Hydrology, Water Quality, and Phosphorus Loading of Kirby Lake, Barron County, Wisconsin

Introduction

In 1992, residents near Kirby Lake, located about five miles northwest of Cumberland, in Barron County, Wisconsin, formed the Kirby Lake Management District. The Lake District immediately began to gather information needed for the preparation of a comprehensive lake-management plan that would be used to protect the natural and recreational assets of the lake. The Lake District completed a land-use inventory of the watershed and an evaluation of available lake water-quality data. The land-use data were used to assess the potential contribution of nutrients to the lake from the watershed. The evaluation of lake water-quality data, which were collected as part of the Wisconsin Department of Natural Resources (WDNR) Self-Help Monitoring Program, indicated the lake has relatively good water quality. Before a comprehensive lake-management plan could be prepared, however, a better understanding of several aspects of the lake and its surroundings was needed. To address those aspects—including the definition of the lake's hydrology and the principal sources of nutrients, and the relation of the lake's water quality to nutrient loading—the U.S. Geological Survey, in cooperation with the Lake District and the WDNR (through a Lake Management Planning Grant), conducted a study of Kirby Lake and its watershed. This Fact Sheet presents the results of that study.

The Lake and its Watershed

Kirby Lake has a surface area of 92 acres, a maximum depth of 19 feet, and an average depth of 8 feet (Wisconsin Department of Natural Resources, 1995). The area and depth of the lake vary, however, with changes in lake stage, which in turn depends on inflow and outflow of water. Water enters Kirby lake from precipitation, numerous small, intermittently flowing tributaries, and ground-water inflow. The lake's outlet stream flows only intermittently, and water is lost primarily through outflow to ground water or through evaporation.

The watershed of Kirby Lake (fig. 1) has a total area of 1,070 acres, although part of this area is made up of depressions that do not normally drain to the lake. Some of these depressions overflow after prolonged periods of above-normal precipitation and drain to Kirby Lake. About 60 percent of the watershed is forested; the remainder consists of wetlands, small lakes, agricultural land, residential development, and roads.

An aeration system was installed in the lake in 1989. The system is operated during winter to keep a small part (less than one acre) of the lake free of ice, which prevents oxygen depletion and the resulting fish kills.

Data Collection

Data used to describe the lake's hydrology, water quality, and sources of phosphorus were collected during the period from November 1, 1995 to November 6, 1996. Lake water-quality properties were measured eight times at as many as six sites in the lake (fig. 2). At all sites, depth profiles of water temperature, dissolved oxygen, specific conductance, and pH were measured. Water samples were collected at these sites at either or both near-surface (1.5 ft below surface during open water or just below ice during ice cover) or near-bottom (1.5 ft above bottom) depths. Near-surface water samples from the deepest part of the lake (Site 1 in fig. 2) were analyzed for concentrations of total phosphorus (an indicator of nutrient availability) and chlorophyll *a* (an indicator of algal population),

