Four Township Environmental Carrying Capacity Study

Pine Lake
Upper Crooked Lake
Gull Lake
Sherman Lake

Prepared for:
Four Township Water Resources Council, Inc.
The Townships of Prairieville, Barry, Richland, and Ross

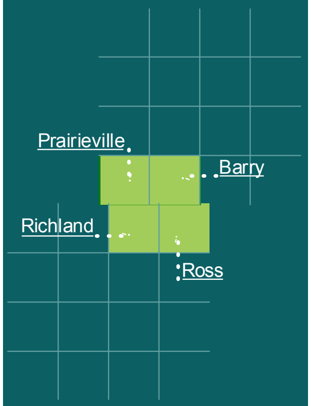
Prepared by:
Progressive AE
1811 4 Mile Road, NE
Grand Rapids, MI 49525-2442
616/361-2664

January 2002

Project No: 51830106

ProgressiveAE

Four Township
Water Resources
Council, Inc.



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Background

The Four Township Water Resources Council is a volunteer, non-profit group dedicated to protecting water quality in Prairieville and Barry Townships in Barry County and Richland and Ross Townships in Kalamazoo County. The Council's mission is to *assist with the development and implementation of land use strategies that retain the rural environment currently enjoyed by township residents, protecting lakes, streams, drinking water, agriculture, and open space*. In 1998, the Council received a U.S. Environmental Protection Agency nonpoint source pollution control grant under Section 319 of the Federal Clean Water Act to implement the Four Township Water Resources Project.

Land use activities directly impact water quality. The four townships are blessed with an abundance of water resources including many high quality lakes, streams, and wetlands. However, like many communities in Michigan, development within the four townships is occurring at a rapid pace. Given the aesthetic and recreational appeal of water, development often concentrates in close proximity to it. Without giving proper consideration to the impact this development may have on water quality, the integrity of the area's water resources could be compromised.

This report is proposed to be used as a guide to assist local governmental decision makers in formulating policies and regulations to help minimize the impact of future development on the water resources of the four townships. The report focuses on four lakes: Pine Lake, Upper Crooked Lake, Gull Lake, and Sherman Lake (Figure 1). The report includes a description of land use in the water-

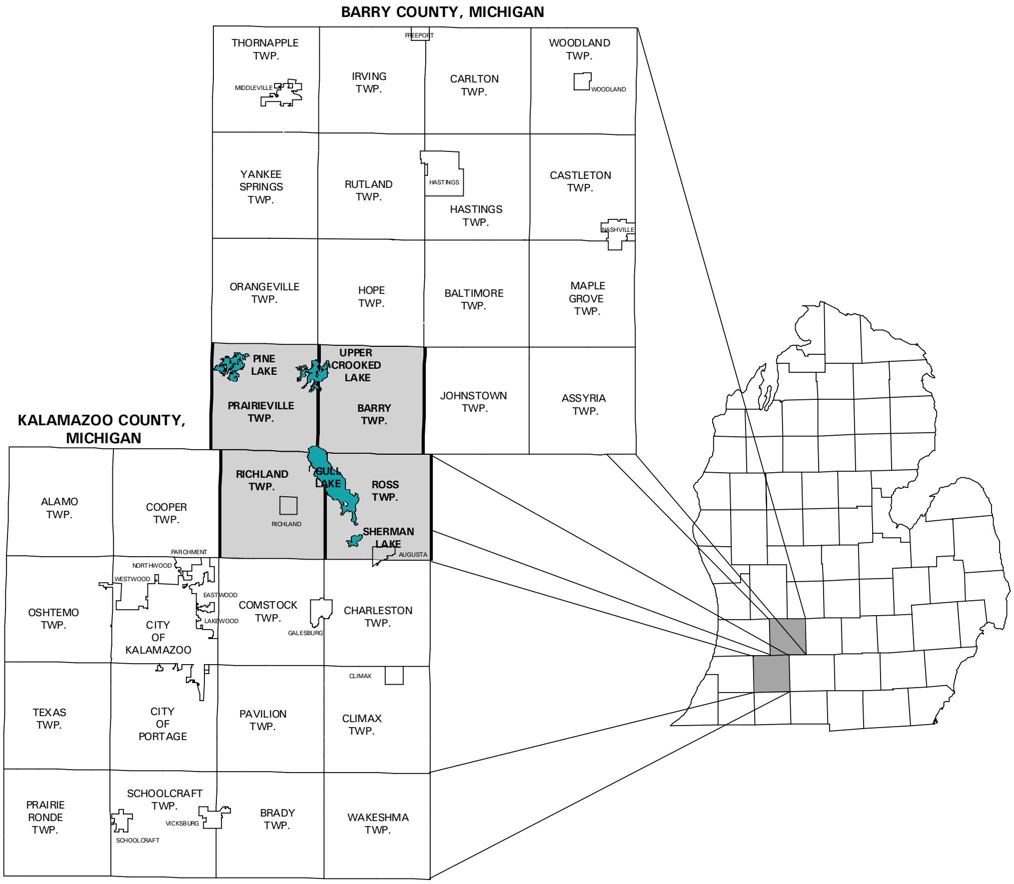


Figure 1. Project Location Map.

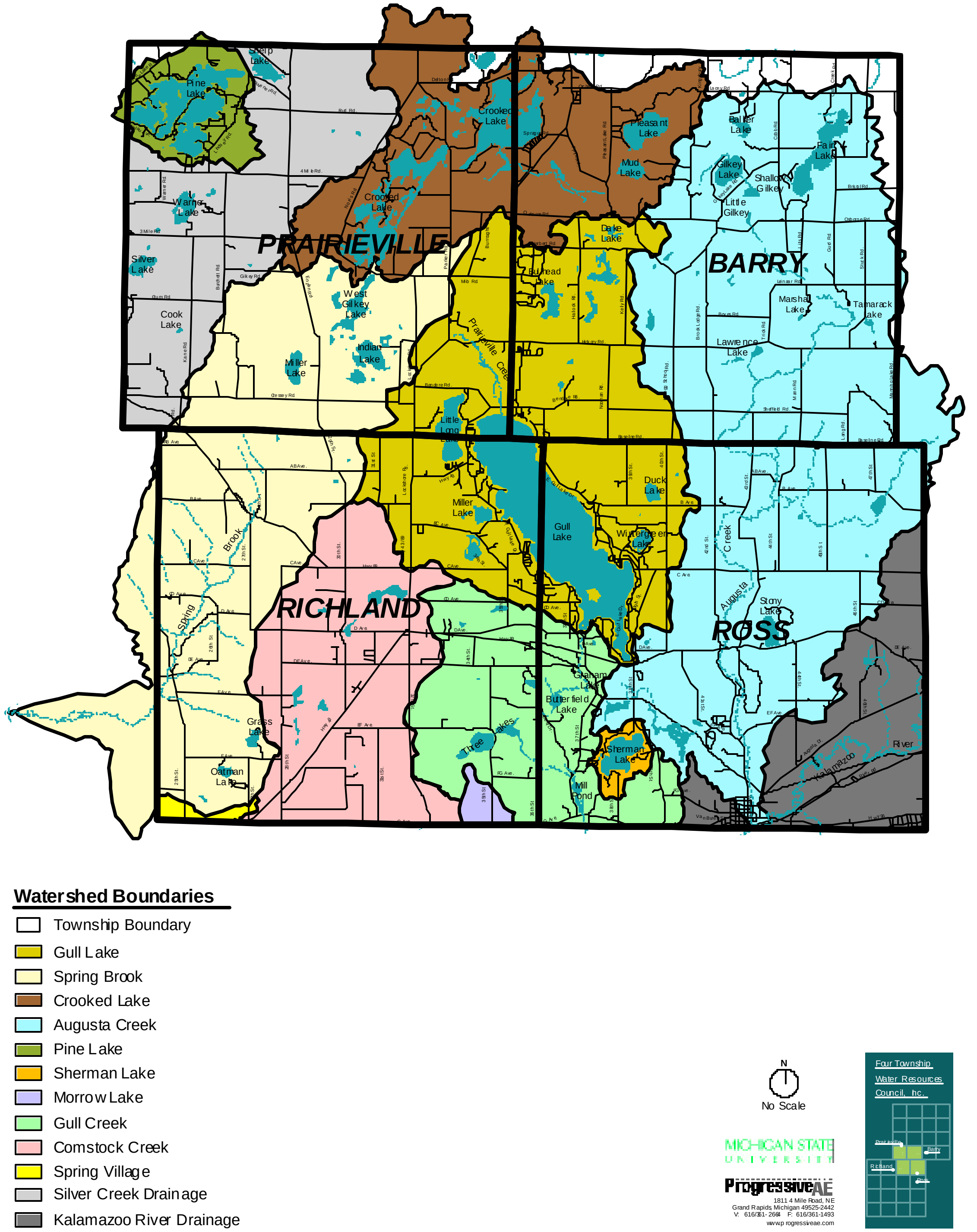


Figure 2. Four Township watershed map.

sheds of each of the four lakes, a discussion of current water quality conditions, an assessment of the environmental carrying capacity of each of the lakes, and a discussion of approaches local units of government can use to protect area water resources.

The Watershed Concept

A watershed is a geographic region within which water drains to a particular lake or stream. Watershed management has become the prime focus of several state and federal pollution control programs. From a management perspective, focusing on the watershed is important since land use activities in a watershed can directly impact water quality. The major watersheds within the four townships are shown in Figure 2. It is apparent from viewing this map that watersheds do not respect political jurisdictions. Recognizing this fact, the stated goal of the Four Township Water Resources Project is *to implement land use policies on an intergovernmental basis that will proactively manage growth and protect water quality*. Attempts to implement water quality protection strategies that do not focus on the watershed are often unsuccessful in that they fail to address problems and issues holistically.

