U.S. Department of the Interior
U.S. Geological Survey

Effects of Residential Development on the Water Quality of Higgins Lake, Michigan 1995-99

Water-Resources Investigations Report 01-4055

In cooperation with Gerrish and Lyon Townships,
Roscommon County, Michigan, Higgins Lake Property Association and
Higgins Lake Foundation

USGS
science for a changing world

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By Russel J. Minnerick

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U.S. DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVATIONS

For use of readers who prefer the International System of Units (SI), the conversion factors for terms used in this report are listed below.

Multiply	By	To obtain
	Length	
inch (in)	2.54	centimeter
foot (ft)	0.3048	meter
	Area	
acre	4.047	square hectometer
mile (mi)	1.609	kilometer
square mile (m^2)	2.59	square kilometer
	Volume	
cubic foot (ft^3)	0.02832	cubic meter
acre foot	1,233.5	cubic meter
	Flow	
cubic foot per second (ft^3/sec)	2.832	liter per second

Temperature in degrees Celsius (^oC) may be converted to degrees Fahrenheit (^oF) as follows:

$$^oF = 1.8^oC + 32$$

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

ABBREVIATIONS (in addition to those above)

MRL, minimum reporting level
LT-MDL, long term method detection level
TSI, trophic-state index
col/100 ml, colonies per 100 milliliters (of sample water)
µS/cm, microSiemens per centimeter at 25 degrees Celsius
NTU, nephelometric turbidity units
mL, milliliter
µg, microgram
mg, milligram
L, liter
<, less than

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By R. J. Minnerick

ABSTRACT

Higgins Lake, a popular recreation area in the north-central Lower Peninsula of Michigan, drains an area of 58 square miles and is composed of two deep basins separated by a narrow channel between Flag Point and Point Detroit.The North and South Basins have a maximum depth of about 141 and 100 feet respectively. Ground-water inflow is the major source of the lake's water supply, with precipitation and inflow from two small tributaries providing the remaining water.

The quality of the lake water near shore has been affected by residential development. The concentration of chloride and turbidity in the lake water near the shore increases with increases in building and road density. Nitrogen concentration in lake water near shore also has increased the most in areas where buildings exceed a density of 0.50 building per acre. Ground water beneath the lake showed higher concentrations of phosphorus, nitrogen, chloride, and boron than the lake-water samples. *Escherichia Coliform* (*E. coli*) bacteria was found in ground water at sites where building density exceeded 0.40 building per acre, indicating that water from septic systems, is leaching to the ground water that flows to the lake. Phosphorus concentration in lake and ground water appears to be more affected by site-specific conditions, such as soil type and distance of sampling sites from individual septic systems, than by building density alone.

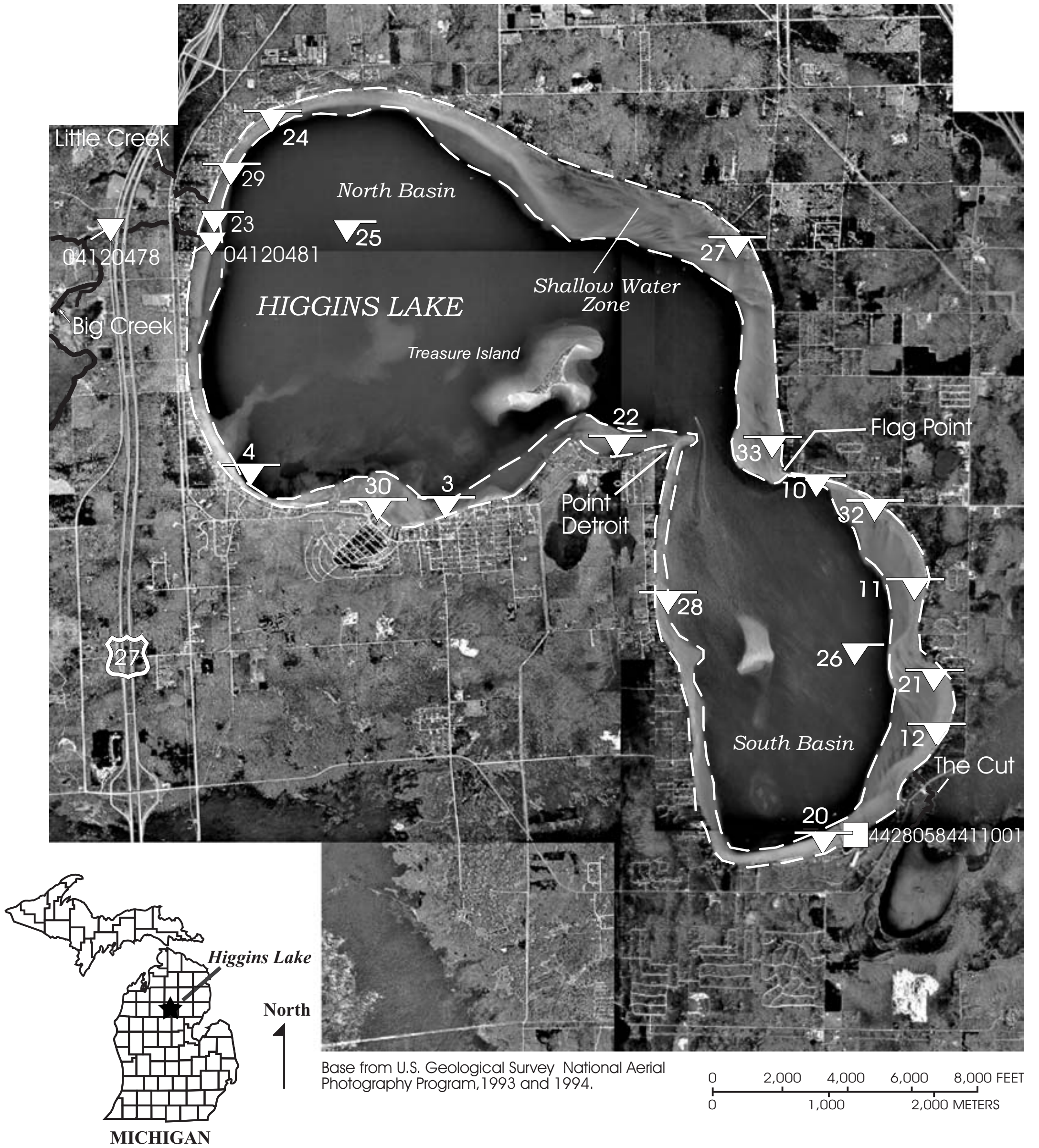
INTRODUCTION

Higgins Lake (fig. 1) lies in the north-central Lower Peninsula of Michigan. Rapid population growth and increased residential development around Higgins Lake and the vicinity around Higgins Lake has created concern for lake water quality during the past 30 years. Gerrish and Lyon Townships in and around Higgins Lake, also have undergone rapid growth. Between 1970 and 1990, the population of Gerrish Township grew by 246 percent, whereas Lyon Township grew by 185 percent (Robert Smith, Roscommon County Clerk, written commun., 1999). Summer cottages, condominiums and permanent homes, as well as State and municipal parks surround Higgins Lake. With the increased development around the lake, much of the native vegetation has been replaced by lawns and roads. Each household around the lake has its own septic-tank system with drain field or dry-well. The condition of these individual systems vary with age and prevailing building codes at the time of installation.

Local government and concerned citizen groups believe that any degradation of lake water quality is a result of increased nutrient loading from septic systems, fertilization of lawns, and runoff from roads. In 1995, the U.S. Geological Survey (USGS), in cooperation with Gerrish and Lyon Townships, Roscommon County, Higgins Lake Property Owners Association and Higgins Lake Foundation began a sampling program to monitor changes in water quality that may have been a result of increased development around the lake.

Purpose and scope

This report summarizes the results of a sampling program conducted over five years (1995-99) and describes the effects of residential development associated land use on lake water quality. Also, water quality of surface-water inflow to the lake, shallow ground water, water in the North and South Basins of Higgins Lake, and near shore lake water is discussed. The trophic status of each deep basin was determined, compared and evaluated over time. This study provides a tool for community leaders in making decisions as to the best way to protect the water quality of Higgins Lake.



EXPLANATION

23 — Lake-water-quality measurement site number and identifier

Ground-water-quality measurement site number and identifier

Inlet-water-quality measurement site number and identifier

Lake gage

Figure 1. Study area and location of data-collection sites at and near Higgins Lake, Roscommon County, Michigan.

Description of the study area

Higgins Lake is approximately 9,900 acres in size, was formed during the last glacial period (Wisconsinan) (Miller and Thompson, 1970). The lake consists of two deep basins separated by a narrow channel between Flag Point and Point Detroit (fig. 1). Higgins Lake watershed is predominately sandy soils and glacial outwash forming rolling moraines. Except those areas with residential development and the small area of wetlands to the west, vegetative cover mostly is mixed northern hardwoods and pine.

Big Creek and Little Creek are two sources of sustained surface-water inflow into Higgins Lake (fig. 1). These two tributaries are predominantly ground-water fed and the tributaries flow from the west into Higgins Lake. Big Creek receives discharge from numerous piped flowing wells near its mouth, which dramatically increases the flow before the creek discharges to the lake. Their headwaters originate in low forested wetlands with organic soils. The watershed upstream from U.S. Highway 27 drains lowlands vegetated predominately with tag alder (*Alnus rugosa*), white birch (*Betula papyrifera*), and bigtooth aspen (*Populus grandidentata*). The tributaries pass through a heavily developed shoreline area of Higgins lake before draining into the lake.

Higgins Lake's only outlet, referred to as "The Cut," flows into Houghton Lake (fig. 1). Lake-water elevations and flow of water from the lake into The Cut are controlled by a low-head dam with removable boards. Manipulation of the boards in the dam is controlled by the Roscommon County Board of Commissioners. The USGS operated a gaging station (USGS station 04120500) on The Cut from 1942 to 1950. During this period, The Cut had an average flow of 44.2 ft^3/s (U.S. Geological Survey, 1958).

The geology and topography in the Higgins lake region enables high recharge of the aquifer and provides Higgins Lake with a constant supply of ground water. Ground-water inflow and the precipitation in the form of rain and snow that falls directly onto the lake surface makes up the major source of the lake's water supply. Because it contains only one outlet and limited sources of water supply, Higgins Lake has a long hydrologic retention time, estimated at 12.4 years (Limno-Tech Incorporated, 1982).

The land use, topographic gradient, soil type, depth to the water table, quantity and quality of surface-water inflow into the lake, and quality of ground water all affect lake water quality. As the topographic gradient increases, the land surface is more easily eroded. Soil characteristics (such as permeability, porosity, and adsorptive capacity) and depth to the water table affect the rate that nutrients will reach the water table. A 1971-72 study of nutrient movement from septic tanks around Houghton Lake (Ellis and Childs, 1973) found that sandy soils absorb small quantities of phosphorus, whereas clay or silt absorb large quantities of phosphorus. Sandy soils, such as those surrounding Houghton and Higgins Lake, were ineffective in sorbing phosphorus. Ground-water flow rate determines the retention time of water in the aquifer and, thus, the amount of time available for microbes to transform the nutrients.