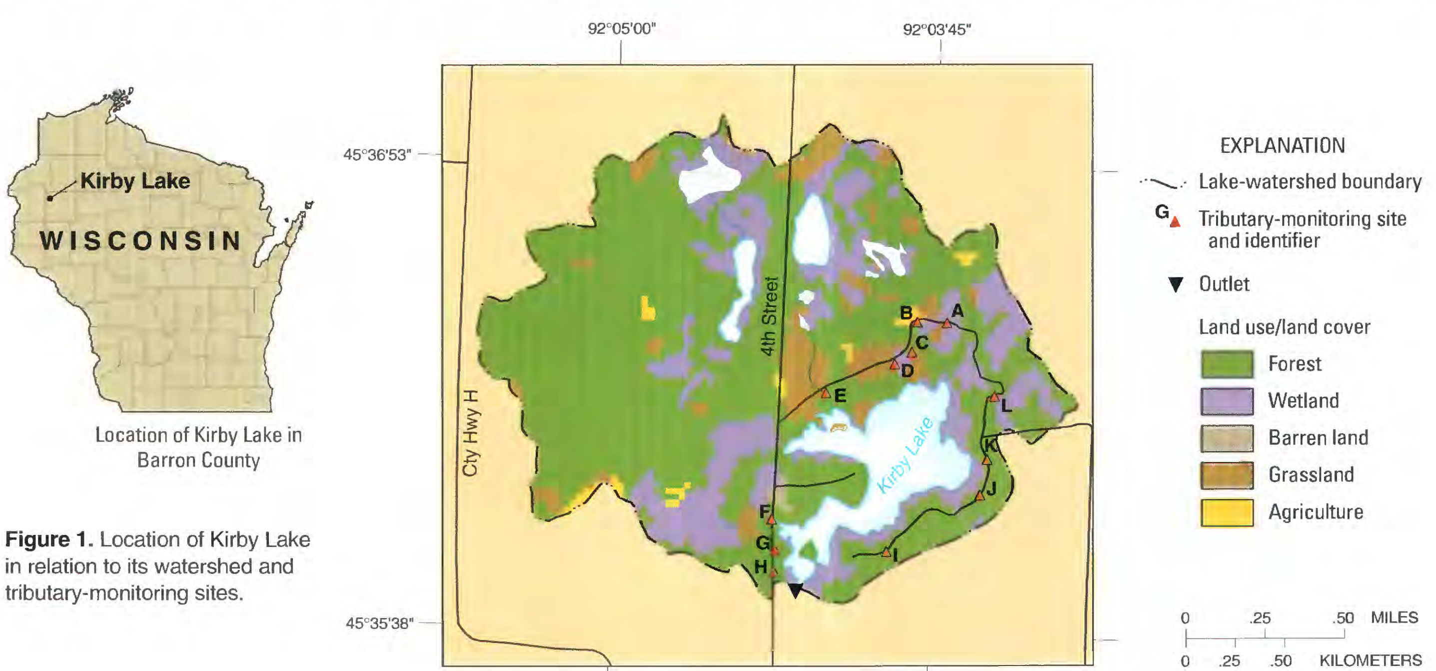

Figure 1. Location of Kirby Lake in relation to its watershed and tributary-monitoring sites.

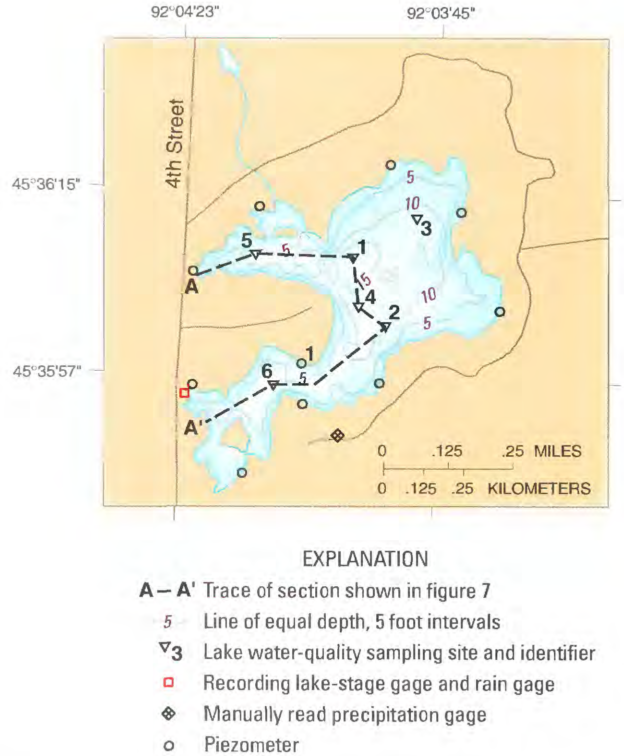

Figure 2. Water depth, and locations of piezometers and water-sampling sites at Kirby Lake.

and, during ice-free periods, Secchi depths (an indicator of water clarity) were also measured. In May 1996, when the lake was completely mixed, near-surface water from Site 1 was also analyzed for dissolved nitrite plus nitrate, total ammonia plus organic nitrogen, and chloride and near-bottom water from this site was analyzed for total phosphorus. Water samples were collected and depth-profile measurements were made at the other five sites (Sites 2–6, fig. 2) in January and March 1996 to assess the conditions under the ice. Selected near-surface and near-bottom samples from Sites 2–6 were analyzed for total phosphorus to define vertical and areal differences in concentration. All water samples were analyzed by the Wisconsin State Laboratory of Hygiene. Additional phosphorus, chlorophyll *a*, and Secchi-depth data for 1992–95 were provided by the WDNR (Danny Ryan, written commun., 1997). Data collected during this study were published in two reports (Holmstrom and others, 1997; U.S. Geological Survey, Wisconsin District Lake-Studies Team, 1997).

