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**CAN THE BIG BAYOU BE SAVED? WATER QUALITY ASSESSMENT AND
MANAGEMENT RECOMMENDATIONS FOR SPRING LAKE WATERSHED,
OTTAWA AND MUSKEGON COUNTIES, MICHIGAN**

By

Theresa Elaine Lamott Lauber

A THESIS

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in partial fulfillment of the requirements
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1999

ABSTRACT

CAN THE BIG BAYOU BE SAVED? WATER QUALITY ASSESSMENT AND MANAGEMENT RECOMMENDATIONS FOR SPRING LAKE WATERSHED, OTTAWA AND MUSKEGON COUNTIES, MICHIGAN

By

Theresa Elaine Lamott Lauber

Spring Lake is a 525-hectare river-mouth lake, lying in a subwatershed of the much larger Grand River Watershed. Appreciated as a resource for recreation, irrigation, and business uses, the scenic eutrophic lake has been plagued during the past several summers with large algal blooms of *Microcystis* and dense mats of *Ceratophyllum* and *Rhizoclonium*. Through a resident survey, 62% of the respondents found the water quality of the lake as unacceptable. Seasonal water and phosphorus budgets completed in this study suggest that the tributaries, septic systems, and lawn fertilizer runoff were the largest external phosphorus loadings, respectively contributing 44%, 28%, and 23% of the total phosphorus inputs from October to April. From May to September, the largest loadings were again from septic systems (86%) and tributaries (10%). In order to reduce the nuisance algal blooms and rootless aquatic plants, lake nutrient concentrations must be lowered by reducing all external nutrient loadings by implementing best management practices in the watershed to control non-point source runoff. Expanded public education in lake ecology will enhance stewardship for the lake ecosystem and aid in the reduction of nutrients. Because nitrogen may be co-limiting with phosphorus, the development of a nitrogen budget is also recommended.

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DEDICATION

To my community neighbors, that we may always strive to maintain, protect, and restore the *natural* community around us, so that future generations may also enjoy its aesthetical, recreational, and economical benefits. This study is dedicated to Leon Langeland, a county commissioner and lake board member who died unexpectedly this spring and who truly was a community steward.

ACKNOWLEDGMENTS

This Spring Lake Watershed study was a large undertaking and would not have been possible without the help of many people. I want to thank my family and friends for their encouragement and participation in my research and studies throughout the past three years. Thank you to my advisor, Dr. Donald Hall, who was ever so patient and encouraging and to my other committee members, Dr. Patricia Soranno and Dr. Stephen Hamilton for steering me in the necessary directions when graduate stresses almost became unbearable.

Thank you to all who helped with field work: Michelle Carlson, Sarah Best, Sally Birkam, Pam Brown, Colin Brown, Kathy Evans, Steve Churchly, Jon Reichardt, the Kotecki family and my family, Tom, Jan, Jeff, Derek, Matt, Jessica and Emily. Thank you to Philip VanGennep for lending me his family's global positioning system receiver. Thank you to Johnston Boiler for printing all of the resident surveys and to Joyce and Dawn for helping in the distribution process. Thank you to Matt and Rochelle Kotecki for entering the endless stream of data into spreadsheets.

The R. B. Annis Water Resources Institute at Grand Valley State University graciously granted me access to their laboratory and equipment for the water analysis and produced the excellent maps. Thank you to Dr. Rick Rediske and all his laboratory assistants for their patience with an outsider in their lab and to Kurt Thompson and Ramona for the maps. Thank you to Dr. Mark Luttenton for use of his own laboratory and fluorometer

and expertise in algae and aquatic plants. And thank you to Lana Brock for all her help in connecting the loose ends and finding the correct pieces.

To the numerous residents, neighbors, and friends who stopped for a conversation and gave encouraging words, thank you. To my readers who offered advice on writing this document for the general public, Kathy Przybytek, Matt Brower, and Chris Rouech, thank you. Thank you to the lake board for your dedication and witty words of wisdom to brighten my day. Lastly thank you to all of the projects' financial supporters: the City of Ferrysburg, Community Foundation of Muskegon County, Fruitport Township, Grand Haven Area Community Foundation, Michigan State University, North Bank Community Fund, Spring Lake Area Resident Association, Spring Lake Township, Village of Fruitport, Village of Spring Lake and the Muskegon Conservation District, the study's financial agent.

PREFACE

In thought this study began many years ago when I and others recognized the need for water quality data for the Spring Lake Watershed. Three years ago when opportunities arose, I returned to school in order to pursue a dream of teaching. My main prerequisite of deciding upon a Master's research topic was that I wanted my research to be directly applicable and useful to my community. As my initial hope and thoughts materialized into reality, my study evolved into the *community's study*, possessive through funding, participation, and future stewardship.

About four years ago, large algal blooms occurred on the lake to the dismay of lake residents and visitors. Coinciding also with this study, the highly visible blooms prompted the formation of the Lake Board of Spring Lake and even coverage by the area newspapers and television stations. The formation of the lake board will enable the community to be represented in decision making through their representatives to address the water quality problems. Although mirroring the formation of the aquatic plant committee in the 1950s organized due to nuisance algae and aquatic plants, the lake board has state granted power to act upon their decisions to improve the water quality of the lake. This study will provide the research and management suggestions to the lake board, enabling them to make more knowledgeable decisions for our community.

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EXECUTIVE SUMMARY

In West Michigan, Spring Lake is the big bayou of the Grand River and is a 525-hectare (1,298 acre) drowned river-mouth lake lying in a 13,412-hectare (33,141 acre) watershed. With 75% of its lands in Muskegon County and 25% in Ottawa County, the Spring Lake watershed is composed of 11 municipalities, of which Fruitport Township and Sullivan Township represent the majority of the watershed land uses. Only five of the municipalities share the benefits of shoreline property: the village of Spring Lake, Spring Lake Township, Village of Fruitport, Fruitport Township, and City of Ferrysburg.

The lake has been plagued with algal blooms and dense mats of aquatic plants for the past several summers. As discovered from a survey, 62% of the watershed residents and 83% of the lakeshore residents find the lake water quality unacceptable and blame the problems on leaching septic systems, water exchange with the Grand River, lawn runoff, and industrial discharges. My research identified the sources of nutrients contributing to the increased algal growth as coming primarily from the tributaries, septic systems, and lawn fertilizer.

Research conclusions and recommendations:

- Water inflow and outflow from Spring Lake is seasonally dynamic. During the months from October to April, the lake received 95% of its water from the tributaries and 25% from precipitation. The mean water residence time for the lake during this period was 4.9 months. From May through September, water sources were from the tributaries (87%) and precipitation (13%). Summer water

residence time averaged 11.2 months. From October through April, water loss from evaporation was 5% and during the summer season evaporative loss was 24% of the lake volume output. The volume of groundwater exchange is unknown and its quantification is recommended for future studies.

- Water exchange between the Grand River and Spring Lake is most likely influenced by water inputs from the watershed, water temperature, and wind. Similar water temperatures between the Grand River and Spring Lake, which lessen potential mixing barriers, occurred four times out of the 17 monitoring dates. Although some mixing does take place, the overall effects of intruding waters of the Grand River on Spring Lake are probably not large. Future research is recommended to quantify the importance of this potential source of water.
- The lake is eutrophic, nutrient-rich, with shallow water clarity depths (Secchi depths), and high phosphorus, nitrogen, and algal concentrations. Average lake clarity depths were 1.1 meters for the summer and 2.0 meters for the winter. Annual concentration means in the lake were 0.08 mg/l for total phosphorus, 0.25 mg/l for nitrate, and 40 μ g/l for chlorophyll *a*. A molarity ratio of nitrogen to phosphorus of 11:1 suggests that nitrogen and phosphorus are potentially co-limiting nutrients for algal growth. Although a nitrogen budget was not completed for this study, it is recommended due to its potential role in co-limitation. Seasonal phosphorus budgets suggest that during October to April: the tributaries, septic systems, and lawn fertilizer respectively contributed 44%, 28%, and 23% of the total phosphorus inputs. From May to September, the largest loadings were septic systems (86%) and tributaries (10%). Although internal loading of

phosphorus may be occurring, no in-lake management techniques to reduce this loading are recommended until a nitrogen budget and nutrient limitation/dilution experiments are completed. Otherwise, expensive management techniques may be misdirected and wasteful.

- Aquatic plants cover approximately 27% of the surface area of the lake and provide habitat for aquatic organisms. Although this amount of coverage is good for fisheries, some nuisance plants, *Ceratophyllum* and *Rhizoclonium*, do exist and hinder recreation. The wetlands beyond the perimeter roads of the lake were not included in this study and need to be documented for plant and wildlife species because wetlands are important for water quality.
- Because 79% of watershed residents surveyed pinpointed increased algae and aquatic plants as a water quality problem, the management of aquatic plants is important. To reduce the blooms of the nuisance blue-green algae, *Microcystis*, external loadings of nutrients need to be reduced. Best management practices in the watershed, including connecting to the municipal sewer system, reducing fertilizer use, developing buffer strips, and managing stormwater are recommended. Residents are encouraged to rake the dense aquatic plant mats of *Ceratophyllum* and *Rhizoclonium* from the water and to practice other management techniques which include controlling runoff into the lake, composting away from the shoreline, and using non-phosphorus fertilizer and detergents.
- Forests (6,355 hectares) are the largest land cover in the watershed and are known to contribute relatively low phosphorus concentrations in runoff water. Residential area (1,990 hectares) and crop land (1,909 hectares) are known to contribute

higher concentrations of phosphorus in their runoff. The monitoring of land use plans and changes are recommended through the development of a watershed-wide land use committee.

- A watershed resident survey revealed that knowledge of lake ecology is marginal, but 60% of the respondents wanted to know how to minimize their impacts on the watershed. Expansion of public education opportunities is recommended as an essential factor for the long-term management of the Spring Lake watershed, and include programs for continued lake and stream monitoring.

INTRODUCTION

Historically known as the Big Bayou of the Grand River, Spring Lake is situated on the border of Muskegon and Ottawa counties in central West Michigan. Its watershed is 134 square kilometers (52 square miles) and its waters are collected in its basin, Spring Lake (Figure 1). The watershed covers Fruitport Village, Fruitport Township, and parts of Sullivan Township, Eggleston Township, Crockery Township, Ravenna Township, Spring Lake Township, Moorland Township, City of Norton Shores, City of Ferrysburg, and Spring Lake Village. The Spring Lake Watershed is actually a subwatershed of the much larger Grand River Watershed, which is 14,431 square kilometers (5,572 square miles) (U. S. Army Corps of Engineers 1970).

Prior to this study, water quality data for the Spring Lake Watershed were very limited, consisting of only two single samplings in 1967 and 1981 by the state, and periodic measurements since 1986 of dissolved oxygen, temperature, pH, and Secchi depths by participants aboard the R. B. Annis Water Resources Institute / Grand Valley State University's research vessels. This lack of data and the belief of many people that the lake's water quality is unacceptable provided the impetus for this study. The lake's water quality problems were commonly blamed on the Grand River, which connects with Spring Lake between the City of Ferrysburg and Spring Lake Village by way of a dredged channel. Therefore in this study, the Grand River's influence upon Spring Lake is one of the topics that will be addressed along with these objectives:

1. Assess the current water quality of Spring Lake and its controlling factors.
2. Assess the watershed residents' perceptions and attitudes about Spring Lake and its uses.
3. Suggest management actions for water quality improvement.

The water quality of Spring Lake is influenced by historical changes in the land use and practices in the watershed. In order to understand what influences have driven the changes in Spring Lake, the past needs to be revisited. The following historical overview summarizes the major changes that affected the Spring Lake Watershed during four specific periods: pre-European, European settlement to 1930, 1930 to 1970, 1970 to present time.

Pre-European Settlement

Similar to the Muskegon and White Rivers, the Grand River and its bayous (including Spring Lake) were areas of diverse habitats for many different plants, fishes, animals, and birds. The Native American tribes of the Sac, Fox, Kickapoo, Muscotan, Chippewa, Pottawotamie, and Ottawa fished, hunted, and farmed in the area. Although they used seasonal grass burnings to control weeds (Lillie 1980), the Native Americans' impact upon the watershed did not seem to drastically alter the Grand River Valley, because old growth forests and many animals existed abundantly when European explorers arrived (Lillie 1980). The Native Americans' population density and cultural impacts on the Spring Lake Watershed are thought to be minimal.

FIGURE 1: Spring Lake Watershed Location

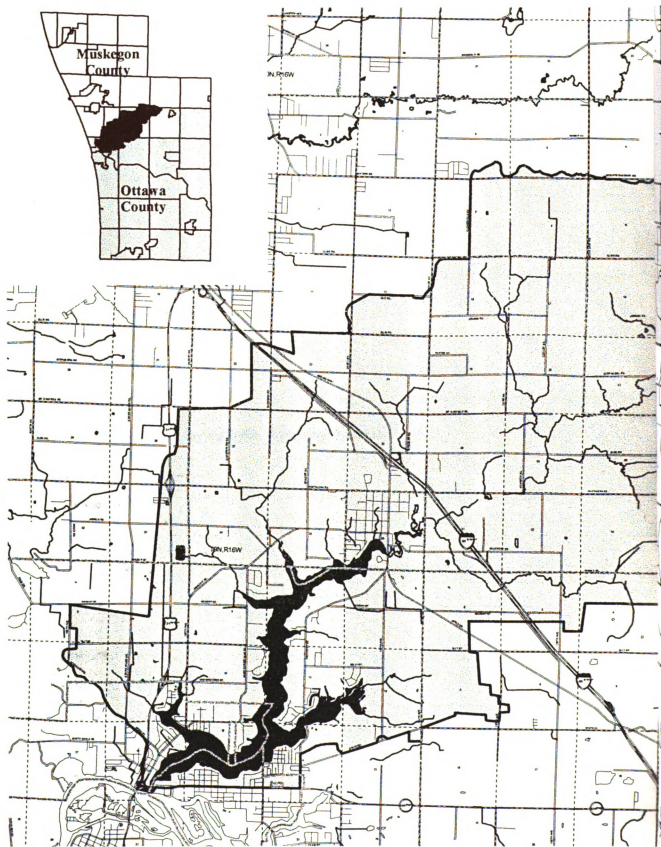


FIGURE 1
**Spring Lake
 Watershed Project
 Location Base Map**



Legend

-  Spring Lake Watershed Boundary
-  Lakes and Ponds
-  Rivers, Streams and Drains
-  Township and Municipal Boundaries
-  State and Federal Highways
-  County Roads
-  Residential Streets
-  Section Lines

1 0 1
 Miles

1 0 1
 Kilometers

Spring Lake Watershed Project:
 compiled for Theresa Lauber with
 the help of supporting local
 government entities, Community
 Foundation of Muskegon County,
 Grand Haven Area Community
 Foundation, North Bank Community
 Fund, and other local groups.

**Base Information - Michigan
 Resources Information System (MIRIS).**

Information Services Center
 R.B. Annis Water Resources Institute
 Grand Valley State University

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1969) The Spring

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European Settlement - 1930

Europeans discovered that as part of a wooded river ecosystem, Spring Lake offered a diversity of food and shelter from the rougher waters of Lake Michigan. After the exploration years of 1660s through 1700s, fur trading became important in the Grand River Valley because bear, beaver, mink, muskrat, and river otter were abundant (Lillie 1980, Crockery History Group 1996). Soon afterwards, the lumbering era began when the first logs floated down the Grand River in 1838. At its height, the Spring Lake shoreline hosted six lumberyards (Lillie 1980, Kitchel 1969). Logging mostly during the winter, the lumbermen almost completely cut the forests leaving the soils exposed to water and wind erosion. Vast amounts of soil were eroded and carried with the snow and rains to the bottom of creeks and lakes. A log slide existed on the lake between Alden and Buchanan streets in the Spring Lake Village (Kitchel 1969). Lumbering wastes, chips and planks were also commonly used as fill along the shores and wetlands and even were used to construct a "sawdust road" across a portion of the Grand River in 1852 (Lillie 1980). By 1890s most of the lumberyards closed due to the depletion of surrounding forests. The last lumberyard, Cutler & Savidge, ceased operating in 1904 (Kitchel 1969).

Other commercial businesses also depended on lake and watershed resources. In Jerusalem Bayou, clay mining for bricks began in 1859 and continued until 1871, when it was then moved to Stahl Bayou and where it operated between 1874 and 1906 (Kitchel 1969). The Spring Lake Iron Works located near Fruitport on the west shores of the lake operated during 1879 to 1912, utilizing iron ore from Michigan's Upper Peninsula to make pig iron (Kitchel 1969). Their wastes were dumped in the ravines and shores

making man-made land that is noted on the United States county soil maps (USDA 1968). Johnston Boiler, the oldest continuous industry on the lake, began making engines at its present location in 1887 (Lillie 1980, Kitchel 1969). Farmers raised fruit and vegetables and shipped them from the lake shores (Lillie 1980). Spring Lake Clinker Boat Company was founded in 1887. In 1898, the Spring Lake Ice Company was built on Strawberry Point and sold cut ice from the lake until the 1930s (Kitchel 1969).

Recreational activities on the lake included regatta races beginning in the middle 1870s. Good fishing was advertized in Chicago newspapers to attract tourists. Speckled bass, blue gill, and perch were caught by the bushel (Kitchel 1969). Tourism became a lucrative business. Catering to visitors in the 1870s, many large homes and hotels were built: Spring Lake House, Pomona House, The Willows, The Lorimer, Prospect Point Manor, The Pines, and many more (Kitchel 1969). As a result, population densities began to rise seasonally and more permanent residents settled in the area.

In 1869, the Village of Spring Lake was incorporated and enacted several ordinances one of which forbade the dumping of “dead animal, fish or putrid meat entrails, oyster or clam shells, decayed fruit or vegetable, or any other filthy or offensive substance in or upon any public street, etc. or on the surface of the ground in any lot or river or lake or on any bank thereof in the Village” (Kitchel 1969). By 1911, the Village of Spring Lake had a primitive sanitary sewer which dumped into the Grand River. Later in 1928 and 1936, the village sewer system was updated and the village residents were mandated to connect (Kitchel 1969).

1930 - 1970

The population around the lake continued to grow as the tourists began to recognize that the area was not only a nice place visit but a place to live. More cottages and homes were built with septic tanks or dry wells for sanitary systems and gray water from sinks and tubs may have also been dumped directly into the lake. Recreation on the lake increased.

Advertisements for good fishing were still common. Speed boat and sail boat races were held weekly (Kitchel 1969). The beaches in the village of Spring Lake and Fruitport were popular spots for swimming. The Pomona Pavilion in Fruitport was built 1941 and attracted many band groups and visitors until it burned down in 1963 (Kitchel 1969).

Beginning in 1946, a duck farm began operating on 68 acres with 3,300 feet of lake frontage at Harbor Point. Blowing feathers and all night quacking from about 35,000 ducks led neighbors to take the farm to court in 1952. Court action forced the closure of this business which was sold in 1954 (Grand Haven Tribune 1952, 1954a).

In 1954, the nuisance algal blooms prompted a weed control meeting with representatives from Spring Lake Township and the villages of Fruitport and Spring Lake. The formation of the Spring Lake Algae Control Committee was authorized in Aug. 17, 1954. (Grand Haven Tribune 1954d & e). This committee hired Dr. B. P. Domogalla from the Applied Biochemist & Associates of Butler, Wisconsin to apply chemicals to kill the algae and aquatic plants (Grand Haven Tribune 1954b). The herbicide was a mixture of copper sulfate and arsenic which was a predecessor to the company's patented Cutrine formula (Burris 1997) and was applied to the water from platform-type boats (Grand Haven Tribune 1954c). In 1955, Applied BioChemist was hired again to spray the algae and

aquatic weeds for \$15,000 (Grand Haven Tribune 1955f). The lake was sprayed three times that summer. After the first 6,000 pounds of algaecide spraying, the lake cleared of its green hue and remained that way for only several weeks. The second spraying began in the middle of July to kill the rebounding population of algae (Grand Haven Tribune 1955g).

The Spring Lake Algae and Weed Committee eventually evolved into the Spring Lake Improvement Association which held its first annual meeting in 1956 (Grand Haven Tribune 1956h). In that same year, approximately 27,000 feet of shoreline was sprayed once for weeds and three times for algae (Grand Haven Tribune 1956i). Ironically, while Dr. Domogallo did not “guarantee permanent relief,” a state conservationist said “while not a cure or permanent solution, it (the spraying) has been reasonably successful ... adequate treatment of four years may be most permanent” (Grand Haven Tribune 1954j).

1970 - Present

During this period, many environmental laws were passed which accelerated the efforts to improve our use of land, air, and water. Laundry detergents were no longer produced with phosphates. The state permitted fewer whole lake algae and aquatic chemical weed treatments but allowed residents to apply treatments with a permit. The Village of Spring Lake closed their sanitary system near Millpoint, which dumped treated waste into the Grand River. Afterwards, the village connected to North Ottawa Wastewater Treatment in 1972 with the City of Ferrysburg and parts of Spring Lake Township following in 1982 (Krohn 1997). Although efforts increased to reduce pollution, some pollution had

already occurred in and around Spring Lake. Some businesses and industries such as Superior Plating, Anderson, Amoco, and etc. have become groundwater hazards because of leaking chemicals (Koches et al. 1995). Heavy metals were discovered in the lake sediments: moderate to high levels of arsenic, zinc, iron, cadmium, nickel, manganese, chromium, and copper (Thorpe 1994). The pollution is a reminder that past practices may have long-term effects on the community.

Spring Lake continues to be a popular recreational and residential area. Focusing on recreational safety and the water quality of Spring Lake, the Lake Improvement committee that began in the 1950s became the Spring Lake Area Residents Association. Recently, the Lake Board was formed to address the water quality problems of the late 1990s because Spring Lake continues to provide many irreplaceable benefits for the community.

Conclusion

The watershed of Spring Lake has undergone many changes in water and land uses that have impacted its waters in some way. The resulting effects are present in the quality and quantity of its water, soils, lake sediments, plants, and animals. The following chapters address the current water quality status of the lake and the effects of some past influences, beginning with a study of the lake's water sources.

CHAPTER 1

HYDROLOGY

INTRODUCTION

To address the question of the Grand River's effect upon the water quality of Spring Lake, the exchange of waters between the river and Spring Lake and other sources of water were studied. This exchange and other water sources are all part of Spring Lake's hydrology, the study of water movement in the watershed. The Spring Lake Watershed has many different inputs and outputs of water: precipitation, springs (from groundwater), seepage (to groundwater), streams, evaporation, and the Grand River exchange (Figure 2). Beginning as a small ditch in Sullivan Township, the water becomes the larger stream of Norris Creek and eventually widens into Spring Lake. Hence, this watershed represents a dynamic water gradient collecting water from its upper reaches to its channel connecting to the Grand River.

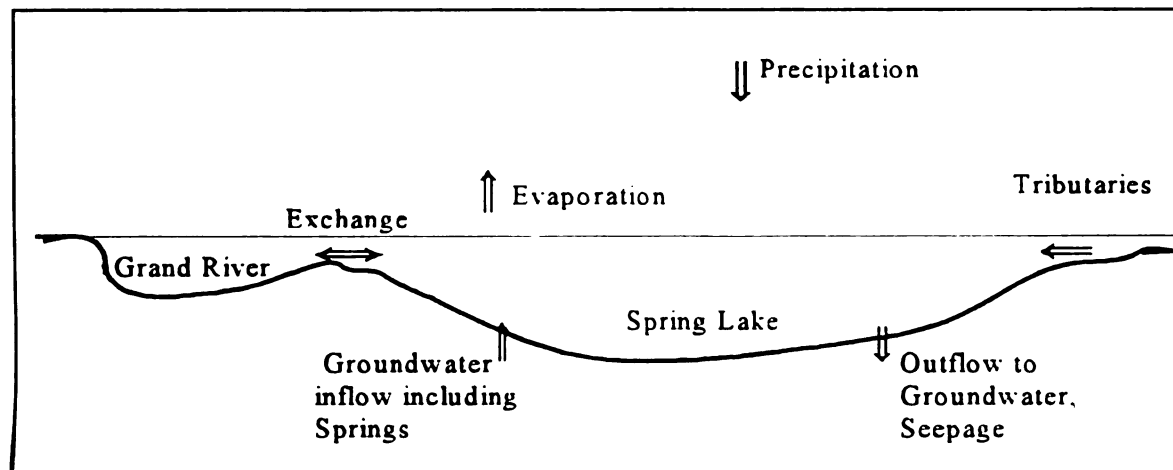


FIGURE 2: Cross-sectional diagram of the Grand River and Spring Lake with its inputs and outputs of water (not to scale)

By the time the water reaches the lake, it is not just *water*. Water accumulates and transports nutrients and other substances as it travels (Wetzel 1983):

- Through the atmosphere,
- Through water bodies such as the lake, streams, and ditches,
- Through the soil as it filters down to the water in the ground (groundwater),
- Over the soil if it can't be absorbed,
- Over impermeable surfaces where it is usually directed to the closest water body via a storm drain or other means.

Nutrients, just as those in garden fertilizer, are the primary food necessary for the growth of all aquatic plants. Through its course, water also transports soil, decomposing plant and animal tissues, chemicals, fast food containers and other litter. Therefore, knowledge of the hydrology of the Spring Lake Watershed is essential to understand and manage the water quality, plants, and algae.

GEOLOGICAL FORMATION

The flow of water and its dissolved and suspended contents is affected by the shape and texture of a watershed's terrain. The soils and topography of the Spring Lake Watershed were drastically altered many times by the glaciers. Two hypotheses exist concerning the formation of the watershed and its flow of water. An early geologist believed that the state of Michigan was on a gradual upward rebound after the massive weight of the glaciers retreated about 10,000 years ago (Scott 1921). The upward movement of the land plate was not equally distributed and the east side of the state rose quicker than the west side, tilting the state. The tilt caused the pooling of waters on the western side of the state forming the drowned river-mouth or river-valley lakes such as Spring Lake, Lake Macatawa, Muskegon Lake, and White Lake. The other hypothesis suggests an effect caused by water movement in the Grand River. The Grand River is a meandering river in

its lower reaches, etching out soils and depositing them in other areas. Soils in the area of the river and Spring Lake's mouth were deposited in this manner by the Grand River. In an 1867 map, the far west corner of the Spring Lake Village — where a hotel, brewery, and condominiums are now situated — was identified as shallow wetlands and wild rice beds (Lillie 1980). In the past when water levels were lower, the deposition of soil in this area may have been so great that the passage of water coming out of Spring Lake into the Grand River was impeded and caused back flooding, forming Spring Lake. It is also possible that discharges of seasonal flooding from Spring Lake into the Grand River may have periodically washed out the sediment accumulation in its connection to the Grand River. Spring Lake was probably formed from a combination of these geological events and the flow of Grand River.

Water movement is affected by the texture of the watershed — the soils. Water infiltrates through different soil types at different rates, with sandy soils being the most rapid.

Spring Lake's watershed is underlain by 100 to 300 feet of glacial deposits, including sandy soils from the bottom of a glacial lake that preceded Lake Michigan (U. S. Army Corps of Engineers 1970, U. S. Department of Agriculture 1968, 1972). As tributary or stream waters cut through these sandy deposits, deep ravines, such as those along Norris Creek north of Pontaluna Road in Fruitport Township, were formed. When the stream current slowed, the soils were deposited and formed flood plain areas such as the wetland area north of Fruitport Village along Norris Creek. The large clay deposits of Stahl and Jerusalem Bayou, which were mined for bricks, may have been deposited in this same manner long ago. Willow's Bay also has banks of clayey soil. The watershed soil types

are illustrated in Figure A1 of Appendix A.

WATERSHED AND LAKE CHARACTERISTICS

Recent Formation

The draining of wetlands by ditches, ponding of small tributaries, constructing and draining of roads, and dredging of the waterways have also altered the watershed. After the arrival of European settlers, laws were enacted to drain Michigan wetlands for highways (1819), tillable land (1827), and human health (1839, 1846) (Hulka 1996).

The current Michigan Drain Code was adopted in 1956 after many years of revisions. In the Spring Lake Watershed, there are 20 major drains totaling 43 kilometers (about 27 miles) in length and are monitored by the drain commissioner of each county (Table 1 & Table A1 in Appendix A). Stormsewer drains for street and housing development runoff are also common around the lake and tributaries. There are at least 81 outfalls from such drains around the lake (for locations, see maps in chapter 3, Figures 33, 34 and 35).

Water entering from each of these drains has traveled over and through surfaces and in the process removed and dissolved substances to be deposited into a stream or the lake itself.

TABLE 1: Drains of the Spring Lake Watershed

DRAINS	NUMBER OF DRAINS	LENGTH OF DRAINS kilometers (mile)
Ottawa County	7	8.45 km (5.3)
Muskegon County	13	34.9 km (21.7)
Stormwater	81	?
TOTALS	101	43 km+ (27+)

The Connection Between the Grand River and Spring Lake

Another change in water movement resulted from the dredging of the channel connecting Spring Lake and the Grand River. In 1867, the depth of the channel was about 2.7 meters (9 feet) (Lillie 1980) and hindered the movement of larger boats. The first recorded dredging by the government was in 1902, but by 1904 sediments had filled the channel and caused a ship grounding (Kitchel 1969). The last dredging was in 1989 by the U. S. Army Corps of Engineers (NOAA 1990), and the channel is currently about 5 meters deep (16 feet) and 77.5 meters wide (254 feet). The increased channel depth increases the likelihood that larger volumes of water may mix between Spring Lake and the Grand River.

Mixing Waters of the Grand River and Spring Lake

Water has special characteristics that can impede different types of waters from mixing easily. If the temperature or density of the waters greatly differs, the two waters resist mixing. The water with the highest temperature will flow to the top layer and the water with the lowest temperature will flow to the bottom. One way to explore the possibility of mixing waters between the Grand River and Spring Lake is to look at temperature and dissolved oxygen depth profiles through time.

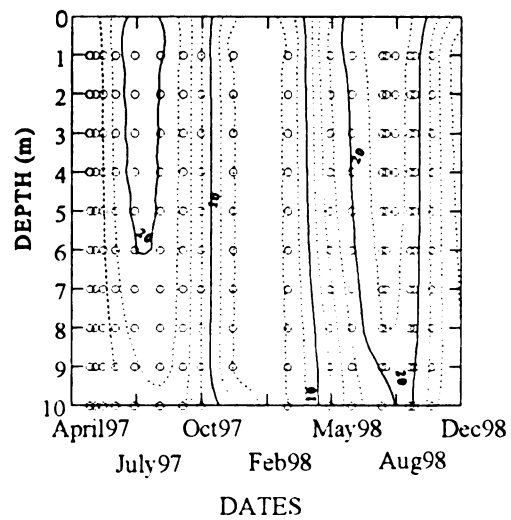


FIGURE 3: Time-Depth Diagram of Water Temperatures for Spring Lake at the Spring Lake Sampling Site (Celsius)

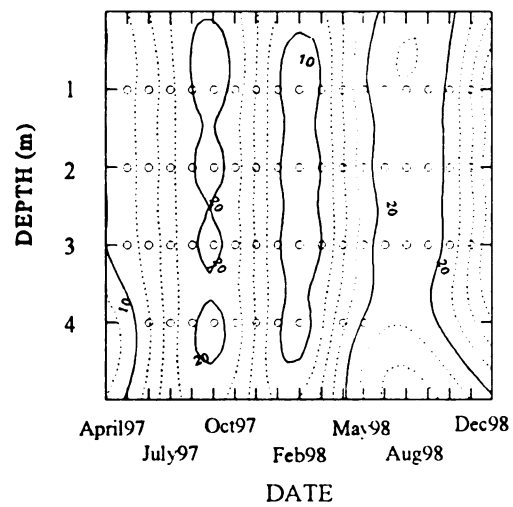


FIGURE 4: Time-Depth Diagram of Water Temperatures for the Grand River (Celsius)

The lake temperatures at the Spring Lake sampling site remained constant for a longer period than the Grand River water temperatures, which fluctuated more rapidly than Spring Lake (Figure 3 & 4). The river water warmed and cooled faster than the lake water. From late winter until early summer, the lake is usually colder than the river. If river water is forced into Spring Lake during this period, the river water would flow on top of the lake water. During the summer (August 1997 and June 1998), the lake waters warmed to a similar temperature of the river, beginning a period of potentially easy mixing of the waters. In late summer, the lake temperatures were higher than the river until the lake began to cool in the fall. In late summer if the river is forced into Spring Lake, the river water would flow to the lower lake water layers that are similar to the river's temperature. The water temperatures of the river and the lake were again similar in September 1997 and December 1998, easing mixing barriers. Of the 17 sampling times, only four times were the differences between river and lake water temperatures one degree Celsius or less. During these four occasions, the river and lake water may have easily mixed.

Dissolved oxygen time-depth diagrams are also useful in the analysis of potential intrusion of water from the Grand River. Since the Grand River is usually well-oxygenated (Figure 6 & Table B21) and Spring Lake has lower dissolved oxygen levels most of the time (Figure 5 & Table B15), unusual high dissolved oxygen levels in Spring Lake's water layers could indicate that water from the Grand River is flowing into Spring Lake.

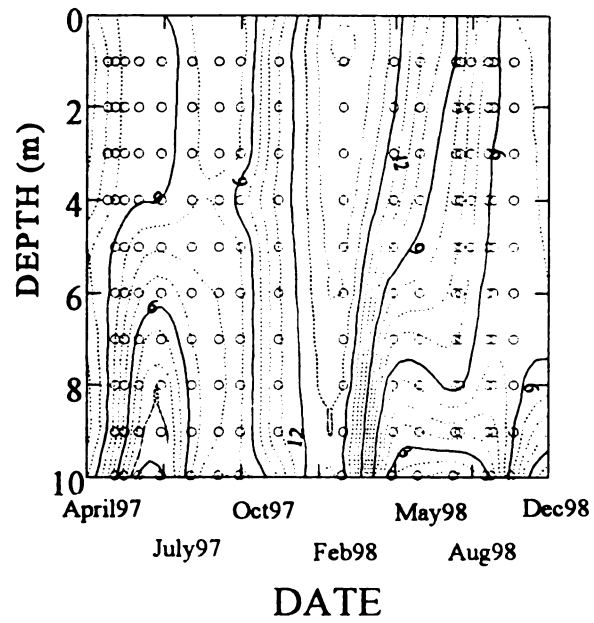


FIGURE 5: Time-Depth Diagram of Dissolved Oxygen for Spring Lake Sampling Site (mg/l)

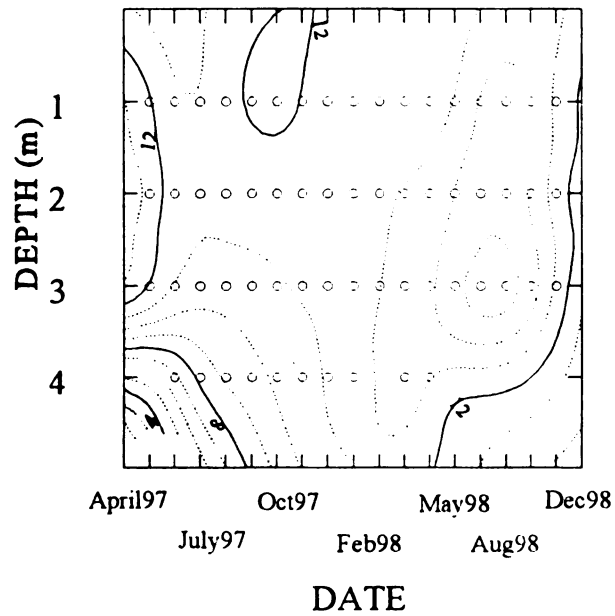


FIGURE 6: Time-Depth Diagram of Dissolved Oxygen for the Grand River site (mg/l)

The periods of similar water temperatures but different dissolved oxygen levels, August 97, September 97, December 97, and June 98 showed no unusual high dissolved oxygen levels at the Spring Lake site compared to the deep water site of Prospect Point (Table B17). Nor were there any high dissolved oxygen levels found during the other sampling dates. The lack of high dissolved oxygen levels at the Spring Lake site may be indicative of several possibilities: the Grand River is not a large intruding source of water, the water from the Grand River is physically mixed within the channel, or the Grand River input spreads out into a very thin layer in Spring Lake; thereby, reducing the contrasting dissolved oxygen levels that are detectable at the Spring Lake sampling site.

The exchange of waters between the Grand River and Spring Lake is also likely to be greatly influenced by the wind direction and speed because wind can “pile up” water on one side of large water bodies. During a measurement period of two hours in July 1997, a flow reversal was observed when wind direction changed from northerly to southerly and water began to flow from the Grand River into Spring Lake. A study on the Detroit River explored the relationship between wind direction and flow reversals (Derecki and Quinn 1990). This study found that collected data should be in time spans of no greater than 15 minutes to document the wind direction and flow reversal relationship. Although data for this study were not acquired to that extent, there were 36 days during the winter and 49 days during the summer when the prevailing wind was from the south to southwest (October 1997 - September 1998) (Midwestern Climate Center 1999). If wind speed from these directions was high enough and sustained long enough (Rutherford 1994), the Grand River waters could be laterally pushed into the channel of Spring Lake and possibly affect

Spring Lake water quality.

Water Levels

Since Spring Lake is connected to the Grand River and thereby Lake Michigan, the water levels of Spring Lake are similar to those of the river and Lake Michigan. (See Appendix A for methods and materials.) Stage levels of the Grand River at Grand Haven and Lake Michigan reflect the same trend found in the average water level of Spring Lake; whereas the stage level of Grand River at Grand Rapids do not reflect the stage levels found in the lake (Figure 7). Therefore, Spring Lake's water levels seem to be greatly dependent upon Lake Michigan water levels and do not seem to be strongly dependent upon the water levels and discharge of the upper Grand River.

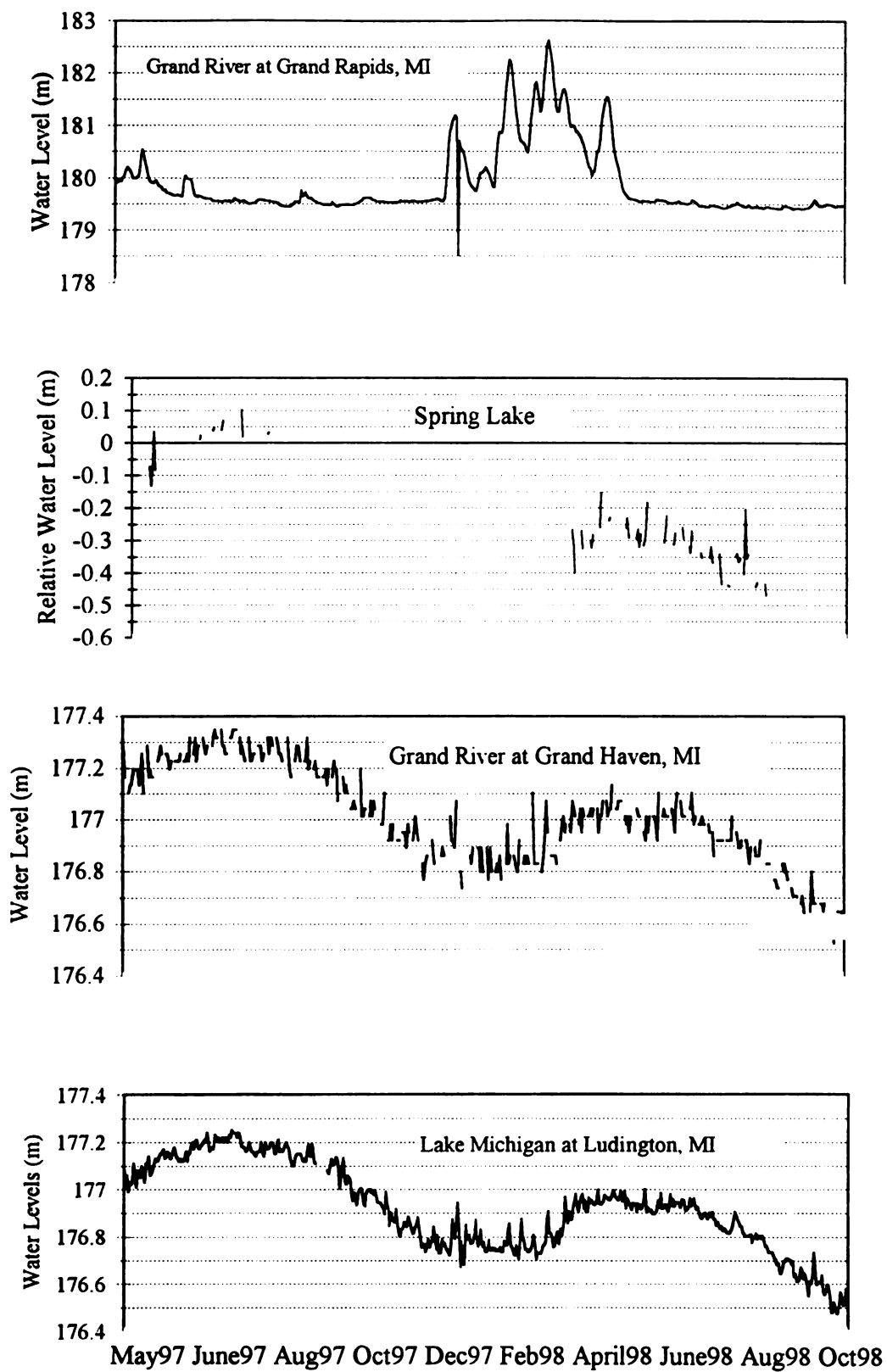


FIGURE 7: Stage Levels of the Grand River, Spring Lake and Lake Michigan (m)

Tributaries, and Other Lake Characteristics

Although the trend in Spring Lake's water levels follows the lower Grand River and Lake Michigan, Spring Lake is also influenced by its many tributaries. Willow's Hill Creek and Vincent Creek join Norris Creek, forming the largest tributary, which enters the lake near Fruitport (Figure 8). Norris Creek's average discharge is $1.9 \text{ m}^3/\text{sec}$ during the winter season (October - April) and $0.5 \text{ m}^3/\text{sec}$ during the summer season (May -September). Steven's Creek, Jerusalem Creek, Smith Creek, Beckwith Creek, Gildner Creek, Timber Creek, and many other small intermittent streams also contribute to Spring Lake, but with much smaller discharges. The total average discharge from the small streams is estimated as $0.7 \text{ m}^3/\text{sec}$ during the winter season and $0.4 \text{ m}^3/\text{sec}$ during the summer season. The measured and estimated stream discharges are reported in Table A4 in Appendix A.

The lake has a surface area of 525 hectares (1,298 acres), although in previous studies it has been listed differently: 925 acres (U.S. Army Corps of Engineers 1970) and 1047 acres (MDNR 1967). The average volume of the lake is $3.1 \times 10^7 \text{ m}^3$ (Table 2). The ratio of the watershed area to lake area (26:1) reflects the relationship of the size of the watershed to the size of the lake. There are 26 hectares of upland for each hectare of lake surface, suggesting that changes in land use may strongly affect the lake. I will discuss land uses in the following chapters. As Table 2 shows, the shoreline length is large — 23 miles — and the shoreline development ratio is 5:1. Because the shoreline is irregular in shape, this large ratio implies that effects from development around the lake may be high by providing more waterfront property for development. Shoreline effects such as stormwater runoff may be great. These ratios are important in the water budget study

because any changes in upland areas have direct and indirect influences on the flow of water into Spring Lake. For example, if more housing developments with stormwater drains are built, more runoff water would enter the lake.

TABLE 2: Characteristics of Spring Lake and its Watershed

Characteristic	Size	Size (metric)
Watershed area	51.8 miles ² 33,141 acres	134 kilometers ² 13,412 hectares
Lake surface area	2.03 miles ² 1298 acres	5.3 kilometers ² 525 hectares
Lake volume	1.1 x 10 ⁹ feet ³	3.1 x 10 ⁷ meters ³
Shoreline length	23 miles	37 kilometers
Average Depth	19.7 feet	6 meters
Maximum Depth	42 feet	12.8 meters
Watershed to Lake area ratio	26:1	26:1
Shoreline development ratio	5:1	5:1

Another type of graph which characterizes Spring Lake is a hypsograph (Figure 9). The graph shows the relationship of lake's water area and depth. Spring Lake has a large shallow water area and then its area decreases rapidly with depth.