Environmental Carrying Capacity

As used in this report, environmental carrying capacity is an assessment of a lake's ability to accommodate pollution inputs without degrading water quality. Each lake has a finite ability to assimilate pollutants. Eventually the pollution input, or load, becomes so large that water quality in the lake begins to decline. The ability of a lake to withstand pollution inputs is a function of several variables including lake size and depth, flushing rate, and water chemistry. To a large extent, the quality of water in a lake mirrors land use activities in the surrounding watershed. Lakes in highly developed areas that receive large inputs of pollutants from their watersheds tend to be of poorer quality than lakes with less intensively developed watersheds. In this report an estimate is made of the potential pollution load being transported to each of the study lakes, and the lake's response to this load is evaluated to gauge the sensitivity of the lakes to future developmental pressures.

Lake and Watershed Characteristics

A listing of the physical characteristics of each of the study lakes and their respective watersheds is provided in Table 1. Maps which depict land uses in each of the watersheds are provided in Figure 3. The percent land use in each of the watersheds is presented in Figure 4.

TABLE 1

FOUR TOWNSHIP STUDY LAKES PHYSICAL CHARACTERISTICS[1]

	Pine	Upper Crooked	Gull	Sherman
Lake Surface Area (acres)	660	645	2,047	148
Maximum Depth (feet)	34	48	110	36
Mean Depth (feet)	10.4	10.1	41.1	15.3
Lake Volume (acre-feet)	6,871	6,493	84,068	2,258
Shoreline Length (miles)	12.1	13.8	13.4	2.9
Shoreline Development Factor	3.4	3.9	2.1	1.7
Estimated Water Residence Time (years)	2.1	0.6	3.7	3.2
Lake Elevation (feet)	892	924	880	851
Watershed Area (acres)	1,357	8,886	12,833	322
Ratio of Lake Area to Watershed Area	1:2.1	1:13.8	1:6.3	1:2.2
Watershed Land Use (Acres)				
Agriculture	514	3,957	7,041	34
Urban (Residential and Commercial)	399	766	2,109	87
Wooded/Undeveloped	353	2,209	2,833	183
Wetland	91	1,954	850	17

The ratio of lake area to watershed area is a comparison of the size of the lake to the size of the watershed. With the exception of Upper Crooked Lake, which has a lake area to watershed area ratio of 1:13.8, the watersheds of the study lakes are relatively small when compared to the area of the lakes. (Lake area to watershed area ratios range from 1:2.1 for Pine Lake to 1:6.3 for Gull Lake). From a water quality perspective, a small watershed can be advantageous in that there is less potential for pollutants to drain or run off to the lake.

[1] Watershed areas, shoreline length, lake elevation, and lake surface area were determined by examining United States Geological Survey topographic maps of the Four Township area (scale: 1" = 2000'). Watershed areas are based on surface topography only and may not be representative of local groundwater flow conditions. Lake volume and maximum and mean depths were derived from Michigan Conservation Department depth contour maps of Gull, Pine, and Upper Crooked Lakes and a Michigan Department of Natural Resources depth contour map of Sherman Lake. Lake volume and shoreline development factor were calculated according to Lind (1974) using shoreline and contour areas derived from Microstation computer-aided design mapping. Land use acreage derived from Michigan Department of Natural Resources' Michigan Resource Information System mapping, updated with 1994 aerial photography for Prairieville and Barry Townships and 1996 aerial photography for Richland and Ross Townships.

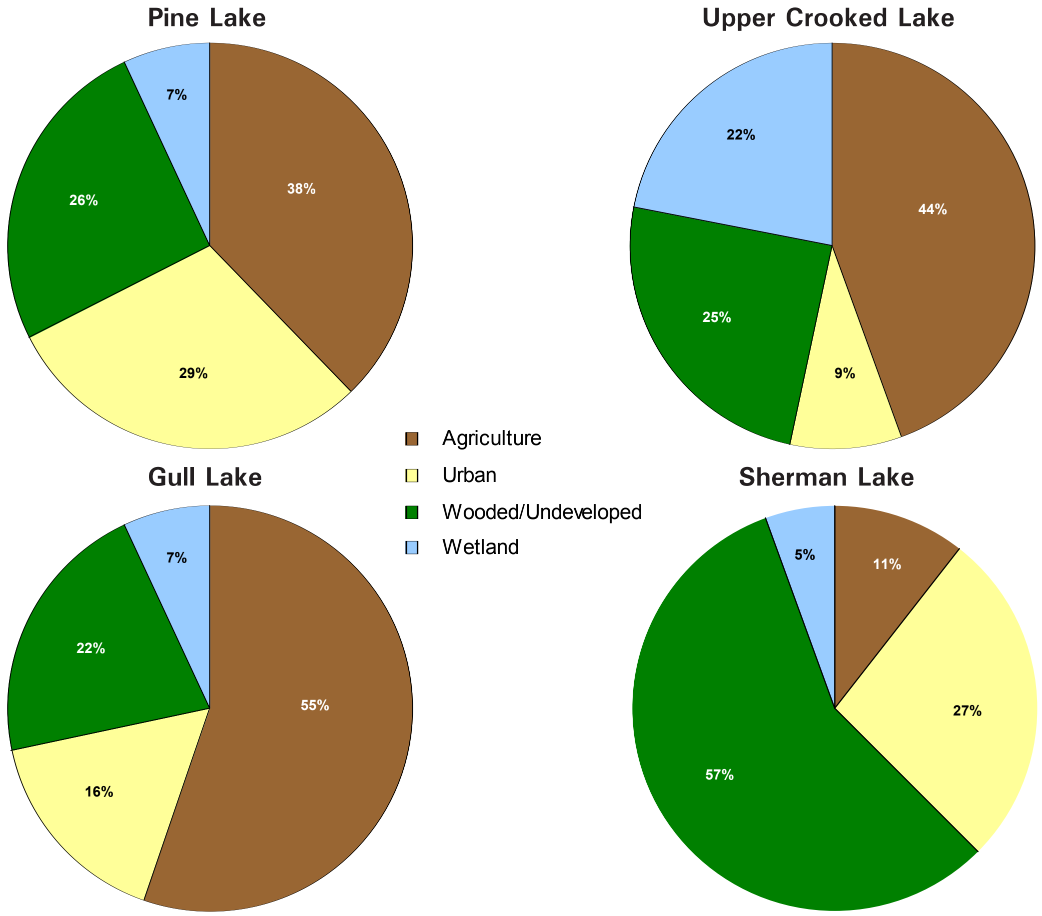


Figure 4. Watershed Percent Land Use.

For the most part, residential development in each of the watersheds is concentrated in close proximity to the lakes. Much of this residential development has occurred on relatively small lots which directly abut the lakes. Concentrated development of this nature can be problematic in that it increases the amount of imperviousness (i.e., hard surfaces such as roof tops, roads, driveways) and allows water to run directly into the lake. Often runoff from residential areas contains fertilizers, oil, and grease residues which can significantly degrade water quality. A major potential source of pollution input to the lakes was eliminated with the construction of sanitary sewers around Pine, Upper Crooked, and Gull Lakes. Residents of Sherman Lake still use on-site septic systems for wastewater disposal.

With the exception of the Sherman Lake watershed, agriculture is the largest single land use in each of the watersheds. The predominant agricultural use at present appears to be row crops intermixed with pasture lands, non-row crops, and fallow areas. Fortunately, the soils in the study lake watersheds are predominately well-drained with moderate infiltration capabilities. Thus, water tends to infiltrate into the ground after rain events which eliminates the need to construct extensive farm drainage systems. No significant agricultural drains appear to discharge directly to the study lakes. Many of the agricultural lands which exist in the watersheds are separated from the lakes by natural forested areas or wetlands. These areas act as a natural buffer which prevent agricultural fertilizers and other potential contaminants from washing directly to the lakes.

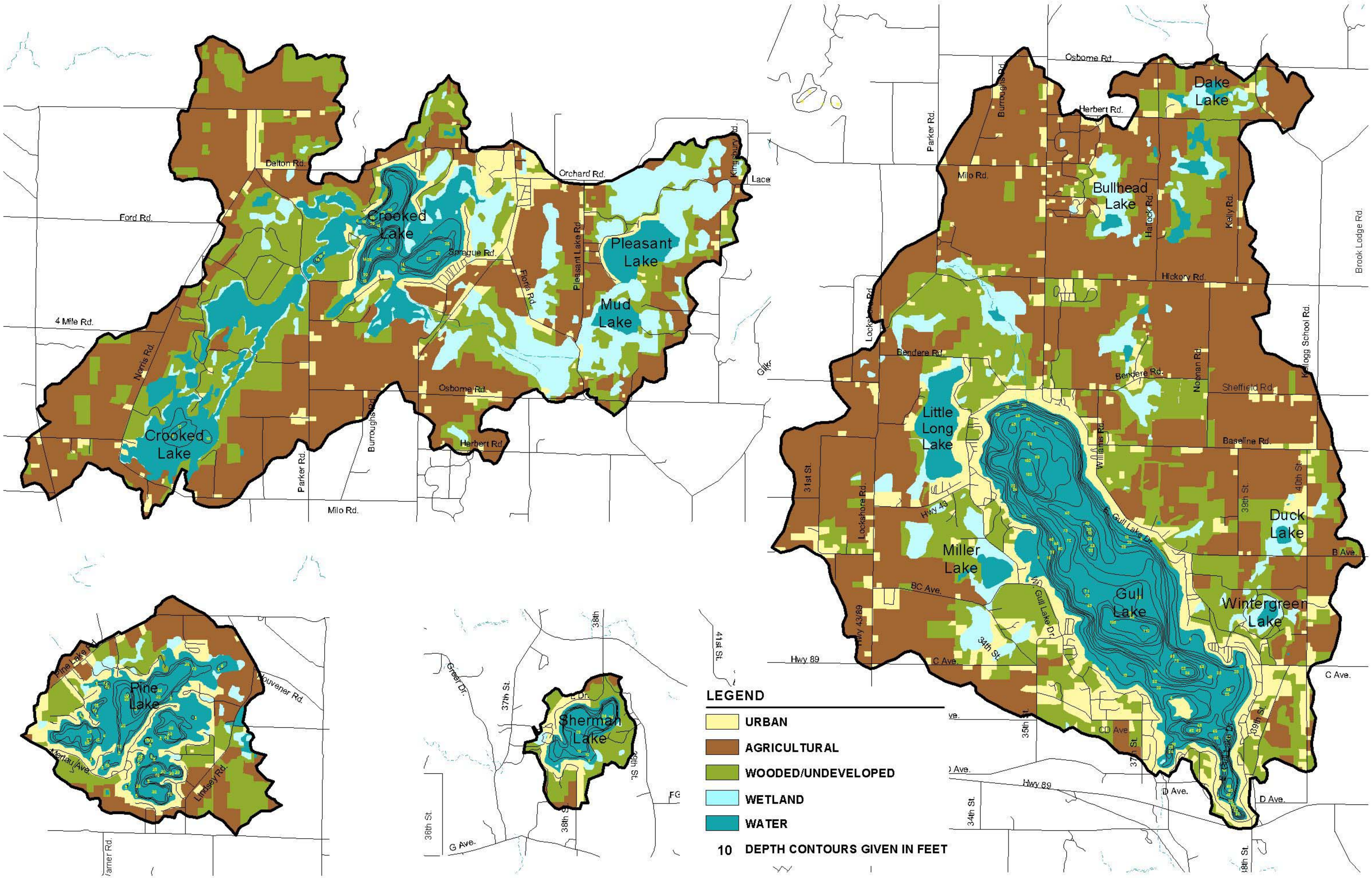


Figure 3. Study lakes watershed land use maps.

