HYDROLOGY, WATER QUALITY, TROPHIC STATUS, AND AQUATIC PLANTS OF FOWLER LAKE, WISCONSIN

By P.E. Hughes

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

Multiply	*By*	*To obtain*
inch (in.)	25.4	millimeter
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	0.4047	hectare
square mile (mi^2)	2.590	square kilometer
acre-feet	1,233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
pound (lb)	453.6	gram
ton, short	0.9072	megagram

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

$$°C = \frac{(°F - 32)}{1.8}$$

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ABSTRACT

The U.S. Geological Survey, in cooperation with the Fowler Lake Management District, completed a hydrologic and water-quality study of Fowler Lake in southeastern Wisconsin during calendar year 1984. Data on temperature, pH, specific conductance, and concentrations of dissolved oxygen, total phosphorus, dissolved orthophosphate phosphorus, and various nitrogen species were collected from January through November 1984. The water-quality data indicate that Fowler Lake can be classified as a mildly fertile lake with excellent water clarity as indicated by Secchi depth readings generally greater than 12 feet. Although phosphorus concentrations are generally less than 0.01 milligram per liter, the lake does produce dense stands of macrophytes during the open-water period. The lake is thermally stratified during the summer months, resulting in oxygen depletion in the deepest parts of the lake.

The average hydraulic residence time for Fowler Lake during 1984 was 6.9 days, which is substantially less than the 305 days for upstream Okauchee Lake or the 145 days for downstream Lac La Belle. Precipitation during 1984 was about 27 percent higher than normal and streamflows in the area were about 55 percent higher than normal. The Oconomowoc River contributed 98 percent of the inflow and 88 percent of the phosphorus load to Fowler Lake.

The low annual phosphorus input (28 pounds per square mile) to the lake from the Oconomowoc River shows the benefit of upstream lakes on the Oconomowoc River. Fourteen percent of the phosphorus input load to Fowler Lake is deposited in the lake sediments and the rest is transported through the lake by surface-water flow to downstream Lac La Belle. Dense growths of macrophytes in the lake change in composition seasonally; *chara sp.* (muskgrass) and *Myriophyllum sp.* (milfoil) are abundant in June and *Najas marina* and *Vallesneria Americana* (wild celery) are abundant in August.

INTRODUCTION

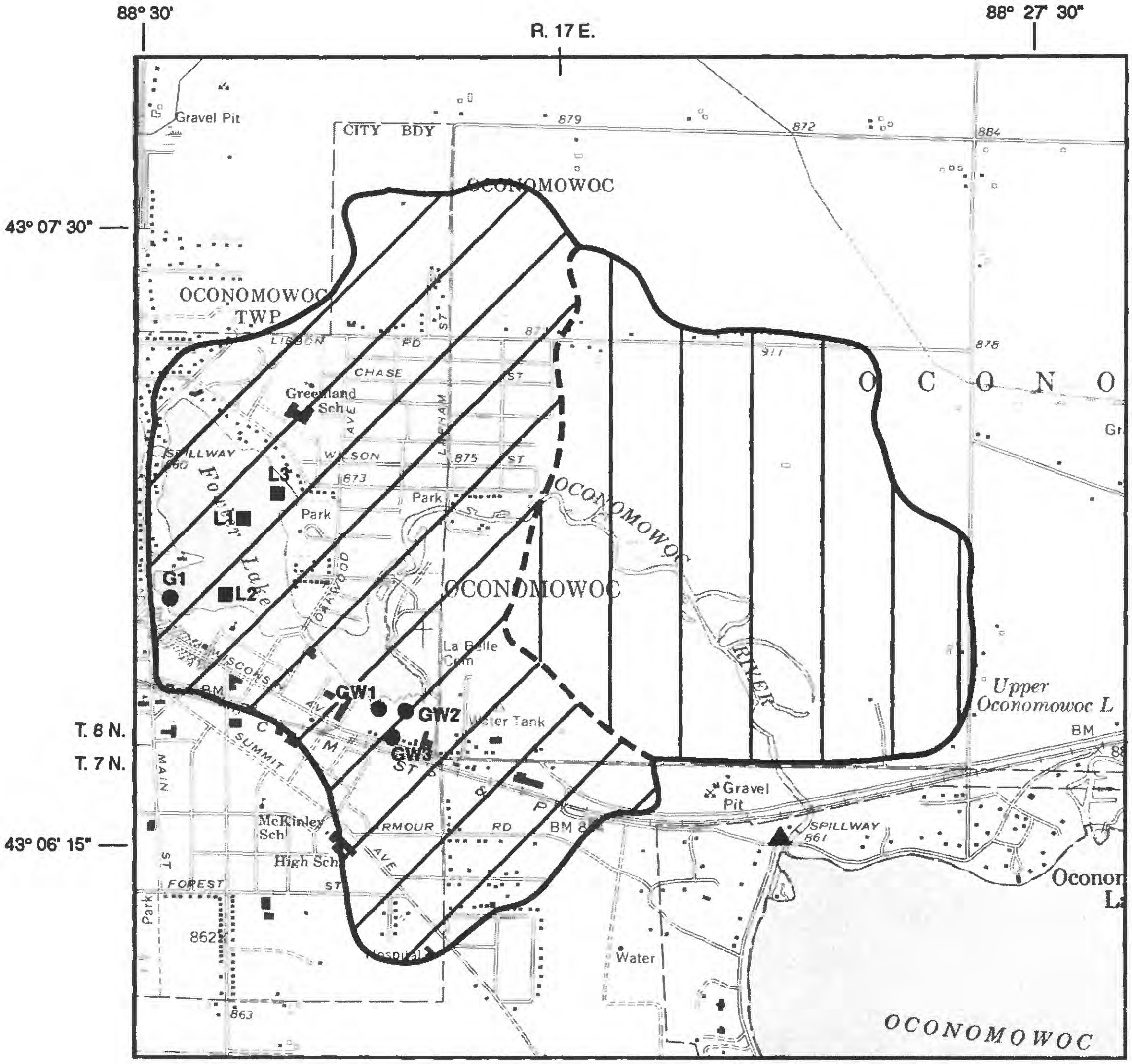
Background

Fowler Lake is located entirely within the city of Oconomowoc in Waukesha County, in southeastern Wisconsin (fig. 1). Rooted aquatic vegetation and algae are found throughout most of the lake, and lakeshore residents have been concerned because the unsightly, and often noxious, plants are becoming more abundant despite implementation of a plant-harvesting program. On January 1, 1984, the U.S. Geological Survey (USGS), in cooperation with the Fowler Lake Management District, began an intensive 10-month study of the water quality and physical features of Fowler Lake.

Purpose and Scope

This report documents the present water-quality conditions and identifies the types and densities of aquatic vegetation present in Fowler Lake. This information is needed by the Fowler Lake Management District to plan for the management of the lake. More specifically, the report (1) describes the chemical and physical characteristics of the lake water, (2) describes the streamflow and chemical loads into and out of the lake, (3) describes the potential for contaminant movement by ground-water flow into the lake from an abandoned landfill site, (4) estimates the phosphorus release from the lake sediments, and (5) identifies and maps the location of the rooted aquatic macrophytes in the lake. Algae within the lake were not identified and quantified as part of this study because algae in the lake do not cause water-quality problems. Collection and analyses of the data will provide a baseline data base to evaluate improvement or degradation of the lake water quality in the future.

Data collection for the study include (1) monitoring streamflow at the outlet from Oconomowoc Lake, (2) collection and analysis of water-quality samples to determine lake and river water-quality conditions in



Base from U.S. Geological Survey
Stonebank, 1971; Oconomowoc East, 1976
1 : 24,000

SCALE
0 0.5 MILE
0 0.5 KILOMETER

EXPLANATION

- Area draining to Fowler Lake
- Area draining to Oconomowoc River
- Fowler Lake drainage basin
- ■ L1 Lake-water sampling site – deepest point
- ■ L2 Bottom-sediment sampling site
- ■ L3 Bottom-sediment sampling site
- ● GW1 Ground-water observation well
- ● GW2 Ground-water observation well
- ● GW3 Ground-water observation well
- ● G1 Lake-staff gage
- ▲ USGS gaging station (05425070) on Oconomowoc River

Location of Fowler Lake

Figure 1. Fowler Lake, surface-drainage areas, and sampling sites.

1984[1], and (3) water-level measurements in a former city disposal area adjacent to the lake. This report summarizes the results of the sampling program and provides an evaluation and interpretation of the data. All water quality and streamflow data used in this report are stored in the U.S. Geological Survey's National Water Information System (NWIS) computer data bases.

Description of Study Area

Lake Basin, Shoreline, and Sediments

Fowler Lake is located entirely within the city of Oconomowoc, Waukesha County, Wisconsin (fig. 1). The study area consists of the Fowler Lake drainage basin and a gaging station on the Oconomowoc River. The lake has a main body surface of 78 acres and an expanded inlet area of 21 acres. The principal inlet and outlet of Fowler Lake is the Oconomowoc River and the outlet flows directly into Lac La Belle. Fowler Lake lies in a glacial valley, and has been increased in surface area and depth by a dam at the outlet which raises the water surface by about 8.0 ft (feet). Basic hydrographic and morphometric data are presented in table 1. The morphometry of the lake is illustrated in figure 2.

The depth and type of soft sediment on the lakebed were sampled at depths less than 25 ft during the macrophyte survey. Forty-three percent of the surveyed bottom is covered by a muck/clay mixture, 23 percent by a muck/sand composition, 15 percent by muck, and 11 percent by rubble or a muck/rubble composition. Gravel was found in less than 6 percent of the surveyed area. The depths of the soft sediments ranged from 0 ft over the gravel and rubble areas to

[1]Unless specified otherwise, years are calendar years.

Table 1. *Hydrology and morphometry of Fowler Lake*

Size	
Area (main body)	78 acres
(enlarged inlet)	21 acres
Total drainage area	[1]49,757 acres
Direct drainage area	[1]862 acres
Volume	[1]1,021 acre-feet
Residence time (1984 study period)[2]	6.9 days
Shape	
Maximum length of lake	0.6 mile
Length of shoreline	1.7 miles
Maximum width of lake	0.35 mile
Shoreline development factor[3]	1.37
Depth	
Area of lake with depth less than 5 feet	33 percent
Area of lake with depth between 5 to 10 feet	23 percent
Area of lake with depth between 10 to 15 feet	16 percent
Area of lake with depth between 15 to 25 feet	13 percent
Area of lake with depths greater than 25 feet	15 percent
Mean depth	13 feet
Maximum depth	50 feet

[1]Southeastern Wisconsin Regional Planning Commission, written commun., 1985.
[2]Residence time--time required for full volume replacement by inflowing waters.
[3]Shoreline development factor--ratio of shoreline length to that of a circular lake of the same area.

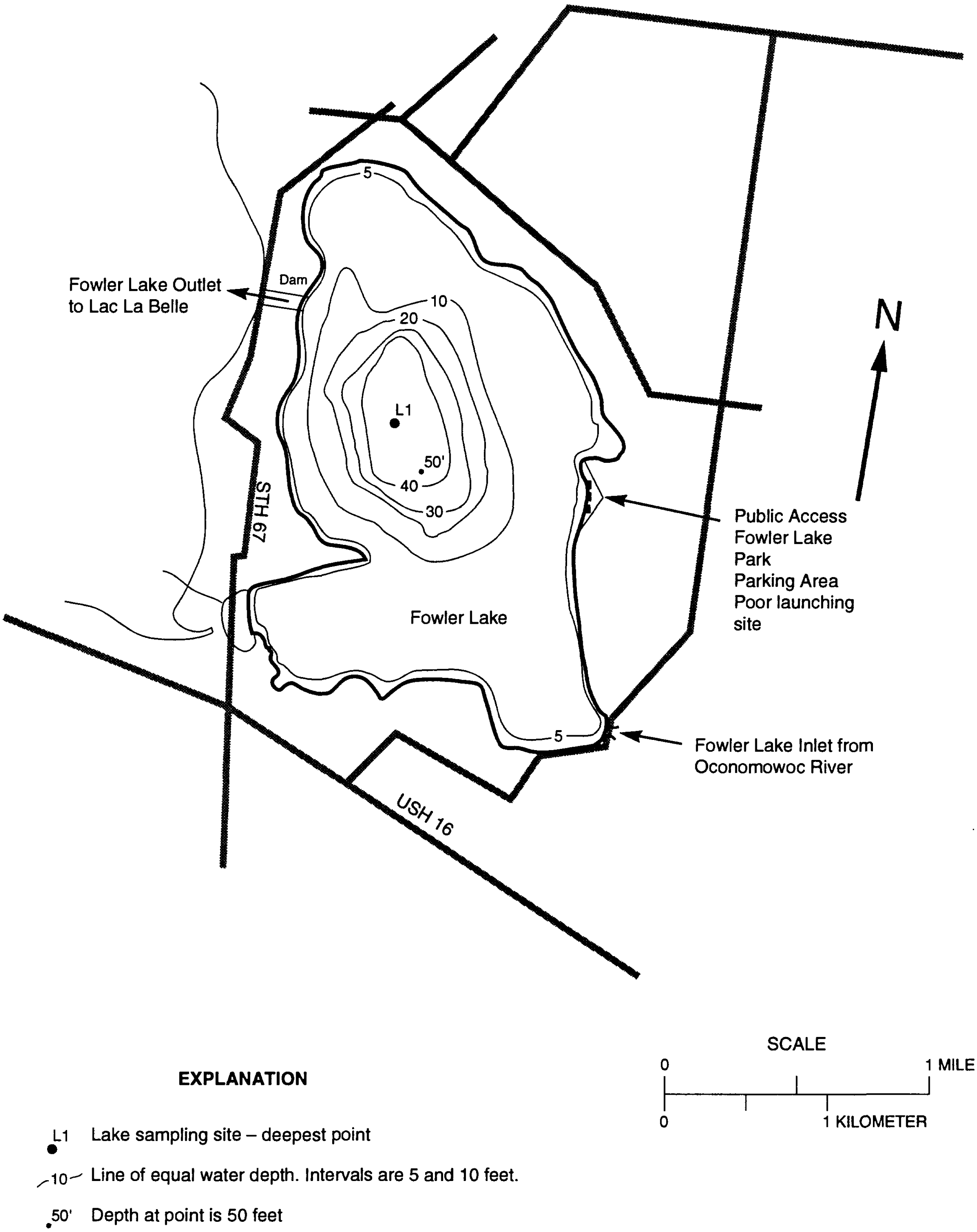


Figure 2. Bathymetric map of Fowler Lake (from Wisconsin Conservation Department).

more than 7 ft in some of the muck areas. The sediment data for the sampled points within the lake are included in appendix 4.

