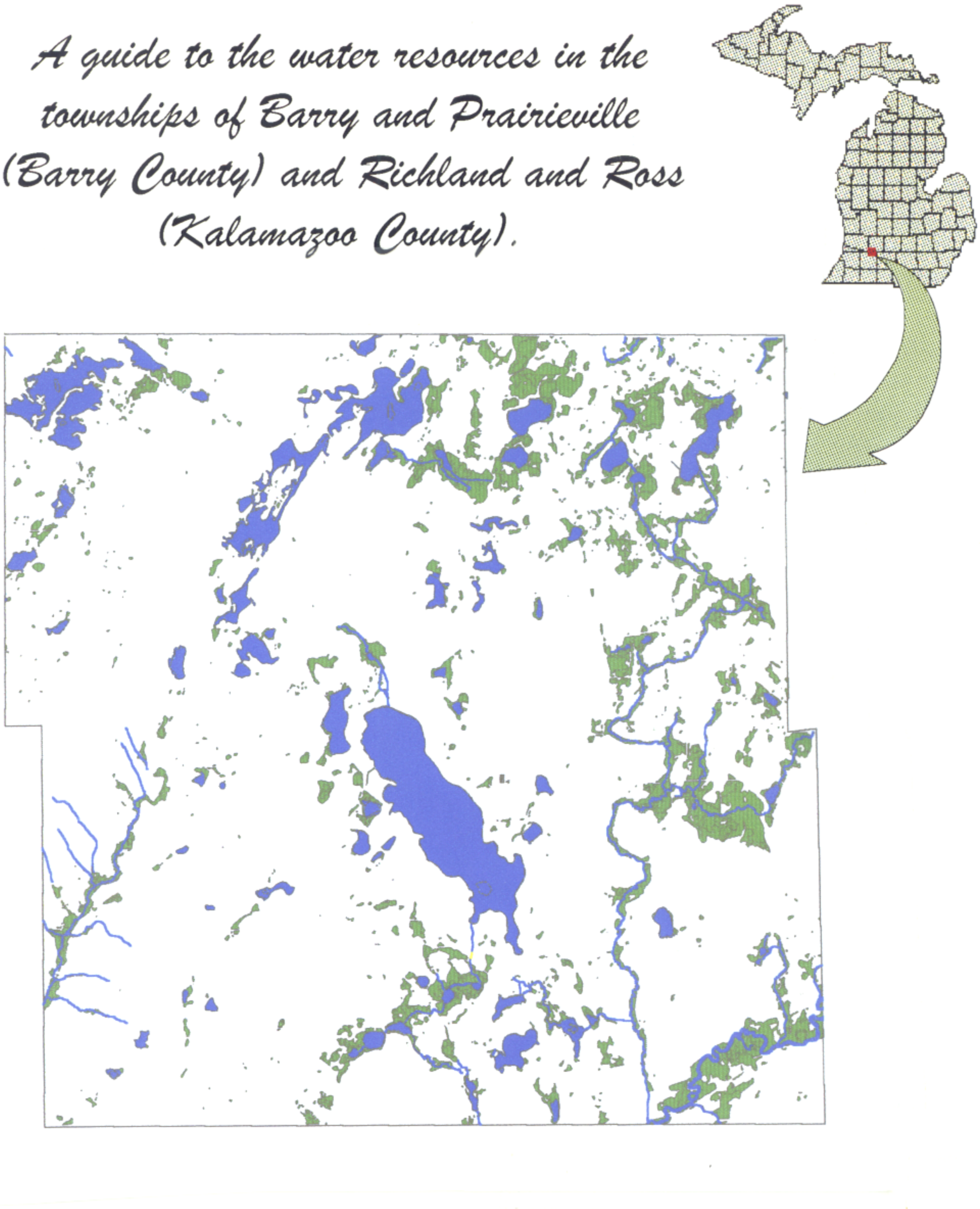
Four-Township Water Atlas

A guide to the water resources in the townships of Barry and Prairieville (Barry County) and Richland and Ross (Kalamazoo County).



Four Township Water Resources Council, Inc.

The Four-Township Water Atlas

A guide to the water resources in the townships of
Barry and Prairieville (Barry County) and
Richland and Ross (Kalamazoo County), Michigan.

Prepared by the Four Township Water Resources Council, Inc.
December 1998

Supported by the Kalamazoo Foundation

Contributing Scientists: Suzanne Sippel, M.A. and Stephen Hamilton, Ph.D.

Table of Contents

Preface

Living in a landscape so richly endowed with groundwater, lakes, streams, and wetlands, we have a special responsibility to care for our water resources. Citizens and their leaders in government need to understand and appreciate these resources to properly manage and protect them now and into the future. For this Water Atlas, the Four Township Water Resources Council surveyed water quality in the streams, lakes and wetlands throughout the area, and also compiled and synthesized existing scientific information on the water resources, including groundwater and precipitation. We hope that this document will contribute to a greater awareness of the nature and value of water resources in the four-township area, and also serve as a baseline against which changes in water quality can be evaluated in the future.

Suzanne Sippel and Dr. Stephen Hamilton designed and carried out the water sampling. Samples were analyzed in Dr. Hamilton's laboratory at the Kellogg Biological Station (KBS) of Michigan State University.

Acknowledgements

We would like to thank the Kalamazoo Foundation for funding this project. The Kellogg Biological Station of Michigan State University provided use of their facilities for the production of this document. A research grant from the National Science Foundation contributed to covering the costs of sampling and analytical work in Dr. Hamilton's laboratory. Dr. Madhav Machavaram and Jeff Bouma assisted with the laboratory analyses and David Raikow, Alan Wilson, Eric Thobaben, and Stefanie Whitmire assisted with some of the water sampling. Maps were created using the Geographic Information System (GIS) prepared by KBS and Michigan State University's Geography Department. National Wetland Inventory maps of the four-township area were digitized by researchers at Western Michigan University with funding by the Michigan Department of Environmental Quality (MDEQ). Jenny Molloy of the MDEQ provided information as well as suggestions to the manuscript. We are also grateful to all of the local residents who provided us with access to their properties for water sampling.

The late Wendell Shafer collected lake level data at Fair Lake for more than 40 years, and his data appear in Figure 6 of this document. His diligent efforts over four decades produced one of the few long-term records of inland lake levels in Michigan.

INTRODUCTION

The four townships that are the subject of this Water Atlas are Richland and Ross Townships in northeastern Kalamazoo County and Barry and Prairieville Townships in southwestern Barry County, Michigan (Figure 1). Figure 2 shows the lakes, streams and wetlands found in our area. Almost all of the land in this four-township area lies within the watershed of the Kalamazoo River, which flows across the southeastern corner of Ross Township on its way to Lake Michigan. The divide between the watersheds of the Kalamazoo River and the Grand River corresponds approximately with the northern boundary of the four-township area.

The four townships encompass two important watersheds that drain to the Kalamazoo River: 1) Gull Lake and its outflow, Gull Creek; and 2) Augusta Creek. The four-township area also includes parts of the Spring Brook and Sevenmile Creek watersheds, as well as substantial area that is difficult to assign to a particular tributary stream watershed but probably drains toward the Kalamazoo River by groundwater flow (e.g., the northern half of Prairieville Township).

Figure 1. Four Township location (Four Township Water Resources Council, 1997).

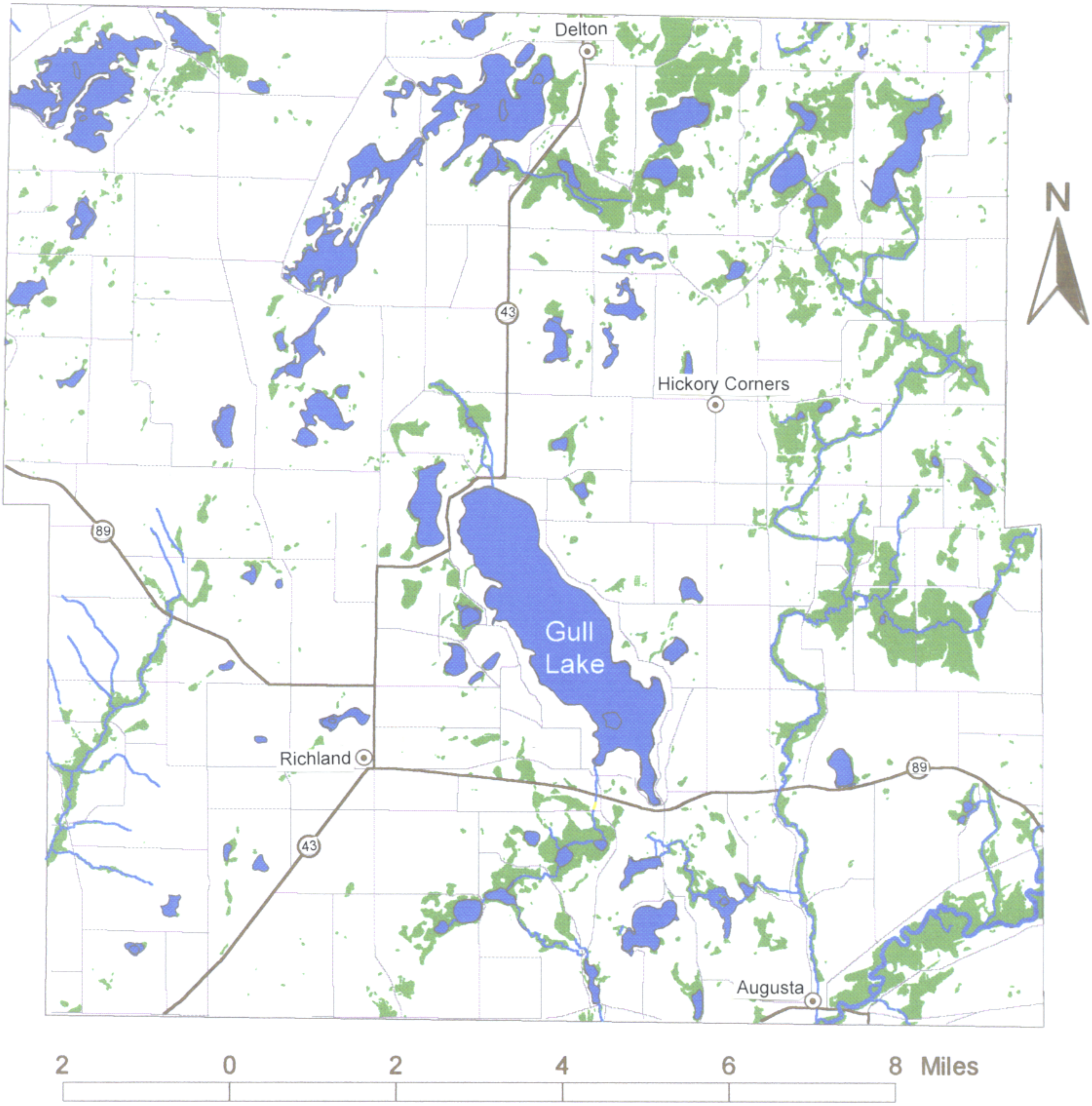


Figure 2. Streams, lakes and wetlands of the four-township area. Lakes and streams are blue and wetlands are green (National Wetland Inventory-U.S. Fish and Wildlife Service).

Lakes and wetlands are abundant in the four-township area. Gull Lake, which is one of the largest inland lakes in Michigan, occupies 2% of the four-township area (Figure 3). All lakes and wetlands combined cover 16% of the area. The upland area remains largely rural, and is a mosaic of row-crop agriculture, pastures, old fields, forest, and residential areas. Residential growth since 1960 has doubled the population in the western half of the four-township area, which is closer to the City of Kalamazoo, and this growth is increasingly spreading further into the four-township area. Information on land use and socioeconomic characteristics of the four townships is available in the Four Township Water Resources Council Issues Paper (1997) which can be found in the Richland, Delton and Kellogg Biological Station Libraries. Towns and villages within the four townships include Delton, Hickory Corners, Richland, and Augusta.

This document begins with a brief overview of the Hydrologic Cycle and the Watershed Concept. We then provide a more in-depth discussion of particular aspects of our water resources, including precipitation, groundwater, streams, lakes and wetlands, presenting and interpreting hydrologic and water quality data from the four-township area as we go along.

The Appendix provides definitions of the various water-quality measurements that are mentioned throughout the text, and a list of references at the end of the text documents our sources and points the way to further information.

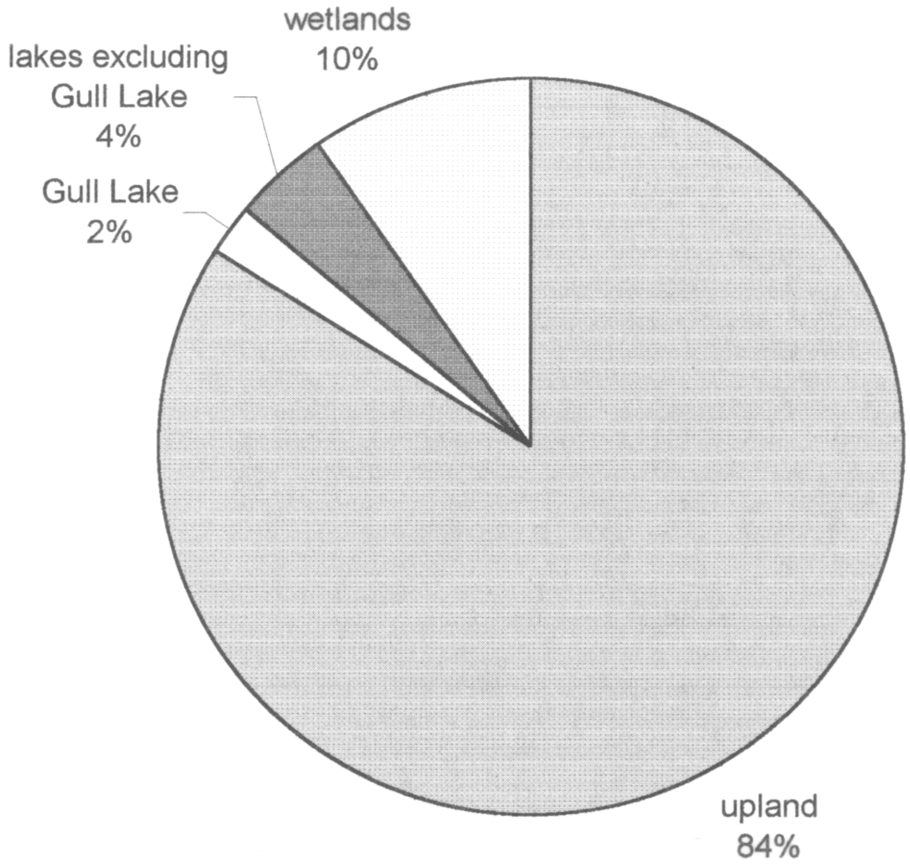


Figure 3. The area proportions of upland, lakes and wetlands in the four-township area. Data are from the National Wetland Inventory- U.S. Fish and Wildlife Service.

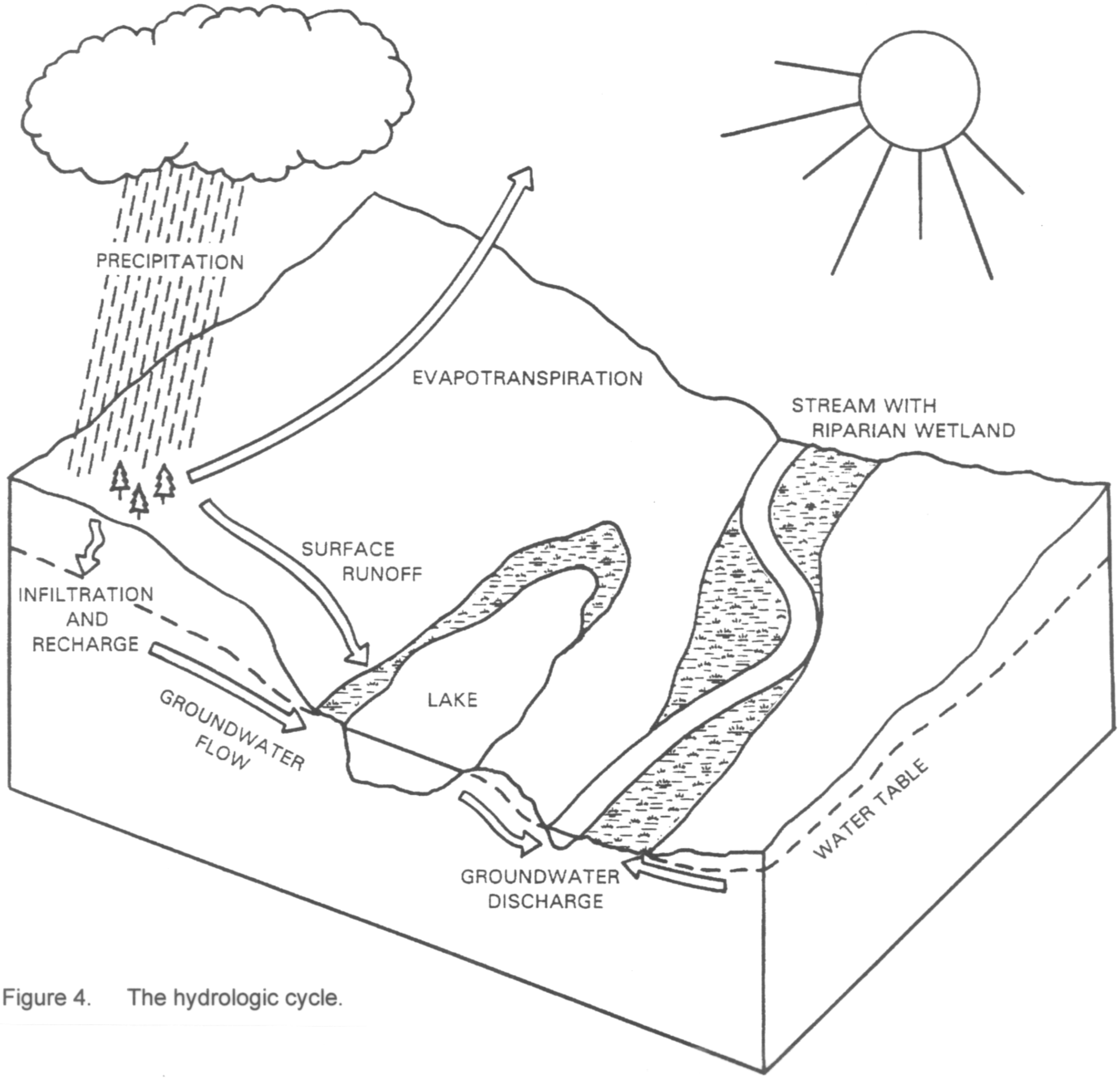


Figure 4. The hydrologic cycle.

Movement of Water Through the Landscape

The Hydrologic Cycle

The movement and endless recycling of water between the atmosphere, the land surface, surface water bodies, and ground water reservoirs is called the Hydrologic Cycle (Figure 4). Understanding the hydrologic cycle is fundamental for proper management of our water resources.

Water in the atmosphere originates by evaporation from the land surface and from water bodies (lakes and oceans). Evaporation from oceans is the main source of water for precipitation over the continents, even in places like Michigan that are far from the oceans, although the Great Lakes also contribute measurably to Michigan's precipitation.

Precipitation, as either rain or snow, returns atmospheric moisture to the land surface. The fate of water from precipitation depends on the climate and the characteristics of the land surface. After a substantial rainfall, water may evaporate back to the atmosphere, run off over the surface of the land (surface runoff), or seep into the ground to reach the water table (infiltration). If plants are abundant, their roots may take up much of the infiltrating water and return it to the atmosphere by transpiration (evaporation from the leaves).

Evaporation increases with warmer temperatures. On land and in wetlands with abundant vegetation, most evaporation occurs by plant transpiration. The sum of water losses by evaporation and transpiration is called evapotranspiration. Evaporation rates are expressed as the depth of water evaporated over a time period (e.g., inches/year).

The relative importance of surface runoff and infiltration depends on the slope of the land surface and on how permeable the surface soils are. Gently sloping lands with loamy soils tend to promote infiltration, while steeper slopes and denser soils (such as clays) will promote surface runoff.

Urban and suburban development can alter the hydrologic cycle by increasing the area of impervious surfaces. Most of the precipitation falling on impervious surfaces such as roads, parking lots, and rooftops will become surface runoff, which in urbanized areas is often directed to a storm drain that conveys this water to a nearby stream or lake. Impervious surfaces therefore reduce infiltration and increase surface runoff. Reduced infiltration reduces groundwater recharge, and increased runoff increases the potential for flooding and surface water contamination.

Infiltration of precipitation to recharge the groundwater varies over the seasons, and occurs mostly between November and May in southern Michigan. During the summer, high water demand by plants often results in little infiltration of water beyond the root zone. The same amount of precipitation during the winter can result in much more infiltration because of the lower evapotranspiration rates.

During the winter, snowfall may accumulate on the land surface until a thaw occurs. When the snow melts, the water may flow overland across frozen soils in places where during warmer periods it would infiltrate downward into the soil.

Addition of infiltrating water to the groundwater is known as recharge. Recharge of groundwater reservoirs by infiltrating precipitation drives groundwater flow from places with higher water tables towards places with lower water tables. In general the elevation of the water table, which is the depth below which soils are saturated with water, approximately follows the elevation of the land surface. Groundwater flow is very slow but is extremely important because the discharge of groundwater at low-lying points on the landscape supplies water to streams, rivers and many lakes. Groundwater flow can also spread contaminants in both vertical and horizontal directions from a source at the land surface.

The Watershed Concept

A watershed is the area of land that drains to a stream, river or lake (Figure 5). This drainage could be underground (i.e., by groundwater flow) as well as over the land surface. The Watershed Concept is important in the management of water resources because it helps people to understand the hydrologic linkage between the land surface and nearby water bodies. Knowledge of watershed boundaries is needed to understand whether human activities far from lakes and streams can potentially affect the water quality of these surface waters through surface runoff and groundwater flow.