FIGURE 8: Map of Sampling Locations in the Spring Lake Watershed

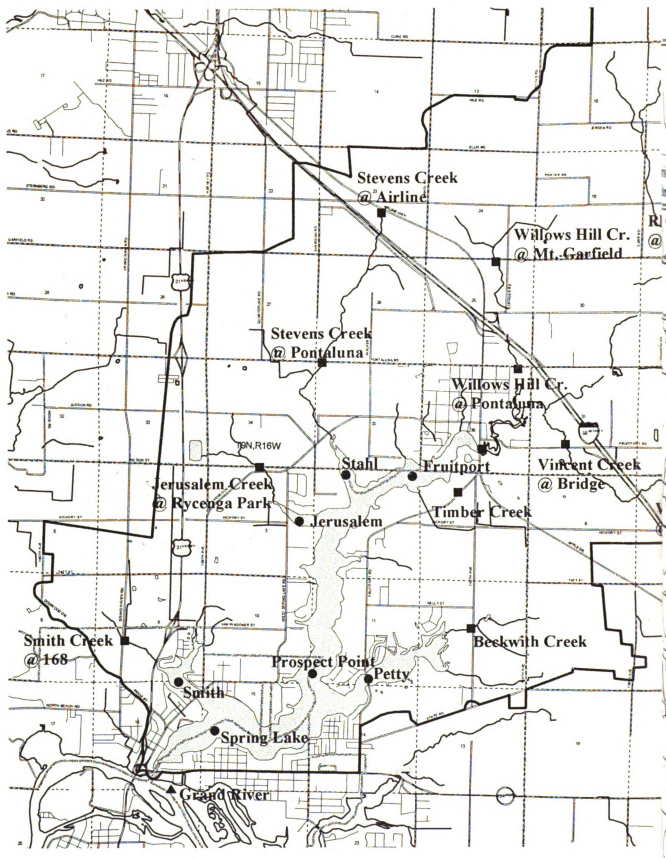


FIGURE 8
Spring Lake
Watershed Project
Sampling Locations

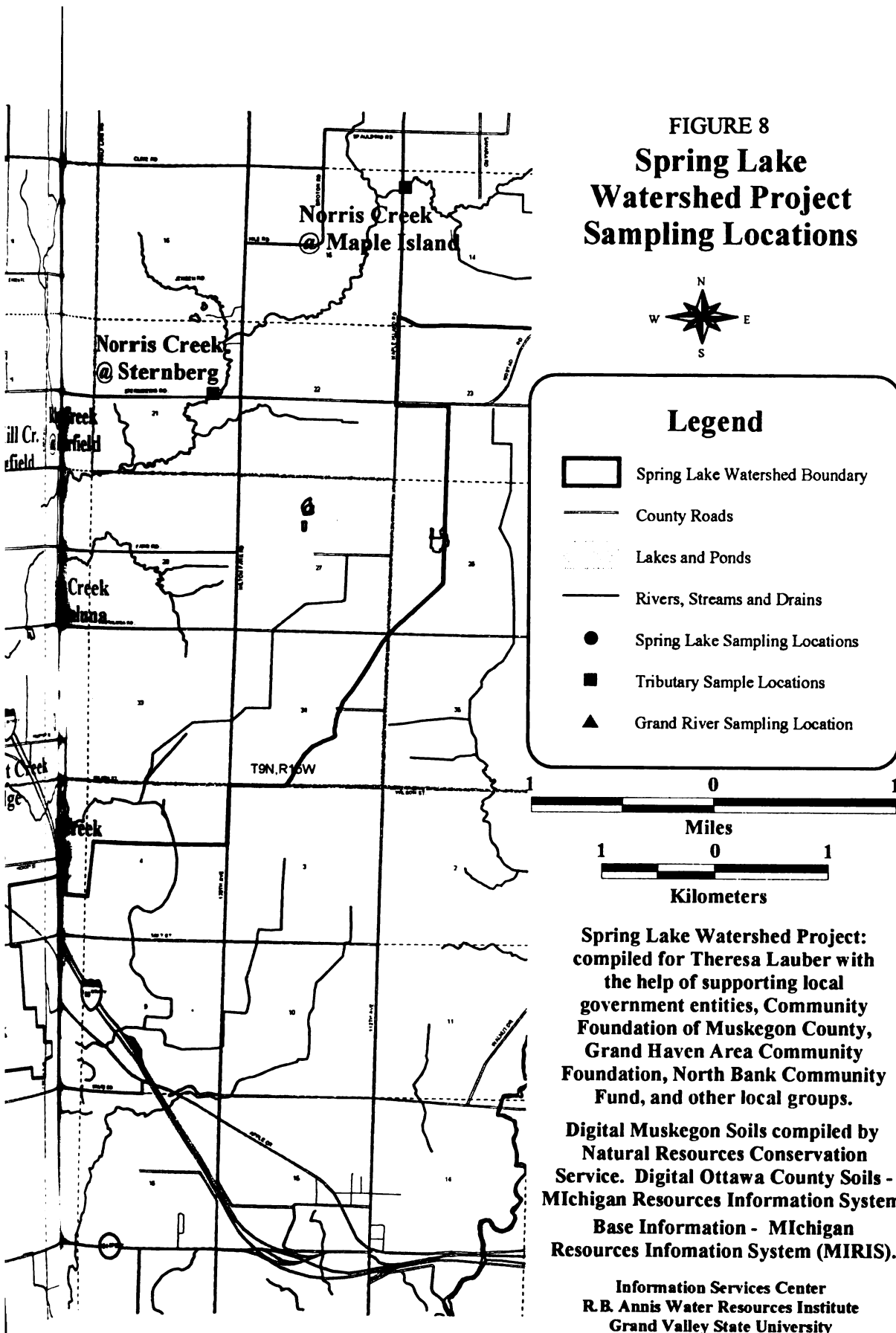


FIGURE 9 HYP

WATER BUDGET

The accounting

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$$\Delta L = P -$$

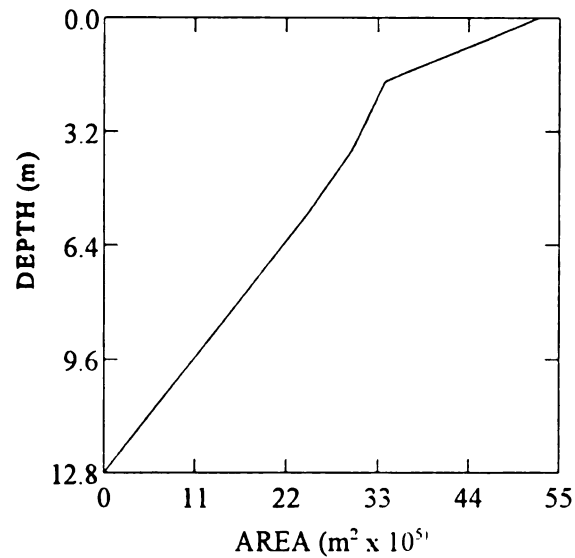


FIGURE 9: Hypsograph of Spring Lake

WATER BUDGET

The accounting of all the water inputs and outputs in a watershed is called a water budget.

These inputs and outputs include precipitation on the lake surface, streams, inflow from groundwater including springs, outflow to groundwater (seepage), stormwater runoff from drains, evaporation from the lake surface, and the Grand River exchange. The following budget equation incorporates these sources and losses of water:

$$\Delta L = P + T - E \pm R$$

L = the change in the lake volume

P = precipitation on the lake's surface

T = inflow from tributaries

E = lake evaporation

R = residuals (unmeasured components and error)

The streams, the connecting channel to the Grand River, lake water levels, and precipitation were monitored to estimate the water budget of Spring Lake. Several attempts were made to directly measure the flow in the channel connecting Spring Lake to the Grand River but this was difficult due to boat traffic and flow reversals. Groundwater was not directly measured. Net groundwater exchange is commonly obtained by difference in a water budget equation, but this could not be done for Spring Lake because the exchange with the Grand River could not be accurately measured. Therefore, the residual contains not only error but also the exchange with the Grand River and with groundwater. The calculated inputs and outputs are in Table A3 in Appendix A, along with the methods and materials for the water budget calculations. Instead of an annual water budget, Spring Lake's water budget was developed in intervals, then separated into seasons because stream discharges, precipitation, and evaporation seemed to vary greatly with the seasons.

In the winter season (October - April), tributary inputs accounted for 95% of the measured inputs into Spring Lake, whereas lake precipitation was only 5% (Figure 10). Tributary sources accounted for 87% of the inputs for the summer season (May - Sept) and 13% of the inputs were from precipitation on the lake. Tributary inputs were higher in the winter season due to the winter snow melts and spring rains. The winter season also spans seven months and the summer season spans only five months. Evaporation was greater in the summer budget, 25% of the outputs, than in the winter (5%) because of higher temperatures and no ice cover. During the winter, the lake lost 1% of its average seasonal volume ($- 3.8 \times 10^5 \text{ m}^3 / 3.08 \times 10^7 \text{ m}^3 \times 100$) and during the summer, the lake

gained 0.2% of its average seasonal volume ($0.63 \times 10^5 \text{ m}^3 / 3.13 \times 10^7 \text{ m}^3 \times 100$).

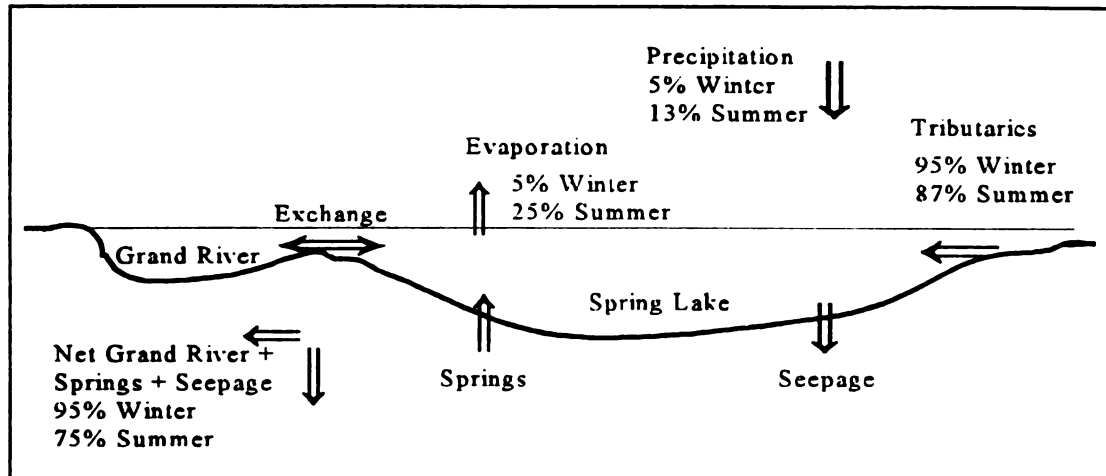


FIGURE 10: Percentages of Seasonal Averages of Water Inputs and Outputs for Spring Lake

TABLE 3: Seasonal Water Budget Estimates for Spring Lake ($\times 10^5 \text{ m}^3$)

Season	Average Lake Volume Change	Average Tributary Input	Average Precipitation on Lake Surface	Average Lake Evaporation	Average Residuals
Winter	-3.82	+ 97.66	+ 4.91	- 4.80	- 101.6
Summer	+0.63	+ 5.88	+ 0.87	- 1.47	- 4.33

The residuals of the water budget are the leftovers from the budget accounting (Table 3).

For instance, if an unmeasured large volume of water is flowing out of Spring Lake

(output) and a smaller unmeasured amount of water is coming into the lake (input), the net residual for this example would be negative output because the output is greater than the input. Changes in the volumes would increase or decrease the magnitude of the residual.

If the input was greater than the output, the net residual would be a positive input. In the Spring Lake budget, the residuals are large and negative and include the net groundwater

exchange, the Grand River exchange, direct stormwater drain inputs, and error. Notice that the residuals are net estimates that could be a combination of water input and output volumes of the two flows, the Grand River and groundwater which were not adequately measured. In the winter the average residual is 95% of the outputs, and in the summer the average residual is 75% of the outputs. To explore the residuals, scenarios can be developed to look at possible net flows:

1. Assume net groundwater flow and stormwater input are zero, therefore the residual is the net exchange with the Grand River.
2. Estimate the net exchange into the Grand River based on the discharge measured on one date, and assume the remaining residual is due to the net groundwater exchange and stormwater runoff.
3. Estimate stormwater runoff from drains and assume that the net groundwater exchange is positive, and study the water budget intervals.

Scenario 1: No Net Groundwater Exchange

In some lakes the net annual inflow and outflow of groundwater are nearly balanced, meaning that groundwater flow out of a lake into the groundwater table is similar to the groundwater flow into a lake (Lerman et al. 1995). For Spring Lake, if we assume that the net seasonal groundwater exchange and stormwater runoff are minimal, then the residual would be mostly due to the Grand River exchange. Both seasonal residuals are negative, indicating a net flow out of Spring Lake. The two seasonal residual averages can be used to estimate flow velocity out to the Grand River by dividing the volume in m^3 by the average number of days in the seasonal intervals (49.4 for winter and 7.25 for summer) and by the cross-sectional area of the channel (244.9 m^2). This daily flow is converted to m/sec thereby providing possible channel flow velocities out of Spring Lake: winter channel flow of $9.7 \times 10^{-3} \text{ m/sec}$ (0.0097 m/sec) and summer channel flow of $2.8 \times 10^{-8} \text{ m/sec}$ ($0.000000028 \text{ m/sec}$). In this scenario one, net summer channel flow velocity is

much smaller than the winter net flow, suggesting perhaps that more equal exchanges may occur between the Grand River and Spring Lake during the summer. Both of the net scenario flows are quite possible, especially since measured channel flow velocities were 0.04 m/sec out of Spring Lake and 0.05 m/sec into Spring Lake (see the next scenario). The lack of stormwater input is not a reasonable assumption since there is definitely stormwater drain input into the lake from the 81 stormwater outfalls; nor is the assumption of no net groundwater flow reasonable. Net groundwater flow has been documented as being significant in other Michigan lakes (see scenario 3). Therefore the assumptions of no net groundwater exchange and no stormwater input are not reasonable for Spring Lake and scenario one should be rejected.

Scenario 2: Measured Grand River Exchange

To estimate a volume for the net exchange with the Grand River, let us use the measured channel discharge as the constant rate of water flowing through the channel connecting the Grand River and Spring Lake, even though this most likely varies in time and with the wind. The channel flow between Spring Lake and the Grand River was successfully measured on 21 July 1997 during a time span of two hours. Taken at various places across the channel, these flows going into the Grand River were measured: 0.016, 0.014, 0.04, 0.075, 0.056, 0.081, 0.04, 0.08, and 0.078 m/sec. When the wind direction changed from the north to south, these flows were measured going into Spring Lake: 0.083, 0.071, and 0.0 m/sec. Averaged, the flows are 0.04 m/sec flowing from Spring Lake and 0.05 m/sec flowing into Spring Lake. The discharge out of Spring Lake was 9.8 m³/sec and the discharge into Spring Lake from the Grand River was 12.2 m³/sec. The difference, the net

discharge from the Grand River into Spring Lake, is $2.4 \text{ m}^3/\text{sec}$. Although this discharge is from a single sampling period and is most likely not representative throughout the year, let us assume that this is an average summer net discharge from the Grand River. An average summer volume input into Spring Lake was calculated by multiplying the average number of days in the summer season and converting seconds to days for a volume of $15 \times 10^5 \text{ m}^3$. Now a recalculation of the summer water budget including the estimated net flow of Grand River into Spring Lake was completed: lake change ($0.63 \times 10^5 \text{ m}^3$) - tributary input ($5.88 \times 10^5 \text{ m}^3$) - precipitation ($0.87 \times 10^5 \text{ m}^3$) - Grand River input ($15 \times 10^5 \text{ m}^3$) + evaporation ($1.47 \times 10^5 \text{ m}^3$) = new residual. The new residual of $-19.6 \times 10^5 \text{ m}^3$ suggests that the net groundwater exchange is large and it would be seeping out of Spring Lake into the groundwater table. A flow into the groundwater such as this seems highly unlikely; even Gull Lake's largest outflow into the groundwater was estimated at only $1.4 \times 10^5 \text{ m}^3$ (Tague 1977). When a recalculation was redone for the winter season, the residual became even larger, $-116.6 \times 10^5 \text{ m}^3$, again indicating large outflows into the groundwater. Therefore, because the large outflows into the groundwater seem improbable, the average net exchange between Spring Lake and the Grand River must be much lower than the measured net discharge of $2.4 \text{ m}^3/\text{sec}$ into Spring Lake. Stormwater runoff in this scenario is zero, even though an input does exist. Thus, scenario two is rejected.

Scenario 3: Stormwater Runoff, Groundwater, and Water Budget Intervals

Stormwater runoff (non-tributary runoff) was not directly measured from the outfalls, but I believe it can be reasonably estimated and inserted into the water budget intervals to

give new calculations for residuals (Appendix A). I also suspect that Spring Lake has a significant net groundwater input into the lake (a positive component) because:

1. The watershed consists of mostly sandy soils through which groundwater can readily flow.
2. I have observed springs on several banks around the lake. Since these springs were above lake water level, they indicate that the groundwater water table is above the lake level and groundwater is flowing into the lake at those areas (Jerusalem Bayou, Willow's Bay, Stahl Bayou). Topography around the lake is high except near the Village of Spring Lake and the City of Ferrysburg. Therefore following topographical gradients, groundwater mostly likely flows into the lake except possibly near its connection to the Grand River.
3. Two other West Michigan lakes, Gull Lake in Kalamazoo County and Glen Lake in Leelanau County, have net inflow into the lake from groundwater. Although topography and size of these watersheds are different from Spring Lake, both consist of mostly sandy soils like the Spring Lake Watershed. Gull Lake had an annual net groundwater input of 45% of all inputs, a winter groundwater input of 124% of the winter tributary input, and a summer groundwater input of 90% of the summer tributary input (Tague 1977). Glen Lake's annual net groundwater input was 170% of its tributary input (Keilty 1996).

Assuming that the water budget component for groundwater is a net positive, let us now study the sampling intervals used to produce the water budget. The stormwater interval volumes were averaged for each seasonal water input: 18,513 m³ for the winter and 3,284 m³ for the summer (Table A12).

TABLE 4: Summary of Water Budget for Each Sampling Interval for the Spring Lake Watershed

Intervals	Lake volume change during interval ($\times 10^3 \text{ m}^3$)	Lake change to initial lake volume of the interval %	Tributary Input ($\times 10^3 \text{ m}^3$)	Precipitation Input ($\times 10^3 \text{ m}^3$)	Evaporation Input ($\times 10^3 \text{ m}^3$)	Stormwater Input ($\times 10^3 \text{ m}^3$)	Residuals ($\times 10^3 \text{ m}^3$)
16May-23May97	0.57	0.19	8.24	0.12	-1.04	0.00	-6.75
16June-1July97	3.09	1.02	13.02	2.23	-3.53	0.08	-8.72
1July-2July97	0.56	0.18	0.78	0.07	-0.24	0.00	-0.05
2July-8July97	-0.43	-0.14	5.95	0.66	-1.41	0.02	-5.66
8July-9July97	1.52	0.49	0.67	0.00	-0.24	0.00	1.08
9July-14July97	-0.17	-0.06	4.10	0.09	-1.41	0.00	-2.95
14July-23July97	1.86	0.60	4.18	1.24	-2.12	0.05	-1.48
23July-12Aug97	0.39	0.12	16.56	2.35	-3.94	0.09	-14.67
12Aug-13Aug97	0.26	0.08	0.76	0.00	-0.21	0.00	-0.30
29May-30May98	2.17	0.74	0.83	0.00	-0.15	0.00	1.48
18July-19July98	1.69	0.58	0.57	0.07	-0.24	0.00	1.29
30Aug-19Sept98	-3.99	-1.40	14.85	3.62	-3.17	0.14	-19.42
Summer Average	0.63	0.20	5.88	0.87	-1.47	0.03	-4.68
13Aug-22Nov97	-18.85	-6.07	97.65	10.36	12.61	0.39	-114.64
22Nov97-11Jan98	-9.61	-3.30	110.07	4.87	6.05	0.18	-118.69
11Jan-31Jan98	1.04	0.37	56.32	1.03	0.00	0.04	-56.35
31Jan-22Mar98	11.18	3.95	192.87	5.31	2.31	0.20	-184.88
19Sept-16Oct98	-2.86	-1.02	31.39	3.00	3.02	0.11	-34.34
Winter Average	-3.82	-1.21	97.66	4.91	4.80	0.19	-101.78

Positive residuals occurred during the three intervals of 8-9 July 1997, 29-30 May 1998, and 18-19 July 1998, indicating a net inflow of water from the Grand River and groundwater (Table 4). Assuming that groundwater is a positive net input, then this residual suggests that the net exchange with the Grand River is an input during these intervals. The percent change of the lake volume from the initial interval volume for all three intervals is less than 1%, meaning that the net input was relatively small compared to the entire lake volume. Mostly likely, this small input did not influence the lake's water quality. For instance, suppose the average total phosphorus concentration (a nutrient) in

the lake during the 29-30 May 1998 interval was 0.06 mg/l and the river total phosphorus concentration was 0.1 mg/l. Then if the residual was entirely from an input from the Grand River, the river input would cause a total phosphorus change, $(0.74\%)(0.1 \text{ mg/l}) = 0.00074 \text{ mg/l}$ in the lake. This is a very minute change in the concentration of the lake and would not greatly affect the lake. Because only three intervals had positive residuals, the net inflow from the Grand River and groundwater is most likely episodic as previously discussed and would have a small overall influence on Spring Lake's water quality.

The other residuals of the water budget intervals are negative, suggesting a net outflow from Spring Lake into the Grand River. Since the net groundwater input is assumed to be positive, it is most likely that groundwater is a larger influence on the water quality of Spring Lake than is the Grand River. The possibility also exists that the interval periods masked the inflow from the river or the sampling dates missed the occurrences of large inputs of river water. The interval components suggest that another source besides precipitation on the lake and the tributary inputs influences the change in lake levels. If precipitation volumes are compared to lake volume changes, there are conflicting directions of volume change. Some precipitation inputs are reflected in a loss of lake volume, not a gain in lake volume which is expected. Hence as discussed in the water level section, Spring Lake seems to be greatly influenced by Lake Michigan water levels. Even though the Grand River seems to be a lesser influence, quantification of the exchange between Spring Lake and the Grand River is recommended because direct measurements in this study were minimal.

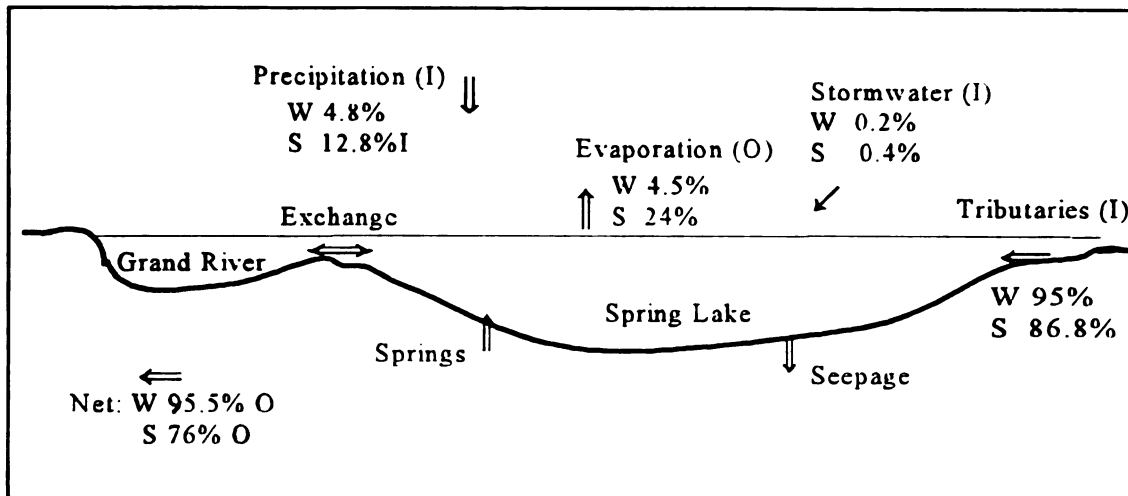


FIGURE 11: Scenario 3 Percentages of Inputs (I) and Outputs (O) for the Spring Lake Water Budget, W = Winter, S =Summer

The average input from stormwater outfalls during the winter season was 0.2% of all the inputs and during the summer season was 0.4% (Figure 11). The average residuals were 95.5% during the winter and 76% during the summer of all the outputs; the decrease in the summer percentages reflects the increase in evaporation. Of the three scenarios, this water budget scenario seems to be the most realistic.

Spring Lake's Water Year

Typically a water year in a hydrological system is considered to begin at the low water period and in Midwestern temperate areas, this period usually begins in September 30. For this study of Spring Lake, the water year begins with the interval that includes September 1997 and ends with September 1998. Cumulative volumes of the water year's inputs and outputs are represented in Figure 12.

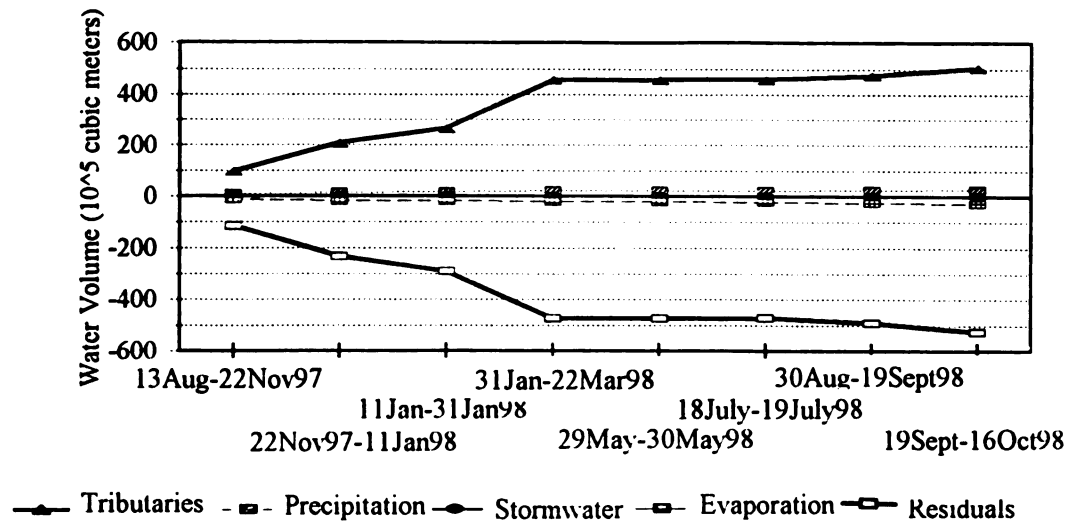


FIGURE 12: Cumulative Volumes from Water Budget Intervals ($\times 10^5 \text{ m}^3$), 13 Aug 97- Oct 98.

For the water year of 13 August 1997 to 19 September 1998, the cumulative totals for the inputs are 47,316,000 m^3 for tributaries, 2,525,000 m^3 for precipitation on the lake, and 95,000 m^3 for stormwater outfall. Cumulative totals for the same period for the outputs are 2,452,000 m^3 for evaporation from the lake and 49,121,000 m^3 for the residual. As percentages, the input volumes are 94.7% for the tributaries, 4.9% for the precipitation, and 0.2% for the stormwater and for the output volume percentages, 5% for evaporation and 95% for residuals. The cumulative change in water storage for the water year was -1,637,000 m^3 which is 3% of the residual. This small percentage suggests that the residual is real and not an artifact of the methods. This real residual of the exchange of groundwater and the water between the Grand River and Spring Lake needs to be quantified. Without these measurements, the largest input into Spring Lake is from tributaries and the largest output is the net outflow, via the Grand River or groundwater exchange or both.

Water Residence Time

Knowing the amount of time that water remains in a lake also aids in the description of its water flow and water quality. The theoretical amount of time for all of the water to be replaced in a water body is called the residence time. The maximum residence times for Spring Lake is 4.9 months for the winter season and 11.2 months for the summer season as calculated from the input sums of tributaries and precipitation. The annual residence time is 6.8 months as calculated from the cumulative water inputs. Inputs of water from groundwater or the river would reduce these residence times. During the winter season, Spring Lake is theoretically flushed completely, meaning that the water at the beginning of the season is completely replaced with incoming water by the end of the winter season. Because the summer residence time is longer than its seasonal length, the summer waters are not flushed out of the lake. The summer waters are not completely replaced in volume until the winter season. Therefore, the waters that flow into Spring Lake during the winter season are the “initiator” waters, with all their nutrients, for the following summer season. Although during the summer season there are additional inputs of nutrients into the lake, the winter waters provide the nutrient starting levels for plant and animal growth that occurs in the following summer season. The lake’s flushing rates and lower residence times may enable the lake to clean itself in time. The relationship of hydrology to water quality will be further addressed in the next chapter.

RECOMMENDATIONS

Limited in scope, this study could not fully describe the water budget because the exchange with the Grand River and groundwater could not be measured, nor daily changes in the lake water level. Although an attempt was made to measure the exchange between the Grand River and Spring Lake, this potential flow of water still remains unknown for most of the water year and needs to be quantified because management recommendations for water quality are dependent upon its potential influence. If the Grand River is a large input into Spring Lake, management recommendations for Spring Lake water quality would be extremely difficult to attain because it would involve addressing nutrient sources throughout the entire Grand River Watershed. Whereas, if the Grand River input is relatively small as I predict, management recommendations would include only recommendations for the Spring Lake Watershed.

Therefore, to more fully understand the water budget, additional research incorporating the groundwater exchange, the Grand River exchange and daily changes in the water level is warranted before any expensive in-lake management techniques are undertaken. The groundwater exchange may be estimated by conducting a groundwater flow analysis that estimates potentiometric gradients from well information (Lerman et al. 1995). These estimates may then be used to modify the water budget. Because of possible influences on the lake's water quality, the water exchange with the Grand River should be monitored throughout an annual cycle. The exchange may be measured directly with an electronic flowmeter that measures instantaneous flow reversals. This instrument would best be mounted several feet from the bottom of the channel or on one of the bridge pilings for

several periods within each season. For these data to be useful, wind direction and speed would need to be recorded at a minimum of every 15 minutes (Derecki & Quinn 1990). If local airports do not record at this interval, then an anemometer would also need to be obtained and mounted. Depending on the monitoring instruments, the data may be stored for certain periods or may be directly connected to a computer for instantaneous downloading. If one cannot be borrowed from a federal or state agency, the flowmeter would need to be purchased, ranging in price from \$3,000 to \$10,000 or even more depending on the model. For any modification of the water budget, water levels will need to be monitored. I suggest that the daily monitoring of the lake and stream levels become another activity for the LakeWatch volunteers on Spring Lake, a program coordinated by Michigan State University - Ottawa County Extension. The trained volunteers currently take lake water samples and other water quality parameters in an effort to begin long-term monitoring of Spring Lake.

RECOMMENDATION LIST

- Quantify the exchange of water with the Grand River and the groundwater exchange before expensive in-lake management techniques are undertaken.
- Expand water level monitoring of the lake through the LakeWatch program.

SUMMARY

- Spring Lake's hydrology is seasonally dynamic with a winter residence time of 4.9 months, a summer residence time of 11.2 months, and an annual residence time of 6.8 months.

- Spring Lake receives its water input from tributaries (95%), precipitation on the lake (4.8%), stormwater outfalls (0.2%) in the winter; and tributaries (86.8%), precipitation (12.8%), stormwater outfalls (0.4%) in the summer. The outputs in the winter are evaporation (4.5%), and residual (95.5%). In the summer, the outputs are evaporation (24%) and the residual (76%). The residuals are composed of the net groundwater exchange, which is predicted to be positive, the net Grand River exchange, and also reflect the cumulative error in the budget.
- Waters between the Grand River and Spring Lake do mix, but the Grand River is believed not to be a large input into Spring Lake.
- Besides precipitation on the lake and the tributary inputs, other factors, especially the backwater effect from Lake Michigan, seem to be influencing the water levels of Spring Lake.
- Because of measurement difficulty and their potential influence on management recommendations, the exchanges between the Grand River and Spring Lake and groundwater need to be studied further in order to fully understand the hydrology of Spring Lake.

CHAPTER 2

WATER QUALITY

INTRODUCTION

A lake is a reflection of its watershed. Spring Lake's reflection, its water quality, is the result of its hydrological gradient and land use within the watershed. Therefore activities happening within the watershed, from its northern reaches in Sullivan Township to its shoreline, affect the lake's water quality. Climatic events, such as precipitation, wind, and temperature, affect the water quality and trigger algal blooms (Lathrop et al. 1998). To begin to address the possible causes of algal blooms, many aspects of water quality are examined and then compared to another drowned river-mouth lake.

TROPHIC STATUS INDEX

The water quality of a lake is sometimes simplified into a trophic status index, a number that can be used to rank its water quality among other lakes. In September 1981, the Michigan Department of Natural Resources (MDNR) reported that Spring Lake's trophic status index was 59, the lake was eutrophic, and at a depth of 30 feet, very little dissolved oxygen was present (MDNR 1981).

- Eutrophic is a trophic state classification for lakes derived from water quality. There are three basic states: oligotrophic, mesotrophic, and eutrophic. As lakes age over thousands of years, the lake's trophic state may progress from oligotrophic to mesotrophic to eutrophic. Oligotrophic lakes are usually clear, free of weeds, and low in nutrients. Mesotrophic lakes range between the oligotrophic

and eutrophic characteristics. Eutrophic lakes are subject to frequent algal blooms, high in nutrients, and usually weedy (Cooke et al. 1993). These trophic states are not a good or bad classification but rather one of water quality and age.

- A lack of dissolved oxygen in lower water levels affects the deep cold-water fish and other organisms that need oxygen to breathe. Low oxygen levels are also termed as anaerobic or anoxic conditions, during which the organisms surviving in the deep must obtain their oxygen from other processes or move to another water level with more oxygen. Low oxygen levels at the bottom of the lake also cause nutrients to be released from the sediments, increasing the nutrient concentration in the overlying layer of water.
- Trophic status index numbers are calculated from equations using a variety of water quality factors. Using Carlson's equation, a range of numbers from 0 - 100 are possible with the lower numbers corresponding to oligotrophic lakes and the higher numbers to eutrophic lakes. The status index numbers are used to compare one lake to another and also used as comparisons as a lake changes through time (Carlson 1977).

Currently, Spring Lake's trophic index ranges from 70-66 depending on the season (Table 5). This trophic status measurement is based on the amount of chlorophyll *a* (a measure of algal abundance) and total phosphorus concentrations. However, based on the Secchi depths (water clarity depth), the index is 57 - 60. The 1981 index of 59 that MDNR reported was calculated solely from the Secchi depth of September 2, which was 1.06 meters. Although the trophic index calculations from single dates such as was done in

1967 and 1981 are not from the recommended summer averages, the numbers do provide an instantaneous picture of the lake. The lack of abundant earlier data makes establishing a trend difficult, but what is available suggests that in the past 30 years the lake's trophic status has changed little; therefore the water quality of the lake is also most likely to have been similar throughout those years. (See Appendix B for the methods, materials, and detailed data tables for this chapter.)

TABLE 5: Water Quality Averages and Trophic Status Indices of Spring Lake

	Average Total Phosphorus, Epilimnion (mg/l)	Average Chlorophyll a, Epilimnion (μg/l)	Average Secchi Depth (m)
November 4, 1967 * TROPHIC STATUS	.08 *67	not measured	1.73 *52
September 2, 1981 * TROPHIC STATUS	.056 *62	not measured	1.06 *59
June - Aug 1997 * TROPHIC STATUS	.07 *66	41.8 *67	1.00 *60
June - Aug. 1998 * TROPHIC STATUS	.10 *70	36.2 *66	1.15 *58
(Sept. 97- Sept. 98) * TROPHIC STATUS	.08 *67	41.0 *67	1.26 *57

(1967 and 1981 data are from MDNR STORET records)

SECCHI DEPTH AND CHLOROPHYLL *a*

Secchi depth was one of the variables used to calculate the trophic status index for Spring Lake. Secchi depth (water clarity) is the depth that one can see through the water. This depth is approximately half the depth of the photic zone, the region where plants and algae can utilize the sunlight that is penetrating the water (Wetzel and Likens 1991). If the

Secchi depth is large, the photic zone is deep, and the water is clear. High levels of suspended sediments, algae, and dissolved organic compounds such as tannins will decrease Secchi depths. Decreasing Secchi depths are also caused by human activities on the lake and water, including activities that disturb the bottom sediments, increase sediment inputs, and increase nutrient inputs. In time, reductions in these activities may lead to larger Secchi depths for the lake, although only to a certain degree. Each lake is unique in its own “natural” aspect and will improve only within its “natural” boundaries or limitations. For instance the deep water clarity depth of Higgins Lake in central Michigan is not a realistic goal for Spring Lake because the lakes are very different in composition and in hydrological characteristics.

Since 1986, Grand Valley State University has operated an educational program for students and the general public aboard the D. J. Angus. The participants commonly measured Secchi depth, temperature, and dissolved oxygen in Spring Lake. The range of Secchi depths during May through September are 0.6m (Sept. 1988, July 1992, July 1995) to 3m (May 1991) and during October are 0.8 (1991, 1992, 1995) to 1.25m (1994, 1995) (R. B. Annis WRI/GVSU 1986-1995). In comparison, Secchi depth means for all lake sites during 1997 and 1998 for this study ranged from 0.61-1.69m in the summer (May-September) and 1.56-1.58m in October (Figure 13 & Table B13).

In Spring Lake as in all lakes, Secchi depths, algae concentrations, and nutrient concentrationss are all correlated to some degree with each other and each parameter may be used in trophic status index calculations (Carlson 1977, Stauffer 1991). Usually if

more nutrients are available, the algae concentrations are higher and the Secchi depths are smaller. Algae concentrations are easily observed by testing the water for chlorophyll *a*, as was done for this study (see Appendix B for methods and raw data). Chlorophyll *a* is a dominant light-absorbing pigment in plants and algae and it is commonly used to represent algae concentrations.

Summer and annual chlorophyll *a* concentrations in Spring Lake's epilimnion range from 36.2 - 41.8 $\mu\text{g/l}$ (Table 5). Chlorophyll *a* concentration means and standard errors for the entire sampling period (May 1997 - October 1998) were $35.9\mu\text{g/l} \pm 1.72$ for the epilimnion, $22.4\mu\text{g/l} \pm 3.51$ for the metalimnion, and $22.4\mu\text{g/l} \pm 1.48$ for the hypolimnion. Chlorophyll *a* concentrations varied seasonally (Figure 14) with the highest concentrations in the summer because warmer temperatures in the summer increase growth in algae populations. Higher chlorophyll *a* concentrations correspond to lower Secchi depth readings during the summer (Figure 13). The different water layers of the lake also vary in chlorophyll *a* concentration between seasons (Figure 15). Marshall and Peters (1989) showed that in eutrophic lakes, chlorophyll *a* concentrations will rise in early spring, then decline, then rise again in late summer and early fall. Spring Lake fits this seasonal description of two distinct blooms in the spring and fall (Figure 14).

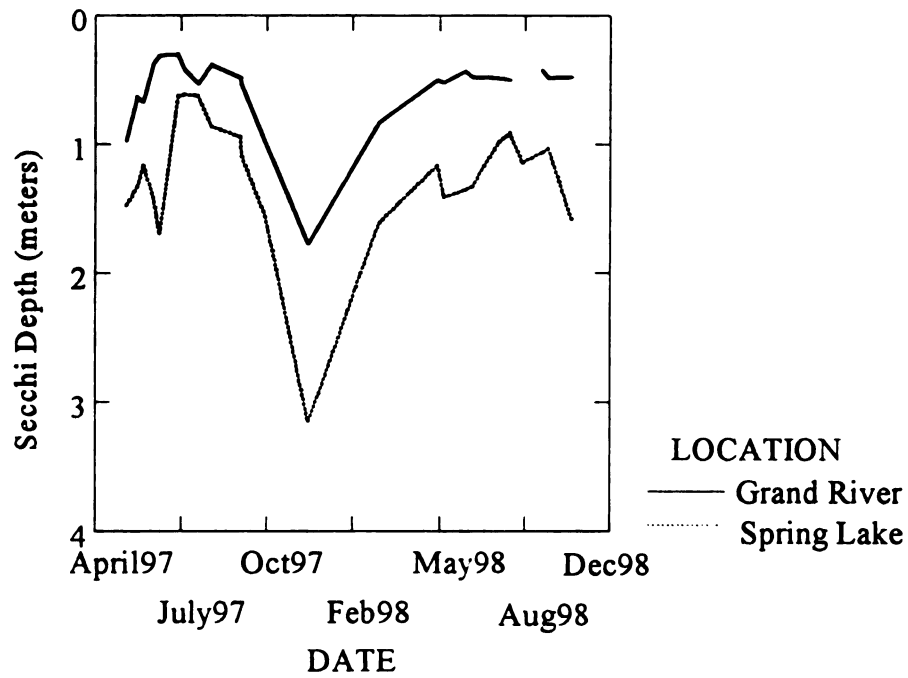


FIGURE 13: Secchi Depths in Spring Lake and the Grand River (meters)

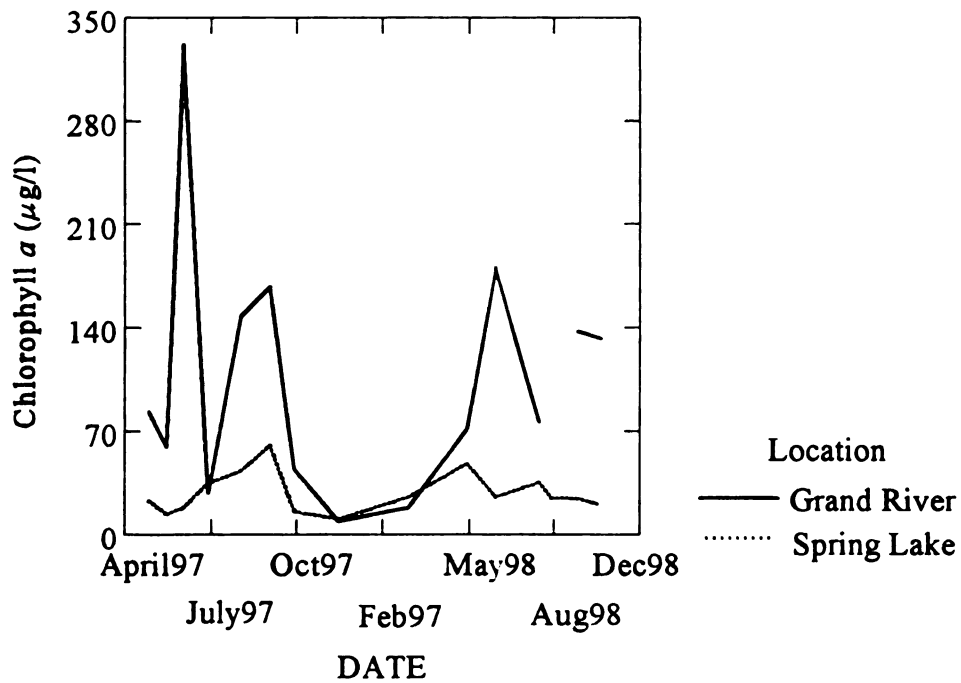


FIGURE 14: Chlorophyll *a* Concentrations in Spring Lake and the Grand River ($\mu\text{g/l}$)

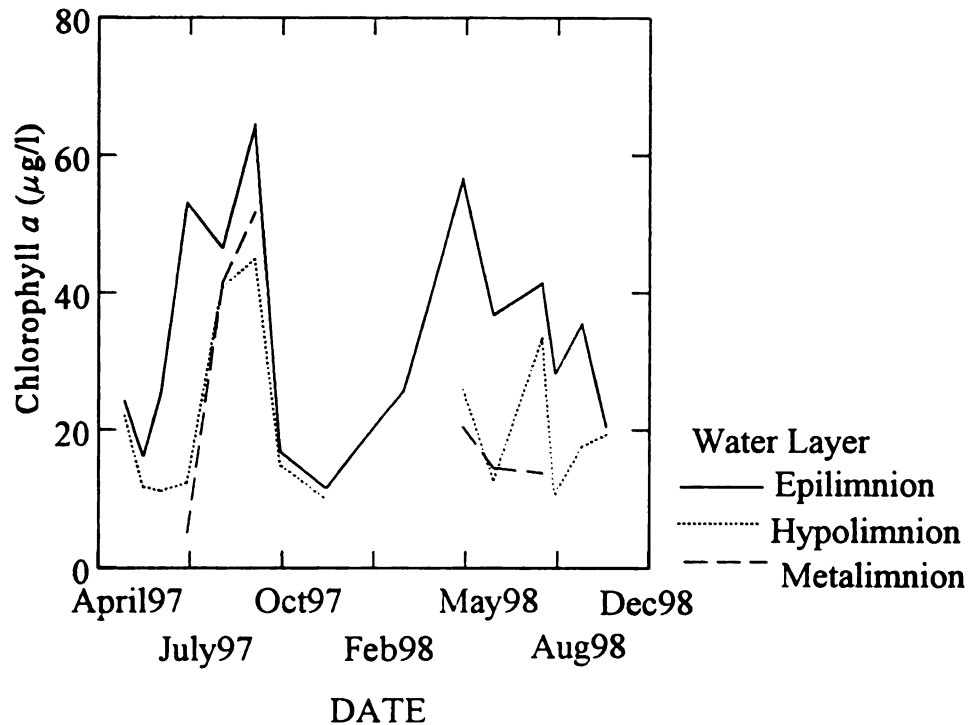


FIGURE 15: Chlorophyll *a* Concentrations of Water Layers in Spring Lake (µg/l)

When Spring Lake's total phosphorus and chlorophyll *a* concentrations are log-transformed and graphed (a simple model), the variance is large and the correlation is low (Figure 16). Increasing chlorophyll *a* concentrations in Spring Lake does not correlate well with increasing phosphorus concentrations as seen by the wide spread of Spring Lake data points. This tendency illustrates Marshall and Peters' warning that variances from chlorophyll *a* may be large due to large episodic algal blooms which tend to make model use difficult. A lack of linearity in Spring Lake may also be due to the small range of total phosphorus and chlorophyll *a* concentrations. In the lake, total phosphorus concentrations may be high enough to support larger populations of algae but other environmental factors, such as light limitation by shading, nitrogen limitation, and

predation from zebra mussels, zooplankton and other organisms (Stauffer 1991) may be limiting algae growth. A more linear relationship is seen in the Grand River data; whereas the total phosphorus concentrations increased, chlorophyll *a* concentrations increased. Since the correlation between the logarithms of total phosphorus and chlorophyll *a* concentrations in Spring Lake is low, this simple relationship (model) cannot be used to predict chlorophyll *a* concentrations from total phosphorus concentrations or vice versa.