Watershed Characteristics

Figure 1 shows the drainage area directly tributary to Fowler Lake--that is, the area that drains directly into the lake instead of draining into the Oconomowoc River and then to the lake. This drainage area is 862 acres, or 1.35 mi^2 (square miles). The total drainage area to the lake is 49,757 acres, or 77.7 mi^2 (David B. Kendziorski, Southeastern Wisconsin Regional Planning Commission, written commun., 1985). Fowler Lake has a low watershed-to-lake area ratio of 9:1 if only the direct tributary area is considered. The ratio is 502:1 if the total drainage area is included. The Oconomowoc River is the major inlet to the lake and enters from the southeast. The Oconomowoc River flows continuously and had a daily mean discharge into the lake of 148 acre-ft (acre-feet) during the study period. The lake outlet is a dam spillway at the northwest side of the lake just upstream of State Highway 67. The spillway discharge flows through a 60-ft wide channel directly into Lac La Belle, which is immediately west of State Highway 67. The Oconomowoc River, which is also the outlet from Lac La Belle, discharges into the Rock River in Jefferson County, about 13 mi (miles) downstream from the Lac La Belle outlet.

Acknowledgments

The author would like to thank Bernard Schultz, Director of Public Works for the city of Oconomowoc, and his staff for their assistance on this project, as well as land owner Harley Mainz, who allowed emplacement of a gaging station on his property and who obtained daily water-quality samples from the Oconomowoc River.

HYDROLOGY

Data-Collection Methods

A stream-gaging station was operated on the Oconomowoc River (fig. 1) at the outlet of Oconomowoc Lake from January 20 through November 30, 1984. The water stages of Fowler Lake were recorded daily by city of Oconomowoc personnel using a staff gage located at the southwest shoreline near the auxiliary discharge control structure. The city also maintained a daily precipitation gage at the sewage-treatment plant. Recording precipitation gages were installed at the sewage-treatment plant and at the southeast corner of the expanded inlet near the ground-water observation wells. Long-term temperature and precipitation values were obtained from official National Oceanic and Atmospheric Administration records (National Oceanic and Atmospheric Administration, 1984).

Precipitation

Air temperature and precipitation values for 1984 are compared to long-term data for the Fowler Lake area in table 2. These averages are based on National Oceanic and Atmospheric Administration records (1951-80) of temperature and precipitation for Oconomowoc, Wis. Table 2 also contains runoff values derived from USGS flow records (1919-78) for the Oconomowoc River near Oconomowoc and the Rock River at Afton. The mean summer and winter temperatures of 67°F (degrees Fahrenheit) and -25°F at Oconomowoc are similar to those of other recording locations in southeastern Wisconsin. Mean annual precipitation at Oconomowoc is 30.14 in. (inches). More than half the normal yearly precipitation falls during the growing season, from May to September. Runoff rates generally are low during this period because evapotranspiration rates are high, vegetation cover is abundant, and soil infiltration capacity is high. Usually less than 15 percent of the summer precipitation produces surface runoff, but intense summer storms can occasionally produce higher percentages of runoff. Approximately 30 percent of the annual precipitation occurs during winter to early spring when the ground is frozen resulting in peak runoff during that period from snowmelt or rain. Impervious areas, such as street surfaces, parking lots, and rooftops, increase the amount of surface runoff and decrease infiltration.

As table 2 shows, precipitation in 1984 was 8.36 in., or 28 percent greater than the long-term average (1951-80) at Oconomowoc. Precipitation in October, the wettest month, was 7.51 in., which is 5.25 in. greater than the long-term average. This abundant precipitation is also shown by a 56 percent increase in the mean annual runoff recorded by the USGS streamflow gage on the Rock River at Afton.

Table 2. *Long-term and 1984 study-year climatological data for the Fowler Lake area*

[°F, degrees Fahrenheit; --, not applicable]

1984 climatological data for Oconomowoc	January	February	March	April	May	June	July	August	September	October	November	December	Totals
Average air temperature (°F)[1]	14.6	30.8	27.4	45.8	54.5	68.8	69.6	72.2	59.2	52.6	36.0	26.3	--
Departure from normal (1951-80) monthly mean air temperature (°F)[1]	-2.3	+9.2	-4.6	-.9	-3.7	+1.4	-2.4	+2.1	-2.8	+1.5	-.8	+2.5	--
Total precipitation (inches)[1]	.42	1.39	1.38	3.20	4.57	5.90	4.20	1.91	2.47	7.51	2.28	3.27	38.50
Departure from normal (1951-80) precipitation (inches)[1]	-.65	+.55	-.33	+.29	+1.69	+2.12	+.10	-2.05	-.90	+5.25	+.45	+1.84	8.36
Runoff (inches) (Rock River at Afton)[2]	.48	.86	1.16	.89	1.28	1.18	1.19	.41	.34	.79	1.53	.99	11.10
Departure from normal (water-years 1914-78) runoff (inches) (Rock River at Afton)[2]	+.07	+.40	+.03	-.45	+.44	+.63	+.75	+.07	-.01	+.40	+1.08	+.58	+3.99 (1914-78)
Runoff (inches) (Oconomowoc River at Oconomowoc)[2]	.48	1.04	1.09	.74	1.27	1.63	1.61	.62	.54	1.14	1.75	1.26	13.17

[1]Data from National Oceanic and Atmospheric Administration (1984).
[2]Data from U.S. Geological Survey records (1919-78).

Hydrologic Budget

A hydrologic budget for Fowler Lake (fig. 3) was computed using the following formula:

$$Qout = Qin + PRECIP - EVAP \pm \Delta\ STORAGE,$$

where

Qout = discharge from Fowler Lake to Lac La Belle (acre-feet),

Qin = discharge to lake from Oconomowoc River gage plus discharge from direct drainage area (acre-feet),

PRECIP = precipitation on lake surface (acre-feet),

EVAP = evaporation loss from lake surface (acre-feet), and

Δ STORAGE = change in lake volume (acre-feet).

Lake-level fluctuations are shown in figure 3. During the 10 months of monitoring, 45,050 acre-ft of water entered the lake as inflow from the Oconomowoc River. The average inflow from the Oconomowoc River during this period was 148 acre-ft/d (acre-feet per day). The calculated outflow from Fowler Lake during this period was 45,900 acre-ft or 151 acre-ft/d.

Ground-water levels were measured at three observation wells located just south of the expanded inlet (fig. 1). The slope of the water table near these wells indicates that ground water flowed toward the lake during the entire study period. However, because of the 8-ft head difference between the lakes, caused by the dam, ground-water flow from the lake toward Lac La Belle is probable.

A discharge measurement made on February 23 at the outlet of Fowler Lake was calculated as 6.0 ft^3/s (cubic feet per second) greater than the discharge measured at the Oconomowoc River gaging station. This was the only acceptable period to attempt a

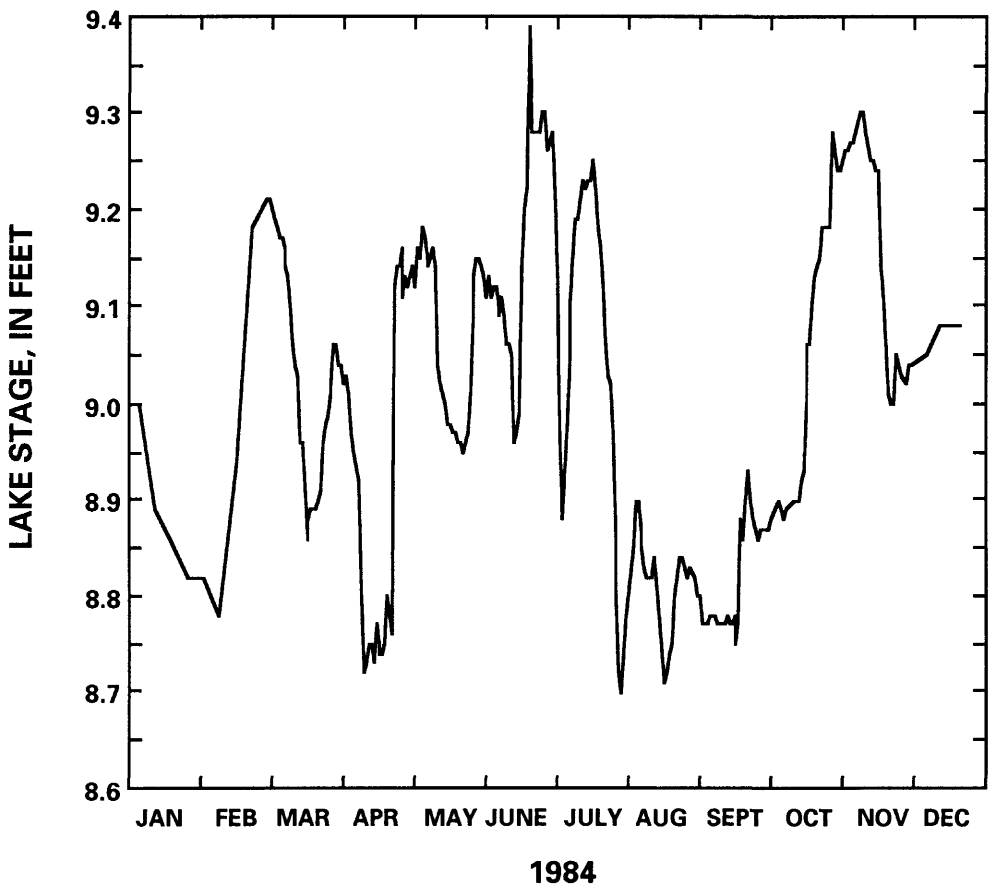


Figure 3. Stage fluctuations of Fowler Lake during the 1984 study period.

measurement at the outlet because there was (1) ice cover on both Fowler Lake and Lac La Belle, (2) a stable lake stage at Fowler Lake, and (3) stable discharge at the upstream gage. The 6-ft^3/s increase in discharge between the lake inlet and the lake outlet could be interpreted as the contribution from ground water because there was no precipitation, evaporation, or urban runoff during the week prior to the measurement. However, because the discharge was relatively high (112 ft^3/s), the difference falls within the normal range of error for the measurement. Therefore, the contribution of ground-water flow into or from the lake could not be estimated.

The 1984 annual hydrologic budget for Fowler Lake (table 3) was estimated from the average daily mean discharge for the 1984 study period. This budget shows that 56,500 acre-ft of water entered the lake from the Oconomowoc River, direct drainage runoff, and direct precipitation on the lake's surface. The runoff from the direct drainage area was computed by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) using the Wisconsin Urban Runoff Model (WURM) (David Kendziorski, Southeastern Wisconsin Regional Planning Commission, written commun., 1985). Direct precipitation volume to the lake was estimated from the surface area of the lake multiplied by the recorded daily precipitation (National Oceanic and Atmospheric Administration, 1984). The Oconomowoc River constituted 98 percent of the estimated inflow to the lake during the study period; 40 percent of that occurred during May, June, and July. Direct precipitation of 280 acre-ft to the lake surface was approximately equaled by a loss of 220 acre-ft through evaporation (evaporation pan data, National Oceanic and Atmospheric Administration, 1984). A loss of 56,600 acre-ft through the lake outlet and by evaporation was calculated; this loss, if ground-water inflow is not considered, should have resulted in a net water loss of 120 acre-ft, or a 1.21-ft drop in the level of the lake surface. However, the lake level increased by 0.08 ft; this represents a total volume increase of 130 acre-ft. These calculations indicate that the net ground-water inflow to the lake is 130 acre-ft or less than 0.2 percent of the total outflow. The hydrologic budget, as presented above, shows that flow through the lake from the Oconomowoc River is the single most important source of water for Fowler Lake. All other direct sources contributed no more than 2 percent of the inflow to the lake during 1984. The

Table 3. *Hydrologic budget for Fowler Lake, 1984*

		Inputs and losses in acre-feet	
		February to November 1984 (measured)	January to December 1984[1] (annual summary)
Inputs			
Oconomowoc River inflow		45,000	55,300
Direct precipitation[2]		280	300
Direct drainage[3]		830	900
	Total[5]	46,100	56,500
Losses			
Oconomowoc River outflow		45,900	56,400
Evaporation[4]		220	220
Lake volume increase		30	10
	Total[5]	46,200	56,600

[1]Inputs and losses for January 1984 and December 1984 estimated from partial records.
[2]Precipitation data for Oconomowoc, Wis. (National Oceanic and Atmospheric Administration, 1984).
[3]Direct drainage volumes from Southeastern Wisconsin Regional Planning Commission (written commun., 1985).
[4]Evaporation data for Arlington, Wis. (National Oceanic and Atmospheric Administration, 1984).
[5]Rounded to three significant figures.

evaporation and ground-water volumes of the hydrologic budget, which rely on differences between lake volume and river inflow, should be considered to be estimates based upon engineering judgment.

Hydraulic Residence Time

The hydraulic residence time is defined as the time period required for the inflow to equal the volume of the lake. Hydraulic residence time is an important factor in determining the expected response time of the lake to increased or reduced nutrient loadings. The hydraulic residence time for Fowler Lake during the 1984 study was approximately 6.9 days. In comparison, the hydraulic residence time for upstream Okauchee Lake is 305 days and for downstream Lac La Belle is 145 days. Delavan Lake, also in southeastern Wisconsin, had a 2.2-year hydraulic residence time (Field, 1988). The short residence time for Fowler Lake implies that the water quality of the lake will resemble that of the influent Oconomowoc River. However, the water quality in the lake also can be affected by the resuspension of sediments from the lake bottom.

WATER QUALITY

Data-Collection Methods

The water quality of Fowler Lake was monitored from January through November 1984 to (1) determine the condition of the lake and (2) characterize its suitability for recreational use as well as supporting fish and aquatic life. Water-quality samples from the lake were collected monthly during January through March and biweekly from April through November 1984. The primary sampling station was located at the deepest point in the lake (fig. 2). Temperature, dissolved oxygen, pH, and specific conductance were measured using a multiparameter meter. A standard 8-in. Secchi disc was used to measure water clarity. Water samples were collected by a 2.2 liter Wildco trap sampler at depths 3 ft below the surface, near the center of the thermocline, and 1 to 2 ft from the lake bottom. Chemical analysis was done by the U.S. Geological Survey Central Laboratory in Doraville, Ga., using standard methods.