Watershed boundaries are often estimated from the slope of the land surface (topography), under the assumption that

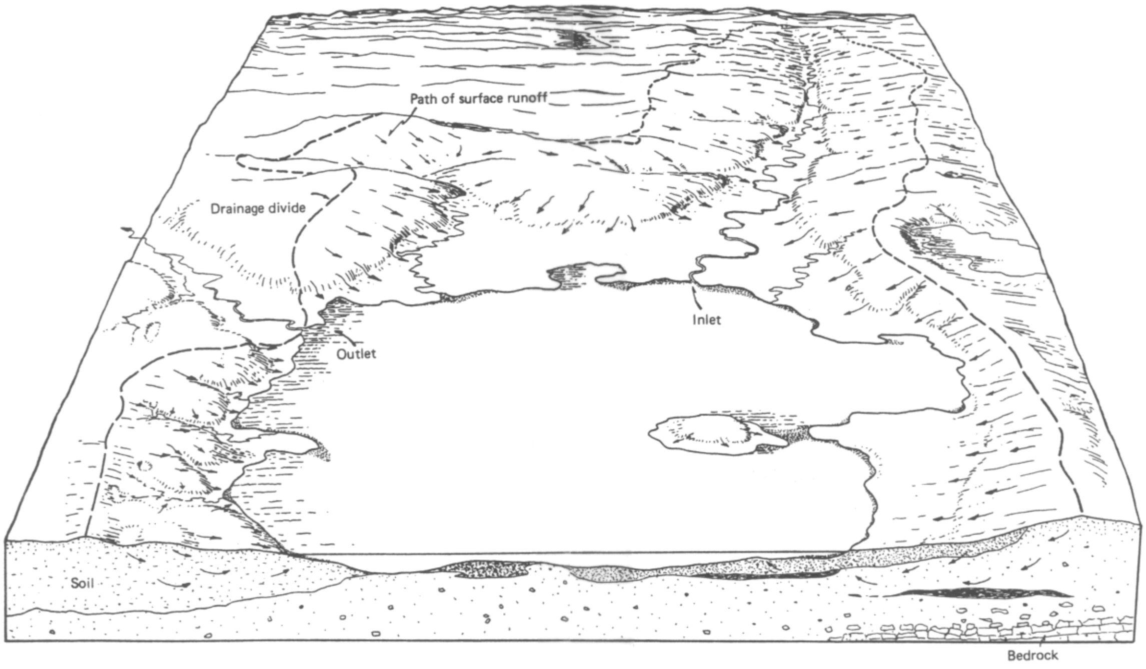


Figure 5. A lake and its watershed. Arrows show the direction of the flow of water. Modified from Marsh and Borton, 1975.

groundwater flow as well as surface runoff occur in the downhill direction. This assumption is generally true, although in the gently rolling glacial terrain common in southern Michigan, the delineation of watersheds based on topography alone can be difficult. This is because some areas do not slope downward to reach a stream valley, even though water from such areas may drain towards a stream by groundwater flow.

Streams draining smaller watersheds combine to form larger watersheds. For example, in southern Michigan, small streams flow into larger rivers, which in turn flow into the Great Lakes system, whose waters ultimately drain to the Atlantic Ocean. Watersheds can be delineated at each of these levels, with each larger watershed composed of sub-watersheds. This hierarchy of watersheds is important to keep in mind because it helps us to realize how small streams can, in a cumulative way, produce an impact on the water quality of Lake Michigan and other downstream waters.

Watersheds ignore political boundaries such as township and county lines; they obey only gravity and the movement of water. To manage a watershed as a whole, it is critical to consider the entire watershed, rather than just the part within the local jurisdiction of a township or county. The Four Township Water Resources Council (FTWRC) was formed with this in mind. Watersheds can unite us as a community because caring for a watershed is a community responsibility.

WATER RESOURCES OF THE FOUR TOWNSHIPS

Precipitation

Precipitation varies in amount from year to year, and this variation has a myriad of consequences for human activities such as agriculture as well as for natural ecosystems. In dryer years, crop yields can be adversely

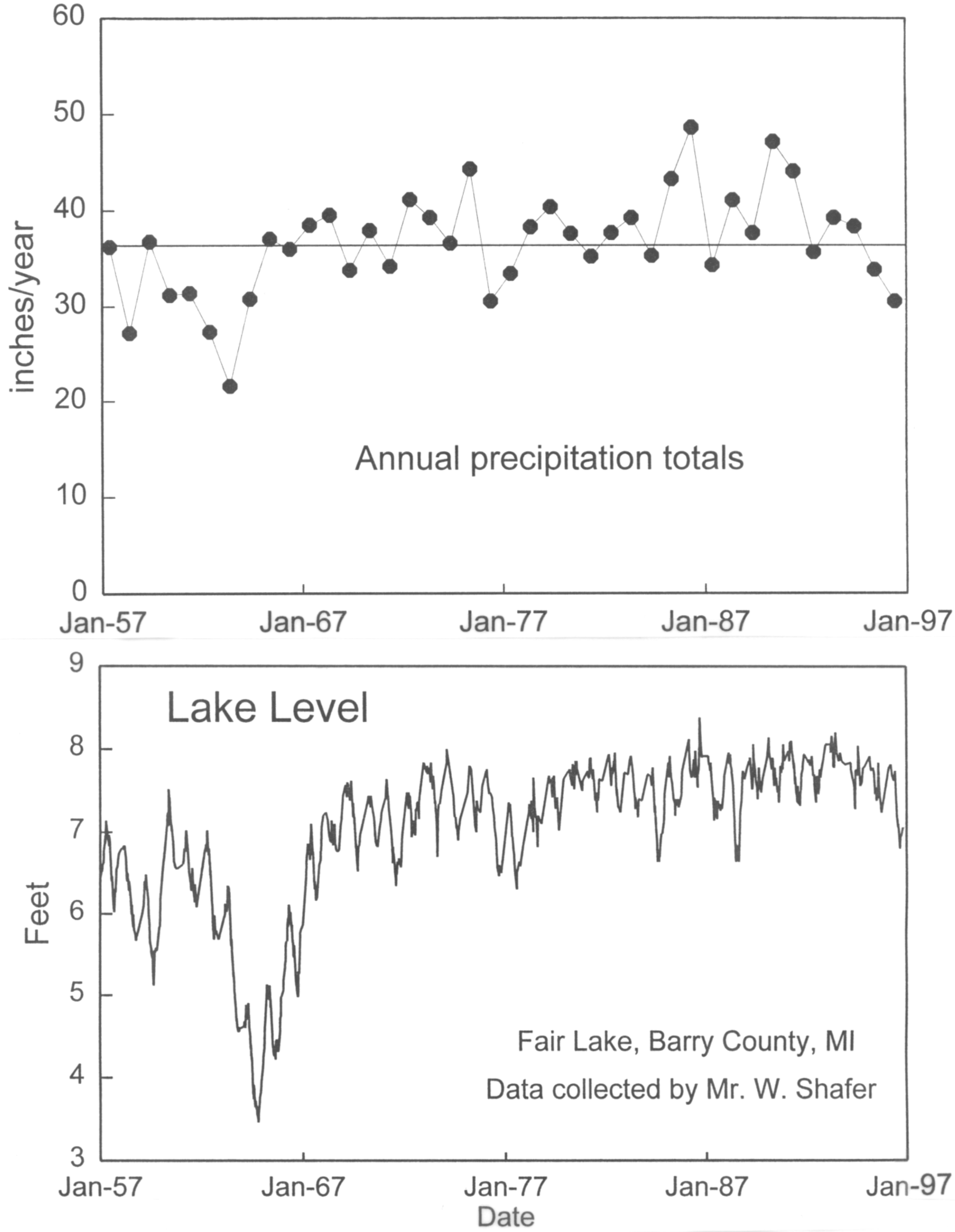


Figure 6. (a) Annual precipitation from 1957-1997 for the four-township area (composite record for stations at Kellogg Biological Station). The 40-year average is indicated by the horizontal line. (b) Fair Lake water levels. Fair Lake data were collected by Wendell Shafer.

affected by lack of water. Water levels in streams and especially lakes fall to where they may impede recreational uses and negatively impact aquatic life. Wetlands that normally persist all year may dry completely. Wetter years, in contrast, are generally less harmful but may produce undesirable flooding of property and excessive soil moisture for crops, depending on the timing of the precipitation.

Precipitation amounts have been monitored since 1929 at several locations on the Kellogg Biological Station property, located within the four-township area. In Figure 6, we have averaged data from the 2-4 stations that have operated in the past 50 years to produce a continuous local record for 1947-96. This record shows a mean annual precipitation of 36.4 inches, with annual totals varying from a minimum of 21.6 inches to a maximum of 48.5 inches. These annual totals include both rainfall and the water contained in snow or other frozen forms.

The most protracted drought in this local precipitation record occurred during the early 1960's. Longtime residents vividly recall that drought because it caused many of our wetlands and shallow lakes to dry entirely. Evidently, the four consecutive years of below-average precipitation produced a cumulative effect on the water table and on water levels in surface water bodies.

The effect of the drought of the early 1960's on water levels in Fair Lake (Barry County) is apparent in the water-level record for that lake (Figure 6), which has been maintained for 40 years by Wendell Shafer, a citizen who lives on the lake. Each year shows the typical increase in water level during winter and spring, followed by a decrease through the summer and fall, reflecting the balance between inputs of water and losses by outflow and evaporation. During the drought period, the seasonal drops in water level greatly exceeded the subsequent rises, yielding a cumulative drop over several years. Fair Lake did not dry completely, but its drop in water level did cause considerable concern among lakeside residents.

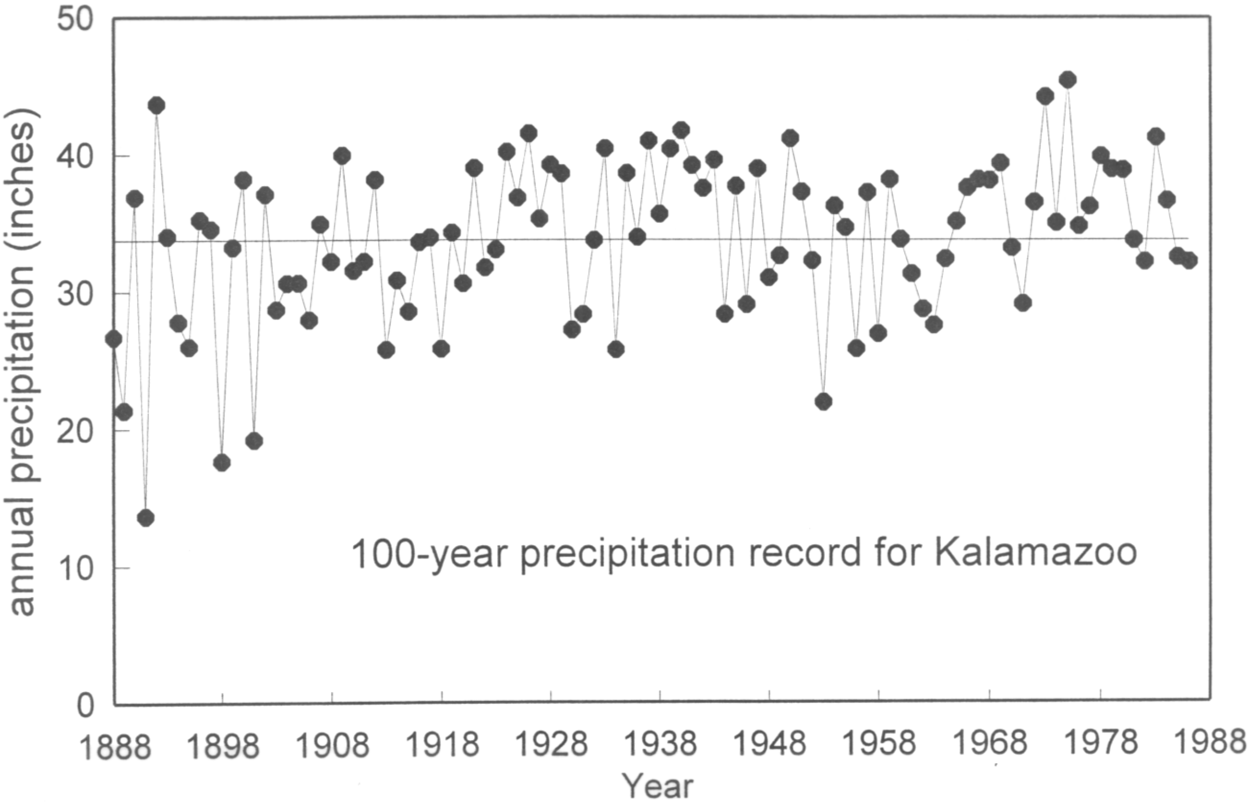


Figure 7. 100-year precipitation record for Kalamazoo (measured at the Kalamazoo State Hospital). The 100-year average is indicated by the horizontal line.

Can we expect another drought as severe as the one in the early 1960's, or was that an anomalous climatic event? A longer record of precipitation is available for Kalamazoo, located to the southwest of the four-township area, where a station operated at the former State Hospital beginning in 1876. We present that record in Figure 7 to give an indication of whether the 40-year precipitation record for the four-township area is typical of the past century. The mean annual precipitation for 1888-1986 is 33.8 inches. The annual totals of precipitation reveal that periods such as 1960-65, in which precipitation was below normal for several consecutive years, occurred several times in the late 1800's and early 1900's, and that recent decades have actually been wetter then usual. The record therefore suggests that the protracted drought of the early 1960's may not have been so unusual, and that similar conditions may have existed during several periods since records have been maintained.

The frequent drier periods that are evident in the precipitation record for the past century are likely to occur again in the next century. Climate change is expected to exacerbate the impact of such dry periods. Sophisticated climate models have been developed to predict the regional patterns of global warming due to "greenhouse gas" emissions to the atmosphere. Those models show that, if emissions continue at present rates, average air temperatures in southern Michigan will rise, which will enhance evapotranspiration rates (Mortsch and Quinn 1996). The predicted change in precipitation is more uncertain, but even if precipitation remains unchanged, the higher evapotranspiration will decrease soil moisture and lower water tables. Thus over the long term, management of our water resources will require consideration of both natural climatic variability, which is substantial but not predictable, as well as the possibility that the regional climate is undergoing changes driven by greenhouse gas emissions.

It is important to consider the seasonal distribution of precipitation in addition to the total annual amount. On average, precipitation in the four-township area is well distributed throughout the year, although within a particular year the precipitation may show considerable variability from month to month. More than half of the annual precipitation tends to fall during the growing season (April-September). Snowfall is higher in the four-township area than in more inland locations of southern Michigan because the area lies on the eastern edge of the Lake Michigan snow belt. The higher snowfall in this belt results when cold air moving across the region from the west crosses the open waters of Lake Michigan. The air increases in temperature and moisture content as it crosses the lake. Upon passing over the relatively cool land surface of West Michigan, the moisture condenses as precipitation. In nearby Kalamazoo the mean annual snowfall is 73.6 inches. The presence of Lake Michigan also moderates the air temperature throughout most of the year.

The balance between gains of water from precipitation and losses of water by evapotranspiration determines soil moisture and the potential for surface runoff and infiltration to the groundwater. Comparison of monthly rates of precipitation and Potential Evapotranspiration (PET) provides an approximate indication of this balance. PET is a measure of the evapotranspiration that would occur under the meteorological conditions of the region if unlimited moisture were available. In months in which PET exceeds precipitation, surface soils would experience a net loss of moisture by evapotranspiration, whereas in months with more precipitation than PET, the soils would have a net surplus of water. The effect of temperature on evaporation rates is clearly visible in the seasonal cycle of PET.

The monthly means of precipitation and PET in Figure 8 show that surplus water is typically available only from October to April, which is when most surface runoff and infiltration to the groundwater take place. During the warmer months, evapotranspiration consumes more water than is replaced by precipitation, and thus surface soils tend to dry out. The replenishment of soil moisture during the cooler months is obviously

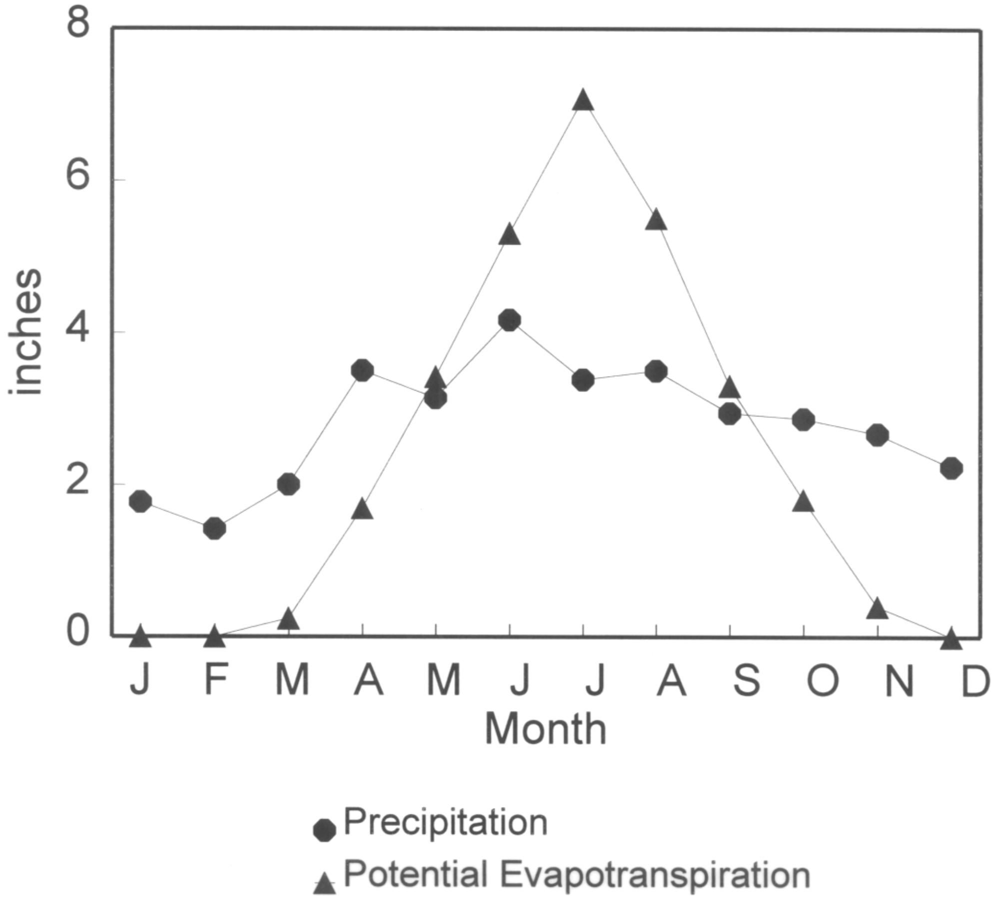


Figure 8. Mean monthly precipitation and PET (Potential Evapotranspiration), based on data collected at KBS from 1951-80 (Crum et al. 1990).

important to the success of agriculture in the area, as area farmers often do not have access to irrigation equipment. Much of the groundwater recharge and the seasonal increase in water levels in lakes and wetlands also occur during the cooler months of the year.

The chemistry of precipitation in the four-township area has been monitored since 1979 at Kellogg Biological Station, which operates a station as part of the National Atmospheric Deposition Program/National Trends Network (NADP/NTN). These data are available on the Internet at http://nadp.nrel.colostate.edu/NADP/. In addition, Rheaume (1990) analyzed one year of data on precipitation chemistry from a collector installed by the U.S. Geological Survey near the mouth of Gull Creek, and measured some variables not included in the NADP/NTN program.

The chemical composition of precipitation in this area appears typical of the region and reflects the presence of substantial pollution sources in the heavily populated and industrialized Chicago area, which lies in the prevailing upwind direction (Table 1). The precipitation is acidic with a mean pH of 4.45 and a mean specific conductance of 26 µS/cm (25°C). (See the Appendix for explanations of these water-quality measurements.) The natural pH of precipitation in this region is not known but would likely be closer to 5.5, which is ten times less acidic since pH is a logarithmic scale. The acidity of precipitation is due largely to sulfuric and nitric acids, which are air pollutants originating mainly from the combustion of fossil

Table 1. Chemical composition of precipitation, groundwater, and surface waters in the four-township area.

Measurement	Precipitation[1]	Ground Water[2]	Streams: Augusta[3]	Prairieville[4]	Lakes: Lawrence[5]	Gull[6]	Lower Crooked[7]	Pleasant[8]
Conductance (μS/cm; 25°C)	26.1	485	496	606	413	343	172	46
pH	4.45	7.34	7.81	7.75	8.02	8.18	9	6.94
Alkalinity (mg $CaCO_3^-$/L)	0	198	240	288	195	145	63	24
Ca^{2+} (mg/L)	0.22	69.83	73.8	89.7	38.87	34.04	13.78	5.8
Mg^{2+} (mg/L)	0.05	22.50	22.0	27.4	20.56	20.64	8.37	2.7
Na^+ (mg/L)	0.10	4.33	5.1	5.2	6.12	6.53	5.88	1.1
K^+ (mg/L)	0.02	0.77	0.8	1.1	2.72	1.11	0.24	0.49
NH_4^+ (μg N/L)	333	30	8	9	---	---	---	7
Cl^- (mg/L)	0.16	6.28	8.61	10.15	5.941	8.873	9.187	0.62
SO_4^{2-} (mg/L)	2.72	22.47	19.16	31.6	15.684	19.5	3.954	2.41
NO_3^- (μg N/L)	420	3360	1070	5180	718	134	< 30	< 30
SiO_2 (mg/L)	---	11.8	10.7	13.9	5.5	1.8	0.12	0.57
Total dissolved phosphorus (μg/L)	---	10	6	3	17	8	7	7

Data sources:

[1] National Atmospheric Deposition Program (NRSP-3)/National Trends Network means of annual volume-weighted means for 1979-96 from the KBS station (MI26), printed 2 December 1997. NADP/NTN Coordination Office, Illinois State Water Survey, 2204 Griffith Dr., Champaign, IL 61820.