Because a substantial proportion of the water supply to Higgins Lake originates as ground water entering the lake directly or by the way of its tributaries, the protection of local ground-water sources is critical to ensuring good lake water quality.

Study design

Phosphorus and nitrogen are the critical nutrients that stimulate aquatic growth of plants and algae in a lake.These nutrients are present naturally in the environment, but elevated concentrations above background levels may come from anthropogenic sources including septic systems and lawn fertilization. The nutrient in the shortest supply will tend to be the limiting control on production of phytoplankton and other algae (Hem,1985). In lakes, a concentration of 0.10 mg/L of total phosphorus generally is considered the threshold where accelerated eutrophication will result (U.S. Environmental Protection Agency, 1986). The U.S. Environmental Protection Agency (USEPA) also has established a recommended limit of 0.05 mg/L for total phosphates in streams that enter lakes.

Increased phosphorus and nitrogen concentration together also may have a greater combined effect on stimulation of aquatic growth than either element alone (Goldman and others, 1990). Limiting the input of phosphorus and nutrients into a lake is essential to controlling the rate of eutrophication.

To understand the relation of residential development and the water quality of Higgins Lake, water-quality characteristics of the ground water and near-shore lake water were compared to the building and road density around the lake. The primary tributary to Higgins Lake, Big Creek, was sampled at two sites. The upstream site was above all residential development and the downstream site was near the mouth below residential development. The concentrations of selected constituents and instantaneous loading at the two sites on Big Creek were compared. The North and South Basins were sampled at their deepest points to determine the trophic status of each basin and monitor any changing water-quality trends within the basins.

Data collection for this study focused on four general components where their effect on lake water quality of could be evaluated:

1. Ground water: Inflow from ground water makes up a substantial portion of the water supply to Higgins Lake. Therefore, ground-water quality should heavily affect Higgins Lake water quality.
2. Near shore: Inspection of aerial photographs and field surveys showed that approximately 19 percent of the lake surface area contains water that is about 4 ft or less in depth. The lake-bottom gradient near the shoreline is gentle until it reaches the deep basins. Water in this shallow zone is slow to mix with water from the deeper part of the lake because of the shallow zones large area. Closer to shoreline, mixing by wind is restricted by trees, buildings, and topography. It is in this shallow zone that changes in water quality resulting from land-use activities first would be expected.
3. Inlets: Two small tributaries are the only continuous sources of surface water to Higgins Lake. They contribute a small portion of the water inflow but drain a part of the watershed with one of the highest home densities.
4. Deep basins: The deepest water column in each basin was treated as separate sample sites to document any physical and chemical variation between basins. Samples were collected before and after the lake became thermally stratified. The thermally stratified zones in each water column were treated as separate sample sets because of the unique chemical and biological activities that can occur in each zone.

In this study, total phosphorus, $NO_2 + NO_3$ as nitrogen, chloride, boron, pH, dissolved oxygen concentration; physical characteristics such as turbidity, specific conductance, water temperature, secchi depth observations; and the biological indicator chlorophyll *a* were measured. Bacterial examinations for *E.coli* were made to help determine the possible sources of nutrient input into the lake. Because *E.coli* is a group of bacteria found only in the gastrointestinal tract of warmblooded animals, its presence could suggest effects of septic systems (American Public Health Association and others, 1998).

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STUDY METHODS

During this 5-year study, water-quality characteristics were monitored, of those sources of water to Higgins Lake that would be most affected by residential growth. The various components of the watershed were examined and evaluated to determine how the water quality of one source may affect the water quality of another.

Lake water, near shore ground water, and Big Creek (the largest tributary to Higgins Lake) were sampled to evaluate their contribution of chloride, boron, and nutrients to the lake. To differentiate possible sources of nutrient input, the presence of *E. coli* bacteria in ground water was used to confirm that septic systems were the most likely source.

Temporal changes in the level of eutrophication in the North and South Basins were evaluated by means of using Carlson's Trophic-State Index (Carlson, 1977), or (TSI). This index was used to evaluate nutrient concentration and its effects on the biological productivity of Higgins Lake and to track the eutrophication process. The Carlson's TSI was computed from the total phosphorus (collected from the epilimnion), chlorophyll *a* concentrations (collected from the photic zone, which for this study, is considered to be twice the depth at which the secchi disc could be seen from the water surface), and secchi-disc depths. The TSI is a numerical scale ranging from 0 to 100. Lakes with index values less than 40 are classified as oligotrophic (low productivity). Lakes with index values greater than 50 are classified as eutrophic (high productivity). The range between 40 and 50 usually is associated with mesotrophy (moderate productivity). Carlson's TSI was developed for use with lakes that have few rooted aquatic plants and little nonalgal turbidity. Higgins Lake meets these criteria. The following equations were used to determine the TSI for the North and South Basins of Higgins Lake during the study period.

$$TSI_{secchi} = 60 - (14.41) * \ln(\text{secchi depth, in meters})$$

$$TSI_{chlorophyll\ a} = 9.81 * \ln(\text{chlorophyll } a, \text{ in } \mu g/L) + 30.6$$

$$TSI_{total\ phosphorus} = 14.42 * \ln(\text{total phosphorus, in } \mu g/L) + 4.15$$

To detect subtle changes in water quality, low-level analyses were used when available. The reported units and the Minimum Reporting Levels (MRLs) as established by the USGS National Water-Quality Laboratory (NWQL) are the following.

Specific conductance: Specific conductance is reported in microsiemens per centimeter (µS/cm). The MRL for specific conductance is 1.0 µS/cm and is referenced to 25°C.

Turbidity: Water clarity is measured as turbidity in nephelometric turbidity units (NTU).The MRL for turbidity as NTU during this study is 0.10 NTU.

pH: The MRL for pH in this study is 0.1 standard unit.

Chlorophyll *a*: Chlorophyll *a* in phytoplankton is measured and reported as Chromo Fluorom in micrograms per liter (µg/L). The MRL for chlorophyll *a* in this study is 0.10 µg/L.

Phosphorus: Total phosphorus is reported in milligrams per liter (mg/L). The MRL for total phosphorus for this study was 0.001 mg/L.

Nitrogen: $NO_2 + NO_3$ as nitrogen is reported in milligrams per liter. The MRL for $NO_2 + NO_3$ as nitrogen in this study was 0.005 mg/L.

Chloride: Dissolved chloride is reported in milligrams per liter. The MRL for chloride in this study is 0.10 mg/L.

Boron: Dissolved boron is reported in micrograms per liter. The MRL for boron in this study was 16 (µg/L). Analytical results that were less than 16 µg/L are reported as "less than" (<).

Escherichia coli (E.coli): *E. coli* bacteria are reported as numbers of colonies per 100 milliliters (mL) of cultured water. These values are reported as whole numbers when less than 10, and two significant figures are reported for results equal to or greater than 10. Colony counts of 20-80 produce the most accurate statistical data. Counts of less than 20 or greater than 80 colonies per sample are considered non-ideal and are noted with a K. Samples that do not produce a colony count in 100 mL of water are reported as <1 col/100mL (Myers and Sylvester, 1997).

Secchi disc: The physical measurement of lake clarity based on a secchi disc is reported in meters (m). The reporting level is to the nearest 0.1 m.

Dissolved oxygen: The dissolved oxygen concentration of water is reported in milligrams per liter. The reporting level is to the nearest 0.1 mg/L.

Water temperature: Water temperate is reported in degrees Celsius (^{o}C). The reporting level for water temperature is 0.5^{o}C.

Water-quality sites

Water-quality data were collected for this study at 2 sites on Big Creek, at the deepest point in the North and South Basins, at16 sites near shore, and at 15 piezometer sites (table 1). A lake gage monitored lake elevation during the study period (fig.1, table 1).

The deep basins in Higgins Lake were sampled four times a year in 1995 and 1996, three times in 1997, and twice a year in 1998 and 1999. In each instance, a vertical profile of depth and water temperature, specific conductance, pH, and dissolved oxygen was made with a water-quality multiprobe meter to determine thermal stratification. One sample was collected each year from each basin before stratification. The remainder of the samples were collected from each basin after the lake stratified. A submersible pump sampler was used to collect the water samples. Each stratum (epilimnion and hypolimnion) was subdivided into 10 sections, and equal amounts of water were collected from each section. These samples were composited, and subsamples were drawn for chemical analysis. Before stratification, the total water column was sampled based on the same method.

Lake-water samples were collected at 16 sites (sites 3, 4, 10-12, 20-24, 27-30, 32, and 33) in shallow water near the shoreline around the lake (fig. 1). These sites are just offshore from areas that represent an areal distribution of topography and a variation in land-use characteristics, such as building and road density and permanent or seasonal homes. Sites were between 10 and 30 ft from shore, in depths of 1 to 2 ft of water, and were sampled once or twice per year between May 1 and September 30, 1995-99. Sites were added or dropped as data became available and water-quality characteristics of near-shore areas needed further definition. Point samples were collected at mid-water depth with a peristaltic pump. Water temperature, specific conductance, pH, and dissolved oxygen concentration were measured with a water-quality multiprobe meter.

