	PS	PS
Water temperature	PS	PS	PS	PS	PS
pH	PS	PS	PS	PS	PS
Specific conductance	PS	PS	PS	PS	PS
Dissolved oxygen	PS	PS	PS	PS	PS
Vertical profiles (Water temperature, pH, specific conductance, dissolved oxygen, and depth at sampling point)	P	P	P	P	P
Transparency	P	P	P	P	P
Fecal coliform	---	---	PS	PS	PS
Fecal Streptococci	---	---	PS	PS	PS
Chlorophyll a and b	P	P	P	P	P
Phytoplankton	---	P	P	P	P
Dissolved calcium	---	---	PS	PS	PS
Dissolved magnesium	---	---	PS	PS	PS
Dissolved sodium	---	---	S	S	S
Dissolved potassium	---	---	S	S	S
Bicarbonate	---	---	PS	PS	PS
Carbonate	---	---	PS	PS	PS
Dissolved sulfate	---	---	S	S	S
Dissolved chloride	---	---	PS	PS	PS
Dissolved flouride	---	---	S	S	S
Total alkalinity	---	---	PS	PS	PS
Dissolved silica	---	---	PS	PS	PS
Dissolved solids	---	---	PS	PS	PS
Total Phosphorus	PS	PS	PS	PS	PS
Dissolved phosphorus	---	---	P	P	P
Dissolved orthophosphorus	---	---	P	P	P
Total nitrogen	P	P	---	---	---
Total nitrate plus nitrite nitrogen	P	P	---	---	---
Total ammonia nitrogen	P	P	---	---	---
Total organic nitrogen	P	P	---	---	---
Total ammonia plus organic nitrogen	P	P	S	S	S
Dissolved nitrite plus nitrate nitrogen	---	---	PS	PS	PS
Dissolved ammonia nitrogen	---	---	P	P	P
Dissolved ammonia plus organic nitrogen	---	---	P	P	P
Daily suspended sediment	---	---	S	S	S
Instantaneous suspended sediment	S	S	S	S	S
Suspended-sediment particle size	---	---	S	S	S
Bed material size	---	---	S	S	S

WATER QUALITY OF IMPOUNDED AND UNIMPOUNDED STREAMS

Streams of the Coteau drain watersheds that differ in geology, soil type, and land use; therefore, water quality can be expected to differ among streams. Although suspended-sediment and chemical samples commonly were collected at different times and frequencies at the various Coteau sampling sites, analysis of the data allows characterization and comparison the water quality in the streams.

Suspended Sediment

Suspended-sediment transport can be an important indicator of water quality. Plant nutrients and toxic substances can be sorbed and transported by sediment particles. Sediment deposition can shorten the useful life of an impoundment.

Spearman correlation coefficients (Ray and others, 1982) between streamflow and instantaneous water samples are listed in table 5. Correlation coefficients are listed only for relations among instantaneous streamflow and concentrations of dissolved and suspended substances significant at $\alpha = 0.05$. Correlation coefficients range from +1 to -1 (+1 means that, as streamflow increases, the measured concentration increases proportionally; -1 means, that as streamflow increases, the measured concentration decreases proportionally). A coefficient of 0 indicates that no correlation exists.

Data given in table 5 indicate that suspended-sediment concentrations were positively correlated with streamflow in the unimpounded streams and at some of the impoundment inlets. However, significant correlations were not found between suspended sediment and streamflow at the impoundment outlets.

Daily mean suspended-sediment concentrations from one or more sediment samples per day were calculated for 10 sites. Some data were not recorded because of operational problems; thus, reliable comparisons of long-term sediment-transport characteristics among all the sites are not possible. At the La Bolt inlet and outlet, the Lac qui Parle River, and the Dillon-Syltie inlet and outlet, no flow occurred on many days during the study.

Daily mean suspended-sediment concentrations were calculated at the inlet and outlet of La Bolt impoundment only during March-July 1983; because these data were not collected concurrently with other sediment data, they were not analyzed. At eight other sites, daily mean suspended-sediment concentrations were calculated from April through June 1984. Although this was a relatively short period, two large discharge fluctuations and four to five smaller discharge fluctuations occurred at each of the eight sites.

Daily mean sediment concentrations for concurrent periods of record at the eight sites are summarized in table 6. Minimum concentrations are similar for all sites, but maximum concentrations differ more widely. Maximum concentrations were highest at the unimpounded sites and at inlets to the impoundments, and were lowest at outlets from impoundments which suggests that the impoundments reduce the range in suspended-sediment concentrations.

Median concentrations of suspended sediment tended to be higher at the inlets than at the outlets. The median concentration of suspended sediment at the outlet from Lake Laura was about half the concentration at the south inlet, but was nearly double the concentration at the north inlet. Mean sediment concentrations for these sites, which are affected by a few elevated concentrations, probably are not good indicators of the central tendency of the data.

Nonparametric analysis of variance and use of Duncan's multiple-range test (significant at $\alpha = 0.05$) showed that many of the differences apparent in table 6 are statistically significant. Suspended-sediment concentrations at Dry Creek, Dillon-Syltie inlet, the south inlet to Lake Laura, and the Lac qui Parle River were significantly higher than at the other sites. Concentrations at the outlets from Lake Laura and from Dillon-Syltie impoundment, and at the north inlet to Lake Laura were significantly lower than at the other sites. Concentrations in Florida Creek were intermediate to each of the other groups.

Significantly lower concentrations at the outlets of the impoundments, when compared to the inlets, indicate that the impoundments have an effect on water-quality. Sediment probably is being deposited as the velocity and turbulence of water decreases through the pools. Daily suspended-sediment concentrations at La Bolt impoundment during March through May 1983 were lower at the outlet than at the inlet. The maximum concentration at the outlet was 59 mg/L (milligrams per liter)--about half that measured at the inlet. Mean and median concentrations were 24 and 26 mg/L at the inlet, but were 14 and 10 mg/L at the outlet. La Bolt impoundment probably traps substantial quantities of sediment that otherwise would be transported downstream. Deposition was further substantiated by a visual inspection of the inlet and probing of the pool bottom. At one location, approximately 6 ft of sediment had collected since the pool was built during the 1930's. Near the inlet, approximately half an acre of the pool appeared to have filled with sediment.

Daily suspended-sediment discharge is summarized in table 7. Suspended-sediment discharge is the load of suspended-sediment transported past a site, and can show the amount of sediment being carried into or out of an impoundment. The daily suspended-sediment discharges listed in table 7 reveal a somewhat different situation than was apparent in table 6. Minimum sediment discharges were less than 1 ton/d (ton per day) at all sites; and minimum discharges at the north inlet to Lake Laura and at the inlet and outlet of Dillon-Syltie impoundment were less than 0.04 ton/d. Maximum suspended-sediment discharge transported to impoundments and by unimpounded streams ranged from 64 ton/d for the Lake Laura south inlet to 1,230 ton/d for Dry Creek. Maximum sediment discharges from the outlets of the impoundments were less than 20 percent of maximum discharge entering the impoundments, which indicates that the impoundments are trapping much of the peak sediment discharge.

Suspended-sediment discharged from impoundment outlets was much less than the amount carried into the impoundments. A total suspended-sediment load of 1,110 tons was carried into Dillion-Syltie impoundment during the study period, but only about one-fifth that amount was discharged at the outlet. At Lake Laura only about one-fifth of the 1,200 tons carried into the impoundment during the study period was discharged at its outlet.

Table. 5.--Spearman correlation coefficients significant at α = 0.05 for relations between instantaneous streamflow and concentrations of dissolved and suspended substances in the water

[The number of observations are in perenthesis; .., indicates correlation was not significant; µs/cm, microsiemens per centimeter at 25 degrees Celsius; L, liter; mg, milligram;]

Constituent or property	La Bolt impoundment Inlet	La Bolt impoundment Outlet	West Branch Lac qui Parle River	Florida Creek	Lac qui Parle River	Dillon-Syltie impoundment Inlet	Dillon-Syltie impoundment Outlet	Lake Laura impoundment North Inlet	Lake Laura impoundment South Inlet	Lake Laura impoundment Outlet	Dry Creek
Oxygen, dissolved.....	.. (21)	.. (19)	.. (28)	.. (43)	.. (42)	.. (34)	.. (24)	.. (19)	.. (22)	.55 (20)	.. (9)
PH....................	.. (24)	.. (21)	.. (28)	-.34 (44)	-.34 (40)	.. (32)	.. (27)	.. (21)	.. (22)	.. (19)	.. (9)
Specific conductance (µS/cm).............	-0.82 (26)	-0.62 (22)	-0.73 (33)	-0.74 (48)	-0.67 (48)	-0.69 (37)	-0.53 (30)	.. (20)	-0.85 (25)	-0.78 (21)	-0.82 (30)
Solids, dissolved.....	-.96 (5)	.. (4)	.. (13)	-.83 (12)	-.81 (11)	.. (5)	.. (5)	.. (3)	-.93 (5)	-.91 (5)	.. (1)
Calcium, dissolved (mg/L as Ca)........	-.86 (6)	.. (4)	.. (12)	-.73 (12)	-.79 (11)	-.85 (7)	.. (5)	.. (3)	-1.0 (5)	.. (5)	.. (1)
Magnesium, dissolved (mg/L as Mg)........	-.86 (6)	.. (4)	.. (12)	-.76 (12)	-.89 (11)	.. (7)	.. (5)	.. (4)	-.91 (5)	.. (5)	.. (1)
Sodium, dissolved (mg/L as Na)........	-.86 (6)	.. (4)	.. (12)	-.74 (12)	.. (11)	.. (7)	.. (5)	.. (3)	-1.0 (5)	-.97 (5)	.. (1)
Potassium, dissolved (mg/L as K).........	.. (6)	.. (4)	.73 (13)	.. (12)	-.66 (11)	.. (7)	.. (5)	.. (3)	-1.0 (5)	.. (5)	.. (1)
Chloride, dissolved (mg/L as Cl)........	-.82 (7)	.. (4)	.. (13)	.. (14)	.. (11)	.. (7)	.. (5)	.. (4)	.. (6)	.. (6)	.. (1)
Sulfate, dissolved (mg/L as SO4).......	-.86 (6)	.. (4)	.. (13)	-.72 (12)	-.88 (11)	-.87 (6)	.. (5)	.. (3)	-.93 (5)	.. (4)	.. (1)

Table. 5.--Spearman correlation coefficients significant at α = 0.05 for relations between instantaneous streamflow and concentrations of dissolved and suspended substances in the water--Continued

Constituent or property	La Bolt impoundment		West Branch Lac qui Parle River	Florida Creek	Lac qui Parle River	Dillon-Syltie impoundment		Lake Laura impoundment			Dry Creek
	Inlet	Outlet				Inlet	Outlet	North Inlet	South Inlet	Outlet	
Fluoride, dissolved (mg/L as F).........	.. (6)	.. (4)	.. (13)	.. (12)	.. (11)	.. (6)	.. (5)	.. (3)	.. (5)	.. (4)	.. (1)
Silica, dissolved (mg/L as SiO_2)......	.. (6)	.. (4)	-.70 (13)	.. (12)	-.64 (11)	.. (6)	.90 (5)	.. (3)	.. (5)	.. (4)	.. (1)
Alkalinity, as $CaCO_3$..	-.92 (5)	.. (5)	.. (10)	-.86 (14)	-.61 (13)	-.92 (8)	.. (10)	.. (4)	.. (5)	.. (5)	.. (..)
Nitrite plus nitrate nitrogen, dissolved.	.. (7)	.. (7)	.. (14)	.. (15)	.62 (13)	.74 (9)	.. (7)	.. (5)	.. (8)	.. (10)	.. (3)
Phosphorus, total.....	.56 (17)	.. (14)	.71 (18)	.51 (19)	.75 (16)	.. (19)	.68 (16)	.. (15)	.. (18)	.. (15)	.91 (6)
Sediment, suspended...	.67 (28)	.. (24)	.49 (29)	.80 (47)	.66 (45)	.. (34)	.. (28)	.. (11)	.78 (23)	.. (14)	.71 (15)
Coliform fecal bacteria............	.. (3)	.. (3)	.. (6)	.. (12)	.. (9)	.. (5)	.. (4)	.. (2)	.. (4)	.. (4)	.. (1)
Streptococci fecal bacteria...........	.. (3)	.. (3)	.. (6)	.. (12)	.82 (10)	.. (5)	.. (4)	.. (2)	.. (4)	.. (4)	.. (1)

Table 6.--*Summary of suspended-sediment concentrations from streams and impoundment inlet and outlet sites in the Coteau region, March 31 to July 6, 1984*

[Concentrations in milligrams per liter]

Site	Number of days used in analysis	Minimum concen-tration	Maximum concen-tration	Mean concen-tration	Median concen-tration
Dillon-Syltie inlet	98	23	869	154	82
Dillon-Syltie outlet	98	6	192	53	36
Lake Laura north inlet	98	5	1,590	98	23
Lake Laura south inlet	98	20	507	113	92
Lake Laura outlet	98	17	96	47	42
Florida Creek	98	14	1,260	104	42
Lac qui Parle River	98	9	536	142	100
Dry Creek	98	23	1,920	199	80

Table 7.--*Summary of daily suspended-sediment discharges, yields and loads from stream and impoundment inlet and outlet sites in the Coteau region, March 31 through July 6, 1984*

[Discharges are in tons per day; total load is in tons for the period; total yield is in tons per square mile for period]

Site	Number of days used in analysis	Minimum discharge	Maximum discharge	Total load	Total yield
Dillon-Syltie Inlet	98	0.03	258	1,110	232
Dillon-Syltie Outlet	98	.01	49	227	47.3
Lake Laura North Inlet	98	.02	304	615	549
Lake Laura South Inlet	98	.11	64	582	116
Lake Laura Outlet	98	.36	8.6	260	38.1
Florida Creek	98	.23	589	4,780	95.6
Lac qui Parle River	98	.66	995	14,500	78.0
Dry Creek	98	.32	1,230	2,600	831

Comparison of suspended-sediment discharges at the inlet and outlet of La Bolt impoundment, sampled during March through May 1983, shows less of a reduction in sediment load than was found at Dillon-Syltie and Lake Laura impoundments. The total sediment load at the outlet of La Bolt, 35.5 tons, was about half of the 65.2 tons measured at the inlet. The maximum sediment discharge at the outlet also was only about half of the 18 ton/d at the inlet. La Bolt impoundment was nearly full of sediment during this study, indicating that it probably was less efficient than Dillon-Syltie and Lake Laura impoundments at trapping sediments.

The trap efficiency of an impoundment is a useful way to evaluate it's ability to remove sediments from tributary streams. Dillion-Syltie and Lake Laura impoundments had trap efficiencies of 80 and 78 percent, respectively, indicating that about 80 percent of the suspended sediment carried by tributary streams was deposited in the impoundments. La Bolt impoundment had only a 46-percent trap efficiency.

Chemical and Physical Quality

The median values of chemical and physical characteristics measured in the Coteau streams are shown in table 8.

Nutrients (nitrite plus nitrate nitrogen and total phosphorus) can contribute to eutrophication of lakes and impoundments, and are possible indicators of contamination by runoff from feedlots or fertilized fields. Median concentrations of nitrite plus nitrate nitrogen were greater than 5.0 mg/L in Dry Creek, and in the outlet and the two inlets to Lake Laura; these concentrations were significantly higher than at the other sites. Concentrations were less than 0.4 mg/L at the La Bolt sites and at Florida Creek, which were significantly lower than at all the sites except the West Branch Lac qui Parle River. The median concentration of 0.10 mg/L in the West Branch Lac qui Parle River was significantly lower than that at any of the other sites sampled.

Differences in median concentrations of total phosphorus (table 8) were statistically significant at only two sites. The median total phosphorus concentration (0.56 mg/L) at the northern inlet to Lake Laura, which is immediately downstream from a small feed lot, was significantly higher than the median at the other sites. The West Branch Lac qui Parle River had a significantly lower median concentration of total phosphorus (0.03 mg/L).

Variations in nutrient concentrations throughout the Coteau region probably result from many factors. Soil types, surface slope, and drainage area, as well as land use and agricultural practices all could affect concentrations measured at the sites sampled.

At most of the impounded sites, the median concentration of total phosphorus at the outlet was less than at the inlet. Total phosphorus correlates positively with sediment concentration, indicating that the apparent reduction probably results from the settling out of phosphorus attached to sediment particles or the uptake of phosphorus by phytoplankton that subsequently die and settle to the bottom of the impoundment. However, the differences in concentration between the inlets and the outlets of the impoundments are not statistically significant.