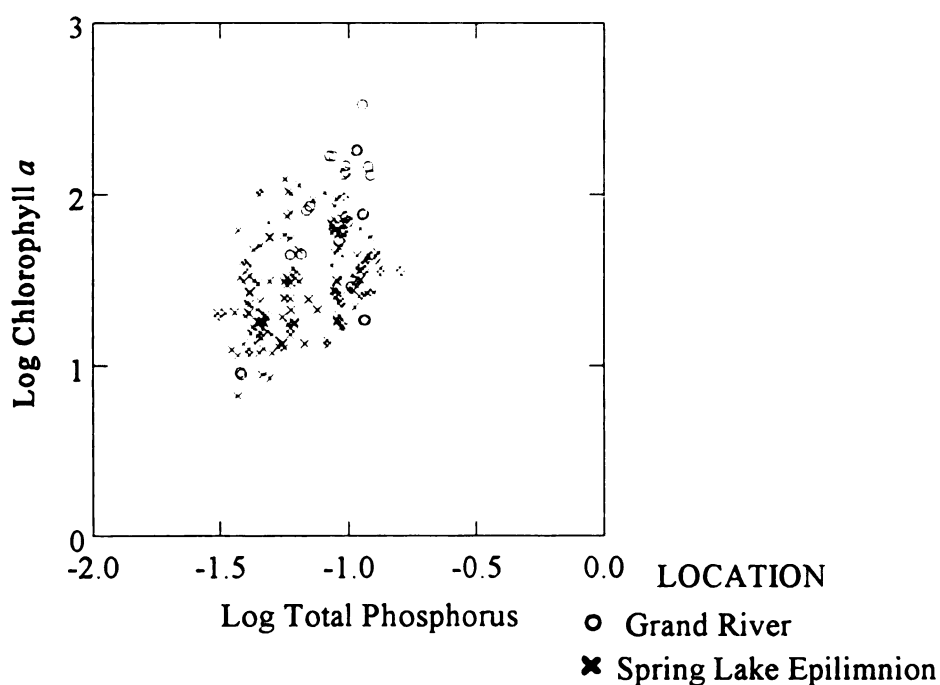


FIGURE 16: Relationship of Logarithms of Chlorophyll *a* ($\mu\text{g/l}$) to Total Phosphorus (mg/l) Concentrations in Spring Lake and the Grand River.

TEMPERATURE, OXYGEN, AND OTHER CHARACTERISTICS OF THE LAKE

Temperature, dissolved oxygen, alkalinity, specific conductivity and pH are all important water quality characteristics for plant and animal growth that were measured and analyzed (Table B14 - B22). The pH of the surface water ranged from 7.9 to 9.3, which is toward the basic end of the pH scale and is common in many Michigan lakes with high alkalinity.

Alkalinity of the epilimnion for all the sites ranged from 114 to 183 mg CaCO₃/l.

Temperatures in the epilimnion ranged from 3 to 15°C during the winter and 11 to 26 °C during the summer season; as an example see the time-depth diagrams for Fruitport and Jerusalem Bayou (Figure 17 & 21). At the deepest sampling site, Prospect Point, the hypolimnion ranged from 2.8 to 20.6 °C during the entire sampling period (Figure 19). In eutrophic lakes, dissolved oxygen concentrations tend to decrease as depth increases while total phosphorus concentrations tend to increase from the surface to the bottom of the lake. Dissolved oxygen in the epilimnion ranged from 6 to 15 mg/l throughout the year, while during the summer the hypolimnion concentrations decreased to detection limits (Figures 18, 20, 22). Because low dissolved oxygen levels began at about 7 to 8 meters deep, approximately 9% of the entire lake volume and virtually the entire hypolimnion became uninhabitable for cold-water fish during these periods. When the water layers of a lake diverge in dissolved oxygen concentration, temperature, and other dissolved compounds, the lake is stratified. During the 1997 and 1998 summers, stratification in Spring Lake occurred during the summer, usually beginning in late June and ending during the fall turnover in late September or October. It is during this period of stratification that cold-water fish may become stressed.

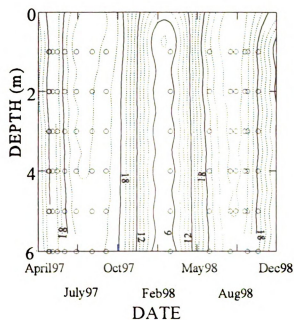


FIGURE 17: Time-Depth Diagram of Temperature for the Fruitport Sampling Site (Celsius).

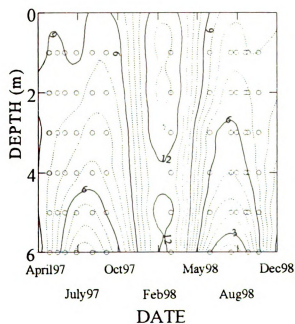


FIGURE 18: Time-Depth Diagram of Dissolved Oxygen for the Fruitport Sampling Site (mg/l).

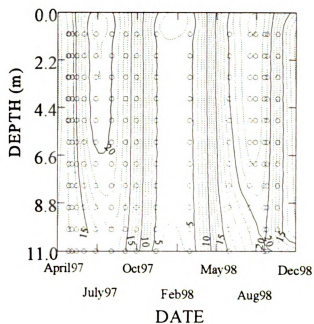


FIGURE 19: Time-Depth Diagram of Temperature for Prospect Point site (Celsius)

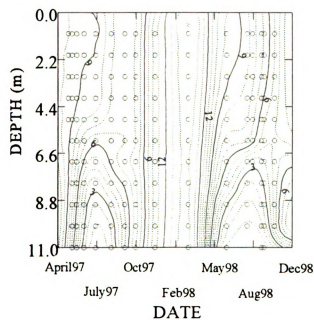


FIGURE 20: Time-Depth Diagram of Dissolved Oxygen for Prospect Point site (mg/l)

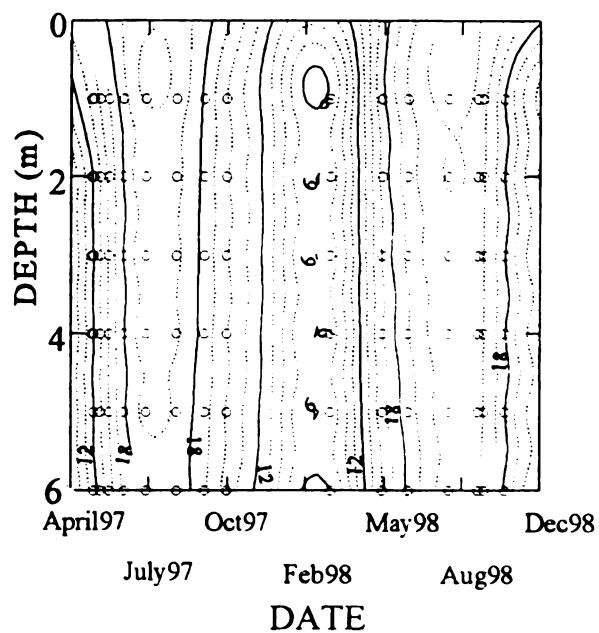


FIGURE 21: Time-Depth Diagram of Temperature for Jerusalem Bayou (Celsius)

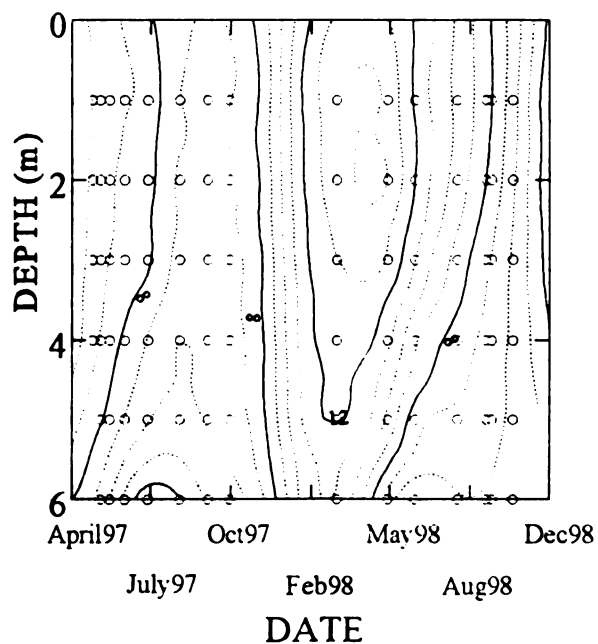


FIGURE 22: Time-Depth Diagram of Dissolved Oxygen for Jerusalem Bayou (mg/l)

NUTRIENTS

Nutrients are food sources that plants, including algae, must have to live. The most commonly discussed nutrients in aquatic ecosystems are phosphorus and nitrogen, both of which are available in some form and quantity. If the supply of one of these nutrients is less than demand (i.e., it is limiting), then algae that are tolerant to minimal levels of the limiting nutrient will usually begin to dominate (Wetzel 1983). For example, if nitrogen was not available in the water in its soluble form and phosphorus was plentiful, the common algae will usually be types that can obtain nitrogen directly from the air. The relationship between algae types and nutrients will be discussed further in Chapter 3.

NITROGEN

Nitrogen is abundant in the air, precipitation, groundwater, and runoff. More specifically, air pollution, fertilizers, and combustion are the predominant human-caused sources that increase local and global pools of nitrogen (Berner and Berner 1996). Loss of nitrogen from a lake is through its outflow, to the atmosphere by denitrification, and to the sediments by sedimentation (Wetzel 1983). The forms of nitrogen measured for this study were ammonium and nitrate. Ammonium is the form of nitrogen preferred by most plants, algae, and bacteria; and, measured concentrations are usually low (Wetzel 1983). In Spring Lake, the ammonium concentrations in the epilimnion ranged from <0.05 to 0.14 mg/l, and in the hypolimnion they ranged from <0.05 to 1.77 mg/l (Table B10). The upper end of these ammonium ranges is quite high for Michigan lakes. In Spring Lake, nitrate concentrations ranged from <0.01 to 1.1 mg/l in the epilimnion and from <0.05 to 0.70 mg/l in the hypolimnion (Table B11). Average nitrate concentrations in the

epilimnion were 0.14 mg/l for the 1997 summer, 0.16mg/l for the 1998 summer and 0.25 mg/l for September 1997 through September 1998.

Ratios of nitrogen to phosphorus concentrations are useful to predict which nutrient is limiting algae growth, and therefore which nutrient requires loading reductions for algae management. Redfield's ratio, 16:1 (nitrogen to phosphorus), is the ratio of nutrients that algae need for normal growth (Wetzel 1983). The average nitrate concentration in the epilimnion for the entire sampling period was 0.28mg/l or 0.02mM, and ammonium concentrations averaged 0.083mg/l or 0.0059mM. The sum of nitrate and ammonium molarities give the dissolved inorganic nitrogen level of 0.0259mM. In the epilimnion for the same period, the mean total phosphorus concentration was 0.07mg/l or 0.0023mM. Spring Lake's ratio of N:P is 11.3 : 1 (0.0259mM : 0.0023mM); nitrogen is eleven times more abundant than phosphorus. Since the ratio is less than Redfield's ratio, nitrogen and phosphorus may be co-limiting.

Co-limiting nutrients suggest that throughout a growing season, nitrogen and phosphorus could be alternating as limiting factors for algal growth. Hence, in order to reduce algal growth, loadings into the lake for both nutrients need to be reduced. Although only a phosphorus budget was constructed for this study (see the rest of this chapter), additional research including a nitrogen budget and a nutrient limitation/dilution experiment is suggested before expensive in-lake management techniques are initiated for phosphorus reductions in Spring Lake.

Another critical limit for algal blooms has been suggested as 0.3 mg/l dissolved inorganic nitrogen and 0.01 mg/l of phosphorus during spring and fall overturn (Wetzel 1983).

Spring Lake exceeded those critical limits; the average overturn concentrations for 1997 and 1998 were 0.71 mg/l for nitrate and 0.04 mg/l for total phosphorus. Needless to say, algal blooms did occur during both summers, and nutrients drive the dynamics and composition of the algae.

PHOSPHORUS

From May 1997 to October 1998, water samples from Spring Lake, its tributaries, and the Grand River were analyzed for total phosphorus, soluble reactive phosphorus, and total dissolved phosphorus (methods and materials are in Appendix B). Total phosphorus is just as its name implies; the sum of all types of phosphorus compounds in the water sample, including phosphorus within living and dead cells and other suspended solids. Soluble reactive phosphorus is the measurement of the most readily available form of phosphorus. Concentrations of soluble reactive phosphorus are usually very low in well-lit surface waters of lakes because when available, this form of phosphorus is immediately absorbed by algae and other plants (Wetzel 1983). In the winter season, the soluble reactive phosphorus concentrations in the epilimnion of Spring Lake (surface water layer) ranged from <0.01 to 0.08 mg/l and in the hypolimnion (lower water layer) ranged from 0.01 to 0.07 mg/l. During the summer season, the soluble reactive phosphorus concentrations in the epilimnion ranged from <0.01 to 0.1 mg/l and in the hypolimnion ranged from <0.01 to 0.78 mg/l (Table B2). Total dissolved phosphorus is another partitioning of total phosphorus and is the phosphorus remaining in the water after

particles and algae have been filtered from the water sample. During the winter, concentrations of total dissolved phosphorus in Spring Lake were 0.01 to 0.12 mg/l in the epilimnion and 0.03 to 0.04 mg/l in the hypolimnion. During the summer, the total dissolved phosphorus in the epilimnion ranged from <0.01 to 0.13 and in the hypolimnion ranged from <0.01 to 0.58 mg/l (Table B3).

Primary sources of phosphorus into lakes often include precipitation, stormwater runoff, agricultural runoff, and streambank erosion (Berner and Berner 1996). Many times phosphorus sources also include leaching from septic systems, discharge from sewage treatment facilities, and point-source discharges from industries. Fortunately, no discharge from sewage treatment facilities is known to flow directly into Spring Lake and only one permitted point-source discharge exists, but it is not a source of phosphorus. Johnston Boiler Company is permitted by the government to discharge a maximum of 25,000 gallon/day of boiler test water into the channel between Spring Lake and the Grand River. The discharge is regularly measured for flow and temperature (MDEQ 1996).

Total Phosphorus Concentrations in Spring Lake

Most of the sampling sites on the lake were similar to each other in total phosphorus concentrations except for the hypolimnion and metalimnion of the deepest sites, Prospect Point and Spring Lake (Figure 23), indicating that internal loading from sediments or from new sedimenting debris may be occurring at the deepest layers. Because the epilimnion and hypolimnion concentrations of the other sites are similar, the bayous do not seem to differ in total phosphorus concentrations and thus probably respond similarly to lake

mixing and stratification. These other sites include Fruitport, Jerusalem Bayou, Petty Bayou, Smith Bayou, and Stahl Bayou (for locations see Figure 8).

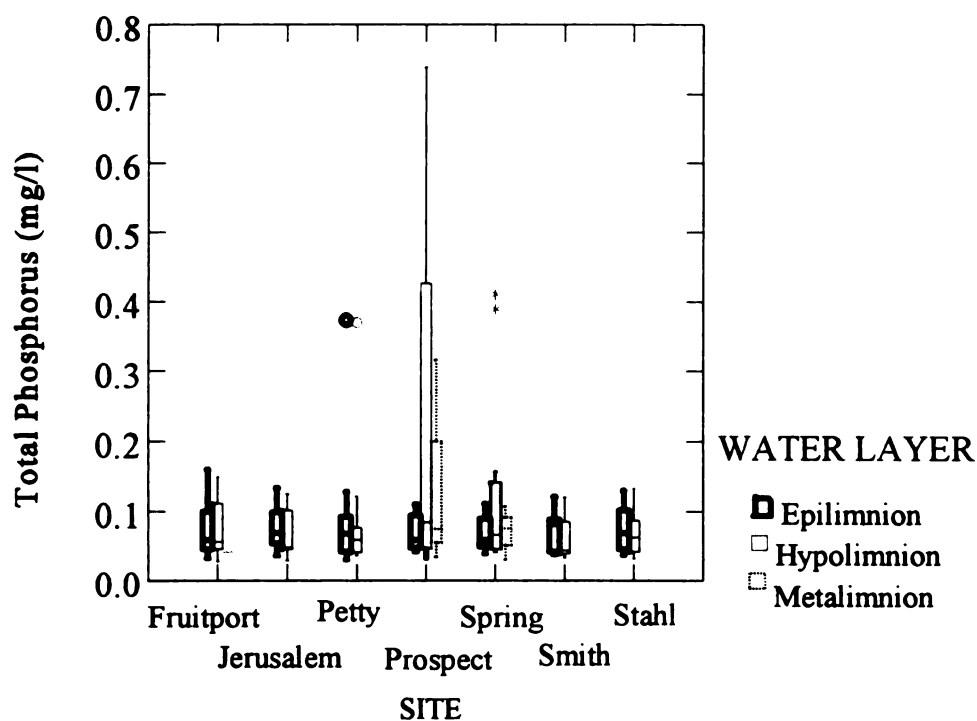


FIGURE 23: Box Plots of Total Phosphorus Concentrations at the Spring Lake Sampling Sites, May 1997-October 1998 (mg/l). Box plots provide much detail about the raw data. The line or notch in the box is the median which is the middle of data. The length of the box illustrates the central spread of data. The lines outside the boxes show the spread of the data and the asterisks and circles beyond the lines are extreme data outside the spread.

Spring Lake's total phosphorus concentrations in the surface water layer, the epilimnion, varied less than in the lower water layer, the hypolimnion (Figure 24 & 25). The unweighted total phosphorus means of the water layers were $0.07 \text{ mg/l} \pm 0.003$ (standard error) for the epilimnion, $0.09 \text{ mg/l} \pm 0.015$ for the metalimnion, and $0.10 \text{ mg/l} \pm 0.011$ for the hypolimnion. These water layer statistics include all dates and sampling sites,

therefore the means are generally robust and the hypolimnion in this case is the lower water layer, whether stratified or unstratified. During the summer stratification, the greater range of total phosphorus concentrations in the hypolimnion (Figure 25) is most likely due to the episodic inputs of algal blooms, sedimentation of the dead algae, and loading from the sediments (Stauffer 1991).

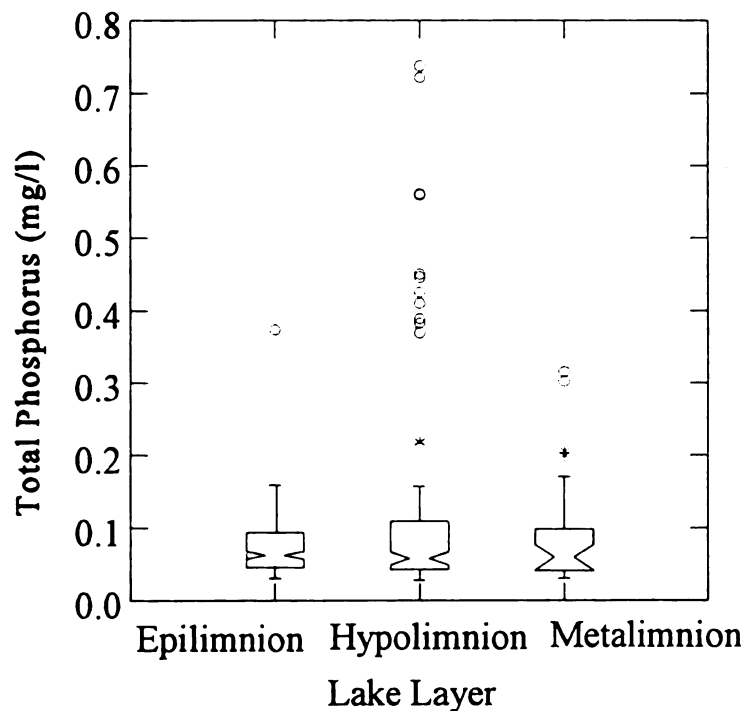


FIGURE 24: Box Plots of Total Phosphorus Concentrations in the Water Layers of Spring Lake, May 1997 - October 1998.

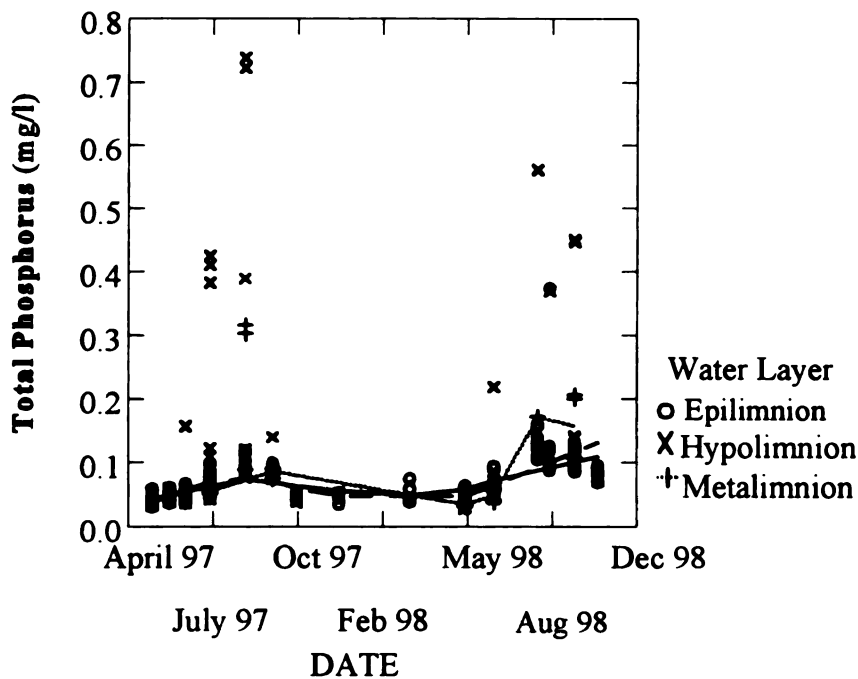


FIGURE 25: Time Series of Total Phosphorus Concentrations in the Water Layers of Spring Lake (mg/l)

Total Phosphorus Concentrations in Spring Lake's Tributaries and the Grand River

During the sampling period, total phosphorus concentrations in the Grand River, Spring Lake, and its tributaries fluctuated seasonally. The Grand River had the highest concentrations and the tributaries had the lowest concentrations (Figure 26). In the spring, Spring Lake's concentrations were more similar to the tributaries' concentrations. Then as the summer progressed, the total phosphorus concentrations in Spring Lake increased until the following winter and spring and became more like the concentrations found in the Grand River. These concentration differences begin to show the hydrological characteristics which exist in this water system. Usually water bodies lower in the

landscape are higher in nutrient concentrations and other suspended solids due to point and non-point sources. Therefore since the Grand River is the lowest in landscape, nutrient concentrations in the Grand River will usually be higher than those found in the tributaries that flow into Spring Lake. However, high nutrient loads in the tributaries may occur with large precipitation events, especially after long dry periods because pollen, dust and other things that settle on structures are picked up with the stormwater runoff. These types of events usually happen during the summer. Seasonally, total phosphorus concentrations from the Grand River, Spring Lake, and its tributaries were the highest in the summer and the lowest in the winter (Figure 26 & 27).

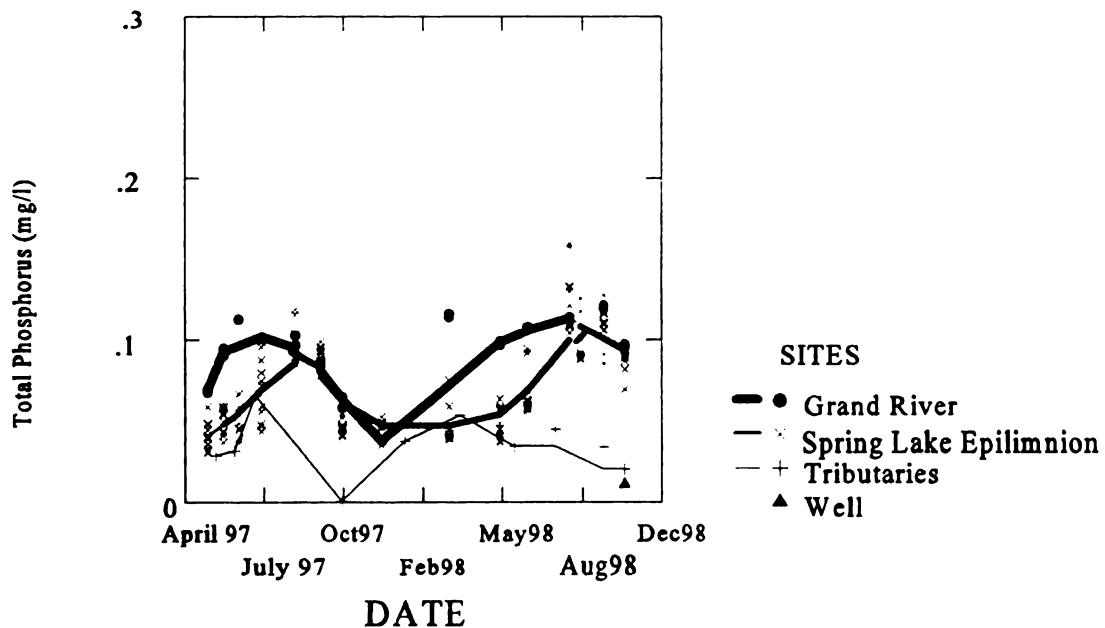


FIGURE 26: Total Phosphorus Concentrations in the Grand River, Spring Lake, and its Tributaries

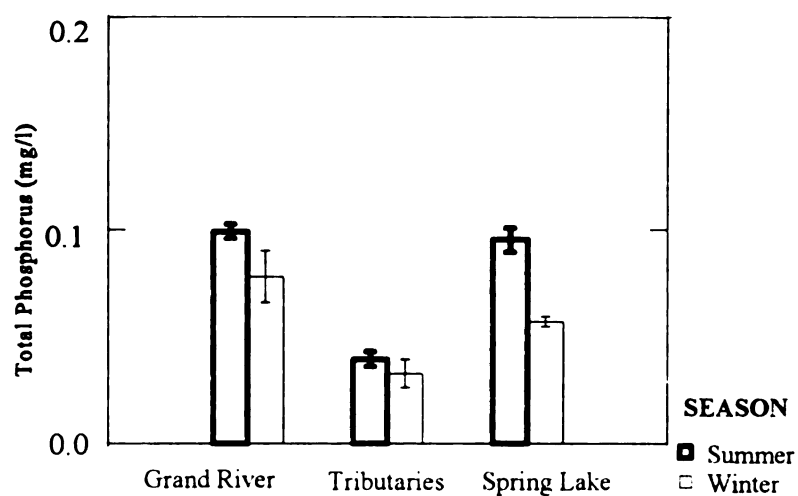


FIGURE 27: Seasonal Means of Total Phosphorus Concentrations with one Standard Error for the Grand River, Spring Lake and its Tributaries (mg/l)

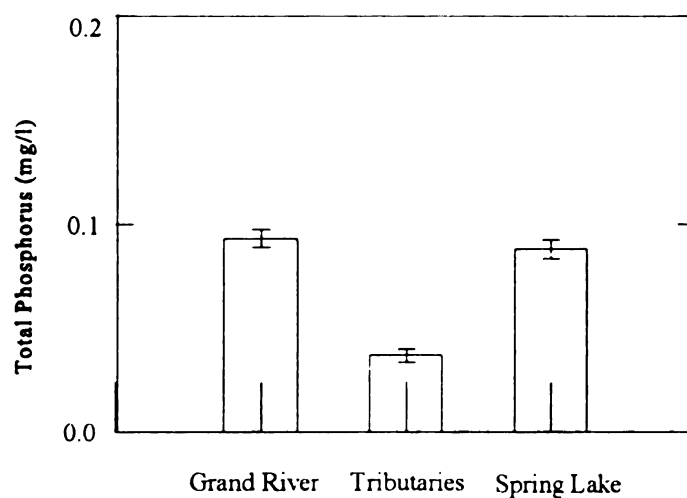


FIGURE 28: Means of Total Phosphorus Concentration with one Standard Error of Mean for May 1997-October 1998 for the Grand River, Spring Lake and its Tributaries (mg/l)

All of the following are the means with one standard error of the mean that are illustrated in Figure 27 & 28. Overall total phosphorus means were $0.09 \text{ mg/l} \pm 0.0047$ for Spring Lake, $0.04 \text{ mg/l} \pm 0.0033$ for its tributaries, and $0.09 \text{ mg/l} \pm 0.0043$ for the Grand River. During the summer, total phosphorus means (not volumetrically-weighted) were $0.1 \text{ mg/l} \pm 0.0057$ for Spring Lake (volumetrically-weighted mean for Spring Lake was also 0.10 mg/l), $0.04 \text{ mg/l} \pm 0.0034$ for its tributaries, and $0.1 \text{ mg/l} \pm 0.0034$ for the Grand River. During the winter, Spring Lake's total phosphorus averaged $0.06 \text{ mg/l} \pm 0.0024$, its tributaries averaged $0.03 \text{ mg/l} \pm 0.0064$, and the Grand River averaged $0.08 \text{ mg/l} \pm 0.011$.

So, during the summer, why is the total phosphorus concentration in the lake higher than its tributaries and more closely aligned to the Grand River? Several phosphorus sources are possible: internal loading from the sediments, exchange with the Grand River, fertilizer runoff, precipitation directly on the lake and stormwater runoff. One way to differentiate between these phosphorus inputs is to develop seasonal mass budgets.

PHOSPHORUS BUDGET

Construction of an annual and seasonal phosphorus mass budgets provides estimates of the phosphorus inputs into Spring Lake, and then questions pertaining to these loadings may be addressed. The phosphorus budget equation is similar to the water budget equation. Appendix B contains information on how the individual components were calculated. Phosphorus loadings with low and high estimates are summarized in Table 6.

$$\Delta[TP_{lake}] = [TP_{trib}] + [TP_{precip}] + [TP_{duck}] + [TP_{septic}] + [TP_{run}] \\ + [TP_{fert}] \pm [TP_{residual}]$$

$\Delta[TP_{lake}]$ = Change in lake mass of total phosphorus

$[TP_{trib}]$ = Tributary mass loading

$[TP_{precip}]$ = Atmospheric loading on lake surface

$[TP_{duck}]$ = Waterfowl loading

$[TP_{septic}]$ = Septic system loading

$[TP_{run}]$ = Stormwater runoff loading

$[TP_{fert}]$ = Lawn fertilizer loading

$[TP_{residual}]$ = Residuals

TABLE 6 : Summary of Total Phosphorus Budget for Spring Lake (a positive number indicates a gain of phosphorus to the lake, whereas a negative number indicates a loss of phosphorus from the lake)

Source	Winter			Summer			Annual		
	Low Estimate (kg, %)	Average (kg, %)	High Estimate (kg, %)	Low Estimate (kg, %)	Average (kg, %)	High Estimate (kg, %)	Low Estimate (kg, %)	Total (kg, %)	High Estimate (kg, %)
Lake	-25.7	-22.9	-16.1	5.2	6.3	8.2	-146.6	-131	-91.7
SUPPLY									
Tributaries	238 61%	293 44%	485 44%	19 15%	24 10%	32 6%	1533 78%	1893 67%	2555 59%
Atmospheric	18 5%	19 3%	21 2%	3 3%	3 1%	4 1%	90 5%	95 3%	109 3%
Stormwater	5 1%	9 1%	19 2%	1 0.6%	2 0.7%	3 0.6%	24 1%	48 2%	95 2%
Septic systems	94 24%	188 28%	376 34%	102 80%	204 86%	408 78%	246 12%	491 17%	982 23%
Waterfowl	1 0.3%	3 0.4%	5 0.4%	2 2%	5 2%	10 2%	8 0.4%	16 0.6%	32 0.7%
Lawn fertilizer	34 9%	155 23%	206 18%	0	0	70 13%	59 3%	267 10%	521 12%
LOSS									
Residuals	-415	-689	-1128	-122	-231	-518	-2106	-2941	-4386

Lake Storage Mass

Seasonally, the phosphorus mass in the lake seems to vary mostly due to flushing rates as in other lakes (Dillon 1975). The net loss of phosphorus from Spring Lake during the winter occurs during the lake's period of lower residence time and higher flushing rates (Table 6). During the summer, the lake gained a net average of 6.3 kg of phosphorus during its lower flushing rates and higher residence time; yet, on an annual water year basis, the lake had a net loss of 131 kg of phosphorus. During the summer periods, Spring Lake began to take on the appearance of a lake with a longer retention time and more eutrophic conditions. High flushing rates decrease the likelihood of sediments and phosphorus settling to the bottom of the lake (Dillon 1975, Galicka 1992). In fact during high flushing rates, lake total phosphorus concentrations should be similar to the concentrations found in the major inflows of water to the lake (Cooke et al. 1993). Although the mean total phosphorus concentration in the lake during the winter was 0.06 mg/l and the tributary mean concentration was 0.03 mg/l, the mean concentration of the spring overturn of the lake was 0.045 mg/l which is similar to the summer and winter tributary means. The difference between the winter lake and tributary concentrations may be caused by loadings from septic systems and other external and internal phosphorus sources.

Tributary Loading

The tributaries contributed an average of 293 kg (44%) of phosphorus to the lake during the winter season and 23.5 kg (10%) during the summer season, and for a cumulative total of 1893kg (67%) (Table 6). The phosphorus contribution was higher during the winter

because the larger flows, including snow melts and spring rains flush the soils of the watersheds. Some common agricultural and residential practices in the fall and the spring, such as manure and fertilizer applications, may contribute to the higher concentrations in winter season. During the summer, except during storm events, the tributaries are usually at baseflow levels, consisting primarily of water originating from groundwater instead of overland runoff. Because groundwater is usually low in phosphorus concentration and summer stream discharge is low, the summer phosphorus loading from tributaries is low. Phosphorus loading in tributaries is directly related to volume of input (Lathrop et al. 1998, Gordon et al. 1992). When summer storms do occur, higher loads flow into Spring Lake. Norris Creek at Pontaluna Road and Steven's Creek at Pontaluna contributed higher loadings than the other tributaries during one storm event (Figure 29). High phosphorus loadings can also be the result of soil erosion. During storm events and the spring flush, soil erosion was observed at road crossings, especially at Vincent Creek at Bridge Street, Norris Creek at Third Street Bridge and Rhymer Creek at Mt. Garfield Road. Tributary loading can be reduced through best management practices (BMPs) for agricultural and residential land uses and also by stabilizing eroding banks at road crossings.

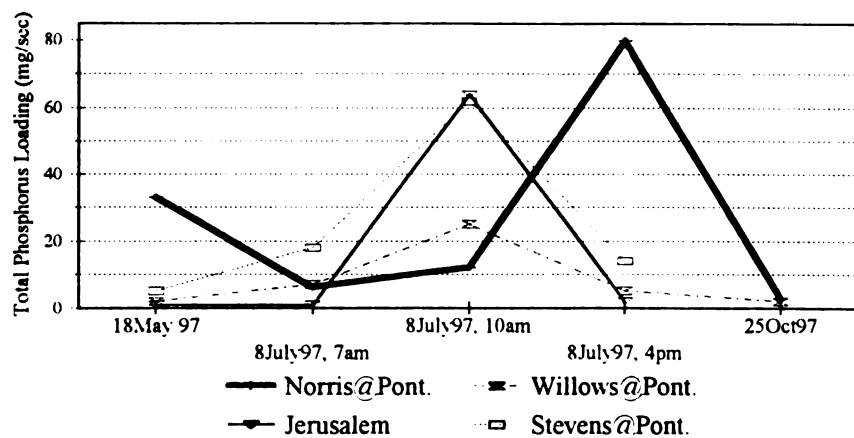


FIGURE 29: Total Phosphorus Loadings of Tributaries from Storm Event of July 8, 1997.

Atmospheric Loading

Atmospheric loading includes wet and dry deposition directly on the lake's surface.

Atmospheric loading for Spring Lake was calculated by using the average of Gull Lake's combined wet and dry phosphorus measurements (Tague 1977). In Spring Lake's budget, precipitation directly onto the lake contributed an average of 3% (18.5 kg) of all the phosphorus inputs during the winter, 1% (3.3 kg) for the summer, and 3% (95kg) for an annual total (Table 6). Because Spring Lake's watershed area to lake area ratio is not extremely large (26:1), the relative importance of loading from precipitation is higher than some other types of lakes (Cooke et al. 1993). Reigler found that for Ontario lakes with a 30:1 ratio, precipitation contributed 9% of the phosphorus loading; whereas, for lakes with a 10:1 ratio, precipitation contributed 23% of the loading (Cooke et al. 1993). Spring Lake's precipitation loading percentage was slightly lower than the Ontario lakes, which may be due to climatic variability, error in the phosphorus measurements in precipitation, and greater importance of other external or internal phosphorus sources.

Fortunately, atmospheric loading was small into Spring Lake, because this source cannot be easily altered by the residents in the watershed — atmospheric loading is a regional source of phosphorus.

Stormwater Loading

During the winter, stormwater loaded 1% of the phosphorus inputs and during the summer, the loading was 0.7% of inputs; both of which are very small when compared to the other inputs. Since no combined stormsewer and sanitary systems are known to exist around Spring Lake, the stormwater phosphorus loading is caused from overland runoff from commercial and residential areas (urban land use). When compared to agricultural lands, urban areas, such as portions of Spring Lake's shoreline, export higher concentrations of dissolved phosphorus, which can be easily absorbed by algae and aquatic plants (Soranno et al. 1996). The area used to calculate these figures was a conservative estimate that did not include the impervious areas of roofs, driveways, and parking lots. Although stormwater loading is small at this time, high loadings can occur with large rain events and efforts should begin to reduce this loading source. Reductions of phosphorus in stormwater can easily be achieved through various practices such as more frequent street cleanings and cleaning of stormsewer sediment traps (USEPA 1996). Runoff can be reduced by constructing driveways, parking lots, and sidewalks with materials that allow some penetration of water. Construction of stormwater retention ponds or grassy areas can also be used to reduce the amount of nutrients in runoff by allowing time for infiltration into the groundwater.

Septic System Loading

Within the watershed, 91% of the watershed area is serviced by mostly septic systems and 7% is serviced by mostly municipal sanitary sewer (Figure 30). Approximately 895 lakeshore residential homes surround Spring Lake (Przybytek 1999) and about 27% or 242 of the 895 lakeshore residents continue to be serviced by septic systems. It was estimated that the lakeside residences with septic systems contributed a total of 1.34 kg of phosphorus per day for a winter average of 188 kg, summer average of 204 kg, and an annual total of 491 kg (17%). These sources are 28% and 86%, winter and summer respectively, of all the total phosphorus inputs. The septic system loading is greater than stormwater and waterfowl loadings. This phosphorus source should be eliminated to reduce the nutrient input into the lake. Recommendations to reduce this source are suggested later in the chapter.

Waterfowl Loading

If waterfowl populations per lake surface are high, their excretion can be a large source of phosphorus into the lake (Portnoy 1990, Manny et al. 1975). Average daily waterfowl numbers on Spring Lake were approximately 118 during the winter season and 110 during the summer. Gulls, mallards, domestic ducks, Canada geese, swans, coots, loons, wood ducks, and mergansers were observed and counted (Appendix B). Their phosphorus contribution to Spring Lake is very low compared to the other sources: 0.4% (winter), 2% (summer), and 0.6% (annual). Their minimal loading does not diminish the importance of the current endeavor of educational signs to stop waterfowl feeding. Waterfowl excretion boost nutrients in localized areas as observed at a common waterfowl feeding site,

Fruitport Boat Landing. The droppings along the shoreline increase the nutrients in the runoff and thus probably increase algal growth in that immediate area. Waterfowl have a tendency to congregate along the shoreline areas which many lake residents seem to enjoy: lawns sloping directly to the lake's edge. Not only do these areas attract waterfowl but the lawn does not slow runoff as quickly as other types of plantings. Planting flowers, shrubs, and taller grasses along the shoreline border will establish a buffer strip that will discourage waterfowl and aid in runoff retention.

FIGURE 30: Areas Serviced by Municipal Sanitary Sewers and Septic Systems in the Spring Lake Watershed

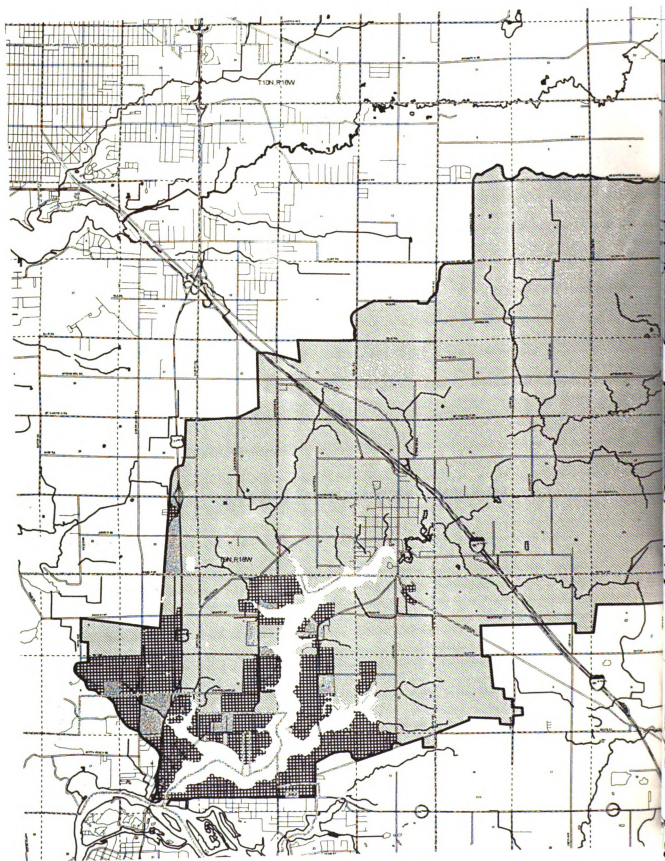
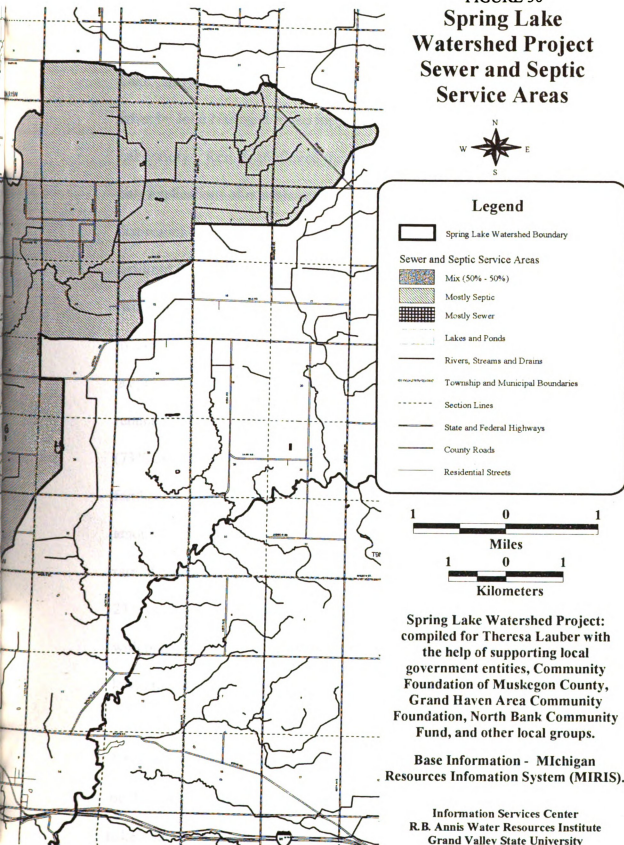


FIGURE 30
Spring Lake
Watershed Project
Sewer and Septic
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Lawn Fertilizer Loading

Fertilizing with phosphorus fertilizer is another source of phosphorus loading into Spring Lake. In 1997, soils from seven different lawns scattered around the lake's shoreline were taken by John Nash and tested for phosphorus at the MSU Soil and Plant Nutrient Laboratory. Results confirmed that all soil samples were saturated with phosphorus and only applications of non-phosphorus fertilizer were recommended. Of the lake residents that responded to the watershed resident survey (see chapter 4), 73% of the lake owners fertilized their lawn or garden at least once a year (16% about once a year + 24% about twice a year + 33% fertilized more than twice a year). This is a high percentage compared to 24% around Gull Lake in the 1970s (Tague 1977). If phosphorus-containing fertilizer is applied to soil that is saturated with phosphorus, the additional phosphorus cannot be retained and runs off into the lake during the next rain. Supposing that the 653 residents (73% of 895 lake residents) who fertilized once a year used 40 pounds of a common lawn fertilizer containing 3% phosphorus (28-3-3) in April during the winter season, then the amount of phosphorus loading into the lake is approximately 155 kg for an areal loading rate of $50 \text{ mg m}^{-2} \text{ yr}^{-1}$. This amount is almost as large as the septic system loading and is 23% of all loadings. Because of this high percentage of possible loading, lawn fertilizing with phosphorus should be eliminated immediately and only non-phosphorus fertilizer with low nitrogen should be applied, in the minimum amount necessary.

Often golf courses are sources of large loadings of phosphorus but this does not seem to be the case on Spring Lake. The Spring Lake Country Club golf course is situated on the lake's shores in Petty's Bayou just east of the public boat landing. For the past several

years, low-phosphorus and often non-phosphorus fertilizers have been applied to the golf course. Management of the greens includes applications of organic fertilizer but this includes relatively small areas away from the lake. Concerned about their potential influence on the lake's water quality, the Spring Lake Country Club began in 1995 to analyze water samples throughout their drainage system for nitrate, ammonium, and total phosphorus. Runoff from the fairways and greens flows into a drainage system which transports the runoff to a series of two retention ponds then finally into the lake. During a period in 1995, which included several rain events, the average concentrations in the second retention pond were 0.02 mg/l for total phosphorus, 0.37 mg/l for nitrate, and 0.2 mg/l for ammonium (Richter 1997). These average total phosphorus concentrations are lower than Spring Lake's concentrations and are more similar to the tributaries' concentrations, but the retention pond's average nitrate and ammonium concentrations were higher than the lake's concentrations. Buffer zones are also maintained around the ponds and the lake shoreline. Overall, the golf course's drainage system, fertilizer applications, and buffer zones are examples of good management practices for water quality.

Residuals for the Phosphorus Budget

The residual contains error and all sources and losses of phosphorus that were not measured: net exchange from the Grand River, net exchange with groundwater, losses to the sediments by sedimentation, and internal loading from the sediments. The influence of phosphorus inputs from the Grand River and groundwater inflows is thought to be small. Although total phosphorus concentrations in the Grand River were usually higher than the

lake, the phosphorus contribution from the river is presumed to be small because the discharge into Spring Lake is believed to be small. Until the channel flow between Spring Lake and the Grand River is studied in more detail, the river's contribution of phosphorus into Spring Lake will remain unknown. As for groundwater, a well about one half mile northeast of Stahl's Bayou was sampled and tested along with the lake samples during one event. The total phosphorus in the well sample was 0.01 mg/l, which is very low. Phosphorus in groundwater is typically this low and therefore is probably not a large source of phosphorus, but is more likely an important source of water for dilution.