At near-shore sites (sites 3, 4, 10-12, 20-22, 24, 27-30, 32 and 33), temporary piezometers were placed into the lake bottom; ground-water samples were collected corresponding to the lake-water samples. These piezometers consisted of a sand well point with a part of the screen sealed with rubber paint to prevent lake water from entering the well casing. The open screen part was positioned approximately 1 to 2 ft below the lake bottom. Before sampling, the static water elevation in the piezometers was measured; if there was a positive

Table 1. Site number and identifier, location, and type of data-collection sites, Higgins Lake, Roscommon County, Michigan [--, not available; ft, feet]

Site number/ identifier	Latitude-longitude sequence number	Site type
04120478[1]	--	Inlet, Big Creek, upstream site
04120478[1]	--	Inlet, Big Creek, at mouth to Higgins Lake
3	442748-0844445-01	Near-shore water, Higgins Lake
3	442748-0844445-04	Ground water, 1-2 ft below lake bottom
4	442803-0844612-01	Near-shore water, Higgins Lake
4	442803-0844612-04	Ground water, 1-2 ft below lake bottom
10	442803-0844116-01	Near-shore water, Higgins Lake
10	442803-0844116-04	Ground water, 1-2 ft below lake bottom
11	442717-0844015-01	Near-shore water, Higgins Lake
11	442717-0844015-04	Ground water, 1-2 ft below lake bottom
12	442617-0844006-01	Near-shore water, Higgins Lake
12	442617-0844006-04	Ground water, 1-2 ft below lake bottom
20	442533-0844106-01	Near-shore water, Higgins Lake
20	442533-0844106-04	Ground water 1-2 ft below lake bottom
21	442640-0844000-01	Near-shore water, Higgins Lake
21	442640-0844000-04	Ground water 1-2 ft below lake bottom
22	442611-0844307-01	Near-shore water, Higgins Lake
22	442811-0844307-04	Ground water, 1-2 ft below lake bottom
23	442958-0844628-01	Near-shore water, Higgins Lake
24	443027084460601	Near-shore water, Higgins Lake
24	442958-0844606-04	Ground water, 1-2 ft below lake bottom
25	442955-0844530-01	Deep-basin water, Higgins Lake (unstratified)
25	442955-0844530-02	Deep-basin water, Higgins Lake (hypolimnion)

1 Site numbered according to downstream order system; all other sites numbered by latitude-longitude sequence number.

Table 1. Site number and identifier, location, and type of data-collection sites, Higgins Lake, Roscommon County, Michigan--Continued [--, not available; ft, feet]

Site number/ identifier	Latitude-longitude sequence number	Site type
25	442955-0844530-03	Deep-basin water, Higgins Lake (photic zone)
25	442955-0844530-05	Deep-basin water, Higgins Lake (epilimnion)
26	442658-0844044-01	Deep-basin water, Higgins Lake (unstratified)
26	442658-0844044-02	Deep-basin water, Higgins Lake (hypolimnion)
26	442658-0844044-03	Deep-basin water, Higgins Lake (photic zone)
26	442658-0844044-05	Deep-basin water, Higgins Lake (epilimnion)
27	442940-0844149-01	Near-shore water, Higgins Lake
27	442940-0844149-04	Ground water, 1-2 ft below lake bottom
28	442629-0844217-01	Near-shore water, Higgins Lake
28	442629-0844217-04	Ground water, 1-2 ft below lake bottom
29	443019-0844613-01	Near-shore water, Higgins Lake
29	443019-0844263-04	Ground water, 1-2 ft below lake bottom
30	442748-0844506-01	Near-shore water, Higgins Lake
30	442748-0844506-04	Ground water, 1-2 ft below lake bottom
32	442755-0844044-01	Near-shore water, Higgins Lake
32	442755-0844044-04	Ground water, 1-2 ft below lake bottom
33	442915-0844129-01	Near-shore water, Higgins Lake
33	442915-0844129-04	Ground water, 1-2 ft below lake bottom
--	442805-0844110-01	Lake gage

1 Site numbered according to downstream order system, all other sites numbered by latitude-longitude sequence number.

head difference (indicating ground-water inflow into the lake), a sample was collected. Water samples were collected with a peristaltic pump. Water temperature, specific conductance, pH, and dissolved oxygen concentration were measured with a water-quality multiprobe meter placed inline to minimize exposure to the atmosphere. Samples from the piezometers were collected at the same time as corresponding lake-water samples near shore.

Big Creek was sampled twice per year in 1998 and 1999 at two locations (sites 04120478 and 04120481). Site 04120478 is upstream from all residential development. Site 04120481 was sampled at the mouth just before it enters Higgins Lake (fig. 1). The watershed between the upstream site and the mouth is well developed with houses, roads, and established lawns. Water samples were collected with an open mouth bottle by wading based on the Equal-Width-Increment (EWI) technique (Wilde and others, 1999). Water temperature, specific conductance, pH, and dissolved oxygen concentration were measured with individual meters.

In this study, samples collected for dissolved constituents were filtered in the field with an inline filtering unit equipped with a 0.45 µm filter. Appropriate samples were chilled on ice and all samples were shipped to the USGS, NWQL in Arvada, Colo., for analysis. Bacteria samples were filtered and incubated onsite using the membrane filtration technique (American Public Health Association and other, 1998). The analytical results were published (Blumer and others, 1995-99).

Water elevations

Lake-stage data have been collected by the USGS on Higgins Lake since September 1, 1942, at gaging station 442805084411001 (fig.1) (Blumer and others, 1999). Lake-stage data during this study period (1995-99) were collected at a staff gage once daily by an observer until November 5, 1998. A telemetered automated recorder then was installed that recorded hourly stage readings since November 6, 1998.

Residential density

At each near-shore sampling site, housing and road density within an approximate 16-acre plot was determined by visual inspection of aerial photographs, taken during 1993 and 1994. An overlay grid was scaled to the aerial photographs to represent 16 acres (417 ft by 1,670 ft). Factors that were considered in using 417 ft for the plot width were (1) the accuracy of the Global Positioning System (GPS) unit in returning to the same sample point and (2) uncertainty about the exact direction of ground-water inflow to the lake. Based on this width, it was assumed that any ground water sampled had flowed beneath the study area. The plot depth, 1,670 ft, was chosen to provide the greatest range in housing and road density in the immediate vicinity of the lake. Stereoscopic analysis was used to count buildings in the study plot and roads intersecting the plot. The number of buildings per acre and the total linear road feet per acre were calculated. The assumption was made that all roads were approximately equally wide and that linear road feet would represent total surface area of roads. No attempt was made to differentiate between seasonal and year-round homes, residences and outbuildings, or paved and gravel roads. It was assumed that the proportion of buildings that represent homes compared to outbuildings (such as garages) was uniform between sample plots (table 2).

Site 20 is offshore from South Higgins Lake State Park. The State Park has no homes within its boundary and was considered a background site, with a density value of 0.00 for buildings. The density value for roads also was 0.00. Access drives to campsites in the State Park were not counted as roads because they are temporary in use and are not plowed or salted during the winter period; thus, access drives would not have been a possible source of chloride. Site 20 should contribute minimally to the nutrient loading into the lake because the park area of interest contains no septic systems and lawns.

Table 2. Building density and lineal feet of road per acre, Higgins Lake, Roscommon County, Michigan

Site number/ identifier	Buildings	Linear feet of roads
3	1.12	130.4
4	.50	52.2
10	.31	26.1
11	.25	52.2
12	.12	26.1
20	.00	.0
21	.38	130.4
22	.50	104.4
23	.93	130.4
24	1.69	3339
27	.25	104.4
28	.81	130.4
29	1.56	2922
30	.81	156.5
32	.19	2087
33	.12	26.1

WATER-QUALITY CHARACTERISTICS

The geologic, hydrologic and biologic components that make up the Higgins Lake watershed interact to affect lake water quality. The four areas where these components have pronounced effects on water quality are discussed below.

Shallow ground water

Water quality varied substantially in water samples that were collected from the shallow aquifer around Higgins Lake. Shallow ground-water samples were collected from 15 sites during the study period (table 3). The median chloride concentrations in ground water at the sample sites ranged from 1.8 mg/L at site 11 to 123 mg/L at site 30. Dissolved boron also varied substantially between sample sites. The median boron concentrations ranged from 16 µg/L at site 11 to 96 µg/L at site 21. The highest measured boron concentration during the study was 557 µg/L at site 3. A clear correlation could not be established between chloride or boron and nutrient concentrations in ground water. Boron concentrations were higher in ground water than in lake water except at site 11. Chloride concentrations also were higher in ground water than in lake water at all sites except for site 11 and 20.

Nutrient concentrations generally were much higher in the ground water than in the near-shore lake water. The median phosphorus concentration (0.023 mg/L) was more than 3 times higher in ground water than in lake water near shore (0.006 mg/L), whereas the median nitrogen concentration (0.20 mg/L) was about 23 times higher in ground water. At five ground-water sampling sites (sites 11, 21, 27, 28 and 33) samples exceeded

Table 3. Summary of selected water-quality constituents in ground water below lake bottom in Higgins Lake, Roscomon County, Michigan
[mg/L, milligrams per liter; col/100 mL, colonies per 100 milliliters; <, less than; K, non ideal count] Number of analyses, *E.coli*: sites 3,21,24,27,29, and 30, *(5)*; sites 4, 10, and 20, *(4)*; sites 28 and 33, *(3)*; sites 11, 12,22, and 21, *(2)*

		Total phosphorus (mg/L)			NO_2+NO_3 as nitrogen (mg/L)			*E. coli,* whole water total urease (col/100 mL)		
Site number/ identi-fier	Number of analyses	Maximum	Median	Minimum	Maximum	Median	Minimum	Maximum	Median	Minimum
3	6	0.087	0.015	0.009	7.730	3.60	0.365	K14	4	<1
4	4	.040	.023	.010	3.320	1.20	.404	K14	4	<1
10	6	.019	.015	.011	1.960	.012	<.005	36	1	<1
11	3	.148	.053	.008	2.970	.531	<.005	K1	1	<1
12	3	.023	.018	.014	.009	.005	<.005	K1	1	<1
20	7	.040	.018	.003	.283	.005	<.005	K10	1	<1
21	7	.447	.024	.009	2.530	.005	<.005	K2	1	<1
22	4	.032	.018	.002	.009	.005	<.005	K17	10	K2
24	7	.035	.013	.008	1.820	.200	.039	K16	5	K3
27	6	.185	.048	.004	.153	.005	<.005	K27	1	<1
28	4	.147	.084	.040	7.650	2.29	.090	22	5	K2
29	6	.087	.023	.011	2.070	.478	<.005	K8	5	K3
30	6	.072	.024	.005	3.660	1.580	.011	40	2	<1
32	4	.058	.020	.010	0.487	.222	<.005	<1	<1	<1
33	4	.194	.084	.008	2.3	.006	<.006	K920	50	<1

0.10 mg/L phosphorus, the level that USEPA recognizes as the threshold where accelerated eutrophication may occur. Median phosphorus concentrations ranged from 0.015 mg/L at sites 3 and 10 to 0.084 mg/L at sites 28 and 33. Measured NO_2 + NO_3 as nitrogen always was below 10 mg/L, the U.S. Environmental Protection Agency maximum contaminate level for nitrate in drinking water (Hem, 1985). The highest measured concentration of nitrogen for the study was 7.73 mg/L at site 3. Median values for nitrogen ranged from 0.005 mg/L at sites 12, 20, 21, and 22 to 3.60 mg/L at site 3.

Bacterial examinations for *E.coli* were made, sites 33 and 22 had the highest median colony counts with 50 and 10 col/100 mL. At sites 24, 28 and 29 median counts were all 5 col/100 mL. The median count at sites 3 and 4 was 4 col/100 mL. The highest recorded concentration for *E. coli* during the study period was K920 col/100 mL sampled at site 33 on May 19, 1999. This site was sampled in 1998 and no *E. coli* colonies were cultured. The elevated *E. coli* counts correspond to increased phosphorus concentrations at site 33 (fig. 2). A septic system near sampling site 33 may have failed sometime between the summer of 1998 and 1999, resulting in these elevated concentrations.