Table 8.--*Median discrete and composite sample values of chemical and physical characteristics of Coteau streams*

[The number of observations are in parenthesis; results in milligrams per liter, except as noted; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, not sampled]

Constituent or property	La Bolt impoundment		West Branch Lac qui Parle River	Florida Creek	Lac qui Parle River	Webber impoundment		Dillon-Syltie impoundment		Lake Laura impoundment			Dry Creek
	Inlet	Outlet				Inlet	Outlet[1]	Inlet	Outlet	North Inlet	South Inlet	Outlet	
[2]Oxygen, dissolved	11.0 (21)	10.7 (20)	10.1 (28)	10.5 (43)	10.9 (42)	15.8 (1)	-- --	10.4 (34)	10.9 (24)	9.4 (19)	10.2 (22)	10.6 (20)	9.9 (9)
[2]pH	8.1 (24)	7.9 (21)	8.0 (28)	8.0 (44)	8.0 (40)	7.9 (4)	-- --	8.0 (32)	7.8 (27)	7.6 (21)	7.75 (22)	8.0 (19)	7.8 (9)
[2]Specific conductance (µS/cm)	662 (26)	642 (23)	793 (33)	653 (49)	850 (48)	930 (2)	-- --	988 (37)	908 (30)	1,100 (20)	1,440 (25)	1,140 (21)	973 (30)
Solids, dissolved	450 (6)	410 (6)	491 (14)	456 (21)	769 (18)	1,010 (1)	-- --	698 (11)	695 (8)	689 (7)	1,150 (9)	826 (8)	356 (6)
Calcium, dissolved	56 (7)	73 (6)	110 (13)	87 (20)	120 (18)	170 (1)	-- --	140 (13)	115 (8)	115 (6)	170 (9)	160 (8)	56 (6)
Magnesium, dissolved	21 (7)	29 (6)	38 (13)	32.5 (20)	50 (18)	68 (1)	-- --	49 (13)	46 (8)	41 (7)	65 (9)	54 (8)	15 (6)
Sodium, dissolved	4.4 (7)	6.2 (6)	7.5 (13)	7.2 (20)	11.5 (18)	20 (1)	-- --	17 (13)	14.5 (8)	12 (7)	18 (9)	15 (8)	4.9 (6)
Potassium, dissolved	6.3 (7)	6.3 (6)	4.75 (14)	5.2 (20)	7.35 (18)	7.0 (1)	-- --	4.30 (13)	4.4 (8)	3.7 (7)	2.5 (9)	3.2 (8)	3.2 (6)
Chloride, dissolved	3.0 (8)	3.05 (6)	2.65 (14)	4.1 (23)	9.8 (21)	4.0 (1)	-- --	5.55 (16)	5.6 (8)	16.5 (8)	12.5 (10)	13 (9)	11 (6)
Sulfate, dissolved	110 (7)	114 (6)	160 (14)	140 (20)	310 (18)	530 (1)	-- --	315 (12)	280 (8)	255 (6)	500 (9)	460 (7)	91 (6)
Fluoride, dissolved	.10 (7)	.10 (6)	.3 (14)	.2 (20)	.3 (18)	.2 (1)	-- --	.3 (12)	.3 (8)	.7 (7)	.9 (9)	.7 (7)	.4 (6)
Silica, dissolved	17 (7)	16.0 (6)	25.5 (14)	19 (20)	16 (18)	21 (1)	-- --	15.5 (12)	12.5 (8)	15 (7)	21 (9)	16 (7)	11.4 (6)

Table 8.--*Median discrete and composite sample values of chemical and physical characteristics of Coteau streams*--Continued

Constituent or property	La Bolt impoundment		West Branch Lac qui Parle River	Florida Creek	Lac qui Parle River	Webber impoundment		Dillon-Syltie impoundment		Lake Laura impoundment			Dry Creek
	Inlet	Outlet				Inlet	Outlet[1]	Inlet	Outlet	North Inlet	South Inlet	Outlet	
[2]Alkalinity, as $CaCO_3$.....	283 (5)	257 (6)	290 (10)	232 (14)	218 (12)	225 (1)	-- --	246 (8)	208 (10)	243 (4)	268 (5)	190 (5)	-- (--)
Nitrite plus nitrate nitrogen, dissolved.....	.34 (10)	.35 (9)	.10 (15)	.40 (26)	1.15 (22)	-- --	-- --	1.8 (15)	1.8 (13)	11.0 (10)	8.50 (12)	6.5 (13)	5.2 (9)
Ammonia, total............	.10 (1)	-- (--)	.06 (2)	.07 (2)	.15 (1)	-- --	-- --	.10 (2)	-- (--)	48 (1)	-- (--)	-- (--)	-- (--)
Phosphorus, total	.15 (21)	.12 (16)	.03 (19)	.11 (32)	.12 (30)	.18 (1)	-- --	.10 (28)	.09 (25)	.56 (22)	.19 (23)	.10 (18)	.16 (13)
Phosphorus, dissolved.....	-- (--)	-- (--)	.01 (1)	.04 (2)	.01 (1)	-- --	-- --	.01 (1)	-- (--)	-- (--)	-- (--)	-- (--)	-- (--)
[2]Sediment, suspended......	39 (32)	33 (26)	36.5 (30)	84.5 (48)	59 (52)	34 (3)	-- --	53 (37)	35.0 (30)	82 (13)	72.0 (23)	36.0 (17)	112 (17)
[2]Coliform, fecal bacteria................	460 (3)	85 (3)	1,100 (6)	460 (12)	240 (9)	-- --	-- --	240 (5)	14 (4)	96 (2)	940 (4)	220 (4)	860 (1)
[2]Streptococci, fecal bacteria................	840 (3)	4,800 (3)	1,000 (6)	620 (12)	760 (10)	-- --	-- --	820 (5)	610 (4)	3,200 (2)	2,400 (4)	2,100 (4)	270 (1)

[1]Not sampled
[2]Discrete samples only

Although eight or more samples were collected from most sites (table 8), only one sample was collected from Webber inlet; no samples were collected from the outlet. Values in the table for Webber inlet may not be representative and data were not included in statistical tests.

Water at the southern inlet and the outlet of Lake Laura, in the Cottonwood River watershed, generally had the highest concentrations of dissolved solids, calcium, sodium, chloride, sulfate, and fluoride. Dry Creek, an unimpounded stream in the same watershed, and water at the northern inlet of Lake Laura had similarly elevated concentrations of chloride and fluoride. Nonparametric analysis of variance combined with Duncan's multiple range test ($\alpha = 0.05$) showed that concentrations of these substances were significantly higher at Dry Creek than at most of the other sites.

Median concentrations of dissolved solids ranged from 410 to 456 mg/L in the inflow and outflow of La Bolt impoundment and in Florida Creek. Dissolved-solids concentrations at those sites, at Dry Creek, and at the West Branch Lac qui Parle River were significantly lower than at the other sites. Median concentrations of dissolved solids ranged from 689 to 1,150 mg/L at the rest of the sites.

Sources of Dissolved Substances

Spearman correlation coefficients in table 5 show that specific conductance and dissolved-solids concentrations have a strong negative correlation with streamflow at most of the sites. This is a common relation, resulting from dilution of these waters during runoff by precipitation. Concentrations of calcium, magnesium, and sulfate, all major constituents in the streams, and of sodium, chloride, fluoride, and silica generally were negatively correlated with streamflow.

Potassium and streamflow were negatively correlated at the southern inlet to Lake Laura and at the Lac qui Parle River, but were positively correlated at West Branch Lac qui Parle River. Most correlation coefficients relating potassium to streamflow did not meet the significance criteria for inclusion in table 5, suggesting that this constituent is a contaminant introduced with runoff. Positive correlations between dissolved potassium and streamflow were found for the northern inlet to Lake Laura and the inlet to Dillon-Syltie impoundment, but were not significant enough to be listed in table 5.

Hem (1985) states that "streams in the north-central prairie region of the United States carry consistently higher potassium concentrations than streams of comparable dissolved-solids content in other parts of the United States," and that "records also show a tendency for the potassium concentration in these streams to be nearly the same at low and high flows." He suggested this may be the result of soil leaching by runoff. A reason for increases in potassium concentration during increases in streamflow in the study area might reflect increases in potassium in runoff from fields treated with chemical fertilizers. Different salts of potassium are incorporated in many fertilizers (Stewart and others, 1975) and could provide a source of potassium during runoff.

Strong positive correlations between nutrient concentrations and streamflow (table 5) indicate that dissolved nitrite plus nitrate nitrogen and total phosphorus are introduced to the streams with runoff. The source of these nutrients can not be determined from the data, but may be runoff from feedlots or fertilized fields.

Biological Quality

Samples collected from Coteau streams were analyzed for fecal coliform and fecal *Streptococcus* bacteria. Several samples were collected from most sites, but only one sample from Dry Creek and two samples from the north inlet of Lake Laura were collected.

Bacteria concentrations exceeded 100 colonies per 100 mL (milliliters) at most of the sites, especially during runoff. Median fecal coliform concentrations ranged from less than 100 colonies per 100 mL at the north inlet of Lake Laura and the outlets of La Bolt and Dillon-Syltie impoundments to 1,100 colonies per 100 mL in the West Branch Lac qui Parle River. Concentrations of fecal *Streptococcus* generally were higher than concentrations of fecal coliform; median values ranged from 270 colonies per 100 mL in Dry Creek (one sample) to 4,800 colonies per 100 mL at the La Bolt impoundment outlet (three samples). Extremely high levels of fecal contamination were indicated at two locations. A maximum fecal coliform concentration of 80,000 colonies per 100 mL occurred in West Branch Lac qui Parle River and 8,500 fecal *Streptococcus* colonies per 100 mL occurred in the Lac qui Parle River.

The ratio of fecal coliform concentrations to fecal *Streptococcus* concentrations can indicate the source of fecal contamination; if the ratio is about 4 to 1, the source probably is human, if less than 0.7, the source probably is animal (Millipore, 1973, p. 39). Ratios for 48 of the 53 measurements of bacteria concentrations were less than or close to 0.7, indicating that the primary source of fecal contamination in these streams is from animals. Two samples collected from the West Branch Lac qui Parle River had greater than the 4:1 ratio indicative of human fecal contamination, which indicates that the river may be contaminated by sewage from homes upstream from the sampling site. On June 7, 1979, and on July 7, 1982, ratios were 5:1 and 13:1. Ratios should be interpreted with caution because bacteria are subject to variable rates of die-off depending on length of time since deposition, temperature, rainfall, and distance from their source to the point of sample collection.

Impoundments do not seem to affect the viability of fecal bacteria substantially. Concentrations of fecal coliform generally were less at the outlets than at the inlets, but, because of the limited number of samples and wide range of values, the differences were not significant. Fecal coliform concentrations at the outlets indicate that contact with these waters could pose a threat to health (U.S. Environmental Protection Agency, 1986). Fecal *Streptococcus* concentrations were similar at the inlets and outlets of all impoundments except that the mean and median concentrations at the outlet of La Bolt impoundment were about five times those at the inlet. This difference in concentration suggests that the origin of the fecal bacteria is overland runoff directly to the impoundment. At both La Bolt and Webber impoundments, livestock were pastured adjacent to the impoundment.

Water Temperature and Dissolved Oxygen Concentration

Mean water temperature ranged from about 8.0 °C (degrees Celsius) at the La Bolt and Dillon-Syltie impoundment inlets and outlets to 15.0 °C at the inlets and outlets of Lake Laura. Maximum measured temperatures ranged from 20.5 °C at the La Bolt impoundment inlet and outlet to 27.0 °C at Florida Creek and the Lac qui Parle River. Minimum temperatures of all streams were about 0 °C. The mean temperature of the water at an impoundment outlet was not significantly higher than that measured at the inlet. At Dillon-Syltie impoundment, the mean outlet temperature was even less than the mean inlet temperature. The largest difference in inlet-outlet temperatures occurred at Lake Laura where water at the outlet was 3.0 °C warmer than at either inlet.

Dissolved-oxygen concentrations ranged from a minimum of 5.6 mg/L at the north inlet of Lake Laura to 17.0 mg/L at Florida Creek. Median concentrations were similar at all sites, ranging from 9.4 mg/L at the north inlet of Lake Laura to 11.0 mg/L at the inlet of the La Bolt impoundment.

Relation of Stream Water Quality to Federal and State Standards and Criteria

Data collected for this study were compared with Maximum Contaminant Levels (MCLs) established by the U.S. Environmental Protection Agency (USEPA) (1986) and the Class A drinking-water criteria established by the Minnesota Pollution Control Agency (MPCA) (1978). Sulfate concentrations exceeded the Class A drinking-water standard of 250 mg/L in most streams. Fecal-bacteria concentrations in water from all the streams and impoundment outlets usually were greater than the most probable number of 1 organism per 100 mL allowed by the Class A criteria.

Criteria for Class A fisheries and recreational waters (Minnesota Pollution Control Agency, 1978) often were met in water from the streams because dissolved-oxygen concentrations occasionally dropped below the minimum concentration of 7 mg/L. The design of the sampling program did not meet the requirement for five samples in a calendar month to determine if the maximum limit of 200 fecal coliform organisms per 100 mL was exceeded. Median fecal-coliform concentrations were found to exceed 200 organisms per 100 mL in many of the streams. At the northern inlet to Lake Laura and at the outlets of Dillon-Syltie and La Bolt impoundments, median concentrations were less than 100 organisms per 100 mL. On the bases of these data, it is probable that the quality of most streams would not meet the Class A criteria for fisheries and recreation if the samples were analyzed using MPCA (1978) methods.

Data collected for this study (Smith and others, 1990), indicate that the streams meet most of the criteria established by MPCA (1978) for Class B and C fisheries and recreational waters including dissolved-oxygen concentration and temperature. The greatest deviation from established criteria were elevated concentrations of fecal coliform bacteria. Class B and C criteria provide a limit of 200 organisms per 100 mL as an average of five samples in a calendar month, but allow no more than 10 percent of the samples to exceed 2,000 organisms per 100 mL. Concentrations of fecal coliform exceeded 2,000 organisms per 100 mL in water from Lake Laura outlet and south inlet, West Branch Lac qui Parle River, and Florida Creek, which suggests that the streams and the lake do not meet Class B or C criteria.

One stream, Dry Creek, was classified by MPCA as a Class C fisheries and recreational stream. Based on the data collected, Dry Creek probably meets the Class C criteria with the possible exception of fecal coliform bacteria. The only sample from Dry Creek analyzed for fecal coliform had a concentration of 860 organisms per 100 mL.

EFFECTS OF IMPOUNDMENTS ON STREAM CHEMISTRY

Data from the Coteau streams were evaluated to determine if the impoundments alter the quality of water in the streams. A comparison of data collected at inlets and outlets and in the impoundments was made by using the Mann-Whitney U test to determine statistical significance at $\alpha = 0.05$. Sufficient data for analysis of changes were available only for three impoundments--Lake Laura, Dillon-Syltie, and La Bolt.

Differences in concentration of constituents between the inlets and outlets of Dillon-Syltie and La Bolt impoundments were noted. Major dissolved substances, dissolved-solids concentration, and specific conductance generally decreased slightly through Dillon-Syltie impoundment. Concentrations of major dissolved substances generally increased through La Bolt impoundment, but specific conductance and dissolved solids decreased. The only changes that were statistically significant were decreases in specific conductance, calcium, and alkalinity through the Dillon-Syltie impoundment, and decreased alkalinity through Lake Laura impoundment.

On the basis of the limited data collected for this study, the only major effect the impoundments have on water quality is to reduce the concentration of suspended sediment. This reduction was significant at Lake Laura and nearly significant ($\alpha = 0.07$) at La Bolt impoundment. More detailed analysis of the data or additional data collection could detect more subtle changes in quality that occur as water passes through the impoundments.

PHYSICAL AND CHEMICAL CHARACTERISTICS OF IMPOUNDED WATERS

Much of the analysis and interpretation of the impoundment water-quality data in this section is focused on water-quality characteristics pertinent to the construction of impoundments that are esthetically appealing, suitable for water-contact recreation, and capable of supporting a sport fishery.

The analysis involved examination of data from four impoundments to determine thermal regime, levels of productivity, transparency, presence of bacterial contamination, dissolved-oxygen concentrations, and presence of toxic substances, all of which are key indicators of overall water quality. Seasonal median data for these characteristics (with the exception of dissolved oxygen) are shown in table 9. The evaluation of these characteristics not only serves to describe water-quality conditions in the impoundments, but also provides insight into how the impoundments respond to input from their watersheds. Furthermore, the quality of water found in the impoundments will significantly affect receiving streams when outflow occurs.

Table 9.--*Median values of chemical and physical characteristics of Coteau impoundments by seasons*

[Results in milligrams per liter, except as noted. Number of samples are shown in parenthesis. µg/L, micrograms per L; spring, February-May; summer, June-September; fall, October-November; --, not sampled]

	La Bolt		Webber		Dillon-Syltie		Lake Laura	
	Top sample	Bottom sample	Top sample	Bottom sample	Top sample	Bottom sample	Top sample	Bottom sample
Chlorophyll a (µg/L)								
Spring	11.2	--	3.32	--	5.13	--	3.60	--
	(6)	(--)	(5)	(--)	(8)	(--)	(1)	(--)
Summer	65.0	--	7.75	--	18.0	--	17.0	--
	(15)	(--)	(10)	(--)	(21)	(--)	(13)	(--)
Fall	102	--	3.22	--	7.0	--	20.0	--
	(2)	(--)	(2)	(--)	(3)	(--)	(1)	(--)
Secchi disk transparency (in feet)								
Spring	2.7	--	8.2	--	3.9	--	1.9	--
	(7)	(--)	(5)	(--)	(11)	(--)	(3)	(--)
Summer	1.3	--	6.3	--	3.2	--	3.7	--
	(22)	(--)	(17)	(--)	(28)	(--)	(14)	(--)
Fall	1.0	--	5.1	--	3.7	--	2.8	--
	(3)	(--)	(3)	(--)	(4)	(--)	(1)	(--)
Solids, dissolved								
Spring	559	--	589	--	811	884	666	--
	(3)	(--)	(1)	--	(4)	(1)	(2)	(--)
Summer	518	478	332	--	746	636	1,060	1,130
	(1)	(5)	(5)	--	(5)	(3)	(2)	(1)
Fall	--	385	323	--	708	--	1,160	--
	(--)	(1)	(1)	--	(2)	(--)	(1)	(--)
Calcium, dissolved								
Spring	87	--	86.0	--	120	120	130	--
	(3)	(--)	(1)	(--)	(4)	(1)	(2)	(--)
Summer	63	61.0	37.0	--	95.0	100	175	200
	(1)	(5)	(5)	(--)	(5)	(3)	(2)	(1)
Fall	--	40.0	45.0	--	93.0	--	180	--
	(--)	(1)	(1)	(--)	(2)	(--)	(1)	(--)
Magnesium, dissolved								
Spring	60.0	--	53.0	--	58.0	55.0	35.0	--
	(3)	(--)	(1)	--	(4)	(1)	(2)	(--)
Summer	54.0	45.0	26.0	--	53.0	57.0	74.0	75.0
	(1)	(5)	(5)	--	(5)	(3)	(2)	(1)
Fall	--	39.0	27.0	--	57.0	--	77.0	--
	(--)	(1)	(1)	--	(2)	(--)	(1)	(--)
Chloride, dissolved								
Spring	7.0	--	7.40	--	7.15	7.60	11.0	--
	(3)	(--)	(1)	--	(4)	(1)	(3)	(--)
Summer	5.3	3.5	5.10	--	5.50	5.10	15.0	15.0
	(1)	(5)	(5)	--	(5)	(3)	(2)	(1)
Fall	--	3.5	5.0	--	6.80	--	15.0	--
	(--)	(1)	(1)	--	(2)	(--)	(1)	(--)
Silica, dissolved								
Spring	22.0	--	2.40	--	15.5	4.80	15.0	--
	(3)	(--)	(1)	--	(4)	(1)	(2)	(--)
Summer	20.0	20.0	3.20	--	10.0	9.10	22.5	32.0
	(1)	(5)	(5)	--	(5)	(3)	(2)	(1)
Fall	--	20.0	.40	--	5.00	--	17.0	--
	(--)	(1)	(1)	--	(2)	(--)	(1)	(--)
Alkalinity (as $CaCO_3$)								
Spring	253	--	176	--	262	--	182	138
	(4)	(--)	(2)	--	(2)	(--)	(2)	(1)
Summer	212	203	134	--	231	222	206	--
	(2)	(1)	(2)	--	(3)	(2)	(4)	(--)
Fall	--	--	--	--	--	--	--	--
	(--)	(--)	(--)	--	(--)	(--)	(--)	(--)

Table 9.--*Median values of chemical and physical characteristics of Coteau impoundments by seasons*--Continued

	La Bolt		Webber		Dillon-Syltie		Lake Laura	
	Top sample	Bottom sample	Top sample	Bottom sample	Top sample	Bottom sample	Top sample	Bottom sample
Nitrite plus nitrate Nitrogen, total								
Spring	.36 (4)	.10 (1)	.10 (5)	-- (--)	.06 (5)	-- (--)	-- (--)	-- (--)
Summer	.005 (2)	.10 (5)	.10 (5)	.04 (2)	.01 (7)	.01 (3)	4.20 (1)	-- (--)
Fall	.02 (1)	.10 (1)	.07 (2)	-- (--)	.06 (2)	-- (--)	-- (--)	-- (--)
Nitrite plus nitrate Nitrogen, dissolved								
Spring	.22 (3)	-- (--)	.56 (2)	-- (--)	2.00 (5)	.96 (1)	6.85 (2)	-- (--)
Summer	.10 (5)	.10 (7)	.10 (6)	-- (--)	.10 (9)	.14 (5)	3.80 (6)	1.00 (3)
Fall	-- (--)	.10 (1)	.10 (1)	-- (--)	.10 (2)	-- (--)	.66 (1)	-- (--)
Ammonia, Total								
Spring	.65 (4)	.06 (1)	.10 (5)	-- (--)	.06 (5)	-- (--)	-- (--)	-- (--)
Summer	.20 (2)	.29 (5)	.07 (5)	.07 (2)	.07 (7)	.04 (3)	-- (--)	-- (--)
Fall	.84 (1)	.91 (1)	.05 (5)	-- (--)	.08 (2)	-- (--)	-- (--)	-- (--)
Ammonia, dissolved								
Spring	1.20 (3)	-- (--)	.11 (2)	-- (--)	.21 (5)	.34 (1)	.28 (2)	-- (--)
Summer	.06 (5)	.80 (7)	.04 (6)	-- (--)	.14 (9)	.05 (5)	.24 (6)	3.90 (3)
Fall	-- (--)	-- (--)	-- (--)	-- (--)	.01 (1)	-- (--)	.55 (1)	-- (--)
Phosphorus, total								
Spring	.06 (8)	.07 (3)	.065 (8)	-- (--)	.04 (11)	.035 (2)	.14 (4)	.01 (1)
Summer	.19 (13)	.25 (14)	.08 (12)	.06 (3)	.08 (22)	.07 (15)	.05 (13)	.08 (5)
Fall	.11 (1)	.16 (1)	.05 (3)	-- (--)	.13 (3)	-- (--)	.03 (1)	-- (--)
Phosphorus, dissolved								
Spring	.12 (3)	-- (--)	.04 (2)	-- (--)	.04 (5)	.01 (1)	.08 (2)	-- (--)
Summer	.07 (5)	.25 (7)	.06 (6)	-- --	.04 (9)	.03 (5)	.03 (5)	.38 (3)
Fall	.20 (1)	-- (--)	-- (--)	-- (--)	.10 (2)	-- (--)	.03 (1)	-- (--)
Coliform, fecal								
Spring	-- (--)	-- (--)	-- (--)	-- (--)	-- (--)	-- (--)	-- (--)	-- (--)
Summer	70 (1)	-- (--)	2 (1)	-- (--)	440 (1)	-- (--)	25 (1)	-- (--)
Fall	-- (--)	-- (--)	-- (--)	-- (--)	-- (--)	-- (--)	-- (--)	-- (--)
Streptococci, fecal								
Spring	-- (--)	-- (--)	-- (--)	-- (--)	-- (--)	-- (--)	-- (--)	-- (--)
Summer	1,400 (1)	-- (--)	2,300 (1)	-- (--)	1,800 (1)	-- (--)	72 (1)	-- (--)
Fall	-- (--)	-- (--)	-- (--)	-- (--)	-- (--)	-- (--)	-- (--)	-- (--)

Productivity and Stratification

Measurements of productivity indicate whether a body of water is capable of sustaining a productive aquatic biological community or has become overproductive to the point where undesirable nuisance algal blooms develop. In this study, productivity was measured by determining the concentrations of chlorophyll *a*.