Assuming that the error and the phosphorus loadings from the river and groundwater are minimal, the residual must be mostly due to internal loading, sedimentation, and loss to the Grand River. Since net residual is negative, this indicates an overall loss of phosphorus, which includes phosphorus leaving Spring Lake's water column by going into the Grand River as well as sedimentation, which can be offset by the release of phosphorus from the sediments. Phosphorus is lost to the sediment by the sinking of dying organisms, suspended solids, and phosphorus bound to calcium carbonate precipitates (Kelts and Hsu 1978). Phosphorus readily binds with calcium carbonate precipitates, which are produced by algae and other aquatic plants during photosynthesis (Kelts and Hsu 1978). I commonly observed this precipitate, called marl, on plants and bottom sediments in several of the bayous and bays, especially in Willows Bay, Petty's Bayou, and Stahl Bayou. The phosphorus associated with carbonate minerals readily dissolves in oxygen-depleted water and thereby contributes to the internal loading in lakes.

Although phosphorus sedimentation rates were not measured, they are probably a significant part of the residual. Sedimentation rates in a variety of lakes have been recorded, ranging from 0.5 to 50 g/m²day (Evans 1994). Lake Mendota, an eutrophic lake in Wisconsin, had sedimentation rates of 3.5 - 33 mg/m²day while Lake Michigan, an oligotrophic lake, had rate of 0.24 - 1.2 mg/m²day during the summer (Hicks et al. 1994). Because Spring Lake is a eutrophic lake, sedimentation rates are probably more similar to Lake Mendota and would be influenced by water residence times. Therefore, the sedimentation rates for Spring Lake would be higher during the summer season and lower in the winter season. The large difference between the winter residual of -689 kg and the summer residual of -231 kg suggests that more phosphorus is leaving the lake via the connection to the Grand River during the winter when sedimentation rates are low, and also possibly indicate that internal loading is larger than sedimentation rates during the summer when flow out into the Grand River is probably lower.

Large internal loadings may occur in eutrophic lakes during very productive periods because often these types of lakes have hypolimnions that are depleted of dissolved oxygen, which triggers the release of phosphorus from the sediments into the overlying waters. One of the causes of low dissolved oxygen levels in the hypolimnion is the oxygen-consuming process of decomposition of algae and other organisms. An indication of internal loading is an increase of phosphorus in the hypolimnion as the summer progresses.

During stratification, the total phosphorus concentrations in the hypolimnion were higher

than the epilimnion. If the concentrations in the hypolimnion are assumed to be from phosphorus being released from the sediments, the rate of concentration change in the hypolimnion can be used to estimate a phosphorus loading rate from the sediments (Auer et al. 1993) (Appendix B). Other studies have found loading from sediments during high oxygen levels (no stratification) to range from -2.0 to 9.6 mg/m²day, and during stratification with low oxygen to range from 1.2 to 150 mg/m²day (Reckhow and Chapra 1983). Therefore, during periods of no stratification in Spring Lake, loading from sediments is probably very small, but not so for periods of stratification. A hyper-eutrophic lake in New York had a mean phosphorus release rate of 13 mg/m²day from the sediment and was the lake's second highest source of phosphorus (24% of all the inputs) (Auer et al. 1993). Spring Lake's mass loading from the sediments during the summer stratification was estimated to be 1.93 mg/m²day and contributed 529 kg of phosphorus to the lake during the summer. This potential amount of phosphorus loading is the highest among all the other inputs during the summer (Table 6) and may be a deep phosphorus source for the algae, *Microcystis* (see chapter 3). But increasing flushing rates during the fall may aid in diluting and flushing out the higher phosphorus concentrations in the water. If the external loadings of phosphorus are lowered and the algal blooms are reduced, the dissolved oxygen levels in the hypolimnion should rise because decomposing organisms are reduced. Then, internal loading from the sediments should also be reduced in time, aided by the seasonal flushing of the lake.

Internal loadings are derived from phosphorus-rich sediments and recent organic sedimentation of decaying matter. Phosphorus concentrations of Spring Lake's sediments

ranged between 820 to 750 mg/kg from cores taken in October 1997 (Rediske 1999), which are lower than Michigan's average background level of 1,160 mg/kg (MDEQ 1998). The sediments consisted of black organic silts and woody fragments. The sediments also contain moderate to high iron concentrations, 18,500 to 24,600 mg/kg (Thorpe 1994). High iron content in sediments interacts with phosphorus in an interesting relationship. In water with oxygen, iron will bind to phosphorus; but, in water with low oxygen levels, the phosphorus is released from the iron (Cooke et al. 1993). Thus as long as the oxygen remains in the hypolimnion, the sediments in Spring Lake should bind and retain phosphorus because of the high iron content.

Internal loading can also occur through the resuspension of sediments. Resuspension of sediments containing nutrients is a common event in shallow lakes (Cooke et al. 1993, Reddy et al. 1996). The main body of Spring Lake is deep but the bayous are shallow with maximum depths ranging from 5 to 6 meters (17 to 21 feet), and may be functioning as sources of resuspended sediments. Resuspension is primarily caused by wind, forming surface and internal waves, seiches, especially during large storms (Evans 1994, Gloor et al. 1994, Pierson et al. 1994). In another large deep lake with a mean depth of 9 m and a maximum depth of 21m, internal waves caused a marked increase of resuspended sediments and nutrients in the hypolimnion (Pierson et al. 1994). During the summer when the hypolimnion has decreased to a sufficient depth, resuspension from internal waves can have "important consequences on both the redistribution of lake sediments and the internal loading of phosphorus" (Pierson et al. 1994). Phosphorus reduction of this loading mechanism is difficult to achieve due to its strong climatic driver.

Even aquatic plants influence the release of phosphorus and sediments, particularly through their ability to reduce sediment resuspension (Dieter 1990). Many aquatic plants obtain much of their phosphorus from the sediments and may release large amounts of phosphorus into the water while decomposing (Wetzel 1983), as can happen after herbicide treatments. A potential but most likely small phosphorus source, the rooted aquatic plant area in Spring Lake covers 27% of the lake surface and is important for good fisheries (see Chapter 3).

LAKE MACATAWA: ANOTHER LOCAL RIVER-MOUTH LAKE

Spring Lake is one of the many drowned river-mouth lakes along the western shore of Michigan. These lakes have some similar characteristics but yet each seem to be unique in its land use and water quality problems. Spring Lake and Lake Macatawa are two such lakes. Located in southern Ottawa county, Lake Macatawa is an 1800-acre drowned river-mouth and its watershed encompasses 175 square miles, over three times as large as the Spring Lake watershed. The average depth of the lake is 12 feet and its maximum depth is 40 feet. The Macatawa River and Pine Creek are its major tributaries along with other smaller tributaries contributing to the lake's residence time of 58 days. Classified as a hypereutrophic lake, Lake Macatawa has had historically high nutrient levels, nuisance algal blooms, low dissolved oxygen, and high sediment loading. Forty-four point sources from shoreline industries and businesses contribute approximately 5436 kg/year of phosphorus (12,000 pounds/year) directly to the lake (MDEQ 1998). The tributaries contribute 57,078 kg/year (126,000 pounds/year), draining agricultural lands and comprising 68% of the watershed area. In 1997, the lake's average spring total

phosphorus was 0.125 mg/l. The lake's watershed area to lake area ratio is 63, as compared to Spring Lake's 26, which indicates its extreme vulnerability to land use change in the watershed. Currently, local and state groups and agencies are developing and initiating a phosphorus reduction strategy in an effort to obtain a lake phosphorus concentration of 0.05 mg/l (Macatawa Area Coordinating Council 1998). The phosphorus reduction strategy primarily targets non-point sources, recommending measures such as stormwater retention, green belts along waterways, and agricultural best management practices. Although the lake occasionally stratifies, causing anoxic (no oxygen) conditions in deeper waters and thereby possibly causing the release of phosphorus, this source of phosphorus was not considered a major source (MDEQ 1998) and was not included in the reduction strategy.

Using Spring Lake as an example, phosphorus loading from the sediments most likely occurs during anoxic conditions and may occur under the same conditions in Lake Macatawa. As long as the point and non-point sources continue at the same levels, internal loading will be of a lower relative importance to other sources (Cooke et al. 1993). But if point and non-point sources are lowered, the internal loading should not be ignored because its relative importance will increase as the other source loadings decrease. The lingering effects of loading from sediments should not be dismissed because of difficulties in obtaining measurements or finding solutions. Therefore, I suggest that the current strategy be revisited to include a missing component of the phosphorus budget, internal loading from sediments, not only for a holistic view but also to aid in realistic future scenarios for the lake.

RECOMMENDATIONS

Without precise knowledge of the inputs from the Grand River, internal loading, and groundwater, the largest known phosphorus loadings into Spring Lake are currently thought to be the tributaries, septic systems, and lawn fertilizers. All of these sources may be reduced by various methods, and thus reduce phosphorus concentrations in the lake. It is not a lost cause as some people may believe. If all phosphorus sources are reduced along with nitrogen sources, the *natural* flushing of the lake should enable this watershed and lake to *rebound* more quickly than other lakes with lower flushing times.

Reduction of loadings from leaching septic systems can be completed through connections to a municipal sanitary sewer system or better maintenance of septic systems. All homes around the shoreline of the lake and tributaries and those near these water courses should be connected to a sewer system. One way to insure this connection is through local ordinances and enforcement. Local municipalities can develop ordinances that mandate sewer hook ups when a residence changes owners. If a city sewer connection is unavailable, the residents should properly maintain their septic system to minimize leaching into the lake system. Home*A*Syst, an excellent MSU County Extension program for homeowners, recommends that waterside septic systems be pumped every 3-5 years (MSU Extension 1997). Perhaps, a joint venture between the municipalities and local septic system pumping businesses is in order. During the spring cleaning season, reminders could be sent to residents around the lake about septic system maintenance.

In Spring Lake, loading from the tributaries was higher than the septic system loading during the winter season. Tributary loading is best reduced by diversion and reduction of point and non-point sources (Cooke et al. 1993). No known point sources exist along the tributaries; therefore, the non-point sources must be addressed. Non-point sources are many diffuse sources that jointly increase nutrients in runoff from the land and is therefore highly influenced by land use and the practices upon that land. State and national programs strongly recommend best management practices, BMPs, to reduce non-point source loadings (USEPA 1996). Many BMPs have been developed for homeowners, agricultural entities, and other businesses and include objectives such as reduction in fertilizer applications, runoff control, and soil erosion control. Specific BMP techniques are:

1. Structural: infiltration and detention basins, sand filters, vegetated filter strips, constructed wetlands, detention dry basins, streambank stabilization.
2. Non-structural: pollution prevention, watershed planning, vegetated buffer areas, street sweeping, stormsewer inspections and cleanings, limitation of impervious surfaces, setback requirements around wetlands and shorelines, protection of wetlands and water resources, strategic planning and zoning so as not to degrade water quality, public education and fertilizer reduction (EPA 1996).

The highest potential phosphorus loading among both seasons may be from internal loading during the summer, which is influenced by the stratification of the lake that is ultimately controlled by the climate. If summer stratification does not occur or occurs on a limited basis, loading from the sediments becomes less important in that water year and the other sources become more important. Because nitrogen reduction may be equally as important as phosphorus reduction, expensive in-lake management efforts to reduce this internal phosphorus loading should not be undertaken until additional research is

completed. All other phosphorus inputs need to be minimized in order to achieve long-term reduction of phosphorus in the sediments. For long term management of this lake with higher flushing rates in the winter and lower flushing times in the summer, lowering phosphorus levels in all inputs will in time lower sedimentation rates to the sediments and thus lower potential internal loading.

This study is limited because phosphorus loading from the Grand River and groundwater could not be measured. More precise estimates of phosphorus loading from the tributaries may be gained by more frequent sampling of the main streams. Because nitrogen may be co-limiting with phosphorus, a nitrogen budget like the phosphorus budget, should be developed to pinpoint nitrogen loadings that may be reduced through management. Furthermore, a nutrient reduction/dilution experiment should be completed in the lake (Dodds et al. 1993, Elser et al. 1990). This type of container experiment will provide information on nutrient concentrations and corresponding algal concentrations which can be used to establish goals for nutrient and algae concentrations in Spring Lake.

RECOMMENDATION LIST FOR NUTRIENT REDUCTION

Future Research

- Quantify the Grand River and groundwater exchanges.
- Complete a nitrogen budget.
- Complete a dilution/reduction experiment.
- Sample the main tributaries for phosphorus and nitrogen more frequently.

To the Municipalities and the Lake Board

- Provide and enforce sewer connections for shoreline residences.
- Develop local ordinances limiting phosphorus fertilizer use and encourage the use of phosphorus-free fertilizers.
- Construct retention ponds for stormwater runoff.
- Sweep streets often to reduce sediment and nutrients in stormwater runoff.
- Clean and maintain stormsewer sediment traps.
- Continue monitoring of the lake water quality.
- Encourage stewardship by expanding public education on watershed ecosystems and nutrient reduction practices.
- Maintain and restore shoreline wetland areas which act as sediment and resuspension traps.
- Reduce impervious surfaces in new developments.
- Control soil erosion along shoreline of the lake and tributaries especially at road crossings by working jointly with owners, Natural Resources Conservation Service, and county soil conservation districts.

Residents

- Connect to city sewer when it is available.
- Maintain septic systems by pumping every 3-5 years.
- Eliminate lawn fertilizing with phosphorus-containing fertilizer and use only non-phosphorus fertilizer sparingly.
- Stop dumping of leaves, limbs, grass clippings or other plant debris into the lake,

tributaries or wetlands.

- Maintain compost piles away from the shoreline.
- If aquatic plants are raked out of the water, place in compost pile away from shoreline.
- Control soil erosion and stormwater runoff by establishing a buffer strip along the shoreline.
- Use low phosphorus soaps in dishwashers and other applications.
- Re-direct rain gutter runoff to lawn or another grassy area instead of directly into the lake.
- Irrigate lawn and gardens appropriately, without causing runoff.
- Maintain or restore shoreline wetlands for sediment and resuspension traps.
- Reduce impervious surfaces.

SUMMARY

- Spring Lake is a eutrophic lake with high summer nutrient and algae concentrations.
- Nitrogen and phosphorus are most likely co-limiting nutrients in the lake.
- Influenced by climate, the higher flushing rates in the winter season result in a “lower trophic status” during this period, as in most lakes, but during the lower flushing rates of the summer season, the lake responds as a higher trophic status lake with low Secchi depths and high algae concentrations.
- The highest phosphorus loadings are from tributaries, leaching septic systems, lawn fertilizer and possibly internal loading from the sediments.

- Municipalities and residents can reduce the phosphorus loadings by incorporating best management practices and connecting to sanitary sewer system.
- Additional research to complete a nitrogen budget and to quantify the exchanges with the Grand River and groundwater is recommended before any expensive in-lake management techniques are implemented.

CHAPTER 3

PLANT AND ANIMAL LIFE IN THE WATERSHED

INTRODUCTION

We humans are mutually tied to other species around us through the food web and habitats. Initiating the web are plants, including the algae in the lake, because they are able to convert sun energy into plant tissues and sugars by utilizing absorbed nutrients. Animals then consume the plants for their energy. For example, a food chain within a lake may consist of an algae being eaten by a minute animal in the water column (zooplankton); the zooplankton is eaten by a minnow; the minnow is eaten by a trout or waterfowl, which may be eaten by a human. Another connection that humans have with plants and other animals is our shared habitat, a living space with all the resources for survival. Just as we need space, food, and water to live, so do plants and animals. Changes in habitats may diminish the quality and quantity of the present plant and animal life. If the habitat is altered and the plant and animals do survive, their number and health may be threatened. If these organisms do not survive, other types of plant and animal species that are tolerant to the changes begin to expand into the habitat. Alterations may include physical manipulation of the land or water, elimination of food and water sources, introduction of nutrients and pollutants, or even introduction of other plants and animals. Although not all habitat changes are harmful, human actions have tremendous impacts on habitats and affect the type, population, and health of plant and animal species. This chapter will give historical and current descriptions of some plant and animals in the watershed and explain how some of practices may be altered to prevent or minimize undesirable habitat and

biological changes.

WOODY PLANTS: THE TREES

Trees not only provide shade for residential homes and habitat for birds and animals, but shoreline trees also provide habitat for many aquatic animals and prevent deep mixing of lake waters. As shoreline trees age, they may fall into the water forming refuge areas for fish and other animals and also provide a centuries-long carbon source (D. Christensen et al. 1996). Spreading residential areas correlated with decreasing shoreline tree falls and it was estimated that 200 years of tree growth in residential areas is necessary to replace the missing habitat and carbon source in some Michigan and Wisconsin lakes (Christensen et al. 1996). Boating around Spring Lake, one discovers that Spring Lake exhibits this correlation with very little tree falls in the lake, with most of the falls occurring in Stahl Bayou which are rapidly being removed. Deforestation of shoreline trees have also been found to expose the lake surface to stronger winds, causing a deeper mixing of water, thereby reducing the lower cold-water layers which are necessary for cold-water fish like trout (France 1997). Currently threatened, Spring Lake's shoreline trees are dense only in portions of Petty's Bayou and areas where small tributaries enter the lake. Although not usually given much thought, trees are important for the aquatic and terrestrial ecosystems.

Tree species and populations have changed throughout the years. The Natural Features Inventory from the original surveyors' notes of the 1800s provides an overview of the dominant tree species and land features from that time (Comer et al. 1995). Around the lake, the dominant tree species were white pine, white oak, hemlock, maple, white and

black ash, beech, birch, and black gum. At the back of Smith's Bayou, a tamarack and cedar swamp existed and north of Fruitport a manipulated alder and willow wetland was noted. Remains of these wetland types can be observed today. Large areas of Spring Lake Village and the City of Ferrysburg, especially where Spring Lake connects to the Grand River, were identified as manipulated Great Lakes Marsh. Other small landscapes including wetlands were under-represented in the Historical Natural Features Inventory due to the surveyors' methods (Comer et al. 1995). Elsewhere in the Spring Lake Watershed, particularly along Norris Creek, these additional tree species were documented: basswood, sugar maple, and sycamore. The forest along a section of Vincent Creek has been designated as a "notable significant" example of the mesic northern hemlock-oak-maple forest (Reese et al. 1988). From my observations, all of the above tree species still exist in the watershed but populations of tamarack and cedar are extremely low and the marshy areas near the Village of Spring Lake and the City of Ferrysburg are now entirely man-made land.

ALGAE

Unlike trees and other terrestrial plants, algae absorb their nutrients directly from the water instead of from the soil and some algae species can even obtain nitrogen directly from the air. If nutrient concentrations are high like they are much of the time in Spring Lake, algal populations will increase until some other factor limits their growth such as exposure to sunlight, temperature, or turbidity of the water. When phosphorus and nitrogen alter in available concentrations, algae species may change depending on their needs and tolerances (Reynolds 1984). Because Redfield's ratio was lower than 16:1 in

Spring Lake, algae growth is predicted to be co-limited between nitrogen and phosphorus (Chapter 2). *Microcystis*, *Aphanizomenon*, and *Anabaena* are all types of blue-green algae that are found in Spring Lake but only *Aphanizomenon* and *Anabaena* can fix nitrogen directly from the air. The algae that has caused the green cast on the lake during the summer for the past few years is due mostly to *Microcystis*, which cannot utilize nitrogen from the air. If nitrogen concentrations were reduced in Spring Lake, *Microcystis* growth would decrease and may be replaced by a type of blue-green algae that can fix nitrogen from the air, such as *Aphanizomenon* and *Anabaena*. Because algae obtain their nutrients from the water (or air for some types), we can influence their growth and abundance through nutrients in runoff from our common practices and uses of the land.

Algal groups that are present in Spring Lake and the Grand River are the blue-greens, diatoms, greens, dinoflagellates, cryptophytes, and chrystophytes. (Appendix C contains information on the materials and methods for this chapter and species lists.) Both micro and macro algae exist in Spring Lake and the Grand River. Compared to Spring Lake, the Grand River is the most productive water for algae with a total of 36 species.

Whereas in Spring Lake, 39 species were identified and are listed in Table C1 (St. Amand 1999). Of the 49 algal species in Spring Lake and the Grand River, the most common genera were *Melosira*, *Asterionella*, *Fragilaria*, *Microcystis*, *Scenedesmus*, *Aphanizomenon*, and *Cryptomonas*. Diatoms, *Melosira*, *Asterionella*, and *Fragilaria*, were the most common algae in cooler weather; and blue-green algae, *Microcystis* and *Aphanizomenon*, were most prolific during the summer (Figure 31 & 32). These types of algae are common for eutrophic lakes, rivers, and reservoirs (Kohler 1994, Galicka 1992,

Bayne et al. 1990). Since the Grand River and Spring Lake are connecting bodies of water, each may serve as an inoculant source of algae and thus it is not surprising that many species are common in both waters. In another river-lake system, lake algae species that were dominate in the spring grew into larger populations in the river; but during the summer, the blue-green populations were greater in the lake than the river (Kohler 1994). In comparison to this river-lake example, Spring Lake's dominating group in the spring was diatoms which became more abundant in the Grand River during late spring (Figure 31 and 32). But, only for a short time each summer were the blue-green populations greater in Spring Lake than in the river even though individual blue-green colonies were larger in Spring Lake. These seasonal differences may be due to the differences in the flushing rates of the lake and the river (Kohler 1994).

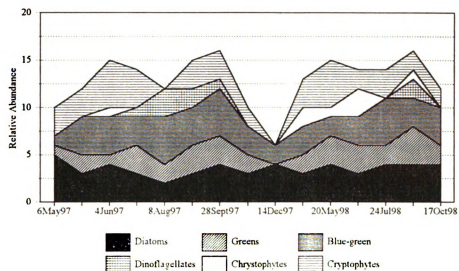


FIGURE 31: Stacked Areas of Algae Relative Abundance in Spring Lake.
The species with the highest ranking of abundance within each group and date is stacked on top (vertically on the graph) of the previous group like blocks and is then like a running sum of the highest abundance ranking of species within each group.

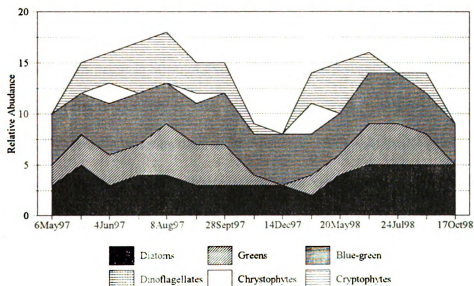


FIGURE 32: Stacked Areas of Algae Relative Abundance in the Grand River.

Causing the algal blooms the past two summers, *Microcystis* cells are unique in their chemical and physical structure and reach prime growth in water temperatures between 20-30°C (Fallon & Brock 1981). The colony-forming algae are capable of altering their buoyancy, producing a toxin, over-wintering in the sediments, and efficiently utilizing sunlight. *Microcystis* cells absorb harmful ultra-violet light with alternative pigments and thus are protected from the rays and can continue growth when other algae cannot (Paerl et al. 1983). Large colonies of *Microcystis* can migrate through the water column to depths as great as 4.5 meters below the surface to utilize nutrients in the deeper metalimnion (Brooks et al. 1998). The algae can also produce a hepatotoxin which has been historically attributed to some animal deaths (Kalbe 1984) and scientists continue to study and debate its toxicity (Aguiar & Azevedo 1998). One such study found no correlation of mice deaths to the ingestion of water from which *Microcystis* had been filtered, but warned that the results should not imply that *Microcystis* blooms are completely harmless to the health and hygiene of humans (Kalbe 1984). Therefore when *Microcystis* blooms occur in Spring Lake, common sense is warranted. Another quality enabling this species is its ability to over-winter by settling on the top few centimeters of the bottom sediments in water as deep as 18-24 meters (Fallon & Brock 1981). The blooms decline because of unfavorable temperatures or rapid temperature declines, physical flushing during high precipitation events, and turbulence from wind mixing (Paerl et al. 1983). Unsightly, the blooms may be controlled by reducing nutrients.

ALGAE, ZOOPLANKTON, AND ZEBRA MUSSELS

Algae populations are also affected by what eats them: zooplankton, fish larvae and mussels. Like algae, zooplankton species, which are minute aquatic animals, come in all sizes and eat a diversity of food: algae, bacteria, and other zooplankton. Larger zooplankton, like *Daphnia*, can eat large algae species such as *Microcystis* (Schoenberg & Carlson 1984). *Daphnia* are not common in Spring Lake but the smaller cousin, *Bosmina*, are abundant and cannot eat the large colonies of *Microcystis*. The lack of large populations of *Daphnia* may be a result of high predation by planktivorous fish such as perch (Shapiro & Wright 1984, Mazumder 1994). Even the presence of the common carp, which are in Spring Lake, have been correlated with decreasing aquatic plants and decreasing *Daphnia* populations (Lougheed & Fraser 1998, Hason & Butler 1994). Other Spring Lake zooplankton are *Diaphanosoma*, *Leptodora*, *Asplanchna*, *Brachionus*, *Kellicottia*, *Keratella*, and copepods – all are not herbivores, *Leptodora* is predaceous.

The large blooms of *Microcystis* may also be influenced by the zebra and native mussel populations. Some researchers believe mussels cause a change in algae composition and sizes (Pace 1998, Welker & Walz 1998). Zebra mussels are capable of filtering lake water at a rate of $8 \text{ cm}^3 \text{ m}^{-2} \text{ day}^{-1}$ for food (Pace 1998). In the Hudson River, zebra mussels have increased water clarity, decreased phytoplankton populations particularly blue-green algae, and decreased smaller zooplankton populations like *Bosmina* (Pace 1998). Zebra mussels were first observed in Spring Lake by some area residents about five years ago. Their population has since expanded to cover many solid or fibrous substrates such as pilings, water pumps, and even aquatic plants. Although their impact

upon the aquatic system is not completely understood, zebra mussels are common in Spring Lake and were observed in 90% of the transects sampled for the aquatic plant survey and were most commonly found on the aquatic plant species, *Ceratophyllum* and *Elodea*. Despite the presence of zebra mussels, the water clarity in Spring Lake has not increased like the Hudson River.

AQUATIC PLANTS AND MACRO ALGAE

Aquatic plants, macrophytes, are a crucial component of lakes and wetlands. They minimize sediment resuspension and provide refuge for small fish, food for waterfowl, and habitat for many aquatic insects, reptiles, and amphibians. Aquatic plants may grow floating on the surface, completely submerged, or partially submerged as emergents. Although most of the plants receive their nutrients from the sediments through their roots (Barko et al. 1991, Nichols 1991), a few aquatic plants are essentially rootless, such as coontail (*Ceratophyllum*) and bladderworts (*Utricularia*), and absorb their nutrients directly from the water like algae. Aquatic plants, like terrestrial plants, range in tolerances although virtually no plant can survive along a shoreline that is constantly pounded by waves or has unstable sediments (Nichols 1991). Hence, in Spring Lake there are areas that are sparse in aquatic plants, while other areas, like the bayous, are prominent aquatic plant zones (Figure 33, 34, & 35).

The aquatic plants and macro algae of Spring Lake cover 141 hectares (348 acres) which is about 27% of the lake's surface area. Only about 32 hectares (80 acres or 6%) of the

lake are covered with each types, emergent and macro algae. Thirty-one different plant species were identified in Spring Lake. This species number does not include exposed wetland areas nor wetlands beyond the lake perimeter roads of Pontaluna, Third, Fruitport, and Spring Lake. Spring Lake's surface coverage of aquatic plants falls within the sparse to medium range of plant coverage for fish diversity, abundance, and size (Randall et al. 1996). Medium to high (31-70% of bottom coverage) produced the highest levels of fish diversity, abundance, and size (Randall et al. 1996). Angler catch rates of largemouth bass were generally greater "when macrophyte cover was highest" (Maceina & Reeves 1996). For good fisheries in Spring Lake, the coverage and diversity of aquatic plants need to be conserved.

**FIGURE 33: Aquatic Plant Map and Stormwater Outfalls on Spring Lake,
Northern Section**

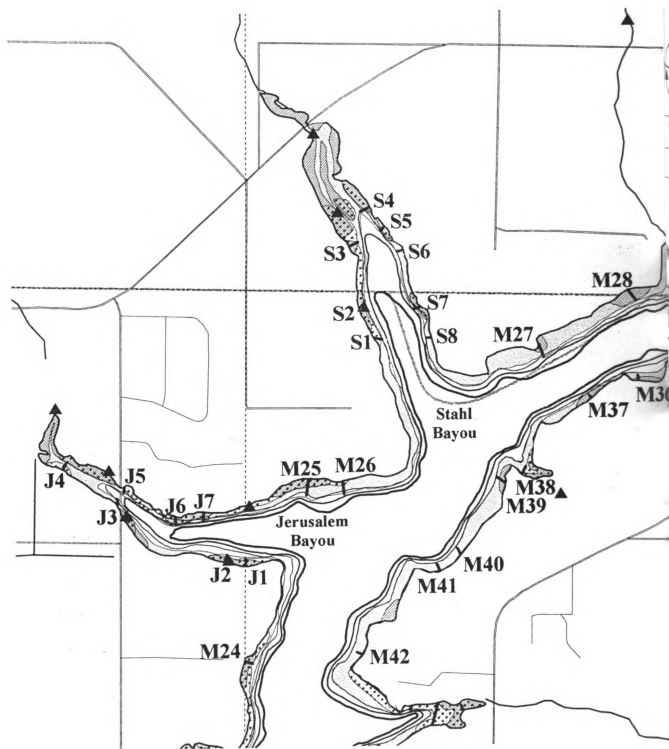
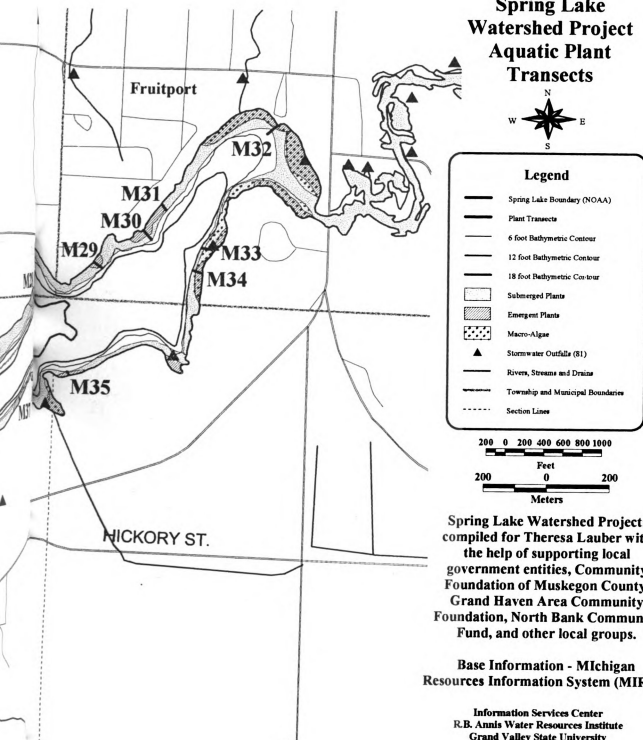


FIGURE 33
**Spring Lake Watershed Project
 Aquatic Plant
 Transects**



**FIGURE 34: Aquatic Plant Map and Stormwater Outfalls in Spring Lake,
Middle Section**

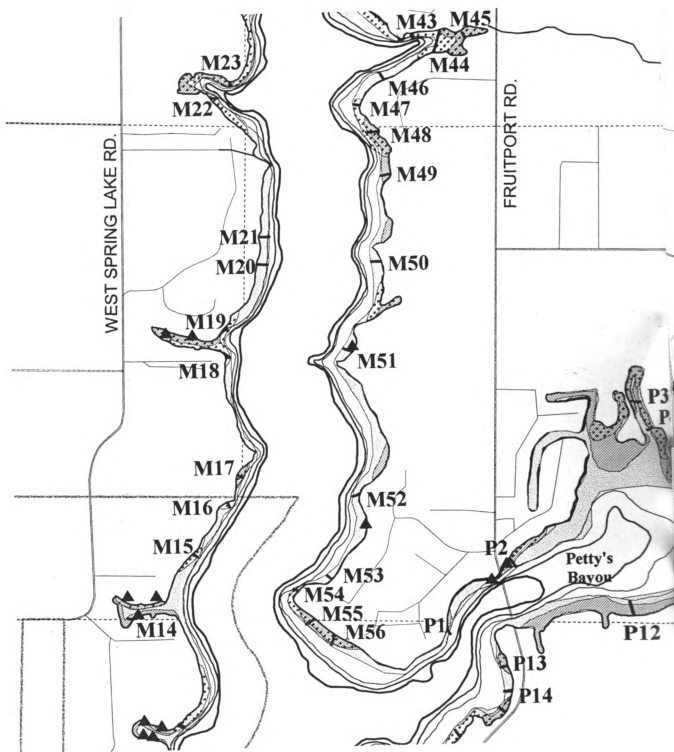
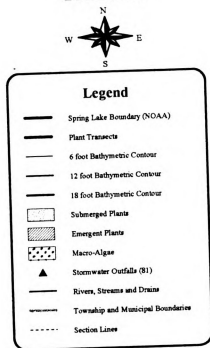
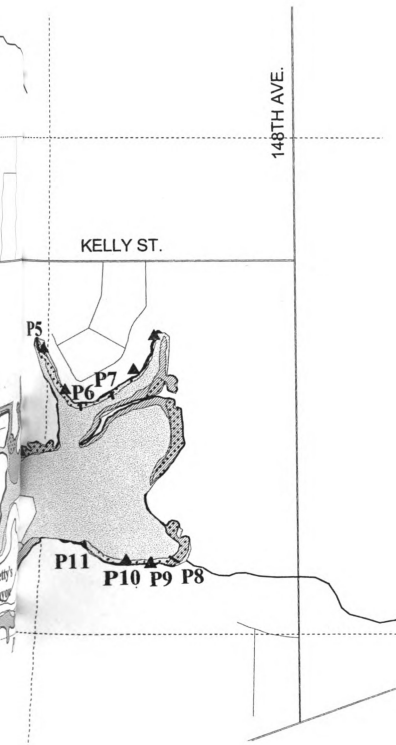


FIGURE 34
**Spring Lake
 Watershed Project
 Aquatic Plant
 Transects**



Spring Lake Watershed Project:
 compiled for Theresa Lauber with
 the help of supporting local
 government entities, Community
 Foundation of Muskegon County,
 Grand Haven Area Community
 Foundation, North Bank Community
 Fund, and other local groups.

Base Information - Michigan
 Resources Information System (MIRIS).

Information Services Center
 R.B. Annis Water Resources Institute
 Grand Valley State University

**FIGURE 35: Aquatic Plant Map and Stormwater Outfalls in Spring Lake,
Southern Section**

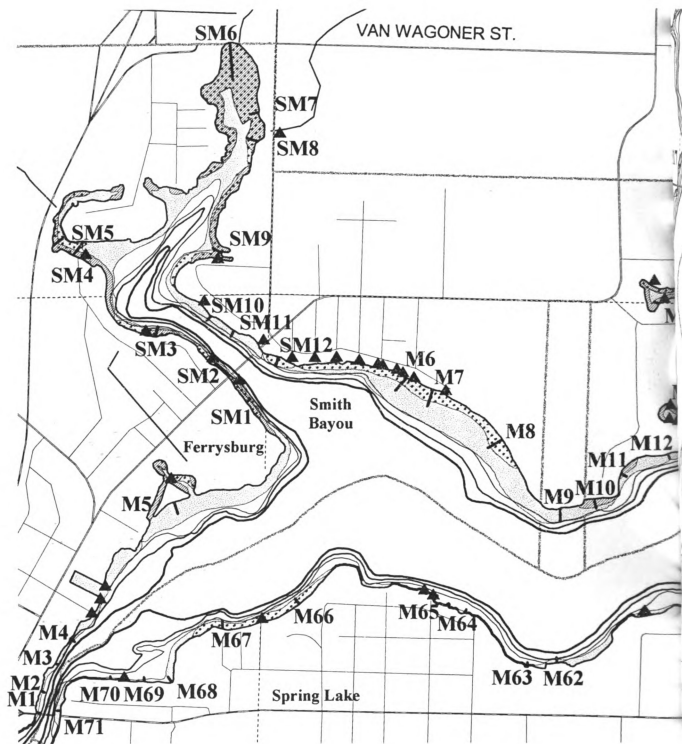


FIGURE 35
**Spring Lake
 Watershed Project
 Aquatic Plant
 Transects**



Legend

- Spring Lake Boundary (NOAA)
- Plant Transects
- 6 foot Bathymetric Contour
- 12 foot Bathymetric Contour
- 18 foot Bathymetric Contour
- ▨ Submerged Plants
- ▨ Emergent Plants
- ▨ Macro-Algae
- ▲ Stormwater Outfalls (81)
- Rivers, Streams and Drains
- Township and Municipal Boundaries
- - - Section Lines

200 0 200 400 600 800 1000

Feet

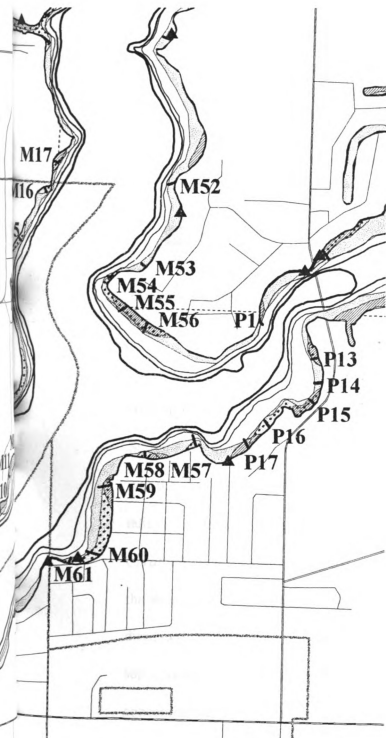
200 0 200

Meters

Spring Lake Watershed Project:
 compiled for Theresa Lauber with
 the help of supporting local
 government entities, Community
 Foundation of Muskegon County,
 Grand Haven Area Community
 Foundation, North Bank Community
 Fund, and other local groups.

**Base Information - Michigan
 Resources Information System (MIRIS).**

Information Services Center
 R.B. Annis Water Resources Institute
 Grand Valley State University



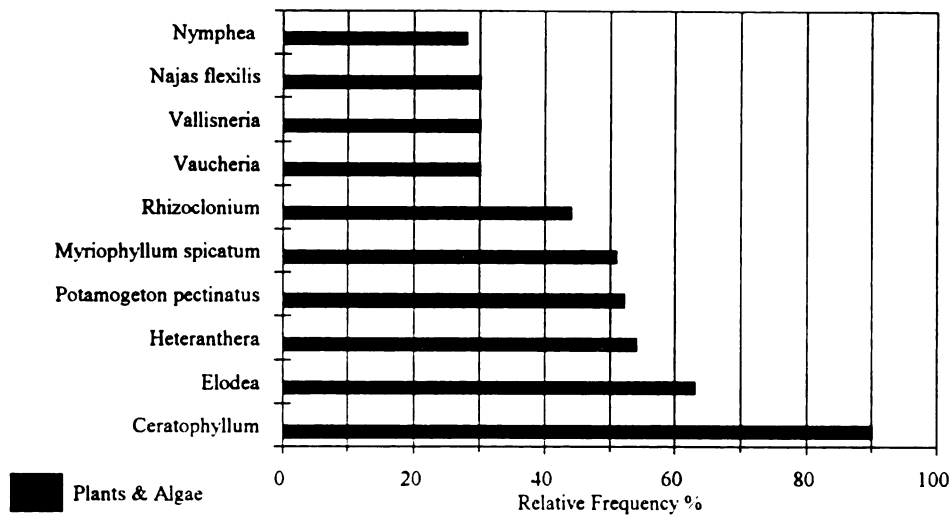


FIGURE 36: Relative Frequency of the Ten Most Abundant Aquatic Plants and Macro-Algae of Spring Lake.

Although the percent coverage and diversity of aquatic plants need to be preserved in Spring Lake for the fisheries, nuisance plant species do exist. *Ceratophyllum* (coontail) was the most common plant throughout the entire lake and therefore is most likely a nuisance species for people boating, docking, and swimming (Figure 36, Table C7). Since *Ceratophyllum* is a drifting rootless plant that absorbs its nutrients directly from the water, the abundance of this species reflects the high nutrient concentrations in Spring Lake. As discussed in chapter two, the nutrients may be from the tributaries, storm water runoff, septic system leaching, lawn fertilizer leaching and internal loading. Hence when nutrient concentrations are reduced through management practices, the large populations of *Ceratophyllum* should decrease. See Tables C2 -C7 for details of aquatic plant transects.

Other abundant species were *Rhizoclonium*, *Vaucheria*, *Heteranthera*, and *Myriophyllum spicatum*. *Rhizoclonium* and *Vaucheria* are both types of macro algae. The relative frequency between these two algae species in Figure 36 is deceptive; *Vaucheria*, a blue-green felt-like algae occurs in most transects because it grows on shoreline rocks, whereas *Rhizoclonium* formed huge dense beds of thick horsehair-like algae weighing down other aquatic plants. These large algal beds are indicators of high nutrient loadings, possibly from leaching septic systems, leaching lawn fertilizer, stormwater runoff, and resuspension of sediments. Each of these sites, near Fruitport boat landing, Greenwood Bay, St. Lazarus Retreat House, and between the Smith Bridge and the yacht club, needs to be investigated for potential loading sources (Figure 33, 34, 35). Often confused with *Cladophora*, *Rhizoclonium* was microscopically identified by its net-like chloroplasts (Prescott 1964). *Heteranthera*, water star-grass, was present in 54% of all the transects and was found in areas showing recent signs of disturbance resulting from seawall construction or dredging. This plant species has been shown to become a dominant species in disturbed areas. In a Wisconsin lake following mechanical harvesting of aquatic plants, the rare *Heteranthera* immediately expanded to become the dominant plant for eight years (74% frequency) (Engel 1990). Another spreading plant species, *Myriophyllum spicatum*, commonly known as Eurasian water milfoil, was present in about 50% of the transects. This plant spreads most commonly by fragmentation, but its current populations were sparse to medium and were dense only in a few isolated areas in Petty's Bayou. Continued disturbance of sediments and aquatic plant beds may increase the frequency of *Heteranthera* and *Myriophyllum*. The macro algae, *Rhizoclonium*, will continue to flourish with high nutrient concentrations in the lake.

FISH, TURTLES, AND WATERFOWL

Lakes that are connected to rivers serve as important refuge, forage, and nursery areas for fish (Van DenBrink 1996). Not only is Spring Lake connected to a major Michigan river but it is a short distance from Lake Michigan, lending to a diversity of the fish species (Randall et al. 1996). The Michigan Department of Natural Resources completed a fish survey in 1978 and documented the following fish counts (the number following the fish count is the average length in mm): 3 brown trout (585), 2 northern pike (755), 14 yellow perch (180), 320 bluegill (150), 149 pumpkinseed (150), 98 black crappie (165), 53 channel catfish (337), 1 steelhead (670), 56 white sucker (430), 25 red horse (373), 2 yellow bullhead (240), 49 quillback carpsucker (350), 7 sheepshead (360), 3 bowfin (590), 45 carp (550), 34 alewives (no average given), 1 golden shiner (180), 264 gizzard shad (93). During the 1998 angler survey, the following fish species were caught by anglers around the seven different fishing sites that were sampled (see Appendix C for methods and materials): smallmouth bass, largemouth bass, shad, bluegill, pumpkinseed, crappie, catfish, sheepshead, pike, perch, alewives, sucker, and muskellunge. During February 1999, a large fish kill consisting of mostly alewives occurred with most drifting ashore along the Fruitport area. A few pike, smallmouth bass, and carp were also observed among the hundreds of dead alewives. It is not known yet what caused this kill but some researchers speculate that it was possibly caused by a lack of food (zooplankton) (Alexander 1999).

Historically, cold-water fish have existed in Spring Lake, indicating that temperature and dissolved oxygen levels have been sufficient. As discussed in Chapter 2, dissolved oxygen

levels in the hypolimnion decreased to very low levels during summer stratification. These levels are not sufficient for cold-water fish and put an additional stress upon the fish during this period. If improvement of cold-water fisheries is a lake management goal, then dissolved oxygen levels must be improved by reducing the lake's productivity through nutrient reductions along with maintaining the present aquatic plant coverage.

Other aquatic life observed were snapping and painted turtles which were commonly seen on the remaining tree falls around the lake. Waterfowl that were observed and counted during the angler creel survey were gulls, mallards, domestic ducks, Canada geese, swans, coots, loons, wood ducks, buffleheads, and mergansers (see chapter 2).

RECOMMENDATIONS

A drowned river-mouth lake, Spring Lake, is very much like a floodplain lake and most likely contributes to the biodiversity of the Grand River Watershed and should be managed as such. The diversity of life within the waters of other floodplain lakes is greater than that of its river and "contribute significantly to the total biodiversity of the entire riverine ecosystem" (Van DenBrink et al. 1996). Phytoplankton, zooplankton, fish, and aquatic plant species all exhibited increased biodiversity in the studied floodplain lakes, thus emphasizing the importance of variation in hydrology and lake morphology. Any alteration in hydrology such as flow velocities and water level fluctuations would cause a change in the biodiversity and should not be attempted (Van DenBrink et al. 1996).

Management for the nuisance aquatic plants and blue-green algae is recommended.

Because the aquatic plants are a nuisance in localized areas such as around docks, I recommend the harvesting of aquatic plants by the residents in these areas and very limited use of chemicals on *Myriophyllum spicatum* by professionals. No large scale mechanical or chemical management for aquatic plants are recommended because

- if good fisheries is desirable, the aquatic plant coverage of the entire lake is presently minimal,
- harvesting obstacles such as docks and submerged objects are present,
- disturbance may increase the abundance of *Heteranthera*,
- fragmentation may spread *Myriophyllum spicatum*,
- small fish and invertebrates may be reduced (Engel 1990)
- some herbicide applications actually increase the available nutrients in the water when the plants decompose.

Mechanical or chemical management of aquatic plants are believed not to alter the plant species found in a community even though species abundance may change (Fox & Murphy 1990).