Phosphorus input to the lake from surface runoff was determined by analyzing water samples collected from the tributaries shown in figure 1 during periods of snowmelt and storm runoff. The amount of phosphorus delivered to the lake by each tributary was calculated by multiplying the flow-weighted phosphorus concentration by the estimated runoff volume.

Hydrology

The hydrology of Kirby Lake can be described in terms of components of its water budget. The water budget for the lake may be represented by the equation,

$$\Delta S = (PPT + SW_{In} + GW_{In}) - (Evap + SW_{Out} + GW_{Out}),$$

where ΔS is the change in the volume of water stored in the lake during the period of interest and is equal to the sum of the volumes of water entering the lake minus the sum of the volumes of water leaving the lake. Water enters the lake as precipitation (PPT), surface-water inflow (SW_{In}), and ground-water inflow (GW_{In}). Water leaves the lake as evaporation (Evap), surface-water outflow (SW_{Out}), and ground-water outflow (GW_{Out}).

The change in the lake volume was determined from data obtained at a continuously recording lake-stage gage installed in the southwestern bay of the lake (fig. 2). Precipitation was measured at the same site by use of an automatic-recording rain gage, and manually measured by Warren Cook, at his residence on the southeastern side of the lake (fig. 2). All of the other components of the lake's water budget were estimated using data from nearby sites or by solving for them as unknowns (residuals) in the budget equation when all of the other components in the equation were known or approximated. Surface-water inflow was estimated by an analysis of precipitation data and intermittently measured flow at the 12 tributary sites (fig. 1). Ground-water inflow was estimated using measurements of water levels in small-diameter piezometers (wells) installed at 10 sites around the lake (fig. 2) and from information from domestic-well construction reports. Ground-water outflow was assumed to be constant throughout the year, and was estimated in September, when surface-water inflow and outflow were known to be zero. During this time, ground-water outflow was the only unknown variable in the equation. Evaporation from the lake was estimated on the basis of evaporation-pan data from a weather station at St. Paul, Minnesota, in conjunction with lake/pan evaporation coefficients of 0.7–1.19. With all the other variables known or estimated, surface-water outflow then was

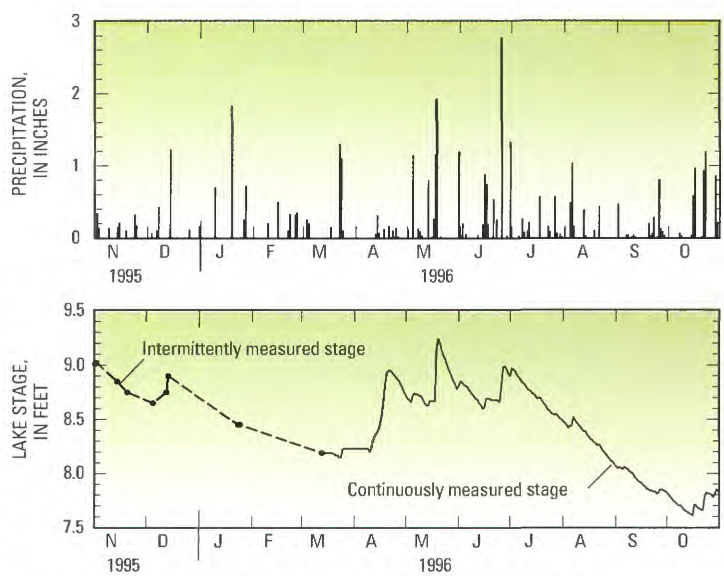

Figure 3. Daily precipitation at, and lake stage of, Kirby Lake.

calculated with the equation except when it was known to be zero—when the lake stage was lower than the outlet level.