Figure 6 shows mean summer concentrations of chlorophyll *a* plotted against mean summer Secchi disk transparency and a regression line developed by Carlson (1977) from a set of similar observations from a large number of lakes in Michigan, Wisconsin and Minnesota. Data that plot significantly to the left of Carlson's line suggest that transparency is being affected by turbidity caused by nonalgal suspended material such as inorganic sediment or organic detritus. Distribution on both sides of Carlson's line is approximately equal, which suggests that algal populations are the primary factor limiting light penetration in the water column.

Figure 6 also shows that water in the La Bolt impoundment differs from the Webber impoundment with respect to transparency. Water in the Dillon-Syltie impoundment and Lake Laura had similar transparency and plot approximately midway between the extremes of the regression line.

Figure 7 shows mean summer concentrations of total phosphorus plotted against mean summer concentrations of chlorophyll *a*. Carlson's regression line for similar data from a large number of lakes is shown for comparison. In this figure, the data do not closely fit Carlson's line, but plot nearly parallel and above the line. A consistent underestimation of chlorophyll *a* concentrations caused by error in preservation or analysis of samples could possibly account for this, but the relation between chlorophyll *a* and transparency shown in figure 6 suggests that the data are not biased. Therefore, productivity of these four impoundments, for a given amount of phosphorus, does not reach levels as high as those in the lakes studied by Carlson. Further evidence of this is shown by the high proportion of soluble phosphorus in some samples, indicating that the algae had not utilized all the phosphorus present in the euphotic zone.

Algal productivity, on the basis of water transparency, does not have a direct relation to total phosphorus concentration (figure 8). Figure 8 shows that a regression line can be drawn through data points for the La Bolt impoundment. Virtually all data points for other impoundments plot to the right of the line, indicating that, for a given concentration of phosphorus, these impoundments will have greater transparency than will the La Bolt impoundment. The line shown may be the worst-case situation for impoundments in the Coteau area and represents levels of total phosphorus that would necessarily have to be maintained to insure a desired level of transparency.

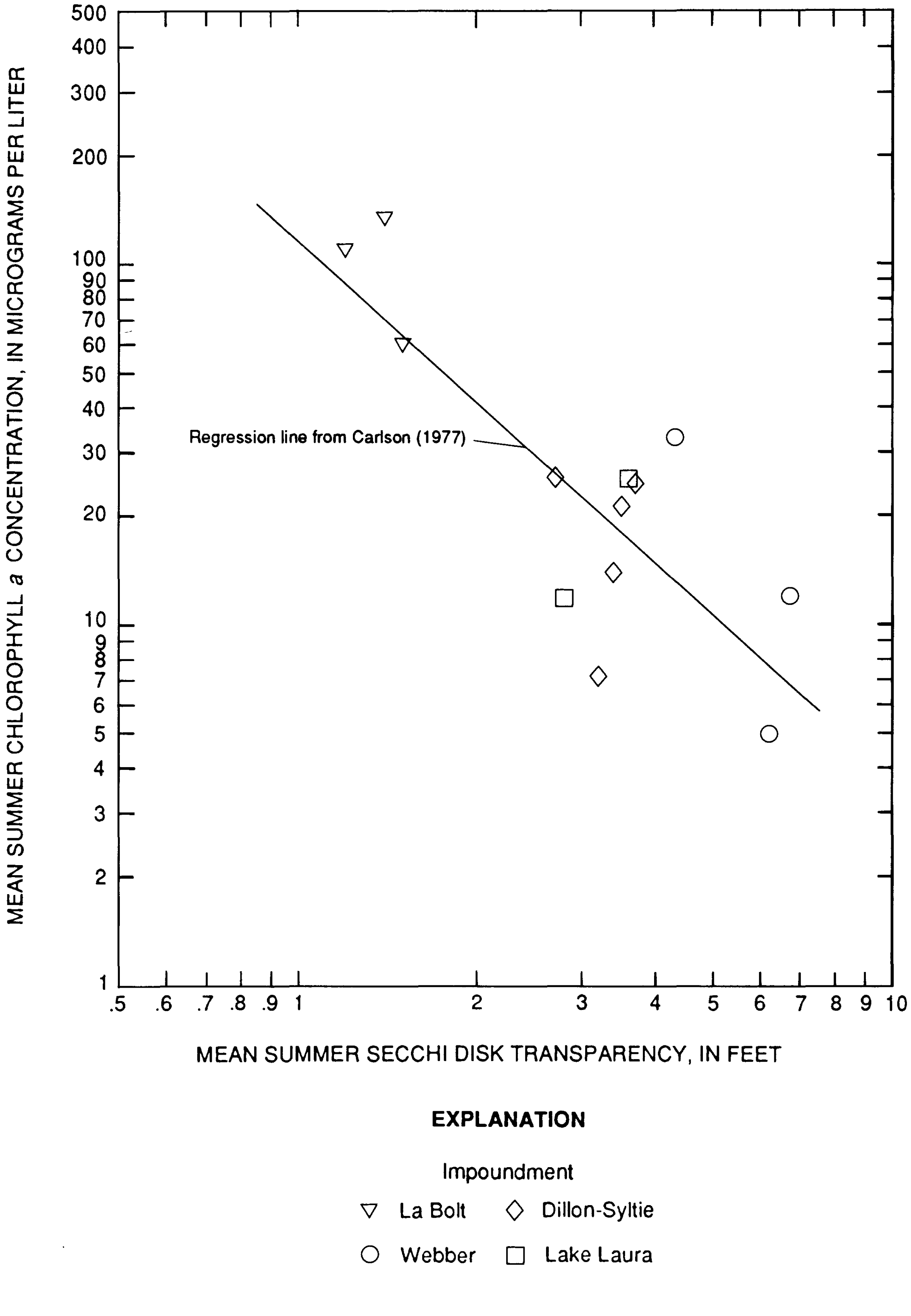


Figure 6.--Relation of chlorophyll *a* concentration to Secchi disk transparency.

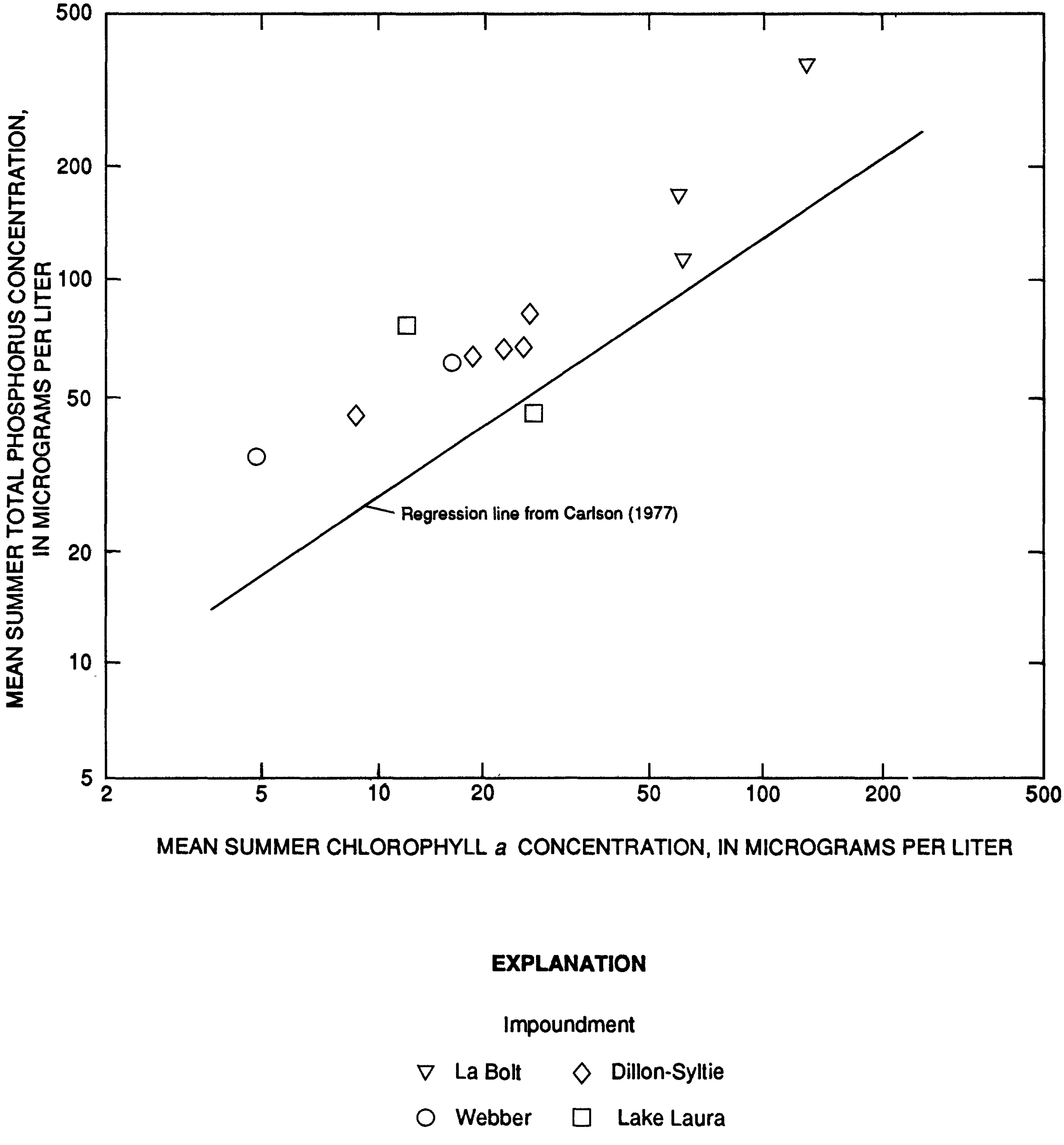


Figure 7.--Relation of total phosphorus concentration to chlorophyll *a* concentration.

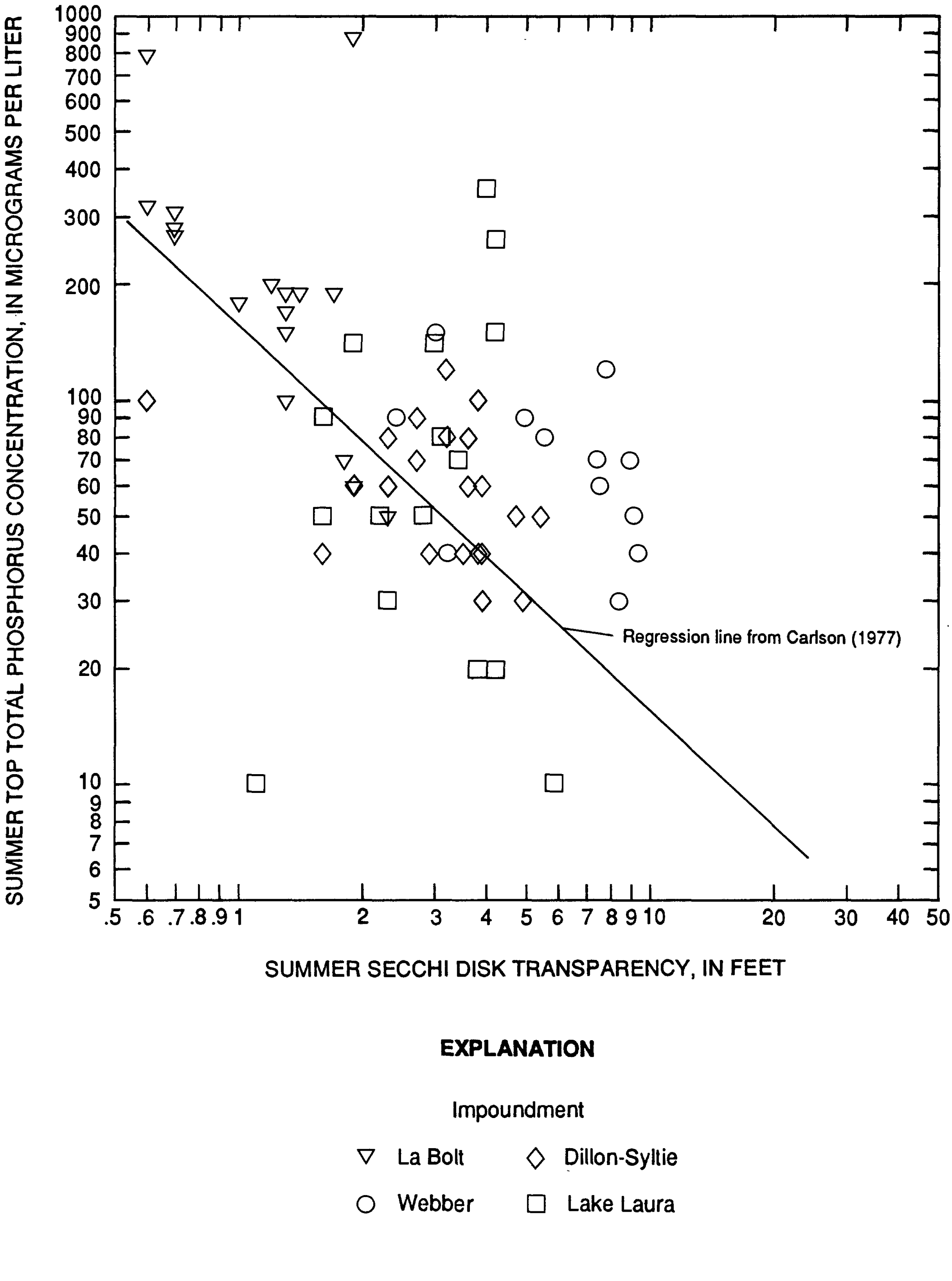


Figure 8.--Relation of total phosphorus concentration to Secchi disk transparency.

The previous discussion has indicated that the impoundments do not have similar trophic-state levels. In order to quantify these differences, maximum, minimum, mean, and median values for the key trophic-state indicators have been calculated and are shown graphically in figures 9-11. Only data for the summer period (mid-May through September) were included in the computations. The distribution over time of these key trophic-state indicators is shown graphically in figures 12-16 using the data available.

Differences in transparency are shown in figures 9, 12 and 13. The range of values for water in the Webber and La Bolt impoundments are at extremes in figure 9. Dillon-Syltie and Lake Laura are very similar, having nearly identical range of values and nearly equal mean and median values. Comparison of the means and medians shows that water in Webber has approximately twice the transparency of water in Dillon-Syltie and Lake Laura, whereas water in La Bolt has only half the transparency of water in Dillon-Syltie and Lake Laura. These differences are very apparent at the impoundments. The mean transparency of more than 6.6 ft in the Webber impoundment would be perceived from a recreational and esthetic point of view to be clear. In contrast, the transparency in the La Bolt impoundment was never greater than 3.3 ft during summer. The mean transparency in the La Bolt impoundment was about 1.6 ft; one measurement was as low as .6 ft.

Chlorophyll-*a* concentrations for each impoundment are summarized in figures 10 and 14. Differences in trophic state are apparent from figure 10. Dillon-Syltie and Lake Laura impoundments are similar, but Webber and La Bolt differ significantly. Because the mean values at Webber and La Bolt are affected by extreme values, the median concentrations offer a better basis for comparison. The median chlorophyll *a* concentration in La Bolt is about four times higher than in Webber.

Figures 11, 15 and 16 show total phosphorus data. Water in the La Bolt impoundment is at a much higher trophic state with respect to total phosphorus than are waters in the other impoundments shown in figure 11. Water in the Webber impoundment, however, is at approximately the same trophic level with respect to total phosphorus as water in Dillon-Syltie and has a slightly higher median concentration than water in Lake Laura. There seems to be little relation between total phosphorus concentration and maximum chlorophyll *a* concentration in these impoundments, in contrast to relations commonly determined in other parts of the country (Carlson, 1977, Dillon and Riglor, 1974).

Each of the impoundments has a characteristic productivity level, and each can be classified as having high, medium, or low productivity with respect to the others. The seasonal productivity of an impoundment varies significantly, which is apparent from the range of values shown in figures 9-11. Water in the Dillon-Syltie and Lake Laura have mean and median transparency values of 3.3 ft but, at times, have transparencies that are as low as those found in the La Bolt impoundment (fig. 9).