[2] Rheaume (1990: Table 19 in Appendix); data are means for six observation wells located within the four-township area (one industrially contaminated well in Richland Township was excluded).

[3] Augusta Creek was sampled at Kellogg Forest on 15 May 1998. [Hamilton code 435]

[4] Prairieville Creek was sampled on 28 April 1998. [Hamilton code 363]

[5] Lawrence Lake was sampled at 2-m depth on 21 August 1996. [Hamilton code 156]

[6] Gull Lake was sampled at 4-m depth on 21 August 1996. [Hamilton code 154]

[7] Lower Crooked Lake was sampled at 1-m depth on 21 August 1996. [Hamilton code 155]

[8] Pleasant Lake was sampled at 1-m depth on 19 August 1998. [Hamilton code 528]

fuels, particularly by power plants and automobiles.

The environmental effects of this acid precipitation are not fully understood. However, as will be shown in the later sections, streams and most lakes in the four-township area are naturally well-buffered against the effects of the acidity. For this reason, we do not face the problems of lake and stream acidification that plague certain regions of North America, including the western Upper Peninsula of Michigan.

Trace pollutants in precipitation are an increasing concern throughout the U.S., and the four-township area is not immune from this problem. Mercury and organic compounds such as PCB's carried by precipitation are believed to be an important source of pollutants that contaminate the food chain leading to fishes in the Great Lakes. In our local area, however, there have not been any studies of contaminants in precipitation.

Groundwater

Extensive and high-quality groundwater reservoirs (or aquifers) underlie the four-township area (Allen et al. 1972, Rheaume 1990, Kehew and Brewer 1992). All residents in the four-township area are dependent on this groundwater for domestic water supplies (including drinking water), and groundwater is used for agricultural irrigation (especially for corn during dryer years). Groundwater is also a critical resource for nearby urban populations and industrial activities. Because groundwater is not visible, it is easy to forget about its importance. However, if we fail to protect the quality of our groundwater, a most important local resource could readily be degraded.

Groundwater in the four-township area is a renewable resource and its exploitation for human uses can be sustainable if it is wisely managed. At present, local domestic water use is largely non-consumptive because most of the water is returned to the aquifer through septic systems. Water extracted for use in urban areas or for irrigation of crops, golf courses, and lawns is not returned to the aquifer and thus can potentially reduce the volume of water stored in the system. Reduced groundwater volume can in turn lower the water table, affecting surface waters that are in equilibrium with the water table or that receive groundwater discharge. The City of Kalamazoo's proposed well field near Gull Creek, which was designed to withdraw water for urban uses, has engendered particular concern among local citizens because they believe the water withdrawals could conceivably lower water levels in nearby streams, wetlands and lakes.

The soils in the four-township area are very permeable to water, and as a result much of the precipitation infiltrates the soils and moves across the landscape via groundwater flow paths. This is the primary way in which local groundwater aquifers are recharged in the long term; some recharge also occurs by seepage out of lakes and wetlands to the groundwater. Discharge of groundwater back to the surface provides much of the water in our streams and lakes, as discussed later. Despite these exchanges, however, the residence time of water in the aquifers (i.e., the time it takes to completely flush the groundwater and replace it with new water) is long, reflecting the immense volume of water stored below ground.

Groundwater discharge to streams, lakes, and wetlands controls both the quantity and quality of many of our surface waters, as discussed later. Residents often refer to a particular lake or stream as being "spring-fed", which they view as a positive feature. Groundwater inputs tend to be stable over time and maintain water bodies even during relatively dry years. Local streams are kept cooler during the summer by groundwater inputs and thereby can support trout. As water infiltrates soils and travels through underground flow paths, filtration and absorption effectively remove many kinds of contaminants. This is one reason that the water that exits from underground to discharge into surface waters tends to be of better quality than if the water had flowed overland to reach those water bodies.

One consequence of the high rate of exchange of water between the land surface, groundwaters, and surface waters is that our groundwater aquifers are highly susceptible to contamination originating at the land surface (Rheaume 1990). The long residence time of water in the aquifers means that once they are contaminated, it will take many, many years for their water quality to be restored. A relatively small quantity of chemical pollutants, if stored or discarded improperly at or beneath the land surface, can degrade the utility of vast amounts of groundwater before the problem is even noticed. It is thus vital that all residents, farmers and businesses in our area understand the susceptibility of our groundwater resources, and that they apply chemicals to crops, golf courses, yards, and water bodies wisely and only when needed. The Home-A-Syst booklets, available through the local MSU Extension office, are a useful resource for residents interested in reducing their impact on our groundwater and surface waters (MSU 1998). Chemical pollutants can also enter the groundwater from sources such as leaking underground storage tanks and abandoned well heads, and a number of these have been discovered in the four-township area.

Nitrate contamination of groundwater is evident throughout the four-township area. Health Department records for Kalamazoo and Barry Counties show that a significant number of domestic wells exceed the U.S. Environmental Protection Agency's drinking water standard of 10 ppm (10,000 ppb) nitrate-nitrogen (1 ppm = 1 mg/L; 1 ppb = 1 μg/L). The concern about high nitrate concentrations in drinking water is primarily due to the link between nitrate consumption and a disease affecting infants and unborn babies known as "blue-baby syndrome" or methemoglobinemia. A U.S. Geological Survey report by Rheaume (1990) noted that nitrate concentrations in groundwater in Kalamazoo County have increased substantially in the past few decades. Rheaume documented the spatial patterns in nitrate contamination during the late 1980's, and formulated a nitrogen budget for the county that implicates agricultural fertilizers and animal wastes as the primary cause of the increased contamination of aquifers. Inputs of nitrate from rain and snow are elevated due to air pollution, and septic systems also contribute to the problem, but these sources do not cause the excessive concentrations that are occasionally found in groundwater throughout the four-township area. Unlike many pollutants, nitrate is mobile in groundwater because it does not chemically bind with soils, and hence it can be transported by groundwater flow. Wetlands, as discussed later, can be effective in reducing nitrate concentrations in groundwater when these water bodies intercept water before it infiltrates to the groundwater.

Contaminants besides nitrate have not been measured frequently in groundwater from the four-township area, although some data on pesticides and phenols are presented in Rheaume (1990). There are a few sites in the four-township area where toxic substances have been found in the groundwater. Information on these sites is maintained by the Michigan Department of Environmental Quality and by the two counties. Specific sites of contamination in Prairieville and Barry Townships are mapped in the Barry County Well Atlas (1996). One site of significant industrial contamination is located in the Village of Richland, at the former site of Production Plated Plastics, Inc,; that site is currently being remediated by the Michigan DEQ. Another significant site of industrial contamination of groundwater has been found in Delton, where a new water supply had to be installed for local residents. There are also several older landfills that present potential groundwater contamination problems.

Municipal sewage sludge from nearby urban areas is disposed of by spreading the solids onto agricultural fields throughout the four-township area. Sites for disposal must meet certain criteria designed to avoid surface-water contamination. Septic tank wastes are also disposed of in this manner, although sites are not regulated. If the sludge is applied instead of fertilizer and if industrial contaminants such as heavy metals are not found in the material, these applications may have little short-term impact on groundwater quality. Sludge is typically rich in phosphorus, so care must be taken to select sites that will not yield surface runoff directly to water bodies because that would deliver this nutrient to waters where it could cause excessive plant or algal growth (see later section on lakes). Longer-term impacts of sludge applications are not well understood.

Non-point-source pollution, which refers to the diffuse entry of nutrients and contaminants from land surfaces to water bodies and groundwaters, will become an increasing problem as the four-township area experiences residential growth. There are two principal reasons that non-point-source pollution is expected to increase as land use changes from predominantly rural/ agricultural to residential. One is the increasing fraction of the landscape covered by impervious surfaces such as driveways and rooftops that generate surface runoff, which bypass soils that normally retain many pollutants. Another is the increasing population density and its attendant increases in the release of a diversity of pollutants from sources such as septic systems, lawns (including golf courses), parking lots and roads, and construction sites. Potential pollutants include nutrients, herbicides and pesticides, de-icing and water-softener salts, and sediments from soil erosion. Concentrated development in the vicinity of surface water bodies will contribute more to the problem than lower density development across the landscape.

Non-point-source pollution is difficult to abate although various approaches are under development throughout the U.S. Stormwater management measures such as runoff detention basins can reduce non-point-source pollution. Southern Michigan has several examples of areas where suburban residential development has resulted in problems for water quality; these problems are presently being addressed by stormwater management.

Despite these current and potential future problems with contamination of groundwater, at present most of the four-township area has good groundwater quality. The chemical data in Table 1 show how groundwater differs considerably from its ultimate source, precipitation. The large increase in various dissolved substances in groundwater compared to precipitation is due to the natural dissolution of minerals in the soils of the area. Particularly important are the remnants of limestone rock found in the soils, because this limestone readily dissolves to yield high concentrations of calcium, magnesium, and bicarbonate in the groundwater. These substances neutralize the acidity in precipitation and impart high hardness and alkalinity to the water, which is why residents commonly use water softeners to remove these substances and produce a "softer" water for domestic use. Local groundwater can sometimes have undesirably high iron concentrations as well as excessive hardness; high iron likely results where wells are close to surface water bodies that recharge the groundwater.

Streams

Streams are important for their intrinsic aesthetic, recreational, and ecological values in addition to being conduits of water and, potentially, of pollutants. The principal streams within the four-township area are Augusta Creek, Gull Creek, Sevenmile Creek, Spring Brook, the Eagle Lake Drain (in Fort Custer State Recreation Area) and Prairieville (also known as Swartout or Otis) Creek (flowing into the northern end of Gull Lake) (Figure 9 and Tables 2 and 3). The much larger Kalamazoo River passes through Ross Township, but here we will emphasize the smaller streams of the four-township area.

Streams in the four-township area are largely unregulated and thus maintain their natural flow regimes, although in some cases there have been historical alterations to their channels. A sluice-gate dam controls the outflow from Gull Lake, which supplies water

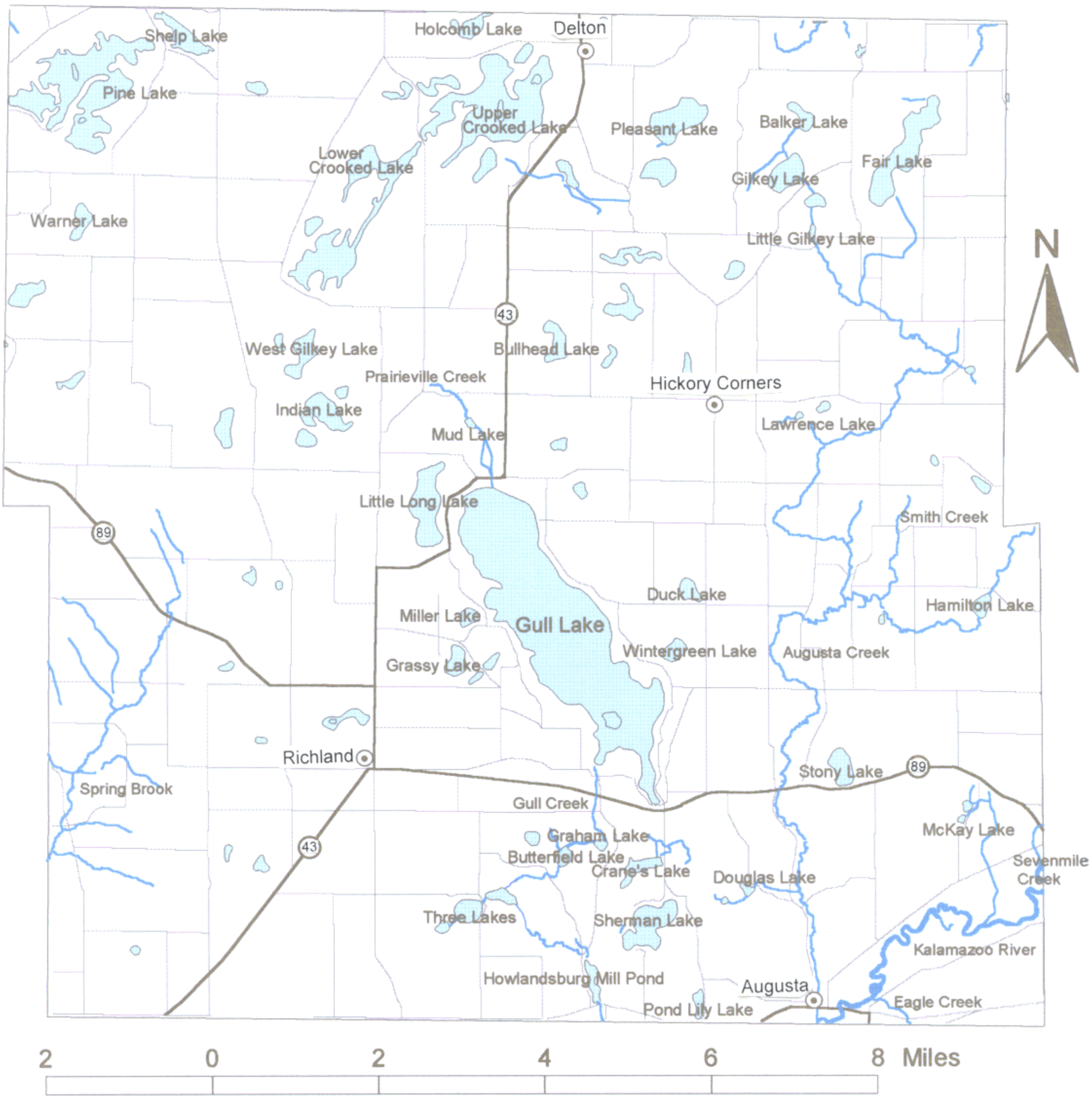


Figure 9. Lakes and streams of the four-township area.

Stream/River	Specific Conductance (µS/cm)	Alkalinity (mg $CaCO_3$/L)	Hardness as $CaCO_3$ (mg/L)	pH	Total Dissolved Phosphorus (µg P/L)	Nitrate (µg N/L)	Ammonium (µg N/L)
Smith Creek (at Baseline Rd.)	435	227	220 (very hard)	7.30	4	457	55
Spring Brook (at C. Ave.)	471	—	150 (hard)	7.61	16	1300	17
Prairieville Creek (at Hickory Rd.)	606	288	357 (very hard)	7.75	3	5177	9
Augusta Creek (at Kellogg Forest)	496	240	275 (very hard)	7.81	6	1065	6
Gull Creek (at Greer Rd.)	383	167	184 (very hard)	7.70	3	192	44
Kalamazoo River (at Fort Custer)	595	238	285 (very hard)	7.80	27	869	32
Sevenmile Creek (at Baseline Rd.)**	491	210	257 (very hard)	7.46	10	3	8
Eagle Creek (at River Rd.)	350	147	201 (very hard)	7.67	9	40	12

Table 2. Stream water chemistry data. See Appendix for an explanation of these measurements.

Stream/River	Approx. Width (feet)	Approx. Depth (feet)	Discharge (ft.^{3}/sec)
Smith Creek (at Baseline Rd.)	3	0.25	1
Spring Brook (at C. Ave.)	6.5	1	21
Prairieville Creek (at Hickory Rd.)	2	0.5	0.65
Augusta Creek (at Kellogg Forest.)	16	1	22-106
Gull Creek (at Greer Rd.)	6 to 12	0.5-5	15-102
Kalamazoo River (at Fort Custer)	106	---	400-3610
Sevenmile Creek (at Baseline Rd.)	15	0.5	21
Eagle Creek (at River Rd.)	13	0.5	5-16

Table 3: Stream widths, depths, and discharge.

Width and depth data in this table are approximate and are to be used only to give the reader an idea of the stream size.

Discharge varies seasonally and annually. Discharge data given as a range are from Rheaume (1990) and include data from multiple dates . The other discharge data are from one date and are included here only to give the reader an idea of the stream discharge.

to the Gull Creek system, and is managed by the Gull Lake Association to control the lake's water level. Gull Creek above G Avenue passes through an old mill pond. The final part of the Augusta Creek channel in Augusta is diverted into a canal, and a dam near its mouth controls the water level in the canal.

Anecdotal evidence indicates that streams and rivers in the four-township area are probably in better ecological condition today than at many times during the historical past. For streams, this is largely explained by changes in land use; most low-lying areas close to the stream channels were once used for agricultural purposes but have been left alone in recent decades as local agriculture has become more focused on row crops in the upland areas. The natural floodplains along the streams are becoming reforested, providing a buffer against surface runoff and soil erosion and stabilizing the stream channels. The maintenance of these riparian buffer areas in the face of future pressures for residential development will be important to protect stream water quality. In the case of the Kalamazoo River, municipal sewage treatment and reductions in industrial point-source pollution in the Battle Creek area have led to considerable improvement in water quality during the past few decades, although non-point-source pollution continues to be a problem.

Augusta Creek provides an example of the streams in the four-township area. This stream is particularly important for recreational opportunities because there is public access at the W.K. Kellogg Experimental

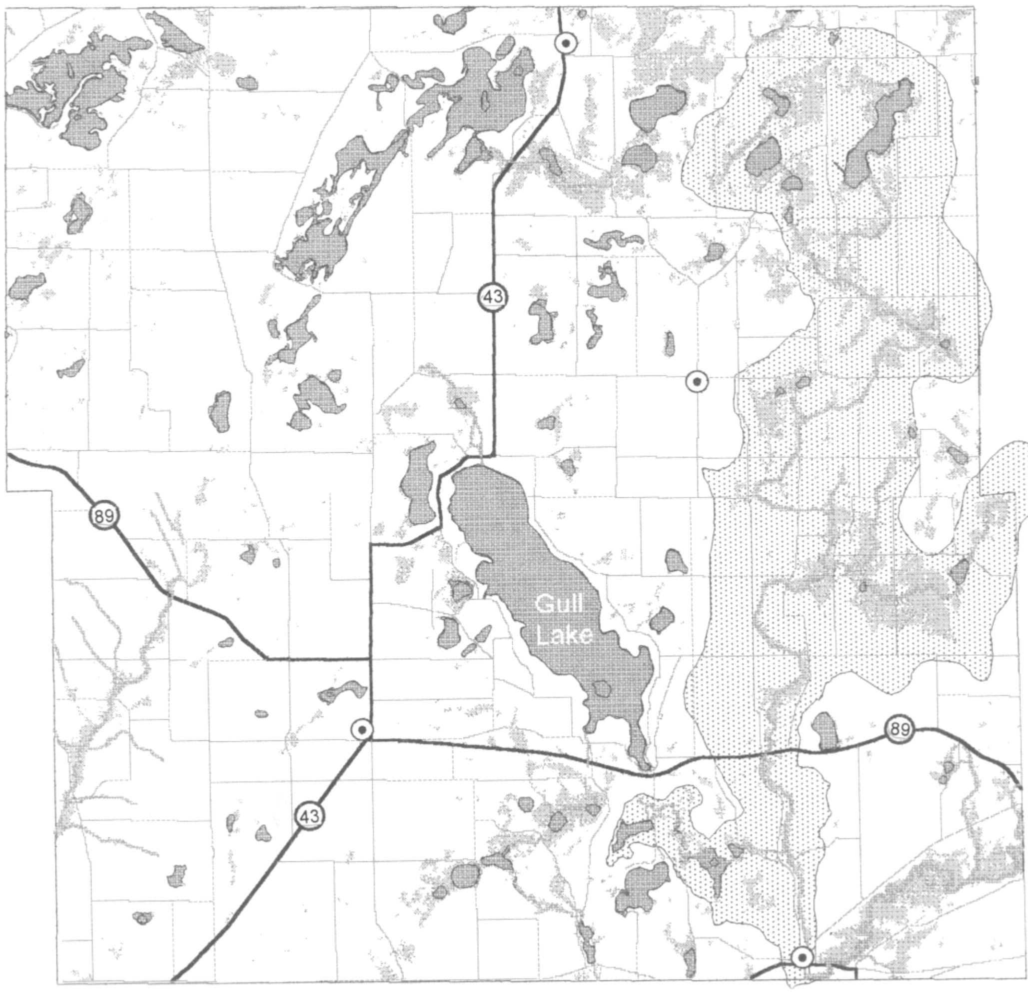


Figure 10. Augusta Creek watershed (delineated by Mahan, 1980).