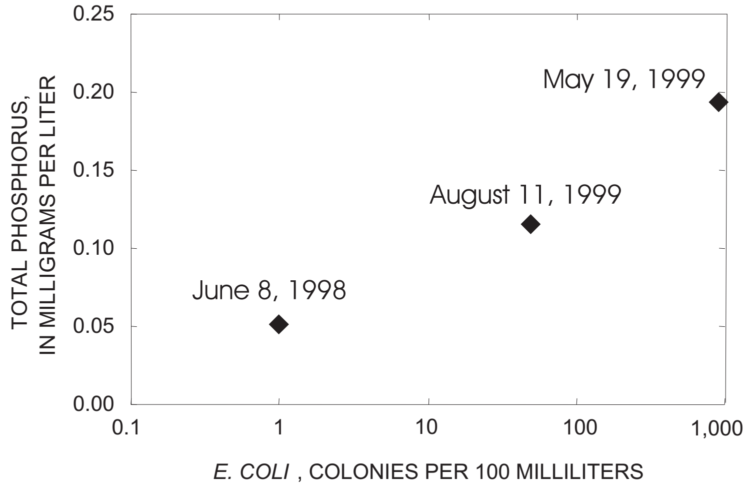


Figure 2. Relation between total phosphorus and *E. Coli* in ground water at sampling site 33, Higgins Lake, Roscommon County, Michigan.

Near-shore lake water

To detect changes in water quality resulting from residential development, 16 sites were monitored in the near-shore lake water during the study period (table 4). All measured constituents except boron were higher in near shore lake water than in lake water from the deep basins. Boron was at or just above the minimum detection level in lake water near shore and in the deep basins. The median phosphorus concentration in lake water near shore was about 50 percent higher than that of lake water in the deep basins prior to stratification, whereas the nitrogen concentration was almost twice as high. Turbidity was higher near shore than in water samples collected from either basin. All near-shore sites with higher measured turbidity and chloride were just offshore from developed areas with a high concentration of homes and (or) roads. The median turbidity values at sites 23, 24 and 29 ranged from 1.3 to 2.0, about 5 times higher than the median observed in the deep basins. The median chloride concentrations also were highest at sites 23, 24 and 29, ranging from 10.4 mg/L to 13.0 mg/L (about 60 percent higher than those samples collected from the deep basins).

Concentration of turbidity, chloride, $NO_2 + NO_3$, as nitrogen and total phosphorus at site 20 were very similar to those measured in the deep basins. Median value for turbidity at site 20 was only slightly higher. This suggests that the elevated levels of nutrients, chloride, and turbidity measured in lake water near the other sites are coming from residential and road sources.

Inlets

During this study, four discharge measurements were made at the time water samples were collected from two locations on Big Creek. The upstream site, 04120478, was upstream from U.S. Highway 27 above all residential development (fig.1). The downstream site, 04120481, was below residential development at the mouth of Big Creek just before it empties into Higgins Lake. Numerous piped flowing wells discharge into Big Creek just upstream from sampling site 04120481. The drainage area between the upstream and downstream sampling sites increases by only 0.1 mi^2. Although the increase in drainage area is small, flow in Big Creek increases by about 17 times along this same section of stream (table 5). Data indi-

Table 4. Summary of nutrients in the near-shore lake water in Higgins Lake, Roscommon County, Michigan
[mg/L, milligrams per liter; <, less than]

		Total phosphorus (mg/L)			NO_2+NO_3 as nitrogen (mg/L)		
Site number/ identifier	Number of analyses	Maximum	Median	Minimum	Maximum	Median	Minimum
3	6	0.020	0.006	0.004	0.086	0.012	0.005
4	4	.008	.007	.005	.019	.012	.005
10	5	.017	.008	.003	.021	.086	.005
11	3	.007	.006	.006	.022	.006	<.005
12	3	.014	.004	.004	.015	.005	<.005
20	8	.011	.004	.002	.011	.006	.005
21	6	.018	.006	.002	.016	.005	.005
22	4	.024	.007	.005	.021	.008	<.005
23	3	.017	.016	.003	.037	.012	.010
24	7	.047	.006	.004	.093	.016	.005
27	6	.012	.008	.005	.025	.010	<.005
28	5	.008	.006	.004	.025	.007	.005
29	6	.022	.008	.004	.026	.010	<.005
30	6	.007	.006	.007	1.040	.023	<.005
32	4	.006	.005	.004	.021	.006	<.005
33	5	.020	.005	<.004	.013	.006	<.005

cate that a large proportion of the ground water that contributes to the increase in Big Creek's flow between the two sampling sites is from artesian flow. An estimated 98 percent of the summer flow at the mouth is from a substantial increase in ground-water inflow. This estimate is based on computed runoff figures for a low-flow measurement made August 17, 1998, at the upstream site, adjusted for the increase of drainage area at the downstream site according to the equation.

$BF_M = BF_U / DA * DDA + BF_U,$
where
BF_M is base flow at mouth,
BF_U is base flow upstream,
DA is drainage area upstream, and
DDA is difference in drainage area between upstream and downstream sites.

The estimated discharge indicates that flow at the mouth would have increased by less than 0.0004 ft^3/s if ground- water inflow to Big Creek was uniform throughout the basin. The estimated discharge at the mouth would be about 0.04 ft^3/s. The actual measured discharge was 1.7 ft^3/s. The same computation and comparison made with a high-flow measurement made May 17, 1999, indicated about 93 percent more flow was measured than would be expected.

The presence of flowing wells near the mouth of the creek indicates artesian flow to Big Creek. The origin of the water from these flowing wells

Table 5. Median values of selected constituents collected from upstream and downstream sites on Big Creek, Higgins Lake, Roscommon County, Michigan

[mi^2, square miles; $ft.^3/s$, cubic feet per second; mg/L, milligrams per liter, µg/L, micrograms per liter; col/100 ml, colonies per 100 milliliters; <, less than]

Site	Drainage area (mi^2)	Streamflow (ft^3/s)	Chloride, dissolved (mg/L as CL)	Boron, dissolved (µg/L as B)	NO_2+NO_3 as nitrogen (mg/L)	Phosphorus, total (mg/L as P)	*E.coli* whole water total urease col/100 mL
04120478	10.3	0.12	2	18	0.120	0.018	375
04120481	10.4	2.1	10	<16	.029	.010	435

was not determined in this study. The source of water for these flowing wells could be from deeper within the shallow aquifer or from aquifers possibly present below the shallow aquifer. It is assumed that nutrients originating from near-lake septic systems and fertilizers may not reach the source of the artesian flow.

Boron, nitrogen, and phosphorus were found in higher concentrations at the upstream sample site than at the downstream site (table 5). The lower concentrations downstream indicate dilution by water from deeper in the aquifer. Chloride concentrations, in contrast, were higher at the mouth of Big Creek. Without background data from the flowing wells, the source of the increased chlorides cannot be identified; however, water softeners and septic fields may contribute to this increase (Hem, 1985).

Concentrations of *E. coli* generally were higher at the mouth of Big Creek than at the upstream site. There are multiple sources of these bacteria in the Big Creek watershed. The upstream site, although little affected by human activity, is susceptible to effects from wildlife. The increase of *E. coli* bacteria downstream could be attributed to septic systems or to the waterfowl that frequent the area.

The mass of a constituent entering a lake over a period of time is referred to as "load". The concentration of a constituent could be high in a stream flowing into a lake, but the total loading may have little effect on the water quality of that lake because of the small amount of water contributed from the stream. Phosphorus loading generally is reported in pounds per day. Instantaneous phosphorus loading is computed from phosphorus concentration and stream discharge according to the equation.

$$Load_p = QM * C_P * 5.4,$$

where

$Load_p$ is instantaneous phosphorus load, in pounds per day;

QM is measured instantaneous discharge, in cubic feet per second; and

C_P is phosphorus concentration, in milligrams per liter.

The loading will change as stream discharge or phosphorus concentration changes. Instantaneous phosphorus loading from Big Creek computed from discharge measurements and accompanying water samples is shown in table 6. Phosphorus loading increased on an average, by about 19 times between the upstream and downstream sample sites, whereas streamflow increased on average, by 22 times. Increase in phosphorus loading is most probably the result of the increase in streamflow rather than an increase in phosphorus concentration. The data also indicate that the phosphorus concentration in water from this source is probably slightly lower than what is found at the upstream

Table 6. Instantaneous phosphorus loading to Higgins Lake computed at sampling sites on Big Creek, Roscommon County, Michigan
[Data are in pounds per day]

Sample date	Upstream sample site (04120478)	Downstream sample site, at mouth (04120481)
July 6, 1998	0.010	0.119
August 17, 1998	.002	.110
May 17, 1999	.034	.178
August 3, 1999	.010	.097

sampling site and is reducing the concentration at the mouth by dilution. It is difficult to identify the primary source of phosphorus in Big Creek without data characterizing the quality of water from all contributing aquifers.

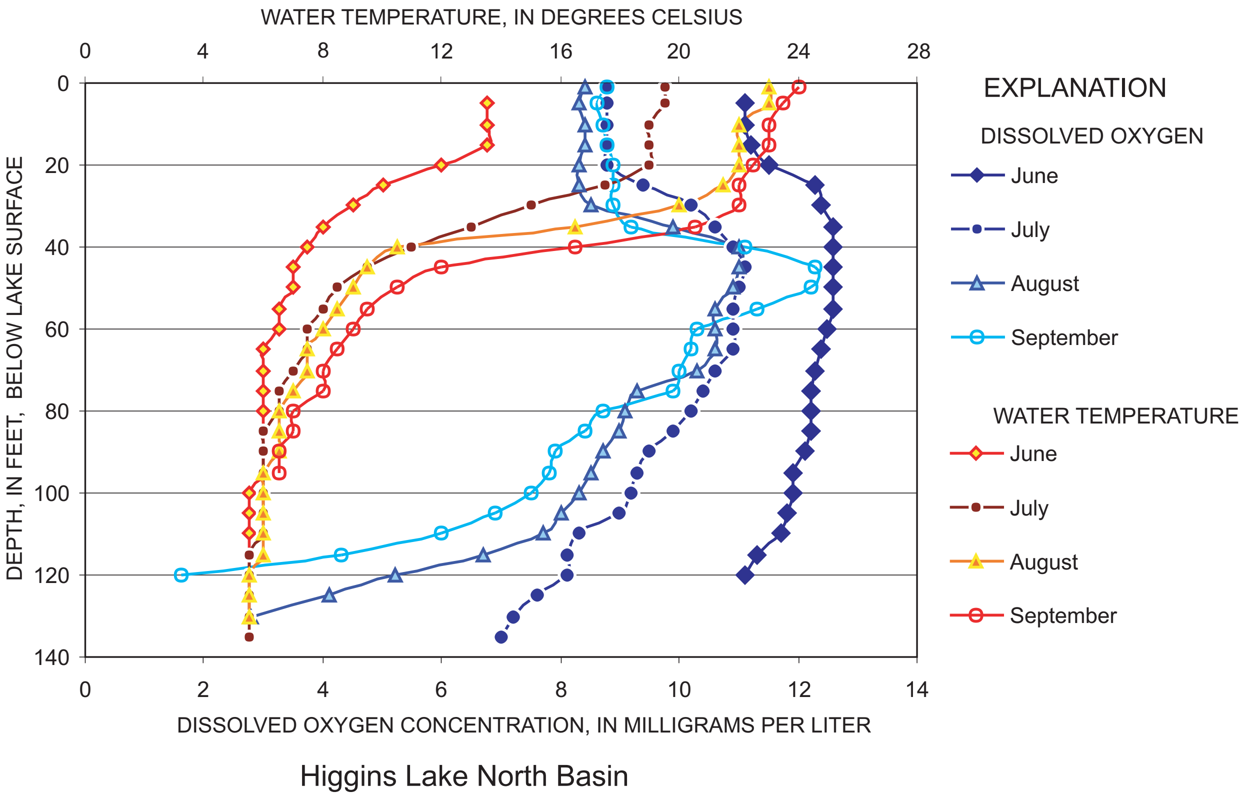
Deep basins

Thermal stratification results in both basins (North and South) of Higgins Lake throughout the summer. This pattern of progressive stratification of water through the warm months, then mixing in the fall before the lake freezes, is typical of deep lakes in a northern climate (Welch, 1952). Before Higgins Lake stratified, water temperature and dissolved oxygen concentration were fairly uniform throughout the water column. Stratification has begun in June (fig. 3) in the North Basin at a depth of less than 20 ft. As summer progresses, the thermocline becomes established and is found at a greater depth (about 30 ft); as water continues to warm, the epilimnion increases in volume.