Physical and Chemical Characteristics

Physical Characteristics

Water samples regularly collected from Fowler Lake and the Oconomowoc River during the study period were analyzed for pH, specific conductance (an indicator of the amount of dissolved solids), and various chemical forms of nitrogen and phosphorus (nutrients). The pH of water is the negative base-10 logarithm of the hydrogen-ion activity in moles per liter. A neutral solution would have a pH of 7.0, an acidic solution would be less than pH 7.0, and a basic solution would be greater than pH 7.0. Ranges and mean values for these constituents and properties are listed in table 4. A complete listing of these constituents and properties is found in Appendixes 1 and 2. Data for additional constituents including calcium, magnesium, sodium, potassium, iron, manganese, and sulfate were obtained from water samples taken during spring turnover at the lake surface and near the bottom, and from the Oconomowoc River near the gaging station. These data and comparison data collected by the USGS for Lac La Belle and Okauchee Lake are listed in table 5. The data in table 5 indicate that the water quality is similar among the above-mentioned sites.

Temperature

Water temperatures ranged from a minimum of 32°F during the winter to a maximum of 81°F during the summer. Temperature, dissolved oxygen, pH, and conductance profiles are shown in figure 4.

Mixing of the lake is restricted by thermal stratification in the summer and by ice cover in the winter. Thermal stratification is the result of differential heating of the lake water. Water is unique among liquids because it reaches its maximum density--weight per unit volume--at about 39°F. As summer begins, the lake absorbs the sun's energy at the surface. Wind action and, to some extent, internal heat transfer convey this energy to underlying water. As the upper layer of water is heated by the sun's energy, a physical barrier begins to form between the warmer surface water and the lower, heavier, colder water. This "barrier" is marked by a sharp temperature gradient known as the metalimnion or thermocline, which separates the warmer, lighter, upper layer of water called the epilimnion, from the cooler, heavier, lower

Table 4. *Water-quality conditions of Fowler Lake and the Oconomowoc River, 1984*

[units are milligrams per liter unless otherwise indicated; <, less than; °F, degrees Fahrenheit; --, data not available]

Constituents and properties	Inlet Oconomowoc River: Range of observed values	Inlet Oconomowoc River: Mean of observed values	Fowler Lake: Range of observed values	Fowler Lake: Mean of observed values
Total nitrite + nitrate nitrogen as N	0.1 - 0.6	0.2	0.1 - 0.8	0.2
Total ammonia nitrogen as N	.01 - 1.70	.20	.01 - 1.70	.31
Total Kjeldahl nitrogen as N	.5 - 4.2	1.0	.25 - 2.50	1.00
Total nitrogen as N	.7 - 4.5	1.2	.45 - 2.70	1.18
Dissolved orthophosphate phosphorus as P	<.01 - .02	.01	<.01 - .06	.01
Total phosphorus as P	<.01 - .02	.01	<.01 - .06	.01
Dissolved oxygen	7.3 - 13.3	10.8	.0 - 12.8	6.3
Temperature (°F)	36.0 - 80.5	60.5	36.5 - 81.0	51.5
pH (units)	8.3 - 9.2		7.2 - 9.1	
Conductivity (microsiemens per centimeter at 25° Celsius)	441 - 511	490	441 - 595	509
Secchi depth (feet)	--	--	9 - 14	13

layer called the hypolimnion. Although this barrier is easily crossed by fish, it essentially prohibits exchange of water between the two layers. This condition, which is discussed later, has a great impact on both the chemical and biological activities within the lake. The development of the thermocline begins in early summer, reaches its maximum in late summer, and disappears in the fall, as illustrated in figure 4. This stratification period lasts until the fall, when air temperatures cool the surface water and wind action results in the erosion of the thermocline.

As water cools, it becomes heavier, sinking and displacing the warmer water below. The colder water sinks and mixes under wind action to erode the thermocline until the entire column of water is a uniform temperature. This lake season, which follows summer stratification, is known as fall turnover. When the water temperature drops below 39°F, it again becomes lighter and "floats" near the surface. Eventually the surface of the water is cooled until at 32°F ice forms and covers the surface of the lake, isolating it from the atmosphere for up to 4 months. The lake was ice covered when the first sample was taken on January 25, 1984, and remained ice covered until April 1, 1984.

Winter stratification occurs as the colder, lighter water and ice remain at the surface, again separated from the relatively warmer, heavier water near the bottom of the lake. Spring brings a reversal to the

Table 5. *Water-quality conditions at spring turnover for Fowler Lake, Lac La Belle, Okauchee Lake, and the Oconomowoc River Inlet, April 1984*

[units are milligrams per liter unless otherwise indicated; µg/L, micrograms per liter; <, less than; --, data not available; µS/cm, microsiemens per centimeter at 25°C; °F, degrees Fahrenheit]

Constituent or property	April 10, 1984			April 11, 1984		April 19, 1984	
	Oconomowoc River	Fowler Lake at 1-foot depth	Fowler Lake at 48-foot depth	Lac La Belle center site at 3-foot depth	Lac La Belle center site at 40-foot depth	Okauchee Lake center site at 3-foot depth	Okauchee Lake center site at 89-foot depth
Total nitrite + nitrate nitrogen as N	0.2	0.2	0.3	0.70	0.70	0.40	0.50
Total ammonia nitrogen as N	.11	.06	.11	.10	.12	.04	.05
Total organic nitrogen as N	.39	.28	.49	.60	.78	.76	.55
Total nitrogen as N	.70	.54	.90	1.50	1.60	1.20	1.10
Dissolved orthophosphates phosphorus as P	.03	<.01	<.01	<.01	<.01	<.01	<.01
Total phosphorus as P	.01	.01	.01	<.01	<.01	.01	<.01
Dissolved calcium	45	45	45	45	45	51	51
Dissolved chloride	20	22	22	27	25	19	19
Hardness, as calcium carbonate	240	240	240	240	240	260	260
Dissolved iron (µg/L)	14	5	5	<4	<3	11	8
Dissolved magnesium	31	32	32	32	32	32	32
Dissolved manganese (µg/L)	2	2	3	<1	<1	1	<1
Dissolved potassium	1.8	1.9	1.9	2.1	2.0	2.0	2.0
Dissolved solids	287	293	277	296	274	332	329
Dissolved silica	2.9	3.6	3.8	3.7	3.7	4.3	4.3
Dissolved sodium	8.5	9.6	9.4	11	11	7.8	7.7
Dissolved sulfate	32	33	33	35	33	32	32
Color (platinum-cobalt units)	25	20	30	20	20	20	--
Conductance (µS/cm)	507	504	510	--	--	--	--
Dissolved oxygen	12.5	11.5	10.5	--	--	--	--
pH (units)	8.8	8.5	8.4	--	--	8.5	8.5
Temperature (°F)	49.0	43.5	43.0	--	--	42.0	42.0
Turbidity (NTU)	1.0	.6	.7	1.5	1.4	<1.0	--
Alkalinity (milligrams per liter as calcium carbonate)	202	208	208	206	206	223	223
Secchi depth (feet)	--	--	13	--	--	--	--

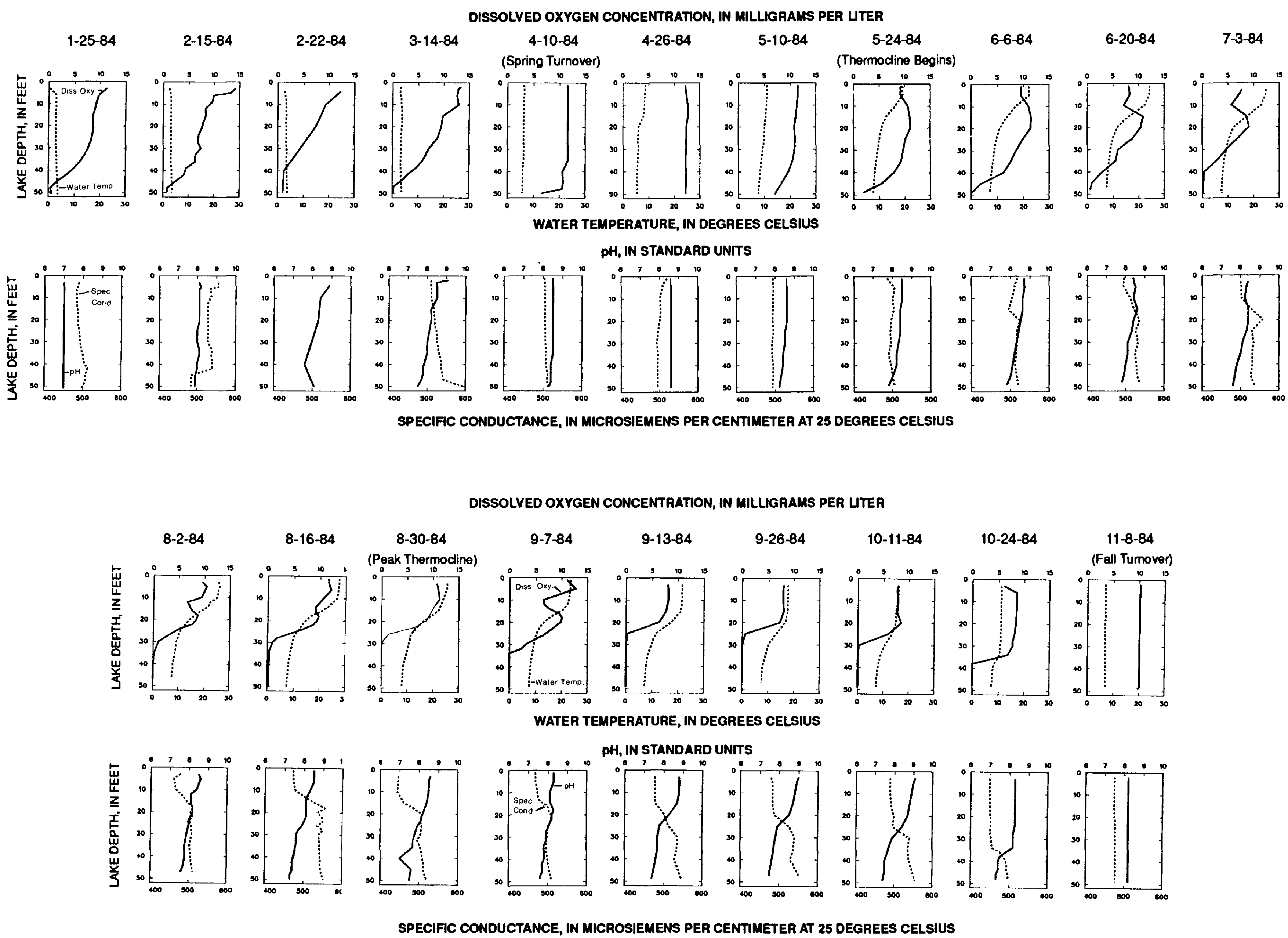


Figure 4. Graphs showing dissolved oxygen, water temperature, pH, and specific conductance as a function of depth for Fowler Lake at Oconomowoc, Wis., 1984.

process. As the ice thaws and the upper layer of water warms, it becomes more dense and begins to approach the temperature of the warmer, deeper water until the entire water column reaches the same temperature. This lake season, which follows winter stratification, is referred to as spring turnover and usually occurs within weeks after ice goes out. After this period, the water at the surface warms, again becoming lighter (less dense), and rises above the colder water. Wind and resulting waves carry some of the energy of the warmer, lighter water to lower depths, but only to a limited extent. Thus begins the formation of the thermocline and another summer thermal stratification.

Specific conductance

The specific conductance in Fowler Lake ranged from 441 to 595 microsiemens per centimeter (see table 4). The time-series plots (fig. 4) show that specific conductance increases with depth, and that the increase is more pronounced the longer the lake has been thermally stratified.

Water clarity

Water clarity in lakes is often measured using a Secchi disc, which is an 8-in. diameter flat plate with black and white quadrants. The disc is lowered into the water and the depth at which it is no longer visible is recorded.

Secchi disc readings in Fowler lake were consistently greater than 9 ft and, during much of the study period, had readings of 12 to 13 ft. This excellent transparency indicates that the concentrations of algae and suspended sediment in the water column are low.

Chemical Characteristics

Dissolved oxygen

Dissolved-oxygen concentrations are one of the most critical factors affecting a lake ecosystem. Winter brings the threat of dissolved-oxygen depletion and fish mortality in shallow, fertile lakes with ice cover. If ice cover is thick and snow cover deep, light penetration is sometimes insufficient to maintain oxygen production from the plants in the lake. When plants die and, along with organic bottom muck, decay, the process consumes dissolved oxygen. These processes result in oxygen depletion that will stress or kill most species of fish if the supply of dissolved oxygen is not sufficient--greater than 5 mg/L (milligrams per liter)--to meet the total winter demands (Southeastern Wisconsin Regional Planning Commission, 1980, p. 24). This condition, commonly referred to as winterkill, has not been a problem in Fowler Lake. Dissolved-oxygen levels were adequate for the support of fish throughout the winter for depths less than 40 ft (fig. 4). Table 4 shows the ranges and means of the dissolved-oxygen concentration measured during the study period.

Dissolved-oxygen profiles during summer stratification on Fowler Lake document total oxygen depletion in the lower portion of the hypolimnion. Beginning in early summer, as the thermocline develops, the lower, colder body of water (hypolimnion) becomes isolated from the upper, warmer layer (epilimnion), restricting the movement of dissolved oxygen from the surface down to the hypolimnion. In contrast, wind turbulence, atmospheric equilibrium, wave action, and plant photosynthesis maintain an adequate supply of dissolved oxygen in the epilimnion. Gradually, if the oxygen demand in the hypolimnion exceeds the supply for a long enough time, the dissolved oxygen will be depleted. This anoxic condition was observed in Fowler Lake during August and September 1984 (fig. 4) and is a common situation in many lakes in southeastern Wisconsin. Anoxic conditions allow phosphorus to be released from the lake sediments and become available during turnover periods for algae and other plant utilization. However, because only 20 percent of the lake is deeper than 20 ft and the residence time so short, the contribution of phosphorus from the anoxic area is probably small. By the middle of July 1984, the dissolved-oxygen concentration at the bottom fell to zero and at a depth of 28 ft it was 5.0 mg/L.