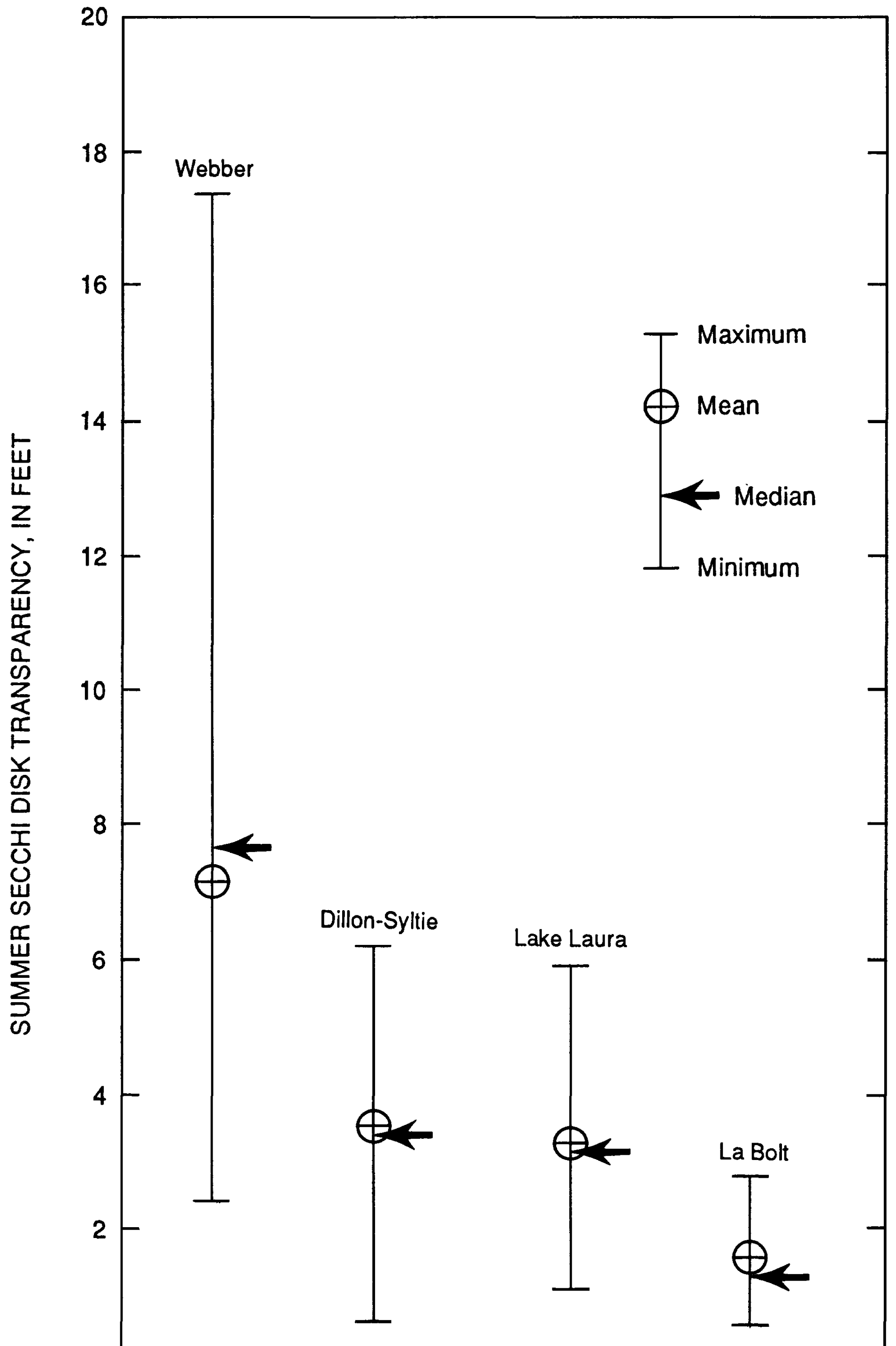


Figure 9.--Maximum, minimum, mean, and median summer Secchi disk transparencies for Webber, Dillon-Syltie, Lake Laura, and La Bolt impoundments.

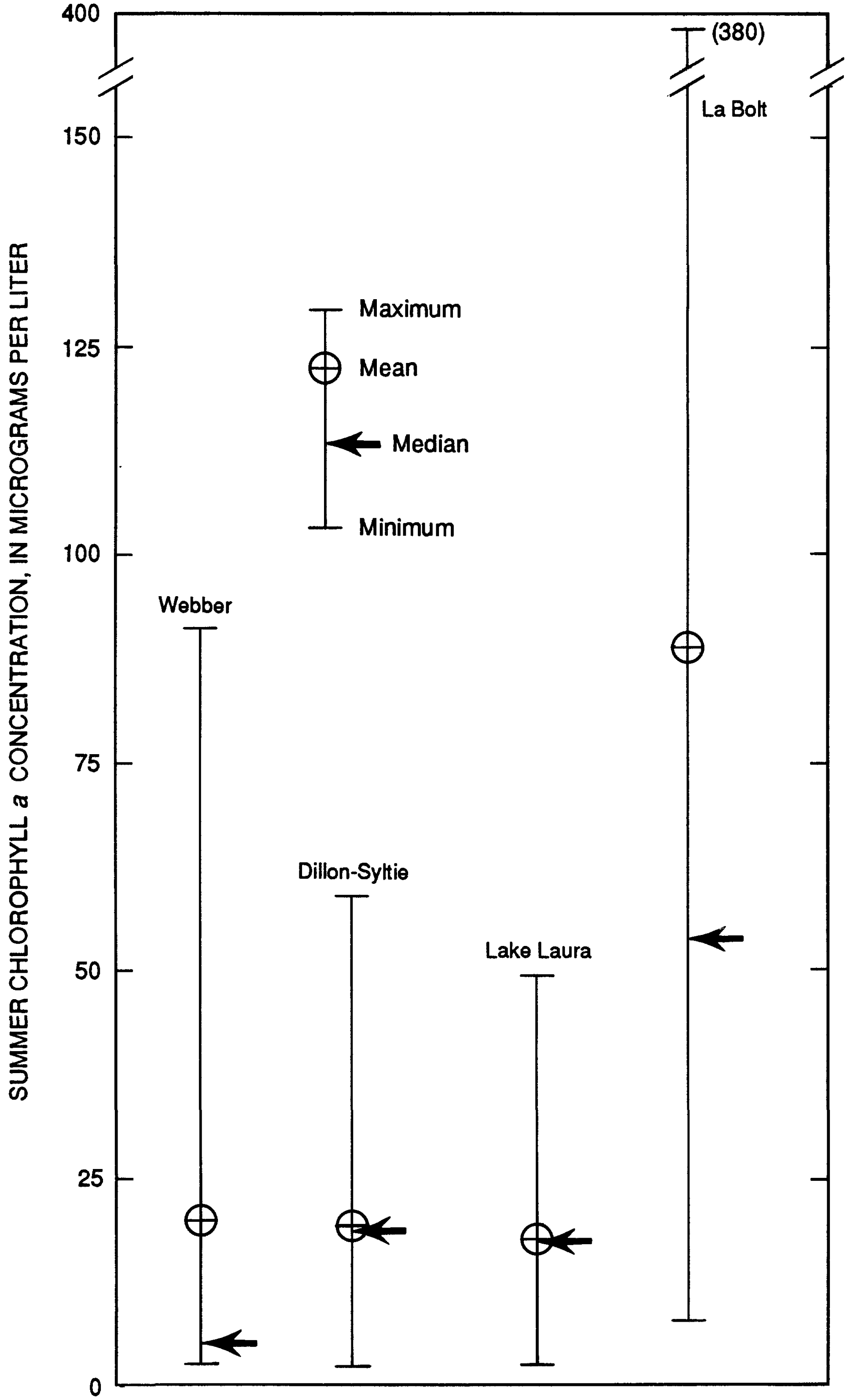


Figure 10.--Maximum, minimum, mean, and median chlorophyll *a* concentrations for Webber, Dillon-Syltie, Lake Laura, and La Bolt impoundments.

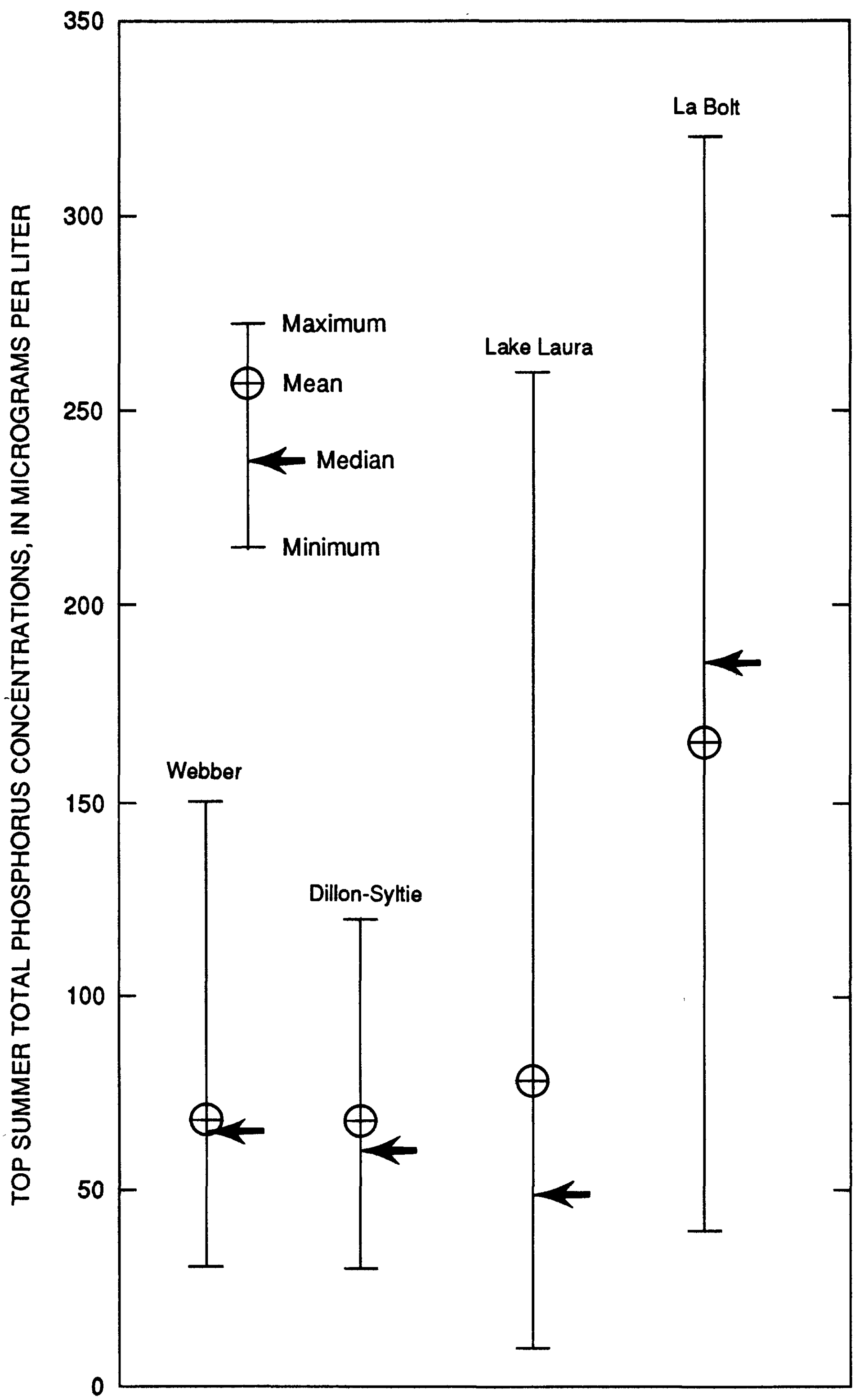


Figure 11.--Maximum, minimum, mean, and median top total phosphorus concentrations for Webber, Dillon-Syltie, Lake Laura, and La Bolt impoundments.

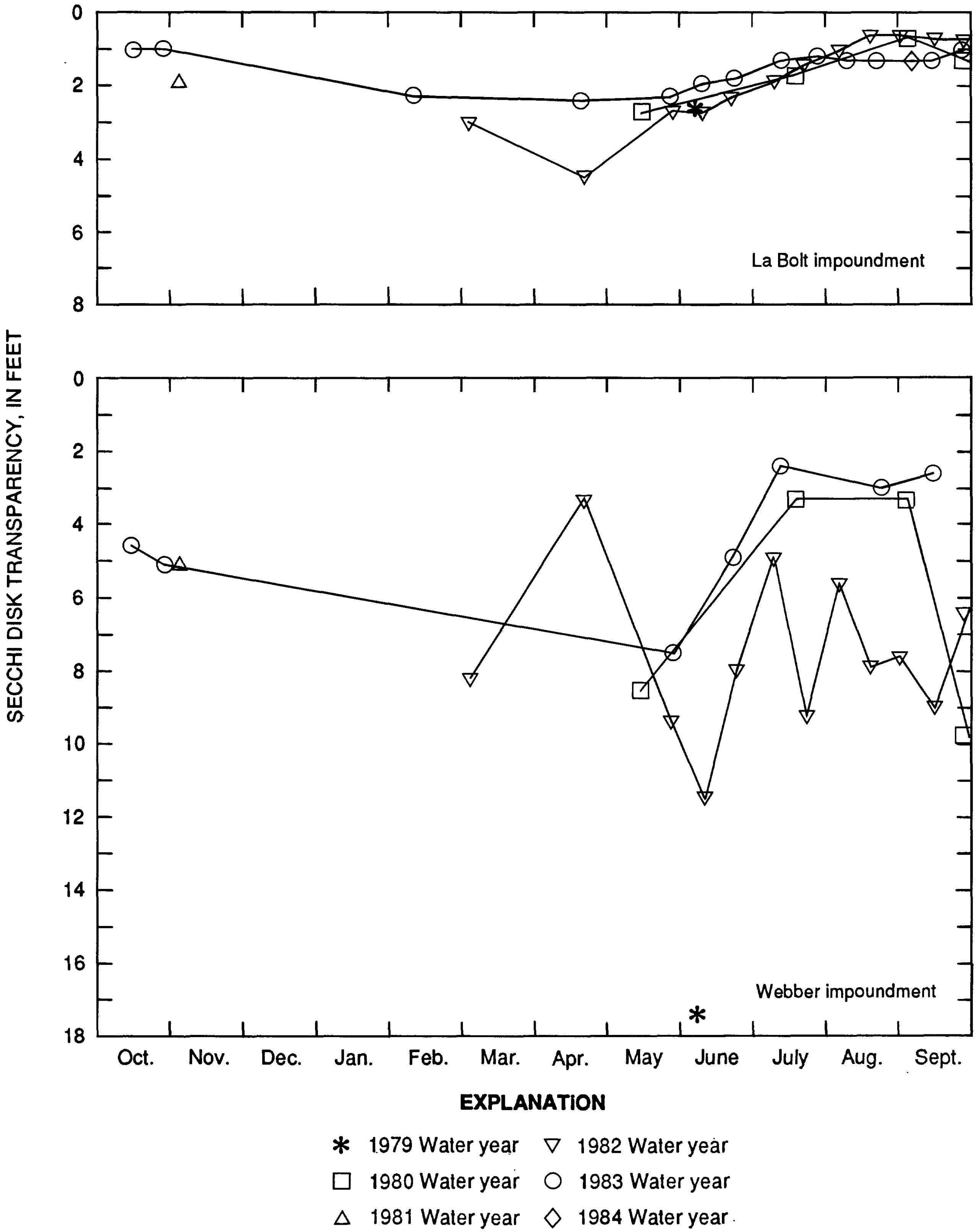


Figure 12.--Time distribution of Secchi disk transparencies for La Bolt and Webber impoundments.

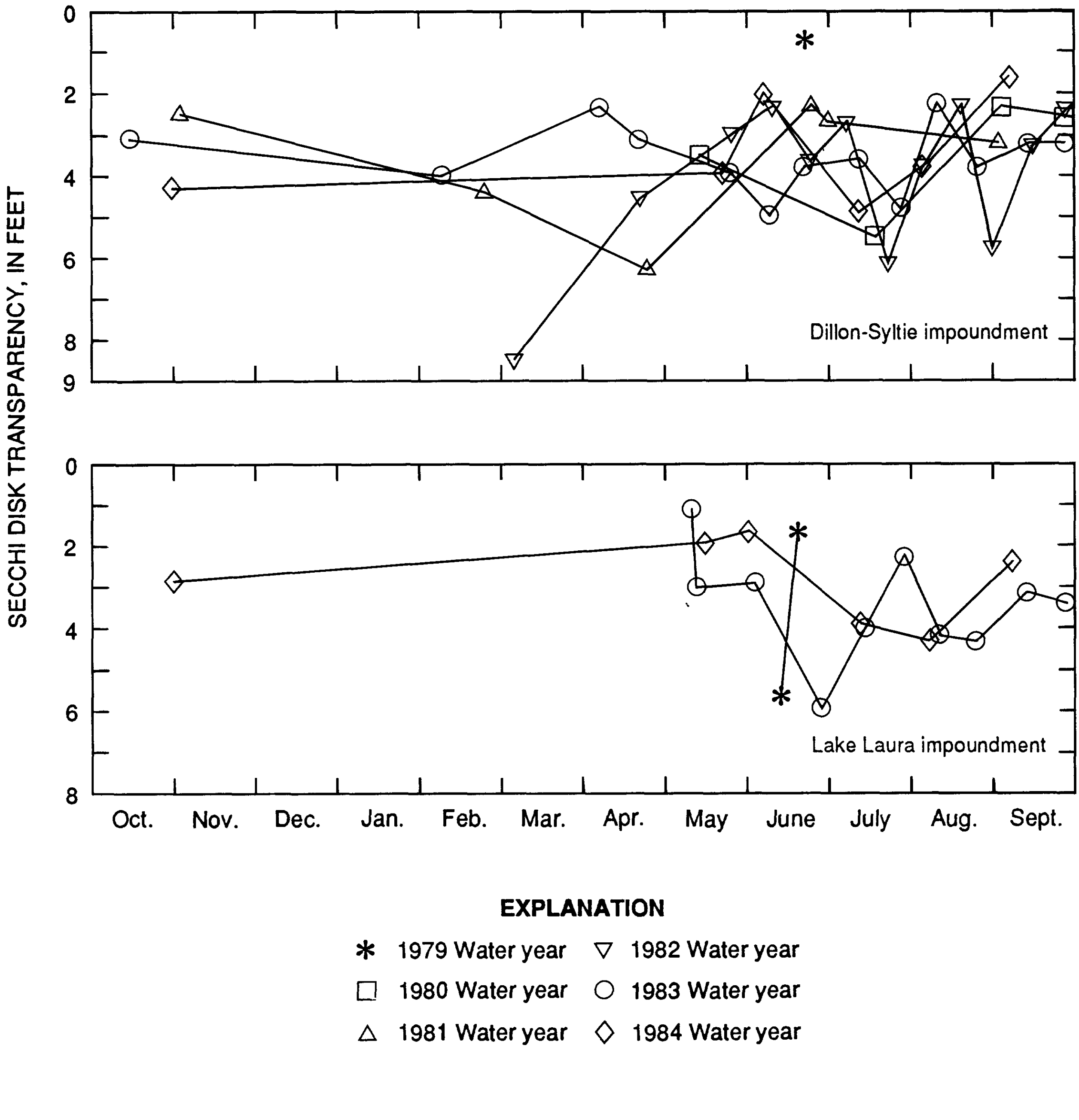


Figure 13.--Time distribution of Secchi disk transparencies for Dillon-Syltie, and Lake Laura impoundments.