The depth of the thermocline in the South Basin is often 10 or more feet lower than that in the North Basin. A thermocline in a large lake often can be tilted from one end of the lake to the opposite end, dependent on the prevailing wind (Welch, 1952). This phenomenon is most noticeable in the June profile, where the statification begins in the South Basin near 35 ft and is at 20 ft in the North Basin. Below the thermocline, the water becomes much cooler and the dissolved-oxygen concentration increases. The cooler water has the capability of holding more oxygen.

In the lower depths of the lake, the hypolimnion shows a progressive oxygen depletion as illustrated in the June to September profile (fig. 3). Aerobic bacteria (bacteria that need oxygen to live) in this stratum are consuming decaying organic matter, such as algae, and using the limited available oxygen. Once all the oxygen is consumed, the water becomes anoxic and phosphorus release from decaying algae is accelerated (James and Barko, 1991). Anoxic conditions never were documented during the study period. The lowest dissolved oxygen concentration was observed on August 26, 1998. Dissolved oxygen concentrations of 1.4 mg/L and 1.8 mg/L were measured in the South and North Basins respectively. The water temperature in the epilimnion eventually will decrease in late fall; and, assisted by wind action, near-surface epilimnion water will mix with hypolimnion water replenishing the oxygen supply.

During the study, water-quality constituents such as specific conductance, oxygen, pH, and temperature were similar between the basins (fig. 4). Specific conductance generally is slightly higher near the lake bottom because of the increased dissolved solids associated with decaying organic matter. The pH is the highest at the thermocline and above the zone of diurnal respira-



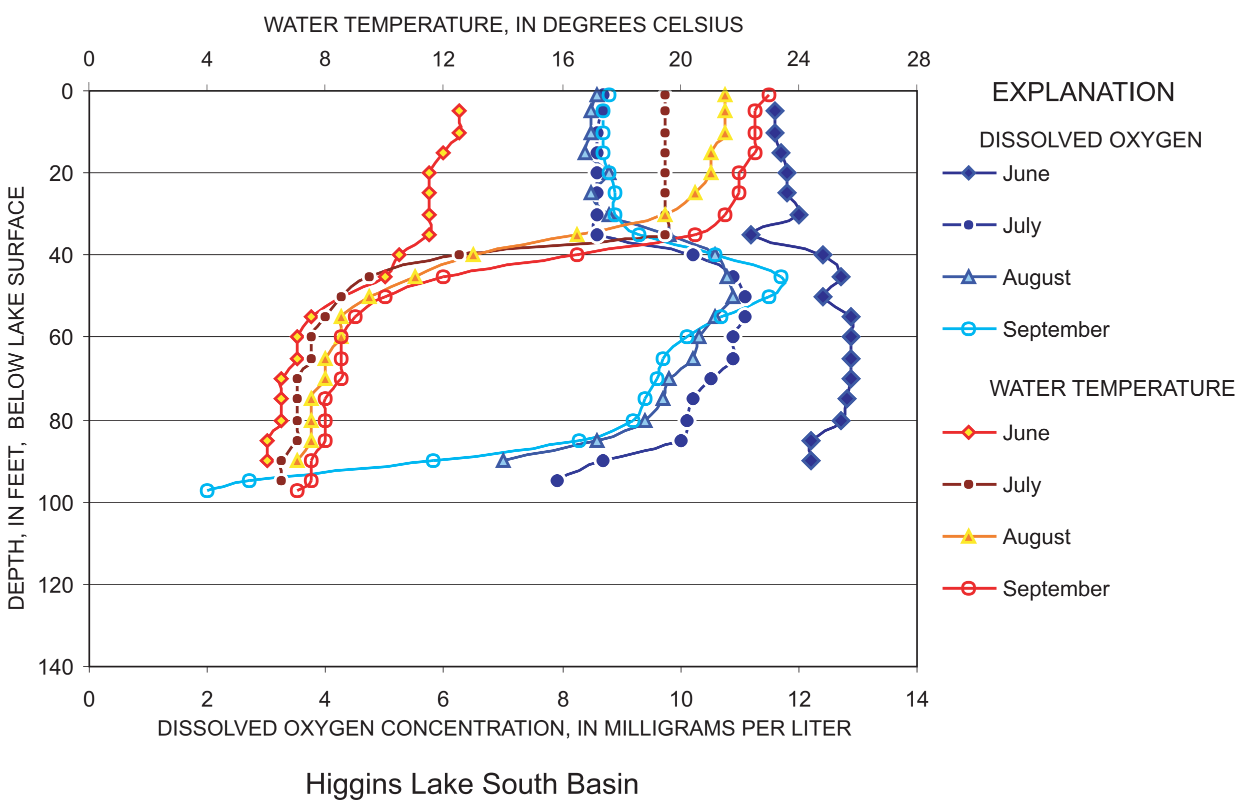


Figure 3. Temperature and oxygen profiles for Higgins Lake, June 1996 to September 1996, Roscommon County, Michigan, June-September 1996.

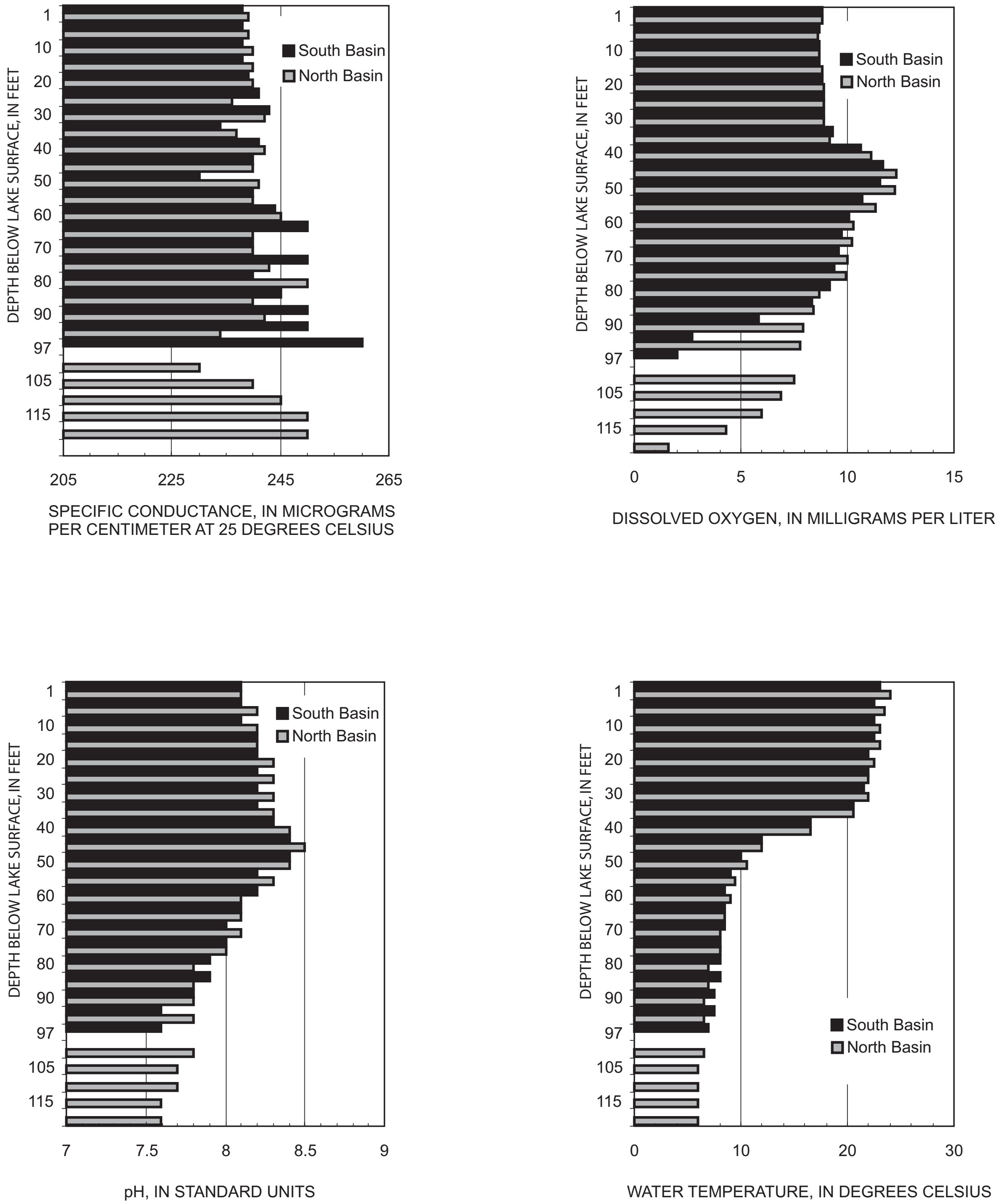


Figure 4. Specific conductance, dissolved oxygen, pH, and water temperature during maximum stratification in late summer, North and South basins in Higgins Lake, Roscommon County, Michigan, September 4, 1996.