By September 26, 1984, the dissolved-oxygen concentration was zero from a depth of 25 ft to the lake bottom. This anoxic condition causes fish to move upward in the water column, where higher dissolved-oxygen concentrations exist.

pH

The pH in Fowler Lake ranged from 7.3 to 9.1 during the study period. The time-series plots (fig. 4) show that pH decreases with increasing depth during the time the lake is thermally stratified.

Chloride

Chloride concentrations ranged from 20 to 22 mg/L and are similar to the concentrations measured during the 1976-77 study of Lac La Belle (Southeastern Wisconsin Regional Planning Commission, 1980). The most important and easily recognized source of chlorides is probably urban runoff containing salt used for deicing streets during the winter. Table 5 shows measured chloride concentrations for Fowler Lake, Lac La Belle, Okauchee Lake, and the Oconomowoc River for the 1984 spring turnover samples.

Nutrients

The nutrients, nitrogen and phosphorus, which are necessary for the growth of aquatic plants, including algae, have a substantial effect on the suitability of lakes for recreational activities. In lakes where supplies of nutrients are low, plant growth is limited and water clarity is not impaired by phytoplankton. Abundant supplies of nutrients can cause prolific aquatic plant growth and nuisance algae blooms, leading to visual and aesthetic limitations caused by the decay of these organic materials. Table 4 lists the ranges and means of observed concentrations of nutrients for the 1984 study period.

Sources and Loads for Phosphorus, Nitrogen, and Sediment

The amount or mass of a constituent that is transported to or from a system, such as Fowler Lake, is termed "load." Loads may be calculated for a standard unit of time (second, day, year), or they may be calculated for a specific period, such as the period of runoff that follows a rainstorm.

The flow in the Oconomowoc River, which is the primary source of loading to Fowler Lake, is moderated by a series of upstream lakes. Because of the relatively stable flow, a time interval of 1 day was selected as the base time period to estimate the constituent loading to Fowler Lake. Estimates require records of lake inflow and outflow, and constituent concentrations in the river and the lake. Discharge records for the Oconomowoc River at the gaging station near the outlet of Oconomowoc Lake were used for the lake inflow; records of daily lake outflow were calculated using the method described under the Hydrologic Budget section of this report. Measurements of constituent concentrations at the gaging station and in the lake were taken by the USGS once per month while the lake was ice covered and twice per month during open-water periods. Suspended-sediment and total-phosphorus samples were taken daily from the gaging station at the Oconomowoc River by an observer.

Load of a constituent for the study period is calculated in a stepwise manner. First, constituent concentrations are estimated for days during which the river and lake were not sampled. Next, a coefficient is used to convert the daily concentrations to the desired units and then the daily concentrations are multiplied by the flow volume for that day. The products from the previous step are then summed for the period of interest. This is expressed mathematically by

$$L = E[(Ci*coef)*Vi],$$

where L = load, in pounds;
E = mathematical notation for a summation;
Ci = concentration of constituent for day i (collected or estimated), in milligrams per liter;
coef = 6.237×10^{-5} (coefficient to convert from milligrams per liter to pounds per cubic foot);
Vi = volume of flow for day i.

The calculation and the summation are done for both the lake inflow and outflow.

Outflow constituent concentrations were assumed to be the same as the concentration of the sample taken near the surface at the sampling location near the center of the lake. Measured constituent concentrations were assumed to represent the water quality for the time period one half of the interval from the preceding sample to one half of the interval to the following sample. The limit of detection for the total-phosphorus analysis used in this study was 0.01 mg/L. There were a total of 20 samples collected from near the lake surface, of which 10 had total-phosphorus concentrations reported as less than 0.01 mg/L. There were also 100 total-phosphorus samples collected from the Oconomowoc River near the gaging station, of which 44 had concentrations reported as less than 0.01 mg/L. In order to determine an estimate of phosphorus loading, a concentration of 0.0099 mg/L was used for those periods when the reported concentration was less than the limit of detection.

The estimated daily loads were summed for the study period from January 25 to November 30, 1984. The average daily load from this period was used to estimate the loading for the remainder of 1984.

These loading estimates were used to develop the annual loading budgets of total nitrogen, total phosphorus, and suspended sediment for the lake (table 6). Loads for the agricultural and wetland area between the Oconomowoc River gaging station and the lake were estimated using the unit area loads calculated for the Oconomowoc River gaging station. Loads for the urban area of Oconomowoc that drain into Fowler Lake were computed by Southeastern Wisconsin Regional Planning Commission using the Wisconsin Urban Runoff Model (WURM) (David B. Kendziorski, Southeastern Wisconsin Regional Planning Commission, written commun., 1985). Atmospheric loads to the water area of the lake were estimated from concentration data available for southeastern Wisconsin (Wisconsin Department of Natural Resources, 1984).

The annual loading budget indicates that the Oconomowoc River contributed 97 percent of the nitrogen load, 88 percent of the phosphorus load, and 92 percent of the sediment load to the lake. Direct drainage areas only contributed 2 percent of the nitrogen, 11 percent of the phosphorus, and 7 percent of the sediment annual load. Atmospheric contributions of nitrogen, phosphorus, and sediment are approximately 1 percent of the total load to the lake.

Table 6. *Annual loading budgets of Fowler Lake for nitrogen, phosphorus, and sediment based on measured data, 1984*

[>, greater than]

Source	Total nitrogen		Total phosphorus		Suspended sediment	
	Amount (pounds)	Total input (percent)	Amount (pounds)	Total input (percent)	Amount (pounds)	Total input (percent)
			Inputs			
Oconomowoc River (U.S. Geological Survey gage)	176,000	97	2,300	88	1,888,700	92
Direct drainage areas:						
Agriculture and wetland drainage	1,390	1	20	1	18,100	1
Urban area	1,670	1	280	10	130,000	6
Atmospheric	1,900	1	30	2	18,800	1
TOTAL[3]	181,000	100	2,630	100	2,060,000	100
			Outputs			
Outlet	140,000	78	2,000	77	Not determined[1]	
Weed harvest	320	>1	50	2	Not applicable	
Net deposition into bottom sediments[2]	40,000	22	600	21	Not determined[1]	
TOTAL[3]	180,000	100	2,650	100		

[1]Sediment loads for outputs were not computed due to lack of sediment data for the outflow.
[2]Deposition computed by difference of total input minus outlet and weed harvest loads.
[3]Rounded to three significant figures.

Phosphorus concentrations in Fowler Lake did not reach the levels necessary to support periodic nuisance algae blooms. The recommended water-quality standards for phosphorus, as set forth in the SEWRPC's adopted area-wide water-quality-management plan for lakes, is 0.02 mg/L or less of total phosphorus during the spring turnover. This is the level considered in the SEWRPC plan as needed to limit algae and aquatic plant growth to levels consistent with the recreational, warm-water fish, and aquatic life water-use objectives. The mean observed concentration of total phosphorus in Fowler Lake during the spring turnover on April 10, 1984, was 0.01 mg/L.

A total of 2,600 lb (pounds) of phosphorus was calculated to have entered Fowler Lake during 1984 (table 6). It is estimated 23 percent or 600 lb was used by the biomass within the lake or deposited in the sediments; this resulted in a net transport of phosphorus to Lac La Belle of 2,000 lb. The city of Oconomowoc weed-harvesting program during 1984 removed 792 yd^3 (cubic yards) of weeds, which would yield approximately 6.3 tons of dried-plant tissue. This amount of plant material would result in about 50 lb of phosphorus being removed from the lake (Burton and others, 1978, p. 177-185; Mace and others, 1984, p. 19-23). The loading budget as presented in table 6 includes both measured and estimated sources of data. Data for the Oconomowoc River inflow and the lake outflow were from manually collected water-quality samples. Estimates of the input from other sources were based upon modeled information provided by the Southeastern Wisconsin Regional Planning Commission. The information in table 6 is presented to emphasize the impact of the Oconomowoc River on the water quality of Fowler Lake.

The total-nitrogen load calculated to have entered the lake during 1984 was 181,000 lb. Ninety-seven percent of the load originated from the Oconomowoc River and less than 1 percent came from the city of Oconomowoc. Approximately 22 percent, or 40,000 lb, of the nitrogen was lost to sediments or used by the biomass within the lake.

The ratio of total-nitrogen to total-phosphorus concentration (N:P) in lake water often indicates which nutrient is the factor limiting aquatic plant growth in a lake (Allum and others, 1977, p. 10). When the N:P ratio is greater than 14:1, the lake is thought to be phosphorus limited. When the ratio is less than 10:1, nitrogen is considered the limiting nutrient. The N:P ratio in Fowler Lake was consistently greater than 50 (table 7); this indicates it is limited by phosphorus.

Bottom-sediment conditions also have an important effect on the condition of a lake. As sediment settles to the lake bottom, valuable benthic habitats and fish-spawning areas are covered, the thickness and area of macrophyte-prone substrates increase, and esthetic nuisances develop. Sediment particles also act as a transport mechanism for other substances, such as phosphorus, nitrogen, organic substances, pesticides, and heavy metals.

Suspended-sediment samples were collected near the Oconomowoc River gaging station (fig. 1) on a daily basis by an observer. Data for those samples selected for analyses are listed in appendix 3. For the period April through September 1984, daily sediment loads were computed using the concentration values determined from the sediment-sample analyses and the flows recorded at the gaging station. Daily sediment loads were estimated for the remainder of 1984 using a concentration of 2.0 mg/L during ice-covered conditions and a flow-weighted average load for the open-water period. The sediment load to Fowler Lake for 1984 was calculated to have been 2,060,000 lb. Ninety-two percent of the sediment-load input was from the Oconomowoc River while approximately 6 percent was contributed by urban runoff from the city. Sediment loads transported out of Fowler Lake were not calculated because no measured data were obtained at the lake outlet.

Ground-Water Quality at Former Disposal Area

Three observation wells were installed as part of the monitoring program (fig. 1). Ground-water quality and levels were measured at two wells (GW-1 and GW-2) placed near the southeastern edge of the expanded inlet to the lake. A third well (GW-3), located approximately 400 ft from the lake, was used only for ground-water-level measurements. The wells were installed in an area formerly used as an open-burning dump, but it had been filled and leveled for more than 10 years. Water levels in the wells, recorded at 2-week intervals, show that the hydraulic gradient is toward the lake. Two water samples, collected from the wells closest to the lake, were analyzed to determine the probability that leachates flowed into the lake from the dump. Elevated chloride concentrations were observed in the two samples (350 and 370 mg/L). Table 8 lists data for calcium, chloride, and sulfate concentrations in the samples and comparison data for the Waukesha County sand and gravel aquifer (Kammerer, 1981).

Table 7. *Nitrogen to phosphorus ratios at three-foot depth for Fowler Lake, 1984*

[<, less than; >, greater than]

Date	Total nitrogen (milligrams per liter)	Total phosphorus (milligrams per liter)	Ratio of total nitrogen to total phosphorus
April 10	0.54	0.01	54
April 26	.87	<.01	>87
May 10	2.70	<.01	>272
May 24	1.08	.02	54
June 6	1.06	.01	106
June 20	1.00	.02	>50
July 3	.50	<.01	50
July 19	1.00	.01	100
August 2	.90	<.01	>90
August 16	.90	<.01	>90
August 30	.60	<.01	>60
September 13	.60	<.01	>60
September 26	.70	.01	70
October 11	1.00	<.01	>101
October 24	1.80	.01	180

Table 8. *Ground-water quality in vicinity of disposal area, Fowler Lake, 1984*

[mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not available]

Well no.	Date	Calcium (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Total phosphorus (mg/L)	pH (standard units)	Specific conductance (µS/cm)
1	June 20	110	--	--	<0.01	--	--
2	June 20	170	--	--	<.01	--	--
1	September 26	--	350	7.1	--	7.3	2,120
2	September 26	--	370	6.3	--	7.3	2,190

Comparison ground-water-quality data--Waukesha County (Kammerer, 1981)

Location	Calcium (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
Waukesha County			
Sand and gravel aquifers			
Range	51-111	5.0-170	16-115
Mean concentration	77	29	47
Number of wells	15	15	15

The elevated chloride concentrations from the wells might indicate that leachate from the disposal area is polluting the ground water. It also is possible that the sand used to pack the wells after drilling could have been contaminated with road deicing salt, because the sand was obtained from the Oconomowoc Maintenance Yard. However, the sand was obtained from within a clean sand storage pile to eliminate any wind-blown salt that could have settled on the surface of the pile. Furthermore, the wells were installed in May 1984, so that 4 months of ground-water flow would likely have leached the salt from the sand pack if it were indeed contaminated. Future samples could be collected to document if chloride is being transported from the disposal area.

TROPHIC STATUS

Lakes are commonly classified according to the degree of their nutrient enrichment or their trophic status. The ability of a lake to support recreational activities as well as healthy aquatic plant and fish communities is commonly correlated to the degree of nutrient enrichment that has occurred. Three terms generally are used to describe the trophic status of a lake: oligotrophic, mesotrophic, and eutrophic.

Oligotrophic lakes are nutrient-poor lakes. These lakes characteristically support relatively few aquatic plants (algal populations are low) and often do not contain productive fisheries. The deepest layers are likely to contain oxygen throughout the year. Oligotrophic lakes are clear, thus they provide excellent opportunities for swimming, boating, and water skiing. Because of the naturally fertile soils and the intensive land-use practices employed in the State, there are relatively few oligotrophic lakes in southeastern Wisconsin.

Mesotrophic lakes are moderately fertile lakes that may support abundant aquatic plant growths and productive fisheries. Nuisance growths of algae and weeds are usually not exhibited by mesotrophic lakes. Occasional oxygen depletions may occur. These lakes may provide opportunities for many types of recreational activities, including boating, swimming, fishing, and water skiing. Many lakes in southeastern Wisconsin are mesotrophic.

Eutrophic lakes are nutrient-rich lakes. These lakes commonly contain excessive aquatic weed growths or experience frequent algae blooms. Fish winterkills are common in shallow eutrophic lakes. Although these lakes may not be ideal for swimming and boating, many eutrophic lakes support very productive fisheries. During summer stratification, the dissolved-oxygen concentration in the hypolimnion often approaches zero.