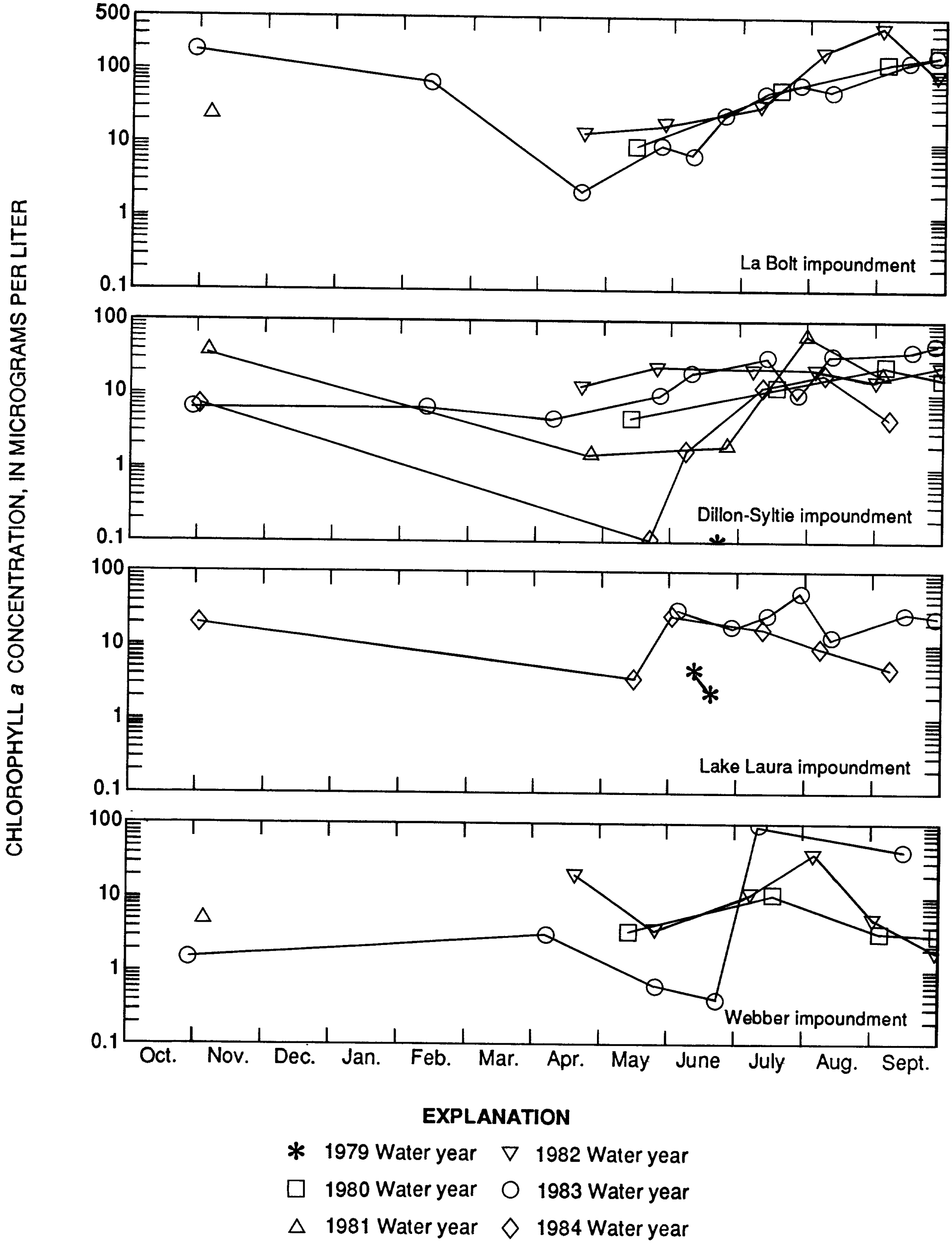
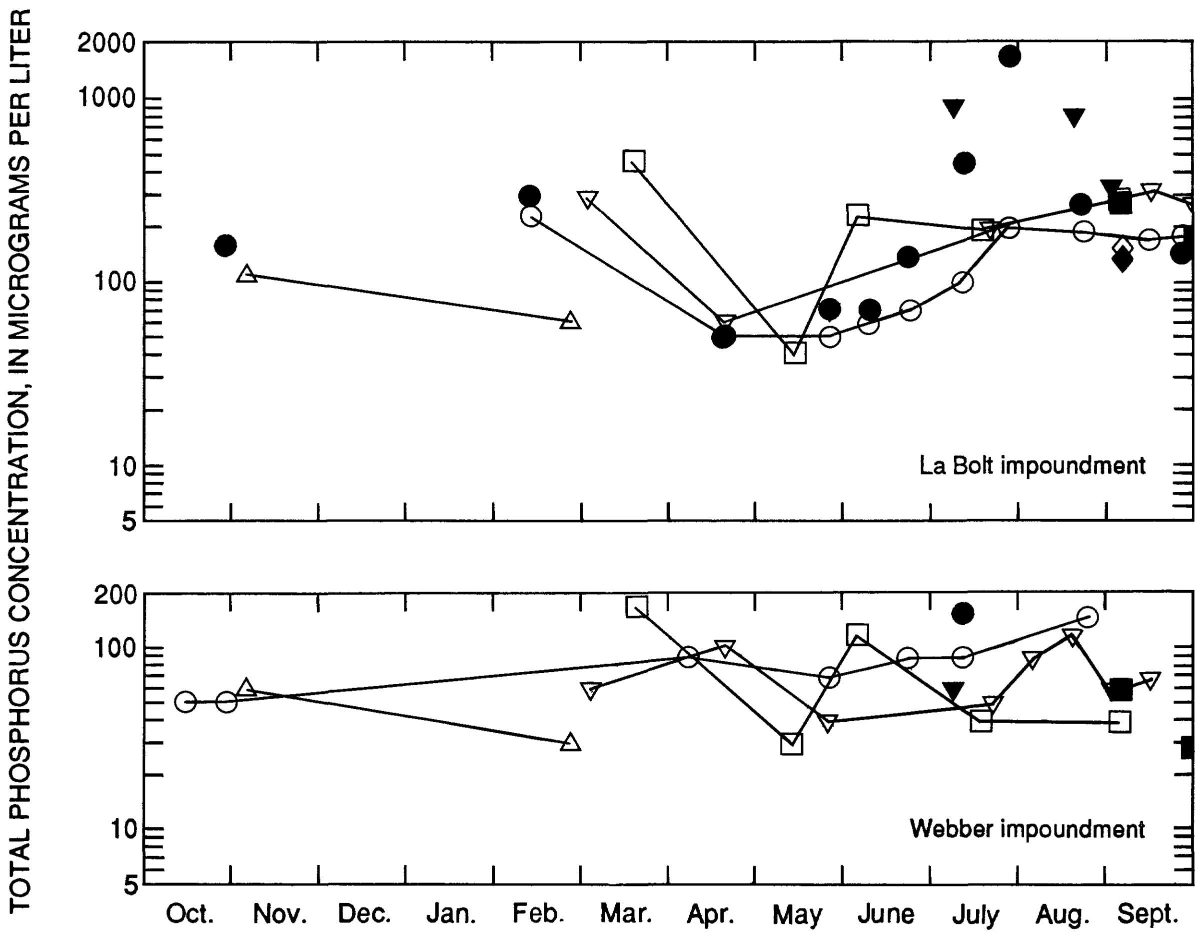


Figure 14.--Time distribution of chlorophyll *a* concentrations for La Bolt, Webber, Dillon-Syltie, and Lake Laura impoundments.



EXPLANATION

Top Layer	Bottom Layer
✱ 1979 Water year	⊛ 1979 Water year
□ 1980 Water year	■ 1980 Water year
△ 1981 Water year	▲ 1981 Water year
▽ 1982 Water year	▼ 1982 Water year
○ 1983 Water year	● 1983 Water year
◇ 1984 Water year	◆ 1984 Water year

Figure 15.--Time distribution of total phosphorus concentrations for La Bolt and Webber impoundments.

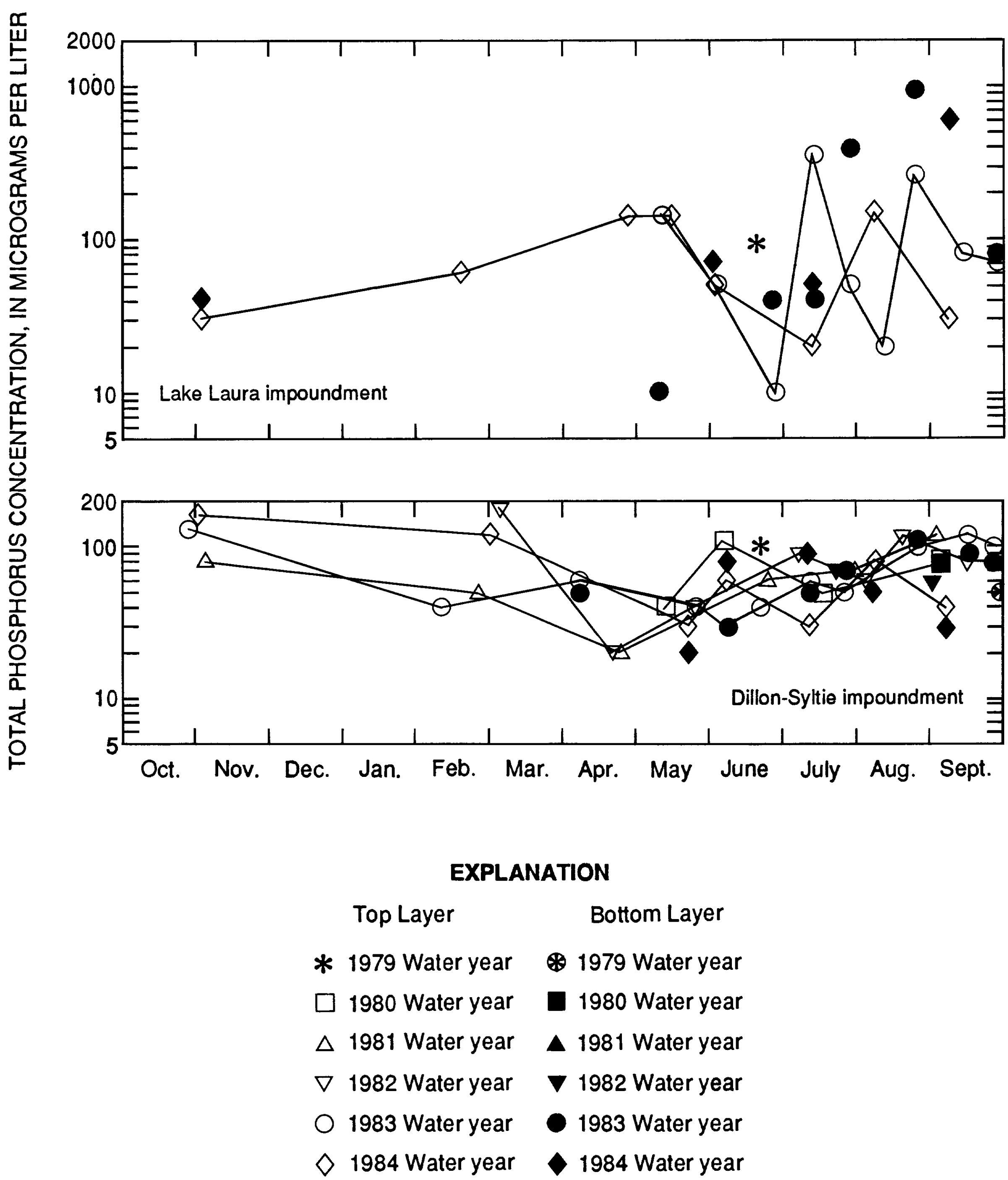


Figure 16.--Time distribution of total phosphorus concentrations for Lake Laura and Dillon-Syltie impoundments.

The Dillon-Syltie impoundment has the longest period of record (1980-84) and, therefore, provides an opportunity to examine seasonal changes over several years. Examination of data for chlorophyll *a* (fig. 14) shows that, in each year except 1982, productivity rose from May through July, peaked during August or September and then declined. During 1982, there was only a moderate rise in productivity during May, and productivity stayed at a moderate level through September.

Data from three summer seasons (1980, 1982, and 1983) are available for the Webber and La Bolt impoundments. A pattern of productivity similar to that in Dillon-Syltie was observed in both, the primary difference being that, in Webber, productivity peaked in July or August, whereas in La Bolt, productivity rose throughout the summer, peaking in September.

Data for only two seasons, 1983 and 1984, are available for analysis for Lake Laura. During 1983, productivity followed a series of peaks and declines. During 1984, there was a sharp increase in productivity from mid-May to early June followed by a gradual decrease throughout the summer into September.

Except for Lake Laura and one season (1982) in Dillon-Syltie, productivity in the impoundments increased steadily from May through July, peaked during August or September, and then declined. In a general sense, this pattern would be expected as the algae respond to increased day length and higher temperatures, expanding their populations in the form of a normal growth curve. The fact that the observed patterns cannot be entirely related to weather and temperature variables is easily seen by noting that, in a given year, productivity in each impoundment peaked at a different time, often separated by several weeks.

Vertical profiles of temperature, dissolved oxygen, pH, and specific conductance were analyzed to determine the occurrence and persistence of stratification in the impoundments. Stratification, particularly that of temperature and dissolved oxygen, may lower dissolved-oxygen concentrations in bottom layers, restrict distribution of fish, increase nutrient release from bottom material, and enhance buildup of ammonia, sulfides, and other substances in the hypolimnion. The seasonal occurrence of stratification and its duration frequently determine whether water-quality of an impoundment is enhanced or diminished.

The onset and duration of thermal stratification is controlled by depth of the impoundment, shape and orientation of the basin, and local weather conditions, the most significant of which are solar radiation and wind velocity (Reid and Wood, 1976).

Water depths ranged from 12 ft at La Bolt impoundment to 33 ft at Lake Laura impoundment. La Bolt underwent long periods of stratification, as did Lake Laura. Dillon-Syltie and Webber, both deeper than La Bolt, at 14 and 17 ft respectively, destratified frequently, which suggests that depth is not a strict determinant of stratification in these impoundments. Other important factors include the shape and orientation of the basin with respect to prevailing winds. In small impoundments, the presence of hills, bluffs, and trees near the shoreline can lessen the destratifying effects of wind. Because average summer weather conditions can be assumed to be similar for all the impoundments, local setting, shape, and orientation probably account for much of the observed variation in stratification.

La Bolt Impoundment

Differences in stratification in La Bolt impoundment are shown in figure 17. Temperature profiles under ice cover in late winter showed weak thermal stratification. The temperature of water in March 1980 was 0.5 °C just under the ice and 3.5 °C near the bottom. An inverse temperature profile with colder water overlying warmer water occurs because water becomes less dense as it cools below 4 °C. Four winter profiles (March 1980, March 1982, February 1983, and March 1983) all showed the same pattern.

Stratification also is indicated during winter by the increase in specific conductance and decrease in dissolved oxygen with depth. Dissolved-oxygen concentrations in March 1980 were less than 5 mg/L about 4 ft below the surface and less than 0.4 mg/L near the bottom during 1982. In 1983, the water column was well oxygenated during February, and dissolved-oxygen concentrations exceeded 4 mg/L even during March. Specific conductance near the bottom of the impoundment was higher than near the surface suggesting that bottom materials (lake bed sediments) release substances to the water, a process that is enhanced when the concentration of dissolved oxygen is low near the sediment-water interface.

La Bolt impoundment was thermally stratified at times during summer. The presence of a sharp thermocline was indicated at times by a change of 3 °C per 3.3 ft. Thermal stratification was accompanied by oxygen depletion below the thermocline. An increase in specific conductance occurred in the bottom layers of water, but the increase was not as large as that measured during winter. Stratification was not persistent throughout the summer. Evidence of destratification and mixing is shown by measurements in August 1983 when temperatures were virtually uniform throughout the water column.

Dissolved-oxygen concentrations were low in the water column (less than 5 mg/L) on August 10, 1983, even at the surface, which suggests that the hypolimnetic water exerts considerable oxygen demand during circulation. Evidence of periodic destratification in summer is indicated by measurements of dissolved oxygen on June 10, 1982, and July 27, 1983. Significant increases in hypolimnetic oxygen, in comparison to conditions on May 26, 1982, and July 11, 1983, indicated that an overturn had occurred in the interval between measurements.

Webber Impoundment

Late-winter profiles were measured in Webber impoundment during 3 consecutive years, 1980-82 (fig. 18). In 1981 and 82 elevated concentrations of dissolved oxygen (values of 11.8 mg/L or higher) were detected throughout the water column. Specific conductance was nearly uniform vertically, which suggests that the release of dissolved substances from bottom material, as occurred in La Bolt impoundment, did not occur in the Webber impoundment.

Well developed summer thermal stratification (greater than 1 °C per 3.3 ft) was observed in only three profiles. All other summer profiles indicated either a lack of thermal stratification or weak stratification.

Of the three profiles indicating a sharply defined thermocline, only those on July 18, 1980, and July 11, 1983, have depressed dissolved-oxygen concentrations in the bottom layer. Low dissolved-oxygen concentrations also were measured on August 23, 1983, when the impoundment was not stratified. The dissolved-oxygen decline measured at that time may have been related to a recent overturn of the oxygen-demanding water that was present on July 11.

Dillon-Syltie Impoundment

Winter profiles were obtained on February 24, 1981, February 12, 1982, March 5, 1982, February 9, 1983, February 25, 1983, and March 1, 1984 (fig. 19). Dissolved-oxygen concentrations were depressed near the bottom of the water column in four of the winter profiles; dissolved-oxygen concentration ranged from 3.1 mg/L on February 25, 1983, to 4 mg/L on March 5, 1982. In two profiles, February 24, 1981, and February 12, 1982, the concentrations near the bottom were 14.5 mg/L and 6.1 mg/L, respectively, indicating dissolved-oxygen concentrations that are high for a late-winter period.

The four winter profiles that had lower dissolved-oxygen concentrations near the bottom also showed an increase in specific conductance with depth that indicates release of substances from the bottom material.

Dissolved-oxygen concentrations were more than 5 mg/L at a depth of 6 ft even in the four profiles that indicated some dissolved-oxygen depression at the bottom of the water column. A 5 mg/L concentration of dissolved oxygen is critical for survival of fish (Minnesota Pollution Control Agency, 1978). The late-winter measurements in Webber and Dillon-Syltie impoundments indicate that winter survival of fish in these impoundments was possible.

During summer, periods of stratification of the Dillon-Syltie impoundment were interrupted by overturn. During summer 1982, five overturn periods were indicated or implied from the profile data. When thermal stratification occurred, dissolved-oxygen concentrations were lowered in the bottom layers. At times, the lowering of dissolved-oxygen was severe; concentrations as low as 0.2 mg/L were measured.

Lake Laura Impoundment

Only one winter profile is available for the Lake Laura impoundment. The profile measured on February 17, 1984, indicated that dissolved-oxygen demand during winter had been moderately severe (fig. 20). Concentrations decreased from 9.8 mg/L at a depth of 3 ft to 4.1 mg/L at a depth of 4 ft. At the sediment-water interface the concentration was 1.8 mg/L. There was a nearly two-fold increase in specific conductance with depth, indicating release of substances from the bottom sediments.