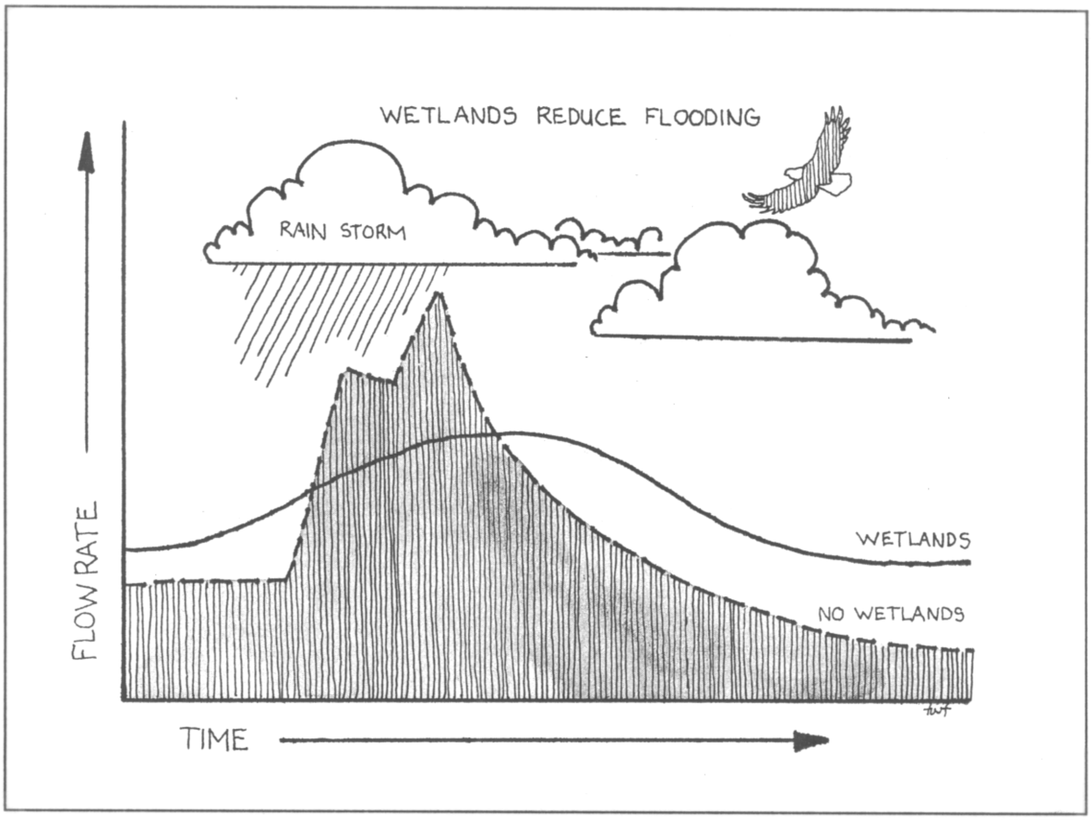


Figure 11. The importance of wetlands in reducing flooding after storms. From Cwikeil (1996) and used with permission from the Tip of the Mitt Watershed Council.

Forest (owned by Michigan State University) and at the Augusta Creek Hunting and Fishing Area (owned by the Michigan Department of Natural Resources). Fly fishing is popular in the stream, which is annually stocked with trout. A group of local citizens called the Augusta Creek Watershed Association works to educate people about the environmental values of the creek and its watershed; they have an Internet site at http://kbs.msu.edu/acwa.

A great deal of ecological research has been performed at Augusta Creek by professors and students from Michigan State University's Kellogg Biological Station (KBS), and the results of this research are found in numerous scientific publications (a complete list is maintained by the KBS library). Mahan and Cummins (1974) wrote an overview of the stream system and its plant and animal life.

Figure 10 shows the Augusta Creek watershed, which is the area surrounding the stream that potentially contributes water to the stream by either surface runoff or groundwater flow. These watershed boundaries are based on topography alone and should be considered approximate. The outflows from Gilkey and Fair Lakes supply water to the headwaters of the Augusta Creek system, and several smaller lakes also drain into the creek system.

The extensive riparian wetlands all along the stream courses in Augusta Creek and its tributaries help to stabilize the flow of water in the creek by absorbing excess water during high flow and slowly returning this excess water over ensuing periods of lower flow. Figure 11 illustrates how riparian wetlands can attenuate a flood peak in a stream.

A study by the U.S. Geological Survey determined a water budget for the Augusta Creek watershed, estimating all of the significant inputs of water that support the discharge of the creek (Rheaume 1990). Figure 12 summarizes the water budget, expressing the inputs and output as the equivalent depth of precipitation over the watershed, and as the percentage of the total precipitation falling in the watershed. Over the long term, 38% of the precipitation falling within the watershed ultimately reaches the stream (the remainder is returned to the atmosphere by evapotranspiration). Most of the stream discharge is supported by groundwater inputs. Since groundwater flow through the watershed is very slow, the groundwater entering the creek in a particular year may have originated as precipitation several years (or possibly even decades) earlier.

The large contribution of groundwater inputs to the discharge of Augusta Creek makes the stream flow relatively stable compared to creeks that receive more surface runoff. The U.S. Geological Survey has maintained records of discharge at EF Avenue since October 1964 (Figure 13). The horizontal line shows the average discharge for this record (45 cfs). The creek maintains much of its flow even in relatively dry periods because the groundwater inputs are less affected by short-term reductions in precipitation. For the same reason, the stream does not respond as strongly to wetter years, and even large rainfalls produce only a moderate increase in stream discharge and water level. Floods tend to occur more in the winter and spring during snowmelt or rainfall when the soils are frozen or saturated, and the floodplains along the stream are usually inundated only for brief periods. Additional hydrologic characteristics for Augusta Creek and other local streams are presented in Allen et al. (1972), and the U.S. Geological Survey annually publishes updated statistics on discharge for Augusta Creek.

The groundwater enters the stream by seepage through its bed and through the beds of lakes in its headwaters. In addition, groundwater on its way to the stream often

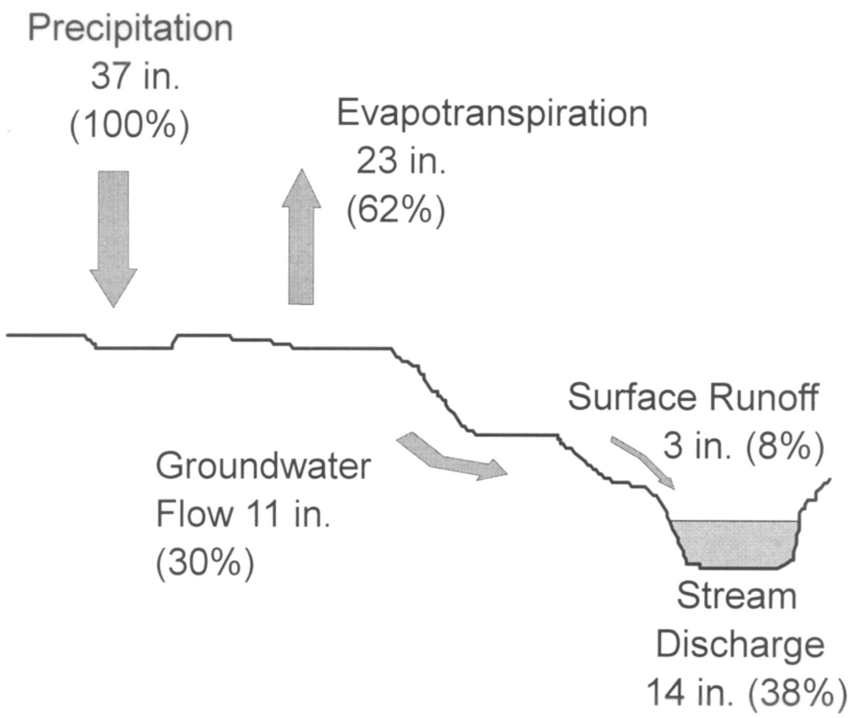


Figure 12. Augusta Creek water budget (based on data in Rheaume 1990)

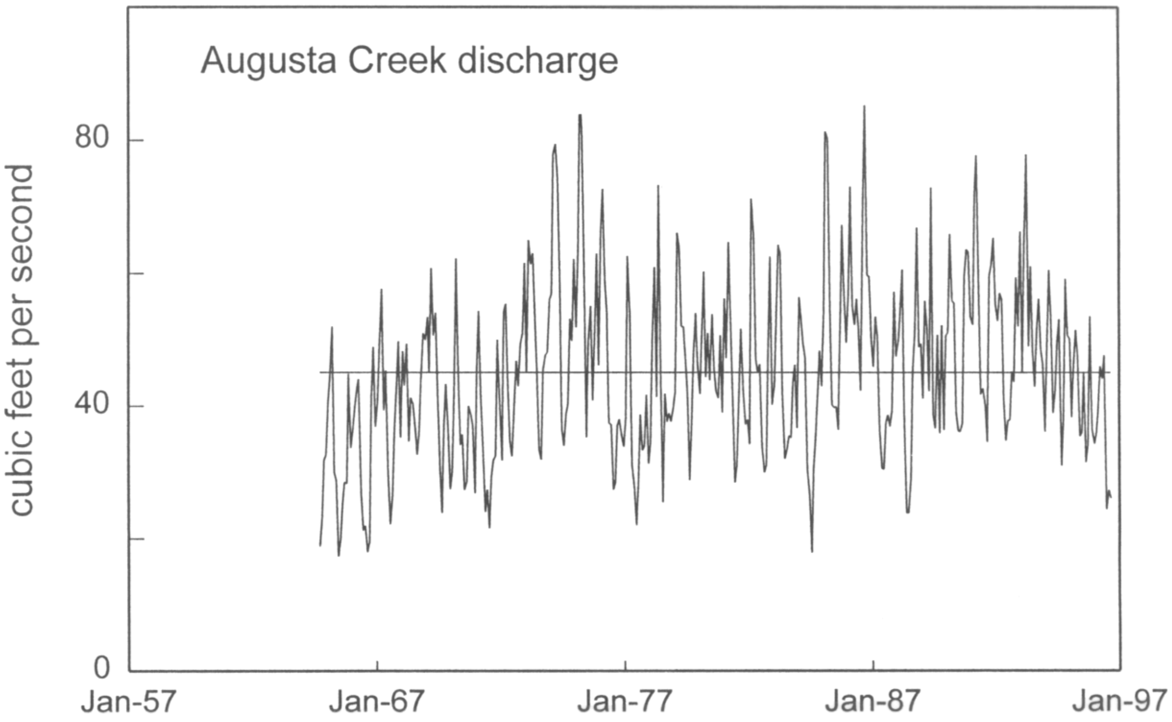


Figure 13. Augusta Creek discharge at EF Avenue (US Geological Survey data). The average discharge for this period is indicated by the horizontal line.

appears near the soil surface in floodplain environments, maintaining riparian wetlands with distinct plant communities; these riparian wetlands are discussed later.

The temperature of groundwater is around 50° F and varies little throughout the year. For streams like Augusta Creek that receive most of their flow from groundwater inputs, this stable temperature has several implications. Water temperatures are moderated by the groundwater inputs, staying cooler in the summer and warmer in the winter. The lower summer water temperatures resulting from groundwater inputs make Augusta Creek a suitable habitat for trout, which cannot survive the warm water temperatures that most local streams experience in the summer. Shading of the stream channel by forest also helps to keep the water cooler, and thus streamside vegetation should be protected whenever possible. In the winter, many stretches of Augusta Creek resist freezing because of the relatively warm groundwater inputs.

This survey of water quality in the streams of the four-township area shows that all of them are rich in dissolved substances, reflecting the importance of groundwater inputs to all streams in this area. Table 1 presents detailed chemical data for Augusta and Prairieville Creeks and Tables 2 and 3 present selected chemical and physical data on all of the streams in the four-township area.

The streams tend to carry low concentrations of phosphorus and ammonium, but many do have high concentrations of nitrate, which is similar to the nutrient concentrations in local groundwater. The stream waters are usually clear and low in suspended sediments, although they may carry considerable amounts of sediment as sand that moves along the stream bottom. Most of our streams originate in or pass through lakes and wetlands, which effectively remove sediment and nutrients and thereby improve the downstream water quality. The streams that flow into lakes are potentially important to the water quality of those lakes, and of course all of our streams contribute water and nutrients to the Kalamazoo River and Lake Michigan.

The Total Maximum Daily Load (TMDL) program of the U.S. Environmental Protection Agency is designed to identify and restore polluted waters. As part of this program, the Michigan Department of Environmental Quality has identified streams and rivers throughout the state that are out of compliance with water quality standards and thus require reductions in the inputs ("loads") of pollutants. As of December 1998, waters in the four-township area that are out of compliance are the Kalamazoo River (for mercury, PCB's, and phosphorus), Augusta Creek where it is channelized at Augusta (which showed a poor invertebrate community), and Gull Lake (for mercury and PCB's found in the tissues of certain fishes).

Lakes

The aesthetic and recreational values of lakes are widely recognized by residents in the four-township area. The larger lakes are popular sites for seasonal and year-round residences, and those with public access also draw visitors from outlying areas to use the lakes for recreational purposes. Protection of the water quality of these lakes is therefore of paramount interest. There are also many smaller, shallow lakes that become filled with plant growth during the summer. These shallower lakes may not be suitable for motorized boating, but they have significant ecological and aesthetic values. The diversity of lake types in the four-township area is associated with a diversity of aquatic plant and animal life as well.

Many aspects of the ecology of three local lakes in the four-township area – Gull, Wintergreen, and Lawrence lakes (Figure 9 and Tables 4 and 5) – have been studied since the 1970's by researchers at Michigan State University's Kellogg Biological Station (KBS). These three lakes contrast in their water quality and ecological characteristics and span the diversity of most lakes found in the four-township area. Results of these studies are reported in numerous scientific publications and textbooks (a complete list is maintained by the KBS Library). Management decisions regarding our local lakes can therefore be based on a strong scientific underpinning that is not available in most places.

Gull Lake is one of the largest inland lakes in Michigan, with an area of 2040 acres and a maximum depth of over 110 feet. This lake is unusual in southern Michigan because it supports a diverse fishery, including both warm- and cold-water species. Gull Lake serves as an important public recreational site for the region. Residential development lines the lakeshore.

The realization by the 1970's that the waters of Gull Lake were becoming more turbid with algae prompted public concern. Studies by researchers at KBS showed the link between nutrient supply and algal blooms and established that phosphorus was the principal nutrient limiting algal growth in the lake (reviewed by Tessier and Lauff 1992). In other words, an increase in phosphorus supply to the lake would stimulate the growth of algae and other aquatic plants.

A water budget for Gull Lake in 1974 revealed that the lake received 40% of its water from groundwater inflow, 25% from direct precipitation onto the lake surface, and 35% from stream inflows (Tague 1977). The water budget was combined with information on the phosphorus concentrations of these inputs to formulate a phosphorus budget for the lake (Tague 1977). The phosphorus budget demonstrated that septic systems and lawn fertilization comprised 76% of the annual phosphorus inputs at that time. The lakeside homes were subsequently put on a sewer system to reduce septic inputs and residents were urged to apply fertilizers sparingly if at all, and these measures apparently led to reductions in summer algal blooms and improvements in water clarity in later years (Tessier and Lauff 1992). Dr. Alan Tessier of KBS has revised the phosphorus budget for Gull Lake based on water sampling during 1994-95.

Lake	Specific Conductance (μS/cm)	Alkalinity (mg $CaCO_3$/L)	Hardness (mg $CaCO_3$/L)	pH	Total Dissolved Phosphorus (μg P/L)	Nitrate (μg N/L)	Ammonium (μg N/L)
Balker Lake	335	162	124 (hard)	7.38	15	27	3
Bullhead Lake	337	150	179 (hard)	6.97	---	< 30	---
Butterfield/ Graham Lake	383	167	184 (very hard)	7.70	3	192	44
Crane's Lake	263	130	139 (hard)	7.60	9	< 30	1
Crooked Lake-Lower	169	70	72 (moderately hard)	8.85	9	< 30	1
Crooked Lake-Upper	231	91	154 (hard)	8.62	7	< 30	3
Douglas Lake	400	186	201 (very hard)	7.60	6	< 30	6
Duck Lake	217	96	105 (moderately hard)	7.50	5	< 30	3
Fair Lake	152	63	119 (moderately hard)	7.13	7	< 30	13
Gilkey Lake	292	135	170 (hard)	8.02	9	< 30	2
Gull Lake	360	150	200 (very hard)	8.11	7	208	27

Table 4. Lake water chemistry data. See Appendix for an explanation of these measurements. Continued on next page.

Lake	Specific Conductance (μS/cm)	Alkalinity (mg $CaCO_3$/L)	Hardness (mg $CaCO_3$/L)	pH	Total Dissolved Phosphorus (μg P/L)	Nitrate (μg N/L)	Ammonium (μg N/L)
Hamilton Lake	358	172	217 (very hard)	7.30	9	84	22
Holcomb Lake	71	27	85 (moderately hard)	7.62	10	< 30	4
Indian Lake	153	75	83 (moderately hard)	6.37	---	< 30	---
Lawrence Lake	413	195	182 (very hard)	8.02	15	718	---
Little Gilkey Lake	344	163	180 (hard)	7.55	7	28	7
Little Long Lake	391	160	221 (very hard)	8.15	8	314	104
McKay Lake	439	177	211 (very hard)	7.30	4	37	6
Howlandsburg Mill Pond	387	168	198 (very hard)	7.60	16	229	27
Miller Lake	370	170	182 (very hard)	8.03	5	287	268
Mud Lake	576	265	312 (very hard)	7.78	9	3652	10

Table 4. continued

Lake	Specific Conductance (μS/cm)	Alkalinity (mg $CaCO_3$/L)	Hardness (mg $CaCO_3$/L)	pH	Total Dissolved Phosphorus (μg P/L)	Nitrate (μg N/L)	Ammonium (μg N/L)
Pine Lake	284	126	161 (hard)	8.61	6	< 30	5
Pleasant Lake	46	24	25 (soft)	6.94	7	< 30	7
Pond Lily Lake	94	40	45 (soft)	6.90	10	< 30	1
Shelp Lake	274	133	165 (hard)	7.36	8	< 30	3
Sherman Lake	174	70	115 (moderately hard)	8.83	6	< 30	6
Stony Lake	172	65	74 (moderately hard)	7.30	3	84	29
Three Lakes-middle	388	165	216 (very hard)	8.34	7	138	39
Warner Lake	248	110	150 (hard)	8.22	6	< 30	5
West Gilkey Lake	289	142	153 (hard)	6.70	---	< 30	na
Wintergreen Lake	400	192	206 (very hard)	8.60	---	542	300

Table 4. continued

Lake	Township	Area (acres)	Approximate Maximum Depth (feet)	Zebra Mussel Status
Balker Lake	Barry	33	___	not susceptible
Bullhead Lake	Barry	53	___	not susceptible
Butterfield/ Graham Lake	Ross	22/11	<6	susceptible
Crane's Lake	Ross	48	>20	susceptible
Crooked Lake-Lower	Prairieville	417	12	susceptible
Crooked Lake-Upper	Prairieville	735	48	susceptible
Douglas Lake	Ross	10	>6	susceptible
Duck Lake	Ross	33	12	not susceptible
Fair Lake	Barry	229	39	not susceptible
Gilkey Lake	Barry	83	33	susceptible
Gull Lake	Ross/ Richland/ Prairieville/ Barry	2040	110	present
Hamilton Lake	Ross	40	35	susceptible
Holcomb Lake	Prairieville	45	___	not susceptible
Indian Lake	Prairieville	98	___	not susceptible
Lawrence Lake	Barry	10	39	susceptible
Little Gilkey Lake	Barry	10	___	susceptible

Table 5. Area, depth and zebra mussel susceptibility of Four Township lakes. Continued on next page.

Lake	Township	Area (acres)	Approximate Maximum Depth (feet)	Zebra Mussel Status
Little Long Lake	Prairieville/ Richland	174	30	susceptible
McKay Lake	Ross	12	<6	susceptible
Howlandsburg Mill Pond	Ross	29	>6	susceptible
Miller Lake	Richland	25	---	susceptible
Mud Lake	Prairieville	7	---	susceptible
Pine Lake	Prairieville	621	34	susceptible
Pleasant Lake	Barry	143	27	not susceptible
Pond Lily Lake	Ross	20	2	not susceptible
Shelp Lake	Prairieville	79	52	not susceptible
Sherman Lake	Ross	120	38	susceptible
Stony Lake	Ross	63	>6	not susceptible
Three Lakes-middle	Richland	51	33	susceptible
Warner Lake	Prairieville	40	26	susceptible
West Gilkey Lake	Prairieville	68	1.7	not susceptible
Wintergreen Lake	Ross	44	21	susceptible

Table 5. continued

Since 1996, blooms of blue-green algae in Gull Lake have decreased water clarity considerably in the late summer and fall. The species has been identified as *Microcystis aeruginosa*, which is undesirable because it often forms surface scums and foam, and because it sometimes produces a potent toxin that can make the water unsafe to ingest if the algal cells are very concentrated. Researchers at KBS are investigating the cause of the blooms in Gull Lake. For more information on *Microcystis*, KBS has a fact sheet on the Internet at: http://www.kbs.msu.edu/extension/microcystis.

In the past five years, the introduced zebra mussel (*Dreissena polymorpha*) has become well established in Gull Lake and is likely to be spreading to other local lakes, particularly those used by boaters. The only other confirmed population of zebra mussels in the area is in Gun Lake, north of Prairieville Township. The impacts of this exotic invasion on the ecology of inland lakes are not well understood; so far most research has been done in the Great Lakes. KBS researchers are currently investigating the hypothesis that the zebra mussels are responsible for the recent occurrence of blue-green algal blooms in Gull Lake as well as in Gun Lake.

Deeper lakes in the four-township area show the typical pattern of seasonal stratification and mixing, as depicted in Figure 14. After the ice melts in the Spring, the entire lake mixes. As the weather warms in the early summer, the surface water of the lake becomes warmer than the deeper waters, stratifying the water column into two distinct layers with the warmer, less dense water on top.

This summer stratification is important to the ecology of the lake because most plant growth occurs in the upper layer, or epilimnion, where light is available. The lower layer, or hypolimnion, may be too dark for plant growth, but microbial decomposition in the deeper waters can deplete the dissolved oxygen over the course of the summer.

As the weather cools in the fall, the surface waters cool, making them denser. Eventually they reach a temperature similar to that of the bottom waters and the lake "turns over", or mixes. At this point the entire water column becomes oxygenated. Later in the winter, a layer of ice forms on top of the water column. If the period of ice cover is protracted, oxygen depletion may occur in the underlying water, resulting in "winterkill" of fishes if the depletion extends through the entire water column. Winterkill tends to occur in the shallower lakes.