Table 7. Summary of water quality in the North Basin, Higgins Lake, Roscommon County, Michigan
[NTU, nephelometric turbidity units; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than]

	Unstratified			Epilimnion			Hypolimnion		
Constituent or property	Maximum	Median	Minimum	Maximum	Median	Minimum	Maximum	Median	Minimum
Turbidity (NTU)	1.40	0.35	0.20	1.00	0.35	0.20	0.91	0.30	0.20
Chloride (mg/L)	9.8	7.5	6.9	8.1	7.2	4.8	7.5	7.1	4.7
Dissolved boron (µg/L)	<16	<16	<16	20.0	<16	<16	<16	<16	<16
Nitrogen as dissolved NO_2+NO_3 (mg/L)	.014	.005	.005	.008	.005	<.005	.021	.005	<.005
Total phosphorus (mg/L)	.005	.004	.003	.019	.004	.001	.016	.006	.003
Number of analyses	5			9			9		

tion of phytoplankton. Dissolved oxygen concentration and water temperature differ only slightly between basins.

The highest concentration of total phosphorus measured in either basin was 0.019 mg/L, recorded in the North Basin on October 31, 1995 (tables 7 and 8). The highest concentration of NO_2+NO_3 as nitrogen was 0.021 mg/L, also in the North Basin, in a sample collected on August 3, 1999. The median values of these two constituents showed little variation between basins during the study period. The median concentration for nitrogen was 0.005 mg/L, was consistent between basins, and showed no change in either of the thermal strata. The median concentration of phosphorus was 0.006 mg/L in the hypolimnion in both basins, slightly higher than the median concentration of 0.004 mg/L in the epilimnion. This slightly higher value probably is the result of limited phosphorus release from algal decomposition in the hypolimnion. The median concentration of phosphorus from samples collected from the lake before stratification was 0.004 mg/L. This value represents mixing of the epilimnion and hypolimnion, when phosphorus concentrations are about average of the two zones.

The concentrations of phosphorus and other constituents in Higgins Lake are generally equal to or less than those of other lakes in the region where similar population growth has taken place. Phosphorus concentrations in Higgins Lake are less than or equal to concentrations in samples collected from 14 other lakes in nearby Grand Traverse County in 1986 (table 9). Chloride concentration in the North and South Basins of Higgins Lake ranged from 4.7 mg/L to 9.8 mg/L (tables 7 and 8). These concentrations chloride concentrations are similar to those found in the Grand Traverse County study of 1986, which reported a mean concentration of 6.0 mg/L chloride for the 15 lakes investigated. Boron concentrations from both studies generally were at or near the detection limit (16 µg/L). The lakes in the Grand Traverse County study varied in depth and size, but soil and geologic characteristics for all lakes were similar to Higgins Lake. The size and volume of water in Higgins Lake may have minimized the effects of development on lake water quality. Higgins Lake is about 4 times larger in surface area than Elk Lake and 40 ft deeper than Green Lake, the largest of the lakes in the Grand Traverse County study. Lakes with deep basins and a small epilimnion to hypolimnion ratio generally have oligotrophic characteristics (Cole, 1983).

Trophic classification for Higgins Lake was determined through evaluation of phosphorus con-

Table 8. Summary of water quality in the South Basin, Higgins Lake, Roscommon County, Michigan
[NTU, nephelometric turbidity units; mg/L, milligrams ; µg/L, micrograms per liter, <, less than]

	Unstratified			Epilimnion			Hypolimnion		
Constituent or property	Maximum	Median	Minimum	Maximum	Median	Minimum	Maximum	Median	Minimum
Turbidity (NTU)	1.00	0.42	0.20	3.2	0.28	0.12	1.10	0.33	0.20
Chloride (mg/L)	8.1	7.4	7.0	7.6	7.4	4.9	8.3	7.0	4.8
Dissolved boron (µg/L)	17	16	<16	21	<16	<16	<16	<16	<16
Nitrogen as dissolved nitrite + nitrate (mg/L)	.013	.005	<.005	.007	.005	<.005	<.005	.005	<.005
Total phosphorus (mg/L)	.007	.004	.003	.009	.003	.001	.120	.006	.003
Number of analyses	6			9			9		

centrations (tables 7 and 8), secchi depth observations, and chlorophyll *a* concentrations (tables 10 and 11). Higgins Lake is classified as oligotrophic based on the TSI scale developed by Carlson (fig. 5). Seasonal variations in the measured constituents often approach the mesotrophic classification. Both basins are similar in their TSI characteristics and their seasonal trends follow each other closely. The data from the North Basin indicates slightly more variation in the TSI than for the South Basin. Determining whether these changes represent long-term trends, however, is difficult. The documented variations in the Carlson's TSI might be attributed to seasonal and climatological differences from year to year combined with sampling and analytical error rather than a change in trophic classification.

EFFECTS OF RESIDENTIAL DEVELOPMENT ON WATER QUALITY

Building and road densities were compared to the water-quality characteristics of the lake water and ground water. Increases in dissolved chloride in lake water in the near-shore area corresponded to building densities greater than 0.50 (fig. 6). The highest turbidity in lake water near shore also was found where building density exceeded 0.50 (fig. 6). Chloride and turbidity could result from multiple sources such as road salts and septic-system effluent. It is difficult to differentiate between road and septic-system sources, because the number of buildings per acre increases as the number of roads increases (fig. 6).

Boron in low concentrations did not appear to relate closely to building density in either the lake water or ground water, although the highest boron concentration in ground water, 557 µg/L, was found at site 3 with a building density of 1.12 building per acre. Only two other sites, 24 and 29, had a higher building density. Sites 24 and 29 are in area of mostly summer homes, whereas, the homes near site 3 are used year round.

The measured constituents in the lake water often had a closer relation to land use than constituents found in the ground-water samples. This relation is a result of the larger variations in concentrations in the ground water, which may have been affected by factors such as soils and sampling locations.

Ellis and Childs (1973) found that nutrients, once leaving the septic systems and entering the ground water, would have a vertical as well as horizontal path of travel. The horizontal path would be determined by ground-water-flow direction, con-

Table 9. Selected chemical characteristics of water in lakes in Grand Traverse County, Michigan Analytical detection level for total phosphorus used in the 1986 Grand Traverse County study was 0.01 mg/L. Data from Grand Traverse County based on one sample per lake (Cummings and others 1990) [mg/L milligrams per liter; µg/L, micrograms per liter; <, less than; --, no data]

Sampled lake	Phosphorus, total (mg/L)	Chloride, dissolved (mg/L)	Boron, total recoverable (µg/L)
Fife Lake at Fife Lake	0.02	5.8	50
Prescott Lake near Old Mission	.02	3.7	<10
Elk Lake in northeast Grand Traverse County	<.01	5.9	<10
Long Lake near Interlochen	.01	2.0	<10
Duck Lake near Interlochen	<.01	5.2	<10
Spider Lake near Mayfield	<.01	7.3	<10
Sand Lake No. 1 near Williamsburg	.01	.7	<10
Brewster Lake near Kingslay	.03	8.7	<10
Green Lake near Interlochen	.01	6.5	--
Silver Lake near Grawn	.01	10	--
Arbutus Lake near Mayfield	.01	10	--
Rennie Lake near Mayfield	<.01	13	--
Fish Lake near Buckley	.01	4.7	--
Grass Lake near Mayfield	--	5.3	--
Bass Lake near Grawn	.02	1.9	--

centrations decreasing with distance from the source. Vertically, concentrations of nutrients were generally highest in a zone 2-6 ft below the water table at the source, decreasing with depth in the aquifer. Concentrations of nutrients in ground-water samples collected in this study could vary substantially with the distance from the source and the depth into the lake bottom that the piezometers were placed.

Phosphorus concentration in ground water was higher than that in lake water but did not relate closely to building density. Nitrogen in the lake water increased only slightly as building density increased but did not relate closely to nitrogen in ground water (fig. 7). In addition to land use, phosphorus concentrations appear to be affected by site-specific conditions such as soil, location of septic systems relative to the water table and the sampling site, and biologic uptake by aquatic vegetation. Nitrogen concentrations in ground water generally increase with an increase in building density but still appear to be affected somewhat by these same local characteristics.

Anthropogenic sources of nutrients entering the lake are septic systems and excessive fertilization of lawns. Bacterial examination was used to distinguish contribution from septic systems from that of lawn fertilizers. It was assumed that any

Table 10. Summary of secchi and chlorophyll *a* depth observations collected from the photic zone in the North Basin, Higgins Lake, Roscommon County, Michigan
[μg/L, micrograms per liter; <, less than]

Constituent or property	Number of analyses	Maximum	Median	Minimum
Secchi disc (depth in meters)	15	17.2	7.4	4.7
Chlorophyll *a,* phytoplankton (μg/L)	15	.94	.43	<.10

Table 11. Summary of secchi and chlorophyll *a* depth observations collected from the photic zone in the South Basin, Higgins lake, Roscommon County, Michigan
[μg/L, micrograms per liter; <, less than]

Constituent or property	Number of analyses	Maximum	Median	Minimum
Secchi disc (depth in meters)	15	10.1	6.2	4.7
Chlorophyll *a,* phytoplankton (μg/L)	15	1.20	.34	<.10

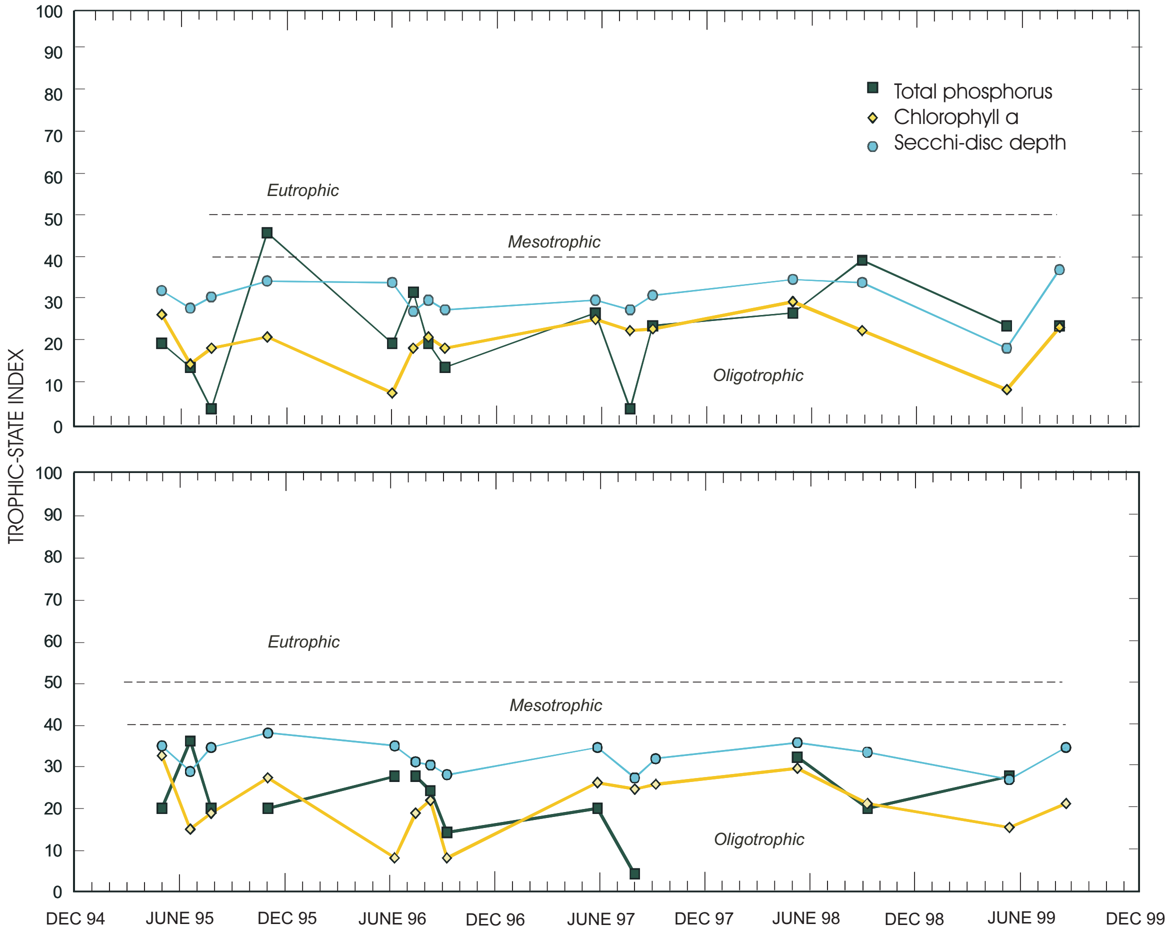


Figure 5. Trophic-State Indices for Higgins Lake, Roscommon County, Michigan.