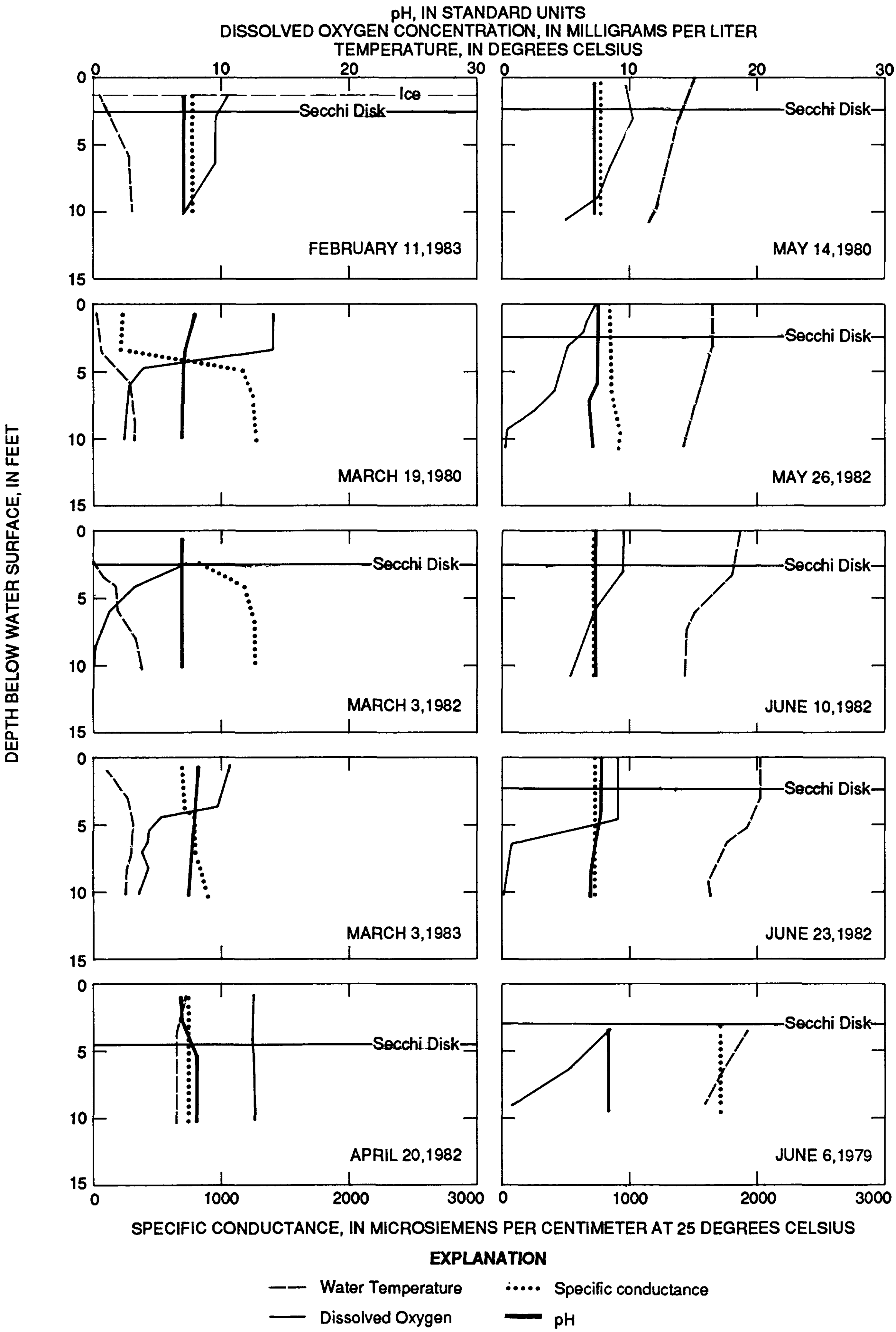
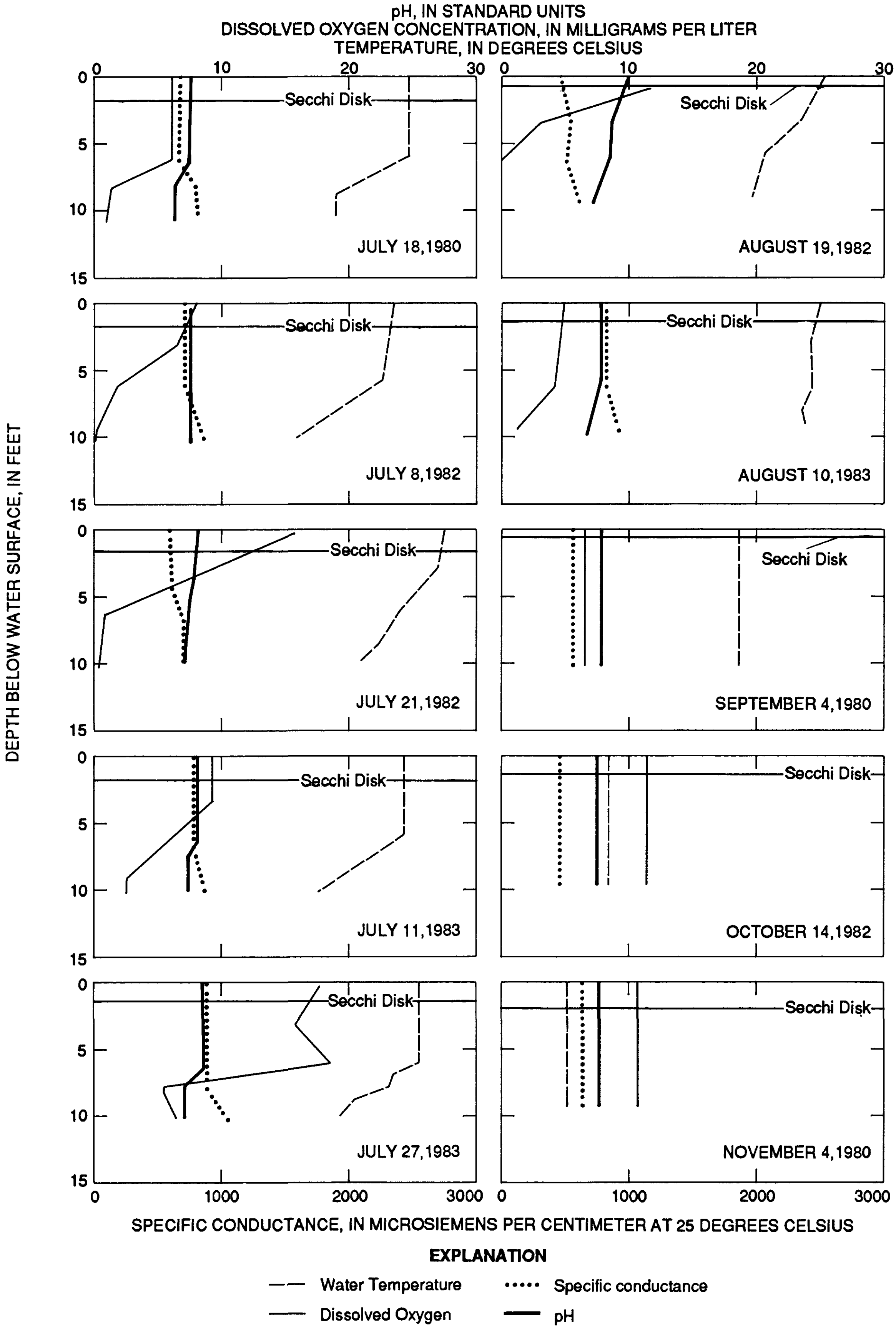


Figure 17.--Vertical profiles of temperature, dissolved oxygen, pH,



and specific conductance in La Bolt Impoundment at La Bolt, South Dakota.

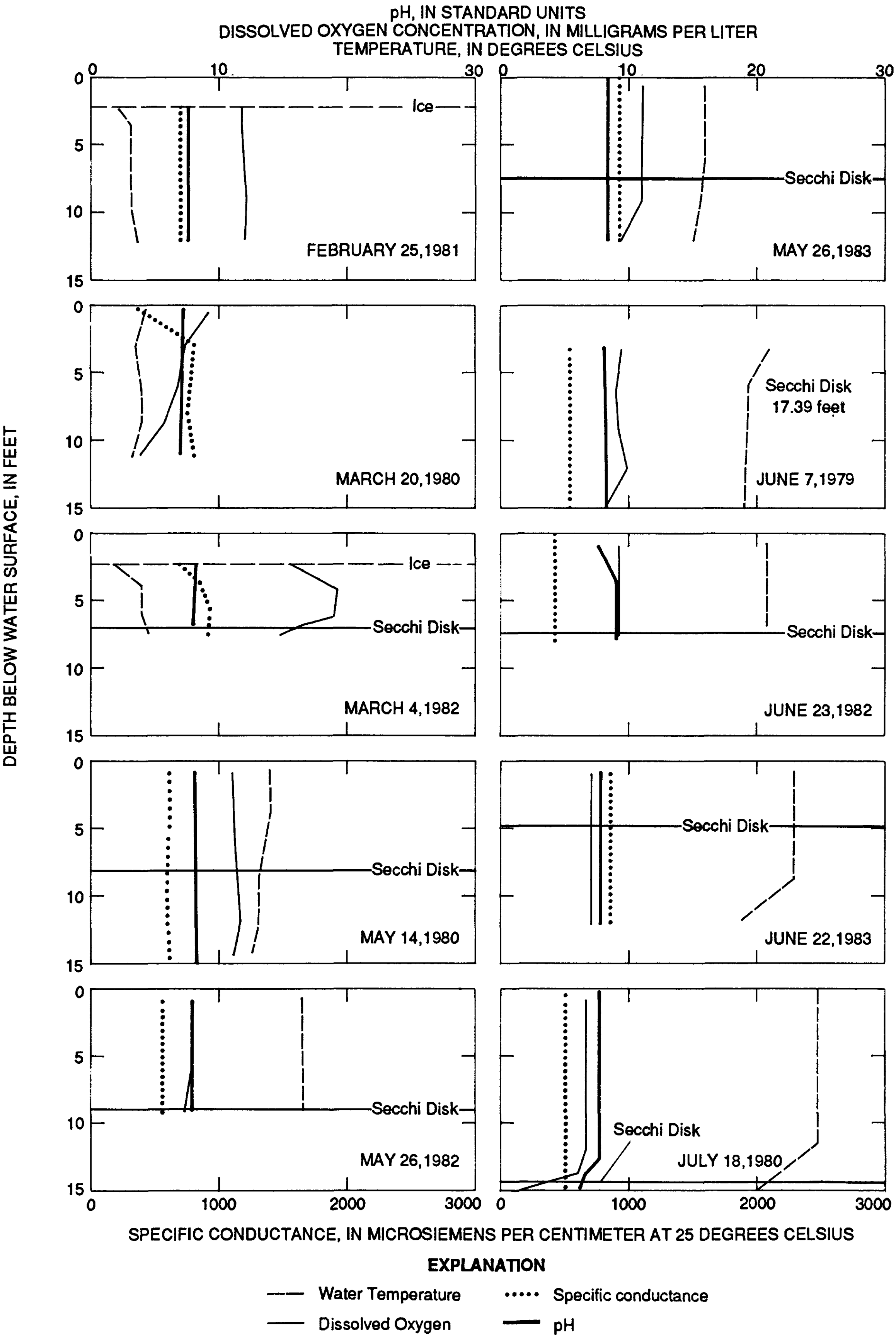
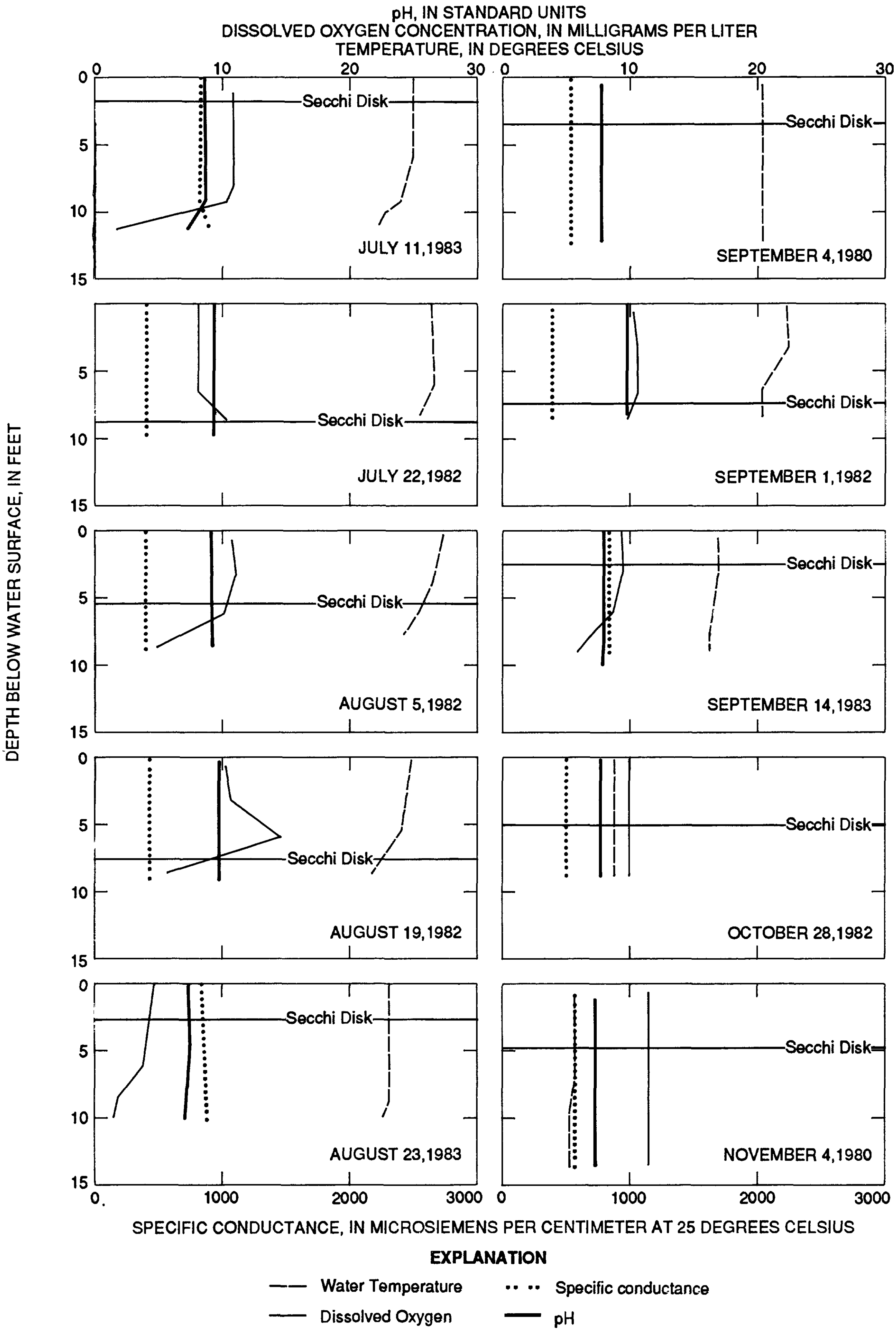


Figure 18.--Vertical profiles of temperature, dissolved oxygen, pH,



and specific conductance in Webber impoundment near Gary, South Dakota.

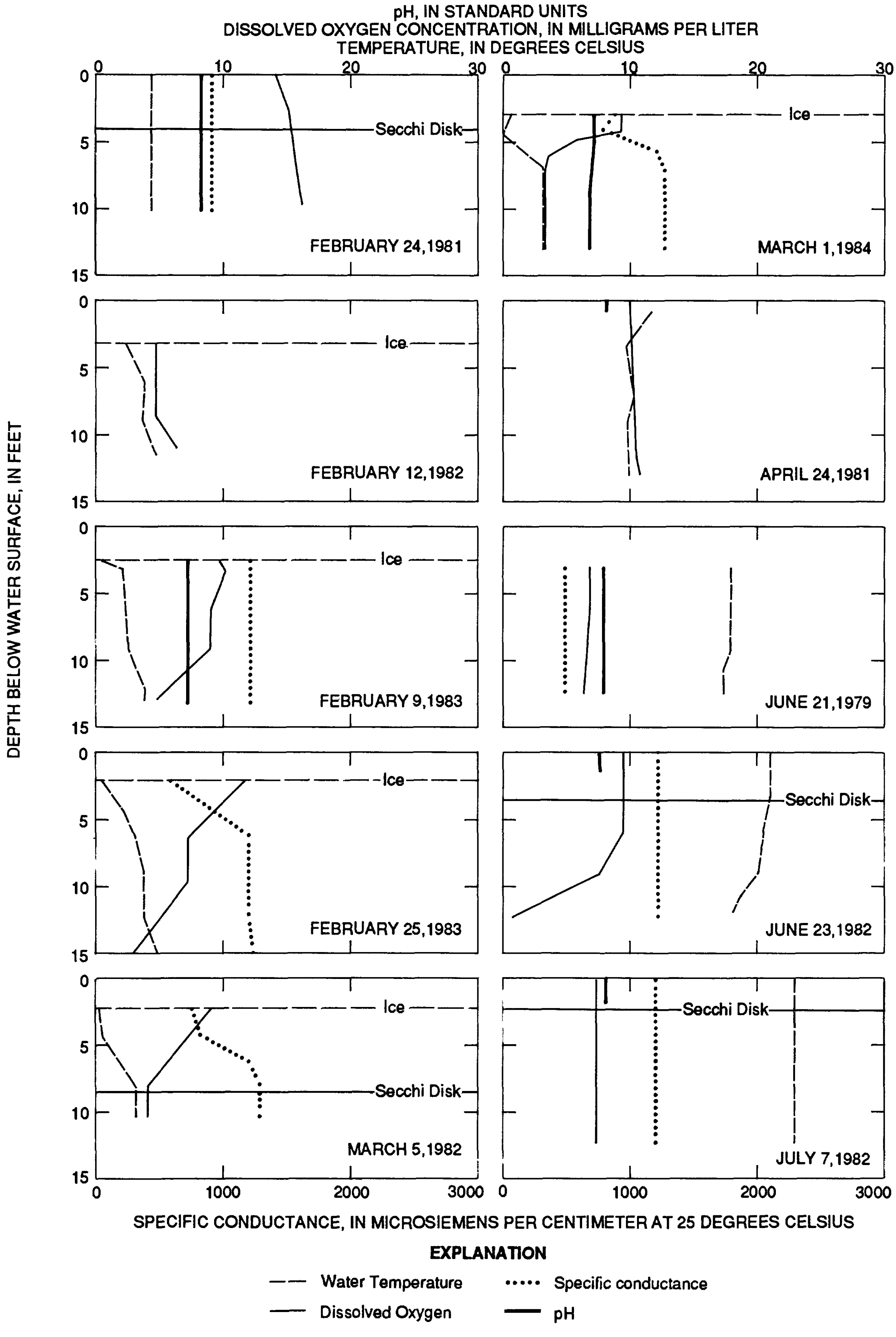
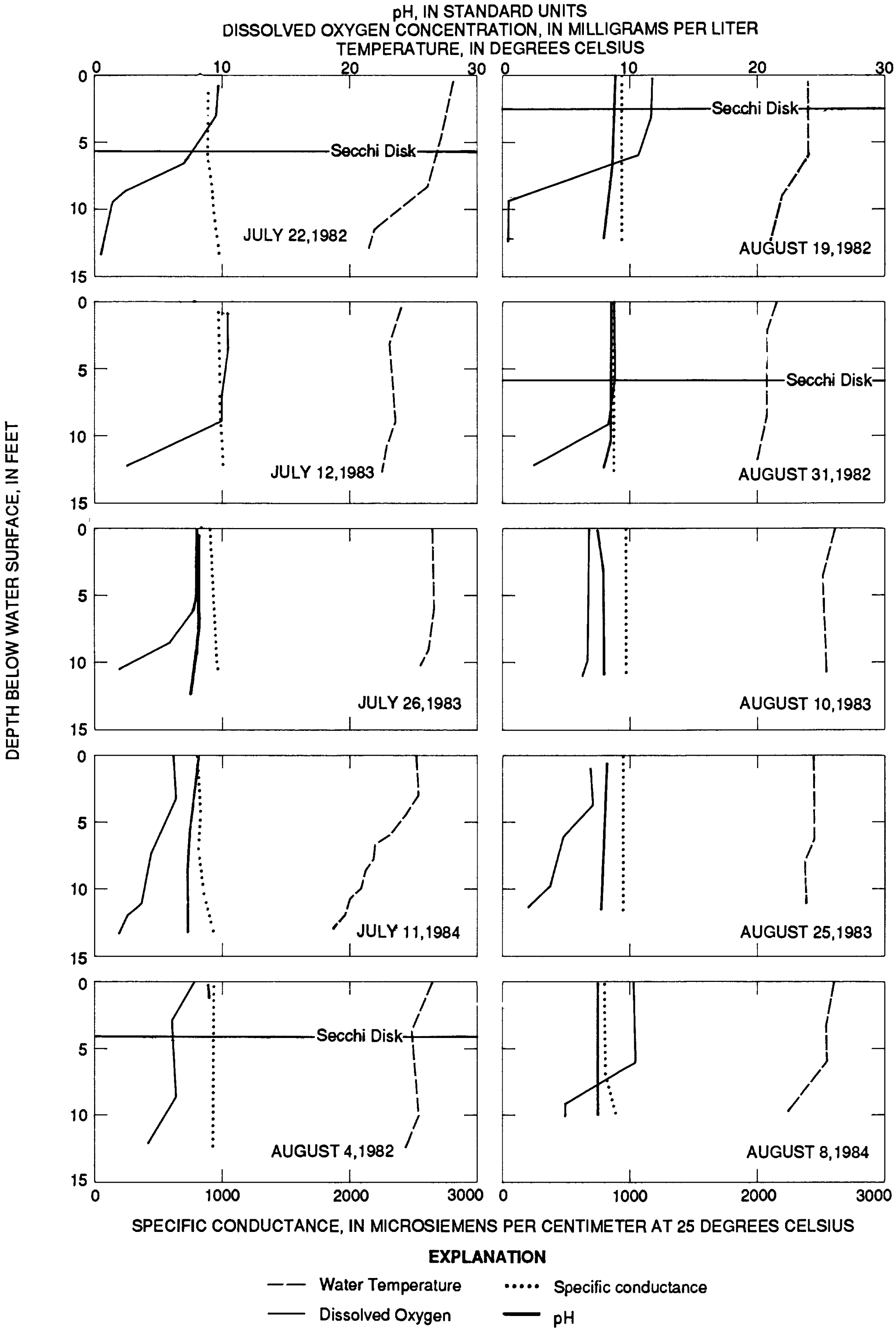