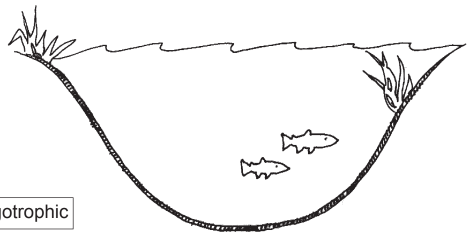
Wetlands are an important natural feature in each of the watersheds, in that they provide a number of important benefits including pollution filtration capabilities, fish and wildlife habitat, and flood control. Preservation of these vital resources will be critical to maintaining the quality of each of the study lakes.

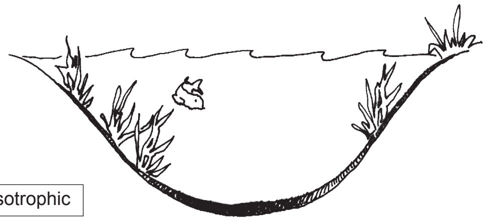
One factor that influences the sensitivity of a lake to pollution loading is its water residence time (sometimes referred to as the flushing rate). Water residence time is the time it takes the volume of water in a lake to be replaced by incoming water. In general, lakes that are flushed periodically by good quality water will tend to recover more quickly from pollution inputs than lakes with long water residence times. Pine Lake and Sherman Lake are "closed-basin lakes" that do not have a surface water outlet. Thus, pollutants are not readily flushed from these lakes and these lakes, in effect, act as pollution sinks. Once polluted, these lakes will take many years to recover and, in some cases, a pollutant could remain in the lake indefinitely. Water drains from Upper Crooked Lake into Lower Crooked Lake and Gull Lake drains to the Kalamazoo River via Gull Creek. Thus, Upper Crooked Lake and Gull Lake may be able to recover more rapidly from pollution inputs as they are "flushed" periodically by incoming waters.

Lake Water Quality

Introduction

Lake water quality is determined by a unique combination of processes that occur both within and outside of the lake. In order to make sound management decisions, it is necessary to have an understanding of the current physical, chemical, and biological condition of the lake, and the potential impact of drainage from the surrounding watershed.


Oligotrophic

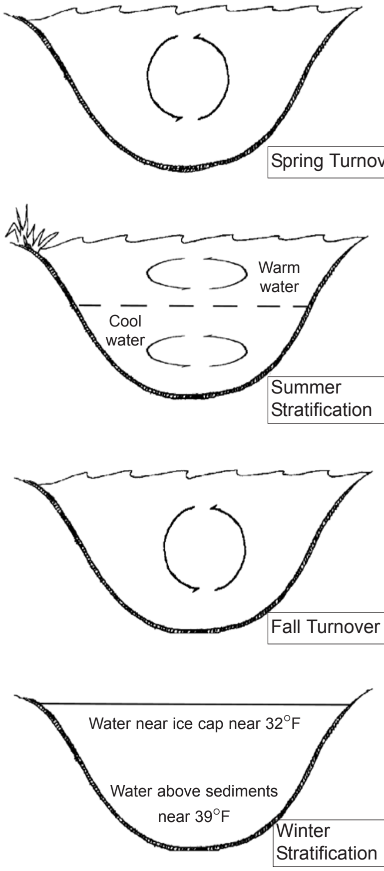

Mesotrophic


Eutrophic

Lakes are commonly classified as **oligotrophic, mesotrophic, or eutrophic.** Oligotrophic lakes are generally deep and clear with little aquatic plant growth. These lakes maintain sufficient dissolved oxygen in the cool, deep bottom waters during late summer to support cold water fish such as trout and whitefish. By contrast, eutrophic lakes are generally shallow, turbid, and support abundant aquatic plant growth. In deep eutrophic lakes, the cool bottom waters usually contain little or no dissolved oxygen. Therefore, these lakes can only support warm water fish such as bass and pike. Lakes that fall between these two extremes are called mesotrophic lakes.

Under natural conditions, most lakes will ultimately evolve to a eutrophic state as they gradually fill with sediment and organic matter transported to the lake from the surrounding watershed. As the lake becomes shallower, the process accelerates. When aquatic plants become abundant, the lake slowly begins to fill in as sediment and decaying plant matter accumulate on the lake bottom. Eventually, emergent plants become established and the lake is transformed to a marshland. The aging process in lakes is called "eutrophication" and may take anywhere from a few hundred to several thousand years, generally depending on the size of the lake and its watershed. The natural lake aging process can be greatly accelerated if excessive amounts of sediment and nutrients (which stimulate aquatic plant growth) enter the lake from the surrounding watershed. Because these added inputs are usually associated with human activity, this accelerated lake aging process is often referred to as "cultural eutrophication." The problem of cultural eutrophication can be managed by identifying sources of sediment and nutrient loading (i.e., inputs) to the lake and developing strategies to halt or slow the inputs. Thus, to effectively manage a lake, it is necessary to determine the limnological (i.e., the physical, chemical, and biological) condition of the lake and the physical characteristics of the watershed as well.

Key parameters used to evaluate the limnological condition of a lake include temperature, dissolved oxygen, total phosphorus, chlorophyll-*a*, and Secchi transparency. A brief description of these water quality measurements is provided here as an introduction for the reader. Particular attention should be given to the interrelationship of these water quality measurements. A more detailed discussion of these parameters is contained in the Four Township Water Resources Council's *Water Atlas*.



Temperature

Temperature is important in determining the type of organisms that may live in a lake. For example, trout prefer temperatures below 68°F. Temperature also determines how water mixes in a lake. As the ice cover breaks up on a lake in the spring, the water temperature becomes uniform from the surface to the bottom. This period is referred to as "spring turnover" because water mixes throughout the entire water column. As the surface waters warm, they are underlain by a colder, more dense strata of water. This process is called thermal stratification. Once thermal stratification occurs, there is little mixing of the warm surface waters with the cooler bottom waters. The transition layer that separates these layers is referred to as the "thermocline." The thermocline is characterized as the zone where temperature drops rapidly with depth. As fall approaches, the warm surface waters begin to cool and become more dense. Eventually, the surface temperature drops to a point that allows the lake to undergo complete mixing. This period is referred to as "fall turnover." As the season progresses and ice begins to form on the lake, the lake may stratify again. However, during winter stratification, the surface waters (at or near 32°F) are underlain by slightly warmer water (about 39°F). This is sometimes referred to as "inverse stratification" and occurs because water is most dense at a temperature of about 39°F. As the lake ice melts in the spring, these stratification cycles are repeated. Shallow lakes do not stratify. Lakes that are 15 - 30 feet deep may stratify and destratify with storm events several times during the year.

Dissolved Oxygen

An important factor influencing lake water quality is the quantity of dissolved oxygen in the water column. The major inputs of dissolved oxygen to lakes are the atmosphere and photosynthetic activity by aquatic plants. An oxygen level of about 5 mg/L (milligrams per liter, or parts per million) is required to support warm water fish. In lakes deep enough to exhibit thermal stratification, oxygen levels are often reduced or depleted below the thermocline once the lake has stratified. This is because deep water is physically cut off from plant photosynthesis and the atmosphere, and oxygen is consumed by bacteria that use oxygen as they decompose organic matter (plant and animal remains) at the bottom of the lake. Bottom-water oxygen depletion is a common occurrence in eutrophic and some mesotrophic lakes. Thus, eutrophic and most mesotrophic lakes cannot support cold-water fish because the cool, deep water (that the fish require to live) does not contain sufficient oxygen. In highly eutrophic, shallow lakes, a "winterkill" of fish can occur as oxygen supplies are depleted under winter ice cover.

Phosphorus

The quantity of phosphorus present in the water column is especially important since phosphorus is the nutrient that most often drives aquatic plant growth and the rate at which a lake ages and becomes more eutrophic. In the presence of oxygen, lake sediments act as a phosphorus trap, retain-ing phosphorus and, thus, making it unavailable for aquatic plant growth. However, if bottom-water oxygen is depleted, phosphorus will be released from the sediments and may be available to promote aquatic plant growth. In some lakes, the internal release of phosphorus from the bottom sediments is the primary source of phosphorus loading (or input).

By reducing the amount of phosphorus in a lake, it may be possible to control the amount of aquatic plant growth. In general, lakes with a phosphorus concentration greater than 20 μg/L (micrograms per liter, or parts per billion) are able to support abundant plant growth and are classified as nutrient-enriched or eutrophic.

Chlorophyll-*a*

Chlorophyll-*a* is a pigment that imparts the green color to plants and algae. A rough estimate of the quantity of algae present in lake water can be made by measuring the amount of chlorophyll-*a* in the water column. A chlorophyll-*a* concentration greater than 6 μg/L is considered characteristic of a eutrophic condition.