The trophic status of Fowler Lake was evaluated by two methods: the Lake-Condition Index and Carlson's Trophic-State Index. A third method, the Vollenweider-Dillon model is not applicable on Fowler Lake because of the shallow mean depth and short hydraulic residence time.

Lake-Condition Rating

Uttormark and Wall (1975, p. 2) developed a lake-classification method based on four indicators of eutrophication: (1) dissolved-oxygen levels, (2) water clarity (transparency), (3) occurrence of fish winterkills, and (4) impairment of recreational use because of algae blooms or weed growth. The method, referred to as a Lake-Condition Index, was devised in which "penalty points" are assigned to lakes for undesirable symptoms of water pollution. Thus, if a lake exhibits no undesirable symptoms of eutrophication, it receives no points and has a Lake-Condition Index of zero. Conversely, a lake with all the undesirable characteristics in the most severe degree has a Lake-Condition Index of 23. Under the Uttormark-Wall classification system, Fowler Lake has a Lake-Condition Index of 8 as shown in table 9; this indicates it is a mesotrophic or moderately fertile lake.

Carlson's Trophic-State Index

The in-lake trophic condition can be evaluated by using Carlson's Trophic-State Index (TSI) (Carlson, 1977). The TSI is computed using total phosphorus and chlorophyll *a* concentrations, and Secchi-disc transparency readings for lake ice-free periods. The TSI equation for Secchi depth was developed by Carlson (1977) whereas those for chlorophyll *a* and total phosphorus were developed by the Wisconsin Department of Natural Resources (DNR) (Ronald Martin, Wisconsin Department of Natural Resources, oral commun., 1985). Carlson's TSI ranged from 0 for unproductive lakes to 100 for very productive lakes. Carlson, however, did not label ranges of his index in terms of traditional trophic-state terminology. The DNR has adopted TSI ranges to classify Wisconsin lakes: they use TSI's of less than 40 to define oligotrophy, 40 to 50 to define mesotrophy, and greater than 50 to

Table 9. *Calculated Lake-Condition Index for Fowler Lake*

[Based on method developed by Uttormark and Wall]

Lake condition	Lake-Condition Index penalty points
Dissolved-oxygen concentrations at 0.0 milligrams per liter during some periods in part of the hypolimnion	4
Average Secchi-disc reading 9 to 13 feet	1
No history of fish winterkills	0
Heavy weed growth in littoral zone	3
TOTAL	8

define eutrophy in evaluating the trophic status (Wisconsin Department of Natural Resources, 1981 and 1983). G.C. Gerloff (University of Wisconsin, written commun., 1984) also uses these ranges. These ranges are used in this report to remain consistent with other Wisconsin lake trophic-state evaluations by the DNR.

The following equations were used to calculate the TSI values for Fowler Lake:

TSI (total phosphorus) =

$$60 - 33.2 \times \log\left(\frac{40.5}{\textit{Total phosphorus concentration in micrograms per liter}}\right)$$

TSI (Secchi) =

$$60 - 33.2 \times \log\,(\textit{Secchi depth in meters})$$

A calculation of the TSI value for Fowler Lake using chlorophyll *a* data was not done because of laboratory error in the analysis of the samples.

The three trophic levels, corresponding ranges of TSI, and the ranges of total-phosphorus concentration and Secchi depth for each trophic level are shown below.

Trophic level	Trophic-State Index	Total-phosphorus concentrations (micrograms per liter)	Secchi disc (meters)
Eutrophic	greater than 50	greater than 20	less than 2.0
Mesotrophic	40-50	10-20	2.0-4.0
Oligotrophic	less than 40	less than 10	greater than 4.0

Table 10 lists the calculated TSI's for Fowler Lake. Figure 5 shows that the TSI for Fowler Lake ranged from less than 40 to a maximum of 60. Based on these TSI values, Fowler Lake would be classified as an oligotrophic to slightly mesotrophic lake.

A comparison of the Secchi-disc readings and total-phosphorus concentrations for Fowler Lake, Lac La Belle, Okauchee Lake, and Delavan Lake is presented in table 11. Data presented are for four sampling periods between spring turnover (April 11-17) and mid-August 1984. Fowler Lake generally has water clarity and nutrient levels comparable to the other two lakes in the Oconomowoc River chain and much better water quality than Delavan Lake.

The TSI calculations based on total-phosphorus concentrations are important for assessing the relative "health" of Fowler Lake. During 1950-69, about 87,456 lb of sodium arsenate were applied to Fowler Lake and the Oconomowoc River near Fowler Lake to control aquatic weeds. Much of the applied arsenic was deposited in the bottom sediments and subse-quently can be released from the sediments into the water column during anaerobic conditions. Therefore, some arsenic may have been in the water during the sampling period. Because arsenic is a positive interference in the normal phosphorus measurement technique, arsenic may have been measured as phosphorus.

Because of this potential interference, duplicate water samples were collected from near the lake bottom and analyzed by two methods. Sodium bisulfite was added to one of the samples to reduce arsenate to arsenious acid prior to the addition of the mixed ammonium molybdate-ascorbic acid-antimony potassium tartrate color reagent. The results of this custom analysis compared with the results from using the standard method showed minor differences between samples. This procedure was used during the entire study period to determine whether release of arsenate

Table 10. *Carlson's Trophic-State Index (TSI) calculations for Fowler Lake, 1984*

[--, data not available; <, less than]

Date	Sample depth (meters)	Total phosphorus (micrograms per liter)	Secchi (meters)	TSI phosphorus	TSI Secchi
January 25	1.8	20	--	50	--
February 15	2.1	<10	--	<40	--
March 14	.9	40	--	60	--
April 26	.3	<10	4.0	<40	40
May 10	.9	<10	3.7	<40	41
May 24	.9	20	3.4	50	43
June 6	.9	10	2.7	40	45
July 3	.9	<10	3.4	<40	43
July 19	.9	10	3.7	40	41
August 2	.9	<10	3.7	<40	41
August 16	.9	<10	--	<40	--
August 30	.9	<10	--	<40	--
September 13	.9	<10	3.7	<40	41
September 26	.9	10	4.3	40	39
October 11	.9	<10	--	<40	--
October 24	.9	10	4.0	40	40
November 8	1.5	<10	4.0	<40	40

Table 11. *Comparison of lake-water quality for Fowler, Lac La Belle, Okauchee, and Delavan Lakes, 1984*

[mg/L, milligrams per liter; <, less than; --, data not available]

Characteristics	Fowler Lake		Lac La Belle		Okauchee Lake		Delavan Lake[1]	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Secchi (feet)	9.8		9.8-11.5		13.8		4.9	
Total phosphorus as P (mg/L)	0.01	0.01	<0.01-0.10	0.01-0.12	0.01	<0.01	0.15-0.16	0.12-0.16
Date sampled	4/10/84		4/11/84		4/19/84		4/17/84	
Secchi (feet)	8.2		6.6		8.5		7.2-8.8	
Total phosphorus as P (mg/L)	.02	<.01	.009- .015	.019- .025	<.01	.04	.11- .23	.13- .30
Date sampled	6/20/84		6/18/84		6/20/84		6/06/84	
Secchi (feet)	9.8		5.6- 8.2		8.2		2.3-2.9	
Total phosphorus as P (mg/L)	.01	.03	.014- .018	.022- .027	.01	.09	.06	.13- .44
Date sampled	7/19/84		7/12/84		7/13/84		7/18/84	
Secchi (feet)	--		6.9- 9.5		5.9		3.6-3.9	
Total phosphorus as P (mg/L)	<.01	.02	<.001	.008- .018	.012	.078	.02- .06	.03- .76
Date sampled	8/16/84		8/20/84		8/20/84		8/15/84	

[1]Holmstrom and others, 1985, p. 222-228.

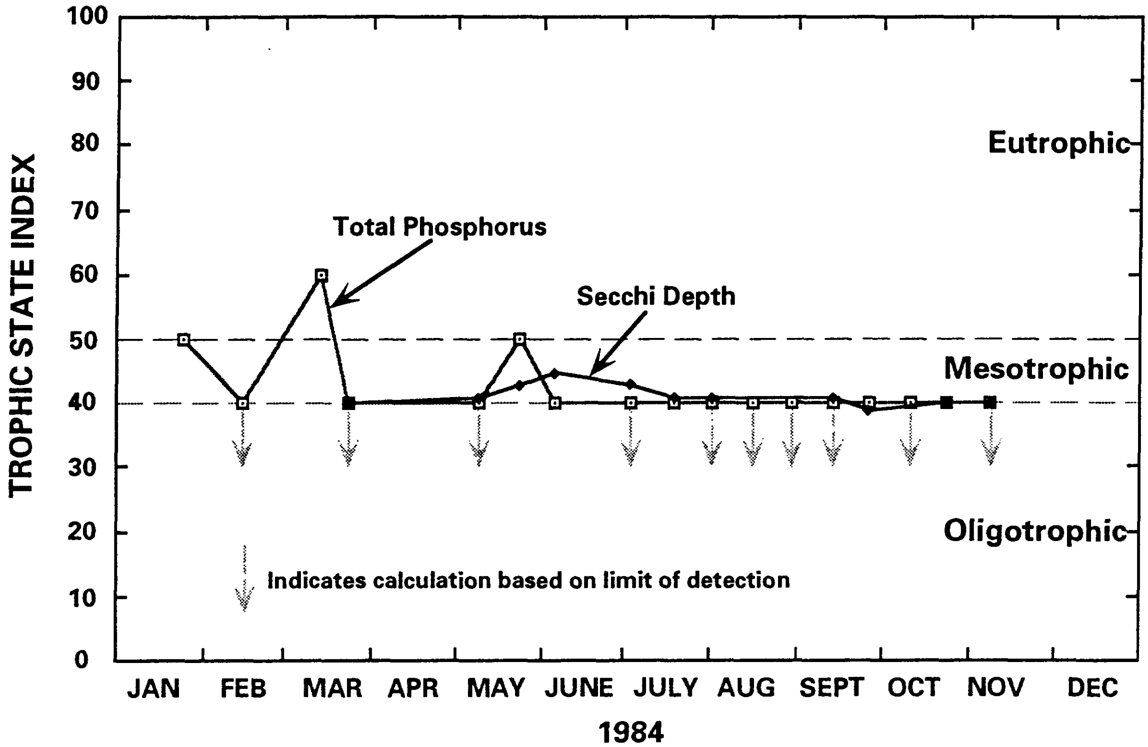


Figure 5. Fowler Lake trophic-state indices during 1984.

from the sediments during anerobic periods affected the measured phosphorus concentrations. The results of these analyses indicate that the arsenate is buried beneath the active sediments and, therefore, analyses for phosphorus can be done by standard methods.

If the results of these special analyses had indicated that the concentrations of phosphorus measured using standard methods were elevated above the actual value, a correction would need to be applied to the concentrations used in the trophic-state analyses.

Lake Sediments

Analyses of sediment cores from three locations within the lake were done to determine the level of phosphorus, iron, and manganese at increasing sediment depths. Figure 1 shows the sampling locations, and table 12 lists the concentrations at the referenced locations and data for similar analyses from Delavan Lake in Walworth County.

According to a classification of the Great Lakes Harbor Sediments (U.S. Environmental Protection Agency, 1977), phosphorus concentrations greater than 650 ppm (parts per million)[2] are indicative of being "heavily polluted." As shown in table 12, phosphorus concentrations were highest (1,500 ppm of sediment) at location L3 (fig. 1), which is near the Fowler Park shoreline. However, the concentrations decreased to less than the "heavily polluted" category within 4 in. of sediment surface. The lower levels of total phosphorus (site L1, 490 ppm) in the anoxic area of Fowler Lake (as contrasted to the high concentrations available for Delavan Lake (1,200 ppm) (Field, 1988)) may, in part, explain why the maximum total-phosphorus concentration in the hypolimnion of Fowler Lake was 0.04 mg/L, although it was 0.76 mg/L in Delavan Lake (table 10). It is also theorized that much of the total phosphorus in the sediments may be in an organic phase associated with the abundant macrophyte

[2]Parts per million is equivalent to milligrams per kilogram.

Table 12. *Lake-sediment chemical data, 1984*

Constituent	Core depth (inches)	Constituent concentration: Fowler Lake, Site L1	Site L2	Site L3	Delavan Lake[1]
Phosphorus (milligrams per kilogram)	0-4	490	410	1,500	1,200
	4-16	500	460	260	1,100
Iron (micrograms per kilogram)	0-4	8,500	6,400	8,000	4,600
	4-16	8,500	7,500	5,700	2,800
Manganese (micrograms per kilogram)	0-4	350	220	2,000	490
	4-16	180	240	180	630
Water depth (feet)		50	7.9	7.9	54

[1]Field and Duerk, 1988, p. 22.

growth present in the lake. In other lakes, such as Delavan Lake, where the phosphorus is present as inorganic phosphate, large amounts of phosphorus can be released to the water column throughout the anoxic periods. In Fowler Lake, it appears that the ongoing sedimentation and the macrophyte life cycle can bury some of the phosphorus before it can be converted to an inorganic form and released to the overlying water. The short detention time causes much of the phosphorus to be flushed out; even more can be removed by weed harvesting.

AQUATIC PLANTS

Macrophytes

Aquatic macrophytes play an important role in the ecology of southeastern Wisconsin lakes. They can be either beneficial or a nuisance, depending on their distribution and abundance. Macrophytes growing in the proper locations and in reasonable densities in lakes are an asset, because they provide habitat for other forms of aquatic life and may remove nutrients from the water that otherwise could cause algae blooms and other problems (David B. Kendziorski, Southeastern Wisconsin Regional Planning Commission, written commun., 1985). However, aquatic plants become a nuisance when they reach high densities that interfere with swimming and boating activities. Many factors, including lake configuration, depth, water clarity, nutrient availability, bottom substrate, wave action, and type of fish population present determine distribution and abundance of aquatic macrophytes in a lake.