Figure 19.--Vertical profiles of temperature, dissolved oxygen, pH, and



specific conductance in Dillon-Syltie impoundment near Porter, Minnesota.

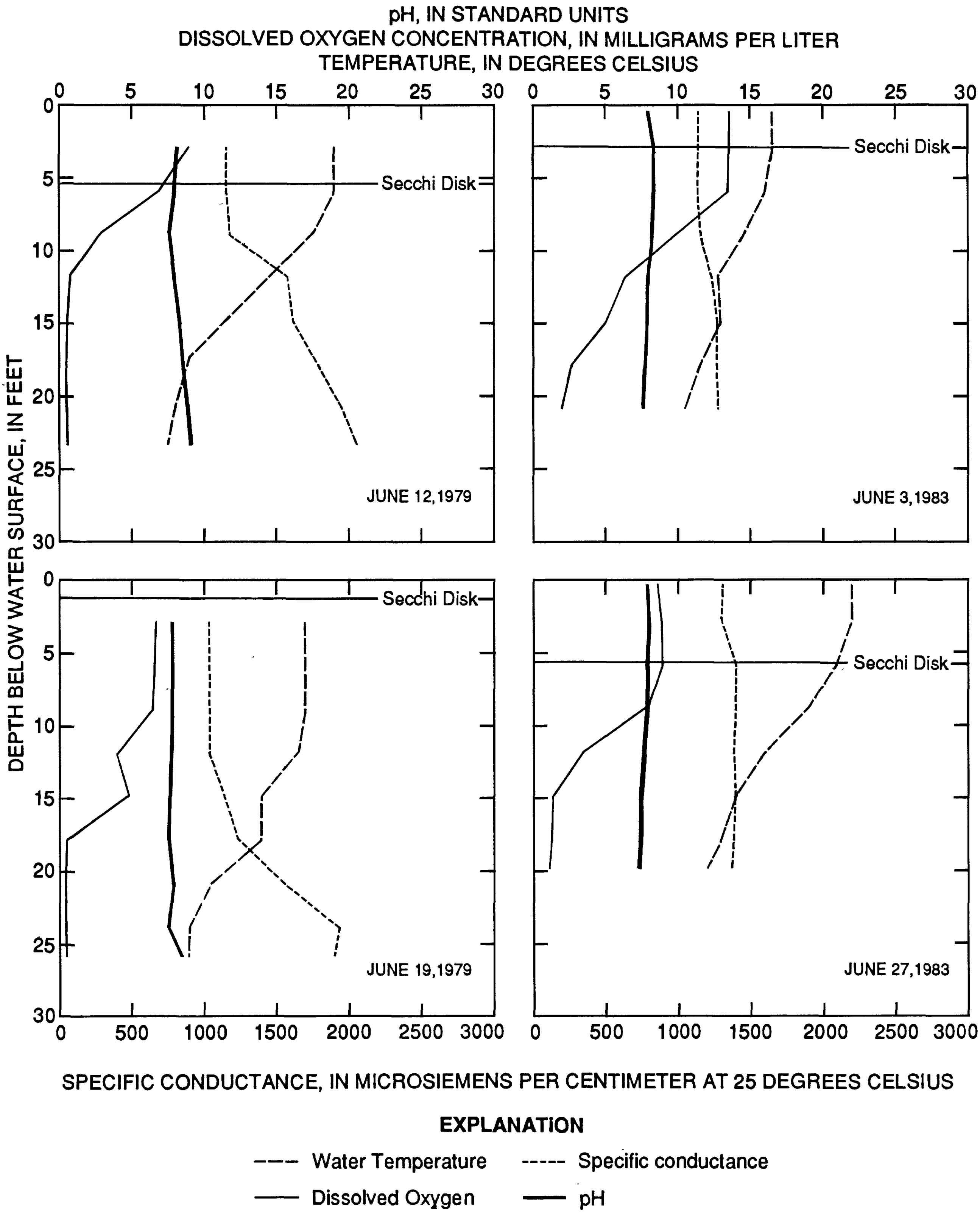
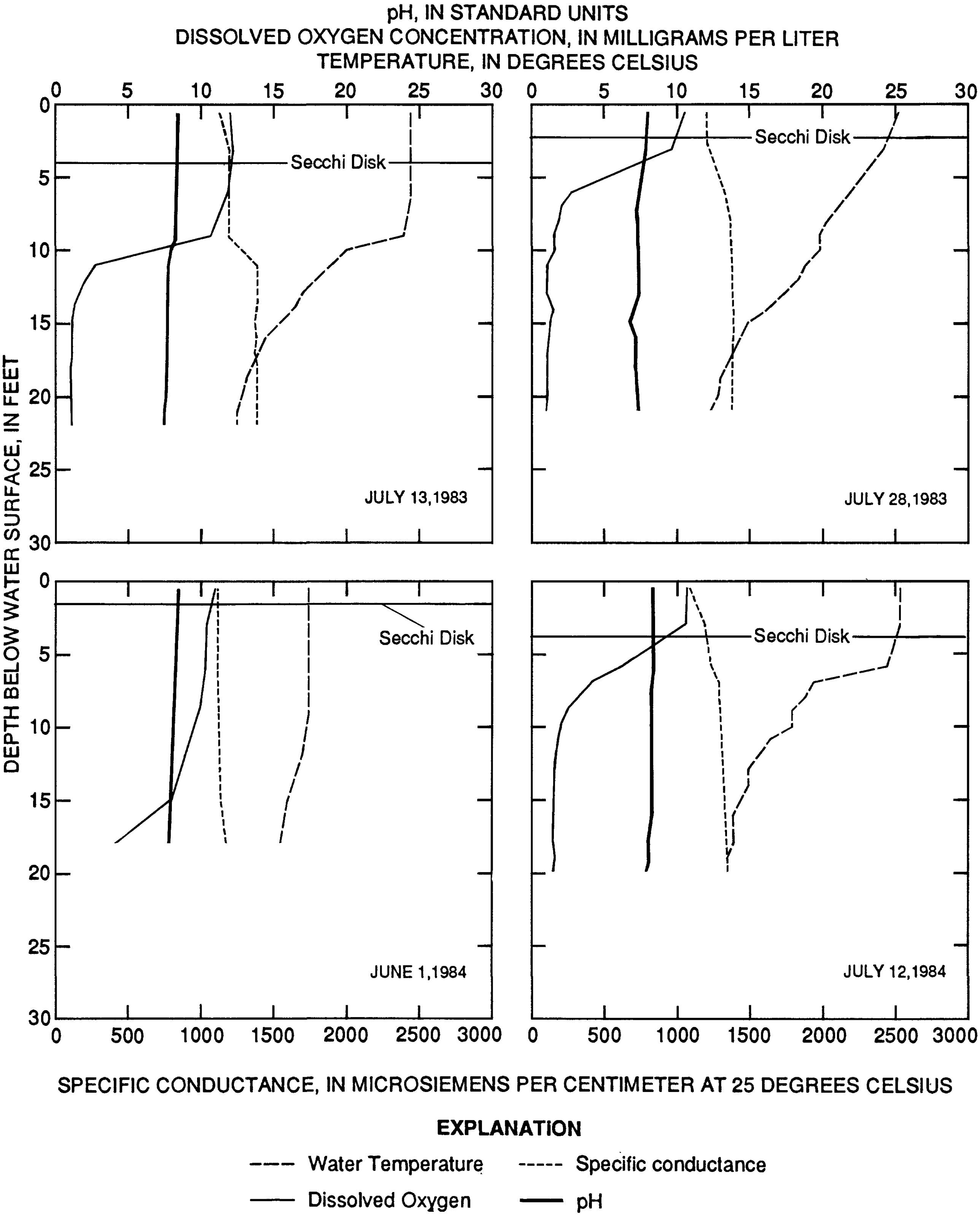


Figure 20.--Vertical profiles of temperature, dissolved oxygen, pH and specific conductance



in Lake Laura Impoundment near Walnut Grove, Minnesota.

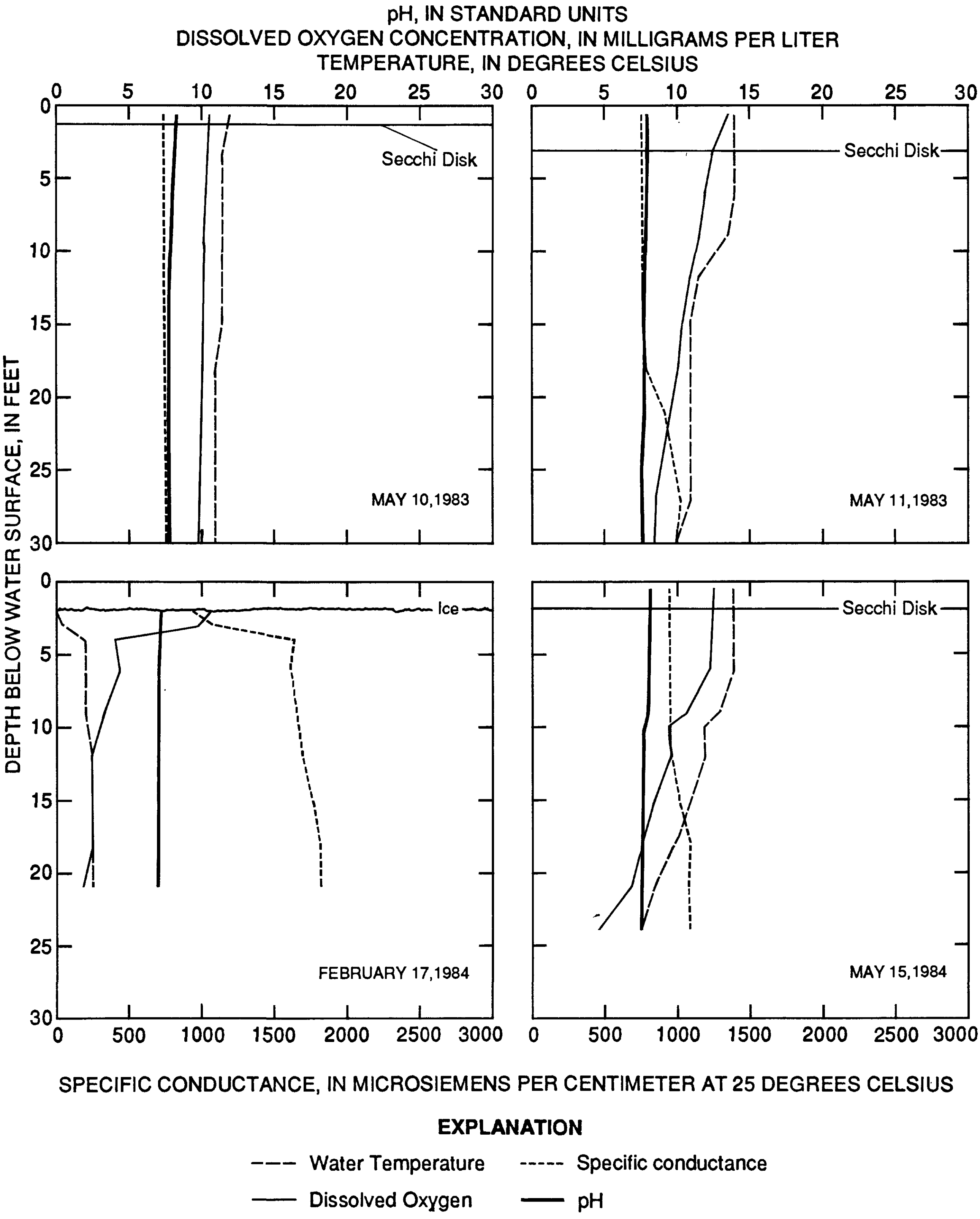
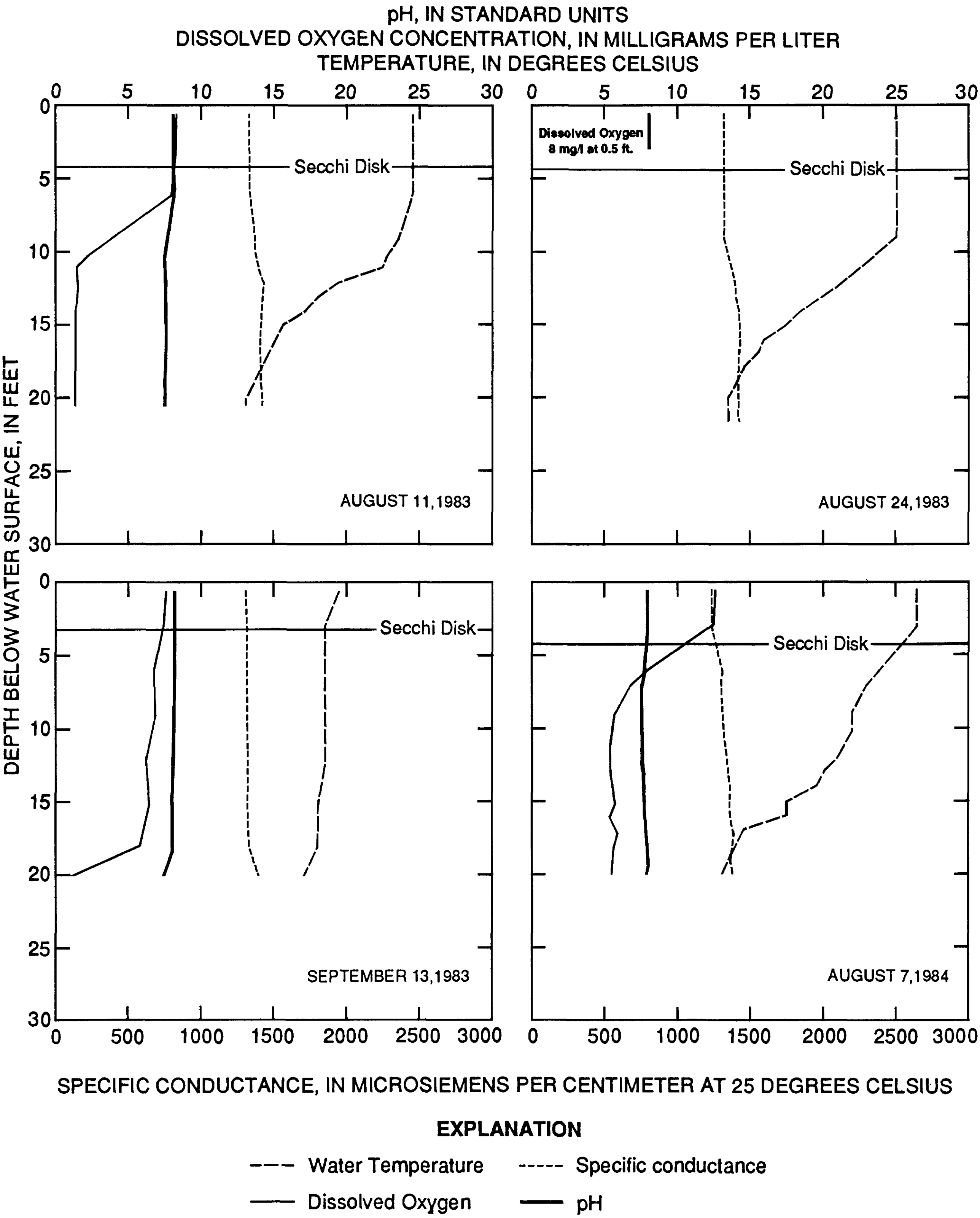


Figure 20.--Vertical profiles of temperature, dissolved oxygen, pH and specific conductance