Vertical profiles of temperature and dissolved oxygen for Gull Lake are shown in Figure 15 to illustrate this seasonal cycle of mixing and stratification. In this year (1994), the lake had nearly uniform temperature and oxygen profiles in May. The stratification became marked over the summer, and complete oxygen depletion was observed in the hypolimnion by September. By November, the depth of the upper mixed layer had increased to about three-quarters of the water column. Complete mixing of the waters likely occurred soon after.

Pine Lake, which is not as deep as Gull Lake, shows similar seasonal changes although the hypolimnion layer is not as thick (Figure 16). Summer profiles for several other lakes in the four-township area are shown in Figures 17-20. All of these lakes show some degree of thermal stratification, although the patterns vary among lakes. This variation reflects their diverse sizes, which determines the exposure of the water surface to mixing by wind, and the depths of their basins.

Dissolved oxygen profiles also show considerable variability among the lakes presented in Figures 15-20. Lakes with extensive plant growth tend to be richer in oxygen in the surface waters, where most algal and plant growth occurs, and more depleted in oxygen near the bottom, where decomposition is the dominant biological process. Among the examples shown here, oxygen depletion to near zero close to the bottom was observed only in Gull, Pine, Lower Crooked, and Sherman lakes.

The lakes in the four-township area are diverse in their water quality and ecological

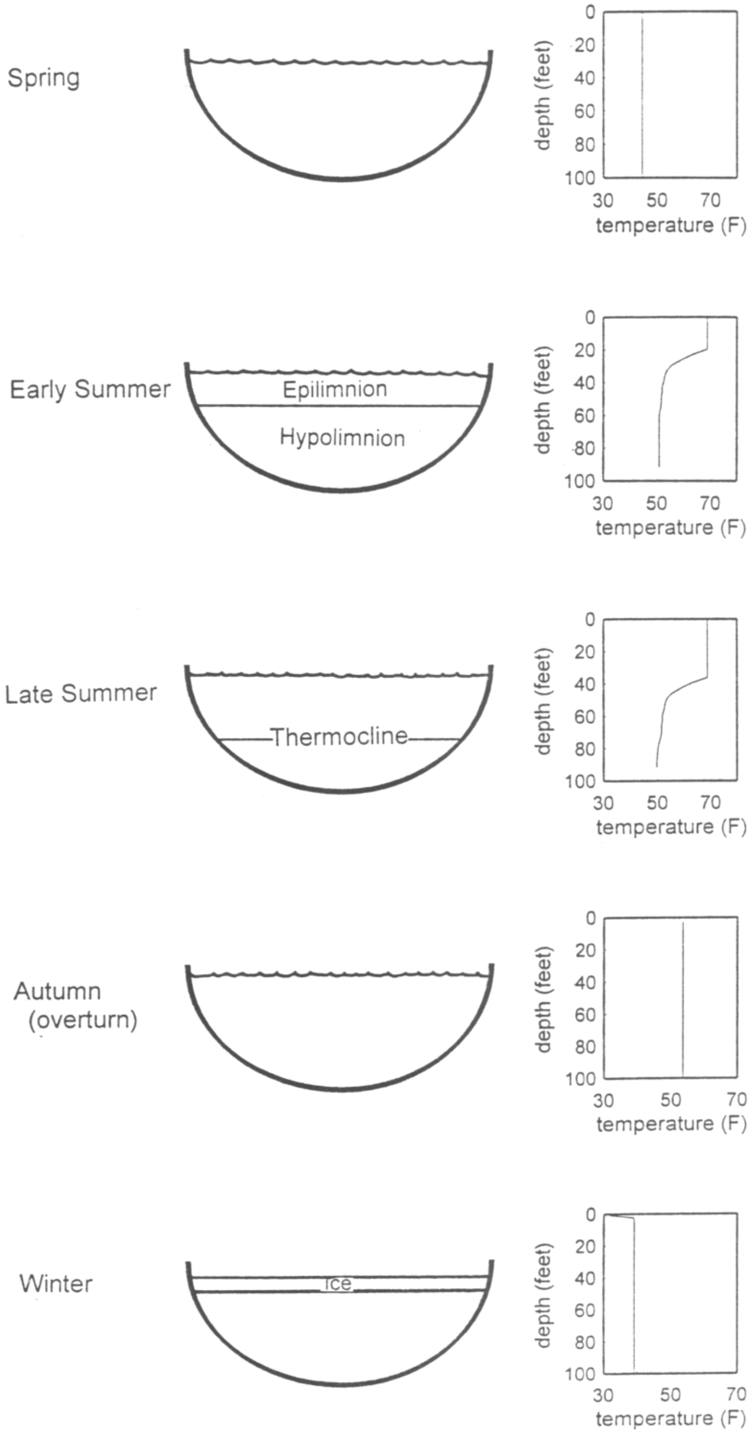


Figure 14. The seasonal cycles of thermal stratification and mixing in lakes.

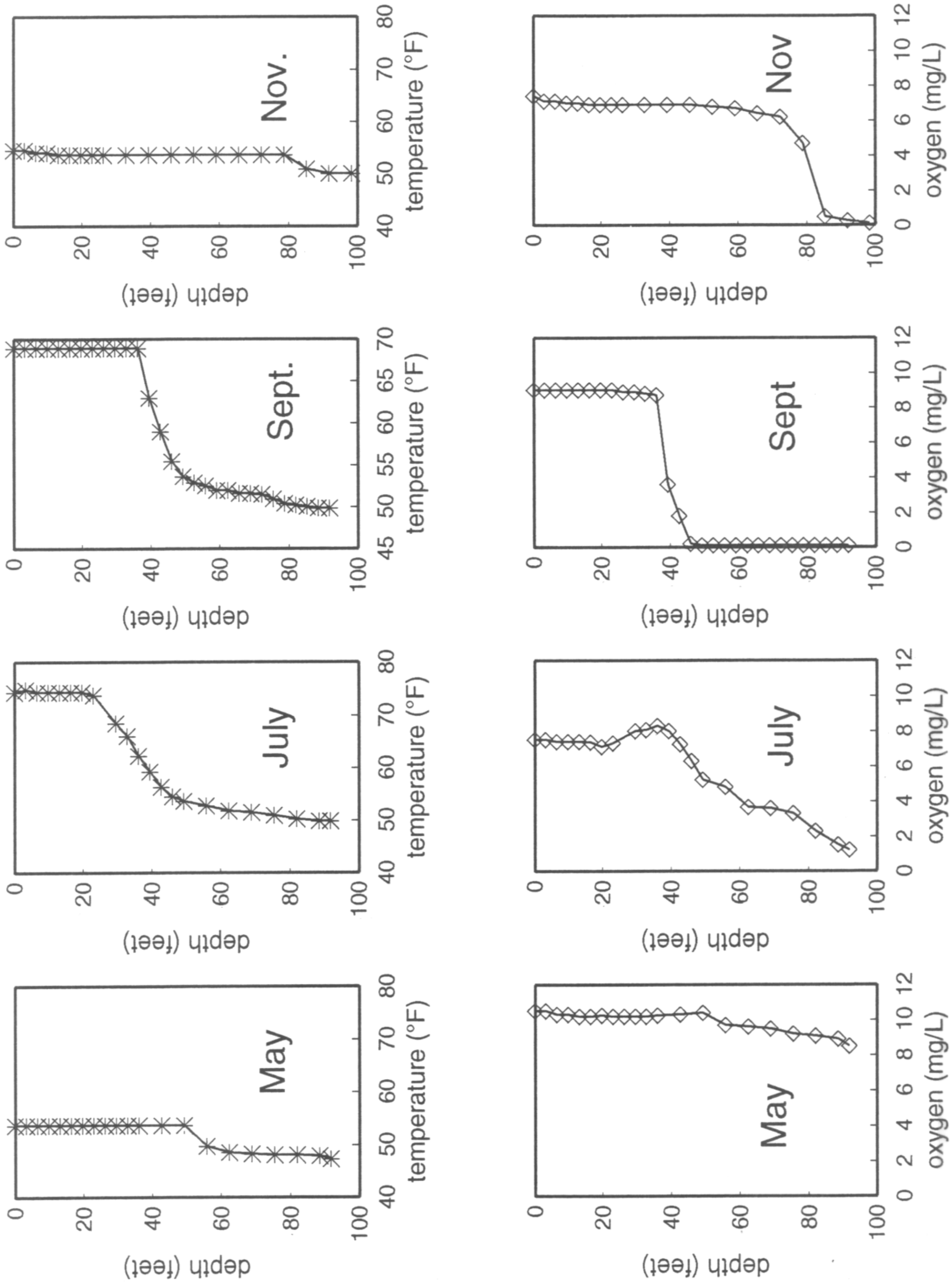


Figure 15. Temperature (top row) and oxygen profiles (bottom row) for Gull Lake from 1994. Data are from Tessier (1994).

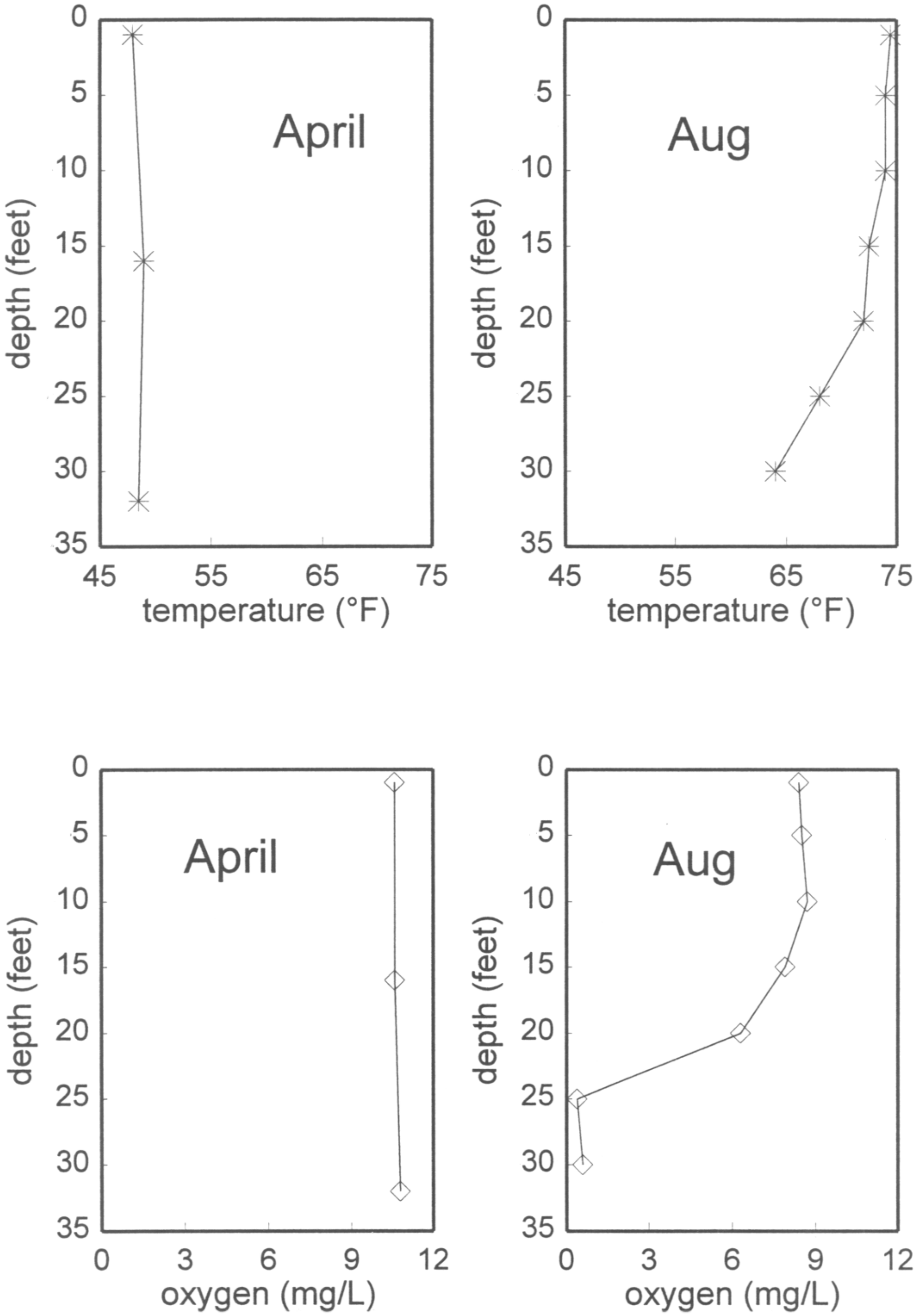


Figure 16. Summer temperature and oxygen profiles from Pine Lake, 1996 (Progressive AE, unpublished field data).

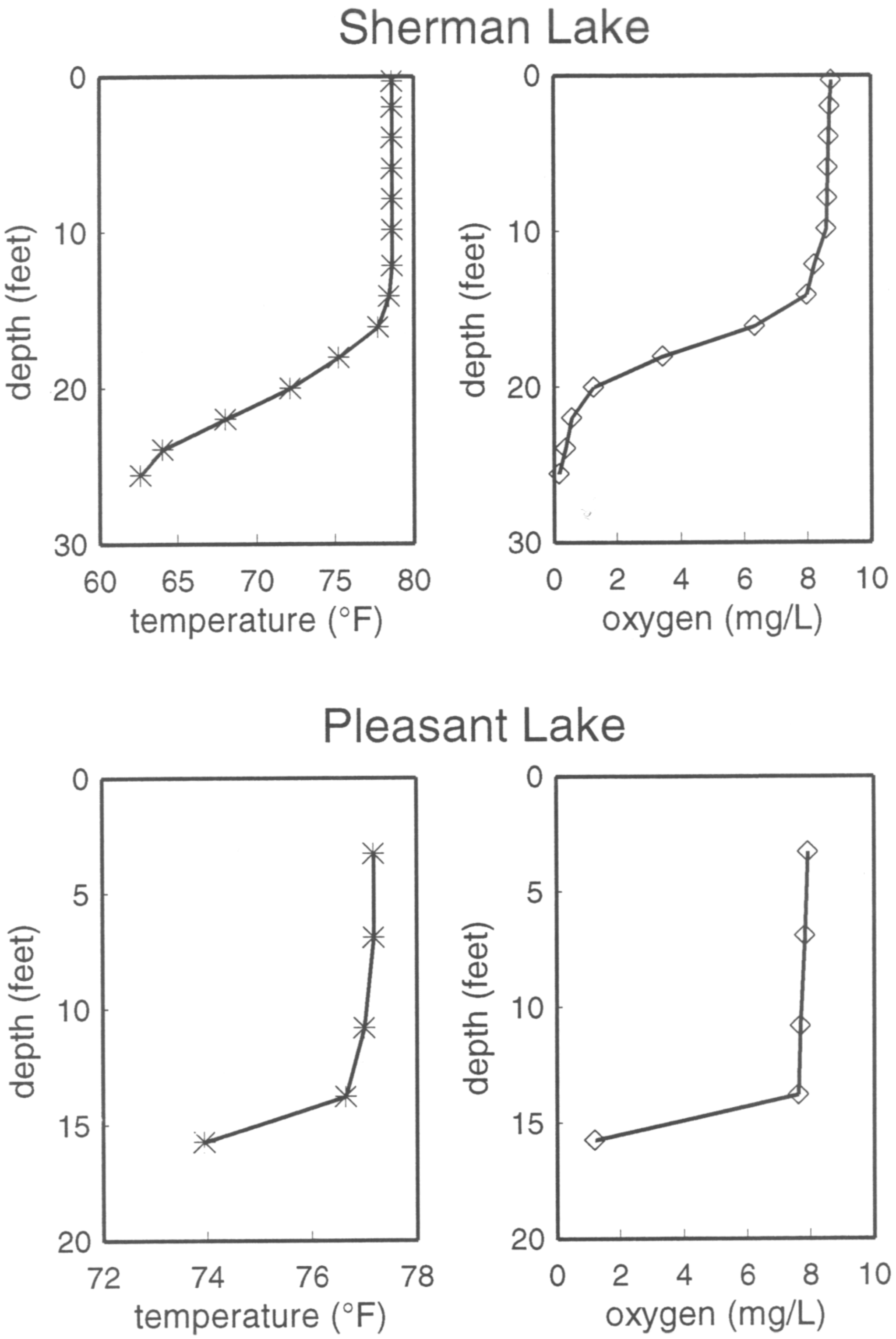


Figure 17. Summer temperature and oxygen profiles from Sherman and Pleasant Lakes.

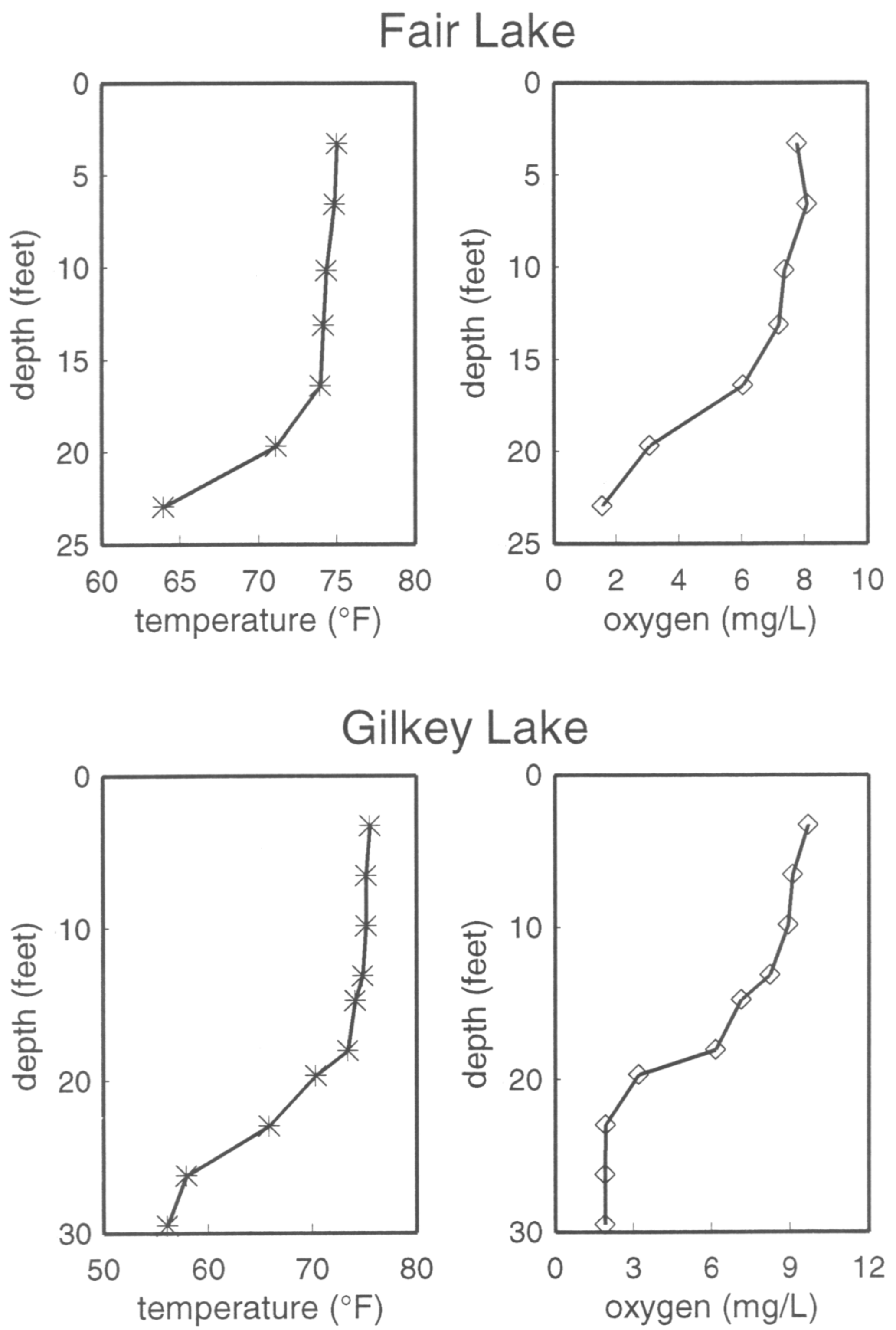


Figure 18. Summer temperature and oxygen profiles from Fair and Gilkey Lakes.