Precipitation during the study and the preceding year was greater than normal and was the predominant source of inflow (57 percent of the total inflow) to Kirby Lake during the study (figs. 3 and 4). Precipitation measured at the lake during the study period (39.00 inches) was 18 percent, or 5.87 inches, greater than the 1961–90 average at Cumberland (National Oceanic and Administrative Administration, 1996). Precipita-

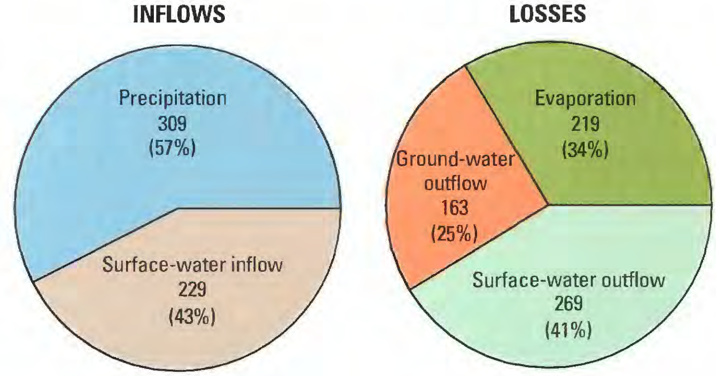

Figure 4. Inflows and losses of water, in acre-feet, for Kirby Lake, November 1, 1995 through October 31, 1996.

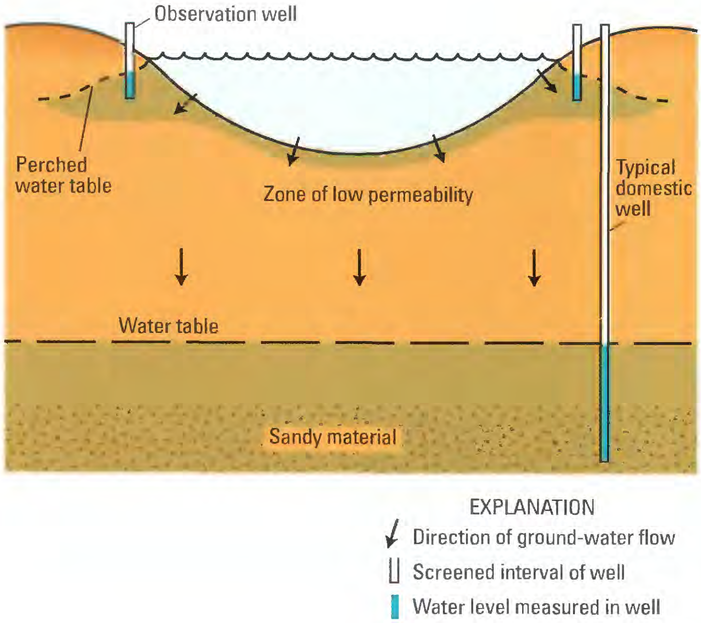

Figure 5. Diagrammatic hydrogeologic section of Kirby Lake showing relation of lake to ground water.

tion at Cumberland during the four months preceding the study (July–October, 1995) was 22.77 inches, or 47 percent greater than normal for that period.

Lake stage fluctuated from a minimum of 7.61 ft (relative to an arbitrary datum) to a maximum of 9.24 ft (fig. 3). Lake stage at the end of the study was 1.19 ft lower than at the start of the study.

The lake's water budget (summarized in fig. 4) is for a "wet period" and probably does not represent years with normal or less than normal precipitation. The lake stage was high and most tributaries to the lake were flowing at the start of the study, owing to the excess precipitation in the preceding four months. Most surface-water inflow (about 94 percent) occurred during four months—November 1995, and April–June 1996. About half of all of the surface-water inflow came from the watershed above monitoring Site G, which drains most of the lake's watershed west of Fourth Street (fig. 1).

Ground-water inflow during the study period was assumed to be zero, because water levels measured in the near-lake piezometers indicated that water generally was flowing from the lake into the ground. Water levels in two domestic wells near the south side of the lake indicated the lake is hydraulically perched about 70 feet above the regional water table (fig. 5). Small local areas, however, may have occasional subsurface seepage to the lake, but their significance in the lake's water budget is thought to be negligible.

During the study, most of the water lost from the lake was from surface-water outflow, which accounts for about 41 percent of all losses (fig. 4). Evaporation and ground-water outflow accounted for 34 percent and 25 percent of all losses, respectively. Losses of water exceeded inflows, resulting in a 1.19 ft lowering of lake stage during the study. Lake stage and surface-water outflow were influenced by vegetation and activity of beavers in the lake's outlet channel, which winds through a marsh at the southwestern end of the lake. Beaver dams in the outlet channel in October through November 1995 contributed to the greater-than-normal lake stage at the start of the study period.