Although chemical applications of copper-based formulas are effective in controlling micro and macro algae for short periods (Hallingse & Philips 1996), the applications increase copper levels in sediments, are toxic to zooplankton and bottom invertebrate organisms (Cooke et al. 1993), and the decomposing algae release nutrients resulting in a rebound explosion of algae. This is what most likely occurred during the whole-lake algal treatments in the mid-1950s on Spring Lake — a rebound growth of algae following

algaecide treatments. About 10 areas around the lake have been chemically treated for aquatic plants and algae by professionals in the past four years. Chemical application for algae management is a very short-term approach (weeks if not days) that regenerates the cause of the algal blooms — high concentrations of nutrients. For resourceful management of blue-green algae blooms, their nutrient supplies must be lowered by reducing internal and external loadings of phosphorus (Soranno et al. 1996).

RECOMMENDATION LIST

To the Municipalities and Lake Board

- Reduce external loadings of nutrients from septic systems, tributaries, stormwater runoff, and lawn fertilizers.
- Zone the back portions of each bayou as wetland sanctuaries for aquatic wildlife and plants. Motor boat access in these areas should be limited to trolling motors or less. This action will reduce the amount of “chopped up” plants and their spread by fragmentation, resuspension of sediments from boat propellers, and will protect habitat area for plants and wildlife such as fish.
- Complete a wetland inventory of plants and animals for the Fruitport wetland north of the Third Street Bridge and other wetlands beyond the perimeter roads to expand the baseline data of the lake and watershed and to aid in the protection of crucial wetland areas.
- Investigate the shoreline areas where macro algae are a nuisance for nutrient sources.
- Before any costly in-lake management technique is implemented, complete studies

detailing groundwater and the Grand River exchange and a nitrogen budget to understand the nutrient status of Spring Lake more fully, so that more detailed management recommendations can be developed. Completion of a reduction/dilution study will also aid in establishing realistic management goals for nutrient and algae concentrations for this particular lake.

- Recognize that when algal blooms are reduced, the increase in water clarity may cause a slow increase in aquatic plant growth. When increased aquatic plant growth occurs, additional in-lake management techniques for aquatic plants may be required.
- Encourage homeowners to rake out their nuisance plants by beginning a composting share program.
- Chemically manage the lake for only *Myriophyllum spicatum* in the isolated areas in Petty's Bayou.

To Shoreline Residents

- Minimize chemical treatment of algae and aquatic plants because the causes of the problems are not being addressed but compounded.
- Rake or pull nuisance aquatic plants out of the water and place in compost pile far from shore. If a plant fragments, try to collect all pieces. This technique is very effective (Luken & Thieret 1997). Share your compost pile with watershed neighbors.
- Maintain and restore shoreline trees. If any have fallen into the lake, let them remain if safety is not compromised.

- Reduce sediment disturbance because it aids in the release of nutrients and spread of some aquatic plants.

SUMMARY

- Although tree species have changed little since the 1880s, their density seems to have changed with only small areas of dense shoreline trees remaining along the back reaches of some bayous.
- Thirty-one aquatic plant species were identified in Spring Lake and covers about 27% of the lake's surface. This number of species does not include wetland emergents.
- Thirty-nine algae species were identified in Spring Lake as compared to the 36 in the Grand River. Most species were common among the lake and the river. Algae abundance for most of the algal groups was higher in the Grand River than Spring Lake during most of the water year.
- The 1997 and 1998 summer algal blooms were mostly of *Microcystis*, which can utilize nutrients from lower water layers and its growth may be limited by other factors besides nutrient concentrations.
- The zooplankton species, *Bosmina*, are more abundant in Spring Lake than *Daphnia*, possibly lending an indirect effect on the blue-green algal blooms.
- *Ceratophyllum*, a rootless aquatic plant, and *Rhizoclonium*, a macro algae, formed massive nuisance beds in several locations around the lake and obtain their nutrients directly from the water. Residents are encouraged to rake the plants

from the lake.

- Lower internal and external loadings of nutrients should lower algal concentrations.
- No large-scale chemical or harvesting management projects are recommended to control algae or aquatic plants because of nutrient rebound, harvesting dangers, and toxicity.
- For good fisheries, the amount of aquatic plant coverage and plant diversity need to be preserved.
- The Spring Lake Watershed most likely contributes to the biodiversity of the Grand River Watershed.

CHAPTER 4

WATERSHED USES AND PERSPECTIVES OF THE RESIDENTS

INTRODUCTION

Area residents and visitors use the lake and watershed for a variety of activities that depend upon their perceptions of the land and water quality. For instance, algal blooms are unsightly, causing many people to be discouraged from swimming, boating, and participating in other lake activities. People not only form perceptions about the environment's quality and make decisions about activities in the watershed; they also change the environment through their use, thus forming a cycle of perceptions, actions, and consequences. Throughout the years, the quality of the watershed has spurred the area's economy through fur trading, logging, tourism and many other types of business ventures. I believe that the quality of the environment will continue to form the basis of the local economy. This chapter will explore how perceptions, economics, and the environment are intertwined by studying resident's perspectives and watershed land uses, all of which will aid in the writing applicable management suggestions for this community. (See Appendix D for materials, methods, and detailed data.)

CURRENT WATERSHED BENEFITS AND LAND USES

Seventy-five percent of the Spring Lake Watershed lies in Muskegon County while the other 25% is in Ottawa County. It consists of 11 different municipalities (Figure 37). The townships of Fruitport, Sullivan, and Spring Lake form the majority of the watershed area.

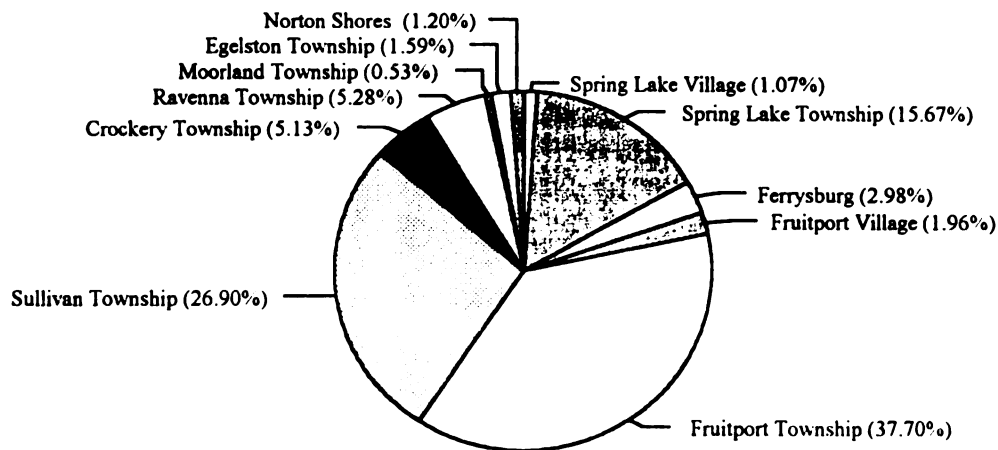


FIGURE 37: Municipality Percentages in Spring Lake Watershed

The watershed provides a wide variety of useful area for agriculture, industry, residential, open space, and recreation (Figure 38, 39, 40, & 41). The predominant 1992-1997 land use areas in the watershed include forests (6355 hectares), residential (1990 hectares), and crop land (1909 hectares) (Table D2). Among all the municipalities, Fruitport Township has the largest percentages of these land uses: 40% of the residential areas in the watershed, 36% of the industrial areas in the watershed, 44% of the open field areas in the watershed, 51% of the orchards in the watershed, 41% of the forests in the watershed and 34% of the wetland in the watershed. Sullivan Township has the highest percentage of crop land in the watershed (32%) and barren land in the watershed (65%). Since 1978, 34% of crop land has changed to some other land use, while orchards and specialty crops have increased by 67% (Table D1 & D3).

Although wetlands have been lost in the past, wetland acreage in the watershed has

basically remained unchanged since 1978. These wetland areas should remain unchanged and unthreatened because of their importance to water quality. Wetlands are transitional zones between upland areas and waterways and occur not only along lake and stream shorelines but also may be located higher in the watershed landscape away from the lake or stream. Wetlands, in general, minimize the effects of flooding, maintain water quality, and “serve as centers of biological diversity” (Lewis 1995). Most of the wetlands remaining in the Spring Lake Watershed are riverine (along the streams) and lacustrine (along the lake). During flooding periods, riverine wetlands remove sediments and nutrients from the water (Whigham et al. 1998). Although these wetlands seem to have little impact on nutrients in the water during non-flooding periods, little is known about their interactions with groundwater (Whigham et al. 1998). Spring Lake’s riverine wetlands such as the one near Fruitport are sediment and nutrient traps, depending on the water level and other hydrological factors, and are thus extremely important for Spring Lake’s water quality.

Lacustrine wetlands, wetlands around lakes, minimize resuspension of sediments (Dieter 1990) and are habitats for many aquatic organisms. Through the years, these shoreline wetlands have most likely been filled and replaced with various types of seawalls. Spring Lake’s shoreline is currently composed of about 23% of rip rap (rock) shore, 47% of solid seawall (concrete, block, steel, or other) and 30% of natural type shoreline. Because the transition in depth from shallow to deep water at most solid seawalls is quick, it seems fewer aquatic organisms would find this type of seawall inhabitable. But in a rip rap shore, the transition is more gradual, therefore more plant and animal species would be

able to inhabit the area. Thus when constructing or reconstructing seawalls, residents should choose a rip rap type over solid seawall types.

Different general land uses have been related to nutrient concentrations in tributary runoff. Agriculture runoff has the highest mean concentration of total phosphorus (0.16 mg/l) while urban runoff (0.09 mg/l) and forested land (0.02-0.03 mg/l) have lower mean concentrations (Cooke et al. 1993). The uses of the land affect the runoff and all its water bodies. *A lake is truly a reflection of its watershed.* It is fortunate that forested lands remain the highest proportion of land use in the Spring Lake Watershed because this type of land use has a lower nutrient concentration in its runoff. If this amount changes, it can be expected that the water quality of Spring Lake will decline. Land use changes in the watershed should be accompanied with aggressive best management practices as discussed in the following list of land use recommendations.

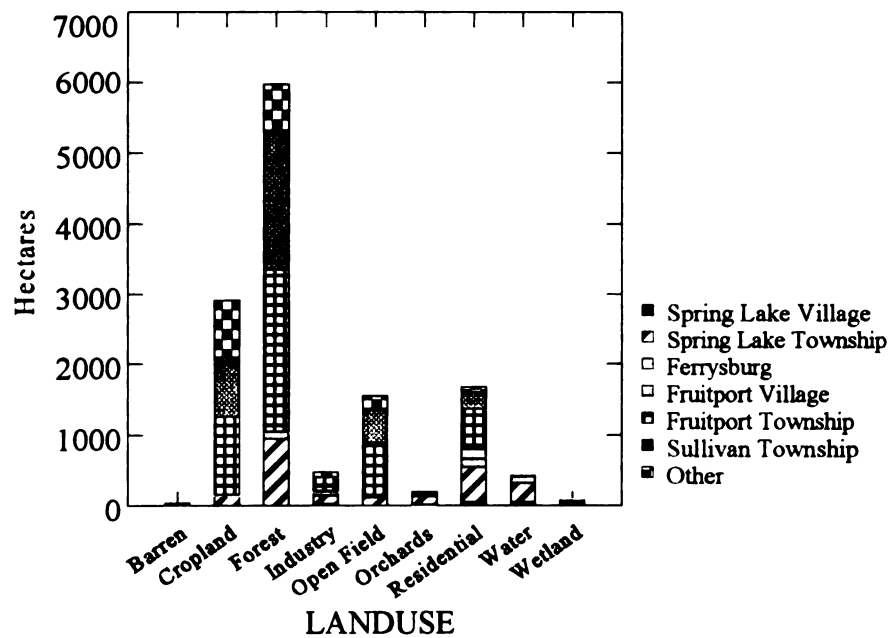


FIGURE 38: 1978 Land Use in Spring Lake Watershed (hectares)

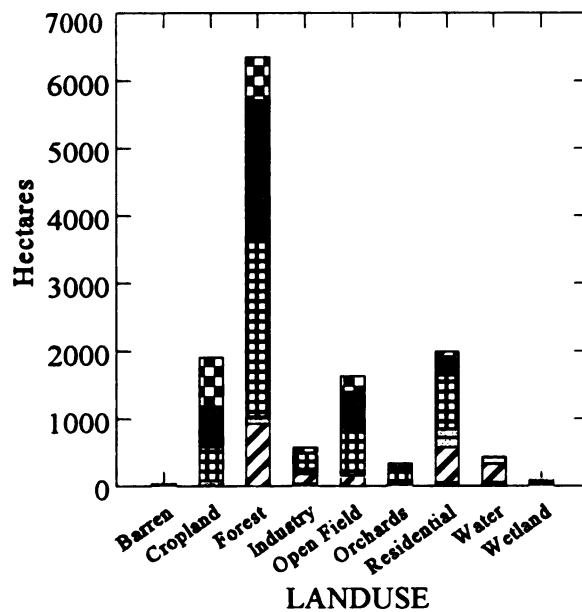


FIGURE 39: 1992-1997 Land Use in Spring Lake Watershed (hectares)

FIGURE 40: Map of 1978 Land Uses in the Spring Lake Watershed



FIGURE 40
**Spring Lake
 Watershed Project
 1978 Land Use and Cover**

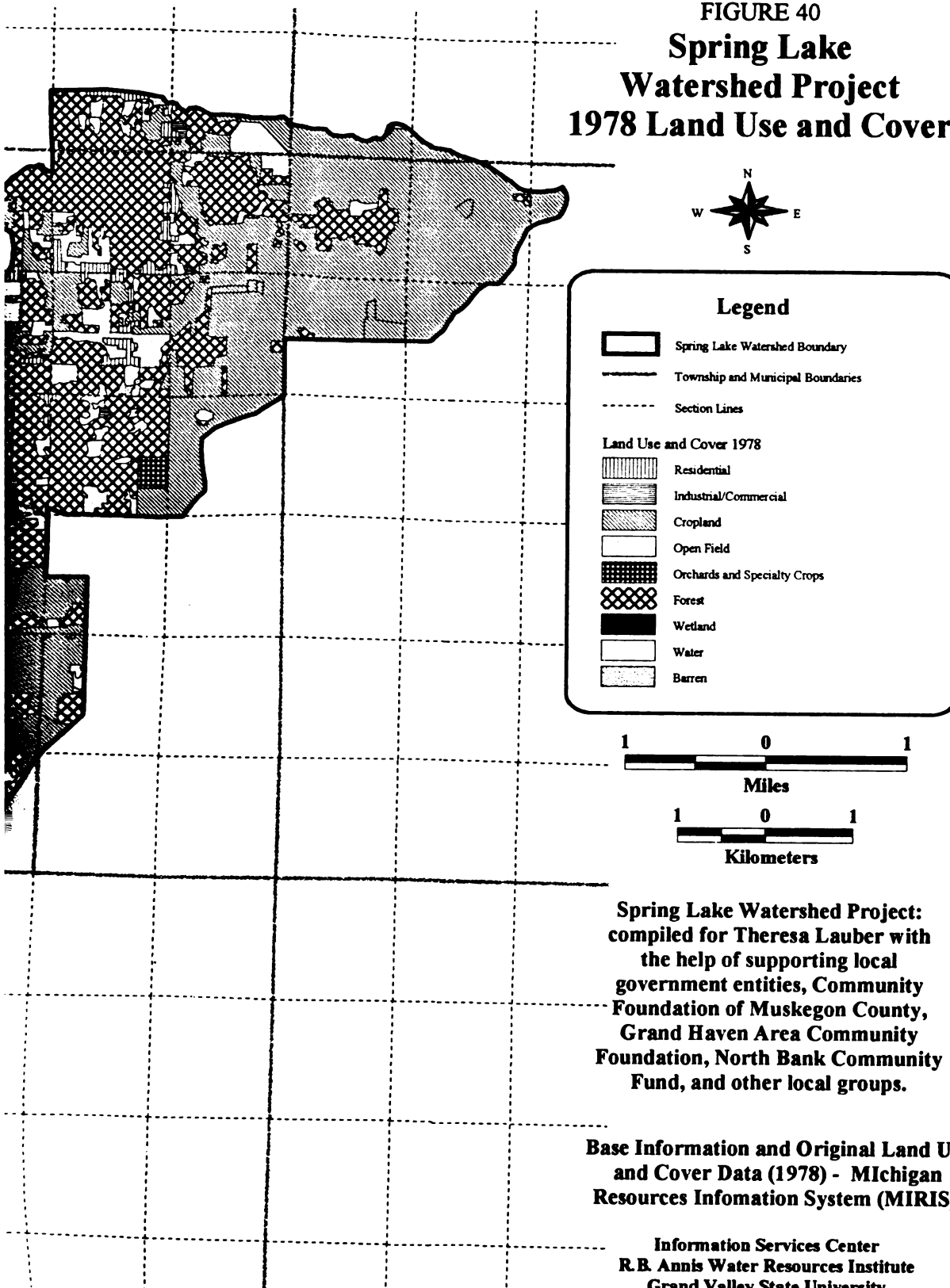
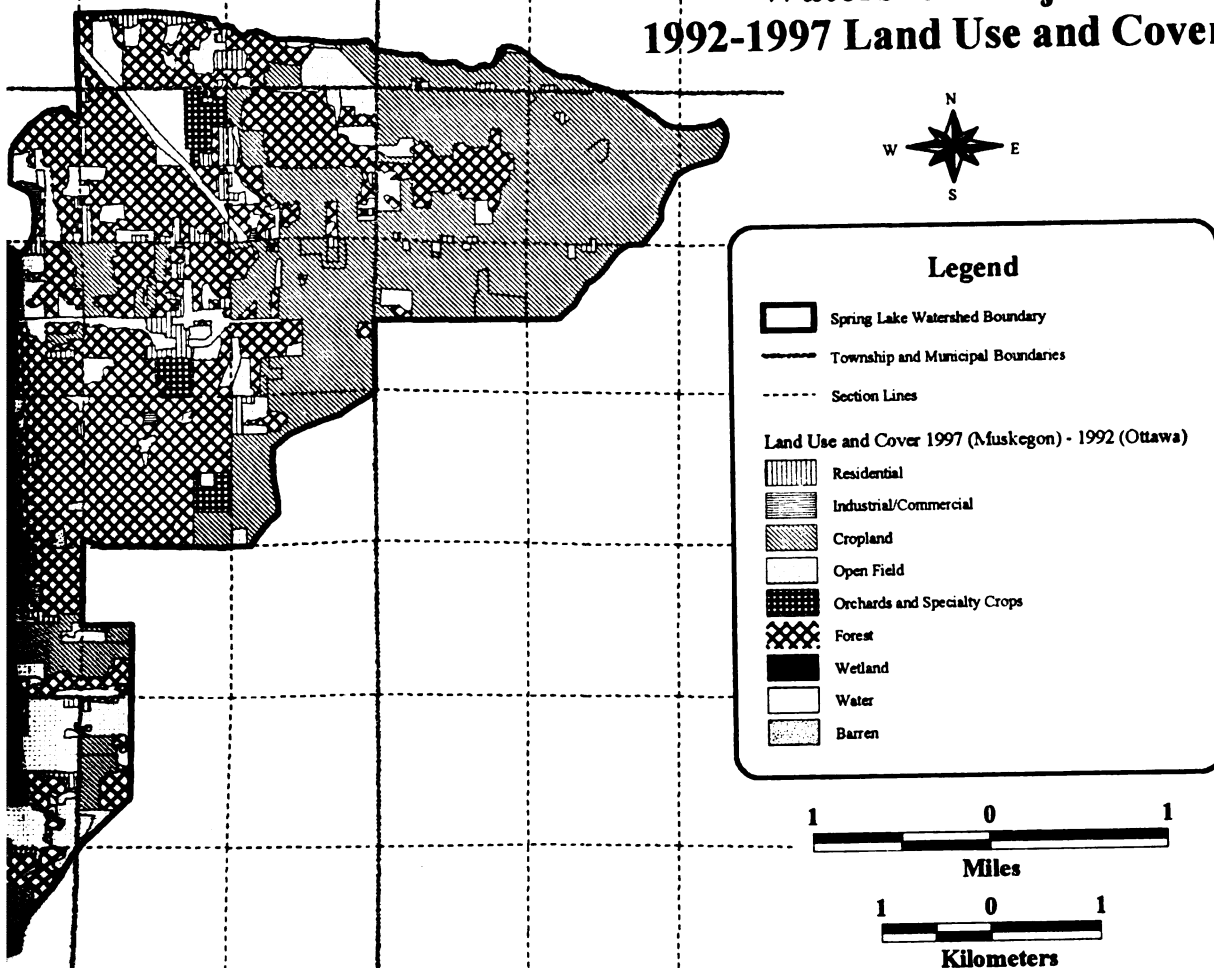


FIGURE 41: Map of 1992-1997 Land Uses in the Spring Lake Watershed



FIGURE 41
Spring Lake
Watershed Project
1992-1997 Land Use and Cover



Spring Lake Watershed Project:
 compiled for Theresa Lauber with
 the help of supporting local
 government entities, Community
 Foundation of Muskegon County,
 Grand Haven Area Community
 Foundation, North Bank Community
 Fund, and other local groups.

**Base Information and Original Land Use
 and Cover Data (1978) - MICHIGAN
 Resources Information System (MIRIS).**

**Information Services Center
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LAND USE AND CHLOROPHYLL MODEL

Recognition that land use changes is reflected in a lake's water quality has driven the development of many lake prediction models (Meeuwig & Peters 1996). These models include a variety of parameters such as land use percentages, precipitation, and nutrient concentrations in order to predict water quality characteristics like chlorophyll *a*. One model is (Meeuwig & Peters 1996): $\log \text{chlorophyll} = 0.418 - 0.272 (\log \text{retention time}) + 0.319 (\log \text{population size in the watershed}) - 0.227 (\log \text{forested area in the watershed})$. With the estimated watershed population of 17,291 (U. S. Department of Commerce 1990), 63.6 squared kilometers of forest, and an average retention time of the lake of 0.67 year, this model predicts that the annual mean of chlorophyll *a* concentration is 25.6 $\mu\text{g/l}$. Standard error in this model was estimated at 0.338. The measured annual chlorophyll *a* average was 41 $\mu\text{g/l}$ which is 1.6 times larger than the predicted concentration. Not reflected in this model, which may account for some of the difference, is the amount of internal loading and shoreline loadings from lawn fertilizers and septic systems. If 50% of Spring Lake Watershed's forests were lost in the future and all other parameters remain the same, the predicted chlorophyll *a* concentration with this model would be 29.9 $\mu\text{g/l}$ which is 17% higher than the first predicted concentration. Although this model is not a good fit for Spring Lake, it illustrates that a loss of forested lands in the watershed may be reflected by an increase in algae.

RESIDENT PERCEPTIONS AND THEIR USES OF THE LAKE

Human perceptions are the driving force behind lake management. People want to enjoy the lake's beauty, use it for recreation, irrigation, and business, and they expect the water

quality to be conducive for their activities. Recreation on Spring Lake includes activities such as swimming, boating, fishing, and bird watching. Thirty-four percent of the residents responding to the 1998 watershed questionnaire normally visited the lake or streams more than 10 times/year to go boating even though 24% did not own a boat (Table D4 in Appendix D for detailed survey counts). Although 51% felt that 1997 was a typical recreation year, about 40% of the people disagreed because of water quality, no time, or for other reasons. Water quality affected the recreational choices of about 10% of the people. Of the residents that did not think that 1997 was a typical recreational year, they normally boated (43%) and fished (25%) more than 10 times/year.

Many watershed respondents (62%) considered the water quality of Spring Lake to be unacceptable, while 83% of the shoreline residents agreed that the water quality was unacceptable. Of the 62% who found the water quality of the lake as unacceptable, 86% felt that fishing was impaired, 100% felt that swimming was impaired, and 70% felt that aesthetics were impaired (Figure 42). They identified the problems of unacceptable water quality as increased algae and aquatic plant growth (93%), water color (83%), and water smell (52%). Fifty-five percent of the respondents agreed that the water quality of the lake had declined in the past 5-10 years and they attributed the problems to increased algae and aquatic plant growth (86%), water color (78%), and water smell (49%).

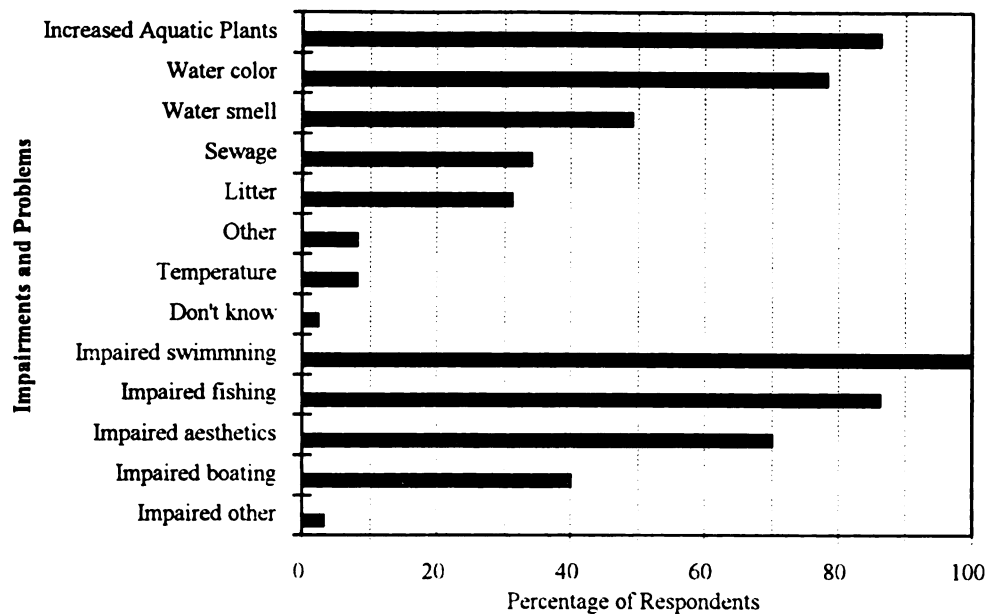


FIGURE 42: Percentage of Respondents' Answers on Impairments and Problems About Spring Lake

The survey recipients were also asked their opinion about the water sources for Spring Lake. When asked to choose the largest contributing water source, 35% chose streams, 32% chose springs, and 21% chose the Grand River. But when asked about the water quality of the largest stream, Norris Creek, 62% didn't know or were unsure and 30% found the water quality of Norris Creek as unacceptable. Those who found Norris Creek's water quality as unacceptable felt that the problem was from increased algae and aquatic plants (79%), increased sediments (65%), water color (65%), and water smell (50%). The large percentage of indecisiveness about Norris Creek may stem from a lack of knowledge and awareness of the creek. Sixty-three percent felt that the water quality of the Grand River was also unacceptable and attributed that to sewage (89%), water color (65%) and water smell (62%). This belief about the Grand River was expected due

to the many news reports about sewage overflows from Grand Rapids.

To explore more of the resident's beliefs about the lake and its benefits, questions were asked concerning the lake, economics, and health. Most respondents realized that fish must have good water quality (85%) but fewer realized that algae (31%), aquatic plants (54%), and zooplankton (56%) are also important for fish survival. Most respondents recognized the benefits of wetlands as a wildlife nursery (78%), improving water quality (61%), controlling floods (59%), and trapping sediments (54%). Ninety-one percent agreed that their health can be harmed by the land, air, and water quality of the watershed. Interestingly though, only 70% agreed that an ecologically healthy watershed is necessary for economic prosperity. The difference in percentages between these two latter statements may be due to the complexity of the questions and a range of beliefs about natural resource use. Holistic, these questions reflect a lack of knowledge and awareness about lake ecology, the life within the lake and how other nonliving things relate to living organisms.

The survey asked the respondents about their practices and about the causes of the water quality problems on Spring Lake. Forty-four percent said their residence was connected to sanitary sewer system and 37% were connected to a septic system. Of the lakeshore residents, 27% of the lake residents were serviced with septic systems. Dishwasher usage was asked because its detergents are a source of phosphates: 24% do not use dishwashers, 34% use them about twice a week and 21% use them about once a day. Car washing is another potential source of phosphates: 54% use car washes, 17% wash their car on the

pavement, 8% wash their car on the grass. Another practice, lawn or garden fertilizing is also a source of phosphates and nitrates: 21% do not fertilize, 18% fertilize once a year, 23% fertilize twice a year, 22% fertilize more than twice a year. Their highest rankings of the perceived causes of Spring Lake's problems were 20% failing septic tanks, 18% the Grand River, 18% runoff from lawn fertilizer, 15% industry/business discharge (Figure 43). When asked if they contribute to the pollution of the watershed, 27% responded as definitely not, 14% responded as probably do, 34% responded as yes, but try to minimize it, and 18% responded that they don't know. Sixty percent of the residents wanted more information on how to minimize their impacts. Therefore many residents do want to improve their practices around the watershed and place the blame of poor water quality on practices that can be easily changed — leaching septic systems and fertilizer runoff.

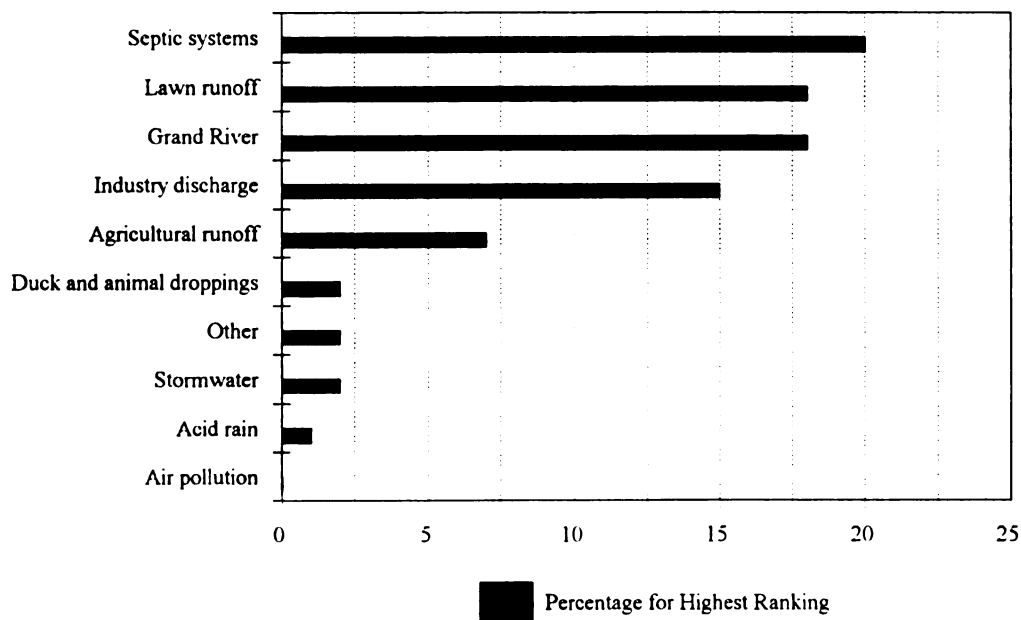


FIGURE 43: Percentage for Highest Rankings for Causes of Problems on Spring Lake from Resident Survey.

To aid in the writing of management recommendations now and in the immediate future, several ranking questions about management were asked. The highest top ranking issues in the watershed were 36% for pollution and 23% for water quality. Addressing speed and congestion (23%) and requiring safety education (20%) were the top-ranking suggestions for boating management. Forty-four percent felt that safety education was the highest ranking for managing swimmers. The top-ranking suggestion for improving businesses and industries treatment of the lake was reducing waste (49%). The respondents' top ranking of improving the residents' treatment of the lake were to connect to sanitary sewer system (22%) and to protect and restore wetlands (10%). Pollution and water quality were important issues to the respondents who also felt that residents should connect to sanitary sewer system and to protect wetlands. These answers are reflected in the management suggestions throughout this study.

Other survey questions were asked about the residents' characteristics. Sixty-four percent of the respondents knew their property was located in the watershed. Forty-five percent of the respondents' residence or property was located on the lake, bayou, or streams, while 50% were located elsewhere in the watershed. Seventy-five percent lived on their watershed property. The largest proportion (27%) of the respondents have lived in the watershed for more than 25 years, 24% have lived in the watershed between 6-15 years, and 17% between 1-5 years. Eighty percent lived in single family homes, did so year round (74%), and their household was composed of 1-2 persons (46%) and 3-4 persons (30%). Sixty-two percent were male and 34% were female of the age 36-45 years old (21%), 46-55 years old (27%), 56-66 years old (21%), and more than 66 years

old (21%). The majority of the respondents have attended college (77%) and have an income between \$20,000-\$79,999 (47%). The “common” survey respondent was a 46-55 year-old male from a family of 1-2 people who has lived year round, away from the shore, for more than 25 years and knew that he lived in the Spring Lake Watershed.

RECOMMENDATION LIST

To the Municipalities and Lake Board

- Address pollution and water quality issues in the watershed because 62% of watershed respondents and 83% of lakeshore respondents said the lake water quality is unacceptable.
- Begin a watershed wide land use committee as a subcommittee of all the planning and zoning boards to monitor and plan land usage within the entire watershed to bolster awareness that changes in land use will affect water quality.
- Protect and restore wetlands.
- Maintain and restore forested areas along all shorelines, lake and tributaries.
- Increase public education within all age sectors including adults on lake ecology and how common practices in and around the home influence water quality. Home*A*Syst and Lake*A*Syst programs, coordinated through Muskegon Conservation District and Ottawa County MSU-Extension office, specifically address these practices.
- Encourage schools and colleges to actively observe the lake and its tributaries as a form of education and long-term monitoring.
- Expand LakeWatch to include a StreamWatch by training volunteers in stream

monitoring.

To the Residents

- Actively participate in programs to increase knowledge about the watershed ecosystem and expand your stewardship of the natural environment.
Home*A*Syst and Lake*A*Syst programs provide useful resource booklets.
- Choose rip rap seawalls over solid seawall when possible. The sloping rocks provide more habitat for aquatic organisms than solid seawalls.
- Restore and protect wetlands. Do not fill wetlands as they provide a habitat to many species, filter water, retain sediments, and control floods.

SUMMARY

- Fruitport and Sullivan Township have the highest percentages of land use types among the 11 municipalities in the watershed.
- Currently, forest (47%), residential (15%), and crop land (14%) are the largest land use acreage in the watershed.
- Wetland areas have remained unchanged since 1978 and are important for water quality, sedimentation, and biodiversity.
- Only about 30% of the shoreline remains natural with the remaining 70% are divided between rip-rap shores (23%) and solid seawall (47%).
- If forested lands are lost in the watershed, a lake model predicts that an increase in algae concentrations may occur.
- Watershed survey respondents clearly identified pollution and water quality as

important issues in the watershed and 62% find the lake quality unacceptable.

- The residents' use of the lake is primarily boating and fishing and is influenced not only by time constraints but also by the lake's water quality.
- Overall knowledge about lake ecology by the residents is minimal.
- Sixty percent of survey respondents are willing to learn how to improve their practices so as to minimize their impact on the watershed.

CHAPTER 5

CAN THE BIG BAYOU BE SAVED?

SAVED FROM NUISANCE ALGAL BLOOMS?

Yes, the summer algal blooms of *Microcystis* and other algae species can be reduced. The current water quality conditions of Spring Lake can improve with widespread commitment to reducing nutrient inputs, phosphorus and nitrogen, through watershed-wide management techniques. During the winter, tributaries load 293 kg, septic systems load 188 kg, and lawn fertilizer runoff loads 155 kg of phosphorus into the lake, respectively contributing 44%, 28%, 23% of the total phosphorus input. Loadings from external non-point sources in the watershed, such as these loadings, are commonly addressed through best management practices that include buffer strips, sanitary sewer systems, compost piles, erosion controls, fertilizer reduction, and other agricultural practices. The highest phosphorus loadings during the summer are from septic systems (204 kg, 86%). Although internal loading from sediment may be large, no expensive in-lake management technique should be initiated until a more detailed water budget and nitrogen budget is developed. In the long run, reductions of the external loadings will eventually lead to a reduction in the internal loadings. The water residence time of this lake will aid in the lake's recovery by flushing out nutrients.

SAVED FROM NUISANCE AQUATIC PLANTS?

Yes, because aquatic plants cover only 27% of the lake and *nuisance* growth of these plants occur only in localized areas. *Ceratophyllum*, *Elodea*, *Heteranthera*, *Potamogeton*

pectinatus, and *Myriophyllum spicatum* were present in at least 50% of the sampled transects. Because of their dense growths, *Ceratophyllum* and *Rhizoclonium*, a macro algae, are most likely the nuisance culprits, disrupting boat movement and swimming. Shoreline residents can control these nuisance plants by raking or pulling them out of the water and then depositing the plants in a compost pile away from the shoreline. Use of herbicides to control them should be minimal because most applications contribute to the problem — high nutrients in the water and sediments. Besides, a lake completely devoid of plants is an unrealistic goal for a lake such as Spring Lake since plants are a necessary habitat and food source for many aquatic organisms. The back reaches of each bayou are fertile shallow areas for aquatic plants and animals and should be zoned as sanctuary areas with limited motor access. This action should decrease the amount of plant fragmentation and resuspension of sediments. When algal concentrations are reduced and water clarity increases, increased aquatic plant growth may occur. If this occurs, the aquatic plants will need to be managed more aggressively.

SAVED FROM THE EFFECTS OF THE GRAND RIVER?

No, unless Spring Lake is diked from the river, Spring Lake and the Grand River will always mix to some degree provided that the River and Harbor Act for dredging its 18 feet deep channel remains active (U. S. Army Corps of Engineers 1981). The degree of mixing is most likely greatly influenced by the flushing rates, water temperature, and the wind. During the winter season, Spring Lake's water residence time was 4.9 months and was 11.2 months during the summer; hence, more water exited Spring Lake and influenced the Grand River during the winter than the summer season. Since some mixing

does occur, it is not surprising to find similarities in their composition of phytoplankton and other water characteristics. The exchange of waters between the Grand River and Spring Lake along with the groundwater exchange need to be quantified more accurately due to the potential influence of these sources of water on Spring Lake's water quality.

SAVED FROM FUTURE CONSEQUENCES OF LAND AND WATER USES?

Perhaps. I believe the management goal for Spring Lake and its watershed should incorporate the needs of the residents for long-term beneficial uses (centuries). Any goal other than this would embrace immediate economic rewards and have potentially devastating consequences upon the watershed ecosystem. How can long-term management be achieved? Empowering the people through education will enable them to make wise decisions about their land and water use practices. Only through public education can some ecosystem management obstacles be overcome: widespread lack of knowledge on the dynamics and functions of the ecosystem that transcends municipality boundaries and fiscal years and the public perception that immediate economic and social value of a resource outweighs the risk of future ecosystem damage (N. Christensen et al. 1996). Education based on watershed research will expand public knowledge, disperse the economical and environmental haze of misunderstandings, and enable the community to plan for long-term management of the watershed ecosystem.

SUMMARY OF ALL RECOMMENDATIONS, PRIORITIES, AND RISKS

In Table 7, all recommendations are prioritized along with difficulty, risks, and cost and are listed as high, medium, low. These rankings are to serve only as a guidance tool.

TABLE 7: Summary of Recommendations for Spring Lake's Water Quality

Recommendations	Priority	Difficulty	Risks	Cost	Comments
Research					
Quantify groundwater and the Grand River Exchange.	high	high	none-if completed, many if not	medium	Requires professional researchers but as a collaborative project costs can be reduced. If not completed, additional management focuses may be wrongly directed.
Develop a nutrient budget for nitrogen.	high	high	none-if completed, many if not	medium	Requires professional researchers but as a collaborative project costs can be reduced. If not completed, additional management focuses may be wrongly directed.
Continue lake and stream monitoring.	high	low	low	low	If done as a collaborative effort, costs are minimal. If volunteers are recruited, trainings need to be held to ensure QAQC.
Develop wetland inventories for wetlands beyond the perimeter lake roads.	medium	medium	low	medium	Requires professional researchers.
Complete a limitation/dilution experiment.	medium	medium	low	low	Requires professional researchers.
To Municipalities and the Lake Board					
Address pollution and water quality issues in the watershed.	high	?	low	?	Important issues identified through the survey.
Encourage non-phosphorus fertilizer use and minimal use of all other types of fertilizer.	high	low	low	low	

TABLE 7: (cont'd).

Provide and enforce sewer connections for the shoreline and near-shoreline residents.	high	medium	low	high	
Divert storm water runoff to retention ponds when possible.	high	medium	low	?	
Control soil erosion at road crossings and along shorelines.	high	low	low	medium	
Begin a watershed-wide land use committee.	high	medium	low	low	Difficulty may come in uniting all municipalities in the watershed.
Protect and restore wetlands.	high	medium	low	medium	High priority because of development pressures.
Encourage schools to actively monitor the lake and its tributaries.	high	low	low	low	
Expand public education programs for all ages on watershed ecosystems and stewardship.	high	low	low	low	
Clean and maintain storm sewer traps.	medium	low	low	medium	
Regularly sweep streets.	medium	low	low	medium	
Reduce impervious surfaces when constructing new developments.	medium	low	low	low	
Maintain and restore forested areas along all shorelines, lake, and tributaries.	medium	medium	low	medium	Matching funds for homeowners may encourage green belt development.
Zone back portions of each bayou for aquatic plants and wildlife.	medium	medium	low	low	Difficulty may stem from some homeowners and legalities of zoning a public body of water.
Expand Lake Watch to include a StreamWatch.	medium	low	low	low	If a collaborative effort, costs will be low.
Develop a future management plan for a potential increase in aquatic plants if water clarity increases.	low	medium	low	medium	Needs to be completed by professionals.

TABLE 7: (cont'd).

To the Watershed Residents	Priority	Difficulty	Risks	Costs	Comments
Connect to city sewer when available.	high	medium	low	medium	
Protect and restore wetlands.	high	medium	medium	medium	
Rake or pull nuisance aquatic plants out of the water.	high	medium	low	low	
Actively participate in lake and watershed educational programs.	high	low	low	low	
For agricultural land uses, utilize BMPs programs recommended through the county conservation districts and National Resources Conservation Service.	high	low	low	medium	
Maintain an efficient septic system by pumping it every 3-5 years.	high	low	low	low	
Use only non-phosphorus fertilizers and reduce using all other types of fertilizers.	high	low	low	low	If fertilizing is reduced, a savings will most likely occur from purchase and mowing costs.
Put all leaves, twigs, grass clippings, and all other plant debris in a compost pile away from the shore instead of in the lake.	high	low	low	low	
Use low-phosphorus soaps in dishwashers and for other applications.	high	low	low	low	
Irrigate lawns and gardens appropriately without causing runoff.	high	low	low	low	
Reduce impervious surfaces when constructing new surfaces.	medium	medium	low	low	
Choose rip rap seawall over other solid types of seawall.	medium	medium	low	medium	
Establish a buffer strip along the shoreline.	medium	low	low	medium	
Maintain and restore shoreline trees.	medium	low	low	low	
Redirect rain gutter runoff to lawn or another grassy area.	medium	low	low	low	
Reduce sediment disturbance.	medium	low	low	low	

APPENDICES

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APPENDIX A

HYDROLOGY METHODS AND MATERIALS

FIGURE A1: Soil types of the Spring Lake Watershed

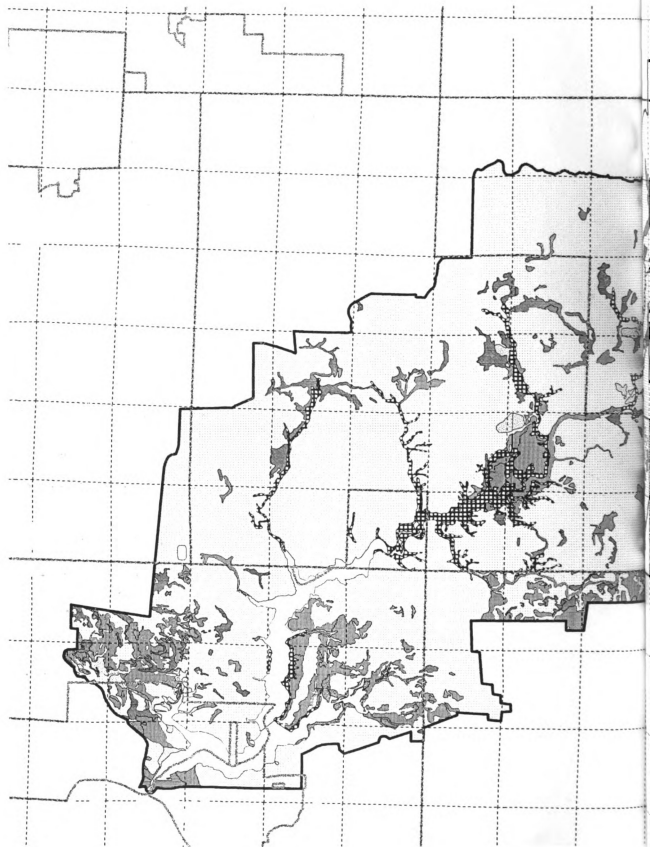


FIGURE A1 Spring Lake Watershed Project Soil Type by Series

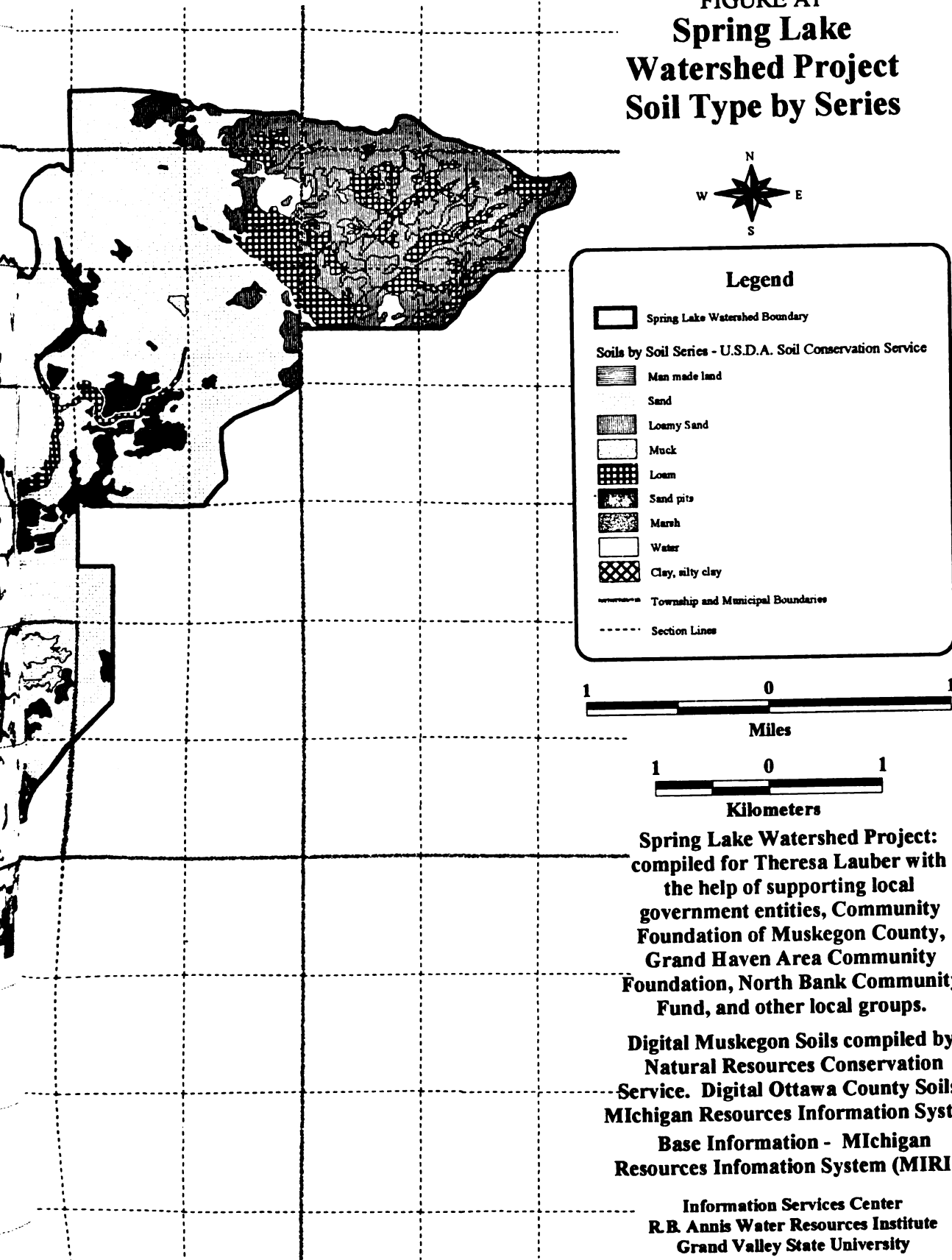


TABLE A1: Status and Details of Major Drains in the Spring Lake Watershed

DRAIN	CONTRIBUTES TO	LENGTH (MILE)	ESTABLISHED	STATUS
OTTAWA CO.				
Bowen/Spencer	Vincent Creek	0.7	1904	Cleaned last in about 1967
Castle	Spring Lake. Petty's	0.2	1975	Inspected regularly since 1988
Hickory Spring	Gildner Creek	0.7	1988	Cleaned. relocated in 1998
Lovell Park Storm	Spring Lake	0.2	1957	Not a drain, but inspected since 1988
Spring Lake	Spring Lake	0.5	1909	Lower end cleaned in 1997
Spring Lake	Spring Lake. Smith	2	1977	Maintained since 1988 and last major
VanderWall	Creek going into Petty's	0.7	1906	Last maintenance in 1993
MUSKEGON CO.				
Artibey	Norris Creek	1	1902	Cleaned last in 1983
Bowen	Vincent Creek	1.3	1900	Cleaned last in 1981
Bussing	Rhymer Creek	0.5	1926	Cleaned last in 1982
Dolph	Norris Creek	1	1906	Cleaned last in 1981
Eadie	Norris Creek	3.5	1899	Cleaned last in 1995
Farkas	Willow Hill Creek	2.5	1927	Cleaned last in 1981
Harvey	Jerusalem Creek	0.2		Not a drain, cleaned last in 1997
Knudsen	Norris Creek	1.4	1919	Cleaned last in 1981
Norris	Norris Creek	2.9	1899	Cleaned last in 1981
Rice	Norris Creek	0.9	1900	Cleaned last in 1985
Westover	Norris Creek	3	1907	Cleaned last in 1982
Wooley Marsh	Rhymer Creek	2	1917	Cleaned last in 1987
Youngs	Norris Creek	1.1	1899	Cleaned last in 1985

Information from Ottawa and Muskegon County Drain Commission Offices.