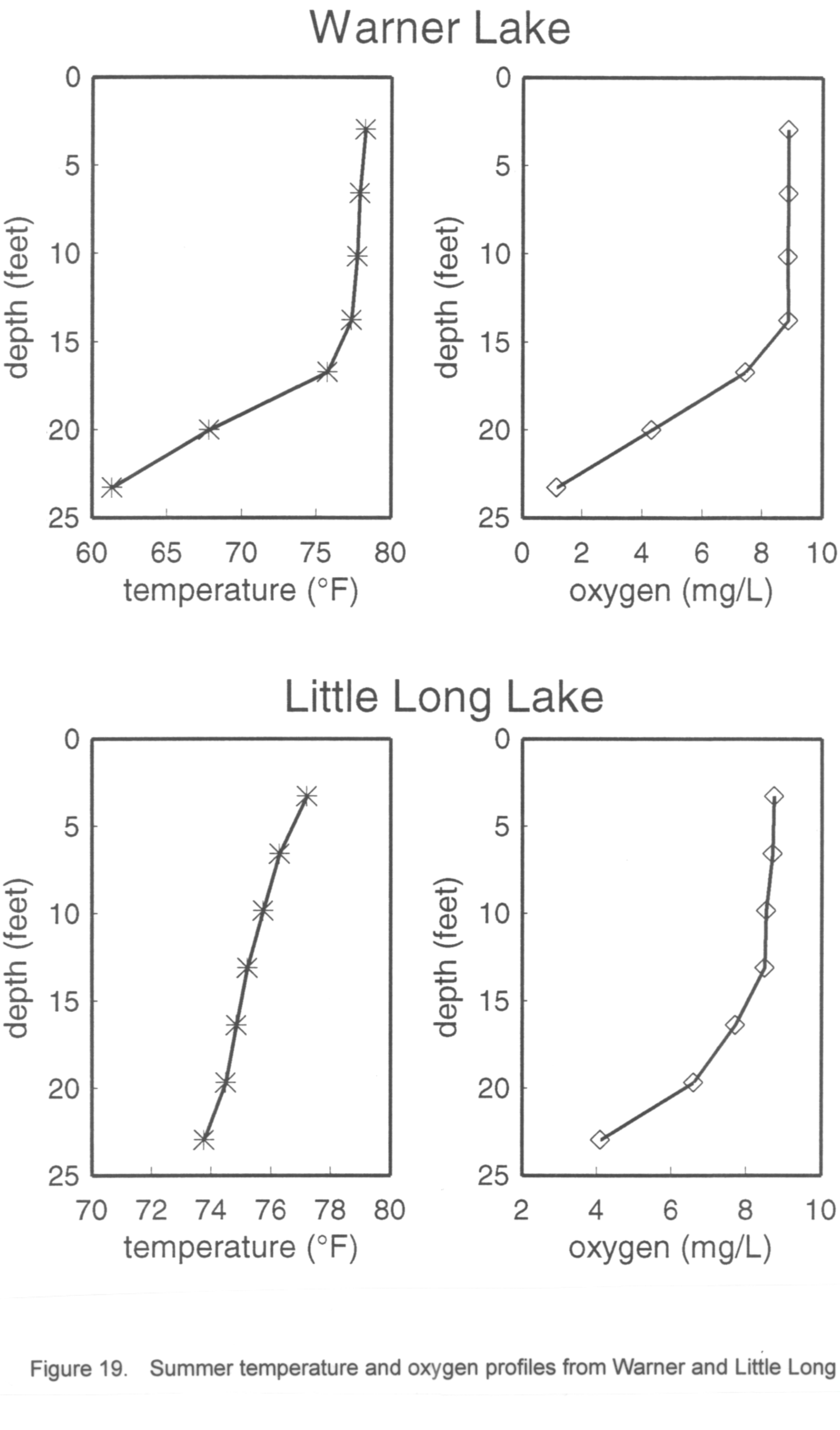


Figure 19. Summer temperature and oxygen profiles from Warner and Little Long Lakes.

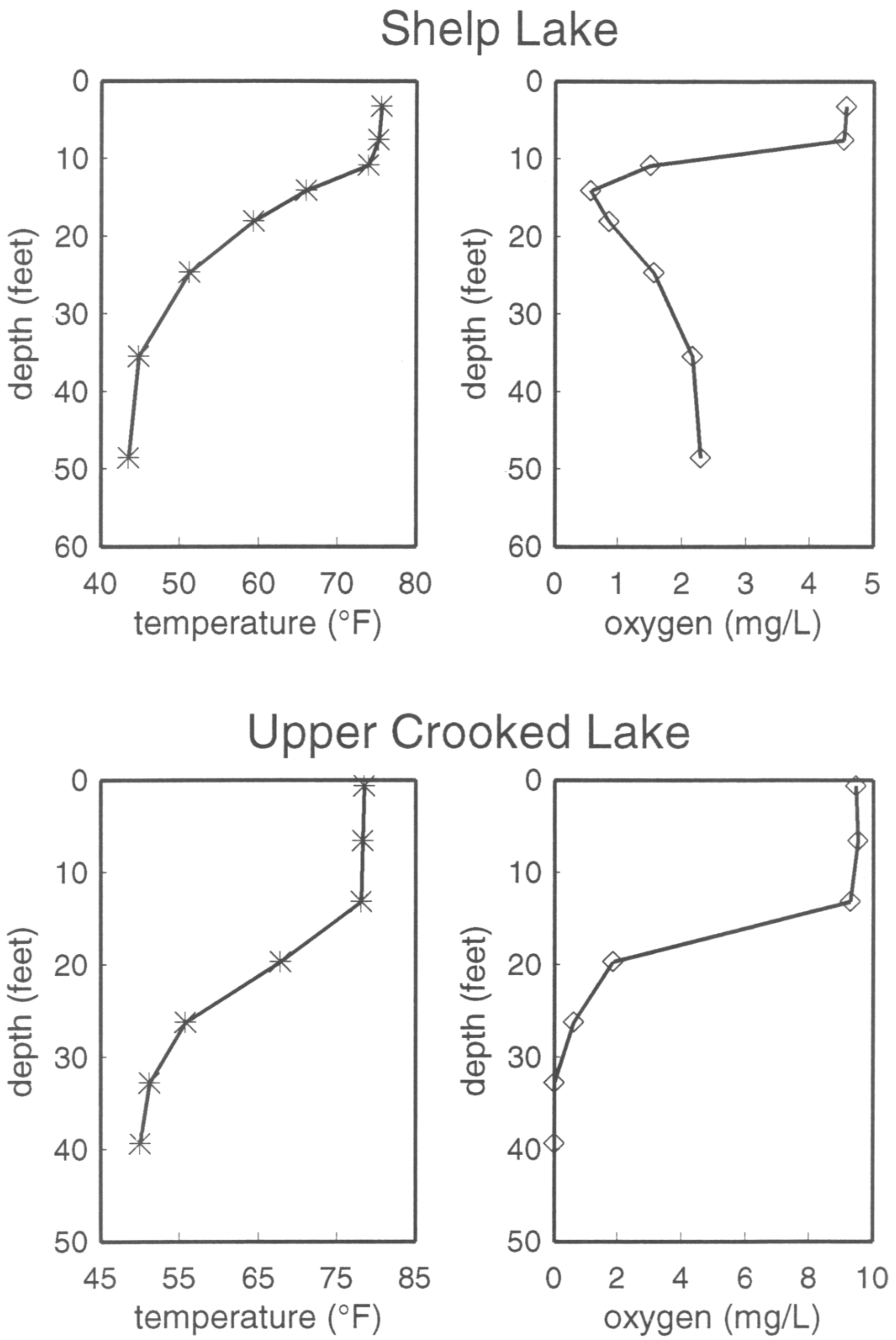


Figure 20. Summer temperature and oxygen profiles from Shelp and Upper Crooked Lakes.

characteristics. Table 1 presents complete chemical data for four contrasting lakes surveyed by the FTWRC to illustrate the variation in water quality among local lakes:

1) Lawrence Lake is a small, privately owned lake that is primarily fed by groundwater, much of which arises in nearby wetlands and flows through small streams to reach the lake. The residence time or turnover time of water in Lawrence Lake, which is the time for complete replacement of the water in the lake by inflows and precipitation, is about 7 months. The water in this lake resembles that of local groundwater, and is low in phosphorus (Wetzel, 1989).

2) Gull Lake, as already discussed, also receives considerable groundwater inputs, either via seepage across the lake bottom or via groundwater-fed streams (especially Prairieville Creek). The chemistry of Gull Lake reflects this high groundwater contribution. The residence time of water in Gull Lake is at least 4 years because of its large volume.

3) Lower Crooked Lake receives less groundwater input and hence contains lower concentrations of most dissolved substances. This lake has no stream inputs although it does receive some flow from Middle and Upper Crooked Lakes. Residence time is unknown.

4) Pleasant Lake is distinct among lakes in the four-township area in its relatively low concentrations of dissolved substances, indicating that the major source of water to the lake is precipitation rather than groundwater. The water quality of this lake is consistent with the presence of *Sphagnum* mosses and other bog vegetation along its shores, which typically develop in precipitation-fed wetlands. Residence time is unknown.

Selected data from our survey of all of the lakes in the four-township area are presented in Tables 4 and 5. These are mostly one-time samplings and thus represent "snapshots" of the water quality and do not reveal possible seasonal and year-to-year variation. In the case of Gull Lake, however, the data represent averages for several samplings over the course of the summer of 1998. The data in Table 4 are for samples that were collected from the upper water layer, and in deeper lakes the bottom waters can develop chemical differences during the summer. Deeper lakes were usually sampled at two depths in the survey, although data for the bottom waters are not presented here. Despite these limitations, the data presented in Table 4 are useful to characterize broad patterns and to detect large differences among local lakes.

Specific conductance of the lakes shows that they range widely in total dissolved minerals (ions), but most are above 200 μS/cm, suggesting substantial inputs of groundwater. (See the Appendix for explanations of water-quality measurements.) The conductance ranges from 46 μS/cm in Pleasant Lake to 576 μS/cm in Mud Lake, a small lake located on Prairieville Creek. Only a few lakes in addition to Pleasant Lake are evidently not fed by groundwater (i.e., they have a conductance below about 100 μS/cm). Alkalinity, hardness, and to some extent pH are all related to specific conductance and therefore to the relative importance of groundwater compared to precipitation as sources of water to the lake.

Few lakes maintain a conductance as high as groundwater because when groundwater enters surface water bodies, it tends to form precipitates of marl (calcium carbonate). This precipitation removes dissolved calcium and bicarbonate ions from the water and reduces the conductance. The tendency for many local lakes to form marl sediments was historically important in the four-township area because many of the smaller lakes, such as Lawrence Lake, were mined for marl to meet the demand for calcium carbonate as a soil amendment in agriculture. Wetlands that receive groundwater discharge can also contain marl sediments and were sometimes mined as well.

Nutrient concentrations in the upper layers of most lakes in the four-township area are not elevated, except for nitrate in lakes that receive high groundwater inputs. Phosphorus is especially important because algal growth is likely to increase with an

Lake Trophic State	Water Quality Measurement		
	Phosphorus (μg/l)	Transparency as Secchi depth (ft.)	Chlorophyll-a (μg/l)
Oligotrophic	Less than 10	Greater than 15	Less than 2.2
Mesotrophic	10 - 20	7.5 - 15	2.2 - 6
Eutrophic	Greater than 20	Less than 7.5	Greater than 6

Table 6: Water quality criteria used to classify the trophic state of lakes. (Michigan Department of Natural Resources, 1990).

increase in phosphorus concentrations. Aquatic plants, including macrophytes (popularly called "weeds"; most of these are flowering plants) as well as algae, require nitrogen and phosphorus in certain proportions to grow. Aquatic plants obtain these nutrients from the water or, for rooted plants, from the sediments as well. Nutrient concentrations and the ratio of nitrogen to phosphorus in lake waters provide an indication of which of these two critical nutrients is likely to stimulate plant growth if its concentration increases. Concentrations of total dissolved phosphorus are low to moderate in the lakes of the four-township area. Wintergreen Lake had the highest concentration, which is perhaps explained by its high waterfowl populations, and algal growth in this lake is highly productive. Among the other lakes, slightly higher concentrations tend to be found in the shallower lakes. In contrast to phosphorus, local lakes are relatively rich in the forms of nitrogen that are available for plant uptake (nitrate and ammonium). Nitrate is particularly elevated in lakes that receive high rates of groundwater or stream inflow.

Eutrophication is the process of nutrient enrichment of a lake and the consequent enhancement of aquatic plant growth. Although eutrophication is a natural process that occurs in many lakes over thousands of years, this process can be greatly accelerated by humans when our activities increase inputs to the lake of critical nutrients such as phosphorus. Nutrient additions increase the growth of aquatic plants, including algae and macrophytes. Dense growths of algae make the water turbid and aquatic plants such as water lilies interfere with recreational uses such as swimming and boating. Many years of enhanced plant growth can lead to faster sediment accumulation and thus reduce the depth of the lake, particularly where conditions favor the accumulation of organic remains (peat or muck).

Lakes can be classified by their plant productivity, or "trophic state", based on certain readily measured variables (Table 6). An oligotrophic lake has low plant productivity, and as a result its waters tend to be clear because they contain little algae, and there may be only sparse growth of macrophytes on the bottom. A eutrophic lake is highly productive and its waters tend to be turbid as a result of dense algal populations. Depending on the depth and other factors, eutrophic lakes may produce abundant growths of macrophytes as well as algae. Eutrophic lakes tend to become depleted in dissolved oxygen in bottom waters during the summer if they are deep enough to develop thermal stratification. Mesotrophic lakes have a productivity that is intermediate between oligotrophic and eutrophic lakes.

It is important to note that lakes of each of these trophic states occur naturally in our area. Oligotrophic lakes were probably relatively uncommon even before European settlement. Lake managers monitor trophic state to be able to detect changes in a particular lake that might be caused by human activities and therefore could be reversed by taking appropriate measures. The history of eutrophication and its successful abatement in Gull Lake that is recounted above is an excellent example. In contrast, reducing the productivity of a naturally eutrophic lake to reach a mesotrophic or oligotrophic state is almost impossible and certainly impractical in most situations.

The variables in Table 6 indicate the trophic state of lakes that are dominated by phytoplankton (microscopic algae that live suspended in the water column). Total phosphorus reflects the availability of the most critical nutrient for aquatic plant growth, as discussed above. Secchi Disk depth is a measure of water clarity or transparency, which is reduced by phytoplankton. Chlorophyll is a plant pigment and its concentration in the water reflects the total abundance of phytoplankton. In southern Michigan, productive waters of depths less than about 6 feet tend to be dominated by macrophytes. The trophic state index was not developed for these shallower, macrophyte-dominated lakes.

The trophic-state index was estimated here for lakes in the four-township area in which at least 50% of the lake area remains free of emergent plants during the summer, because productivity in these water bodies is potentially dominated by phytoplankton (Table 7). These are the larger and deeper lakes of the area. Trophic state was estimated for each lake separately from each of the three variables that are commonly used. Most of these larger lakes are mesotrophic to slightly eutrophic. Wintergreen, Holcomb, and Shelp lakes were the most eutrophic. These trophic-state index estimates show that lakes of the four-township area do not have severe eutrophication problems at the present time, and they serve as a benchmark against which future trends can be compared.

Michigan has fish consumption advisories that apply to all inland waters, and these advisories should be heeded in the four-township area. The only recent measurements of contaminants in fish in local lakes have been made in Gull Lake, where high levels of mercury and PCB's were found in Northern Pike. The most likely source of these contaminants is via precipitation, which carries very low levels, but the continuous loading of these contaminants to a lake over time results in their accumulation in the food chain.

The zebra mussel is one of the most recent exotic invaders of our freshwater ecosystems, and records kept by the Michigan Sea Grant show that at least 98 inland lakes in the state had confirmed zebra mussel populations by late 1998. These animals were apparently introduced to the Great Lakes in 1985 by the discharge of ballast water from a transoceanic vessel. Zebra mussels form dense colonies attached to the lake bottom and feed by filtering particles out of the water. Zebra mussels can potentially produce tremendous ecological changes in lakes, as has been documented where they have invaded in the Great Lakes and the Hudson River. Some of these changes may seem positive, such as the clarification of lake water by filtration of the phytoplankton, but negative impacts are also likely. For example, reduced phytoplankton densities may encourage macrophyte growth and will alter the food chain, potentially leading to reduced production of certain sport fishes. The possible encouragement of undesirable blue-green algae by zebra mussels, as mentioned above in the discussion on Gull Lake, is also a negative impact. Zebra mussels produce direct economic impacts by fouling underwater surfaces of docks and boats and clogging water pipes.

Movement of boats between lakes is evidently the most effective way in which zebra mussels are spread from lake to lake, although other routes of colonization are possible. Even small quantities of water transferred from one lake to another in boats, outboard motors, and bait buckets can carry large numbers of the microscopic larvae of the zebra mussel. Unless a concerted effort is made to take precautions against the spread of zebra mussels, we can expect that within a few years most of our local lakes that are popular with boaters will get colonized by this exotic species, as long as they contain suitable habitat. Precautions include draining and drying all equipment before transferring it between lakes since the larvae

Lake	Total Phosphorus (μg/l)	Secchi Disk Depth (feet)	Chlorophyll -a (μg/l)	Trophic Status Based on:		
				P	Secchi	chlor.-a
Crooked- Lower	12	9.84	3.9	m	m	m
Crooked- Upper	21	9.8	5.9	e	m	m
Duck	20	8.2	5.1	m	m	m
Fair	25	10.8	13.9	e	m	e
Gilkey	18	13.9	8.6	m	m	e
Gull Lake	17	14.3	3.4	m	m	m
Holcomb	30	4.6	28.7	e	e	e
Lawrence	15	7.2	4.1	m	e	m
Little Long	16	9.2	4.7	m	m	m
Pine	28	10.7	4.9	e	m	m
Pleasant	22	8.2	8.9	e	m	e
Shelp Lake	17	6.6	11.8	m	e	e
Sherman Lake	---	13.4	6.1	---	m	m
Three Lakes-middle	---	14.8	5.5	---	m	m
Warner Lake	13	13.1	3.9	m	m	m
Wintergreen	100	---	---	e	---	---

Table 7: Trophic state of lakes with extensive open water.
o = oligotrophic, m = mesotrophic and e = eutrophic.
All lakes were sampled from July-Sept. 1998 except Wintergreen Lake which was sampled Sept. 1990.

cannot survive prolonged desiccation. More information on zebra mussels and how to prevent their spread is found on the Michigan Sea Grant Internet site: www.msue.msu.edu /seagrant/.

To date only one lake in the four-township area – Gull Lake – has a well-established population of zebra mussels. Given the prospect of the spread of zebra mussels into other lakes in the four-township area, we used our survey data to predict which lakes are potentially suitable habitats for zebra mussels and are therefore susceptible to invasion (Table 5). These predictions are based solely on water quality, and specifically on the pH and calcium concentrations in the lake water. A study by Ramcharan et al. (1992) showed that larval zebra mussels have thresholds of pH and calcium below which they are unable to build their shells. We applied their predictive equations to determine that many of the lakes in the four-township area are susceptible to zebra mussel invasion. Some of these lakes may not contain suitable habitat to support large populations of zebra mussels, especially if the sediments are very soft or if phytoplankton abundance is low, which would limit the food supply for the mussels. Nonetheless, residents living on susceptible lakes should take particular caution to avoid transfers of water from other lakes because the particular habitat requirements of zebra mussels in inland lakes are not yet well known.

Wetlands

Wetlands are increasingly appreciated for the functions and values that they provide to society, and as a result a variety of federal and state legislation has been enacted to protect these ecosystems. Michigan has lost more than half of its wetlands to land drainage and conversion to agricultural, suburban, and urban uses (MSPO, 1995; MDNR, 1988). Widespread wetland destruction has resulted in increased flood damages, increased soil erosion, degraded fisheries, degraded water quality, and losses of wildlife and recreational opportunities. While legislative protection has now slowed the loss of wetlands to outright drainage and filling, scientists are realizing that many wetlands are still being degraded by more insidious threats, such as non-point-source pollution and the invasion of exotic plant species. Also, existing legislation does not provide protection to smaller isolated wetlands of less than 5 acres in area, which can be significant in many areas.

What are some of the functions and values of wetlands that pertain to the four-township area? Certainly the maintenance of good water quality is important, especially in the case of wetlands along lakes and streams because these can intercept groundwater discharge and surface runoff flowing towards surface waters, retaining nutrients, sediments, and contaminants from the water. Wetlands are particularly effective in removing nitrate, which is increasingly found at undesirably high concentrations in domestic water wells. Riparian wetlands help to attenuate floods, as discussed earlier with regard to streams, thereby stabilizing stream channels and reducing property damage downstream.

Wetlands are productive ecosystems that offer habitat for a wide variety of plant and animal life. Ducks, geese, turkeys, and deer are often hunted in local wetlands. Wetlands along lakes provide nurseries for sport fish such as pike and bluegills and also export organic material to the lake waters, where it serves as a food source for fishes and other aquatic animals.

Many area residents enjoy viewing plants and wildlife in wetlands and value the "non-game" animals as much as those that can be hunted or fished. Acre for acre, wetlands produce more plants and wildlife than any other Michigan habitat. Of 2300 native plants, 50 percent occur in wetlands and 25 percent of them are threatened or endangered. More than 40 percent of our wildlife species (including fish) live in or use wetlands in part of their life cycle, including 15 mammals, 180 birds, 22 reptiles, and most of our 23 amphibians. Frogs and toads, many of which breed successfully only in wetlands lacking fish, are a particularly popular group of animals that is dependent on wetlands. Local wetlands have significant scenic value as well, adding to the variety of the landscape, and many homes have been built with a view toward the nearest wetland.

Wetlands are exceptionally rich in the four-township area, covering 10% of the landscape (Figure 3). Figures 21-24 are wetland maps for each of the four townships. These maps are based on the National Wetland Inventory, carried out by the U.S. Fish and Wildlife Service, which mapped and classified wetlands throughout the country using aerial photography. The maps show that the largest wetland complexes are associated with streams and rivers: the Kalamazoo River floodplain, the riparian wetlands found along Augusta and Gull Creeks, and "Sheriff's Marsh", located on a tributary of Augusta Creek between B and C Avenues. A considerable amount of wetland also occurs along the edges of some lakes, such as Pleasant and Fair lakes. In addition to these larger wetlands, smaller wetlands lying in isolated depressions are abundant in this part of southern Michigan, and such depression wetlands are exceptionally common in the eastern half of the four-township area.

The present vegetation and, to some extent, the hydrology of local wetlands have been strongly influenced by the history of land use since settlement in the 1830's, as exemplified by the land-use history for the Lawrence Lake area, which was reconstructed from local residents by Rich (1970). Logging, grazing, farming, construction of ponds and drainage channels, and mining of peat and marl were common practices in local wetlands, and some of the ecological effects of these activities on the wetlands still persist today. Many wetlands in the four-township area are in the process of recovery from these impacts, and relatively few are subject to such disturbances today although some still have lowered water tables as a result of the drainage channels. Despite these historical impacts, the four-township area lost a relatively small fraction of its wetland to drainage compared to many parts of southern Michigan.

The National Wetland Inventory data on wetlands were analyzed to characterize the wetlands of the four-township area. The proportions by area of the various wetland classes are depicted in Figure 25. The classes used in the National Wetland Inventory were simplified for this purpose. Most of the wetland area in the four townships is either marsh (i.e., filled with emergent non-woody plants), swamp (dominated by trees), or shrub-filled wetlands.