Secchi Transparency

A Secchi disk is often used to estimate water clarity. The measurement is made by fastening a round, black and white, 8-inch disk to a calibrated line. The disk is lowered over the deepest point of the lake until it is no longer visible, and the depth is noted. The disk is then raised until it reappears. The average between these two depths is the Secchi transparency. Generally, it has been found that aquatic plants can grow at a depth of approximately twice the Secchi transparency measurement. In eutrophic lakes, water clarity is often reduced by algae growth in the water column, and Secchi disk readings of 7.5 feet or less are common.

Lake Classification Criteria

Ordinarily, as phosphorus inputs (both internal and external) to a lake increase, the amount of algae will also increase. Thus, the lake will exhibit increased chlorophyll-*a* levels and decreased transparency. A schematic illustration of the factors influencing a lake's response to phosphorus inputs is presented in Figure 5. A summary of lake classification criteria developed by the Michigan Department of Natural Resources is shown in Table 2.

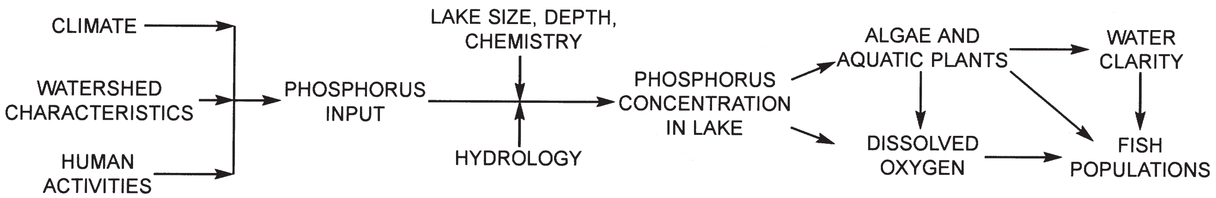


Figure 5. Phosphorus Loading Determinants and Lake Response (modified from Reckhow et al. 1980).

TABLE 2
LAKE CLASSIFICATION CRITERIA

Lake Classification	Total Phosphorus (μg/L)	Chlorophyll-*a* (μg/L)	Secchi Transparency (feet)
Oligotrophic	Less than 10	Less than 2.2	Greater than 15.0
Mesotrophic	10 to 20	2.2 to 6.0	7.5 to 15.0
Eutrophic	Greater than 20	Greater than 6.0	Less than 7.5

Study Lakes Water Quality

Recent water quality data indicate the study lakes exhibit both mesotrophic and eutrophic characteristics (Table 3). The shallower lakes (i.e., Pine Lake, Upper Crooked, and Sherman) generally exhibit higher phosphorus levels while Gull Lake (the largest and deepest of the lakes) has a relatively low phosphorus level.

TABLE 3
STUDY LAKES TROPHIC CLASSIFICATION[1]

				Trophic Status Based On:		
Lake	**Total Phosphorous (μg/L)**	**Chlorophyll (μg/L)**	**Secchi Transparency (feet)**	**Total Phosphorous**	**Chlorophyll**	**Secchi Transparency**
Pine Lake	17.1-23.8	4.3-4.9	9.3-10.7	Eutrophic	Mesotrophic	Mesotrophic
Upper Crooked Lake	15.4	4.5-5.9	9.4-9.8	Eutrophic	Mesotrophic	Mesotrophic
Gull Lake	10.1	3.4-6.1	14.3-15.1	Mesotrophic	Mesotrophic	Mesotrophic
Sherman Lake	14.1	4.2-6.1	12.2-13.4	Mesotrophic	Eutrophic	Mesotrophic

The impact of phosphorus loading has been well documented on Gull Lake (Tessier and Lauff 1992). As indicated in Table 3, Gull Lake exhibits excellent water quality, but this was not always the case. Between 1965 and 1975, a marked increase in shoreline vegetation and open water algae growth was observed in the lake. Monitoring of the lake in the mid-1960's indicated that there was oxygen at the lake bottom during the summer months. However, by the early 1970's, the bottom 50 feet of the lake was typically devoid of oxygen by late summer. This decrease in bottom water oxygen levels apparently led to the extinction of Gull Lake's native cold-water fishery. An increase in phosphorus concentrations was determined to be the likely cause of the accelerated eutrophication process in Gull Lake.

To assess the sources of phosphorus to Gull Lake, a phosphorus loading study was conduced that indicated phosphorus inputs to the lake were excessive (Tague 1977). Area septic systems were estimated to contribute about 68% of the total phosphorus input to the lake. It was noted that if septic phosphorus inputs were eliminated, phosphorus loading would be reduced to a level that the lake should begin to show signs of recovery. With the construction of the sewer system around Gull Lake in the 1980's, phosphorus levels dropped, water clarity more than doubled, and the rates of bottom water oxygen depletion greatly decreased (Tessier and Lauff 1992). Today, Gull Lake supports an exceptionally diverse cold and warm-water fishery with over 50 fish species (Lowe 1988). The successful recovery of Gull Lake illustrates the importance of limiting the input of phosphorus and other pollutants to area lakes. The rate of recovery in Pine Lake and Upper Crooked Lake resulting from the construction of sanitary sewers around these lakes in the early 1990's has been slower to occur since, in general, shallower lakes tend to recover more slowly to reductions in phosphorus loading (Wetzel 1983).

[1] Gull Lake phosphorus data derived from Tessier (1995). Sherman Lake phosphorus data from Tessier (personal communication). Pine Lake phosphorus data derived from Hamilton (personal communication) and Progressive Architects Engineers Planners (1987). Phosphorus data for Upper Crooked Lake, chlorophyll and Secchi transparency data derived from the Four-Township Water Atlas (Sippel and Hamilton 1998) and Hamilton (personal communication).

Environmental Carrying Capacity Analysis

Introduction

Land use activities in a lake's watershed are important from a management perspective in that runoff and drainage from the watershed directly impact lake water quality. In order to evaluate the influence of watershed drainage on lake water quality, it is necessary to estimate the quantity of pollutants contributed from within the watershed. This estimate can be made by conducting an environmental carrying capacity analysis. An environmental carrying capacity analysis is a calculation of pollution inputs to the lake based on land use, soil types, and other conditions in the surrounding watershed.

The type of land use in a watershed directly influences the quantity and quality of runoff. For example, the runoff from residential areas (with rooftops, roads, driveways, and other impermeable surfaces) will generally be of greater quantity and poorer quality in terms of sediment and nutrient content than runoff from a wooded area of equal size. In wooded areas, much of the potential pollution load is retained and assimilated by the vegetative ground cover. In this analysis, four land use classifications were utilized: Agricultural, urban, wooded/undeveloped, and wetland.

In conducting the environmental carrying capacity of the study lakes, an estimate was made of the quantity of phosphorus entering the lake from surface runoff, atmospheric deposition (both wet and dry fall), and (in the case of Sherman Lake) lakeside septic systems. The environmental carrying capacity analysis focused on the control of phosphorus for two reasons:

- Phosphorus is usually the major nutrient in shortest supply relative to the nutritional needs of aquatic plants. Therefore, phosphorus is the nutrient that controls eutrophication.
- Of the major nutrients, phosphorus inputs are more subject to control through management practices.

Environmental Carrying Capacity Calculations

Since it is extremely difficult and cost-prohibitive to directly measure nonpoint, diffuse sources of phosphorus loading such as surface runoff and atmospheric deposition, it was necessary to select phosphorus loading values from other studies in which direct measurements have been made in the field. Great care was taken to apply phosphorus loading values that would be representative of the watershed conditions observed around the study lakes. The values selected were based largely on a comprehensive literature review of the quantity of phosphorus transported to surface water bodies from various land uses (Reckhow et al. 1980) and from previous phosphorus budget analyses of Gull Lake (Tague 1977 and Tessier 1995). Information used to calculate the septic phosphorus contribution to Sherman Lake is contained in Appendix A.

When estimating the phosphorus load transported to the lake via surface runoff, the percent land use and the presence or absence of "buffering areas" (wooded or wetland areas that act to reduce phosphorus inputs) were taken into account before phosphorus loading calculations were made. It is assumed that wetland areas contribute no phosphorus to the lakes.

In a previous analysis of phosphorus inputs to Gull Lake (Tague 1977), it was noted that "the natural export of total phosphorus from the land drainage of Gull Lake is only one-third of the average export from predominately agricultural watersheds. The low rate of export is due to the existence of wetlands and numerous small lakes in the drainage basin that act as highly effective phosphorus traps. With respect to minimizing the impact of agricultural runoff, wetlands and forested areas appear to be providing similar water quality benefits in the watersheds of the other study lakes as well. Phosphorus inputs from agricultural lands in the watersheds are further mitigated by the fact that the soils in the study lake watersheds are predominately well-drained with moderate infiltration capabilities. Thus, water tends to infiltrate into the ground after rain events which eliminates the need to construct extensive farm drainage systems. No significant agricultural drains appear to discharge directly to the study lakes. On the other hand, most of the residential development borders directly on the lakes, allowing pollutants to run directly to the lakes. This underscores the need to preserve area wetlands and to preserve (and in some cases re-establish) shoreline vegetative buffers.

Phosphorus loading values selected for the study lakes are provided in Table 4. An estimate of phosphorus loading from overland runoff can be made by multiplying the acreage in various land covers (e.g., urban, wooded/undeveloped, agricultural) by the appropriate phosphorus loading rate. Similarly, an estimate of phosphorus loading from atmospheric deposition can be made by multiplying the atmospheric loading rate by the lake acreage. Estimates of the total phosphorus load contributed to each of the lakes are presented in Table 5 and Figure 6.