Aquatic-Plant Survey

Methods

Aquatic-plant surveys of Fowler Lake were completed June 9-11, 1984, and August 25, 1984 (Pat Sorge and Tim Lowry, written commun., 1984). The surveys are designed to determine (1) species distribution, (2) species relative abundance, (3) species percent occurrence, (4) maximum depth of growth, and (5) type and depth of soft sediments at each sample period. The techniques used in conducting the surveys are described in Jessen and Lound (1962, p. 1-12) and Phillips (1959, p. 1-107). A grid system based on 200-ft intervals was used to determine 95 sample points (fig. 6) in the portion of the lake with a depth less than 15 ft. Each sample location on the grid system was a 6-ft diameter circle that was visually divided into four quadrants. A garden rake with an extended handle was used to sample aquatic vegetation and measure depth (depths over 15 ft were determined by sonar). Sampling involved casting the rake into each of the quadrants and pulling it toward the center of each point. Each plant species retrieved was recorded and

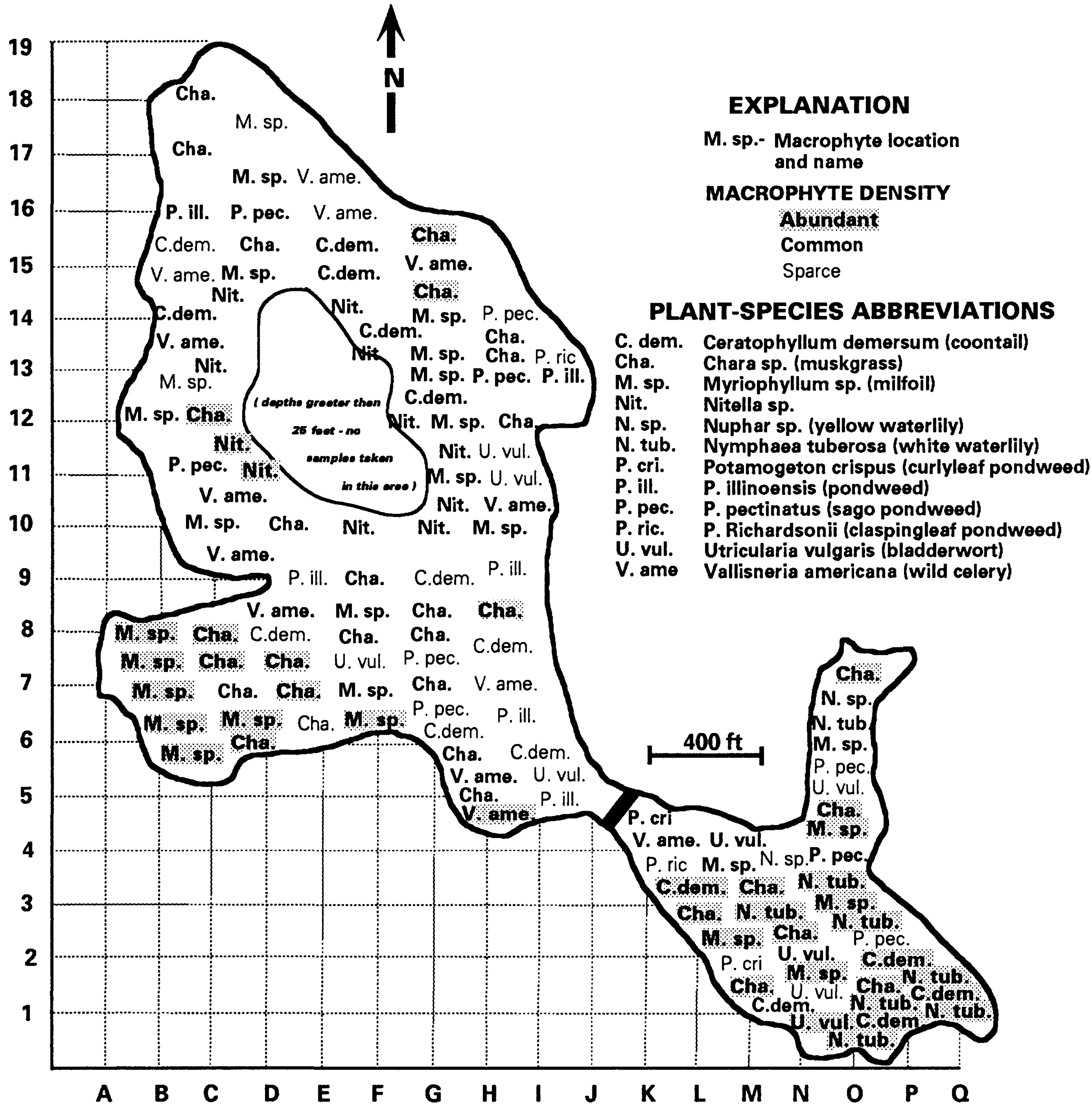


Figure 6. Aquatic macrophyte distribution and relative abundance in Fowler Lake, June 9-11, 1984.

given a density rating according to the following criteria:

Species density
Rating
1 - Present in 1 quadrant
2 - Present in 2 quadrants
3 - Present in 3 quadrants
4 - Present in 4 quadrants
5 - Very abundant in all quadrants

Water depth, depth of soft sediment, and sediment type also were recorded at each sample point. A mean density rating for each species was calculated by taking the average of the individual density ratings for each species. Percent occurrence of a species was calculated by dividing the number of sample points where a species occurred by the total number of sample points. Macrophyte-species distribution was determined using a combination of the methods of Jessen and Lound (1962) and Phillips (1959). Maximum depth of growth was determined by sampling along transects perpendicular to the contour depth lines. Sampling at depths greater than 15 ft was done with a plant-grappling hook.

The August 25 survey involved mapping macrophyte distribution and recording their relative abundance. The objective of this survey was to document major changes in the aquatic-plant population that occurred during the growing season.

An aquatic plant species list was recorded, plant specimens were collected, and voucher specimens were provided for species verification. Macrophyte identifications were conducted using the techniques of Fasset (1975), Voss (1972, p. 200-225), and Ogden (1953, p. 3-9).

Species Occurrence and Density

The results of the macrophyte surveys are given in table 13, figures 6 and 7, and appendix 4. The species list, species percent occurrence and species mean-density rating values are included in table 13. Aquatic-plant distribution and nonquantitative relative-abundance estimates are given for the June and August surveys in figures 6 and 7. Appendix 4 contains the data collected at each sample point during the June survey.

The June aquatic-plant survey indicated that macrophytes are very abundant throughout Fowler Lake at depths less than 15 ft. Aquatic plants occurred at 93 of the 95 points sampled. *Chara sp.* (muskgrass) and *Myriophyllum sp.* (milfoil) were the most frequently occurring aquatic plants; 64.2 and 50.5 percent occurrences, respectively. *Chara sp.* and *Myriophyllum sp.* also were the most abundant species, with mean density ratings of 3.77 and 2.73, respectively. These two species generally were present where water depths were less than 9 feet. The maximum depth of aquatic plant growth in Fowler Lake was 22 ft. *Nitella sp.* was consistently found at depths of 18 to 22 ft.

Aquatic-plant distribution in Fowler Lake is illustrated in figures 6 and 7. Aquatic plants were present throughout the lake except where water depths were greater than 22 ft. The most abundant aquatic plant growth occurred in the southwestern bay and in the southeastern bay above the bridge (figs. 6 and 7).

Major changes occurred in the distribution and relative abundance of aquatic plants from the first survey in June to the second survey in August. The most significant change was that *Najas marina* was found at only 2 percent of the sample points in June, but in August it was abundant and widely distributed over the main section of the lake. *Vallisneria americana* (wild celery) became more abundant in August, but its areal distribution did not increase. *Myriophyllum sp.* abundance appeared to have decreased, but its areal distribution may have increased slightly. *Chara sp.* abundance increased, and its areal distribution remained constant between the June and August surveys. The results of the sediment survey and the sample-point data are given in appendix 4.

SUMMARY

The U.S. Geological Survey, in cooperation with the Fowler Lake Management District, conducted a study to characterize the hydrology and water quality of Fowler Lake in southeastern Wisconsin during 1984. Fowler Lake is located entirely within the corporate limits of the city of Oconomowoc and is one of a number of lakes within the Oconomowoc River chain of lakes. Concern that both urban and rural nonpoint-source pollution may degrade the quality of the lake prompted the study.

Fowler Lake can be classified as a mildly fertile lake that has excellent water clarity as shown by Secchi-depth observations which consistently exceeded 9 ft. Although phosphorus concentrations are typically less than 0.01 mg/L, the lake does produce dense stands of macrophytes where the water depth is less than 25 ft. The lake undergoes thermal stratification in

Table 13. *Summary of the aquatic-plant survey conducted during June 9-11, 1984*

Species	Percent of sampling points where species was found	Mean species density rating[2]
Chara sp. (muskgrass)	64.2	3.77
Myriophyllum sp. (milfoil)	50.5	2.73
Ceratophyllum demersum (coontail)	34.7	2.36
Vallisneria americana (wild celery)	24.2	1.91
Potamogeton pectinatus (sago pondweed)	20.0	1.37
P. illinoensis (pondweed)	14.7	2.36
Nymphaea tuberosa (white water lily)	13.7	2.61
Utricularia vulgaris (bladderwort)	11.6	1.45
Nitella sp.	6.3	2.50
P. crispus (curly-leaf pondweed)	5.2	1.80
P. Richardsonni (clasping-leaf pondweed)	4.2	1.00
Nuphar sp. (yellow water lily)	3.2	2.66
Najas marina	2.0	1.00
N. fexilis[1] (bushy pondweed)		
Ranunculus sp.[1] (buttercup)		

[1]Species found during the surveys but did not occur at any sample points.
[2]Species-density rating is in dimensionless units ranging from 1 (lowest density) to 5 (highest density).

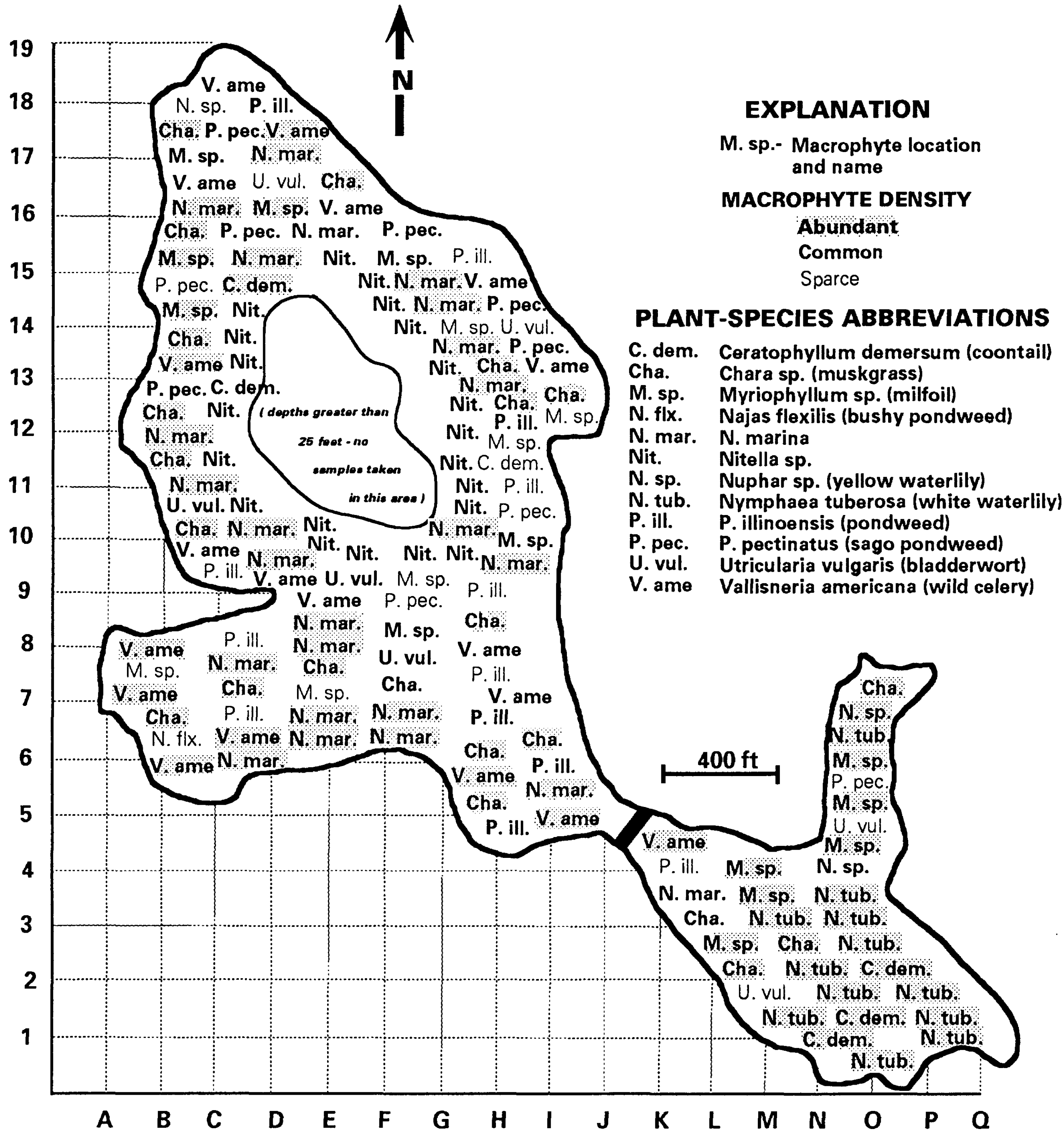


Figure 7. Aquatic macrophyte distribution and relative abundance in Fowler Lake, August 25, 1984.

the summer, resulting in dissolved-oxygen depletion in the deepest parts of the lake. The overall water quality of the lake is equal to or better than that of the other lakes on the Oconomowoc River chain.

The data-collection program was from January through November 1984. Precipitation for the 1984 calendar year was 38.50 in., which is about 8.36 in., or 28 percent, above the long-term (1951-80) average. Streamflows during the study were also high, as reflected by flow at the long-term gaging station on the Rock River at Afton, which was 56 percent above average. Records from the Oconomowoc River gaging station, 2.0 mi upstream from the lake, show that the river contributed 98 percent of the inflow to the lake during 1984. The mean daily inflow to the lake was 151 acre-ft and produced a hydraulic residence time for the lake of 6.9 days.

Water samples were collected monthly from the lake and the Oconomowoc River at the gaging station from January through March and bimonthly from April 10 through November. Profiles of the temperature, pH, specific conductance, and concentrations of dissolved oxygen, total and dissolved phosphorus, and nitrogen species were obtained at these times.