After an extended period of below-normal precipitation, such as the 1987–89 drought, Kirby Lake would likely have almost no surface-water inflow or outflow. Lake stages during 1987–89 were reported to be 3 to 5 ft lower than during the study year (Michael Boland, Kirby Lake District, oral commun., 1995). During these years, almost all water inflow would have been precipitation, and water losses would have been through evaporation and ground-water outflow.

Lake-Water Quality

The pH of water in Kirby Lake ranged from 5 to 6, and specific conductance ranged from 20 to 30 microsiemens per centimeter. The low pH and specific conductance values support the conclusion that ground-water inflow to the lake is negligible and direct precipitation on the lake surface is the main source of inflow. A low chloride concentration of 0.9 milligrams per liter (mg/L) indicates there is little influence on the lake from road salting or septic systems, which are common sources of chloride.

One method of classifying a lake's condition or productivity is by computing water-quality indices based on Secchi depths, and, on near-surface concentrations of chlorophyll *a* and total phosphorus developed by Carlson (1977) and modified by Lillie and others (1993). These three indices are related to each other in complex ways that differ seasonally and among lakes. Secchi depths during the study ranged from 5.6 to 6.6 ft; concentrations of chlorophyll *a* ranged from 4.3 to 7.4 micrograms per liter; and concentrations of total phosphorus ranged from 0.023 to 0.042 mg/L. The trophic-state indices computed for Kirby Lake during this study year and the preceding four years are shown in figure 6. All three indices show the lake to be near the margin between moderately nutrient enriched (mesotrophic) and heavily nutrient enriched (eutrophic).

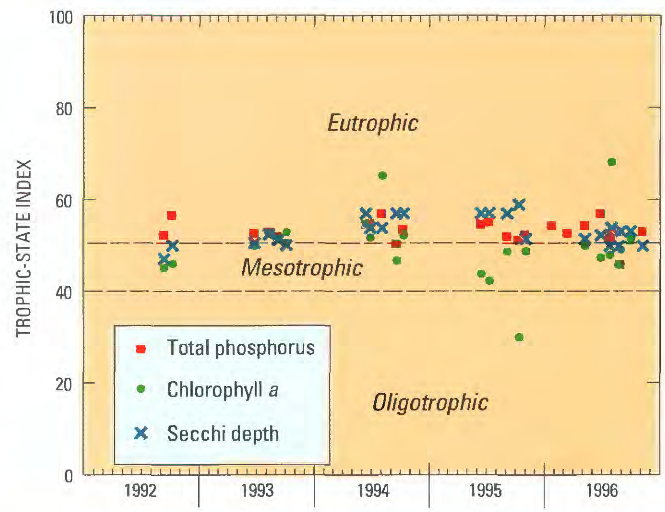

Figure 6. Trophic-state indices for total phosphorus, chlorophyll *a*, and Secchi depth for Kirby Lake.

At the beginning of winter, concentrations of dissolved oxygen were about 11 mg/L, or near saturation, throughout the lake. The concentrations of dissolved oxygen decreased as winter proceeded, however, even with the use of the aerator. The distribution of dissolved oxygen throughout the lake during late winter is shown in figure 7. The aerator significantly influenced the concentrations of dissolved oxygen and mixing patterns throughout most of the lake, except in the northwestern bay. The main effect of the aerator was to mix the water column in the main body of the lake. This area of the lake remained oxygenated, but concentrations of dissolved oxygen became low by late winter. The aerator had little influence on the deep water in the northwestern bay, where water below the sill depth (the shallowest depth separating the bay from the main body of the lake) became almost devoid of oxygen.