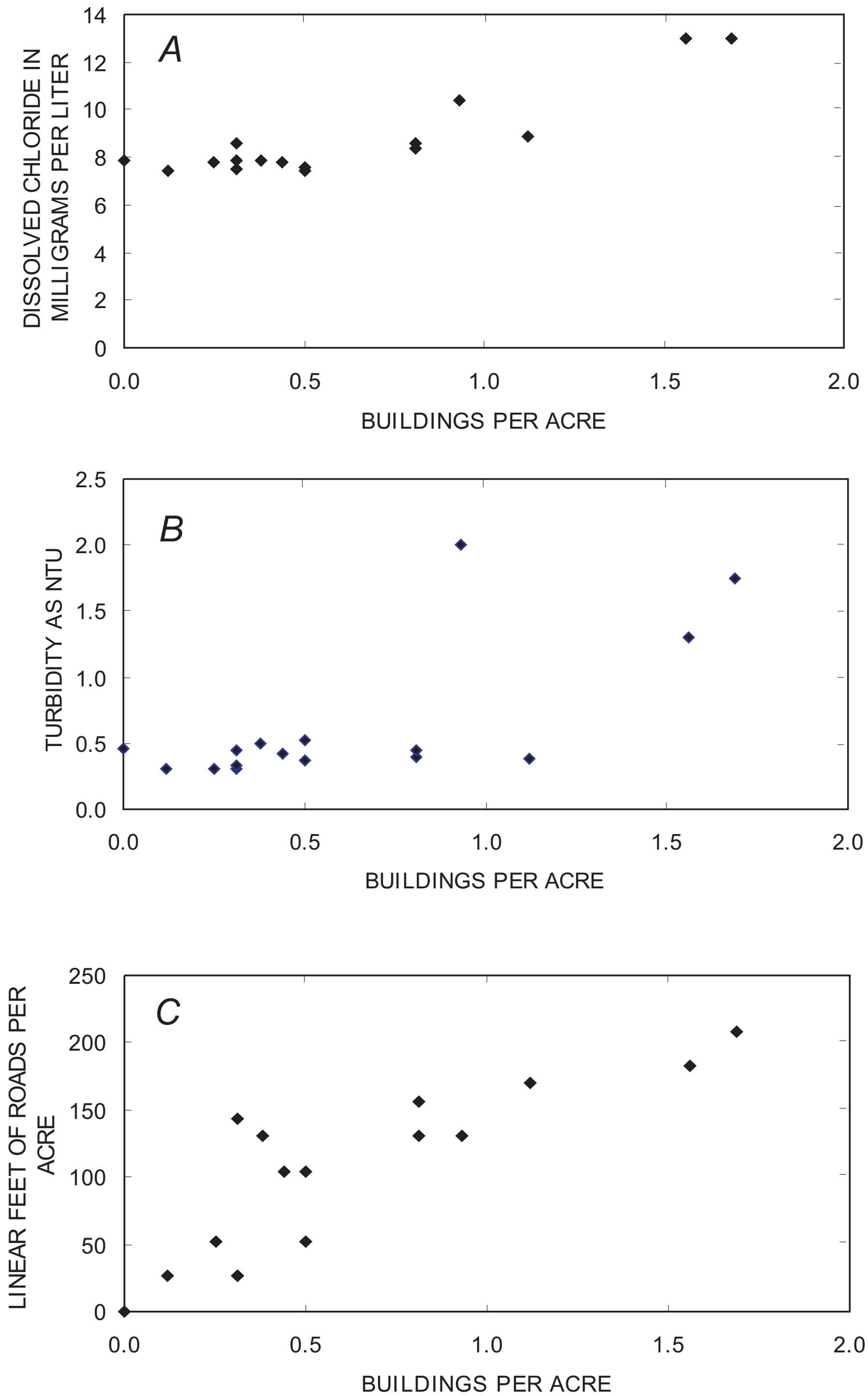


Figure 6. Relation between buildings per acre and (*A*) median dissolved chloride in near-shore lake water, (*B*) turbidity in near-shore lake water, and (*C*) linear feet of roads per acre of study plots, Higgins Lake, Roscommon County, Michigan.

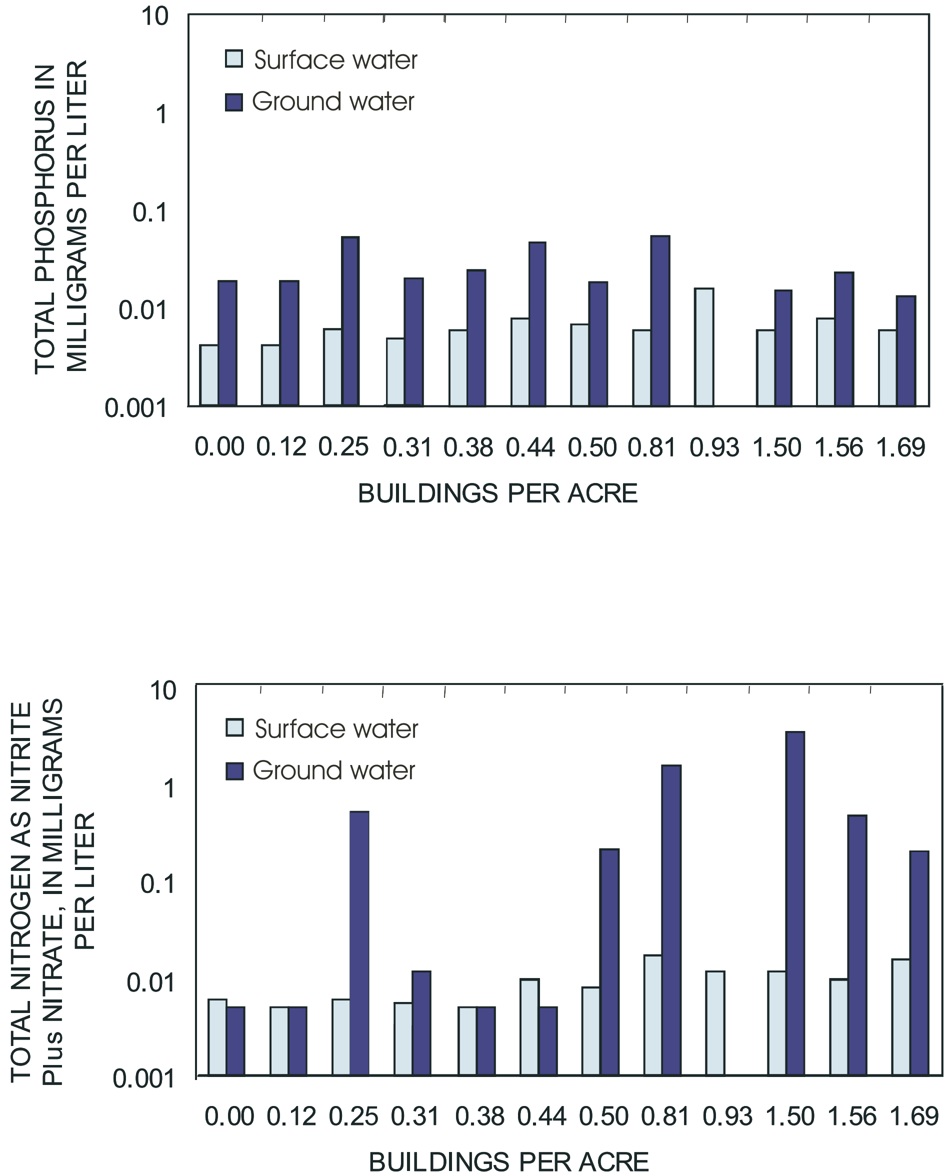


Figure 7. Relation between building density and selected nutrients in lake water and ground water at near-shore sampling sites around Higgins Lake, Roscommon County, Michigan.

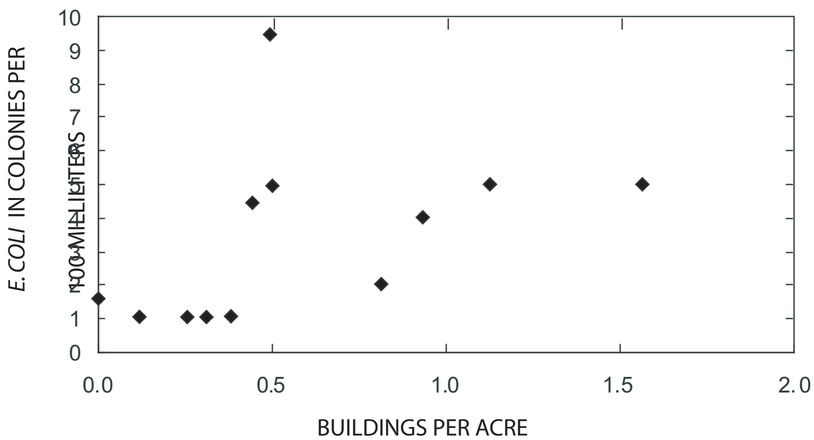


Figure 8. Relation between buildings per acre and *E. Coli* bacteria in ground water at near-shore sampling sites around Higgins Lake, Roscommon County, Michigan.

effects from nonpoint sources such as waterfowl and household pets would be detected randomly at all sites, including site 20. Data from site 33 were not used in analyzing the *E. coli* data with density data because the extremely high *E.coli* count of K920 col/100ml that was measured in the ground water is attributed to septic-system failure. The relation between *E.coli* data and building density indicates an upward trend of fecal contamination as building density surpasses approximately 0.40 building per acre (fig.8). The presence of *E. coli* bacteria in ground water indicates that septic systems are leaching nutrient-rich effluent to the water table but that fertilization also could be a source of some nutrients in the lake and ground water.