Dissolved-oxygen concentrations in the lake's hypolimnion were low during summer thermal stratification. The minimum oxygen concentration was reached on September 19 when 0.0 mg/L was recorded for depths greater than 25 ft. However, sufficient oxygen existed at shallower depths so that fish could migrate upward and escape from the low dissolved-oxygen zone. Only about 15 percent of the area of the lake has depths greater than 25 ft.

Phosphorus is the principal nutrient of concern in Fowler Lake for supporting algae populations. During spring turnover, the lake had a phosphorus concentration in the water column during spring turnover of 0.01 mg/L, which is less than the 0.02 mg/L concentration considered necessary for the occurrence of nuisance algal conditions. The Oconomowoc River contributed 88 percent of the 2,600 lb of phosphorus load into the lake during 1984. The contribution from urban runoff was 10 percent, or 280 lb. The Oconomowoc River outflow also exported 77 percent, or 2,000 lb, of phosphorus from Fowler Lake. A mass balance indicates that 600 lb of phosphorus either is consumed by macrophytes or deposited within the lake sediments. Weed harvesting during 1984 removed an estimated 50 lb of phosphorus. Because water-quality loads generally increase with greater amounts of runoff, the loads computed for the 1984 study period may be slightly higher than the long-term average annual load.

The water quality of Fowler Lake is a direct reflection of the quality of the Oconomowoc River. The lake is oligotrophic to slightly mesotrophic and will respond to improvements or degradation in the quality of the inflow from the river. The maximum dissolved orthophosphate phosphorus concentration measured during the anoxic period was 0.06 mg/L, indicating that the phosphorus load generated from internal recycling is low. The large macrophyte population may benefit the lake by limiting the amount of phosphorus available for algal growth.

Abundant macrophyte growth was observed throughout the lake where depths were less than 15 ft. In a June survey, aquatic plants occurred at 93 of the 95 sampled points. *Chara sp.* (muskgrass) and *Myriophyllum sp.* (milfoil) were the most frequently occurring and had occurrences of 64.2 and 50.5 percent, respectively.

In an August survey, *Najas marina* became very abundant, whereas during June it was found at only 2 percent of the sampling points. Abundant macrophyte growth may prevent the occurrence of algae blooms that would create unsightly and odorous nuisances, and increase the levels of phosphorus in the water column during their decomposition.

The data in this study present a baseline to which future data can be compared. A limited continuing water-quality monitoring program would provide data to evaluate management programs that could be implemented in the Oconomowoc River watershed.

REFERENCES CITED

Allum, M.O., Gessner, R.E., and Gokstatter, J.H., 1977, An evaluation of the national eutrophic data: U.S. Environmental Protection Agency, Working Paper No. 900, 223 p.

Burton, T.M., King, D.L., and Ervin, J.L., 1978, Aquatic plant harvesting as a lake restoration technique: U.S. Environmental Protection Agency, Lake Restoration National Conference, EPA 440/5-79-001, p. 177-185.

Carlson, R.E., 1977, A trophic state index for lakes: Limnology and Oceanography, v. 22, no. 2, p. 361-369.

Fassett, N.C., 1975, A manual of aquatic plants: Madison, Wis., University of Wisconsin Press, 405 p.

Field, S.J., and Duerk, M.D., 1988, Hydrology and water quality of Delavan Lake in southeastern Wisconsin: U.S. Geological Survey Water-Resources Investigations Report 87-4168, 61 p.

Holmstrom, B.K., Kammerer, P.A., Jr., and Erickson, R.M., 1985, Water-resources data--Wisconsin, water year 1984: U.S. Geological Survey Water-Data Report WI-84-1, 373 p.

Jessen, Robert, and Lound, Richard, 1962, An evaluation of a survey technique for submerged aquatic plants: Minnesota Department of Conservation, Game Investigational Report No. 6, 12 p.

Kammerer, P.A., Jr., 1981, Ground-water-quality atlas of Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 39, 39 p.

Mace, S.E., Sorge, P., and Lowry, T., 1984, Impacts of phosphorus on streams: Wisconsin Department of Natural Resources, 89 p.

National Oceanic and Atmospheric Administration, 1984, Climatological data annual summary for Wisconsin: Asheville, N.C., National Climatic Center, v. 89, no. 13, 36 p.

Ogden, E.C., 1953, Key to the North American species of *Potamogeton*: New York State Museum Circular, p. 3-9.

Phillips, E.A., 1959, Methods of vegetation study: New York, Henry Holt and Company, 107 p.

Poff, R.J., and Threinen, C.W., 1963, Surface water resources of Waukesha County: Madison, Wis., Wisconsin Conservation Department, 67 p.

Southeastern Wisconsin Regional Planning Commission, 1980, A water quality management plan for Lac La Belle, Waukesha County, Wisconsin: Southeastern Wisconsin Regional Planning Commission, 126 p.

U.S. Environmental Protection Agency, 1977, Guidelines for the pollutional classification of Great Lakes harbor sediments: Environmental Protection Agency, Region V, 73 p.

Uttormark, P.D., and Wall, J.P., 1975, Lake classification--a trophic characterization of Wisconsin lakes: Environmental Protection Agency Report No. EPA-660/3-75-033, 26 p.

Voss, E.G., 1972, Michigan flora: Bloomfield Hills, Mich., Cranbrook Institute of Science, 488 p.

Wisconsin Conservation Department, 1955, Lake survey map of Fowler Lake in Waukesha County.

Wisconsin Department of Natural Resources, 1983, Evaluation of urban nonpoint source pollution management in Milwaukee County, Wisconsin: v. 1, p. V-45-57.

(PAGE 31 FOLLOWS)

APPENDIXES 1 - 4

(PAGE 33 FOLLOWS)

Appendix 1. *Physical and chemical water-quality data for Fowler Lake (fig. 1.), 1984*

[mg/L, milligrams per liter; °F, degrees Fahrenheit; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not available; <, less than]

Date	Depth (feet)	Gage height (feet)	Total nitrogen as N (mg/L)	Dissolved phosphorus as P (mg/L)	Total phosphorus as P (mg/L)	Dissolved oxygen (mg/L)	Water temperature (°F)	pH (units)	Specific conductance (µS/cm)
Jan. 25	6	8.82	--	0.05	0.02	9.7	37.0	8.3	482
Jan. 25	51	8.82	--	.04	.04	.4	38.5	7.9	495
Feb. 15	7	8.98	--	<.01	<.01	9.9	37.0	8.1	533
Feb. 15	48	8.98	--	<.01	<.01	.8	38.5	7.9	540
Feb. 22	4	9.17	--	--	--	12.3	36.5	8.8	--
Feb. 22	50	9.17	--	--	--	1.0	39.0	8.1	--
Mar. 14	3	8.96	--	.02	.04	12.8	37.0	8.5	510
Mar. 14	25	8.96	--	<.01	<.01	8.8	38.0	8.1	523
Mar. 14	49	8.96	--	.02	.02	.1	38.5	7.5	595
Apr. 10	1	8.74	0.54	<.01	.01	11.5	43.5	8.5	504
Apr. 10	48	8.74	.90	<.01	.01	10.5	42.5	8.4	510
Apr. 26	1	9.13	.87	<.01	<.01	12.3	48.0	8.6	520
Apr. 26	16	9.13	.76	<.01	<.01	12.7	45.0	8.6	503
Apr. 26	48	9.13	.80	<.01	<.01	12.2	41.5	8.6	495
May 10	3	9.15	2.70	<.01	<.01	11.5	52.0	8.6	495
May 10	30	9.15	1.90	<.01	<.01	10.8	48.5	8.5	491
May 10	48	9.15	1.70	<.01	<.01	7.0	46.0	8.2	493
May 24	3	8.68	1.08	.01	.02	9.2	66.5	8.5	487
May 24	20	8.68	.71	<.01	.02	11.1	52.0	8.4	496
May 24	47	8.68	.45	<.01	.01	5.4	46.0	8.0	500
June 6	3	9.10	1.06	.01	.01	9.5	72.0	8.7	518
June 6	15	9.10	1.67	<.01	.01	11.5	56.5	8.6	494
June 6	47	9.10	1.19	<.01	.01	1.8	45.5	8.0	516
June 20	3	9.16	1.00	<.01	.02	7.2	74.0	8.2	507
June 20	20	9.16	1.30	<.01	<.01	10.4	53.0	8.4	535
June 20	46	9.16	1.50	<.01	<.01	.8	45.5	7.9	530
July 3	3	9.24	.50	<.01	<.01	7.7	76.5	8.4	500
July 3	20	9.24	.90	<.01	.01	9.1	54.0	8.4	557
July 3	47	9.24	2.20	<.01	.04	.3	45.5	7.7	526
July 19	3	9.26	1.00	<.01	.01	12.7	74.0	8.3	468
July 19	22	9.26	1.10	<.01	.01	8.7	53.0	8.1	509
July 19	47	9.26	1.70	<.01	.03	--	45.5	7.7	506
Aug. 2	3	8.85	.90	<.01	<.01	9.6	78.0	8.6	478
Aug. 2	18	8.85	.80	<.01	<.01	8.7	61.0	8.2	512
Aug. 2	47	8.85	1.80	.02	.03	--	45.0	7.6	511
Aug. 16	3	8.76	.90	<.01	<.01	11.6	81.0	8.5	472
Aug. 16	24	8.76	.80	<.01	<.01	6.6	53.5	8.0	549
Aug. 16	49	8.76	1.70	.02	.02	.2	45.5	7.3	551
Aug. 30	3	8.82	.60	<.01	<.01	10.7	77.5	8.6	446
Aug. 30	20	8.82	.60	<.01	.02	8.8	61.5	8.2	508

Appendix 1. *Physical and chemical water-quality data for Fowler Lake (fig. 1.), 1984*--Continued

Date	Depth (feet)	Gage height (feet)	Total nitrogen as N (mg/L)	Dissolved phosphorus as P (mg/L)	Total phosphorus as P (mg/L)	Dissolved oxygen (mg/L)	Water temper-ature (°F)	pH (units)	Specific conductance (µS/cm)
Aug. 30	47	8.82	2.00	<.01	.02	--	47.0	7.6	511
Sept. 13	3	8.76	.60	.01	<.01	8.0	70.5	8.8	477
Sept. 13	20	8.76	.70	<.01	<.01	6.4	63.5	8.3	502
Sept. 13	47	8.76	2.30	.06	.05	.1	45.5	7.5	538
Sept. 26	3	8.86	.70	.02	.01	9.6	63.5	9.0	478
Sept. 26	25	8.86	.50	<.01	.06	2.2	55.5	7.9	525
Sept. 26	47	8.86	1.60	<.01	.04	1.5	45.0	7.5	550
Oct. 11	3	8.87	1.00	<.01	<.01	10.2	61.0	9.1	489
Oct. 11	30	8.87	.90	<.01	<.01	2.6	51.0	7.9	540
Oct. 11	47	8.87	1.50	.06	.05	1.7	45.0	7.4	551
Oct. 24	3	9.08	1.80	--	.01	10.2	55.0	8.7	441
Oct. 24	36	9.08	.90	<.01	<.01	3.6	49.0	7.8	474
Oct. 24	46	9.08	2.30	.02	.04	--	45.5	7.3	496
Nov. 8	5	9.26	--	<.01	<.01	10.2	44.5	8.2	474
Nov. 8	25	9.26	--	<.01	.02	10.1	44.5	8.2	477
Nov. 8	48	9.26	.90	.02	<.01	10.1	44.5	8.2	477

Appendix 2. *Physical and chemical water-quality data for Oconomowoc River near the city of Oconomowoc (fig. 1), 1984*

[mg/L, milligrams per liter; °F, degrees Fahrenheit; µS/cm, microsiemens per centimeter at 25 degrees Celsius; --, data not available; <, less than]

Date	Depth (feet)	Gage height (feet)	Total nitrogen as N (mg/L)	Dissolved phosphorus as P (mg/L)	Total phosphorus as P (mg/L)	Dissolved oxygen (mg/L)	Water temper-ature (°F)	pH (units)	Specific conductance (µS/cm)
Jan. 25	--	--	--	<0.01	0.01	--	32.0	8.3	--
Feb. 15	--	1.97	--	<.01	.02	13.0	36.0	8.5	500
Mar. 14	2	--	--	.05	<.01	13.3	38.0	9.1	511
Apr. 10	2	1.08	0.70	.03	.01	12.5	49.0	8.8	507
Apr. 26	2	2.35	.70	<.01	<.01	12.0	46.5	8.5	500
May 10	3	2.44	4.50	<.01	<.01	11.7	50.0	8.8	496
May 24	3	1.23	2.00	<.01	<.01	10.8	62.0	8.7	510
June 6	3	2.62	.80	<.01	.02	9.9	70.0	8.7	508
June 20	3	3.20	1.10	.02	<.01	8.4	74.0	8.7	502
July 3	3	3.35	1.10	.03	<.01	8.6	75.0	8.8	498
July 19	3	3.72	1.10	<.01	<.01	9.9	76.0	8.6	460
Aug. 2	3	2.44	.80	.01	<.01	9.1	77.0	8.7	462
Aug. 16	--	1.97	--	--	<.01	11.2	80.5	8.5	478
Aug. 30	3	2.26	--	--	<.01	9.4	75.5	8.6	468
Sept. 13	2	1.90	.70	.01	<.01	7.3	71.0	8.7	491
Sept. 26	3	2.16	.70	<.01	.01	12.1	65.0	9.2	498
Oct. 6	--	2.05	1.00	--	<.01	--	--	--	--
Oct. 11	3	2.06	1.00	<.01	<.01	11.8	60.5	8.3	508
Oct. 24	3	--	.80	--	.01	10.2	55.0	8.7	441
Nov. 8	3	3.24	1.20	<.01	<.01	10.8	47.5	8.8	467

Appendix 3. *Suspended-sediment concentrations for Oconomowoc River near the city of Oconomowoc (fig. 1), 1984*

Date	Suspended sediment (concentrations in milligrams per liter)	Date	Suspended sediment (concentrations in milligrams per liter)
Apr. 24	5	June 17	23
Apr. 26	23	June 20	24
Apr. 27	98	June 22	45
Apr. 28	4	June 25	25
Apr. 29	17	June 27	16
Apr. 30	0	June 30	34
May 2	25	July 3	29
May 3	9	July 7	26
May 5	3	July 10	32
May 7	3	July 13	8
May 9	3	July 17	7
May 10	21	July 19	7
May 11	13	July 20	12
May 12	7	July 24	15
May 14	7	July 27	15
May 16	21	July 30	10
May 18	10	Aug. 2	12
May 19	16	Aug. 7	3
May 21	49	Aug. 11	2
May 23	11	Aug. 14	2
May 24	17	Aug. 16	10
May 25	25	Aug. 17	3
May 28	28	Aug. 24	1
May 29	29	Aug. 28	2
May 30	13	Aug. 30	1
June 1	15	Sept. 1	4
June 6	12	Sept. 4	2
June 7	7		
June 9	37		
June 13	16		