TABLE 4
PHOSPHORUS LOADING RATES

	Phosphorus Loading Values (lbs/acre/yr)			
Source	**Pine Lake**	**Upper Crooked Lake**	**Gull Lake**	**Sherman Lake**
Agricultural	0.15	0.15	0.1	0.15
Urban	1	0.9	0.8	0.9
Wooded/Undeveloped	0.1	0.1	0.05	0.1
Wetland	0	0	0	0
Atmospheric	0.165	0.165	0.165	0.165

TABLE 5
ESTIMATED ANNUAL PHOSPHORUS LOADS

	Phosphorus Loads (lbs/yr)			
Source	**Pine Lake**	**Upper Crooked Lake**	**Gull Lake**	**Sherman Lake**
Agricultural	77	594	704	5
Urban	399	690	1,687	78
Wooded/Undeveloped	35	221	142	18
Wetland	0	0	0	0
Atmospheric	109	106	338	24
Septic	0	0	0	123
Total	621	1,611	2,871	248

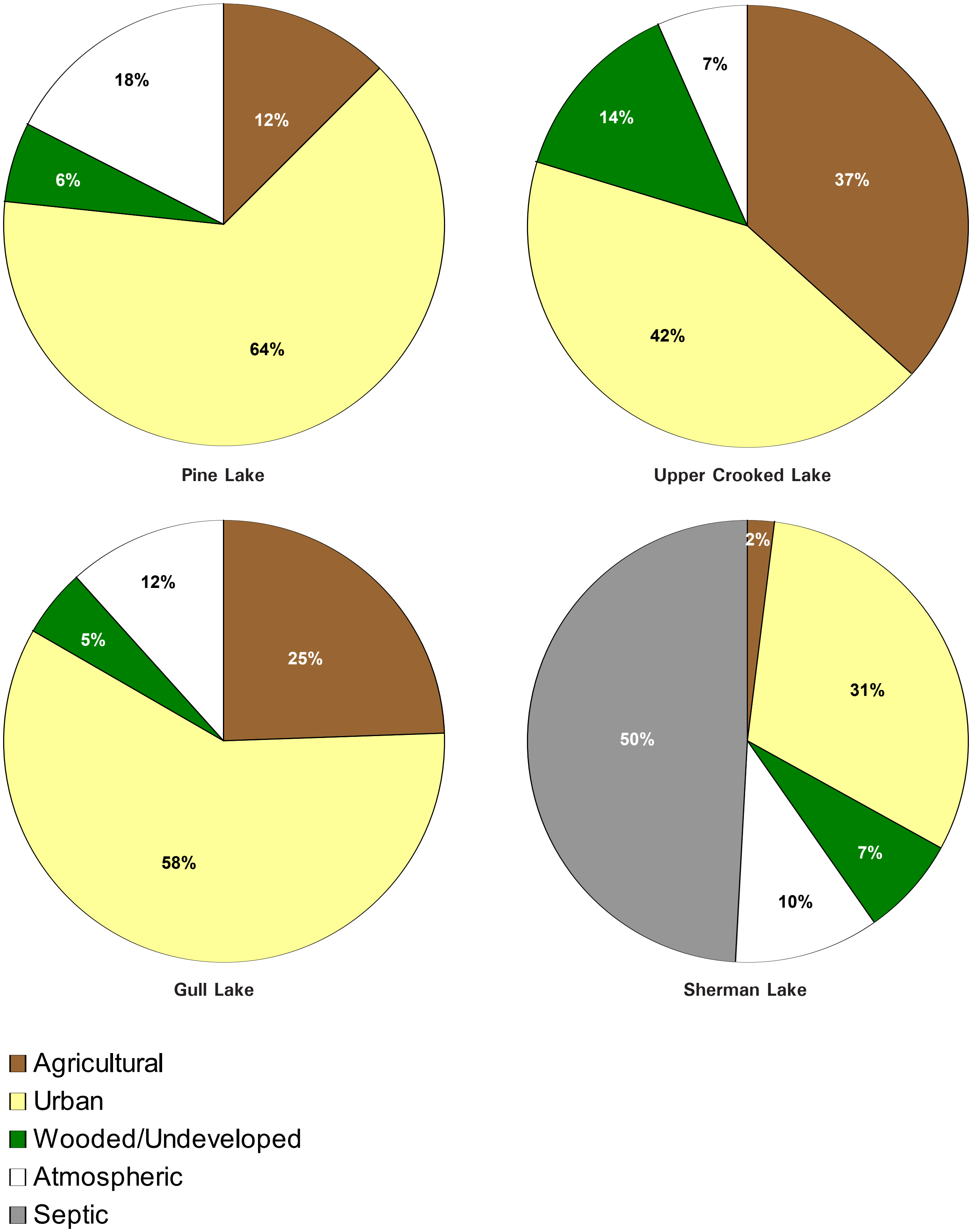


Figure 6. Estimated Phosphorus Loadings from Various Sources.

Various researchers have studied the impact of phosphorus loading on lake water quality, and many have developed techniques for predicting the impact of development on lake trophic status (Reckhow et al. 1980; Dillon and Rigler 1975; Vollenweider 1975). Reckhow et al. (1980) developed a model for north temperate lakes (such as the study lakes) that can be used to predict a lake's average phosphorus concentration as a function of phosphorus loading and lake flushing rate. The model equation is:

$$P = \frac{L}{11.6 + 1.2q_s}$$

$$L = \frac{M}{A_o}$$

$$q_s = \frac{Q}{A_o}$$

$$Q = (A_d \times r) + (A_o \times Pr)$$

P = Lake phosphorus concentration (in parts per billion)
L = Surface area phosphorus loading (in grams per square meter-year)
M = Total mass loading (in kilograms per year)
A_o = Lake surface area (in square meters)
q_s = Surface area water loading (in meters per year)
Q = Inflow water volume to lake (in cubic meters per year)
A_d = Watershed area, excluding the lake (in square meters)
r = Total annual unit runoff (in meters per year)
Pr = Mean annual net precipitation (in meters per year)

By applying this modeling methodology to each of the study lakes, it is possible to estimate the in-lake total phosphorus concentration in each of the study lakes based on current watershed development patterns (Table 6 and Figure 7). With the exception of Pine Lake, the in-lake total phosphorus concentration estimated for each of the lakes is reasonably close to the actual total phosphorous concentrations recently measured in the lakes (Table 3). The disparity between the predicted and measured phosphorus concentrations for Pine Lake may indicate the lake is still recovering from the historical influence of shoreline septic systems.

TABLE 6
ENVIRONMENTAL CARRYING CAPACITY MODEL COMPONENTS[1]

	Pine	Upper Crooked	Gull	Sherman
P	8	16	10	14
L	0.11	0.28	0.16	0.19
M	282	731	1,302	113
q_s	1.5	5.3	3.4	1.4
Q	3,999,125	13,836,515	27,800,000	865,470
A_o	2,672,065	2,611,336	8,287,449	599,190
A_d	5,495,401	35,975,964	51,957,000	1,301,976
r	0.30	0.32	0.39	0.26
Pr	0.9	0.9	0.9	0.9

[1] Total annual unit runoff (r) for Pine, Upper Crooked, and Sherman Lakes estimated according to method of Marsh (1991) using topography, vegetation, slope, and soil type. Mean annual net precipitation (Pr) derived from total monthly precipitation from 1948 to 1999, recorded at W.K. Kellogg Biological Station, provided by Michigan State University Climatology Program. Inflow data for Gull Lake obtained from Tessier (1995). All other parameters derived by calculation.

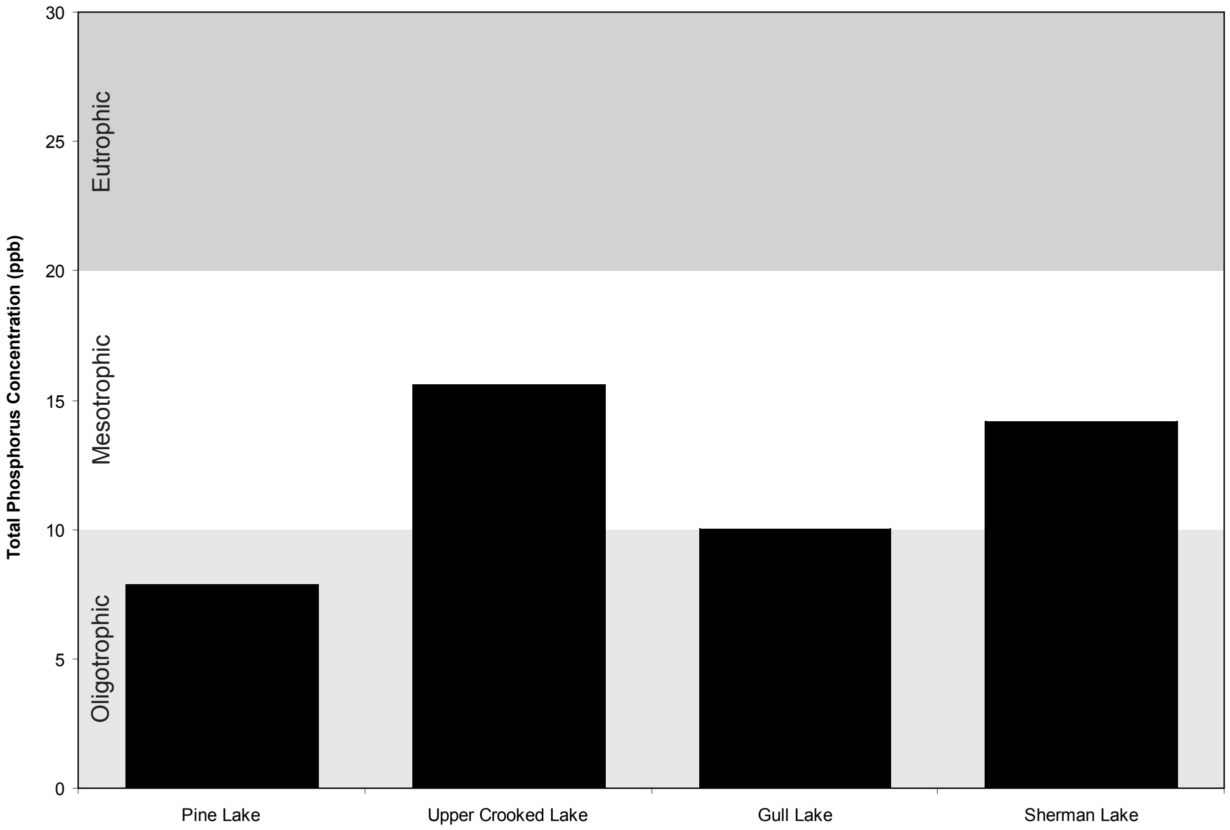


Figure 7. Estimated In-Lake Phosphorus Concentrations Based on Current Conditions.