TABLE A2: The Grand River Water Levels at Grand Haven (m, IGLD) (U. S. Army Corps of Engineers)

Day	May97	June97	July97	Aug97	Sept97	Oct97	Nov97	Dec97	Jan98	Feb98	Mar98	April98	May98	June98	July98	Aug98	Sept98	Oct98
1	177.3	177.3	177.3	177.3	177.2	177.2	177.2	177.0	177.0	176.9	176.8	177.0	177.1	177.0	177.0	177.0	176.8	176.6
2	177.2	177.3	177.3	177.3	177.3	177.1	177.1	177.0	177.0	176.8	176.9	177.0	177.0	176.9	177.0	177.0	176.8	176.6
3		177.2	177.2	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.9	177.0	177.1	177.0	177.0	176.9	176.8	
4		177.2	177.2	177.2	177.2	177.2	177.1	177.0	177.0	176.9	176.8	177.0	177.0	177.0	177.0	176.9	176.8	176.6
5	177.1	177.2	177.2	177.2	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.0	177.0	177.0	176.9	176.8	176.8
6	177.1	177.2	177.2	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.0	177.0	177.0	177.0	176.7	176.7
7	177.2	177.2	177.2	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.1	177.0	177.0	177.0	176.8	176.7
8	177.2	177.2	177.2	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.0	177.0	177.0	177.0	176.8	176.7
9	177.2	177.2	177.2	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.0	177.0	177.0	177.0	176.7	176.7
10		177.2	177.2	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.0	177.0	177.0	177.0	176.7	
11		177.2	177.2	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.0	177.0	177.0	176.9	176.9	
12	177.2	177.2	177.2	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.1	177.0	177.0	176.9	176.9	176.7
13	177.1	177.2	177.2	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.0	177.0	177.0	176.9	176.8	176.7
14	177.2	177.2	177.2	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.1	177.0	177.0	176.9	176.8	176.6
15	177.3	177.2	177.2	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.0	177.0	177.0	176.9	176.8	176.7
16	177.1	177.2	177.2	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.0	177.0	177.0	176.9	176.8	
17		177.2	177.2	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.0	177.0	177.0	176.9	176.8	176.6
18		177.3	177.2	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.0	177.0	177.0	176.9	176.8	
19	177.3	177.2	177.2	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.0	177.0	177.0	176.9	176.8	176.6
20	177.2	177.2	177.2	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.0	177.0	177.0	176.9	176.8	
21	177.2	177.2	177.2	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.0	177.0	177.0	176.9	176.7	176.6
22	177.2	177.2	177.2	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.0	177.0	177.0	176.9	176.7	176.6
23		177.2	177.2	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.0	177.0	176.9	176.9	176.7	176.5
24		177.2	177.2	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.0	177.0	176.9	176.9	176.7	
25		177.2	177.2	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.0	177.0	176.9	176.9	176.7	
26		177.3	177.3	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.0	177.1	177.0	176.9	176.9	176.6
27	177.2	177.3	177.3	177.3	177.2	177.2	177.1	177.0	176.9	176.8	176.8	177.0	177.0	177.0	176.9	176.9	176.9	176.6
28	177.3	177.3	177.3	177.2	177.2	177.0	177.0	176.9	176.8	176.8	176.8	177.0	177.0	177.0	176.9	176.9	176.7	176.6
29	177.3	177.3	177.3	177.2	177.2	177.0	177.0	176.9	176.8	176.8	176.8	177.0	177.0	177.1	176.9	176.9	176.7	176.6
30	177.3	177.3	177.3	177.2	177.2	177.0	177.0	176.9	176.8	176.8	176.9	177.0	177.0	177.0	176.9	176.9	176.7	176.6
31			177.3	177.3	177.2	177.0	177.0	176.9	176.8	176.8	177.0	177.0	177.0	177.0	176.9	176.9	176.7	176.6

TABLE A3: Mean Water Levels for Spring Lake (m)

Day	May97	June97	July97	Aug97	Jan98	Mar98	April98	May98	June98	July98	Aug98	Sept98
1			0.04								-0.44	
2			0.05					-0.24		-0.32	-0.44	
3								-0.23		-0.34		
4							-0.27			-0.27		
5							-0.32			-0.30		
6							-0.40					
7											-0.35	
8			0.04				-0.15				-0.34	
9			0.07								-0.37	
10								-0.23			-0.35	
11		-0.02			-0.52		-0.27			-0.34		
12				0.03			-0.33	-0.21		-0.35		
13				0.03					-0.31		-0.40	
14	-0.07		0.07				-0.24		-0.27		-0.21	
15	-0.13							-0.26	-0.23		-0.36	
16	-0.06	-0.02						-0.23		-0.34	-0.34	
17	0.04							-0.29				
18	-0.08						-0.30			-0.35		
19							-0.32			-0.32		-0.55
20							-0.28	-0.21	-0.31	-0.37		
21		0.01							-0.28			
22		0.02				-0.28					-0.44	
23	-0.04		0.10					-0.30			-0.43	
24			0.02					-0.27				
25							-0.26	-0.32	-0.31	-0.34		
26							-0.15	-0.28		-0.40		
27	0.01								-0.26	-0.44		
28								-0.32	-0.30			
29								-0.30		-0.39	-0.44	
30	0.03							-0.25			-0.47	
31					-0.50			-0.18				

TABLE A4: Stream Discharges (m³/sec) for Discrete Dates (◆) and Total Discharge Volume for Intervals (m³)

Dates	Norris at Pontaluna (m ³ /sec)	Willows at Pontaluna (m ³ /sec)	Stevens at Pontaluna (m ³ /sec)	Jerusalem at Rycenga (m ³ /sec)	Smith at 174 (m ³ /sec)	Vincent at Bridge (m ³ /sec)	Other small streams (m ³ /sec)	Total Discharge (m ³ /sec)	Total Discharge volume per day (x 10 ⁵ m ³)	Total Interval Volume (x 10 ⁵ m ³)
13Aug-22Nov97◆	*0.382	*0.088	*0.315	*0.044	*0.024	*0.216	0.05	1.119	0.97	97.65
22Nov97-11Jan98◆	1.336	0.115	0.426	0.095	0.046	0.480	0.05	2.548	2.20	110.07
11Jan-31Jan98◆	*1.510	*0.186	*0.520	*0.107	*0.076	*0.811	0.05	3.259	2.82	56.32
31Jan-22Mar98◆	*2.070	*0.512	*0.860	*0.206	*0.082	*0.684	0.05	4.464	3.86	192.87
19Sept-16Oct98◆	*0.931	*0.046	*0.245	*0.010	*0.051	*0.064	0.05	1.398	1.21	31.39
Average	1.246	0.189	0.473	0.092	0.056	0.451	0.05	2.558	2.21	97.66
16May-23May97◆	*0.824	*0.170	*0.135	*0.029	0.024	*0.131	0.05	1.363	1.18	8.24
16June-1July97◆	0.389	0.080	0.240	0.077	0.046	0.123	0.05	1.005	0.87	13.02
1July-2July97◆	0.297	0.075	0.250	0.078	0.047	0.106	0.05	0.904	0.78	0.78
2July-8July97◆	0.354	0.133	0.321	0.104	0.056	0.130	0.05	1.147	0.99	5.95
8July-9July97◆	0.224	0.048	0.250	0.069	0.043	0.089	0.05	0.773	0.67	0.67
9July-14July97◆	*0.248	0.039	0.252	0.066	0.042	*0.093	0.05	0.790	0.68	4.10
14July-23July97◆	0.149	0.048	0.252	0.000	0.000	0.038	0.05	0.537	0.46	4.18
23July-12Aug97◆	0.120	0.196	0.354	0.146	0.071	0.072	0.05	1.009	0.87	16.56
12Aug-13Aug97◆	0.297	0.065	0.297	0.062	0.040	0.072	0.05	0.883	0.76	0.76
29May-30May98◆	*0.355	*0.117	*0.367	*0.011	*0.022	*0.042	0.05	0.964	0.83	0.83
18July-19July98◆	*0.293	*0.011	*0.289	*0.004	*0.009	*0.000	0.05	0.656	0.57	0.57
30Aug-19Sept98◆	*0.286	*0.038	*0.362	*0.005	0.007	*0.111	0.05	0.859	0.74	14.85
Average	0.320	0.085	0.281	0.054	0.034	0.084	0.050	0.907	0.78	5.88

* Discharges calculated from measured flows, all others are estimated from stage-discharge regressions.

TABLE A5: Calculations for Seasonal Water Budget

Interval	Average Lake Level, beginning, end of interval, (m)	Lake Volume Change in Interval ($\times 10^5 \text{ m}^3$)	Lake Volume at the interval end ($\times 10^5 \text{ m}^3$)	Total Stream Volume ($\times 10^5 \text{ m}^3$)	Precipitation (inches)	Number of Days in Interval	Precipitation on Lake ($\times 10^5 \text{ m}^3$)	Daily Evaporation (inches)	Evaporation Volume ($\times 10^5 \text{ m}^3$)	Residuals ($\times 10^5 \text{ m}^3$)
13Aug-22Nov97	0.032, -0.33*	-18.85	291.84	97.65	7.84	101	10.36	see notes	12.61	-114.24
22Nov97-11Jan98	-0.33*, -0.52	-9.62	281.96	110.07	3.69	50	4.87	see notes	6.05	-118.52
11Jan-31Jan98	-0.52, -0.5	1.04	283.00	56.32	0.78	20	1.03	0	0.00	-56.31
31Jan-22Mar98	-0.5, -0.28	11.18	294.44	192.87	4.02	50	5.31	0.035	2.31	-184.68
19Sept-16Oct98	-0.54, -0.6*	-2.86	277.80	31.39	2.27	26	3.00	see notes	3.02	-34.23
Average	-0.44	-3.82	285.81	97.66	3.72	49.4	4.91	0.007	4.80	-101.60
16May-23May97	-0.055, -0.04	0.57	306.71	8.24	0.09	7	0.12	0.113	1.05	-6.75
16June-1July97	-0.022, 0.038	3.09	307.02	13.02	1.69	15	2.23	0.178	3.53	-8.64
1July-2July97	0.038, 0.048	0.56	311.50	0.78	0.05	1	0.07	0.178	0.24	-0.05
2July-8July97	0.048, 0.04	-0.43	311.08	5.95	0.5	6	0.66	0.178	1.41	-5.63
8July-9July97	0.04, 0.069	1.52	312.59	0.67	0	1	0.00	0.178	0.24	1.08
9July-14July97	0.069, 0.066	-0.17	312.43	4.10	0.07	6	0.09	0.178	1.41	-2.95
14July-23July97	0.066, 0.1	1.86	314.20	4.18	0.94	9	1.24	0.178	2.12	-1.44
23July-12Aug97	0.1, 0.028	0.39	310.46	16.56	1.78	19	2.35	0.157	3.94	-14.58
12Aug-13Aug97	0.028, 0.032	0.26	310.66	0.76	0	1	0.00	0.157	0.21	-0.30
29May-30May98	-0.3, -0.25	2.17	296.00	0.83	0	1	0.00	0.113	0.15	1.48
18July-19July98	-0.35, -0.32	1.69	292.36	0.57	0.05	1	0.07	0.178	0.24	1.29
30Aug-19Sept98	-0.47, -0.54	-3.99	280.92	14.85	2.74	20	3.62	0.12	3.17	-19.28
Average	-0.1	0.63	305.49	5.88	0.66	7.25	0.87	0.159	1.47	-4.65

* Lake level estimated from lake vs. Grand River regression in Table A9.

Notes: 13Aug-22Nov97: Aug. 0.157, Sept. 0.120, Oct. 0.068, Nov. 0.046;

22Nov97-11Jan98: Nov. 0.046, Dec. 0.029, Jan. 0.0;

19Sept-16Oct98: Sept. 0.120, Oct. 0.068

APPENDIX A

HYDROLOGY METHODS AND MATERIALS

Water Levels

For Spring Lake, staffs were located at the mouth of Spring Lake, Smith Bayou, Jerusalem Bayou, Norris Creek at Third Street Bridge, Petty's Bayou and in the channel between Spring Lake and the Grand River. The means of the lake levels were calculated from at least two of the staff readings. Two different water levels, or stage levels, were obtained for the Grand River: readings at Grand Haven and readings at Grand Rapids. Weekday readings from Grand Haven were acquired from the U. S. Army Corps of Engineers (1997-1998). Hourly stage readings from Grand Rapids, which were used to determine the daily mean, were acquired from the U. S. Geological Service in Lansing (1999). Lake Michigan stage levels were obtained from the National Oceanic and Atmospheric Administration's web site (1999).

Water Budget

A water budget was estimated from varying interval periods of precipitation, stream inputs, evaporation, and lake volume change.

$$\Delta L = P + T - E \pm R$$

L = the change in the lake volume

P = precipitation on the lake's surface

T = inflow from tributaries

E = lake evaporation

R = residuals

Lake Volumes

The change in lake volume was estimated by subtracting the initial lake volume from the final lake volume during that interval. Volumetric stages of the lake were found by using a 1990 National Oceanic and Atmospheric Administration bathymetric map of Spring Lake and metered staff gauges (Lesack & Melack 1995). If lake levels were not measured for a particular date, they were estimated from a regression with Grand River stage levels at Grand Haven. See Table A9 below for the regression equation.

A Tamaya Digital Planimeter Planixle on the 1990 lake bathymetric map was used to measure the volumes of the four lake strata using this equation, $h/3 (A1 + A2 + (A1A2)^{1/2})$ (Wetzel & Likens 1991). To calculate the total lake volume and surface area, the strata were summed (Table A4). Standard error of planimeter usage was ± 0.08 or $\pm 0.04\%$ and a conversion error of 0.12%. Since a 1990 map was utilized, corrections were applied to obtain current total lake volumes. A current Lake Michigan water level from Ludington, 580.1 feet (NOAA 1998) and current Grand River level at Grand Haven, 579.9 feet (U.S. Army Corps of Engineers 1997- 1998) were averaged and compared to the level used in the 1990 map which was the 1955 Lake Michigan level of 576.8 feet. The water level difference was 3.2 feet or approximately 1 meter. For current lake volumes, a correction of $5.2 \times 10^6 \text{ m}^3$ was added to the lake volume obtained from the bathymetric map.

TABLE A6: Lake Strata Volumes and Uncorrected Total Lake Volumes

Strata Layer	Depth Layer	Volume (x 10⁶ m³)
Top Layer	Surface to 6 feet	7.70
Second Layer	6 feet to 12 feet	5.72
Third Layer	12 feet to 18 feet	4.90
Fourth Layer	18 feet to 28 feet (average depth of bottom layer)	7.38
Total		25.7

Precipitation

Beginning May 1997 and until Sept. 1998, precipitation was measured daily from 1 tipping bucket rain gauge located about 0.5 miles northwest of Stahl Bayou by the Kotecki family. These precipitation recordings were compared to the precipitation records from the Muskegon County Airport, which is approximately 1-2 miles from the northwestern corner of the watershed. Very little variation existed; therefore, airport precipitation records were utilized (Table A7 & A8). For water budget calculations, daily precipitation within an interval was summed for the interval precipitation and multiplied by the surface area of the lake to obtain interval precipitation volume on the lake surface. All interval precipitation volumes were averaged for the seasonal water budget.

Tributaries

Stream discharges were calculated from the multiplication of the cross-sectional areas and tributary velocities as measured by surface floats and when available, a pygmy flow meter.

For cross-sectional areas, depths were measured every half meter and along three consecutive transects and averaged. Three to five surface velocities were timed within

these transects and the harmonic average was calculated. Average differences between the velocity measurement methods were approximately 20%. Since all stream bottoms were predominately sand, no correction factors were included in the discharge calculations.

Tributary stage levels were also noted when discharges were measured. Stream stage levels were recorded from posted staff gauges and other permanent structures such as bridges at 10 sites on 7 different streams: Norris Creek @ Pontaluna, Norris Creek @ Sternberg, Norris Creek @ Third, Rhymer Creek @ Mt. Garfield, Willow's Hill Creek @ Pontaluna, Steven's Creek @ Pontaluna, Jerusalem Creek @ Rycenga Park, Smith Creek @ 168th, Vincent Creek @ Bridge, Vincent Creek @ 130th (Figure 8). After a range of different stage levels and discharges were recorded, stage vs. discharge regressions were calculated to estimate discharge directly from stage level. See Table A4 for measured and estimated discharges. Log functions were used only when relationships were improved. Discharges and the stage/discharge relationship for Norris Creek at Third Street bridge were not used because of very low adjusted R^2 , due most likely to direct influences from Spring Lake. Instead, the summed discharges from Norris Creek at Pontaluna Road, Vincent Creek at Bridge Street and Willows Hill Creek at Pontaluna Road, which are the main feeder streams into Norris Creek, were substituted for the total Norris Creek discharge. Small streams such as Beckwith Creek and Gildner Creek were occasionally measured and discharges were approximately 0.01m³/sec. Due to minimal individual influence of these small streams, including Timber Creek, and two unnamed tributaries flowing into Petty's Bayou and through Fruitport, their individual discharges were

summed for an estimated total discharge of $0.05\text{m}^3/\text{sec}$ was used for the water budget.

The following Table A9 records the regression equations. Assuming that discrete tributary discharges taken during the interval were representative of a daily discharge during the interval, the discharges for the tributaries during a discrete measuring interval were summed, converted to cubic meters per day, and then multiplied by the number of days in the interval to obtain the total interval volumes from the tributaries. The average of the interval volumes was calculated for each season for the water budget. This method of calculation assumes that the discharge for a measured interval remains the same for that interval and its error has been estimated at 12% of absolute mean (Cooke et al. 1993).

TABLE A7: 1997 Precipitation at Muskegon County Airport (inches, T=trace)

Day	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1	0.10	0	0.12	0	0.07	0	0	T	0	0	0.48	0
2	0.01	0	0	0	0.38	0	0.05	0	T	0.04	0.32	0
3	0.00	0	0	0.01	T	0	T	0.01	0	0	0.44	0.07
4	0.81	0.5	0.02	0.04	0	0	T	0	0	0.19	0.02	0.05
5	T	0	0.02	0.42	0.22	0	0	0	0.03	0	0.13	0.15
6	T	T	T	T	0	0.29	0	0	0	0	0.09	0.06
7	T	0.01	T	T	0.15	0	0	0	0	0	0	0.04
8	0	T	T	T	0.62	0	0.5	0	0	T	0	0
9	0.07	T	0.17	T	0.04	0	0	T	0.11	0.14	0.04	T
10	0.1	T	T	0	0	0	0	0.11	0.02	0	0.06	0.15
11	T	0.01	T	0.32	0.03	T	0	0.14	0	0	0.01	0
12	0.01	0.04	0	0.18	0	0	0	0.91	0	T	0.01	0.02
13	0.01	0	0.07	0.01	0	0	0.05	0	0	0.28	T	0
14	T	T	0.22	0	0.21	0	0.02	0.03	0.4	0	0.01	0
15	0.1	T	T	0.05	0.12	0.03	0	0.84	0	0	0.04	0
16	0.01	0.09	T	0.11	0.08	0.99	0.03	0	1.31	0	0.01	0
17	T	0	0	T	0	0	0.25	0.23	0.65	0	0	0
18	0.01	0	0	0	0.08	0	0	0	T	0	0	0
19	0.01	0	0	0	0.01	T	0	T	0.5	0.02	0	T
20	0	0.54	0	0	T	0.55	0	0.3	0	0	0.14	0.02
21	0.51	1.44	0	0.05	0	1.14	0.66	T	0	T	0	0
22	0.05	T	0	0	0	0	0	0	0.01	0	T	0.01
23	T	0.03	0.01	T	0	T	0	0.03	0	0.17	T	T
24	0.05	T	0.03	0.11	0.03	T	0	0.04	0	0	0.01	0.34
25	0.03	T	0.1	0	T	T	T	0	0	0	0.02	0.01
26	0.01	0.19	0	0	0	0	0.41	0	0	0.38	0.02	0.02
27	0.09	0.45	0	T	0	0	0	0.13	0	0.03	0.24	T
28	T	0	0.16	0	0	0	0.18	0	0.02	0.02	0.01	0.02
29	0.03	0	0	0	0.21	0	0	0	T	0	0.17	0.22
30	T	0	0.03	0.5	T	0	0	0.1	0.05	0	0.16	0.01
31	0.02	0	0	0	0	0	0	0.01	0	0.01	0	0.03

TABLE A8: 1998 Precipitation at Muskegon County Airport (inches, T=trace)

Day	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1	0	0.01	T	0.12	0.17	T	0	0	0.86	0	0	0
2	0	T	0.05	0.01	0.06	0	0	0	0	0.01	0	0
3	0.08	0.02	T	T	0.01	0	0.35	T	0	0.44	0	0
4	0.58	0	0.05	T	0	0	T	1.61	0	0	0	0.19
5	0.49	0	0	0	T	0.03	0	0.28	0	1.02	0	0
6	0.34	0	0.05	0	0	T	0.12	0.02	T	0.24	0.01	0.82
7	0.05	0	0	0	0	0	T	0.15	0.17	0.01	0	0
8	0.1	0	0.51	0.26	T	0	0	0	T	0	0.1	0
9	0.19	0	0.48	0.02	0	0.31	0	T	0	0	0.27	0
10	T	0.03	0.03	0	0.01	T	0	T	0	0	1.09	0
11	T	0.55	T	T	0	0.57	0	0	0	0	0	0
12	0.05	0.01	0	T	0.02	0	0	0	0	0	0	0
13	T	T	0.13	0.02	0.48	0	0	0	0	0.01	0	0
14	0.1	0	0.01	0.05	0	0	0	0	0.98	0.01	0	0
15	0.01	0	0	0.1	0	0	0	0	0.73	0	0	0
16	0	0.1	0	0.08	0	0	0	0	0	0	0.03	0.07
17	0	0.18	0.3	0	0	0	T	0.08	0	1.22	0.04	0.07
18	0.02	0	0.47	0	0	0.12	0	0	0	0.29	0.01	0
19	0.02	T	0.19	0	0.04	T	0.05	0	0	0	0	0
20	T	0.01	0	0	0	0	0.18	0	T	0	0.05	0
21	T	0	0	0.14	0	0	0.3	0	0.03	0.01	0	0.04
22	0.01	T	0	0	0	T	0.03	0.05	0	0	0	0
23	0.2	0	0	0	0	0	0	0.01	0	0	0	0
24	0	0.06	0	0	0.1	T	0	0.21	0.02	0	0	0
25	0.04	0	T	0.01	T	T	T	0.13	0.01	0	0.07	0
26	0.01	0	T	0.7	0	T	0	0	0.01	0	0	0
27	0	0.27	0	0	0	0.2	T	T	0	0.43	0	0
28	0	0.51	0.22	0	0.17	0.06	0	0.38	0	0.01	0	0
29	0.32	0	0	0.07	0.42	0.02	0	0	0.1	0.2	0.01	0.14
30	T	0	T	0.26	0	0.02	T	0	0.36	0.07	0.55	0
31	0	0	1.16	0	0.41	0	0	0	0	0	0	0.01

TABLE A9: Regressions Utilized in Water Budget Calculations

Regressors	Equations	Adjusted R²
Jerusalem Creek at Rycenga Park	discharge = $-0.072 - 1.279 \log \text{stage}$	0.813
Norris Creek at Pontaluna Road	discharge = $2.48 - 2.932 \text{ stage}$	0.889
Smith Creek at 174 Street	discharge = $0.396 - 0.467 \text{ stage}$	0.791
Smith vs. Jerusalem Creeks	$\log \text{smith} = -0.579 + 0.679 \log \text{jersusalem}$	0.764
Spring Lake vs. Grand River at Grand Haven	$\text{spring lake water level (cm)} = -17501.9 + 30.1 \text{ water level at Grand Haven (ft)}$	0.799
Stevens Creek at Pontaluna Road	$\log \text{discharge} = -0.997 - 1.15 \log \text{stage}$	0.394
Vincent Creek at Bridge Road	discharge = $0.803 - 1.7 \text{ stage}$	0.843
Willows Creek at Pontaluna Road	discharge = $1.313 - 1.687 \text{ stage}$	0.901

Evaporation

Evaporation was estimated by using open pan evaporation rates from South Haven, Michigan that were corrected for Gull Lake, Michigan (Tague 1977). Since ice was only on the lake for one month in 1998 and mostly in January, January's evaporation rate was estimated to be zero. February, March, April, November, and December pan evaporation inches were proportioned between months as Tague did using monthly temperature means (Table A10). Daily evaporation rates were multiplied by the number of days in an interval, converted to meters per day, and multiplied by the lake surface area for the evaporation from the lake surface to obtain interval evaporation in cubic meters. If intervals spanned different months, the evaporation rate for each month was multiplied by

the number of days in that month. The average of the intervals was calculated for each season in the water budget.

TABLE A10: Monthly Pan Evaporation and Spring Lake Evaporation Estimates

Month	Class A Pan Evaporation (inches)(Tague1977)	Lake Evaporation (inches)	Daily Evaporation (inches)
January	0	0	0
February	1.26	0.953	0.034
March	1.42	1.07	0.035
April	2.22	1.68	0.056
May	4.64	3.51	0.113
June	5.6	4.23	0.141
July	7.29	5.51	0.178
August	6.44	4.87	0.157
September	4.78	3.61	0.120
October	2.79	2.11	0.068
November	1.81	1.37	0.046
December	1.18	0.89	0.029
Totals	39.43	29.803	

Grand River Exchange

To measure the flow in the channel connecting Spring Lake to the Grand River, a plexiglass drogue, shaped like an “X,” was constructed which was approximately 0.6m by 0.3m and was connected to a float with a rope. The drogue was placed at approximately 2/3 of the channel depth at varying intervals from the shore. Discharge was then calculated from the average cross section area and average flow velocities measured with the drogue. Measurement of the flow proved to be difficult due to boat traffic, boat

turbulence, and flow reversals.

Another method was attempted in hopes of quantifying the exchange between Spring Lake and the Grand River. This method employed tracers which are existing or applied chemical components of the water that can be analytically tested. Differing concentrations of tracers can determine the extent of mixing of two waters and has been utilized in the study of large South American floodplain lakes (Hamilton 1998). Samples from Spring Lake and the Grand River from a single date were analyzed for reliable tracers of existing chemicals: calcium, magnesium, sodium, potassium, chlorine, sulfate, silica, and fluorine. Because the water chemistry was so similar between the river and lake, this method could not be employed.

Residuals

Residuals were calculated from the remaining differences in the water budget equation.

Seasonal Water Budget

The intervals were grouped into seasons: winter (October - April) and summer (May - September). Averages of the individual components of the seasonal water budgets were obtained by summing all the intervals in each season for each component. Then, the component sums were divided by the average number of days in the seasonal intervals, 49.4 and 7.25, for the winter and summer water budget respectively to obtain the seasonal averages. Winter and summer hydraulic residence times were calculated by dividing the seasonal lake volume by the sum of the seasonal inputs and then multiplied by

the average number of intervals for each season.

Water Budget Error

Total error for this type of water budget equation is a quadratic sum of all the individual errors of each component. As summarized in Table A11, published error limits for each component were multiplied by its seasonal and annual volumes to convert the error to a water volume (Lesack & Melack 1995). To obtain the error volume for the residual, each error volume of the other components was squared, summed, then the square root was taken (Lesack & Melack 1995). Percentages of error for the residuals were found by dividing the error residual volume by the residual volume averages in Table A5.

TABLE A11: Error Limits and Volumes from Water Budget Components ($\times 10^3 \text{ m}^3$)

Component	Lower Error Limit %	Winter	Summer	Annual	Higher Error Limit %	Winter	Summer	Annual
Lake Storage (Lesack & Melack 1995)	12	0.46	0.11	1.96	30	1.14	0.19	4.91
Precipitation (Winter 1981)	5	0.19	0.03	1.26	15	0.56	0.10	3.79
Tributaries (Winter 1981, Cooke et al. 1993)	19	18.5	1.12	89.9	35	34.1	2.06	165.6
Evaporation (Tague 1977, Winter 1981)	10	0.48	0.15	2.45	29	1.39	0.43	7.11
Residuals	18, winter 25, summer 18, annual	18.5	1.14	90.0	34, winter 45, summer 34, annual	34.2	2.11	165.9

The residual error seems to be most sensitive to the tributaries which concurs with Lesack & Melack's (1995) conclusion that their runoff component was the largest influence on their residual. The residual errors of the seasons range from 18% to 45% and the

associated volumes are 1 to 4 times larger than winter input of precipitation and 2 to 7 times larger than the summer input of precipitation. Although error is fairly large, the budget still enables the hydrology of the watershed to be studied.

Stormwater

Stormwater runoff from the 81 stormwater outfalls was not measured but was estimated from precipitation volume on street area within 500 ft of the shoreline. This area was subjectively chosen to represent the most influential area of impervious surfaces and probably underestimates the real area of impervious surfaces which would include houses, driveways, and parking lots. Also not included in the estimated area were areas beyond the 500 ft which may directly contribute stormwater runoff to the lake via stormwater sewers. From Geographical System Information on the Spring Lake Watershed, all highways, county and residential roads within the 500 foot's perimeter were estimated to be 105,450 feet (Thompson 1999). Assuming the average road width is 20 feet wide, the street area is 2,109,000 square feet or 195,926 square meters. Precipitation falling on this area then directly contributes a certain volume to the lake. To obtain this contributing volume for a specific interval, the precipitation amounts are multiplied by the area just as was done for the precipitation volume falling directly onto the lake surface (Table A12).

TABLE A12: Stormwater Volume Estimates for Spring Lake

Dates	Interval Precipitation (inches)	Precipitation volume on streets in 500 ft perimeter (m³)
22Nov97	7.84	39016
11Jan98	3.69	18363
31Jan98	0.78	3882
22Mar98	4.02	20006
16Oct98	2.27	11297
Average	3.72	18513
23May97	0.09	448
1July97	1.69	8410
2July97	0.05	249
8July97	0.5	2488
9July97	0	0
14July97	0.07	348
23July97	0.94	4678
12Aug97	1.78	8858
13Aug97	0	0
30May98	0	0
19July98	0.05	249
19Sept98	2.74	13636
Average	0.66	3284

APPENDIX B

WATER QUALITY METHODS AND MATERIALS

APPENDIX B

WATER QUALITY METHODS AND MATERIALS

Lake and Tributary Water Sampling Regime

Approximately once a month water samples from seven sites in the lake and bayous were taken in the middle of the epilimnion, surface water layer, and hypolimnion, bottom water layer (Figure 8). When stratification occurred, the metalimnion (middle layer) was also sampled at the deep water sites of Prospect Point and Spring Lake. The Grand River was sampled off shore from the former Holiday Inn (Figure 8). These sites were subjectively chosen in the bayous and the main stem of the lake by taking into account common depths in the bayous and the deepest depths in the main stem of lake. Each site was also located in the middle of the water body latitudinally to minimize shoreline effect, except for the Spring Lake site which was located closer to the Village of Spring Lake shore due to potentially dangerous boat traffic in and out of the channel. The water layers were identified from temperature profiles using YSI 85 probe, measuring temperature at every meter. Water samples were taken from the middle of each layer with a two liter Kemmerer stainless steel sampling bottle. About 14 tributary sites were sampled periodically along with one storm event (Figure 8). Six tributary sites were sampled regularly: Smith Creek @ 168th, Jerusalem Creek @ Rycenga Park, Steven's Creek @ Pontaluna Road, Willows Hill Creek @ Pontaluna Road, Norris Creek @ Pontaluna Road, and Vincent Creek @ Bridge Street. Water samples were taken by directly filling sample bottles below the water surface when possible (some tributaries were very shallow).

Sample Processing

All water samples were put into dark Nalgene bottles and immediately placed on ice.

Syringe filtering through a cellulose acetate membrane with pore size of 0.45 μm took place in the field during spring, summer, and fall months, and on shore during winter.

Upon reaching shore, samples were placed in a refrigerator until analysis. Bottles were cleaned with non-phosphate detergent, rinsed 3 times, acid rinsed, and finally rinsed three times with distilled deionized Type 1 water.

Field Measurements

When water samples were obtained, the following field measurements were made at the lake and tributary sites:

1. Temperature, conductivity, specific conductivity, and dissolved oxygen at one-meter depth intervals with YSI 85 probe meter.
2. Surface pH with an Oakton pHTestr 2.
3. Secchi depths with a 20 cm Secchi disk with 0.1 meter increments.

To identify the extent of the mixing zone in the Spring Lake mouth channel, specific conductivity, temperature, and dissolved oxygen measurements were taken a couple of times throughout the 1998 water year at points parallel to the channel shoreline.

Water Analyses

All water analyses were conducted within a week of sampling except for chlorophyll a analysis (Table B1). Upon filtering, chlorophyll samples were placed in a deep freezer or a -70°C freezer until they were analyzed up to four months later. All analyses were

completed by myself or an assistant except for nitrate and ammonium analyses which were done by the R.B. Annis Water Resources Institute / Grand Valley State University.

Laboratory space and equipment was graciously made available at the R.B. Annis Water Resource Institute / Grand Valley State University. Sample scanning for an ion or cation tracer were completed by Dr. Stephen Hamilton's laboratory at Kellogg Biological Station - Michigan State University.

Statistics and Graphing

Statistical analysis and most graphing was completed using SYSTAT 7 and SYSTAT 8. Other graphs were produced using Quatro Pro.

Trophic Status Index

Carlson's trophic status index was used because it is commonly used by the state government. The simplified equations are (Carlson 1977, Reckhow and Chapra 1983):

$$TSI = 60 - 14.41 \ln (\text{Secchi Depth in meters})$$

$$TSI = 9.81 \ln (\text{Chlorophyll a in } \mu\text{g/l}) + 30.6$$

$$TSI = 14.42 \ln (\text{Total Phosphorus in } \mu\text{g/l}) + 4.15$$

TABLE B1: Water Quality Laboratory Methods and Equipment

Parameter	Protocol	Equipment and Detection Limits	Averages: Lab Blank, Field Blank, % Recovery
Total Phosphorus	Persulfate Digestion & Ascorbic Acid Method, #4500 (American Public Health Assoc. 1989)	Shimadzu ASC-5 Auto-Sampler Spectrophotometer, .01 mg/l	<0.01mg/l <0.01mg/l 89%
Soluble Reactive Phosphorus	Ascorbic Acid Method, #4500 (American Public Health Assoc. 1989)	Same as above	<0.01mg/l <0.01mg/l 96%
Total Dissolved Phosphorus	Persulfate Digestion & Ascorbic Acid Method. #4500 (American Public Health Assoc. 1989)	Same as above	<0.01mg/l <0.01mg/l 86%
Alkalinity	Potentiometric Titration to 4.5 pH. #2320 (American Public Health Assoc. 1989)	Orion Model 920A with pH probe	
Suspended Solids	Dried at 105°C. #2540 (American Public Health Assoc. 1992)	Oven. Mettler AE200 Analytical balance	-0.4 mg/l
Volatile Solids	Dried at 550°C. #2540 (American Public Health Assoc. 1992)	Muffle oven and above balance	0.6 mg/l
Chlorophyll a	Acetone Extraction Method using Welschmeyer lens, USEPA #445.0 (Turner 1993)	Turner Model 10-AU Digital Fluorometer with Welschmeyer lens specifications,	<0.01µg/l 0.71µg/l
Nitrate	Ion chromatography except for *Sept. and Oct. 1998	DX500 Dionex *Orion Model 920A with probe	
Ammonium	Cation chromatography except for *Sept. and Oct. 1998	D2020I Dionex *Orion Model 920A with probe	

TABLE B2: Soluble Reactive Phosphorus Concentrations in Spring Lake and the Grand River (mg/l).

Lake Sites	1997										1998					
	8May	16June	15July	23Aug	23Aug	27Sept	25Oct	14Dec	8Mar	12May	15Jun	6Aug	20Aug	19Sept	16Oct	
Fruitport.E1	<0.01	0.01	0.01	0.08	0.08	0.03	0.03		0.01	<0.01	<0.01	0.10	0.08	0.06	0.07	
Fruitport.E2			0.01			0.03	0.03		0.01	<0.01						
Fruitport.E(Field dup)			0.01													
Fruitport.E2(field dup)			0.01													
Fruitport.m1											0.00					
Fruitport.H1	<0.01	0.00	0.10	0.05	0.09	0.04	0.03			<0.01	0.02	0.10		0.07		
Fruitport.H2			0.10			0.04	0.03					0.10				
Fruitport.H(Field dup)																
Fruitport.H2(field dup)			0.10													
Stahl.E1	<0.01	<0.01	<0.01	0.07	0.10	0.04	0.03		0.01	<0.01	<0.01	lost	0.06	0.06	0.08	
Stahl.E2			0.01	0.07		0.04	0.04		0.01	<0.01	<0.01	lost	0.06		0.08	
Stahl.M											<0.01					
Stahl.H1	<0.01	0.01	0.04	0.08	0.10	0.04	0.04			<0.01	<0.01	0.08		0.08		
Stahl.H2			0.04	0.10		0.04	0.04			<0.01						
Jerusalem.E1	<0.01	<0.01	0.01	0.09	0.08	0.04	0.04		0.01	0.01	<0.01	lost		0.06	0.09	
Jerusalem.E2						0.04	0.04		0.01		<0.01					
Jerusalem.H1	0.01	0.02	0.08	0.07	0.07	0.04	0.04			<0.01	0.01	lost		0.07		
Jerusalem.H2						0.04	0.04									
Smith.E1	<0.01	0.01	0.01	0.06	0.05	0.03	0.03		<0.01	<0.01	<0.01	0.05	0.04	0.06	0.08	
Smith.E2			0.01			0.03	0.03		<0.01		<0.01					
Smith.H1	<0.01	<0.01	0.02	0.05	0.01	0.03	0.03			<0.01	<0.01	0.05		0.06		
Smith.H2			0.02			0.03	0.03									
Grand River.1	<0.01	<0.01	<0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.03	<0.01	0.01		0.01	0.01	
Grand River.2						0.03	0.01		0.02			<0.01	0.03	0.06	0.08	
Spring Lake.E1	<0.01	0.01	<0.01	0.04	0.02	0.04	0.03	0.03		0.01	<0.01	0.05				
Spring Lake.E2						0.03	0.03				<0.01			0.06		
Spring Lake.M			0.04	0.03		0.02				0.01	<0.01			0.06		
Spring Lake.M2				0.03		0.02				<0.01	<0.01					
Spring Lake.H1			0.48	0.35		0.01	0.03	0.03		0.01	0.04	0.05		0.08	0.08	
Spring Lake.H2			0.35	0.35		0.01	0.03			0.01	0.02	0.05				
Prospect Point.E1	<0.01	0.01	0.01	0.04	0.05	0.06	0.03	0.03	0.01	0.01	<0.01	0.05		0.08	0.09	
Prospect Point.E2						0.05	0.03	0.02	0.01	0.01					0.09	
Prospect Point.M1			0.04	0.28	0.28	0.04	0.03			<0.01	0.02	0.12		0.18		
Prospect Point.M2						0.05				<0.01						

TABLE B2: (cont'd).

Prospect Point.H1	<0.01	0.14	0.53	0.72	0.78	0.02	0.02	0.02	0.02	<0.01	0.16	0.53	0.43	0.05
Prospect Point.H2	<0.01	0.01	<0.01	0.02	0.04	0.02	0.02	0.02	0.02	<0.01	<0.01	0.53	0.05	0.07
Petty.E1	<0.01	<0.01	<0.01	0.02	0.02	0.02	0.03	0.03	0.03	<0.01	<0.01	0.06	0.04	0.05
Petty.E2	<0.01	<0.01	<0.01	0.02	0.04	0.02	0.03	0.03	0.03	<0.01	0.02	0.05	0.05	0.05
Petty.H1	<0.01	<0.01	0.01	0.01	0.04	0.01	0.02	0.02	0.02	<0.01	0.02	0.05	0.10	0.05
Petty.H2	<0.01	<0.01	<0.01	0.03	0.01	0.01	0.02	0.01	0.02	<0.01	<0.01	0.05	0.35	0.05
Grand River.1	<0.01	<0.01	<0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	<0.01	0.01	0.01	0.01
Grand River.2						0.03	0.01	0.01	0.01	0.02	<0.01	<0.01		

Symbol notation: E, M, H = epilimnion, metalimnion, hypolimnion

1, 2 = laboratory replicates

Field dup = field duplicates

TABLE B3: Total Dissolved Phosphorus Concentrations in Spring Lake and the Grand River (mg/l)

Lake Sites	1997										1998					
	8 May	28 May	16 June	15 July	23 Aug	27 Sept	25 Oct	14 Dec	8 Jan	12 May	15 June	6 Aug	20 Aug	19 Sept	16 Oct	
Fruitport.E1	0.00	0.02	0.03	0.02	0.06	0.04	0.04		0.02	0.01	0.01	0.14	0.09	0.06	0.09	
Fruitport.E2				0.02		0.04	0.04		0.02			0.14	0.09		0.09	
Fruitport.E(Field dup)																
Fruitport.m1											0.02			0.09		
Fruitport.H1	0.01	0.01	0.02	0.10	0.06	0.05	0.04			0.01	0.03	0.11				
Fruitport.H2				0.11		0.05	0.04			0.01						
Fruitport.H(Field dup)				0.10												
Stahl.E1	0.01	0.02	0.02	0.02	0.07	0.05	0.05		0.02	0.01	0.01	0.08	0.07	0.11	0.10	
Stahl.E2						0.05	0.05		0.02							
Stahl.m1											0.01					
Stahl.m2											0.01					
Stahl.H1	0.01	0.01	0.02	0.05	0.08	0.05	0.05			0.01		0.10		0.08		
Stahl.H2																
Jerusalem.E1	0.01	0.02	0.02	0.02	0.07	0.06	0.05		0.02	0.02	0.02	0.08		0.07	0.12	
Jerusalem.E2				0.02	0.07	0.05	0.05		0.02	0.02				0.07	0.12	
Jerusalem.H1	0.01	0.01	0.03	0.09	0.07	0.06	0.05			0.01	0.03	0.08		0.07		
Jerusalem.H2					0.06	0.06	0.05			0.01		0.08				
Smith.E1	0.01	0.02	0.02	0.03	0.04	0.05	0.05		0.01	0.01	0.03	0.07	0.05	0.08	0.10	
Smith.E2					0.04	0.05	0.04		0.01	0.02	0.01	0.07	0.05	0.08	0.10	

TABLE B3: (Cont'd).