Phosphorus Budget

Sources of phosphorus to Kirby Lake include the inflowing streams and precipitation. Phosphorus concentrations in the streams varied only slightly either seasonally or from site to site. The average, flow-weighted concentration of total phosphorus from 43 samples collected at the 12 sampling sites was 0.073 mg/L; the maximum concentration was 0.169

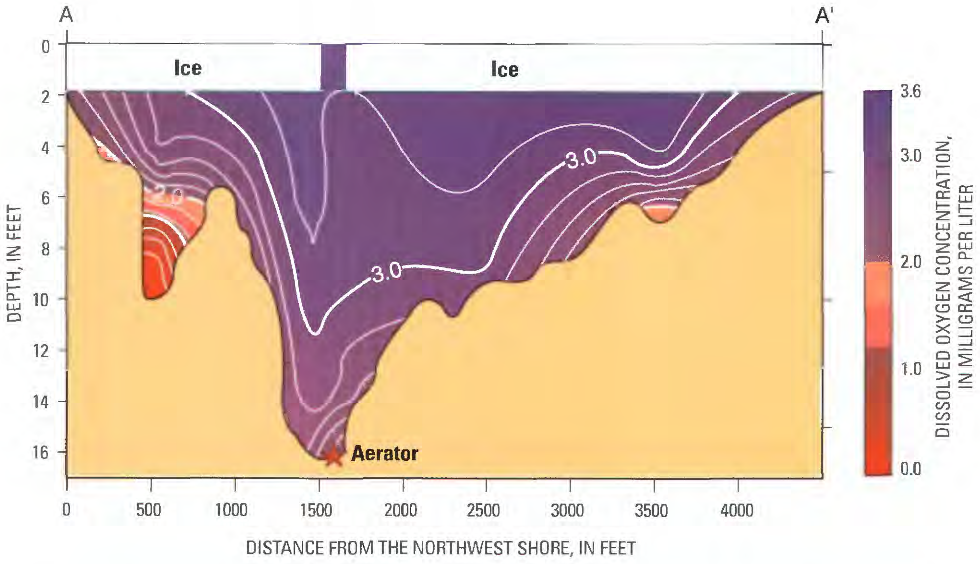

Figure 7. Section showing distribution of dissolved oxygen concentration in Kirby Lake, March 13–14, 1996. Trace of section shown in figure 2.

mg/L and the minimum concentration was 0.019 mg/L. The concentration of phosphorus in precipitation was assumed to be 0.007 mg/L, a value used by Rose (1993) for a study of Balsam Lake in nearby Polk County, Wisconsin. The total estimated external input of phosphorus to the lake (fig. 8) was about 51 pounds, of which 88 percent was transported by the inflowing streams. The watershed contributing to the tributary on the southwestern side of the lake (Site G) accounted for 46 percent of total phosphorus input. Evaluation of internal inputs of phosphorus from lake sediments was beyond the scope of this study.

Approximately 35 percent of the total phosphorus input to the lake was exported through the lake's outlet. Phosphorus not lost through the outlet remained in the lake water or was deposited in the bed sediment of the lake, with a small unknown amount discharged with ground-water outflow.

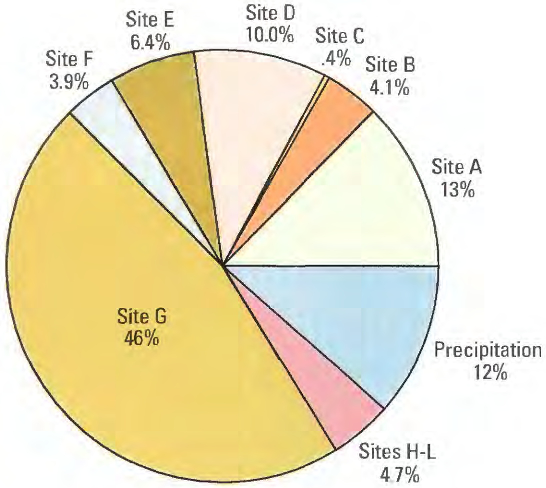

Figure 8. Phosphorus inputs to Kirby Lake from tributary-monitoring sites and precipitation, November 1, 1995 through October 31, 1996. Total inputs were 51 pounds.

Conclusions

During the study period, which was wetter than normal, the principal source of water to Kirby Lake was from direct precipitation and the principal loss was from surface outflow; during a closer-to-normal year, however, the primary losses of water would be through evaporation and ground-water outflow. The main external source of phosphorus to the lake was from surface runoff, most of which was from the single largest tributary draining the western part of the lake's watershed. Kirby Lake's trophic state is classified between mesotrophic and eutrophic. The aerator, which is operated only during the winter, keeps part of the lake free of ice and the water oxygenated and well mixed, except in the northwestern bay of the lake.

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