The phosphorus loading model can be used to estimate a lake's response to increases or decreases in phosphorus loading. For example, if sewer service were extended around Sherman Lake, the elimination of the septic phosphorus load would result in an in-lake total phosphorus concentration of 7 ppb. Vollenweider (1968) approximated generalized phosphorus loading levels to maintain water quality conditions in lakes of various depths. Applying these criteria to the study lakes indicates that current phosphorus loading rates could potentially accelerate the natural aging or eutrophication process in each of the study lakes (Table 7). Should this occur, it is doubtful the accelerated eutrophication process could be reversed without great public expenditures. The environmental carrying capacity analysis demonstrates the sensitivity of the study lakes to even small increases in pollution loading. As additional development occurs around these lakes, it is essential that consideration be given to water quality impacts. Development should be planned and designed to minimize the runoff of pollutants which can adversely impact water resources. Specific development options to protect water quality are discussed in the following report section.

TABLE 7
PERMISSIBLE AND DANGEROUS PHOSPHORUS LOADING RATES

	Pine Lake	Upper Crooked Lake	Gull Lake	Sherman Lake
Current Phosphorus Load (lbs/acre/yr)	0.9	2.5	1.4	1.7
Vollenweider Permissible Loading (lbs/acre/yr)	<0.6	<0.6	<1.1	<0.6
Vollenweider Dangerous Loading (lbs/acre/yr)	<1.2	<1.2	<2.0	<1.2

Recommendations and Conclusions

Discussion

With the construction of sanitary sewers around Pine Lake, Crooked Lake, and Gull Lake in the 1980's and 1990's, a major source of pollution was eliminated. As previously discussed, the benefit of the sewer system was well documented in Gull Lake where several years of monitoring showed a decline in phosphorus levels, greatly improved water clarity, and increased bottom water oxygen levels after installation of the sewer system (Tessier and Lauff 1992). However, the water resources of the four townships are now threatened by the collective impact of development. While the water quality impacts associated with increased development are initially subtle, over time pollution inputs commonly associated with development can have a devastating impact on water resources. These adverse impacts result primarily from an increase in imperviousness (hard surfaces which increase the runoff of pollutants) and the loss of natural areas (such as wetlands and forests) which act to naturally filter and trap pollutants.

An analysis of land use patterns in the four townships conducted with the Four Township Water Resources Council geographic information system indicates that between 1978 and the mid-1990's about 5,000 acres of the four townships was developed for residential or commercial uses. Not surprisingly, much of this urbanization has occurred in the vicinity of area lakes. Also, in recent years, there appears to be a strong trend toward converting what were once seasonal cottages to year-round residences. Often these year-round residences are much larger than the dwellings that existed around area lakes historically (Figure 8). These trends will likely continue as more people appear inclined to "live in the country" and are willing to commute increasingly long distances to the workplace. If recent trends are any indication, it should be apparent that substantial urbanization of the four townships is inevitable. The questions is, how do we accommodate additional development without compromising the resources that attracted the development in the first place?

Figure 8. Seasonal Cottage versus Year-Round Residence.

Development Options

Recognizing the need to protect their valuable water resources, several states, including Maine, Minnesota, and Wisconsin, have adopted shoreland development standards to minimize the adverse water quality impacts often associated with development. However, while Michigan has not adopted statewide development standards for lake shorelands, local units of government can employ a number of options to minimize the impact of development on water resources. These options can be used individually or in concert with one another. Essentially these techniques are designed to minimize imperviousness and to preserve wetlands and forested areas which naturally filter and trap pollutants. A listing of options that may be implemented at the local level is included in Table 8. Many of these development options can be implemented by a community through zoning. A detailed discussion of planning and zoning techniques to protect water quality is contained in a recent Four Township Water Resources Council publication entitled *Watershed Resource Papers - A Guidebook for the Four Townships*. The ensuing discussion will cover some new legislative initiatives and illustrate how these options may be used to maximize water quality benefits.

TABLE 8
DEVELOPMENT OPTIONS TO PROTECT WATER QUALITY

- Retain Open Space
- Protect Wetlands
- Maintain Building Setbacks and Shoreline Vegetative Buffers
- Manage Stormwater

Retain Open Space

An approach that is gaining acceptance in communities across the state is a zoning technique called "Open Space (Cluster) Development." With this approach, the base density for a zoning district doesn't increase (although in some cases density bonuses are given). Open space development typically allows the same number of homes to be built, but they are clustered on to a smaller portion of the development site, thus preserving more undeveloped land. With open space development, a site analysis can be required to identify natural features (such as wetlands, steeply sloped lands, forested areas, stream corridors, or lake shorelands). These natural features can constitute part or all of the designated "open space" portions of the development site. Development is then clustered in appropriate locations on the site and the designated open space elements are protected in perpetuity, typically through a deed restriction or conservation easement.

Properly designed open space developments can provide the following water quality benefits:

- Clustering development can minimize impervious surfaces by shortening road lengths;
- If wetlands and forested areas are preserved as "open space elements," the natural ability of these areas to filter and trap pollutants is not lost;
- Development of erosion-prone areas (such as steeply sloped forest lands) can be avoided;
- The land's natural ability to convey and cleanse stormwaters can be preserved;
- Potential pollution sources are consolidated (versus dispersed) and are more amenable to management; and
- The natural infiltration of stormwaters can be sustained.

In essence, a properly designed open space development can help to protect the functional integrity of the land with respect to the natural conveyance or infiltration of stormwater.

Additional benefits of open space development include:

- Permanent protection of open areas and natural features without restricting property rights;
- Rural character preservation;

- Cost savings to property owners due to less infrastructure construction and maintenance;
- Development potential of the site is not limited;
- Creates a greater sense of community;
- No large public expenditures are required for land acquisition;
- May create continuity of "greenway" open space for wildlife migration and movement; and
- Helps to curtail urban sprawl.

Recognizing the need to protect open space at the state level, Governor Engler signed three land use bills into law on December 14, 2001. A press release from the Governor's office stated:

Governor John Engler today signed a land use bill package that creates a local zoning option for land development preserving open space while increasing capacity on less land.

"This bill package is an important first step in creating incentives to preserve open spaces while using less land to encourage family-friendly neighborhoods," said Governor Engler. Specifically, under this bill package, a landowner could increase the number of allowable residential units on a parcel of land in exchange for preserving a portion in perpetuity.

House Bill 4995, sponsored by State Representative Ruth Johnson (R - Holly), and House Bill 5028, sponsored by State representative Randy Richardville (R - Monroe), creates an option for developers to increase density in exchange for preserving 50 percent of the land as open space. If 50 percent were placed under a perpetual conservation easement, the developer could build up to three dwellings per acre, if a public sewer service were available. In the absence of a sewer system, up to two dwellings per acre could be built.

"We are determined to protect private property rights and keep taxes down," said Rep. Johnson. "These measures should create better growth patterns that will preserve open spaces and our precious natural resources for Michigan families." Johnson chairs the House Land Use and Environment Committee.

"Preserving our state's natural features should be a principal part of any development plan," added Rep. Richardville. "The quiet surroundings of open spaces such as wood lots and wetlands can improve the quality of life for adults and provide a living classroom for young people."

House Bill 5029, sponsored by Chris Kolb (D - Ann Arbor), limits the development in cities and villages to not more than 80 percent of the property to receive the increased density allotment. This takes into consideration the limited space in more urban areas.

The bill package requires local units of government to enact ordinances within 12 months of the effective date of the act to allow this open space preservation. An exemption exists for municipalities that have exercised a similar ordinance as of October 1, 2001 *(emphasis added). In addition, the development of land under this bill package is subject to all other applicable ordinances, laws and rules.*

A press release dated December 14, 2001, from the Michigan Environmental Council, stated:

LANSING - Today Governor Engler signed into law three measures that help local governments and the development community cooperate to conserve land, protect natural resources and retain the character of rural communities. Environmentalists herald the new laws as the first in a series of important tools for local planners.

"The ability to trade denser development for land conservation is a hallmark of Smart Growth, Michigan style," said Conan Smith, Land Programs Director at the Michigan Environmental Council.

"These new laws help our local governments to respect private property rights and simultaneously protect the things they value about their communities."

House Bill 4995, sponsored by state Representative Ruth Johnson (R-Holly), and House Bill 5028, sponsored by Representative Randy Richardville (R-Monroe), allow developers to increase density on a parcel of land in exchange for permanently protecting at least half of it under conservation easements. House Bill 5029, sponsored by Representative Chris Kolb (D-Ann Arbor) allows a similar benefit in urban areas, where developers will preserve at least 20 percent of the land.

"Many small, sensitive habitats - such as unregulated wetlands -- will be preserved by these laws," Smith said. "We're making the development community a partner in protecting Michigan's natural features."

The proposals won the support of both the environmental community and the Michigan Home Builders Association. Smith noted that the bills alone will not solve the problems created by urban sprawl, but agreed that clustering development is a step in the right direction.

"We need to encourage more sustainable patterns of development," he said. "I hope the broad support these bills garnered has opened the door for other important tools for our communities, such as transfer of development rights and coordinated planning."

Locally, Open Space Development Ordinances have recently been adopted by both Barry County and Ross Township. These ordinances require designated open space on at least 40% of the development site. Prairieville Township and Richland Township are currently considering incorporating open space development requirements into their zoning ordinances. To facilitate the preservation of natural features within Open Space Developments, the Four Township Water Resources Council geographic information system can be used to identify critical areas such as wetlands and steeply sloped areas.