Vegetation is a characteristic wetland feature that helps to distinguish among different types of wetlands. Marshes in the four-township area are often composed of a mixture of herbaceous plants that frequently includes cattails, sedges, grasses, swamp loosestrife, and, increasingly, the introduced purple loosestrife. Many of our marshes occur at points of groundwater discharge to lakes or streams. Swamps include mature hardwood forests on the floodplain of the Kalamazoo River as well as stands of conifers such as Tamarack and White Pine that grow in moist areas around lakes and streams. Shrub wetlands are often dominated by buttonbush, alders, willows, dogwoods, or buckthorn, and many of these wetlands may eventually develop into swamps as the trees mature. Bog wetlands in the four-township area are often dominated by an evergreen shrub called Leatherleaf, usually occurring together with a carpet of *Sphagnum* mosses and patches of Highbush Blueberry or other small shrubs. The most extensive bog wetland in the area is "Blachman's Swamp" (also called "Blueberry Marsh"), located to the north of Pleasant Lake.

The water quality of wetlands in the four-township area is variable, as expected because of their variable sources of water. Table 8 contains data on specific conductance and pH to illustrate this variability. Figure 26 shows the wetland locations corresponding to the data in Table 8. As with lakes and streams, wetland waters with higher conductance are likely to reflect the importance of groundwater inputs while those with low conductance (i.e., below 100 μS/cm) are likely to be primarily fed by

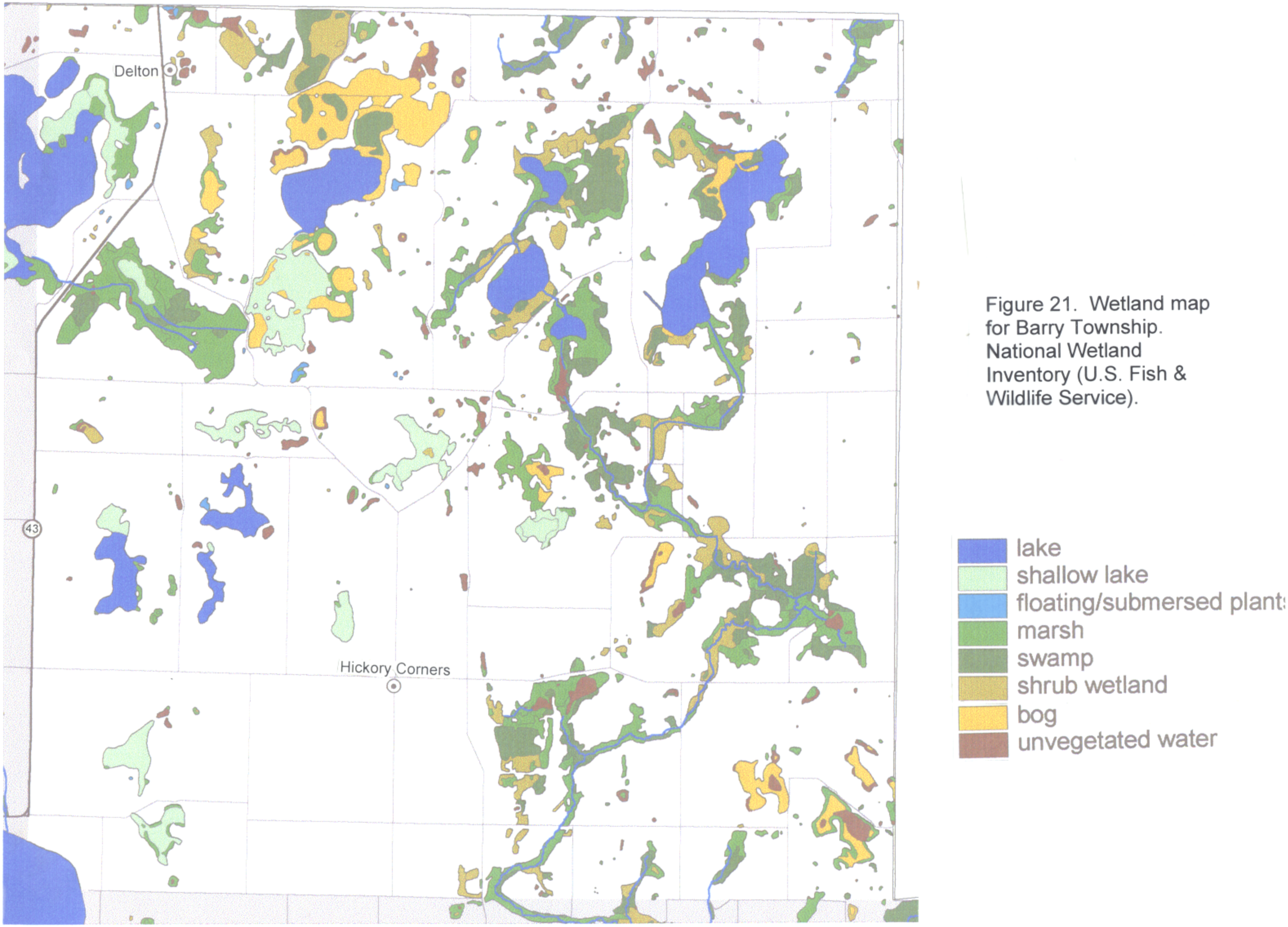


Figure 21. Wetland map for Barry Township. National Wetland Inventory (U.S. Fish & Wildlife Service).

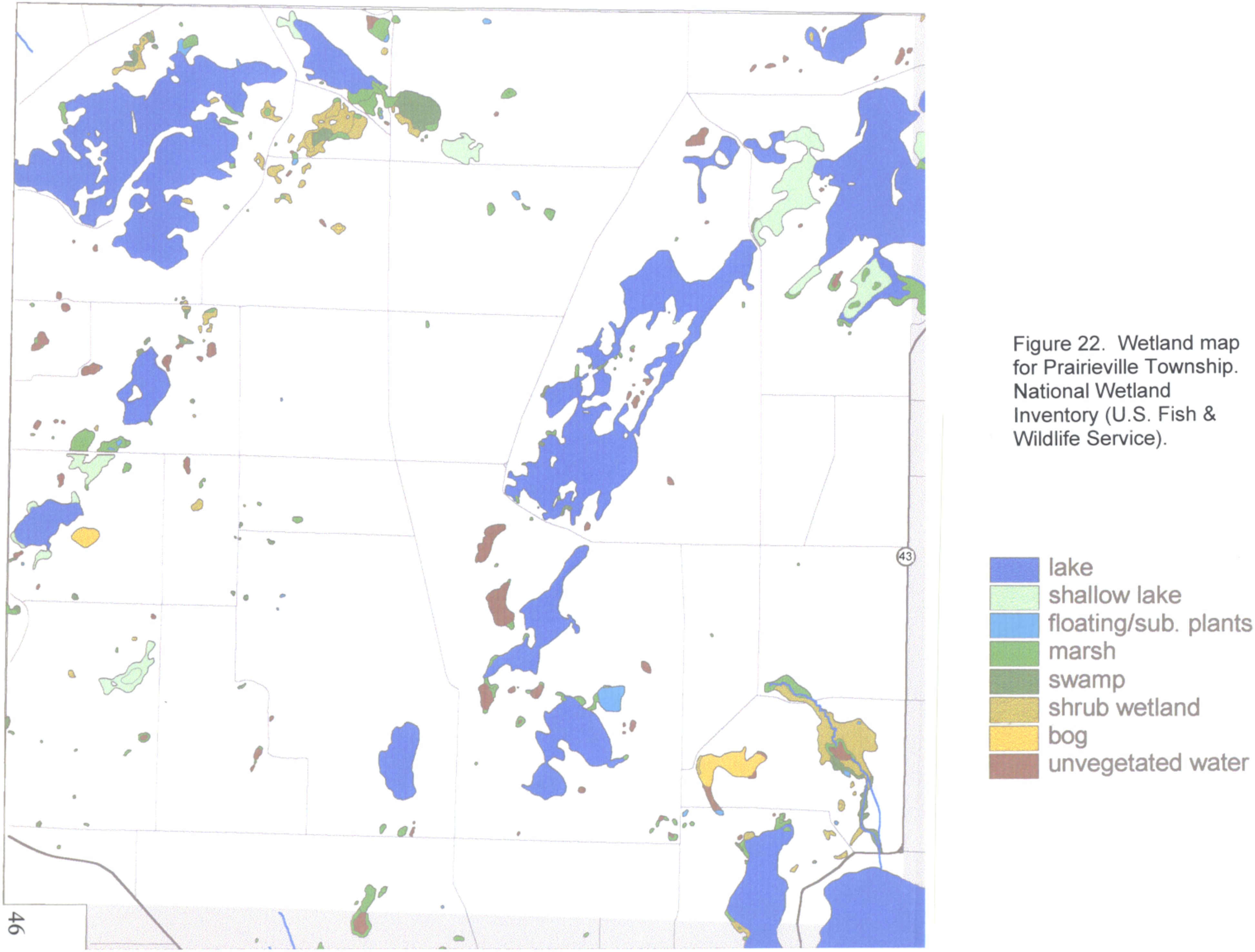


Figure 22. Wetland map for Prairieville Township. National Wetland Inventory (U.S. Fish & Wildlife Service).

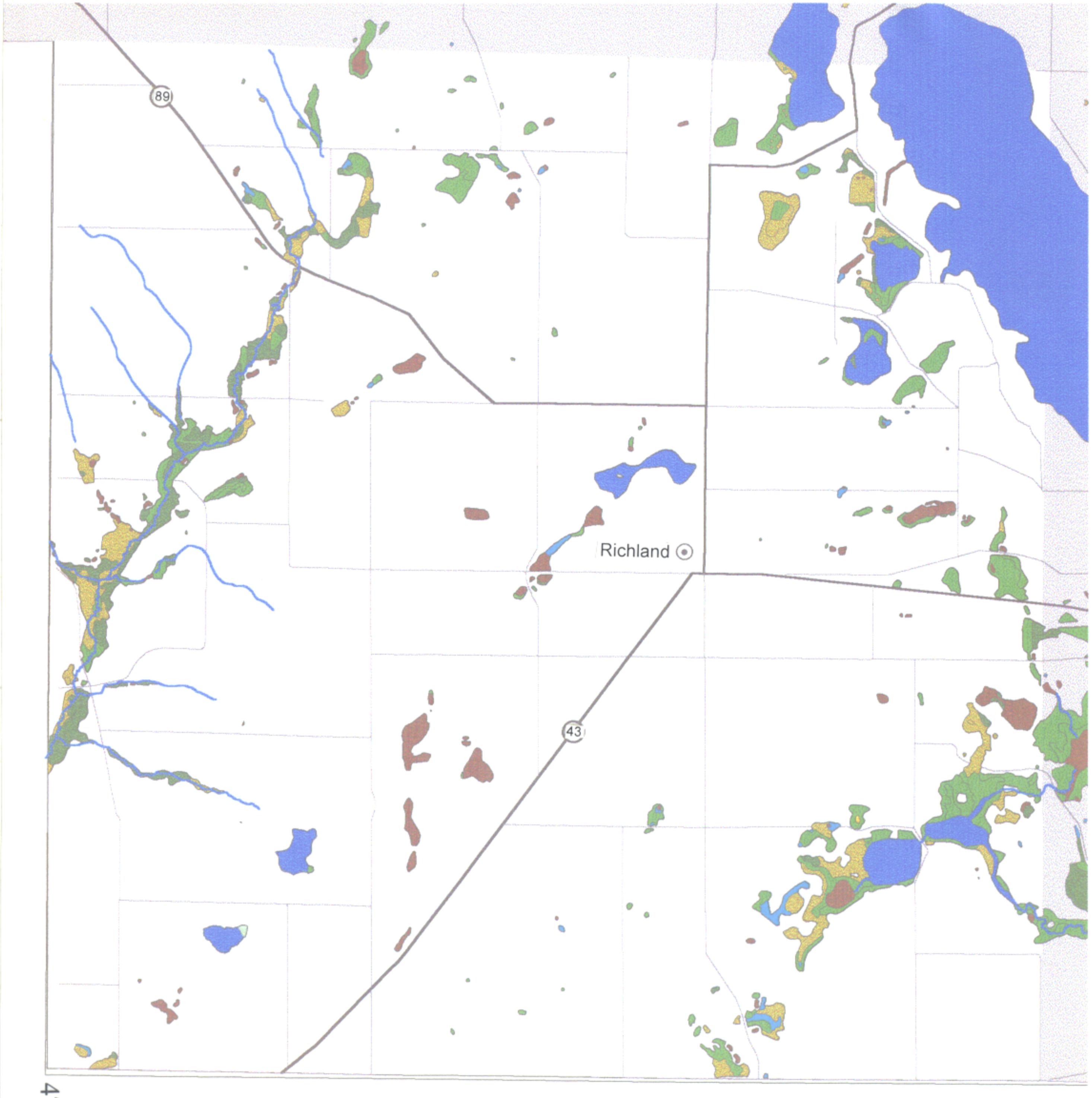


Figure 23. Wetland map for Richland Township. National Wetland Inventory (U.S. Fish & Wildlife Service).

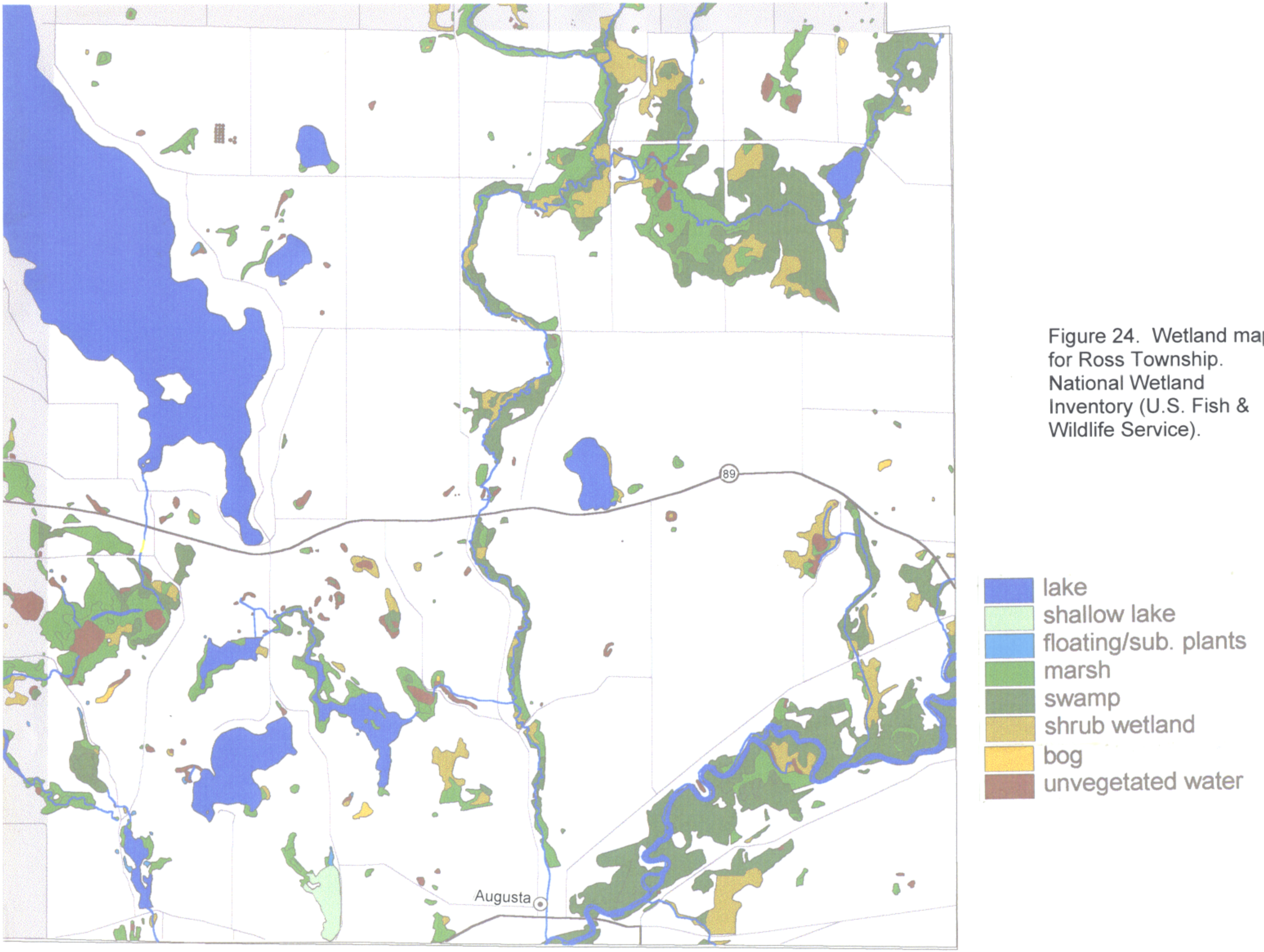


Figure 24. Wetland map for Ross Township. National Wetland Inventory (U.S. Fish & Wildlife Service).

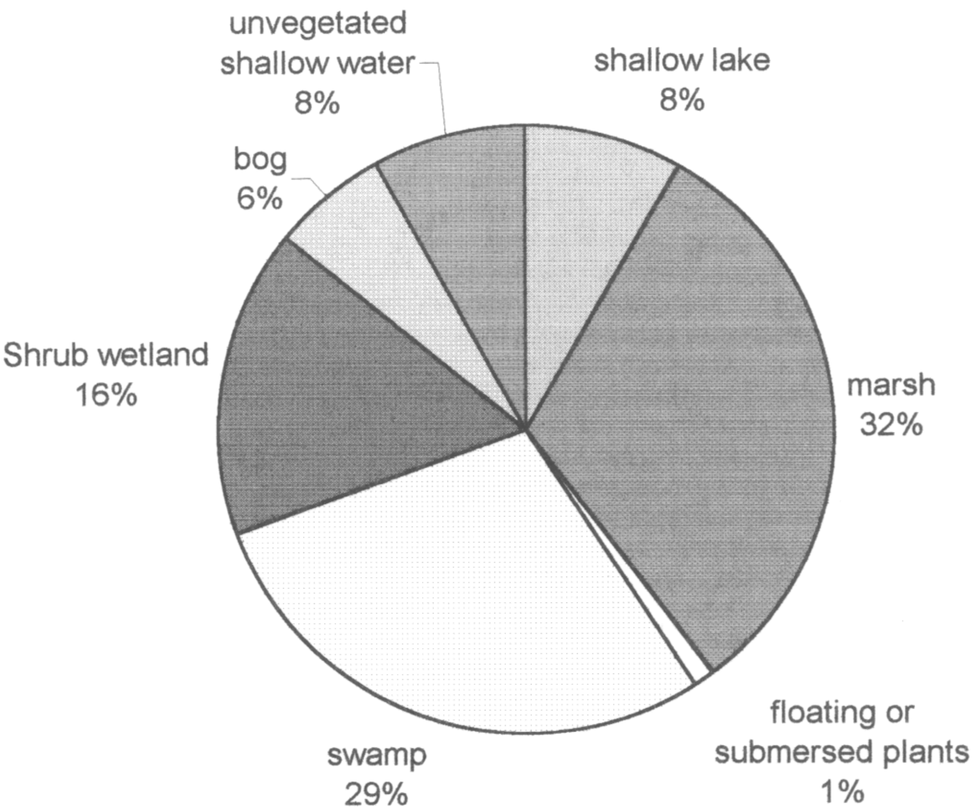


Figure 25. The proportions by area of the various wetland classes. The data are from the National Wetland Inventory, with the classes simplified for this purpose.

Map #	Wetland	Specific Conductance (μS/cm)	pH
1	Warners wetland- West of Richland Post Office	255	---
2	47th street bog (near Baseline Rd.)	45	4.38
3	Augusta Creek floodplain – pool at Kellogg Forest	452	6.94
4	Blachman's (Huckleberry) Swamp	34	4.75
5	Blueberry Swamp – Hickory road (North end)	43	3.87
6	Blueberry Swamp - Open water area at Bendere Rd (South end)	32	6.68
7	Cattail Marsh North of M-89 (Richland Twp)	545	---
8	Garlick's pond (43rd St near B Ave)	279	6.66
9	Gilkey Lake - wetland outflow, West of Scott Park	448	7.33
10	Glasby marsh outflow	315	7.13
11	Grassy Lake	533	---
12	Kalamazoo River floodplain- pool E (Fort Custer)	513	6.94
13	Kalamazoo River floodplain- pool G (Fort Custer)	597	7.20
14	Kalamazoo River floodplain- pool J (Fort Custer)	598	7.33
15	KBS Bird Sanctuary pond (Long Woods)	171	6.51

Table 8. Wetland data. See Figure 26 for map numbers.
Continued on next page.