Smith.II1	0.01	0.01	0.01	0.03	0.04	0.04	0.04	0.04	0.04		0.01	0.02	0.02	0.08		0.08	
Smith.H2					0.04	0.05	0.05				0.02	0.02	0.07	0.02		0.02	0.02
Grand River.1	0.01	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.02	0.04	0.01	0.02			0.02	0.02
Grand River.2		0.03			0.03	0.03	0.02	0.03	0.02	0.02	0.03	0.04	0.01			0.02	0.02
Spring Lake.E1	0.01	0.02	0.02	0.03	0.04	0.05	0.04	0.04	0.04	0.04	0.02	0.02	0.05	0.06	0.05	0.13	0.09
Spring Lake.E2				0.02	0.05	0.05	0.05	0.05	0.04	0.04	0.01	0.02	0.06	0.06			
Spring Lake.M				0.05	0.04	0.04	0.04				0.01	0.02			0.08		
Spring Lake.M2				0.05	0.04	0.04	0.04										
Spring Lake.H1	0.01	0.02	0.12	0.42	0.35	0.02	0.02	0.04	0.03	0.03	0.01	0.05	0.07		0.17		
Spring Lake.H2				0.47		0.02	0.02	0.04	0.03	0.03	0.01	0.04					
Prospect Point.E1	0.01	0.02	0.02	0.02	0.05	0.06	0.06	0.05	0.04	0.04	0.02	0.02	0.07		0.13	0.10	
Prospect Point.E2						0.06	0.06	0.04	0.04	0.04	0.02						
Prospect Point.M1				0.06	0.25	0.05	0.05				0.01	0.03	0.13		0.17		
Prospect Point.M2						0.05	0.05					0.03	0.12				
Prospect Point.H1	0.01	0.04	0.11	0.50	0.58	0.03	0.03	0.03	0.03	0.03	0.01	0.16	0.54	0.38	0.07	0.07	0.07
Prospect Point.H2												0.17					
Petty.E1	0.01	0.02	0.03	0.02	0.03	0.04	0.04	0.04	0.02	0.02	0.02	0.02	0.07	0.05	0.06	0.09	0.09
Petty.E2				0.02		0.04	0.04	0.04	0.03	0.03			0.07			0.09	0.09
Petty.H1	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.04	0.04	0.02	0.03	0.06	0.11	0.35	0.07	0.07
Petty.H2				0.02		0.03	0.04	0.04	0.04	0.04	0.01	0.03		0.11	0.11	0.07	0.07

Phosphorus Mass Budget Estimates

Unweighted means of total phosphorus concentrations in the lake and the Grand River are the last row in Table B4 and B5. Summer lake concentrations of total phosphorus were volumetrically weighted for use in the mass budget. When the lake was stratified, summer total phosphorus concentrations for the lake were volumetrically weighted by the proportion of the limnion volume to the total summer lake volume ($31.2 \times 10^6 \text{m}^3$) for each sampling date. By planimetry the lowest measured lake stratum volume was at the 18 foot depth from the surface and its stratum depth was 24 feet and its volume was $7.4 \times 10^6 \text{m}^3$. By using temperature depth readings, the hypolimnion depth was approximated for each sampling date. Since all hypolimnion depths were deeper than 18 feet, the hypolimnion weighting factor was calculated from the proportion of the hypolimnion depth to the strata depth which was then multiplied to the ratio of the strata volume to total lake volume for changes across sampling days. The epilimnion weighting factors were found by the difference of the hypolimnion weighting factor from one. Total phosphorus means from all epilimnion and hypolimnion (only Spring Lake and Prospect Point) were weighted and summed for the average lake total phosphorus means. See Table B6 for weighting factors and total phosphorus concentrations during stratification. The summer mean for Spring Lake's total phosphorus concentration was 0.1 mg/l. When the lake was not stratified, simple means of total phosphorus concentrations were taken to obtain lake mean such as for the winter which was 0.06 mg/l. After converting to mg m^{-3} , the average total phosphorus concentrations of the winter and summer seasons were then multiplied by the average change in lake volume from the water budget to obtain the change in the lake's phosphorus mass (mg were then converted to kg).

TABLE B4: Total Phosphorus Concentrations in Spring Lake (mg/l)

Year	1997										1998					
	8May	28May	16June	15July	26Aug	27Sept	25Oct	14Dec	8Mar	12May	15Jun	6Aug	20Aug	19Sept	16Oct	
Fruitport.E1	0.03	0.04	0.06	0.10	0.10	0.09	0.05		0.04	0.04	0.06	0.16	0.13	0.11	0.09	
Fruitport.E2	0.05	0.04	0.06			0.09	0.05		0.04	0.05	0.06	0.16	0.12	0.11	0.09	
Fruitport.E(Field dup)				0.09												
Fruitport M1											0.04					
Fruitport M2											0.04					
Fruitport.H1	0.04	0.05	0.05	0.12	0.10	0.09	0.05			0.03	0.06	0.15		0.12		
Fruitport.H2	0.06	0.05	0.04			0.09	0.05			0.03	0.06			0.12		
Fruitport.H(Field dup)				0.12												
Stahl.E1	0.04	0.06	0.05	0.08	0.12	0.09	0.05		0.04	0.04	0.06	0.13	0.10	0.12	0.09	
Stahl.E2	0.04	0.06		0.08		0.09	0.05		0.04	0.04	0.06	0.13	0.10	0.12	0.09	
Stahl M1											0.04					
Stahl M2											0.04					
Stahl.H1	0.04	0.05	0.04	0.06	0.12	0.09	0.05			0.03	0.06	0.13		0.12		
Stahl.H2	0.04	0.05		0.08		0.09	0.04			0.03	0.07			0.12		
Jerusalem.E1	0.04	0.06	0.04	0.10	0.12	0.10	0.05		0.06	0.06	0.06	0.13		0.12	0.10	
Jerusalem.E2	0.04	0.05				0.10	0.05		0.08	0.06		0.13		0.12	0.09	
Jerusalem.H1	0.03	0.05	0.06	0.11	0.10	0.09	0.05			0.03	0.05	0.12		0.10		
Jerusalem.H2	0.04	0.05				0.09	0.05			0.03	0.05			0.10		
Smith.E1	0.04	0.05	0.05	0.04	0.09	0.09	0.04		0.04	0.05	0.09	0.12	0.09	0.12	0.08	
Smith.E2	0.04	0.04			0.09	0.09	0.04		0.04	0.04	0.09		0.09	0.11	0.08	
Smith.H1	0.03	0.04	0.04	0.04	0.09	0.08	0.04			0.04	0.04	0.12		0.10		
Smith.H2	0.04	0.06			0.08	0.08	0.04			0.04	0.04	0.12		0.10		
Spring Lake.E1	0.05	0.06	0.05	0.05	0.09	0.10	0.05	0.05		0.06	0.06	0.11	0.09	0.11	0.09	
Spring Lake.E2	0.04	0.05				0.09	0.04	0.05		0.06	0.06	0.11	0.09	0.11	0.09	
Spring Lake.M1				0.05	0.09	0.09				0.03	0.06				0.11	
Spring Lake M2					0.09	0.09				0.03	0.06				0.11	

TABLE B4 (cont'd).

Year	1997										1998				
	8May	28May	16June	15July	26Aug	27Sept	25Oct	14Dec	8Mar	12May	15Jun	6Aug	20Aug	19Sept	16Oct
Spring Lake.H1	0.05	0.05	0.16	0.41	0.39	0.14	0.05	0.05		0.04	0.08	0.15		0.14	
Spring Lake.H2	0.04	0.05				0.14	0.04	0.05		0.04	0.09			0.14	
Prospect Point.E1	0.06		0.05	0.06	0.09	0.10	0.05	0.05	0.04	0.06	0.06	0.11		0.11	0.09
Prospect Point.E2	0.05	0.06		0.06	0.09	0.10	0.05	0.05	0.04	0.06	0.06	0.11		0.11	0.09
Prospect Point.M2				0.05	0.32	0.08				0.03	0.06			0.20	
Prospect Point.H1	0.04	0.05	0.16	0.43	0.72	0.08	0.04	0.05		0.04	0.22	0.56		0.45	0.08
Prospect Point.H2	0.03	0.05		0.38	0.74	0.08	0.04	0.05		0.04	0.22	0.56		0.45	0.08
Petty.E1	0.03	0.04	0.07	0.07	0.09	0.09	0.05	0.04		0.05	0.06	0.11	0.09	0.09	0.09
Petty.E2	0.03	0.04			0.09	0.09	0.04	0.04		0.05	0.07	0.11	0.09	0.09	0.09
Petty.H1	0.04	0.04	0.04	0.05	0.09	0.08	0.04	0.05		0.04	0.06	0.10	0.37	0.13	0.07
Petty.H2	0.04	0.04			0.08	0.08	0.04	0.05		0.04	0.06		0.37	0.12	0.07
Unweighted Average	0.04	0.05	0.06	0.12	0.18	0.09	0.04	0.05	0.05	0.04	0.07	0.17	0.14	0.14	0.09
Standard Dev	0.007	0.007	0.038	0.117	0.192	0.014	0.004	0.005	0.012	0.01	0.04	0.126	0.107	0.085	0.008

E = Epilimnion, M = Metalimnion, H = Hypolimnion

1, 2 = Laboratory duplicates

Field Dup = Field Duplicates

TABLE B5: Total Phosphorus Concentrations in the Grand River (mg/l)

TABLE 2. Total Insecticide Concentrations in the Grand River (mg/l)														
Year	1997								1998					
	8May	28May	16June	15July	26Aug	27Sept	25Oct	14Dec	8Mar	12May	15Jun	6Aug	19Sept	16Oct
Grand River.1	0.07	0.09	0.11	0.10	0.10	0.09	0.06	0.04	0.11	0.10	0.11	0.11	0.12	0.10
Grand River.2	0.07	0.09		0.10	0.10	0.08	0.06	0.04	0.12	0.10	0.11	0.11	0.12	0.10
Average	0.07	0.09	0.11	0.10	0.10	0.09	0.06	0.04	0.12	0.10	0.11	0.11	0.12	0.10
Standard Dev	0.001	0.002		0.00	0.004	0.002	0.004	0.00	0.001	0.002	0.001	0.001	0.002	0.001

TABLE B6: Total Phosphorus Concentrations and Weighting Factors for Stratified Sampling Days in Spring Lake

Dates	Proportion of Hypolimnion Depth to Lower Strata Depth	Epilimnion Weighting Factor	Mean Epilimnion (mg/l)	Hypolimnion Weighting Factor	Mean Hypolimnion (mg/l)	Weighted Mean Total Phosphorus (mg/l)
16June97	0.95	0.775	0.05	0.225	0.16	0.07
15July97	0.95	0.775	0.08	0.225	0.41	0.15
26Aug97	0.54	0.872	0.1	0.128	0.62	0.16
27Sept97	0.38	0.91	0.09	0.09	0.11	0.09
15Jun98	0.79	0.813	0.06	0.187	0.15	0.08
6Aug98	0.95	0.775	0.12	0.225	0.42	0.19
19Sept98	0.42	0.9	0.11	0.1	0.30	0.13

Low and High Estimates for Phosphorus Budget

For the seasonal low and high estimates, the uncertainty error estimates from the water budget were utilized for the lake mass, deposition, and tributary loadings. The lower error limit volumes for lake storage, precipitation, and tributaries were subtracted from the average volumes to obtain the low budget volume which was multiplied by the appropriate total phosphorus mean. The same method was employed for the high estimate but the limit volume was added to the average volume. For the annual total, the commutative water budget sums were used.

Loading from Atmospheric Deposition

Loading of phosphorus directly onto the lake surface consists of dry atmospheric deposition and wet precipitation, neither of which was directly measured during this study. Other studies have measured the concentrations in different locations throughout Michigan and results vary widely. For the closest location to this watershed, an United States Environmental Protection Agency study from 1980 found atmospheric phosphorus load in Grand Haven, MI to be 236 lbs/m²/yr (Keilty 1996). This annual loading was not used because of difficulties in extrapolating it for the interval periods. Another study done at Gull Lake had measured both dry and wet deposition and estimated loading at 275 kg/year (Tague 1977). Tague also reported mean concentration as 37.6 mg m⁻³. This concentration was then multiplied by each season's precipitation volume in the water budget to obtain the mass loading from the atmosphere.

Tributary Loading

Total phosphorus concentrations for tributary samples are in Table B7. Seasonal averages were obtained by averaging the concentrations in each season: winter 0.03 mg/l and summer 0.04 mg/l. These concentrations were then multiplied by the average tributary inputs from the water budget to obtain the loading mass for the tributaries for each season.

TABLE B7: Total Phosphorus Concentrations of Spring Lake Tributaries (mg/l)

	18May97	11Jun97	8July97	25Oct97	12Jan98	22Mar98	30May98	19Jul98	19Sept98	16Oct98
Norris@Pontaluna.1	0.04	0.04	0.08	<0.01	0.08	0.14	0.05	0.05	0.03	0.02
Norris@Pontaluna.2	0.04			<0.01	0.08	0.14		0.05	0.03	0.02
Willows@Pontaluna.1	0.01	0.02	0.08	<0.01	0.02	0.02	0.02	0.03	0.02	0.01
Willows@Pontaluna.2	0.01	0.02		<0.01	0.02	0.02	0.02	0.03	0.02	0.01
Vincent@Bridge.1	0.03	0.04	0.05	<0.01	0.04	0.05	0.04	0.08	0.04	0.02
Vincent@Bridge.2	0.03			<0.01	0.04	0.05		0.08	0.04	0.02
Jerusalem@168.1	0.03	0.02	0.02		0.02	0.02	0.02	0.02	0.01	0.01
Jerusalem@168.2	0.03				0.01	0.02	0.02	0.02	0.01	0.01
Stevens@Pontaluna.1	0.04	0.04	0.09		0.04	0.04	0.04	0.04	0.07	0.04
Stevens@Pontaluna.2	0.04				0.06	0.04		0.03	0.06	0.04
Smith@168.1					0.04	0.04	0.04	0.04		0.02
Smith@168.2					0.04	0.04		0.04		0.02
Small Trib:Beckwith	0.02	0.03						0.06		
Small Trib:Gildner					0.02					
Average	0.03	0.03	0.07	<0.01	0.04	0.05	0.03	0.04	0.03	0.02
Standard Deviation	0.012	0.01	0.029	0.005	0.023	0.045	0.012	0.02	0.021	0.011

Note: 1, 2 indicate laboratory duplicates.

Stormwater Runoff Loading

Stormwater runoff from the 81 stormwater outfalls was not measured but was estimated from precipitation volume on street area within 500 ft of the shoreline (Appendix A). Total phosphorus concentration in stormwater runoff is usually higher than tributary concentrations because of the additional inputs of debris and other urban residues. The mean total phosphorus concentration in stormwater from all land use types is 0.5 mg/l as reported by the Nationwide Urban Runoff Program (USEPA 1996). This mean was used as the estimated total phosphorus concentration which was multiplied by Spring Lake's stormwater runoff volumes to give the stormwater loadings of phosphorus. The low estimates were half of the average estimate and the high estimates were double the average estimates. The annual estimates were calculated from the cumulative sums.

Waterfowl Phosphorus Loading

Phosphorus loading from waterfowl excretion was estimated from the waterfowl counts completed during the random angler survey and observations on lake sampling days. The angler survey was a bus route design with random starting times, starting sites and survey days and was conducted from April through August 1998. For each season, averages were obtained for each type of waterfowl. All duck averages were multiplied by an estimated number of days spent on the lake to obtain duck-days (Table B8). Then the duck-days were totaled for each season and then were multiplied by goose excretion rate (28 droppings per goose-day), droppings dry weight (1.17g per dropping) and the percentage of phosphorus in droppings (1.34% phosphorus) (Manny et al. 1975). Although a goose may excrete more than the average mallard, utilization of the goose

rates was felt to provide a fair rough estimate for the lake during an average interval. Gulls were separated in the calculation because phosphorus in gull droppings was found to be 4 to 16 times greater than the phosphorus from Canada goose droppings (Portnoy 1990). Gull-hours were necessary for calculations instead of days and were obtained by multiplying gull-days by 12 hours to obtain gull-hours. For each season, gull-hours were multiplied by 3.12 droppings per gull-hour and 8.1 mg of total phosphorus per dropping (Portnoy 1990). Finally the gull and the duck-goose calculations were added together for each season's waterfowl phosphorus loading (Table B8). For low estimates, the average was divided in half. For the high estimates, the average was doubled. For the annual, areal loading rates for the winter and summer averages were calculated ($0.846 \text{ mg m}^{-2} \text{ yr}^{-1}$ and $2.20 \text{ mg m}^{-2} \text{ yr}^{-1}$ respectively) and summed for a total rate. That rate was converted to a annual load and then for its low and high estimate, a half and its double was taken.

TABLE B8: Calculations for Phosphorus Loadings from Waterfowl on Spring Lake

	Winter (Oct. - April)				Summer (May - Sept.)			
	Average Counts	Est. Days on Lake	Average Duck-days	Phosphorus Loading (kg)	Average Counts	Est. Days on Lake	Average Duck-days	Phosphorus Loading (kg)
Mallard	5.3	60	318		10.2	152	1550.4	
Domestic Duck	11	200	2200		10.8	152	1641.6	
Canada Goose	5	60	300		23.7	152	3602.4	
Mute Swan	11.6	60	696		11	152	1672	
Loon	1	60	60		0	0	0	
Bufflehead	25	60	1500		0	0	0	
Merganser	5	60	300		0	0	0	
Wood duck	2	60	180		0	0	0	
Coot	0	0	0		40	30	1200	
Duck Total	105.9		5554	2.4	95.7		9666.4	4.2
Gull	12.4	60	744	0.23	15	152	2280	0.69
Waterfowl Total	118.3			2.63	110.7			4.89

Septic Systems Loading

Phosphorus loading from septic systems around the lake was calculated from a published phosphorus loading rate of 0.8 kg of phosphorus per capita-yr multiplied by the number of lake homes connected to septic systems and then their occupancy in person and year (Tague 1977). The number of lake homes connected to septic systems, residence time and occupancy numbers were obtained from the resident survey: approximately 242 of the 895 residents (27%) around the lake are serviced by septic systems, average 0.875 year per

residence, and average 2.9 persons per residence as indicated by the resident survey (Appendix D). The occupancy rates does not include estimates from St. Lazare Retreat House, parks, or boat landings.

$$[TP_{\text{septic}}] = (.8 \text{ kg/capita-yr})(242 \text{ residences})(.875 \text{ yr/residence})(2.9 \text{ person/residence})$$

The annual load of total phosphorus was 491 kg or a daily load of 1.34 kg. Since the year per residence was not a whole year, it was assumed that the residences were occupied during the entire summer season (5 months for a weighting factor of 1) and only occupied 4.6 months of the winter season (weighting factor of 0.66). The daily load was multiplied by each season's weighting factor and the number of days in the season to obtain the seasonal loading from septic systems. Low estimates were calculated as one half of the average and high estimates were double the average estimates.

The map of the septic and sewer regions was compiled from information gathered at each of the municipalities from current 1998 plat maps or water/sewer billings (Figure 30).

Three types of areas were designated for ease of assignment: mostly sewer (above 50%), mostly septic (above 50%), and mix (50% septic and 50% sewer).

Lawn Fertilizer Loading

From the watershed resident survey responses, lakeshore residents responded as 16% fertilize about once a year, 24% fertilize twice a year, and 33% fertilize more than twice a year for a total of 73% fertilizing at least once a year. Each time a resident fertilized, it was assumed that they used 40 pounds of a common phosphorus-containing fertilizer, 28-3-3. Calculations were completed as in Tague 1977. For the winter average, it was

assumed that 73% of the entire shoreline residents, fertilized once in the spring or fall. For a winter low estimate, it was assumed that only 16% of the residents fertilized in the spring or the fall and for the winter high estimate, it was assumed that in addition to the 73% fertilizing residents that 24% fertilized again. For the summer high estimate, it was assumed that 33% of the residents fertilized again. Then for the annual estimates, areal loading rates from each seasonal estimate were calculated and added together for a low, total, and high rate and finally converted to a loading mass.

Loading from Sediments

To obtain an estimate for loading rate from the sediments, the assumption was made that the change in hypolimnion concentrations is equivalent to the change in the release rate from the sediments. Therefore the rate of change in the hypolimnion's total phosphorus concentrations was used as the release rate from the sediments. The hypolimnion volumes were weighted against each other and the weights were multiplied by the changes in total phosphorus concentrations (Cooke et al. 1993). These concentrations were then divided by the number of days in the period to get the daily rate (Table B9). The average of the daily rates was 0.0009 mg/(l day) and was converted to cubic meters and then was multiplied by the average hypolimnion volume during stratification ($5.3 \times 10^6 \text{m}^3$) and divided by the estimated sediment area. Since the sediment area was not measured, the surface area of the measured bottom strata was assumed to be a good substitution ($2.42 \times 10^6 \text{m}^2$). The outcome of this calculation was a sediment loading rate of total phosphorus of $1.93 \text{ mg m}^{-2} \text{ day}^{-1}$ from the sediments. Multiplying this daily loading rate by the average number of stratified summer days (111) and converting to kg gave the summer

loading of 529 kg. The winter loading was assumed to be zero.

TABLE B9: Calculations of Phosphorus Release from the Sediments in Spring Lake

Interval Period	Number of Days	Volume Weighting Factor	Mean Hypolimnion TP Concentration(mg/l)	Change of TP from Previous Concentration (mg/l)	WeightedChange of Total Phosphorus in Hypolimnion (mg/l)	Release Rate (mg/l per day)
28May97			0.05			
28May-16Jun97	20	0.21	0.16	0.11	0.02	0.001
17Jun-15Jul97	29	0.21	0.41	0.25	0.05	0.0017
16Jul-26Aug97	42	0.12	0.62	0.21	0.03	0.0007
12May98			0.04			
12May-15Jun98	35	0.17	0.15	0.11	0.02	0.0006
16Jun-6Aug98	52	0.21	0.42	0.27	0.06	0.0012
7Aug-19Sept98	44	0.09	0.30	0.12	0.01	0.0002
Average						0.0009

TABLE B10: Ammonium Concentration in Spring Lake and the Grand River (mg/l)

Lake Sites	1997										1998				
	8May	28May	16Jun	15Jul	23Aug	27Sept	25Oct	15Dec	8Mar	12May	15Jun	7Aug	20Aug	19Sept	16Oct
Fruitport.E1	<.05	0.14	0.07	<.05			0.07			<.05	<.05	<.1	<.1	<.1	0.1
Fruitport.E2	<.05			<.05											
Fruitport.E(Field dup)															
Fruitport M		0.11	0.09	0.24	0.10	<.05	<.05			<.05	<.05	<.1			
Fruitport.H1				0.05											
Fruitport.H1(Field dup)															
Stahl.E1	<.05	0.16	0.07	<.05	<.05	<.05	0.11		0.06	<.05	<.05	<.1	<.1	<.1	0.1
Stahl.E2	<.05														
Stahl M															
Stahl.H1		0.08	0.08	<.05	0.13	<.05	0.1			0.08	<.1	<.1	<.1	<.1	
Ferusalem.E1	<.05	0.1	<.05	<.05	0.11	<.05	0.13		0.09	<.05	<.05	<.1	<.1	<.1	0.2
Ferusalem.H1	<.05	0.06	0.09	<.05	0.12	<.05	0.12			<.05	<.05	<.1	<.1	<.1	
Smith.E1	0.07	<.05	<.05	0.06	<.05	<.05	<.05		<.05	0.06	<.05	<.1	<.1	<.1	0.2
Smith.H1	<.05	0.05	0.06	0.1	0.06	<.05	<.05			<.05	<.05	<.1	<.1	<.1	
Grand River.1	0.08	0.05	<.05	<.05	<.05	<.05	0.16	0.33	0.14	<.05	<.05	<.1	<.1	<.1	<.1
Grand River.2	<.05	<.05						0.27		<.05	<.05	<.1	<.1	<.1	0.1
Spring Lake.E1			0.11	<.05	<.05	<.05	0.09								
Spring Lake.E2							0.09								
Spring Lake.M1				0.17	<.05	<.05	0.1			<.05	<.05	<.1		0.2	
Spring Lake.H1		0.11	0.38	0.89	0.79	<.05	0.1	0.29		0.18	0.01	<.1		0.41	
Spring Lake.H2															
Prospect Point.E1	0.06	0.06	0.06	<.05	<.05	<.05	0.13	0.3	<.05	<.05	<.05	<.1		<.1	0.1
Prospect Point.M1	0.08			0.17	0.57	<.05				0.11	<.05	<.1		0.6	
Prospect Point.H1	0.06	0.14	0.45	1.08	1.77	<.05	0.12	0.31		0.15	0.18	<.1		1.47	0.2
Prospect point h2		0.15													
Petty.E1	<.05	0.05	0.07	<.05	<.05	<.05	0.1	0.24		<.05	<.05	<.1	<.1	<.1	0.1
Petty.E2								0.27							
Petty.H1	<.05	<.05	0.09	<.05	<.05	<.05	<.05			<.05	<.05	<.1	<.1	0.31	<.1

TABLE B11: Nitrate Concentrations in Spring Lake and the Grand River (mg/l)

Lake Sites	1997										1998					
	8May	28May	16Jun	15Jul	23Aug	27Sept	25Oct	14Dec	8Mar	12May	15Jun	6Aug	20Aug	19Sept	16Oct	
Fruitport.E1	0.58	0.46	0.22	0.04	0.04	<01	0.15			0.32	0.13	0.04	0.63	0.05	0.18	
Fruitport.E2				<01	0.02											
Fruitport.E(Field dup)																
Fruitport.M																
Fruitport.III	0.53	0.47	0.28	0.1	0.02	0.04	0.15			0.47	0.14	0.04		<.05		
Fruitport.II(Field dup)																
Stahl.E1	0.52	0.46	0.22	0.14	0.02	0.17	0.18		0.52	0.33	0.15	<.01	0.26	<.05	0.17	
Stahl.F2				0.15												
Stahl.M																
Stahl.H1	0.61	2.3	0.2	0.04	0.02	0.31	0.19			0.38	0.17	<.01		<.05		
Jerusalem.E1	0.63	0.46	0.32	0.13	0.02	0.08	0.24		1.1	0.25	0.14	0.04		<.05	0.2	
Jerusalem.III	0.66	2.3	0.22	0.15	0.02	0.08	0.25			0.33	0.19	<.01		<.05		
Smith.E1	0.74	0.55	0.4	0.2	0.08	0.22	0.39		0.71	0.46	0.16	<.01	0.41	<.05	0.3	
Smith.H1	0.76	0.6	0.39	0.25	0.09	0.2	0.39			0.46	0.22	<.01		<.05		
Grand River.1	1.09	1.3	0.4	0.65	0.72	0.89	1.07	1.32	1.4	1.5	0.62	0.23		0.57	0.86	
Grand River.2		1.3				0.99										
Spring Lake.E1	0.83	0.65	0.38	0.19	0.10	0.23	0.4	0.67		0.52	0.24	0.28	0.08	0.06	0.31	
Spring Lake.F2							0.4									
Spring Lake.M1				0.5	0.26	0.33				0.52	0.4			0.11		
Spring Lake.H1	0.78	0.65	0.32	0.13	0.24	0.68	0.42	0.68		0.48	0.29	0.06		0.18		
Spring Lake.H2	0.77										0.15					
Prospect Point.E1	0.73	0.53	0.37	0.04	0.03	0.19	0.37	0.58	0.64	0.25	0.16	0.04		<.05	0.28	
Prospect Point.M1				0.33	0.01	0.34				0.51	0.23	0.05		<.05		
Prospect Point.III	0.73			0.42	0.01	0.57	0.67	0.59		0.42	0.07	<.01		<.05	0.34	
Petty.E1	0.74	0.53	0.29	<.01	0.02	<.01	0.35	0.57		0.28	0.11	<.01	0.04	<.05	0.28	
Petty.F2		0.52														
Petty.III	0.67	0.54	0.32	0.02	0.01	0.01	0.34	0.58		0.5	0.17	<.01	0.4	<.05	0.23	

TABLE B12: Chlorophyll *a* Concentrations of Spring Lake and the Grand River ($\mu\text{g/l}$)

Lake Sites	1997										1998				
	8May	28May	16June	15July	23Aug	27Sept	25Oct	14Dec	7Mar	12May	15Jun	6Aug	20Aug	19Sept	16Oct
Fruitport.E1a	20.3	22.92	24.6	85.58	33.88	64.8	19.65		16.8	99.84	29.48	37.44	26.64	31.44	27.68
Fruitport.E1b		21.24	26.76												
Fruitport.E2a	18	18.12	19.2			59.4	17.9		17.76	106.8	24.72	34.08	26.68	35.76	27.36
Fruitport.E2b		20.76	17.76	78.54											
Fruitport.E(Field dup)															
Fruitport.M1											8.6				
Fruitport.H1a	19.9	14.64	7.428	12.562	19.03	31.5	18.2			26.48	4.84	24.24		24.72	
Fruitport.H1b		15	7.56												
Fruitport.H1c		16.08													
Fruitport.H2a	20.6		6.372			28.71	16.35			26.44	8.52	24.16		23.44	
Fruitport.H2b			6.228	19.58											
Fruitport.H(Field dup)1				19.88											
Fruitport.H(Field dup)2				102.3	25.52	60.9	17.75		20.64	32.88	35.52	40.32	28.6	38.16	23.8
Stahl.F1a	26.6	17.52	8.84												
Stahl.E1b			8.98												
Stahl.F2a	27.1	19.32				57	19.05		19.32	40.56	47.52	45.84	27.32	43.2	22.2
Stahl.E2b		17.88													
Stahl.M1											7.44				
Stahl.M2											8.64				
Stahl.H1a	20.4	14.52	9.04	17.138	16.258	39.3	11.55			17.56	6.84	29.28		26.88	
Stahl.H1b			9.18												
Stahl.H2	18	15.24				44.4	10.9			20.8	7.24	29.04		26.88	
Jerusalem.E1	20.4	15.72	5.496	96.8	44	69	13		21.12	113.76	30.96	33.84		35.04	16.68
Jerusalem.E1b			6.624												
Jerusalem.E2a	23.2	13.92			29.7	71.7	13.4		21.12	123.36	38.16	36.96		40.8	16.76
Jerusalem.E2b		15.12													
Jerusalem.H1a	22.5	15.6	6.72	18.656	21.824	48	11.5			37.88	5.6	30.96		17.83	
Jerusalem.H1b		14.04	6.86												
Jerusalem.H2a	25.1	14.52	5.62		22	53.7	11.05			31.48	4.24	36.48		24.04	
Jerusalem.H2b			5.7												
Smith.F1a	33.5	13.56	17.16	17.908	45.32	67.8	15.4		40.2	50.16	49.2	56.16	24.96	31.68	14
Smith.E1b			18.6												
Smith.F2	36.4	13.32				72	12.5		37.92	47.28	64.32	54.24	27.36	42	13.08

TABLE B12: (cont'd)

Smith.H1a	26.4	9.012	48.96	7.502	42.46	44.4	11.2		13.584	8.24	57.6		13.8
Smith.H1b		9.168	51.36										
Smith.H2a	32.9	10.14		8.096		47.4	11.95		20.16	7.92	49.92		14.208
Smith.H2b	30.8	9.96							74.64	30.52	63.12	31.44	21.912
Spring Lake.E1a		15.12	66.96	56.1	58.74	62.1	14.55						18.12
Spring Lake.E1b			56.4										
Spring Lake.E1c			66.84										
Spring Lake.E1d			60.96										
Spring Lake.E2	31.2	12.7		53.02	50.6	58.2	14.85	8.42	78	32.36		30.96	18.6
Spring Lake.M1				5.412	50.38	58.2			11.64	27.64			15.88
Spring Lake.M2				4.532	56.54	58.2			10.776	29.2			15.64
Spring Lake.H1a	23.9	11.772	8.38	4.774	62.7	117.3	14.25	7.98	19.64	15.24	43.92		20.68
Spring Lake.H1b		10.74	8.34					7.98	21.56	16.64	47.04		22.04
Spring Lake.H2a	20	12.84			62.7	120.9	15.75						
Spring Lake.H2b		12.84											
Prospect Point.E1a	15.8	17.4	16.08	55.22	43.78		15.6	12.56	101.76	32.4	35.76		19.56
Prospect Point.E1b		16.2	17.88										
Prospect Point.E2a	16.6	13.92	22.32	58.08		67.2	16.55	11.88	104.4	31.32	43.68		18.6
Prospect Point.E2b		15.24	20.28										
Prospect Point.M1				5.302	17.556	36.9			28.36	8.36	12.56		8.2
Prospect Point.M2						53.7			31.12	11.6	14.96		8.12
Prospect Point.H1a	15.4	7.776	4.284	2.97	10.076	42.3	15.35	10.72	24.2	5.48	11.92		7.68
Prospect Point.H1b			5.8										
Prospect Point.H2a	17.9	7.944	5.628	2.53		46.2	19	10.04	28.36	3.76	11.16		8.72
Prospect Point.H2b			6.76										
Petty.E1a	20.3	11.424	13.4	93.28	67.76	96	20.2	12.36	61.44	30.96	27.36	32.4	25.44
Petty.E1b			13.38										
Petty.E2	18.7	11.556			66	94.2	23.65	11.87					
Petty.H1a	24.3	8.376	6.42	21.604	59.84	58.5	18.9	11.58	68.4	36.72	29.04	26.16	43.44
Petty.H1b		8.472	6.3		60.94				48.4	71.04	35.04	10.584	6.792
Petty.H2a	22.3	9.984			56.54	55.2	21.15	11.26	26.16	113.52	37.68	10.92	8.808
Petty.H2b		9.492			54.56								18.6
Grand River.1a	85.6	60.6	331.92	28.92	147.4	168	44.4	9.14	74.16	180.72	77.52		129.6
Grand River.1b		60.24											131.04
Grand River.2a	80.9	65.64				168	44.7	8.86	69.12	181.2	76.08		145.92
Grand River.2b													135.36

Notation: E, M, H = epilimnion, metalimnion, hypolimnion; 1, 2, a, b, c = laboratory methods replicates

TABLE B13: Secchi Depths of Spring Lake Sites, Lake Average and the Grand River (meters)

Date	Stahl	Spring	Smith	Prospect	Petty	Fruitport	Lake Mean	Grand River
05/06/97	1.37	1.17	1.13	1.53	1.33	1.27	1.30	0.73
05/16/97	1.47	1.47		1.77	1.27	1.37	1.47	0.97
05/28/97	1.43	1.23	1.17	1.37	1.37	1.43	1.33	0.63
06/04/97	1.13	1.07	1.07	1.13	1.40	1.17	1.16	0.67
06/16/97	1.47	1.36	1.39	1.59	1.30	1.37	1.41	0.37
06/23/97	1.78	1.35	2.02	1.80	1.65	1.52	1.69	0.31
07/15/97	0.50	0.77	0.88	0.57	0.52	0.50	0.62	0.30
07/23/97	0.67	0.62	0.50	0.69	0.59	0.62	0.61	0.42
08/08/97	0.53	0.71		0.69	0.52	0.64	0.62	0.53
08/24/97	0.92	0.97	0.87	0.87	0.68	0.85	0.86	0.38
09/27/97	0.93	0.88	0.98	1.02	0.88	0.92	0.94	0.48
09/28/97	0.88	1.75	0.88	1.13	0.88	1.03	1.09	0.53
10/26/97	1.32	1.48	1.72	1.53	2.02	1.32	1.56	0.97
12/14/97		3.07		3.22			3.14	1.77
03/07/98	1.82	1.47	1.53	1.67	1.47	1.72	1.61	0.83
05/12/98		1.07	1.12		1.28		1.16	0.50
05/20/98	1.32	0.82	2.23	2.03	1.07	1.02	1.41	0.52
06/15/98	1.43	1.43	1.07	1.58	1.23	1.33	1.35	0.43
06/22/98	1.47	1.17	1.28	1.63	0.93	1.48	1.33	0.47
07/24/98	1.03	0.92	0.90	1.07	1.08	0.90	0.98	0.48
08/06/98	0.97	0.97	0.83	0.97		0.80	0.91	0.50
08/20/98	1.20	1.00	1.20	1.12		1.18	1.14	
09/12/98	0.82	1.18	1.42	1.07	0.88	0.97	1.06	0.42
09/19/98	1.05	1.12	0.92	1.08	0.97	1.02	1.03	0.48
10/16/98	1.52	1.53	1.68	1.53	1.48	1.72	1.58	0.47

TABLE B14: Dissolved Oxygen, Temperature, Specific Conductivity and pH of Stahl Bayou in Spring Lake

Dissolved Oxygen (Mg/l)		05/06/97	05/16/97	05/28/97	16/16/97	07/15/97	08/23/97	09/27/97	03/07/98	06/15/98	08/06/98	08/20/98	09/12/98	09/19/98	10/16/98
Depth(m)		1	11.75	8.33	9.36	7.49	13.25	3.91	8.01	13.58	9.76	9.24	6.68	8.69	10.35
		2	10.6	8.27	8.6	7.31	12.63	3.66	7.62	13.25	9.46	8.75	7.24	6.6	9.78
		3	10.48	8.2	8.36	6.98	11.61	3.16	7.55	13.04	7.48	7.98	6.84	5.8	9.12
		4	10.46	8.22	8.06	6.81	8.68	2.93	7.43	12.76	5.33	6.09	6.76	5.44	8.92
		5		8.28	7.93	6.31	4.59	2.91	7.45	12.52	3.91	5.9	6.72	5.28	8.49
		6		7.98	7.48	3.99	1.84	2.68	6.54	12.1	2.04	5.35	4.51	4.53	4.25
Specific Conductivity (μS/cm)		1	401.7	382	411.6	428.9	417.7	450.1	465.9	443.1	430	484.5	497.2	490.7	483.7
		2	405.1	382.7	415.9	429	419.7	455.2	465.9	464.6	428.5	487.9	497.3	492.5	485.2
		3	402.4	383.5	414.9	429.2	422.1	456	464.4	467.9	431.2	486.6	497.3	492.8	485.9
		4	402.1	385.1	416.7	429.5	434.1	454.1	464.1	474.4	432.9	493.3	497.4	493.6	485.9
		5		384.5	418	428.3	439.2	454.3	463.2	479.5	455.5	494	497.4	492.8	480.6
		6		369.8	418.5	434.4	449.4	440.5	458.4	498.7	464.9	494.3	499.5	490.2	443.1
Temperature (C)		1	11.6	11.9	14.6	21.4	25.9	21.4	19.2	4.1	22	25	24.6	23.2	23.3
		2	11.5	11.6	14.1	21.4	25.7	21	19.1	4.1	21.3	24.7	24.6	23	23.1
		3	11.2	11.4	14	21.4	25.5	20.5	19	4.1	20.8	24.6	24.6	22.9	23.1
		4	11.1	11.3	13.7	21.3	24.7	20.7	18.9	4.1	20.1	24.5	24.6	22.9	23.1
		5		11.1	13.5	21.2	23.1	20.7	18.8	4	19.1	24.4	24.6	22.8	22.7
		6		10.5	13.4	20.9	21.9	19.8	18.3	4	18.7	24.4	24.5	22.7	22.2
Surface pH			8.4	8.5	8.3	8.4	9	8.4	8.4	8.7	8.6	8.2	8.2	8.4	7.9

TABLE B15: Dissolved Oxygen, Temperature, Specific Conductivity and pH at the Spring Lake Sampling Site in Spring Lake

Dissolved Oxygen (mg/l)		Depth(m)05/06/97 05/08/97 05/16/97 05/28/97 06/16/97 07/15/97 08/23/97 09/27/97 10/25/97 12/14/97 03/07/98 05/12/98 06/15/98 07/31/98 08/06/98 08/20/98 09/12/98 09/19/98 10/16/98																	
1	11.9	8.77	9.7	7.95	11.25	7.92	7.7	6.94	11.89	14.63	12.98	9.48	9.81	9.02	7.42	4.85	6.17	6.32	
2	11.84	8.75	9.64	7.92	11.1	7.94	7.65	6.96	11.87	14.56	12.86	9	8.66	9.01	6.46	4.84	6.36	6.33	
3	11.7	8.72	9.61	7.96	10.89	7.94	7.51	6.96	11.88	14.69	11.99	8.82	8.01	8.69	7.17	4.2	6.22	6.39	
4	11.13	8.71	9.5	8.31	10.24	7.96	7.44	9.97	11.88	14.53	11.2	8.7	7.52	8.58	7.13	4.23	5.92	6.36	
5		8.72	9.51	6.11	7.58	7.96	7.4	6.96	11.88	14.47	8.9	8.73	7.09	8.33	7.3	4.18	5.67	6.39	
6		8.6	9.4	5.69	4.49	7.96	7.35	6.99	11.86	14.49	6.9	8.43	7.04	8.04		4.11	5.4	6.36	
7		8.59	9.28	2.88	2.72	7.95	7.27	7	11.79	14.31	4.98	6.66	7	7.72		3.89	5.05	6.36	
8		8.51	9.27	1.93	0.3	7.84	7.22	7.05	11.84	14.19	3.25	5.28	6.91	7.47		3.98	3.82	6.37	
9		8.5	9.12	0.9	0	7.65	7.65	7.08	11.85	13.74	1.39	4	6.14	2.35		4.49	1.8	7.01	
10		8.46	4.09	0.35	0	8.36	9.46	7.15		13.4	0.81	1.75	0.01			3.07	1.25	8.39	
Specific Conductivity (µS/cm)																			
1	480.2	463.8	456.1	492.3	485.6	496.6	498.9	550	589	520	437.8	476.6	500	510	517	512	510	541	
2	478.1	463.7	453.3	492.4	485.7	497.1	498.8	550	589	521	426.4	489.4	500	511	515	512	510	541	
3	469.4	463.7	462.2	493.1	485.7	497.2	498.9	550	589	521	422.6	510	500	513	512	513	508	542	
4	465.5	463.7	463.5	525	486.5	497.5	498.9	550	589	521	423.8	517	500	516	513	514	511	542	
5		463.2	462.8	502	487	497.7	499.5	551	589	521	426.1	527	500	517	512	514	512	542	
6		461.6	464.7	497	482.1	499	500	551	589	522	423.3	541	500	517		514	512	542	
7		461	464.7	454.2	503	503	501	551	591	523	417.6	541	500	522		516	518	542	
8		462.1	464.8	444.4	502	516	501	552	596	526	427.8	521	500	541		517	546	542	
9		461.7	464.1	448.9	466.2	614	520	554	631	541	433.8	518	500	454.1		548	579	552	
10		461.7	464.1	450	469.7	497.3	582	619		545	437	513	500			555	591	595	
Temperature (C)																			
1	12	12.5	11	14.6	20.6	24.7	21.3	18.7	12.1	2.6	4.1	19.1	21.3	25.8	24.3	24.5	22.4	22.8	15.2
2	11.7	12.4	11	14.6	20.6	24.6	21.3	18.8	12.1	2.6	4	18.5	20.7	25.3	24.3	24.5	22.4	22.7	15.2
3	11.4	12.2	11	14.6	20.5	24.5	21.3	18.8	12.2	2.6	3.9	18	20.6	25.1	24.3	24.5	22.3	22.6	15.2
4	11.3	11.6	11	14.6	20.4	24.4	21.3	18.8	12.2	2.6	3.9	17.8	20.6	25	24.3	24.5	22.3	22.6	15.2
5		11.5	11	14.6	19.6	23.8	21.3	18.8	12.2	2.6	3.9	17	20.6	24.9	24.3	24.4	22.3	22.5	15.2
6		11.5	10.9	14.6	19.4	22.4	21.3	18.7	12.2	2.6	4	15.8	20.5	24.8	24.2		22.2	22.5	15.2
7		11.5	10.9	14.6	17.4	21.6	21.3	18.7	12.2	2.6	4	14.3	19.6	24.7	24.2		22.2	22.5	15.2
8		11.3	10.9	14.6	16	20.1	21.3	18.7	12.1	2.6	4	12.6	19.2	24.6	24		22.1	22.4	15.2
9		11.1	10.9	14.6	15.3	17.5	20.6	18.6	12.1	2.5	4.2	11.6	18.5	20.7	20.5		22	22.3	15.1
10		11.1	10.9	14.2	15	16.4	17.9	17.8	10.9		4.2	11.6	17.9	18.9			21.8	22.3	14.4

TABLE B15: (cont'd).