Appendix 4. *Aquatic-plant and sediment-survey data for Fowler Lake, June 9-11, 1984*

[--, data not available; footnotes at end of table;
sampling points shown in figure 6]

Coordinates of sample location (fig. 7)	Macrophyte species[1]	Species density rating[2]	Water depth (feet)	Depth of soft-sediment (feet)[3]	Sediment type
(B, 18)	Cha.	2	2.5	0.0	Rubble
(C, 18)	Cha.	5	6.0	1.0	Muck/rubble
(D, 18)	Cha.	4	6.0	1.0	Muck/rubble
(B, 17)	Cha.	3	7.5	.5	Muck/sand
	N. mar.	1			
	M. sp.	1			
	V. ame.	1			
(C, 17)	Cha.	4	6.5	1.5	Muck
	P. pec.	2			
(D, 17)	Cha.	4	6.0	.5	Muck/rubble
	M. sp.	1			
(E, 17)	Cha.	4	6.5	1.0	Muck/rubble
	V. ame.	2			
(B, 16)	P. ill.	4	5.0	.0	Gravel
(C, 16)	P. pec.	4	6.5	1.0	Muck/sand
	Cha.	2			
	N. mar.	1			
	P. ill.	1			
(D, 16)	Cha.	5	7.0	1.5	Muck/sand
	V. ame.	2			
	P. pec.	1			
(E, 16)	M. sp.	5	8.5	2.0	Muck/sand
	V. ame.	1			
	C. dem.	1			
(F, 16)	M. sp.	5	8.0	4.0	Muck/sand
	V. ame.	2			
	U. vul.	1			
(G, 16)	Cha.	4	5.0	2.5	Muck/clay
	V. ame.	3			
	P. ill.	2			

Appendix 4. *Aquatic-plant and sediment-survey data for Fowler Lake, June 9-11, 1984*--Continued

Coordinates of sample location (fig. 7)	Macrophyte species[1]	Species density rating[2]	Water depth (feet)	Depth of soft-sediment (feet)[3]	Sediment type
(B, 15)	M. sp.	5	10.0	5.0	Muck/sand
	V. ame.	2			
(C, 15)	M. sp.	3	15.0	--	Muck
	Nit.	2			
	C. dem.	3			
(F, 15)	C. dem.	4	12.0	[3]4.0	Muck
	M. sp.	1			
(G, 15)	Cha.	5	6.5	3.0	Muck/sand
(H, 15)	Cha.	5	6.5	3.0	Muck/sand
(B, 14)	C. dem.	4	12.0	[3]4.0	Muck
	M. sp.	3			
	Nit.	3			
(F, 14)	Nit.	4	15.0	[3]1.0	Muck
	M. sp.	1			
(G, 14)	M. sp.	4	9.0	[3]7.0	Muck
	C. dem.	3			
(H, 14)	Cha.	5	6.0	.0	Rubble
	P. ill.	3			
(I, 14)	Cha.	5	5.0	1.0	Muck/sand
(B, 13)	C. dem.	2	9.5	3.0	Muck/sand
	Cha.	2			
	V. ame.	1			
	M. sp.	1			
(G, 13)	M. sp.	4	11.5	[3]5.0	Muck
	C. dem.	3			
(H, 13)	M. sp.	4	9.0	5.0	Muck/sand
	C. dem.	2			
	P. pec.	2			
(I, 13)	V. ame.	4	5.5	2.0	Muck/sand
	Cha.	2			
	M. sp.	1			
	P. ric.	1			

Appendix 4. *Aquatic-plant and sediment-survey data for Fowler Lake, June 9-11, 1984*--Continued

Coordinates of sample location (fig. 7)	Macrophyte species[1]	Species density rating[2]	Water depth (feet)	Depth of soft-sediment (feet)[3]	Sediment type
(B, 12)	Cha.	4	7.0	2.0	Muck/gravel
(G, 12)	M. sp.	4	10.0	[3]6.0	Muck
	C. dem.	1			
(H, 12)	U. vul.	2	9.0	[3]6.0	Muck
	Cha.	1			
	C. dem.	1			
(I, 12)	None		2.5	.0	Gravel
(B, 11)	V. ame.	4	6.0	3.0	Muck/sand
	P. pec.	2			
	Cha.	2			
(C, 11)	M. sp.	3	11.0	[3]5.0	Muck
	Nit.	1			
	C. dem.	1			
	Cha.	1			
(H, 11)	M. sp.	4	10.0	[3]6.0	Muck
	P. pec.	1			
(I, 11)	None	--	3.0	--	Rubble
(B, 10)	M. sp.	1	3.0	4.0	Muck/gravel
	C. dem.	1			
	Cha.	1			
	P. ric.	1			
	P. pec.	1			
(C, 10)	Cha.	5	7.0	4.0	Muck/sand
(D, 10)	Nit.	3	13.5	[3]4.0	Muck
	M. sp.	2			
	C. dem	2			
(G, 10)	Nit.	2	15.0	[3]1.0	Muck
	M. sp.	1			
(H, 10)	M. sp.	5	9.5	[3]6.0	Muck

Appendix 4. *Aquatic-plant and sediment-survey data for Fowler Lake, June 9-11, 1984*--Continued

Coordinates of sample location (fig. 7)	Macrophyte species[1]	Species density rating[2]	Water depth (feet)	Depth of soft-sediment (feet)[3]	Sediment type
(I, 10)	M. sp.	2	7.0	4.0	Muck/clay
	Cha.	2			
	P. pec.	1			
	U. vul.	1			
	V. ame.	1			
(D, 9)	P. ill.	4	3.0	.0	Gravel
	Cha.	2			
	V. ame.	1			
(E, 9)	Cha.	3	8.0	3.0	Muck/clay
	V. ame.	2			
	M. sp.	1			
(F, 9)	Cha.	4	8.0	3.0	Muck/clay
	C. dem.	1			
	M. sp.	1			
(G, 9)	Cha.	2	6.0	6.0	Muck/clay
	P. pec.	2			
	C. dem.	1			
(H, 9)	Cha.	4	7.0	5.0	Muck/clay
	P. ill.	1			
(I, 9)	Cha.	5	4.5	3.0	Muck/clay
	V. ame.	2			
(A, 8)	M. sp.	5	5.0	4.0	Muck/clay
	C. dem.	1			
(B, 8)	M. sp.	5	6.0	3.0	Muck/clay
(C, 8)	Cha.	5	7.0	5.0	Muck/clay
(D, 8)	Cha.	5	7.0	2.0	Muck/clay
(E, 8)	M. sp.	1	8.0	3.5	Muck/clay
	C. dem.	1			
	P. pec.	1			
(F, 8)	Cha.	3	7.0	4.0	Muck/clay
	M. sp.	2			
	U. vul.	1			

Appendix 4. *Aquatic-plant and sediment-survey data for Fowler Lake, June 9-11, 1984*--Continued

Coordinates of sample location (fig. 7)	Macrophyte species[1]	Species density rating[2]	Water depth (feet)	Depth of soft-sediment (feet)[3]	Sediment type
(G, 8)	Cha.	2	7.0	5.5	Muck/clay
	M. sp.	1			
	C. dem.	1			
	P. pec.	1			
	V. ame.	1			
(H, 8)	C. dem.	2	7.0	2.5	Muck/clay
	P. pec.	1			
	V. ame.	1			
(I, 8)	Cha.	5	5.0	1.5	Muck/rubble
(A, 7)	M. sp.	5	4.0	1.0	Muck/rubble
(B, 7)	M. sp.	5	6.0	3.0	Muck/clay
	Cha.	1			
(C, 7)	Cha.	4	7.0	3.0	Muck/clay
	M. sp.	1			
(D, 7)	P. ill.	1	5.0	.0	Sand/gravel
	Cha.	1			
(E, 7)	Cha.	5	5.5	2.0	Muck/clay
(F, 7)	M. sp.	4	8.0	4.0	Muck/clay
	C. dem.	3			
(G, 7)	C. dem.	2	7.0	2.5	Muck/clay
	Cha.	2			
	P. pec.	1			
	U. vul.	1			
(H, 7)	Cha.	2	7.5	2.0	Muck/clay
(I, 7)	P. ill.	3	7.0	1.5	Muck/clay
	M. sp.	2			
	C. dem.	1			
	P. pec.	1			
(O, 7)	Cha.	5	2.0	1.5	Muck/sand
	N. tub.	2			
(B, 6)	M. sp.	5	5.5	3.0	Muck/sand
	P. ric.	1			

Appendix 4. *Aquatic-plant and sediment-survey data for Fowler Lake, June 9-11, 1984*--Continued

Coordinates of sample location (fig. 7)	Macrophyte species[1]	Species density rating[2]	Water depth (feet)	Depth of soft-sediment (feet)[3]	Sediment type
(C, 6)	P. ill.	5	5.0	1.0	Muck/rubble
	Cha.	1			
	M. sp.	1			
(D, 6)	Cha.	5	5.5	2.5	Muck/clay
	M. sp.	2			
	V. ame.	1			
(G, 6)	V. ame.	3	5.0	2.5	Muck/clay
(H, 6)	Cha.	5	5.5	3.0	Muck/clay
	V. ame.	1			
(I, 6)	C. dem.	3	5.5	2.0	Muck/clay
	Cha.	2			
	U. vul.	2			
	P. ill.	1			
	V. ame.	1			
(O, 6)	Cha.	5	2.0	2.0	Muck/sand
	N. tub.	3			
	N. sp.	1			
(H, 5)	Cha.	5	4.0	2.0	Muck/clay
	P. ill.	1			
(I, 5)	V. ame.	3	4.5	2.0	Muck/clay
	Cha.	3			
	P. ill.	2			
(J, 5)	V. ame.	4	5.0	2.0	Muck/clay
	Cha.	2			
	P. ill.	2			
	M. sp.	1			
(K, 5)	P. cri.	4	4.0	2.5	Muck/clay
	M. sp.	2			
	V. ame.	1			
	U. vul.	1			
	P. ric.	1			
	C. dem.	1			
(O, 5)	Cha.	5	3.0	4.0	Muck/sand

Appendix 4. *Aquatic-plant and sediment-survey data for Fowler Lake, June 9-11, 1984*--Continued

Coordinates of sample location (fig. 7)	Macrophyte species[1]	Species density rating[2]	Water depth (feet)	Depth of soft-sediment (feet)[3]	Sediment type
(K, 4)	M. sp.	3	5.5	1.0	Muck/sand
	C. dem.	3			
	P. cri.	2			
(L, 4)	Cha.	3	4.0	3.0	Muck/sand
	P. ill.	3			
	U. vul.	2			
	P. cri.	1			
	P. pec.	1			
	C. dem.	1			
(M, 4)	Cha.	5	2.0	4.0	Muck/sand
	N. tub.	2			
	U. vul.	1			
(N, 4)	Cha.	5	2.0	2.0	Muck/sand
	M. sp.	4			
	N. sp.	4			
(O, 4)	Cha.	5	2.0	3.5	Muck/clay
	N. tub.	4			
	P. pec.	1			
	M. sp.	1			
(L, 3)	M. sp.	4	4.0	3.0	Muck/clay
	N. tub.	1			
	C. dem.	2			
	P. cri.	1			
(M, 3)	Cha.	5	3.0	2.5	Muck/clay
	N. tub.	1			
(N, 3)	N. tub.	4	2.5	3.5	Muck/clay
	M. sp.	1			
(O, 3)	N. tub.	4	2.5	2.0	Muck/clay
	M. sp.	3			
	C. dem.	2			
	N. sp.	2			
	Cha.	2			
	P. pec.	1			
(M, 2)	Cha.	5	3.5	2.5	Muck/clay
	M. sp.	4			

Appendix 4. *Aquatic-plant and sediment-survey data for Fowler Lake, June 9-11, 1984*--Continued

Coordinates of sample location (fig. 7)	Macrophyte species[1]	Species density rating[2]	Water depth (feet)	Depth of soft-sediment (feet)[3]	Sediment type
(N, 2)	Cha.	2	3.0	3.5	Muck/clay
	M. sp.	2			
	U. vul.	2			
(O, 2)	M. sp.	4	3.5	2.5	Muck/clay
	N. sp.	2			
	C. dem.	1			
	Cha.	1			
	P. pec.	1			
(P, 2)	C. dem.	5	3.5	2.5	Muck/clay
	N. tub.	2			
(N, 1)	C. dem.	5	2.0	4.0	Muck/clay
	N. tub.	3			
	U. vul.	2			
(O, 1)	C. dem.	5	3.5	2.5	Muck/clay
	N. tub.	2			
	P. pec.	1			
(P, 1)	C. dem.	5	3.5	3.0	Muck/clay
	N. tub.	1			
(Q, 1)	C. dem.	5	2.5	2.5	Muck/clay
	N. tub.	5			
	P. cri.	1			

[1]Plant-Species Abbreviations:

C. dem. *Ceratophyllum demersum* (coontail)
Cha. *Chara sp.* (muskgrass)
M. sp. *Myriophyllum sp.* (milfoil)
N. flx. *Najas flexilis* (bushy pondweed)
N. mar. *N. marina*
Nit. *Nitella sp.*
N. sp. *Nuphar sp.* (yellow waterlily)
N. tub. *Nymphaea tuberosa* (white waterlily)
P. cri. *Potamogeton crispus* (curlyleaf pondweed)
P. ill. *P. illinoensis* (pondweed)
P. pec. *P. pectinatus* (sago pondweed)
P. ric. *P. Richardsonii* (claspingleaf pondweed)
Ran. *Ranunculus sp.* (buttercup)
U. vul. *Utricularia vulgaris* (bladderwort)
V. ame *Vallisneria americana* (wild celery)

[2]Species density rating is in dimensionless units ranging from 1 (lowest density) to 5 (highest density).
[3]Maximum soft-sediment depth able to be measured due to the use of a 16-foot probe.

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