<u>Protect Wetlands</u>

Wetlands are important to water quality because they effectively reduce levels of pollutants such as sediments, nutrients, and pesticides in runoff before the water reaches lakes, streams, and groundwaters. Wetlands are particularly efficient in removing nitrate; high nitrate concentrations in domestic well water are a growing problem in the four townships. Many fishes are dependent on wetlands adjacent to open waters as spawning sites; waterfowl feed and nest in wetlands; and various game animals use wetlands for food and cover. In addition, local wetlands support unique plant communities such as Tamarack forests, harbor some rare non-game animals such as the Spotted Turtle, and serve as breeding sites for a variety of frogs, toads, and salamanders. With about 10% of the land area in the four townships composed of wetlands, the four township area is exceptionally rich in wetland resources (Figure 9). There are many local wetlands that remain in more or less natural condition, or are in a process of recovery from disturbances that occurred decades ago. There are extensive wetlands along the edges of some lakes, and many of the smaller lakes are really wetlands because they become entirely filled with emergent vegetation during the growing season. The Kalamazoo River in Ross Township has a broad, largely forested floodplain, and its smaller tributary streams, such as Augusta Creek, are lined with floodplain wetlands containing a mix of trees, shrubs, and wet meadows. In addition to wetlands associated with lakes or streams, there are numerous small, isolated wetland depressions in the upland areas, some of which are permanently flooded while others may contain water for only part of the year.

According to the Fish and Wildlife Service, over half of wetlands in Michigan have been lost through piecemeal and wholesale destruction. In recognition of the huge economic losses that were result-

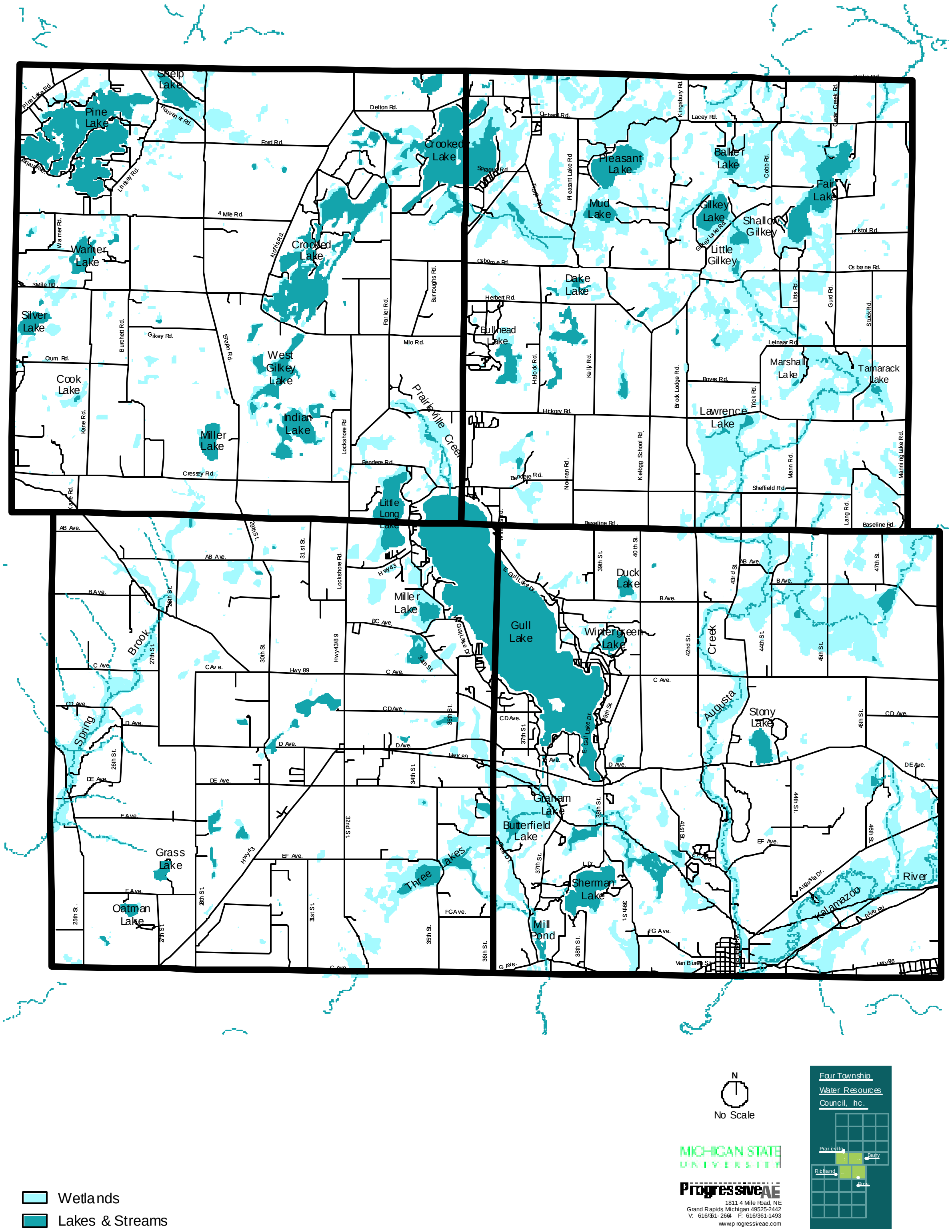


Figure 9. Four Township wetland map.

ing from the destruction of wetlands, nationwide wetland protection regulations were incorporated into the Federal Clean Water Act of 1972. In 1980, Michigan enacted its own law regulating development of wetlands consistent with federally mandated wetland protection efforts. Michigan's wetland protection regulations are contained within Part 303 of the Natural Resources and Environmental Protection Act (P.A. 451 of 1994), as amended. Under Part 303, wetlands are defined as follows:

> "Wetland" means land characterized by the presence of water at a frequency and duration sufficient to support and that under normal circumstances does support wetland vegetation or aquatic life and is commonly referred to as a bog, swamp, or marsh.

In accordance with Part 303, the following activities require a permit from the Department of Environmental Quality (MDEQ):

- Deposit or permit the placing of fill material in a wetland;
- Dredge, remove, or permit the removal of soil or minerals from a wetland;
- Construct, operate, or maintain any use or development in a wetland; and
- Drain surface water from a wetland.

Certain activities, such as fishing, trapping and hunting, grazing of animals, certain farming activities, and harvesting of lumber are exempt from permit requirements.

Part 303 requires that the Department of Environmental Quality not issue a wetland permit unless the applicant shows either of the following:

a) The proposed activity is primarily dependent on being located in a wetland.

b) A feasible and prudent alternative does not exist.

In the four township area, wetlands which meet any of the following criteria are regulated by the Michigan Department of Environmental Quality:

- Wetlands which have direct physical contact or a permanent or intermittent surface water connection to a lake, pond, river, or stream.
- Wetlands which are located partially or entirely within 500 feet of a lake, pond, river, or stream.

In counties with population greater than 100,000 (such as Kalamazoo County), noncontiguous wetlands (i.e., wetlands not bordering or within 500 feet of a lake, pond, or stream) greater than 5 acres in size are also regulated. In counties with a population less than 100,000 (such as Barry County), noncontiguous wetlands greater than 5 acres are not regulated until the MDEQ completes a wetland inventory for that county. Regardless of population, noncontiguous wetlands 5 acres or less in size are generally not regulated by the state.

To date, an official wetland inventory for the four township area has not been completed by the state. To assist local wetland protection efforts, the Four Township Water Resources Council has utilized a geographic information system to create a map which depicts the generalized location of wetlands. The map was created by combining information regarding hydric (i.e., muck type) soils, U.S. Fish and Wildlife Service National Wetland Inventory maps, and Michigan Resource Information System (MIRIS) land use/cover data. This data has been made available to each of the four townships. The townships are encouraged to use these maps to gauge the potential impact of development proposals on area wetlands. These maps can help property owners and developers identify wetland locations in advance of the formulation of development proposals, thereby avoiding wetland impacts and potential conflicts.

Part 303 requires that the MDEQ send copies of wetland permit applications to the local units of government where the wetland is located. Communities then have an opportunity to recommend approval, modification, or denial of a permit to the department. The MDEQ often gives considerable weight to the recommendations of local governmental units. Township officials in the four townships are strongly encouraged to review wetland permit applications sent by the MDEQ and to provide written recommendations to the department if the activity proposed in the permit application would adversely impact area wetlands.

Many communities have elected to adopt their own wetland ordinances. However, there are several requirements that must be considered in doing so. Part 303 requires a local unit of government that adopts its own wetland ordinance to do the following:

- Use the state definition of wetland, rather than a local definition;
- Conduct a local wetland inventory and make an inventory map available to the public at a reasonable cost (the Four Township Watershed Council wetland map could satisfy this requirement);
- Upon completion of the wetland inventory map, the community must notify each record owner of property that the inventory map exists, where the maps may be reviewed, that the owner's property may be designated as a wetland on the inventory map, and that the community has an ordinance regulating wetlands;
- If a community denies a wetland permit, it must allow a landowner to request a re-evaluation of the affected property for assessment purposes to determine its fair market value under the use restriction imposed by the permit denial; and
- If a community desires to regulate wetlands less than two acres in size, the community must provide a formal finding that the wetland is essential to the preservation of the natural resources of the community.

Although local wetland regulation is desirable, it may prove administratively burdensome and open the community to potential "takings" claims. At a minimum, communities should use available wetland maps to evaluate potential wetland impacts, closely monitor and provide comment on pending MDEQ wetland permit applications, look for opportunities to permanently protect area wetlands (such as conservation easements), and explore alternatives to avoid impacting area wetlands (such as open space development). Another local wetland protection option would be to require site plan review before building permits are issued for construction in designated wetland areas.