Maximum and minimum lake stages for Higgins Lake for the study period, May 1, 1995, to August 30, 1999, are shown in figure 9. The maximum lake stage observed during this period was 5.89 ft, on August 17, 1995. The minimum lake stage, 4.73 ft, was observed on December 18, 1997. As the water level rises in the lake, so does the height and gradient of the contributing water table near the lake shore. Lake elevations may rise from increased precipitation and runoff or through manipulation of the dam at the outlet on the The Cut. As the water table rises, it comes in closer contact with the land surface and becomes more susceptible to the effects of septic systems and leaching of fertilizers. This effect would be most noticeable in areas of high building density in a lowland area. No clear evidence was found to indicate that lake elevation during the period of study had a major effect on the quality of ground and lake water.

The water quality in the deep basins is very similar to that in the lake and ground water at site 20, where there are no septic systems. The median concentration of phosphorus and nitrogen in lake water at sample site 20 was nearly identical to concentrations in the deep basins (North and South Basins). Lake water near shore at all other sites contained phosphorus concentration about 1.5 times greater than that of the deep-water sites prior to stratification. Nitrogen was approximately twice as high in lake water near shore than from water samples collected in the deep basins. It is difficult to determine what effect the increased residential

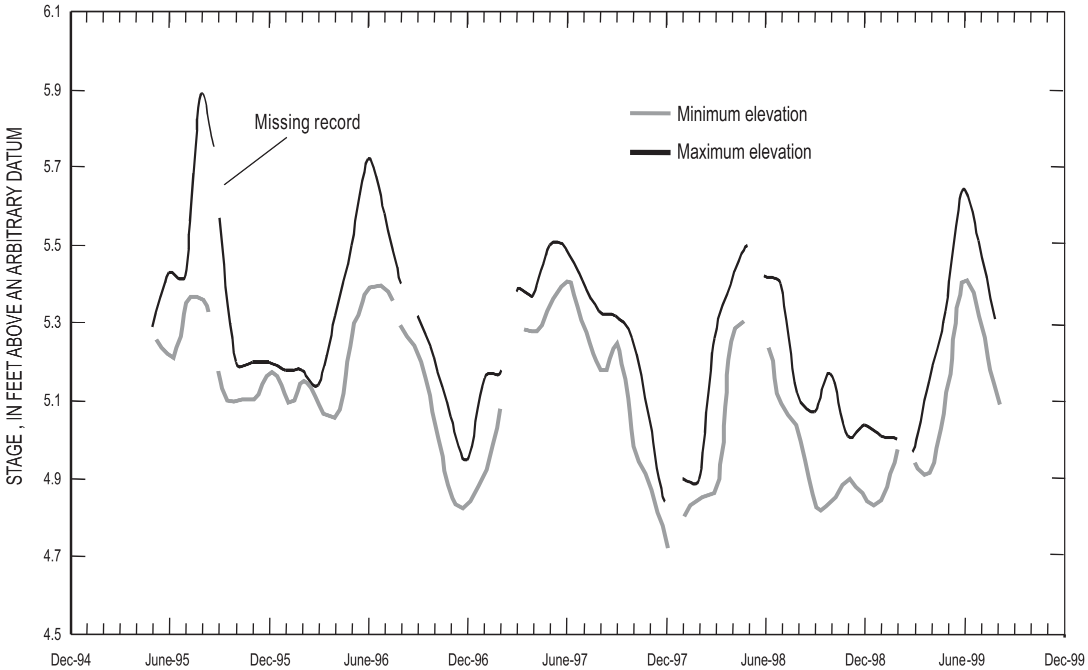


Figure 9. Monthly maximum and minimum stages for Higgins Lake, Roscommon County, Michigan.

development has had on the water quality in the deep basins. The deep basins may receive some water from a deeper aquifer not affected by shoreline development. An estimated rate of eutrophication in the deep basins cannot be determined without better knowledge of the quantity, quality, and source of all water discharging to these deep basins.

SUMMARY AND CONCLUSIONS

Higgins Lake is in the north-central Lower Peninsula of Michigan. Gerish and Lyon, Townships in and around Higgins Lake increased in population by as much as 246 percent during 1970-90. This rapid population growth created a concern that with increased residential development of the shoreline around Higgins Lake, changes in water quality may occur, resulting from the effects of septic systems, fertilization of lawns, and runoff from roads. In 1995 the USGS in cooperation with Gerish and Lyon Townships, Higgins Lake Property Owners Association and Higgins Lake Foundation began a sampling program to monitor changes in water quality that may have been a result of increased development around the lake.

Higgins Lake consists of two basins, North and South; the North Basin has the greater depth, about 141 ft and the South Basin is about 100 ft in depth. The sandy soils around the lake provide rapid recharge to the ground water that supplies most of the water to Higgins Lake. The lake has two spring-fed tributaries, Big Creek and Little Creek, flowing from the west. The summer base flow from these tributaries determined from discharge measurements was estimated to be about 2 ft^3/s. This flow is less than 5 percent of the historical daily outflow through Higgins Lake's only outlet, The Cut. Except for direct precipitation falling on the lake's surface, the remainder of the water supply to Higgins Lake originates as ground water; protecting this resource is critical to ensuring good water quality in the lake.

About 19 percent of the near-shore surface area of the lake is less than 4 ft in depth. It is in this shallow zone that subtle changes in water quality are starting to occur. The concentration of most measured constituents in lake and ground water near shore increased with the increase of residential development. The dissolved chloride and turbidity in the lake water increase as building density becomes greater than 0.50 building per acre. The phosphorus concentration in near-shore lake water averaged about 1.5 times the concentration found in the deep basins. Nitrogen concentration in lake water off shore from areas where the building density was about 0.50 building per acre or greater was about twice as high as in water in the deep basins. Concentrations of most constituents in near-shore lake water at site 20, with no residential development, generally was lower than at other near-shore sites with residential development.

The quality of ground water varied around Higgins Lake. At five locations, ground-water samples exceeded 0.10 mg/L total phosphorus, the level that USEPA recognizes as a threshold where accelerated eutrophication may result. Nitrogen concentrations at sites 3 and 28 exceeded 7.0 mg/L, approaching the established 10 mg/L guideline where nitrogen in drinking water becomes a health concern. *E. coli,* a bacterial indicator of fecal contamination, increased in concentration in ground water as building density exceeded 0.40 building per acre. Septic systems are the most likely source of increases in phosphorus and nitrogen in lake and ground water near shore, because presence of *E. coli* bacteria in ground water indicates that septic systems are leaching effluent to the water table. High-building-density areas in sandy soils where septic systems are close to the water table are most likely to contribute excess nutrients to the lake.

Tributary inflow minimally effects nutrient loading to Higgins Lake. Most measured constituents were found in higher concentrations upstream from residential development than at the mouth of Big Creek, the inlet to the lake. It is assumed that approximately 98 percent of the summer base flow of Big Creek originates from a part of the shallow aquifer and/or possibly deeper aquifers that is not affected by residential development near Higgins Lake.

The Carlson Trophic-State Index classifies Higgins Lake as an oligotrophic lake, low in algal productivity. Occasional variations in phosphorus concentration, notably in the North Basin, indicates a slight tendency toward eutrophication. The median concentration of nitrogen also indicated little variation between basins. The median concentration of chloride in the two basins ranged from 7.0 to 7.5 mg/L. Boron concentrations generally were at or near the detection limit (16 µg/L). Anoxic conditions never were documented in either of the basins during this study. A minimum of 1.4 mg/L dissolved oxygen was recorded during this period. Water-quality-depth profiles indicated a progressive oxygen depletion in the hypolimnion as summer progressed.

The time period that the data cover in this study was too short to determine how fast and to what extent water quality is changing in the center of the lake as a result of increased residential development around the lake. Variations in the Trophic-State Index might be attributed to seasonal and climatological differences from year to year combined with sampling and analytical error rather than a change in trophic classification.

REFERENCES CITED

American Public Health Association and others, 1998, Standard methods for the examination of water and wastewater (20th ed.): Washington, D.C., American Public Health Association, p. 4-132.

Blumer, S.P., Behrendt, T.E., Ellis, J.E., Minnerick, R.J., LeuVoy, R.L., and Whited, C.R., 1995-99, Water resources data, Michigan, 1995-99:

U.S. Geological Survey Water-Data Report MI-95-1, 96-1, 97-1, 98-1, 99-1.

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

Cole, G.A., 1983, Textbook of Limnology: Prospect Heights, Ill., Waveland Press, 401 p.

Cummings T.R., Gillespie J.L., and Grannemann, N.G., 1990, Hydrology and land use in Grand Traverse County, Michigan: U.S. Geological Survey Water-Resources Investigations Report 90-4122, 99 p.

Ellis, B., and Childs, K.E., 1973, Nutrient movement from septic tanks and lawn fertilization: Michigan Department of Natural Resources Technical Bulletin no. 73-5, p. 83.

Goldman, C.R., Marzolf, E.R., and Elser, J.J., 1990, Phosphorus and nitrogen limitation of phytoplankton growth in fresh waters of North America —A review and critique of experiment enrichments: Canadian Journal of Fisheries and Aquatic Sciences, v. 47, p. 1468-77.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3rd ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

James, W.F., and Barko, J.W., 1991, Littoral-pelagic phosphorus dynamics during daytime convective circulation: Limnology and Oceanography, v. 36, no. 5, p. 946-960.

Limno-Tech, Incorporated, 1982, Higgins Lake diagnostic and feasibility study: Ann Arbor, Mich., 30 p.

Litke, D.W., 1999, Review of phosphorus control measures in the United States and their effects on water quality: U.S. Geological Survey Water-Resources Investigations Report 99-4007, 33 p.

Myers, D.N., and Sylvester, M.A., 1997, Fecal indicator bacteria, *chap. A7.1 of* National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9 [variously paged].

Miller, J.B., and Thompson, T., 1970, Compilation of data for Michigan lakes: U.S. Geological Survey Open-File Report, 368 p.

U.S. Environmental Protection Agency, 1986, Quality criteria for water 1986: Washington, D.C., U.S. Environmental Protection Agency Report 440/5-86-001, Office of Water [variously paged].

U.S. Geological Survey, 1958, Compilation of records of surface waters of the United States through September 1950; Part 4, St. Lawrence River Basin: U.S. Geological Survey Water-Supply Paper 1307, 397 p.

Welch, P.S., 1952, Limnology (2nd ed.): New York, McGraw-Hill Book Company, 538 p.

Wilde, F.D., Radtke, D. B. Gibs, Jacob, and Iwatsubo, R.T., 1999, Collection of water samples, *chap. A4 of* National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, p. 23-32.