In Lake Laura impoundment near Walnut Grove, Minnesota --Continued

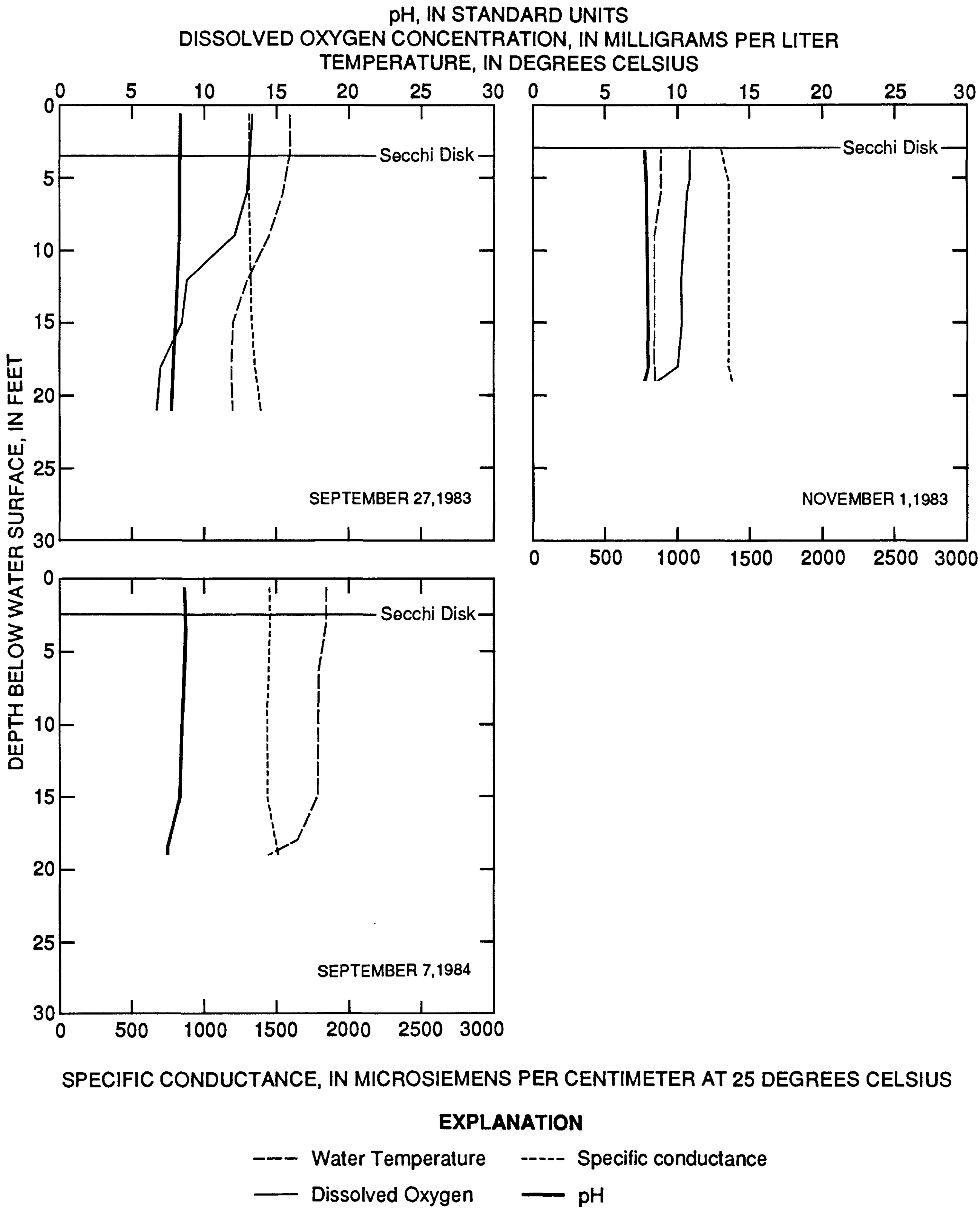


Figure 20.--Vertical profiles of temperature, dissolved oxygen, pH, and specific conductance in Lake Laura impoundment near Walnut Grove, Minnesota.

Three summer seasons are available for analysis--1979, 1983, and 1984--but only two profiles were measured during 1979. The 1979 profiles were obtained during June and the measurements were separated by only 7 days. This provided an opportunity to observe rapidly occurring changes in the profile. On June 12, the top of the thermocline was located between depths of 6 and 9 ft. A dissolved-oxygen concentration of 2.6 mg/L at the 9-ft depth indicated a severe oxygen decline within the thermocline. Dissolved-oxygen concentrations decreased to 0.6 mg/L at the 12 ft depth and were as low as 0.4 mg/L in that area below the thermocline. Release of substances from the sediments was indicated by a 900-μS/cm (microseimens per centimeter at 25 degrees Celsius) increase in specific conductance from the top to the bottom of the water column.

When the profile was measured again on June 19, Lake Laura remained sharply stratified. Dissolved-oxygen concentration remained low in the hypolimnion and specific conductance remained high near the bottom of the water column. The top of the thermocline was now at a depth of 12 ft, and the oxygen depression within the thermocline was not as severe as it was at a depth of 19 ft. Concentrations were 4 mg/L and 4.8 mg/L at depths of 12 and 15 ft, respectively. The result was a significant increase in the thickness of the oxygenated zone and restriction of water having a high specific conductance to a much narrow, 5-ft thick layer at the bottom of the water column.

Ten profiles, measured at approximately 2-week intervals, were obtained from May through September 1983. The first profile was measured on May 10, 1983, and shows virtually uniform temperatures from top to bottom with little evidence of stratification and no large decline in oxygen or increase in specific conductance with depth. Just 1 day later, however, another profile measurement showed a 2 °C warming of the upper 6 ft of the water column. Development of a thermocline was indicated by a 2 °C temperature decrease between depths of 9 and 12 ft. In 1 day, the specific conductance increased by more than 100 μS/cm in the bottom 6 ft of the water column. These measurements indicate that stratification in the Lake Laura impoundment can occur rapidly.

By June 3, 1983, the thermocline was strongly developed and was located close to the surface between depths of 6 and 9 ft. Dissolved-oxygen concentrations in the hypolimnion had declined since the last measurement on May 11 and the concentration near the bottom of the water column was only 2 mg/L. Stratification persisted throughout subsequent profile measurements during late June, July, and August, ending with an overturn that occurred sometime between August 24 and September 13. The impoundment remained nonstratified throughout the fall until freeze up.

An examination of the profile data did not indicate periods of destratification prior to August 24. The position of the top of the thermocline lowered to a depth of 9.0 ft on June 27 and stayed there until the final overturn at the end of summer, except for a period in late July when it was between depths of 3 and 6 ft.

Dissolved-oxygen concentrations in the hypolimnion continued to decrease throughout the summer as stratification persisted. As the summer progressed, the zone of oxygen depletion thickened, extending to the top of the thermocline by July. Specific conductance continued to increase in the hypolimnion reaching 1,430 μS/cm on August 24, which exceeded the 1,020 μS/cm measured on May 11.

At the time of the first profile measurement following overturn, the water column had been reoxygenated except for a 1-ft thick layer at the sediment-water interface. The profile data suggest that the oxygen demand of the recirculated hypolimnetic waters may have been high because the dissolved-oxygen saturation was only 86 percent at the surface and even less at depth. Nonetheless, dissolved-oxygen concentrations were 5.7 mg/L to 7.6 mg/L throughout the water column except for the narrow zone at the bottom. Specific conductance was nearly uniform from top to bottom, ranging from 1,300 to 1,320 μS/cm in the oxygenated zone, suggesting mixing of the waters. At the time of the next profile measurement on September 27, the surface dissolved-oxygen concentration had risen to 13 mg/L and the water column was supersaturated with respect to oxygen to a depth of 9 ft.

During 1984, profile measurements were made on a monthly basis, decreasing the detail of the record of the stratification patterns. The monthly data show a sequence of events similar to those observed in 1983; stratification began in mid-May, and a well developed thermocline was in place by mid-July. Dissolved-oxygen concentrations in the hypolimnion decreased to less than 2 mg/L during mid-July and specific conductance increased near the bottom.

Lake Laura destratified between July 12 and August 7, 1984, and probably remained destratified for the rest of the summer as no stratification was indicated by the profile measurement on September 7. The early overturn may have been brought about by moderate inflow at both inlets that began on August 1 and peaked on August 3, just prior to the profile measurement on August 7. Two runoff events of similar magnitude at one inlet during 1983 did not, however, disrupt stratification in Lake Laura.

Relation of Trophic State to Stratification

Thermal and chemical stratification, or the absence of it, may be one of the strongest controlling influences on overall water quality in the four impoundments and in the proposed impoundments.

Although direct cause-and-effect relations are not easily derived from the data, it is interesting to note that Webber impoundment, which has the best water quality, has a unique aspect to its stratification pattern. Webber is polymictic (frequent summer overturns), as is Dillon-Syltie and La Bolt, but it frequently has much higher concentrations of dissolved oxygen in the lower part of the water column, even during periods of stratification. Dissolved-oxygen concentrations may be sufficiently high to prevent the onset of reducing conditions in the interstitial water of the bottom sediments, thereby preventing release of phosphorus to the overlying water column. Oxygenated conditions also were observed more frequently during late winter in Webber impoundment, which may have reduced the availability of soluble phosphorus at the onset of the early summer period.

Although analysis of the data indicates that total phosphorus in the epilimnion is a poor determinant of productivity, much of the phosphorus measured may have been in a biologically nonreactive form. The phosphorus that promotes productivity may be that which is recycled from bottom sediments.

The polymictic impoundments that frequently approached oxygen depletion (Dillon-Syltie and La Bolt) are more likely to release reactive phosphorus from the sediments, some of which reaches the euphotic zone during mid-summer overturns. By this mechanism, phosphorus can be resupplied to the euphotic zone frequently, thereby maintaining steadily increasing algal populations throughout the summer. This increase in summer-season productivity was observed in the polymictic impoundments, but it was not observed in Lake Laura, which is dimictic (spring and late summer overturn).

Bacteria

Sampling for determination of fecal coliform and fecal *Streptococci* bacteria was not extensive. Lake Laura, Webber, and Dillon-Syltie were each sampled once. Lake Laura was sampled June 1, 1984, about three weeks after a runoff event. Bacterial counts were low; fecal coliform was 25 col/100 mL (colonies per 100 milliliters) and fecal *Streptococci* was 72 col/100 mL. Dillon-Syltie impoundment, in contrast, was sampled on June 7, 1984, during heavy runoff. Counts of fecal coliform and fecal *Streptococci* bacteria were 440 col/100 mL and 1,800 col/100 mL, respectively. The Webber impoundment was sampled on September 4, 1983, during low flow. The fecal coliform count was 2 col/100 mL, but the fecal *Streptococci* count was 2,300 col/100 mL.

Because the data are sparse, it is impossible to draw conclusions about the extent of bacterial contamination in the impoundments. The impoundments are not directly affected by domestic septic or waste systems, so the source of the bacteria would have to be either internal, from local populations of wild birds and small mammals, or external, from runoff draining feedlots and pastures or from overflowing septic systems upstream. Bacteria, once in the impoundments, appear to remain viable and are present in the outlet discharges. This is documented by data collected at the outlets of the impoundments. Two samples from the Lake Laura outlet collected in July and August 1983, for example, show counts that ranged from 410 to 3,000 col/100 mL for fecal coliform and from 3,800 to 6,100 col/100 mL for fecal *Streptococci*. Both samples were collected 2 or more weeks following the peak of the most recent runoff. These bacteria counts indicate that the bacteria remain viable after entering the impoundments or that substantial numbers of bacteria continue to be delivered to the impoundments during the recession periods of runoff.

Ammonia Toxicity

The primary focus of investigations in the impoundments was on indicators of trophic state, such as nitrogen and phosphorus, and on dissolved substances such as calcium, magnesium, and bicarbonate. Only one potentially toxic substance, ammonia, was sampled frequently. Samples were analyzed for dissolved and total ammonia (NH_4^+ and NH_3). The proportion of nonionic ammonia (NH_3), which can be toxic, can be calculated from measurements of pH, temperature, and a standard curve relating these characteristics to percent nonionic ammonia.

Table 10 is a summary of total and dissolved concentrations for each impoundment. Mean ammonia concentrations are much higher near the bottom of the Lake Laura and La Bolt impoundments, where organic matter decomposes. However, the maximum concentration of ammonia near the surface of La Bolt also was high (2.8 mg/L). Because only a part (commonly less than 10 percent at the prevailing pH) of the ammonia is in the nonionic form, ammonia concentrations of concern are normally those greater than 1 mg/L. Owing to the pH of the surface water of these impoundments, however, nonionic ammonia can at times exceed concentrations recommended by the MPCA (1978) for freshwater aquatic life.

The ammonia concentrations found in the hypolimnions of the Dillon-Syltie, La Bolt, and Lake Laura impoundments normally do not pose a threat to aquatic life, because most life forms will be excluded from that zone by the lack of oxygen below the thermocline.

The buildup of ammonia in the hypolimnions may pose a problem for proposed impoundments that are designed for stratified release. Ammonia-laden water could exceed MPCA water-quality recommended concentrations in the receiving streams.

Table 10.--*Concentration of ammonia, as nitrogen, at Webber, Dillon-Syltie, Lake Laura and La Bolt impoundments. Total ammonia was collected and analyzed in 1980-82 and dissolved ammonia in 1983-84*

[Concentrations are in milligrams per liter; <, less than]

Impoundment	Minimum concentration		Maximum concentration		Mean concentration		Median concentration		Number samples of	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Webber	0.02	0.03	0.45	0.11	0.11	0.06	0.08	0.06	17	5
Dillon-Syltie	<.01	.03	.64	.49	.13	.18	.07	.12	30	8
Lake Laura	.04	.55	.55	6.5	.24	3.25	.24	3.2	8	7
La Bolt	.30	.04	2.80	6.4	.48	2.16	.15	.80	19	9

SUMMARY AND CONCLUSIONS

Streams

This report presented an analysis of the data collected in the reconnaissance sampling 1979 and during the subsequent intensive monitoring from 1980 through 1984. The purpose was to describe and evaluate the quality of water in streams draining the Coteau and to describe the effects of impoundments on quality of the water in streams. Effects were assessed by comparing data from the inlets of the impoundments to data from the outlets.

Unimpounded streams in the study area exhibit a wide range of water-quality characteristics. The streams differ in total dissolved-solids concentration, nutrient concentration, sediment concentration, and sediment discharge. Differences in dissolved-solids concentration are related to wide differences in common dissolved substances, principally calcium, magnesium, sodium, chloride, and sulfate.

Differences in nutrient and suspended-sediment characteristics between streams probably are related to land use and variations in drainage area, slope, and soil type. Differences in nutrient concentrations were statistically significant at some stream sites; concentrations were highest in streams of the Cottonwood Basin, but lowest in the West Branch Lac qui Parle River.

In most instances, concentrations of the common dissolved substances decreased with increasing streamflow, but strong positive correlations with streamflow for nitrite plus nitrate and total phosphorus suggest that these constituents reach streams in overland runoff.

Tests to determine the effects of the impoundments on concentrations of dissolved solids, and nutrients were mostly inconclusive; the statistical significance for most comparisons of inlets and outlets could not be demonstrated.

Suspended-sediment concentrations show the modifying effects of the impoundments. Maximum and median suspended-sediment concentrations were lower in outlet streams, and did not increase with increasing streamflow at the outlets. Maximum daily discharge of suspended sediments also were lower at outlets than at inlets.

Temperature of outlet streams was approximately the same as the temperature of inlet streams, based on comparisons of mean values calculated from measurements of stream temperatures made during the periodic samplings.

Comparisons of dissolved-oxygen data between inlets and outlets showed that median concentrations were comparable, suggesting limited impact from the impoundments. None of the dissolved-oxygen data indicate severe lowering of concentrations in either impounded or unimpounded streams, although criteria for Class A fisheries and recreation streams were not met by many streams because of violation of the minimum limit of 7 mg/L dissolved oxygen. Most criteria for Class B and C fisheries and recreation streams probably would be met, including temperature and dissolved-oxygen concentrations, but criteria for contamination by bacteria probably would not be met.

Analyses for bacteria indicated widespread contamination throughout the study area, with high levels of fecal contamination present at times. Bacteria counts in the outlet streams were high, indicating that the impoundments did not substantially reduce the number of bacteria carried into the impoundments by streams.

Impoundments

Water quality differs significantly between impoundments. The most significant differences detected in this study were in (1) trophic-state indicators and (2) the occurrence, extent, and persistence of stratification.

Analysis of the trophic-state data have shown that, although transparency is controlled by the level of productivity in the impoundments, the level of productivity cannot be predicted by measurements of total-phosphorus concentrations in the epilimnions, except within very wide limits.

Analysis of trophic-state data from the four impoundments studied suggest that future impoundments would be eutrophic, having relatively high concentrations of total phosphorus, nitrate, and ammonia in the waters. Chlorophyll *a* productivity, and related transparency, also would likely fall within a range generally considered to be indicative of eutrophy, but the values would be centered near those obtained for Lake Laura and Dillon-Syltie, which have mean transparencies of about a 3.3 ft depth and mean chlorophyll-*a* concentrations of about 20 μg/L. Extreme transparency values would be about 6.6 ft (as in Webber) at the less eutrophic end of the range and about 1.6 ft (as in La Bolt) at the most eutrophic end of the range.

Seasonal changes also were shown to be of importance when evaluating the trophic-state data. Three of the four impoundments showed a strong tendency towards increasing productivity, with a corresponding decline in transparency as the summer season progressed from mid-May through September. This seasonal progression affects the mean values and suggests that, in regard to transparency, some impoundments would satisfy aesthetic criteria in the early summer but not in late summer.

Thermal stratification, like trophic state, also was found to vary significantly among the four impoundments. Conditions ranged from dimictic in Lake Laura to highly polymictic in Dillon-Syltie.

The occurrence and duration of thermal stratification were found to have significant effects on other aspects of water quality, because chemical stratification (dissolved oxygen and dissolved solids) frequently occurred when thermal stratification was present. Extended periods of summer thermal stratification brought about hypolimnetic conditions characterized by near depletion of dissolved oxygen, elevated concentrations of ammonia, and increased dissolved solids. Similar conditions occurred in some of the impoundments during winter when inverse stratification served to prevent circulation in the water column. Of significance to the winter survival of fish were late-winter concentrations of dissolved oxygen in Webber and Dillon-Syltie that exceeded the critical minimum level of 5 mg/L; supersaturation was reached at times.

Patterns and duration of summer stratification were not observed to have a high correlation with depth of the impoundment. The results of this study suggest that stratification will be influenced more by shape, orientation, and local setting of the impoundment than by depth.

Profile data and a comparison of trophic-state data between polymictic and dimictic impoundments indicate that trophic state may be influenced by the frequency and duration of periods of thermal and chemical stratification.

Scant bacteria data showed that fecal coliform and fecal *Streptococci* bacteria may be frequent contaminants in the impoundments. Data collected in the outlet streams verified that bacteria transported to the impoundments can pass through the impoundments in high numbers, potentially affecting downstream areas.

Ammonia concentrations reached high levels, particularly in the hypolimnetic zones, when stratification persisted for long periods. This may pose a potential hazard to fish populations in downstream areas if impoundments are designed to release water from near the bottom of the water column.

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