Maintain Building Setbacks and Shoreline Vegetative Buffer Strips

The preservation of natural vegetative cover on lands abutting lakes and streams in the four townships is essential to protecting both the environmental and aesthetic quality of these resources. In general, there is a tendency for unplanned development to dramatically and adversely impact lands adjacent to lakes and streams. Typically, vegetative cover, which provides a natural buffer between land and water, is cleared to accommodate building sites, landscaped lawns, roads, and a variety of other uses (Figure 10). These activities, in turn, can adversely impact lake and stream quality by increasing the rate of runoff and pollution transport to these resources. In addition to pollution control, natural vegetative cover adjacent to lakes and streams provides habitat for wildlife and can help to shade and cool adjacent waters. Regulations to prevent excessive encroachment into lake shoreland and stream corridor areas are essential to preserving the environmental attributes of these lands.

Figure 10. Loss of Natural Vegetative Cover Associated with Building Activity.

All of the townships should consider enacting zoning provisions which limit excessive encroachment into natural vegetative cover adjacent to lakes and streams. One way this could be accomplished is through the creation of an overlay district. An overlay district is a zoning district that applies to a specific geographic area, such as a lake shoreland or a stream corridor. In an overlay district, proposed developments must meet all the conditions of the underlying district in addition to the provisions set forth in the overlay district. Overlay zoning can be used to help ensure uniform zoning regulations are in place across several zoning districts or political jurisdictions. The overlay zoning approach may be especially effective in a lake such as Gull Lake whose shores are bordered by each of the four townships.

An overlay district for lands adjacent to lakes and streams could require building setbacks, shoreline vegetative buffers, limits on imperviousness, and prohibit specific uses and activities that could be detrimental to water quality, such as gas stations and confined feedlots. All of the four townships should consider the adoption of an overlay zoning district along environmentally sensitive lake shorelands and stream corridors.

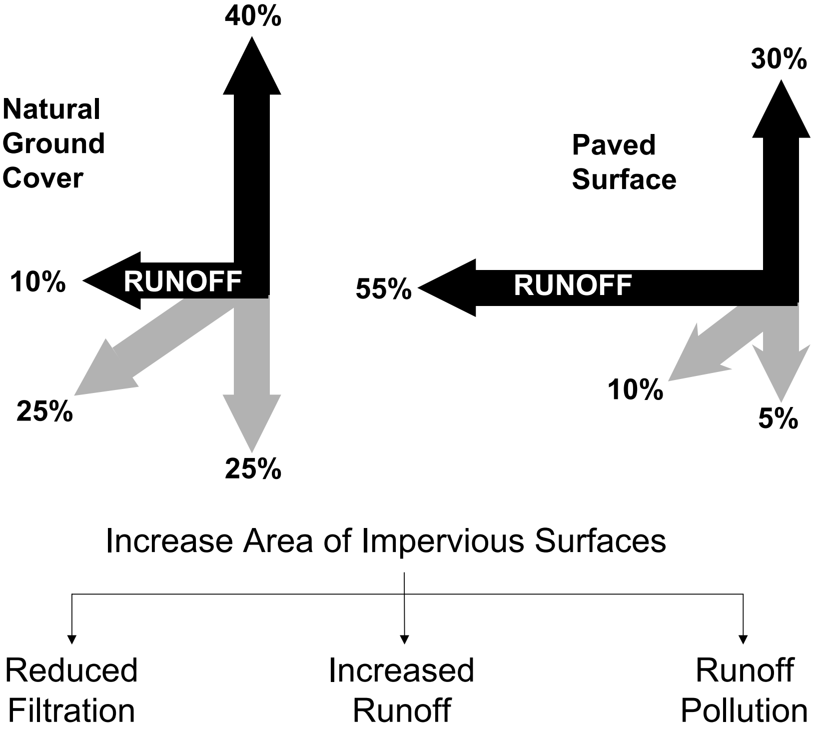


Figure 11. Increases in Impervious Surfaces and Runoff.

<u>Manage Stormwater</u>

As urbanization increases in a community, natural vegetative cover is replaced by rooftops, roadways, parking lots, and other impervious surfaces. The increase in impervious area greatly increases the rate and volume of runoff and decreases water infiltration into the ground (Figure 11). With an increase in the quantity of runoff, a concurrent increase in the quantity of pollutants transported generally occurs as well. The "first flush" of stormwater runoff often contains high concentrations of oil and grease residues, nutrients, sediment, trace metals, fecal bacteria, oxygen-consuming wastes, and a variety of other contaminants. These pollutants can cause siltation, nutrient enrichment (and accelerated eutrophication), bacterial contamination, and severe degradation of an area's water resources.

Recognizing the potential adverse impacts of stormwater runoff to downstream properties and water resources, many communities are adopting stormwater management regulations. In an effort to reduce the quantity and improve the quality of stormwater emanating from development sites, these regulations generally require onsite detention or retention of stormwater. Often, standards are adopted that require post-development rates of runoff not exceed pre-development runoff rates. Townships can adopt stand-alone (police power) regulations or incorporate stormwater management regulations into their zoning ordinances.

As more land in the four townships is converted from rural to more urbanized uses, stormwater management will take on greater importance. In the absence of a strategy to effectively manage stormwater at its source, publicly financed remedial stormwater projects will invariably become the norm. In many cases, remedial stormwater systems require enormous public expenditures to construct and maintain. By planning proactively, the cost of stormwater infrastructure can be more equitably shared between the private and public sectors. This approach requires the cost of stormwater facilities to be assumed by stormwater dischargers that increase the quantity or decrease the quality of stormwater runoff. Stormwater management measures and facilities are required to be phased into development as it occurs, thereby minimizing public expenditures for stormwater infrastructure improvements.

Stormwater management rules have recently been adopted by the Kalamazoo County Drain Commissioner, and the Barry County Drain Commissioner is in the process of drafting new regulations. At the federal level, the USEPA recently mandated that all communities with a population greater than 50,000 enact comprehensive stormwater management programs. The four townships are strongly encouraged to consider incorporating stormwater management requirements and standards into the Site Plan Review provisions of their zoning ordinances.

Recommendations and Conclusions

Lakes have a finite ability to withstand pollution inputs. The results of the environmental carrying capacity analysis indicate that each of the study lakes is extremely sensitive to increases in phosphorus loading. Without proper development controls, additional development will greatly accelerate the natural aging or lake eutrophication process. This, in turn, would result in increased aquatic plant growth, murky water, degraded fisheries, and an overall decline in the quality of these resources.

The preceding discussion has focused on various options units of government in the four townships can use to protect water quality. The Four Township Water Resources Council will soon be publishing a document entitled *Watershed Resource Regulations - A Regulatory Guidebook For The Four Township Water Resources Project*. This document contains a series of sample regulations to address many of the issues discussed herein.

Land use activities in the watershed directly impact lake water quality. If natural areas are simply "paved over" to accommodate additional development, the quality of the four townships water resources will certainly decline. Decisions made at the local level today will have a profound impact on the character of the area's land and water resources. By integrating water resource protection into the local decision-making process, the social, economic, and environmental value of these resources can be preserved for future generations to enjoy.

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Appendix A

The rationale used for estimating the septic contribution to the nutrient budget is as follows:

1. Estimate the average phosphorus load from household wastewater discharged to septic systems:

   3.26 lbs/capita/year (Table A-1).

   Reduce the estimate by 50 percent to account for the Michigan ban on phosphorus detergents (Sawyer 1962; Rodiek 1979):

   0.50 x 3.26 = 1.6 lbs/capita/year.

2. Multiply the estimate in Item No. 1 by the average capita per residence and the average occupancy rate in the local municipality:

   1.6 lbs/capita/year x 2.48 capita/residence[1] x 0.50 occupancy (assumed) = 1.98 lbs/residence/year.

3. Estimate the quantity of phosphorus from septic system effluent that is retained by the soil (Table A-2) for each household adjacent to the lake (Table A-3). Estimate the quantity of phosphorus that is not retained by the soil and leaches to the lake (Table A-4).

TABLE A-1
PHOSPHORUS LOADS FOR HOUSEHOLD WASTEWATER DISCHARGED TO SEPTIC SYSTEMS
(lbs/capita/year)

Total Phosphorus	Reference
3.29	Ligman et al. 1974
3.15	Laak 1975
1.63	Chan 1978
3.51	Ellis and Childs 1973
3.29	Siegrist et al. 1976
6.62	Bernhard 1975
1.76	Otis et al. 1975
2.82	U.S. EPA 1974

Mean = 3.26
Standard Deviation = ±1.53

[1] Source: U.S. Census data 2000.

TABLE A-2
SOIL EFFICIENCY RATING FOR IMMOBILIZING PHOSPHORUS FROM SEPTIC SYSTEMS[1]

Drainage	Phosphorus Adsorption Capacity (lbs/acre-ft)	Retention Coefficient (R.C.)	Fraction of Phosphorus Not Retained By Drainfield Soil (1 - R.C.)
Good	High - Very High 480 - 650	0.75	0.25
Good	Medium 380 - 480	0.55	0.45
Good	Low - Very Low 325 - 380	0.35	0.65
Poor	High - Very High 480 - 650	0.65	0.35
Poor	Medium 380 - 480	0.45	0.55
Poor	Low - Very Low 325 - 380	0.25	0.75

TABLE A-3
NUMBER OF RESIDENCES PER SOIL TYPE ADJACENT TO SHERMAN LAKE[2]

Soil Type	Number of Residences[3]
Oshtemo sandy loam	95
Kalamazoo loam	1

[1] Schneider and Erickson 1972; Ellis and Childs 1973.

[2] Source: Soil Survey of Kalamazoo County (USDA-SCS 1979).

[3] Only residences abutting the lake were counted in this analysis.

TABLE A-4
ESTIMATE OF ANNUAL SEPTIC CONTRIBUTION TO SHERMAN LAKE

Soil Type[1]	Drainage[2]	Phosphorus Adsorption[2]	(1 - R.C.)[3]	Number of Residences Per Soil Type[1]	Load To Septic Systems (lbs/res/yr)	Phosphorus Loading Per Soil Type (lbs/yr)
Oshtemo sandy loam	Good	Low	0.65	95	1.98	122.3
Kalamazoo loam	Good	Medium	0.45	1	1.98	.89
				96	TOTAL	123.2 lbs/yr

[1] Table A-3.

[2] Schneider and Erickson 1972.

[3] Table A-2.