Map #	Wetland	Specific Conductance (μS/cm)	pH
16	KBS Lux Arbor Reserve pond - 1	43	6.24
17	KBS Lux Arbor Reserve pond - 10	34	6.76
18	KBS Lux Arbor Reserve pond - 11	25	6.81
19	KBS Lux Arbor Reserve pond - 14	25	6.48
20	KBS Lux Arbor Reserve pond - 23	269	7.73
21	KBS Lux Arbor Reserve pond - 5	65	5.68
22	KBS Lux Arbor Reserve pond - 6	96	6.60
23	KBS Lux Arbor Reserve pond - 9	18	5.67
24	Pond NE of B Ave and 40th St	25	7.27
25	Pond West of 42nd St. at Kellogg Forest	455	7.13
26	Lang's Marsh (Baseline & 47th St.)	148	7.67
27	Mud Lake -South of Pleasant Lake, (Barry Twp)	24	6.20
28	"Pitchfork lake" (bog)	18	4.85
29	Pond along Brook Lodge Rd., South of Gilkey Lk. Rd.	320	7.53
30	Sheriff's Marsh Outflow at 44th St	411	7.63
31	Shrubby pond	33	5.13
32	Tamarack Lake	462	---
33	Turkey marsh	314	7.09

Table 8. continued

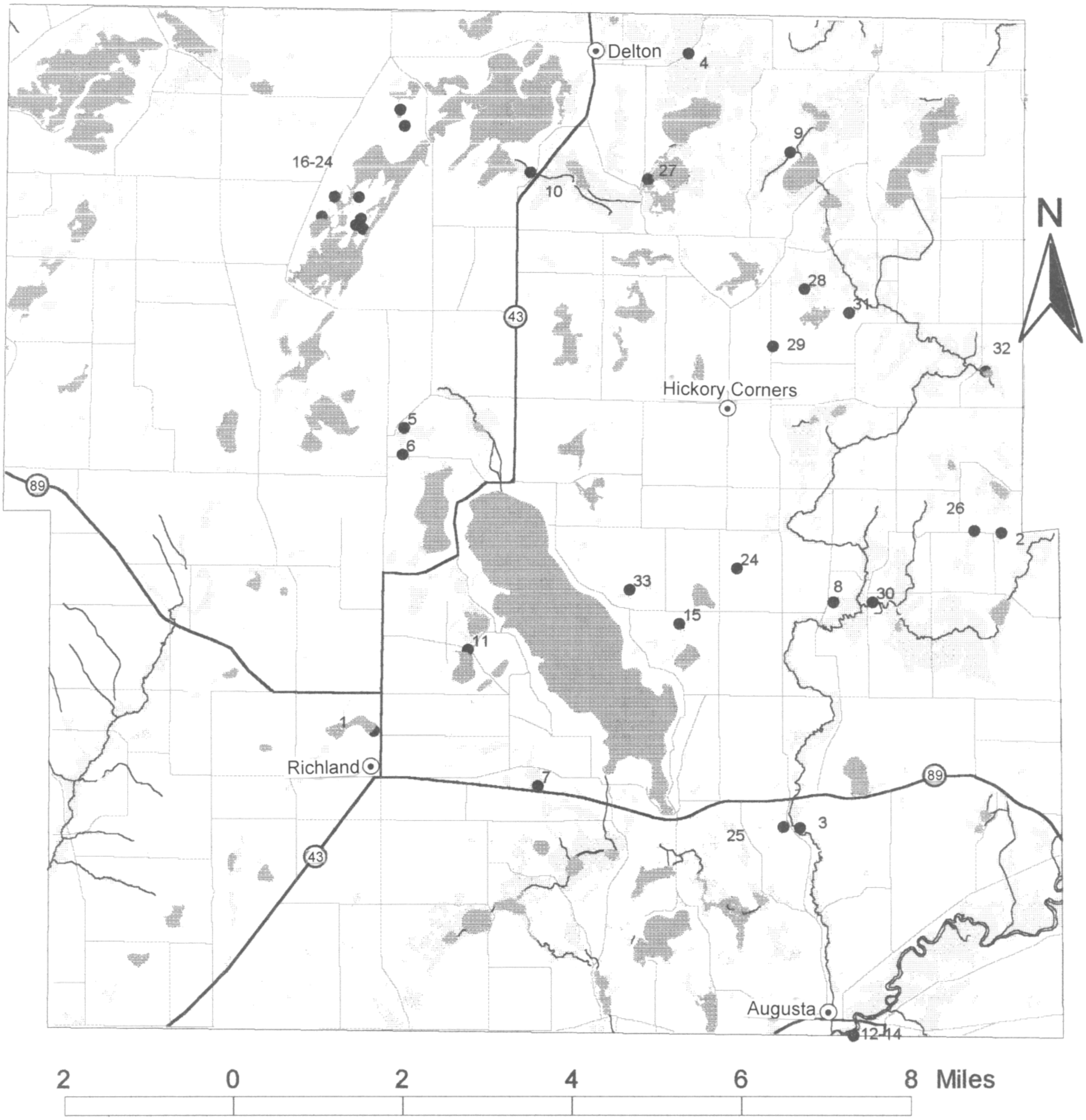


Figure 26. Map showing wetland locations that correspond to the wetlands listed in Table 8.

precipitation. Wetlands that receive groundwater discharge are common along the margins of lakes and streams, and these tend to be either marshes or shrubby vegetation, or a mixture of the two. Examples include the upper stretches of Prairieville Creek (north of Gull Lake) and the wetlands that fringe much of the main course of Augusta Creek. The hardwood forests of the Kalamazoo River floodplain are only infrequently flooded by the river, but throughout much of the year their soils are saturated by groundwater that is making its way from adjacent uplands towards the river channel.

The wetlands with lower conductance include temporary water bodies that tend to fill during heavy rains or snowmelt on frozen soils, then lose their water by infiltration and evaporation during the ensuing months. Because they dry occasionally, they lack fishes and are especially suitable as amphibian breeding sites for species whose tadpole larvae are susceptible to fish predation.

There are some wetlands that would be characterized as acidic peat bogs in the four-township area, although these are more common in neighboring townships to the north and west. Such wetlands would normally be expected to occupy topographic high points in the landscape where they do not receive groundwater inputs, or to lie in areas of exceptionally sandy soils. Blachman's Swamp and Pitchfork Bog are the most extensive examples of these peat bogs.

Protection of wetlands in the four-township area is not guaranteed under the present legislation for several reasons. The legal protection deals with direct impacts to the wetlands such as drainage and filling, requiring a permit to conduct such activities for wetlands greater than 5 acres, or of any size if the wetland is contiguous with or close to a lake or stream (Cwikiel, 1996). Many of the wetlands in the four-township area are smaller than 5 acres and lie in isolated depressions, and are thus not protected by these laws. In addition, most wetlands receive water from the land surrounding them, and thus can be affected by nearby land uses.

Further public education regarding the importance and vulnerability of wetlands is needed in the four-township area, even though many residents appreciate the value of wetlands for wildlife. One problem that can frequently be observed along roadways is the disposal of garbage and animal carcasses in wetlands. The direct linkage between wetlands, groundwater, and streams makes their use as dumping grounds a very unwise act.

Another problem that may be significant in a cumulative way is the excavation of ponds on residential properties, most often in the vicinity of streams. These ponds are frequently dug at groundwater discharge seeps or springs in the hopes of producing a spring-fed "trout pond", and their construction often results in the loss of a unique and restricted kind of wetland environment. Unfortunately, most of these ponds soon become filled with plants and algae and require continuous maintenance, often including chemical treatments, to remain as open water. Drainage from these ponds into the nearby stream potentially carries any herbicides, pesticides, and fertilizers applied to the pond and surrounding lawns.

Residents who live along shallow, weed-filled lakes commonly desire to alter their lakes to make them open waters that are more suitable for boating and swimming, and there are numerous companies that eagerly promise to accomplish this through costly herbicide treatments, mechanical weed removal, or even massive dredging projects. For many of our lakes, such intervention would produce only short-term results because the lakes are naturally productive and the factors promoting their productivity cannot be changed. Lakeside residents should be aware that waters filled with plants are not necessarily that way because of excessive nutrient inputs from human activities, and that these ecosystems have many intrinsic values, often resembling those of wetlands. At the same time, residents should realize that excessive fertilization of their lawns and the failure to properly maintain their septic systems could aggravate the problem. Given that phosphorus inputs increase the growth of aquatic plants in many of our lakes and that phosphorus is generally not in short supply for lawn grass, the use of lawn fertilizers that do not include phosphorus is a good practice. The MSU Extension office can identify local vendors of phosphorus-free fertilizers. Golf courses should also minimize their use of fertilizers containing phosphorus, particularly because they often maintain intensively managed turfgrass in close proximity to water bodies.

CONCLUSIONS

The four-township area possesses a rich diversity of surface waters that remain in relatively good ecological condition. These surface waters – lakes, streams, and wetlands – are highly valued by local residents for recreational and aesthetic reasons. In addition, the local landscape is underlain by groundwater aquifers of good water quality that meet domestic water requirements. None of these waters exists in isolation because the permeable soils of the area promote exchanges of water between the land surface, groundwater, streams, lakes, and wetlands, and thus the entire hydrologic system is potentially vulnerable to the degradation of water quality. Wetlands serve to improve water quality because they are often situated at the interface between groundwaters, surface runoff, and lakes and streams, and they remove excess nutrients, sediments, and contaminants.

Future residential and urban development and changes in land uses will present challenges for the protection of our water resources. Good stewardship of these resources requires a sound scientific understanding of their nature and of potential threats to their integrity. Equally important is an educated public that supports the protection of our water resources through legislation as well as through individual actions. By producing this Water Atlas, the Four Township Water Resources Council hopes to contribute to these requirements.

APPENDIX

Understanding water quality measurements

Specific Conductance

Specific conductance is a measure of the ability of water to conduct an electrical current. It is an indication of the amount of dissolved solids (such as salt) in the water. Pure water, such as distilled water, will have a very low specific conductance, and sea water will have a high specific conductance. Rainwater often dissolves airborne gases and airborne dust while it is in the air, and thus it often has a higher specific conductance than distilled water.

The units for specific conductance are microSiemens per centimeter ($\mu S/cm$). These units are equal to the former units, $\mu mhos/cm$. Measurements are standardized to a temperature of 25 degrees C.

pH

The pH is a measure of how acidic or basic the water is. The pH scale ranges from 0-14, with 7 being neutral, and it is a logarithmic scale. Low values are acidic and high values are basic. Many natural waters fall within a pH range of 6-9, although many wetlands are naturally more acidic (pH < 6).

Plants and animals are adapted to a certain pH range, and therefore if the pH changes too much they can be harmed. Very acidic water cannot support fish. Our lakes and streams tend to be stable in pH, ranging around 7-8.5.

Alkalinity and hardness

The stable pH of many of our surface waters is explained by a chemical characteristic of the water known as alkalinity, which is defined as the capacity of water to neutralize added acid. This acid neutralization comes largely from solution of limestone minerals in the deeper groundwater.

Precipitation has virtually no alkalinity, but as the water passes through a groundwater flow path it picks up alkalinity. Most lakes in the four-township area have fairly high alkalinity because they receive groundwater discharge.

Hardness is a measure that is related to alkalinity. We define hardness as the sum of calcium and magnesium ions; these ions also come largely from the solution of limestone minerals. In this area, high conductance usually indicates high alkalinity and "hard" water, since all three are related to how much contact the water has had with minerals in the soil.

Alkalinity and hardness are routinely measured water-quality variables, in part because water used for domestic or industrial purposes may be too alkaline and hard, and require treatment with a water softener system.

In lakes and wetlands, high alkalinity and hardness are also of interest because they are often associated with the precipitation of calcium carbonate minerals, which form marl sediments. Marl is the crusty, cream-colored mineral that forms in the summer on plants, sediments, and even boat hulls in the surface waters of many of our lakes. Marl formation is essentially the reverse of the reaction for limestone solution in water, and therefore it decreases alkalinity, hardness, and conductivity.

Calcium carbonate precipitation is important for the ecology of the lake not only because it coats underwater surfaces, but also because it can reduce light penetration when it forms as suspended particles, and when those particles settle out, they can bind to phosphorus and carry it out of the water column. When suspended calcium carbonate is abundant in the lake water the water appears milky white and this situation is often referred to as a "whiting" or "whitening".

Phosphorus

Nitrogen and phosphorus are the principal nutrients that potentially limit plant growth by their restricted availability, although phosphorus is most likely to be the limiting nutrient in our surface waters. An increase in phosphorus can lead to increased plant growth. Phosphorus does not move very readily down through the soil and into the ground water because it tends to bind with soil particles, and thus groundwater is usually low in phosphorus. Phosphorus enters lakes primarily by surface runoff in the course of natural stream bank erosion. High levels of erosion caused by human activities bring an unnaturally high level of phosphorus into a lake. Phosphorus in septic wastes attaches to soil in the drain field, and is locked there until the system is overloaded in time, and the soil has absorbed all it can. Additional phosphorus then moves into the groundwater, or onto the surface to be washed into the lake.

Three forms of phosphorus can be measured: ortho-phosphate, total dissolved phosphorus and total phosphorus. Plants can most readily use ortho-phosphate, but total phosphorus is most often measured. Total phosphorus measures all forms of phosphorus in the water, including phosphorus dissolved in the water and also phosphorus in non-living and living particles such as algae and zooplankton (microscopic aquatic animals). Total dissolved phosphorus measures the inorganic and organic forms of dissolved phosphorus.

Nitrogen

Two forms of nitrogen are often measured; nitrate and ammonia. Both are potentially available as nutrients for plants. Since plant growth in inland lakes is usually limited by phosphorus availability, high nitrogen concentrations in surface waters generally do not cause lake eutrophication. However, high levels of nitrate in groundwater can be a health hazard, especially to young children. And unlike phosphorus, infiltrating precipitation can carry nitrogen (as nitrate) down into the groundwater very readily. When excess nitrogen is added to farm fields or to fertilize lawns, much of this becomes nitrate and can be carried into our groundwater. Nitrate concentrations exceeding 10 ppm as nitrogen (10,000 ppb) in drinking water are considered a health hazard.

Discharge

Discharge is the volume of water passing a given location in a given period of time, and is measured in flowing waters such as creeks and rivers. The discharge of creeks varies with precipitation and season, so it is especially interesting to have a continuous record of measurements over time. The United States Geological Survey (USGS) measures discharge daily in Augusta Creek (figure 13) and the Kalamazoo River at Comstock. At those sites, the water levels are automatically monitored and discharge is estimated from a formula. When a time series of discharge is unavailable, a single measurement can be useful to give us an indication of the size of the creek.

Chlorophyll-a

Algae levels in lakes are usually approximated by a measurement of chlorophyll-a, which is the primary pigment in most algae.

Transparency

Transparency (the clarity of water) is measured using a Secchi disk. This is a black and white circle that is lowered from a boat on a string. The depth (in feet) at which the disk goes out of sight is the "Secchi disk depth". A deep depth indicates that the water is clear and thus there is little suspended algae or inorganic matter such as silt in the water. A shallow Secchi depth may indicate high concentrations of algae in the water column, unless there is a lot of inorganic matter suspended in the water.

References

Allen, W.B., Miller, J.B., and Wood, W.W. 1972. Availability of water in Kalamazoo County, Michigan. U.S. Geological Survey Water-Supply Paper 1973. 129 p.

Barry-Eaton District Health Department Environmental Health Division. 1996. Barry County Well Atlas.

Cowardin, L.M., Carter, V., Golet, F.C., and LaRoe, E.T. 1979. Classification of wetlands and deepwater habitats of the United States. Fish and Wildlife Service. U.S. Dept. Interior, FWS/OBS-79/31. 131 p.

Crum, J.R., G.P. Robertson and F. Nurnberger. 1990. Long-term climate trends and agricultural productivity in southwest Michigan. Pp. 53-58 in: Climate variability and ecosystem response. Proceedings of a Long-Term Ecological Research Workshop, Boulder, CO, 12-23 Aug 1988. USDA Forest Service, Southeastern Forest Experiment Station, General Technical Report SE-65.

Cwikiel, W. 1996. Living With Michigan's Wetlands: A Landowner's Guide. Tip of the Mitt Watershed Council, Conway, MI 132 p.

Michigan State University Extension Bulletiin WQ-51. 1998. Home*A*Syst, Home Assessment Guide. 87p.

Four Township Water Resources Council. 1997. Issues Paper. 24 p.

Kehew, A.E. and Brewer, M.K. 1992. Groundwater Quality Variations in Glacial Drift and Bedrock Aquifers, Barry County, Michigan, USA. Environmental Geology and Water Sciences 20: 105-115.

Mahan, D. C. and K. W. Cummins. 1974. A profile of Augusta Creek in Kalamazoo and Barry Counties, Michigan. Technical Report No. 3. W. K. Kellogg Biological Station. Michigan State University.

Mahan, D.C. 1980. Land-cover and coarse particulate organic influxes to a small stream. (Ph.D.)- Michigan State University. Kellogg Biological Station and Dept. of Fisheries and Wildlife.

Marsh, W.M. and Borton, T.E. 1975. Inland lake watershed analysis - A Planning and Management Approach. Michigan Department of Natural Resources.

MDNR. 1990. Protecting Inland Lakes: A Watershed Management Guidebook.

MDNR. 1988. Wetland Protection Guidebook. Lansing: Michigan Department of Natural Resources, Land and Water Management Division, Michigan.

Michigan Society of Planning Officials. 1995. Patterns on the land: Our Choices- Our Future, Trend Future Project-Final Report. Lansing: Planning & Zoning Center, Inc.

Mortsch, L.D. and Quinn, F.H. 1996. Climate change scenarios for Great Lakes Basin ecosystem studies. Limnology and Oceanography 41: 903-911.

Ramcharan, C.W., D.K. Padilla and S.I. Dodson. 1992. Models to Predict Potential Occurrence and Density of the Zebra Mussel, *Dreissena polymorpha*. Canadian Journal of Fisheries and Aquatic Sciences 49:2611-2620.

Rheaume, S.J. 1990. Geohydrology and water quality of Kalamazoo County, Michigan, 1986-88. U.S. Geological Survey Water-Resources Investigations Report 90-4028. 102 p.

Rich, P.H. 1970. Post-settlement influences upon a southern Michigan marl lake. Michigan Botanist 9:3-9.

Tague, D.T. 1977. The hydrologic and total phosphorus budgets of Gull Lake, Michigan. Master of Science thesis, Dept. of Fisheries and Wildlife, Michigan State University.

Tessier, A.J. 1995. Gull Lake Phosphorus Budget. (Report is kept at the KBS Library.)

Tessier, A.J. and G.H. Lauff. 1992. The Gull Lake story. The Michigan Riparian, February 1992.

Wetzel, R.G. 1989. Wetland and Littoral Interfaces of Lakes: Productivity and Nutrient Regulation in the Lawrence Lake Ecosystem. Freshwater Wetlands and Wildlife, CONF-8603101, DOE Symposium Series No. 61, R.R. Sharitz and J.W. Gibbons (Eds.), USDOE Office of Scientific and Technical Information, Oak Ridge, Tennessee. Pp. 283-302.

Lakes and wetlands are abundant in the four-township area. Gull Lake, which is one of the largest inland lakes in Michigan, occupies 2% of the four-township area (Figure 3). All lakes and wetlands combined cover 16% of the area. The upland area remains largely rural, and is a mosaic of row-crop agriculture, pastures, old fields, forest, and residential areas. Residential growth since 1960 has doubled the population in the western half of the four-township area, which is closer to the City of Kalamazoo, and this growth is increasingly spreading further into the four-township area. Information on land use and socioeconomic characteristics of the four townships is available in the Four Township Water Resources Council Issues Paper (1997) which can be found in the Richland, Delton and Kellogg Biological Station Libraries. Towns and villages within the four townships include Delton, Hickory Corners, Richland, and Augusta.

This document begins with a brief overview of the Hydrologic Cycle and the Watershed Concept. We then provide a more in-depth discussion of particular aspects of our water resources, including precipitation, groundwater, streams, lakes and wetlands, presenting and interpreting hydrologic and water quality data from the four-township area as we go along.

The Appendix provides definitions of the various water-quality measurements that are mentioned throughout the text, and a list of references at the end of the text documents our sources and points the way to further information.

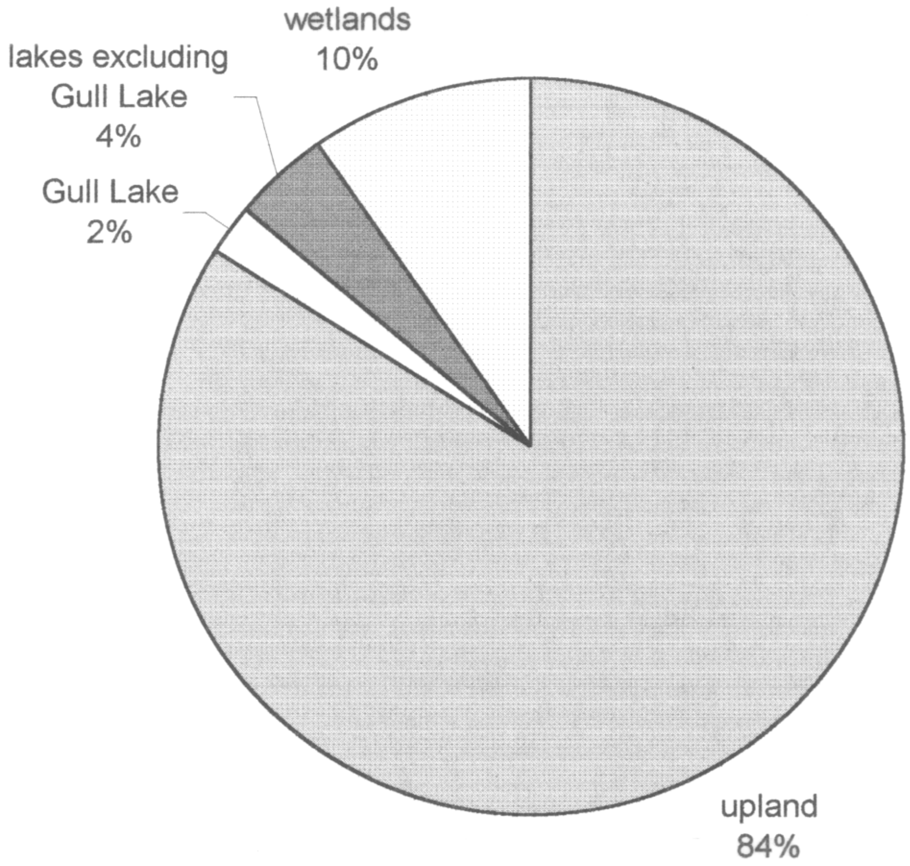


Figure 3. The area proportions of upland, lakes and wetlands in the four-township area. Data are from the National Wetland Inventory- U.S. Fish and Wildlife Service.