Surface pH	8.5	8.4	8.6	8.3	8.4	8.7	8.4	8.5	8.1	8.6	8.3	6	8.8	8.4	8	8	7.8
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TABLE B16: Dissolved Oxygen, Temperature, Specific Conductivity and pH in Smith Bayou in Spring Lake

Dissolved Oxygen (Mg/l)	1	2	3	4	5	6	7	10/16/97	05/08/97	05/16/97	05/28/97	06/16/97	07/15/97	08/23/97	09/27/97	10/25/97	03/07/98	04/04/98	05/12/98	06/15/98	07/31/98	08/06/98	08/20/98	09/12/98	09/19/98	10/16/98
	11.46	11.06	11.14	10.97	9.01	9.07	8.86	9.3	10.92	8.72	9.79	7.92	9.32	7.11	15.13	11.42	14.41	12.69	9.58	10.35	6.65	8.01	8.95	6.71	6.71	6.71
	8.86	10.86	7.64	8.11	6.44	9.09	7.14	15.06	11.33	13.13	10.69	8.19	10.21	6.24	8.3	6.64	4.09	7.01	6.63	4.39	6.49	6.57	4.22	4.3	6.52	6.28
	8.88	10.57	7.68	7.29	5.84	8.81	7.21	14.66	11.14	10.8	8.73	7.62	10.06	4.09	7.01	6.63	4.39	7.01	6.63	4.39	6.49	6.57	4.22	4.3	6.52	6.28
	9.01	9.99	7.41	6.75	5.84	8.75	7.23	14.57	11	10.28	7.92	6.72	10.02	4.39	6.49	6.57	4.39	7.01	6.63	4.39	6.49	6.57	4.22	4.3	6.52	6.28
	9.07	9.52	6.87	5.77	5.73	8.8	7.2	14.45	11.07	9.6	1.63	6.36	10.01	4.22	4.3	6.52	4.22	4.3	6.52	4.22	4.3	6.52	4.22	4.3	6.52	6.28
	8.86	9.05	5.88	2.88	5.71	8.12	7.11	14.11	11.02	7.44	6.35	4.98	9.98	2.96	4.12	6.12	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98	6.12
Specific Conductivity (μS/cm)	1	2	3	4	5	6	7	452.3	458.7	446.6	489.9	476.6	494.8	495	546	512	460.2	416.4	479.2	512	507	509	505	497.9	537	537
	453.1	460.3	446.7	500	478.4	465.4	494.8	495	546	512	460.2	416.4	479.2	512	507	509	505	497.9	537	537	537	537	537	537	537	537
	457.4	457.4	447.1	502	479.2	499.4	496	496	545	514	464.6	420.7	485.5	521	507	513	499.1	537	537	537	537	537	537	537	537	537
	459.2	454.5	449.9	504	488.6	499.2	495.5	495.5	545	515	465.4	421	486.2	525	507	513	499.5	537	537	537	537	537	537	537	537	537
	454.4	454.4	450.9	508	489.2	498.7	495.5	495.5	545	516	466.4	422.9	488.3	525	506	514	502	537	537	537	537	537	537	537	537	537
	454.5	454.5	451.2	505	493.8	497.4	495.2	495.2	545	517	466.9	426.1	491.7	525	506	516	496	537	537	537	537	537	537	537	537	537
Temperature (C)	1	2	3	4	5	6	7	11.4	12.9	10.9	15.4	21.5	25.1	22.1	18.9	11.9	4.2	10	19.1	21.5	25.2	24.5	24.6	23.2	22.7	15.2
	11.1	12.4	10.8	10.7	11.7	11.6	10.7	10.8	15.4	20.9	20.7	23.4	21.2	18.7	11.9	4.1	9.8	18.3	21.1	24.9	24.4	24.4	22.6	22.6	22.6	15.2
	11	12.2	10.8	10.7	11.7	11.6	10.7	10.8	15.2	20.7	23.4	21	18.7	11.9	4	9.1	17.9	20.8	24.8	24.4	24.4	22.4	22.6	22.6	22.6	15.2
	10.7	12	10.7	10.7	11.7	11.6	10.7	10.7	15.1	20.6	23.5	20.9	18.6	11.9	4	8.9	17.8	20.5	24.6	24.3	24.3	22.4	22.5	22.5	22.5	15.2
	11.7	11.7	10.7	10.7	11.7	11.6	10.7	10.7	14.8	20.4	23.3	20.9	18.6	11.9	4	8.9	17.6	20.2	24.6	24.3	24.3	22.3	22.5	22.5	22.5	15.2
	11.6	11.6	10.7	10.7	11.6	11.6	10.7	10.7	14.7	19.9	22.2	20.7	18.5	11.9	4	8.9	17.1	19.8	24.3	24.3	24.3	22.3	22.4	22.4	22.4	15.1
																										15.1
Surface pH	8.1	8.4	8.6	8.6	8.6	8.6	8.5	8.7	8.5	8.5	8.1	8.1	8.1	8.7	9	8.4	8.4	8.2	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1

TABLE B17: Dissolved Oxygen, Temperature, Specific Conductivity and pH at Prospect Point in Spring Lake

Dissolved (mg/l)	Oxygen	05/06/97 05/08/97 05/16/97 05/28/97 06/16/97 07/15/97 08/23/97 09/27/97 10/25/97 12/14/97 03/07/98 06/15/98 08/06/98 08/20/98 09/12/98 09/19/98 10/16/98																			
Depth(m)		1	10.39	8.53	10.49	7.58	11.09	7.02	6.94	6.48	11.46	14.48	9.3	9.67	7	5.44	8.5	5.02			
		2	9.76	8.55	10.44	7.5	10.91	6.68	6.94	6.45	11.38	14.51	8.99	9.42	7.61	5.38	8.25	5.03			
		3	9.9	8.52	10.37	7.48	10	6.64	6.94	6.45	11.56	14.58	8.65	8.84	7.66	5.33	7.56	5.04			
		4	9.5	8.51	10.33	7.3	10.66	6.71	6.9	6.43	11.54	14.3	8.23	8.28	7.61	5.31	6.22	5.05			
		5	9.67	8.51	9.89	7.19	9.14	6.71	6.87	6.45	11.54	14.26	7.21	8.44	7.56	5.3	3.98	5.11			
		6		8.5	9.48	5.79	4.89	6.72	5.89	6.52	11.5	14.27	6.53	8.11	7.49	5.16	3	5.13			
		7		8.47	9.35	3.78	2.84	6.45	8.72	6.57	11.51	14.08	5.71	4.65	0.07	5.1	1.58	5.7			
		8		8.47	9.02	1.17	0.44	5.97	5.74	6.58	11.46	14.42	5.11	0.19		4.86	0.23	5.81			
		9		8.48	7.9	0.51	0.02	2.53	5.43	6.67	11.45	14.32	2.33	0.02		3.4	0.01	5.98			
		10		8.46	6.62	0.04	0.02	0.03	5.67	6.72	11.39	14.53	0.94	0.01		0.89	0.01	6.14			
		11		8.33	4.89	0	0.01	0.02	5.9	7.49	11.35	14.46	0.01			0.03	0				
Specific Conductivity (µS/cm)		1	424.6	429	432	463.9	452.2	472.4	486.4	547	559	507	450.4	499	506	503	495.3	527			
		2	426.2	429.4	431.2	464.2	453.3	472.7	488.2	547	563	506	451.5	498	506	504	495	527			
		3	428	429.8	431.5	465.1	453.9	472.9	488.4	546	568	507	452.8	498	506	504	495.2	528			
		4	428.2	430	430.3	468.1	456.1	473	488.1	546	569	507	455.6	502	506	504	495.5	528			
		5	431.9	450	432.6	470.7	453.4	473.1	488.7	546	570	508	482.3	505	506	504	493.4	528			
		6		429.8	436.8	466	463.2	473	496.5	547	571	508	502	510	506	504	498.3	530			
		7		430.2	442.7	456.4	484.2	472.8	501	547	572	512	505	531	529	504	503	534			
		8		430.2	444.1	442	486.2	472.8	508	549	573	513	502	536		505	518	546			
		9		430	449.3	445.1	485.7	475.1	527	549	572	514	489	520		505	526	547			
		10		430.1	449.5	444.9	462.9	486.4	570	562	573	514	487.7	519		517	535	560			
		11		430.9	453.9	447.1	462.9	489.3	581	625	573	515	476.8			550	550				
Temperature (C)		1	11.1	12.1	11.3	14.8	21.1	24.8	21.3	18.8	12.3	3	3.9	20.8	24.7	24.5	22.6	23.1	15.6		
		2	11	12.1	11.3	14.8	21.1	24.7	21.2	18.9	12.3	2.9	3.8	20.7	24.6	24.5	22.6	22.9	15.6		
		3	10.9	11.8	11.4	14.8	21	24.7	21.2	18.9	12.4	2.8	3.8	20.8	24.6	24.5	22.6	22.8	15.6		
		4	10.9	11.7	11.3	14.8	20.8	24.7	21.2	18.9	12.4	2.8	3.8	20.6	24.5	24.5	22.6	22.7	15.6		
		5	10.8	11.5	11.3	14.6	20.7	24.5	21.2	18.9	12.4	2.8	3.8	20	24.4	24.5	22.6	22.6	15.6		
		6	11.3	11.3	11.3	14.4	20.1	22.9	21.2	18.8	12.4	2.8	3.8	19.5	24.3	24.1	22.6	22.5	15.5		
		7	11.2	11.3	11.3	14.3	18.8	21.7	21.2	18.7	12.4	2.8	3.8	19.1	23.8	22.8	22.6	22.4	15.4		

TABLE B17: (cont'd).

8	11.1	11.3	14	16.5	20.7	21.1	18.7	12.4	2.8	3.8	18.8	22.5	22.3	15.2
9	11	11.3	13.3	16	17.9	20.5	18.5	12.3	2.8	3.8	17.7	20.1	22.5	15.1
10	11	11.3	12.9	14.9	16.1	19.5	18.2	12	2.8	3.8	17.1	18.5	21.9	14.9
11	10.7	11.3	12.4	14.6	15.4	17.2	18	10.6	2.8	3.8	15.5		19.9	20.6
Surface pH	8.3	8.4	8.5	8.5	8.6	8.3	8.5	8.1	8.7	8.4	8.4	8.4	8.2	7.8

TABLE B18: Dissolved Oxygen, Temperature, Specific Conductivity and pH in Petty's Bayou in Spring Lake

Dissolved Oxygen																			
(Mg/l)																			
Depth(m)		05/08/97	05/16/97	05/28/97	06/16/97	07/15/97	08/23/97	09/27/97	10/25/97	12/14/97	03/07/98	05/12/98	06/15/98	07/31/98	08/06/98	09/12/98	09/19/98	10/16/98	
1	11.5	9.27	9.21	7.66	14.27	8.98	12.65	7.96	12.78	15.09	12.56	12.49	9.87	4.84	8.12	10.81	6.48		
2	10.45	9.23	9.17	7.65	13.44	8.13	12.32	7.93	13.69	14.92	12.15	11.8	7.09	4.71	8.23	8.83	6.39		
3	10.4	9.24	9.18	7.42	11.61	7.5	11.95	7.9	13.04	14.95	11.17	7.3	6.06	4.56	8.28	3.19	6.61		
4	10.22	9.2	9.04	6.74	9.6	6.88	8.74	8.02	12.31	14.24	7.85	6.11	4.44	4.43	7.4	1.69	7.08		
5		9.22	9.06	6.03	7.75	7.88	7.63	8.1	12.27	13.62	5.29	4.48	3.73	4.9	7.94	1.17	8.13		
6		9.04	8.87	5.15	7.35	7.88	7.04	8.14	11.51	13.48	4.06	3.87	4.73	7.92	0.65	8.13			
Specific Conductivity																			
(μS/cm)																			
1	423.9	429.7	441.4	452.8	427.6	470.4	480	538	558	482.5	409.4	452.4	487	506	496.7	477.4	530		
2	421.4	429.5	441.5	453.2	435.8	469.5	480.2	538	559	482.5	409.6	462.5	498	506	490.3	482.2	529		
3	421.8	428.9	441.4	455.1	435.8	469.5	482.6	538	566	482.3	409.9	487.7	507	505	488.9	503	528		
4	421.8	428.6	442.2	456.9	448.3	467.3	474	537	567	488.3	420.9	485.8	522	501	483.8	511	526		
5		427.8	442.9	460.6	447.4	463.1	476.8	536	567	505	418.1	485.9	532	496	481.6	514	522		
6		425.6	444.5	464.6	450	459	493.4	536	569	507	419	486.4	494	481.4	516	519			
Temperature (C)																			
1	12.7	12.5	11.8	14.3	21.9	26.2	21.9	19.6	11.6	2.2	4.6	18.5	22.7	25.7	24.2	23.1	23.4	15.4	
2	12.2	12.4	11.8	14.3	21.9	26.1	21.4	19.3	11.6	2.2	4.5	18.5	21.6	25.4	24.1	22.7	23.1	15.2	
3	11.8	12.2	11.8	14.3	21.7	25.6	21.1	18.8	11.7	2.3	4.4	18.3	20.1	25.2	24.1	22.6	22.6	15.2	
4	11.5	11.8	11.8	14.1	21.6	25.1	20.8	18.6	11.6	2.4	4.3	16.5	19.8	25.1	24	22.4	22.5	15.1	
5		11.2	11.7	14	21.3	24.7	20.52	18.5	11.5	2.4	4	15.3	19.6	24.9	24	22.3	22.4	14.9	
6		11.1	11.7	13.9	20.9	24.4	20.4	18.5	11.5	2.5	3.9	14.8	19.5	24	22.3	22.4	14.8		
Surface pH																			
		8.4	8.4	8.7	8.3	8.5	9.1	8.7	9	8.3	8.8	8.4	9	9.3	8.2	8.4	8.6	8	

TABLE B19: Dissolved Oxygen, Temperature, Specific Conductivity and pH in Jerusalem Bayou in Spring Lake

Dissolved Oxygen																			
(Mg/l)																			
Oxygen																			
Depth(m)																			
1	11.2	8.25	9.74	7.39	12.33	3.95	8.31	6.25	13.51	15.69	9.89	9.75	6.68	10.47	5.84				
2	11.07	7.85	9.78	6.89	12.07	3.56	7.89	6.28	13.33	16.69	9.85	9.51	6.49	9.72	5.75				
3	10.82	7.78	9.67	6.71	12.07	3.48	7.64	6.21	12.94	14.93	9.32	8.47	5.09	8.97	5.7				
4	10.33	7.54	9.63	6.6	8.26	3.39	7.52	6.17	12.76	13.33	6.39	7.78	4.69	8.54	5.67				
5		7.38	9.51	5.82	6.35	3.88	7.18	6.15	12.71	12.25	3.68	7.62	4.18	8.4	5.66				
6		5.47	8.56	4.54	0.06	3.51	6.34	5	11.98	7.07	2.15	7.33	4.41	7.08	5.64				
Specific Conductivity																			
(μS/cm)																			
1	408.4	397.3	411.4	437.5	425.2	463.6	475.4	510	44.3	396.4	434.4	489.1	496.9	488.3	497				
2	410.7	397.5	413	435.3	425.3	464.1	475.2	509	468.6	394.3	433.9	489.6	496.8	488.2	497.2				
3	410.7	398	413.1	439.6	425.2	464	474.8	510	481.8	396	436.3	489.9	496.8	487.8	496.6				
4	410.1	397.6	413.1	439.5	431	463.3	474.8	510	488.3	396.8	438.7	489.2	496.8	487.7	496.2				
5		396.3	413.6	424.6	437.1	462.2	475	510	492	395.7	457.1	488.4	496.9	487.2	497.2				
6		345.8	414.3	441.1	453.6	462.9	468.8	510	497.9	403.4	463.7	486.1	495.2	486.5	497				
Temperature (C)																			
1	17.8	12.8	11.7	14.8	21.4	25.3	21.4	19.6	12.3	3.9	18.9	22.3	24.9	23.2	23.2	15.7			
2	11.3	12.4	11.3	14.6	21.3	25.2	21.1	19.2	12.3	3.8	18.2	22	24.8	22.9	23	15.6			
3	11	12.1	11.3	14.5	21.3	25.2	21	19.1	12.3	3.9	17.9	21.2	24.6	22.8	22.9	15.6			
4	11	12	11.2	14.5	21.2	24.7	21	19	12.3	3.9	17.7	20.4	24.5	22.8	22.9	15.6			
5		11.9	11	14.4	20.8	23.9	20	18.8	12.3	4	17.4	19.1	24.5	22.8	22.8	15.6			
6		11.8	9.9	14	20.1	21.5	20.6	18.2	12.2	4	16	18.8	24.3	22.6	22.5	15.6			
Surface pH																			
		8.6	8.4	8.6	8.4	8.4	8.7	8.1	8.5	8.1	8.3	8.7	9.3	8.3	8.2	8.5	7.9		

TABLE B20: Dissolved Oxygen, Temperature, Specific Conductivity and pH at the Fruitport Sampling Site in Spring Lake

Dissolved Oxygen (mg/l)	06/08/97 05/08/97 05/16/97 05/28/97 06/16/97 07/15/97 08/23/97 09/27/97 03/07/98 06/15/98 08/06/98 08/20/98 09/12/98 09/19/98 10/16/98																	
Depth(M)	1	10.56	8.11	7.84	7.49	12.5	6.7	8.64	13.01	8.22	6.11	5.79	7.95	8.78	6.92			
	2	9.48	8.12	7.78	7.36	11.99	5.62	8.43	13.22	8.16	4.77	5.79	5.77	8.25	6.93			
	3	9.71	8.01	7.75	7.18	9.98	4.79	8.01	13.15	5.48	4.66	6.16	5.34	7.8	7.02			
	4	8.87	7.86	7.68	7.05	8.16	4.18	8.24	12.11	5.29	4.53	5.42	5.29	6.19	7.4			
	5		7.83	7.54	6.85	3.32	3.54	7.2	13.04	4.28	2.32	4.78	5.04	2.75	7.65			
	6		7.75	7.37	5.97	0.29	2.61	5.65	12.52	2.55	0.42			1.43	7.08			
Specific Conductivity (uS/cm)	1	391.7	361.5	416	424.8	418.6	445.4	444.9	441.2	421.1	491.7	494	487.9	477.3	472.1			
	2	392.4	361.7	416.2	424.8	419.9	455.3	448.5	448	425.1	494	495	487.6	478.5	471.2			
	3	392.7	362.4	416.6	426	423	448.6	449.1	462.1	443.3	488.5	495	486.7	480.7	471.8			
	4	392.6	363	416.8	426.7	427.4	450.7	448.9	462.9	450.9	497.1	496	486.5	480.5	468			
	5	391.2	356.6	417.9	426.4	436.6	444.1	462.1	465.7	455.2	505	489	486.5	479.3	465.1			
	6		327.6	418.2	429	457.5	437.5	464.1	474	466.6	522			483.9	462.2			
Temperature (C)	1	12	13.1	12	13.9	21.5	26.1	21.4	19.8	4	21.7	24.6	24.7	23.2	23.2	15.2		
	2	11.5	15.8	12	13.7	21.5	25.9	21.1	18.8	4	21.4	24.3	24.6	22.8	23.1	15.2		
	3	11.4	12.6	11.9	13.6	21.5	25.7	21.1	18.8	4	20	24.3	24.6	22.8	23	15.2		
	4	11.3	12.4	11.9	13.5	21.4	25	21	18.7	4	19.6	24.3	24.6	22.7	22.9	15.1		
	5	11.1	11.6	11.8	13.4	21.4	23	21	18.7	4.1	19.2	24.2	24.5	22.7	22.5	15		
	6	11	11.3	11	13.3	21.2	22.1	20.5	18.7	4.1	18.8	24		22.5	14.9			
Surface pH		8.2	8.5	8.2	8	8.6	8.9	8.3	8.5	8.6	8.6	7.9		8.1	8.2			

TABLE B21: Dissolved Oxygen, Temperature, Specific Conductivity and pH in the Grand River

Dissolved Oxygen (Mg/l)																
Depth(m)	03/06/97	05/16/97	05/28/97	06/16/97	07/15/97	08/23/97	09/27/97	10/25/97	12/14/97	03/07/98	05/12/98	06/15/98	07/31/98	08/06/98	09/12/98	10/16/98
1	12.83	10.3	9.86	11.93	12.79	12.18	12.86	9.79	12.86	11.47	9.29	15.85	9.86	8.57	9.49	11.66
2	13.6	10.38	10.2	11.73	11.46	12.21	11.94	9.8	12.92	11.42	9.19	13.18	9.22	8.23	7.89	11.81
3	12.78	10.45	9.6	11.31	9.24	11.21	11.81	9.78	12.9	11.31	8.78	12.54	8.1	7.87	7.42	11.98
4	1.95	10.48	9.67	9.6	9.1	10	11.72	9.78	12.86		8.64	12.13				
Specific Conductivity (µS/cm)																
1	613	611	609	628	608	634	624	703	753	583	573	627	600	658	594	605
2	615	612	609	623	610	645	620	704	754	584	572	634	600	658	594	605
3	618	612	609	618	614	649	623	705	754	584	572	633	600	656	595	608
4	619	612	609	615	614	651	623	706	754		571	633				674
Temperature (C)																
1	13.4	10.3	15.6	22.1	26	21.1	17	8.6	2	5.1	20	21.4	24	23.4	21.6	22.7
2	13.3	10.2	15.5	22	25.7	20.9	16.9	8.5	2	4.9	19.7	20.8	23.8	23.4	21.4	22.5
3	13.2	10.1	15.4	21.7	25.1	20.5	16.9	8.6	2	4.8	19.3	20.7	23.6	23.3	21.4	22.3
4	13.2	10.1	15.4	21.7	25.1	20.2	16.8	8.5	2		19.2	20.6				12.5
Surface pH																
	8.2	8.6	8.5	8.6	8.7	8.8	8.8	8.5	8.7	8.1	8.2	9.7	8.1	8.2	8.6	8.4

TABLE B22: Alkalinity of Spring Lake and the Grand River (mg CaCO₃/l)

	1997							1998							
	8May	28May	15July	23Aug	27Sept	25Oct	14Dec	8Mar	12May	15Jun	6Aug	20Aug	19Sept	16Oct	16Oct
Fruitport.E1	114	127	130	125	150	150		141	132		152	152	142	134	
Fruitport.E(Field dup)			140												
Fruitport.M										140					
Fruitport.H	112	127	138	121	144	149			134	148	150		141		
Fruitport.II(Field dup)			134												
Stahl.E	110	126	128	133	148	156		149	132		150	154	139	133	
Stahl.M										139					
Stahl.II	118	130	133	131	144	164			126	146	152		141		
Jerusalem.E	116	125	128	128	150	161		151	131	137	152		144	132	
Jerusalem.III				130											
Jerusalem.II2	120	126	135	131	151	163			136	147	154		144		
Smith.E	132	137	146	140	155	174		160	139	156	148	150	144	148	
Smith.II	134	140	146	140	159	173			140	158	157		143		
Spring Lake.E	150	144	150	143	158	174	183		135	155	156	152	142	150	
Spring Lake.M			147	154	166		184		139	174			150		
Spring Lake.H	144	146	156	171	198	174	185		142	174	166		157		
Spring Lake.H				180											
Prospect Point.E	126	134	143	142	154	174	180	158	133	143	156		162	146	
Prospect Point.M			147	158	162				133	160	157		154		
Prospect Point.II	132	144	153	176	182	197	180		146	162	186		166	164	
Petty.E	128	135	130	131	158	174	168		141	147	140	150	136	147	
Petty.H	128	138	131	131	154	169	172.4		133	155	150	172	148	147	
Grand River.1	206	204	182	187	211	232	242.4	202	218	221	182		176		198
Grand River.2		202													

APPENDIX C
PLANT AND ANIMAL LIFE IN THE WATERSHED
METHODS AND MATERIALS

APPENDIX C

PLANT AND ANIMAL LIFE IN THE WATERSHED METHODS AND MATERIALS

Aquatic Macrophyte Survey

During the summer of 1998, the aquatic macrophyte survey was completed as a random presence or absence survey within stratified depths in the bayous of Smith, Jerusalem, Petty and Stahl and the main body of the lake. A straight baseline was drawn parallel to the main shorelines and enumerated every 100 meters for possible transect starting sites. Numbers, from a SAS generated random list with a start number of 11330, were multiplied as fractions to the number of possible transect sites to obtain the random transect starting sites. Forty-one percent of the possible random sites were sampled and each randomly chosen transect was perpendicular to shoreline. Along each transect, samples were taken approximately every 3 meters. At these sampling points, depth was recorded and a twelve-inch garden rake attached to a rope was lowered to the bottom and pulled a meter along the bottom three times. Upon retrieval, plant and algae species were noted for presence. Voucher specimens were collected. If species could not be identified due to lacking reproductive tissues, the site was revisited later when species was flowering. Frequencies of plant species in each bayou and for the entire lake were calculated and information on presence in these depth strata was maintained: 0-1 meter depth, 1-2 meter depth, 2-3 meter depth. Dominant species lists were compiled for each bayou and a total watershed list along with a map illustrating dominant species zones. The maps were produced by R. B. Annis Water Resources Institute / Grand Valley State University. Aquatic plant references were:

- Voss, E. 1972, 1985, 1996. Michigan Flora: Part I, II, III. Cranbrook Institute of Science. Michigan.
- Fassett, N. 1957. A Manual of Aquatic Plants. University of Wisconsin Press.
- Aiken, S. 1981. A conspectus of Myriophyllum (Haloragaceae) in North America. Brittonia. 33(1):57-69.

Phytoplankton Sampling

Through a depth of double the Secchi depth or no deeper than 3 meters, composite plankton samples were taken about once a month at all lake sites and the Grand River site. A 3/4 inch PVC pipe was lowered vertically through the water to the estimated depth and capped. In a quick maneuver the pipe was flipped so as to preserve its sample which was poured into a rinsed milk jug. Three column samples at each sampling site were mixed and a 200 ml subsample of the composite sample was preserved with approximately 1 ml of Lugol's solution in glass jars. After allowing each 200 ml sample to settle, the top portion of approximately 190 ml was siphoned off. The remaining 10 ml was subsampled (0.1ml) for plankton in a Palmer-Maloney counting slide under a compound scope. The efficiency of this settling and siphoning method was examined by settling the initial decanted 190 ml again and decanting again and examining the remaining settled water for plankton. No plankton was found indicating that the process was sufficient. Plankton was identified and abundance was scaled by relative abundance which was similar to the scales used for rapid abundance scaling in terrestrial plant communities (Oosting 1958).

Abundance	Scaling	Relative Percentage
Very Abundant	5	60% and higher
Abundant	4	20 - 59%
Some	3	5- 19%
Few	2	2-1%
Rare	1	lower than 1%

Samples from Jerusalem, Prospect Point, Fruitport, and the Grand River were chosen as representative samples of the lake and the Grand River to be ranked by abundance. All samples are preserved so actual counts can be done at a later date. Species were listed in a composite list for Spring Lake and the Grand River. The highest abundance mode according to genera among lake and river samples was used to graph the relative abundance of algal groupings: blue-greens, greens, diatoms, dinoflagellates, cryptophytes and chrysophytes. For example, if in the diatoms, *Melosira* was ranked 4 and *Fragillaria* was ranked 3, the highest mode among the diatom genera was 4 and was used for the graph on that particular date. Four samples were analyzed by Ann St. Amand, a trained specialist, at Phyco Tech to confirm species and to generate a species list.

Zooplankton Sampling

Condensed zooplankton samples were taken at the same time as above the plankton samples with a plankton net (1/4 meter opening, #20, 150 micron mesh net) either as a diagonal or vertical tow throughout the entire water column. The net was rinsed with lake water and samples were collected into a glass pint jar. Samples were preserved in 4% formaldehyde solution (2 ml for every 100 ml of sample); if samples were dense, the ratio was increased (Wetzel & Likens, 1992). Quantitative analysis remains to be completed. Small fresh samples of each site were collected in film canisters for immediate identification once on shore. General observations from these fresh samples are reported in the discussion text.

Fish Survey

Information about fish in Spring Lake was derived from the 1998 angler creel survey. Even though this type of information is biased toward the type of fish the anglers are fishing for, it nevertheless provides useful fish data. As approved by MSU-University Committee on Research Involving Human Subjects, anglers at each of the sites were interviewed April 1998 through August 1998. Following a bus route method (Pollock et al. 1994), six access sites were visited at random times, days, starting sites and route direction: Ferrysburg Park, Smith Bridge, Jerusalem Bridge, Third Street Bridge, Petty's Bridge, and Fruitport Landing. Seventy-five percent of the weekends and 25% of the weekdays were sampled. During the 30 minutes at each site, only adult individuals were asked if they would like to participate in this anonymous fish survey. Any fish being held were measured for length. Detailed analysis of this data remains to be completed.

Zebra Mussels

Observations of zebra mussels were recorded as presence or absence at each transect of the aquatic plant sampling sites and whether they were attached to plants or another substrate.

TABLE C1: Algae list for Spring Lake and the Grand River

Algae	Spring Lake	Grand River
Blue-green		
<i>Anabaena sp.</i>	✓	✓
<i>Aphanizomenon flos-aquae</i>	✓	
<i>Aphanocapsa elachista</i>		✓
<i>Dactylococcopsis sp.</i>	✓	
<i>Merismopedia</i>	✓	✓
<i>Microcystis aeruginosa or viridis</i>	✓	✓
<i>Oscillatoria sp.</i>		✓
<i>Pseudanabaena sp.</i>		✓
Green		
<i>Actinastrum hantzschii</i>	✓	✓
<i>Ankistrodesmus falcatus</i>	✓	✓
<i>Carteria platyrhyncha</i>		✓
<i>Chlamydomonas sp.</i>	✓	✓
<i>Chlorococcales, non-motile</i>	✓	
<i>Closteriopsis longissima</i>	✓	
<i>Coelastrum sp.</i>		✓
<i>Gloeocystis sp.</i>		✓
<i>Oedogonium sp.</i>	✓	
<i>Oocystis sp.</i>	✓	✓
<i>Pediastrum duplex</i>	✓	✓
<i>Pediastrum boryanum</i>	✓	✓
<i>Scenedesmus bijuga</i>		✓
<i>Scenedesmus abundans</i>	✓	✓
<i>Scenedesmus dimorphus</i>		✓
<i>Scenedesmus quadricauda</i>	✓	✓
<i>Scenedesmus smithii</i>	✓	✓
<i>Schroederia setigera</i>	✓	
<i>Sphaerocystis schroeteri</i>	✓	
<i>Tetrastrum staurogeniaeformis</i>		✓
Diatom		
<i>Achnanthes sp.</i>	✓	✓
<i>Asterionella formosa</i>	✓	✓
<i>Cocconeis sp.</i>	✓	
<i>Cyclotella sp.</i>	✓	✓
<i>Cymbella sp.</i>		✓

TABLE C1: (cont'd).

Algae	Spring Lake	Grand River
<i>Diatoma sp.</i>	✓	✓
<i>Fragilaria capucina, crotonensis</i>	✓	✓
<i>Melosira varians</i>	✓	✓
<i>Navicula sp.</i>	✓	✓
<i>Nitzschia sp.</i>	✓	✓
<i>Rhoicosphenia curvata</i>	✓	
<i>Stephanodiscus hantzschii</i>	✓	✓
<i>Synedra ulna, tenera</i>	✓	✓
<i>Cyclotella choctawhatcheeana</i>	✓	✓
Chrysophyte		
<i>Chrysolykos sp.</i>	✓	
<i>Dinobryon divergens</i>	✓	✓
<i>Ellipsoidion sp.</i>	✓	
<i>Stelethomonas dichotomus</i>	✓	
Cryptophyte		
<i>Cryptomonas sp., cysts</i>	✓	✓
<i>Rhodomonas minuta</i>	✓	✓
Dinoflagellate		
<i>Ceratium hirundinella</i>	✓	
TOTAL	39	36

TABLE C2: Aquatic Plant & Algae Presence and Frequency Counts in Jerusalem Bayou

z = with zebra mussels on it 1 = at 0-1m depth 2 = at 1-2m depth 3 = at 2-3m depth 4 = at #1 & #2 5 = at #2 & #3 6 = at #1 & #3 7 = at all depths	Jerusalem Bayou Transects							Frequency Transect Counts
	1	2	3	4	5	6	7	
Spirogyra	1			4	4	1	4	5
Hydrodictyon								0
Rhizoclonium	1							1
Vaucheria	1	1			1			3
Spirodela polyrhiza				4				1
Lemna minor				4				1
Lemna trisulca								0
Najas flexilis		4						1
Heteranthera dubia	4z	1		4z	1	•	1	5
Potamogeton Richardsonii								0
Potamogeton filiformis				2z				1
Potamogeton pectinatus		1z	1	2z	4	1z		5
Potamogeton crispus								0
Ceratophyllum demersum	5z	4z	1z	7z	2z	4z	7z	7
Myriophyllum spicatum		4z		2z		1z	1z	4
Myriophyllum spp.								0
Utricularia vulgaris								0
Elodea canadensis	2z	1z	1					3
Peltandra virginica								0
Pontederia cordata								0
Nuphar advena								0
Nymphaea odorata	1	4		4		1	1	5
Vallisneria americana								0
Total number of species	7	8	3	9	5	5	5	13

TABLE C3: Aquatic Plant & Algae Presence and Frequency in Stahl Bayou, Spring Lake

z = with zebra mussels on it 1 = at 0-1m depth 2 = at 1-2m depth 3 = at 2-3m depth 4 = at #1 & #2 5 = at #2 & #3 6 = at #1 & #3 7 = at all depths	Stahl Bayou Transects								Frequency Transect Counts
	1	2	3	4	5	6	7	8	
<i>Spirogyra</i>	3			4	1				3
<i>Hydrodictyon</i>									0
<i>Rhizoclonium</i>	4	7	7	1	1		1		6
<i>Vaucheria</i>									0
<i>Spirodela polyrhiza</i>	4	7	7	1	1		1		6
<i>Lemna minor</i>	4	7			1				3
<i>Lemna trisulca</i>									0
<i>Najas flexilis</i>		1	1					1	3
<i>Heteranthera dubia</i>	7	4	7z	4z	1		7z	2	7
<i>Potamogeton Richardsonii</i>									0
<i>Potamogeton filiformis</i>				1			7		2
<i>Potamogeton pectinatus</i>									0
<i>Potamogeton crispus</i>		3	1				7		3
<i>Ceratophyllum demersum</i>	7z	7	7	7	7z	3z	7z	7z	8
<i>Myriophyllum spicatum</i>									0
<i>Myriophyllum spp.</i>	3			1z	1z	3z		4z	5
<i>Utricularia vulgaris</i>									0
<i>Elodea canadensis</i>	1	1	5	4	1z		4z		6
<i>Peltandra virginica</i>									0
<i>Pontederia cordata</i>			1						1
<i>Nuphar advena</i>									0
<i>Nymphaea odorata</i>	1	7	1	1	1		4		6
<i>Vallisneria americana</i>	1						1		2
<i>Lythrum salicaria</i>			1	1				1	3
<i>Scirpus validus</i>				1					1
Total Number of species	10	9	10	11	9	2	9	5	16

TABLE C4: Aquatic Plant & Algae Presence and Frequency Counts in Petty Bayou

z = with zebra mussels on it 1 = at 0-1m depth 2 = at 1-2m depth 3 = at 2-3m depth 4 = at #1 & #2 5 = at #2 & #3 6 = at #1 & #3 7 = at all depths	Petty Bayou Transects											
	1	2	3	4	5	6	7	8	9	10	11	12
<i>Spirogyra</i>		1			1	1		1				1
<i>Hydrodictyon</i>												
<i>Rhizoclonium</i>		1	4	4	4	1	1	4	7	1	1	1
<i>Vaucheria</i>												
<i>Spirodela polyrhiza</i>		1	1	1	1			1				1
<i>Lemna minor</i>			1	4	1							1
<i>Lemna trisulca</i>			2									1
<i>Najas flexilis</i>		1z			1	1z	1	3z	4		4	
<i>Heteranthera dubia</i>	1	1	7									
<i>Potamogeton Richardsonii</i>	1						1					4
<i>Potamogeton filiformis</i>		1						1	1z			4
<i>Potamogeton pectinatus</i>	1z		5			1	1					
<i>Potamogeton crispus</i>		4z	6			2		1				
<i>Ceratophyllum demersum</i>	4z	4z	7z	7z	7z	4z	7z	7z	7z	7z	5	4z
<i>Myriophyllum spicatum</i>	1	1z					1z	4z	4z	1z	4z	4z
<i>Myriophyllum</i> spp.			4z	4z	7	1z						
<i>Utricularia vulgaris</i>												
<i>Elodea canadensis</i>	1	1z	4	1	4	1z	1	1z	4	4z		
<i>Peltandra virginica</i>					1							1
<i>Pontederia cordata</i>												1
<i>Nuphar advena</i>												
<i>Nymphaea odorata</i>			4	4	1			1				
<i>Vallisneria americana</i>		1					1					
<i>Lythrum salicaria</i>												1
<i>Scirpus validus</i>	1											
<i>Polygonum</i> spp.									1z			
<i>Sagittaria latifolia</i>								1				
<i>Sparganium</i>												
Total number of species	7	11	11	7	10	8	8	11	7	4	4	12

TABLE C4: (cont'd).

z = with zebra mussels on it 1 = at 0-1m depth 2 = at 1-2m depth 3 = at 2-3m depth 4 = at #1 & #2 5 = at #2 & #3 6 = at #1 & #3 7 = at all depths	Petty Bayou Transects					Frequency Transect Counts
	13	14	15	16	17	
<i>Spirogyra</i>			1			6
<i>Hydrodictyon</i>						0
<i>Rhizoclonium</i>	1		4	4	1	15
<i>Vaucheria</i>		1			1	2
<i>Spirodela polyrhiza</i>	1					7
<i>Lemna minor</i>	1					5
<i>Lemna trisulca</i>						2
<i>Najas flexilis</i>		4	4	4	1z	11
<i>Heteranthera dubia</i>					4	4
<i>Potamogeton Richardsonii</i>	1	1			4	6
<i>Potamogeton filiformis</i>	4z		4	2	2	8
<i>Potamogeton pectinatus</i>	4z			1	4	7
<i>Potamogeton crispus</i>		1				5
<i>Ceratophyllum demersum</i>	4z	4z	4z	2z	4z	17
<i>Myriophyllum spicatum</i>					4z	9
<i>Myriophyllum</i> spp.	4z		4z			6
<i>Utricularia vulgaris</i>						0
<i>Elodea canadensis</i>	4z	4	4	2z	4z	15
<i>Peltandra virginica</i>			1			3
<i>Pontederia cordata</i>						1
<i>Nuphar advena</i>						0
<i>Nymphaea odorata</i>			1			5
<i>Vallisneria americana</i>	4z					4
<i>Lythrum salicaria</i>			1			2
<i>Scirpus validus</i>						1
<i>Polygonum</i> spp.						1
<i>Sagittaria latifolia</i>						1
<i>Sparganium</i>			1			1
Total number of species	10	6	11	6	11	25

TABLE C5: Aquatic Plant & Algae Presence & Frequency Counts in Smith Bayou

z = with zebra mussels on it 1 = at 0-1m depth 2 = at 1-2m depth 3 = at 2-3m depth 4 = at #1 & #2 5 = at #2 & #3 6 = at #1 & #3 7 = at all depths	Smith Bayou Transects									
	1	2	3	4	5	6	7	8	9	10
<i>Spirogyra</i>					1	1	1	4		
<i>Hydrodictyon</i>			1							
<i>Rhizoclonium</i>	1	1	1	1	1	1			1	1
<i>Vaucheria</i>										
<i>Spirodela polyrhiza</i>	1		1	4	1	4	1	4	1	
<i>Lemna minor</i>	1		1	4	1	4	1	4	1	
<i>Lemna trisulca</i>			1	4	1	4	1	4	1	
<i>Najas flexilis</i>		4z	1	2	1				1	
<i>Heteranthera dubia</i>	1	1z		4	1	1			1	
<i>Potamogeton Richardsonii</i>	4									
<i>Potamogeton filiformis</i>		4	3					1		
<i>Potamogeton pectinatus</i>	1	1	1	2		1				1
<i>Potamogeton crispus</i>				2	1	1		1		
<i>Ceratophyllum demersum</i>	7z	7z	7z	4z	4z	4z	1	4z	4z	4z
<i>Myriophyllum spicatum</i>	1		6z	4z	4z	1			1	
<i>Myriophyllum</i> spp.							1			1
<i>Utricularia vulgaris</i>							1			
<i>Elodea canadensis</i>	4z	7z	7z	4z	4z	4z	1	4	1	1z
<i>Peltandra virginica</i>			1	1	1	1	1		1	
<i>Pontederia cordata</i>				1	1z		1			
<i>Nuphar advena</i>				1	1	1	1			
<i>Nymphaea odorata</i>			1	4	1	4	1	4	1	
<i>Vallisneria americana</i>	4									
<i>Wolffia</i>	1		1	4	1	4	1	4	1	
<i>Typha</i> spp.				1	1					
Total number of species	11	7	14	17	17	15	13	10	12	5

TABLE C5: (cont'd).

z = with zebra mussels on it 1 = at 0-1m depth 2 = at 1-2m depth 3 = at 2-3m depth 4 = at #1 & #2 5 = at #2 & #3 6 = at #1 & #3 7 = at all depths	Smith Bayou Transects		Frequency Transect Counts
	11	12	
Spirogyra			4
Hydrodictyon		1	2
Rhizoclonium			8
Vaucheria			0
Spirodela polyrhiza	2		9
Lemna minor			8
Lemna trisulca			7
Najas flexilis			5
Heteranthera dubia	2		7
Potamogeton Richardsonii			1
Potamogeton filiformis			3
Potamogeton pectinatus		1	7
Potamogeton crispus			4
Ceratophyllum demersum	5z	4z	12
Myriophyllum spicatum			6
Myriophyllum spp.		4z	3
Utricularia vulgaris			1
Elodea canadensis	2z	1z	12
Peltandra virginica			6
Pontederia cordata			3
Nuphar advena			4
Nymphaea odorata			7
Vallisneria americana		1	2
Wolffia			8
Typha spp.			2
Total number of species	4	6	24

TABLE C6: Aquatic Plant & Algae Presence & Frequency Counts in Main Spring Lake

z = with zebra mussels on it 1 = at 0-1m depth 2 = at 1-2m depth 3 = at 2-3m depth 4 = at #1 & #2 5 = at #2 & #3 6 = at #1 & #3 7 = at all depths	Main Transects											
	1	2	3	4	5	6	7	8	9	10	11	12
Spirogyra												
Hydrodictyon								1				
Rhizoclonium					1	1	4	1				
Vaucheria							1	1		1		
Spirodela polyrhiza					1		4					1
Lemna minor					1		1					1
Lemna trisulca												
Najas flexilis										4z		
Heteranthera dubia		1			1	1	4	1z	2z	4z		4
Potamogeton												4
Potamogeton filiformis											1z	4
Potamogeton pectinatus		1		1	1	4	4	1				
Potamogeton crispus			1	1	1	4	1				1z	
Ceratophyllum demersum					4z	4z	4z	4z	7z	5z	4z	4
Myriophyllum spicatum			1	1	4	2	2z	2z				
Myriophyllum spp.						1	4z	1z			4z	4
Utricularia vulgaris												
Elodea canadensis					4	4	4	4z	3z	7z	1	
Peltandra virginica	1				1							
Pontederia cordata												
Nuphar advena												
Nymphaea odorata												
Vallisneria americana					1		4	1		4z	1	1
Lythrum salicaria	1				1							
Scirpus validus												
Polygonum spp.												
Sagittaria latifolia												
Sparganium												
Wolffia					1		4					
Typha	1											
Total number of species	3	2	2	3	13	8	13	10	3	6	6	8

TABLE C6: (cont'd).

z = with zebra mussels on it 1 = at 0-1m depth 2 = at 1-2m depth 3 = at 2-3m depth 4 = at #1 & #2 5 = at #2 & #3 6 = at #1 & #3 7 = at all depths	Main Transects											
	13	14	15	16	17	18	19	20	21	22	23	24
Spirogyra												
Hydrodictyon												
Rhizoclonium			1z				4				4z	4z
Vaucheria	4			1	1				1			
Spirodela polyrhiza												
Lemna minor												
Lemna trisulca												
Najas flexilis			2z									
Heteranthera dubia			1z	1		4z		2z		1z		4
Potamogeton	4				1z		1z					
Potamogeton filiformis	4z								2z			
Potamogeton pectinatus			1z	1z	1z	1z	1z	4z	4z	1z		
Potamogeton crispus			1z							1z		2
Ceratophyllum demersum	7z	3z	7z	4z	7z		7	2	5z	1z	7z	7z
Myriophyllum spicatum			1z	1	4z		7z		2z		4z	5
Myriophyllum spp.			1z	1								
Utricularia vulgaris												
Elodea canadensis			2z							1	2z	
Peltandra virginica												
Pontederia cordata												
Nuphar advena												
Nymphaea odorata												
Vallisneria americana	1			1	1		1					1
Lythrum salicaria												
Scirpus validus												
Polygonum spp.												
Sagittaria latifolia												
Sparganium												
Wolffia												
Typha												
Total number of species	5	1	9	7	6	2	6	3	5	5	4	6

TABLE C6: (cont'd).

z = with zebra mussels on it 1 = at 0-1m depth 2 = at 1-2m depth 3 = at 2-3m depth 4 = at #1 & #2 5 = at #2 & #3 6 = at #1 & #3 7 = at all depths	Main Transects											
	25	26	27	28	29	30	31	32	33	34	35	36
Spirogyra	2		1					1				
Hydrodictyon												
Rhizoclonium	1			2z				1	4	1		
Vaucheria			1		1	1			1		1	1
Spirodela polyrhiza					1			1				
Lemna minor								1				
Lemna trisulca								1				
Najas flexilis	4z		2z						4z	1z		
Heteranthera dubia	4z	4z						4z		1		1z
Potamogeton												
Potamogeton filiformis			4z	2z					4z			
Potamogeton pectinatus	1z	4z	1z	1z						1z	1z	1z
Potamogeton crispus	1		1z	1z					1z	1z		
Ceratophyllum demersum	7z	4z	4z	7z	4z	7z	5z	5z	4z	4z		1z
Myriophyllum spicatum	5z	4z	2z		4z	4z	2z			4z		1
Myriophyllum spp.			2z									
Utricularia vulgaris												
Elodea canadensis		2z	4z	4z	2z	1z	2z	4z	4z	1z		
Peltandra virginica												
Pontederia cordata												
Nuphar advena												
Nymphaea odorata					1	1	1	1			1	1
Vallisneria americana	1	1		4	4				1z	4z		
Lythrum salicaria												
Scirpus validus			1									
Polygonum spp.								1				
Sagittaria latifolia												
Sparganium												
Wolffia												
Typha												
Total number of species	9	6	11	7	7	5	4	10	8	9	3	6

TABLE C6: (cont'd).

z = with zebra mussels on it 1 = at 0-1m depth 2 = at 1-2m depth 3 = at 2-3m depth 4 = at #1 & #2 5 = at #2 & #3 6 = at #1 & #3 7 = at all depths	Main Transects											
	37	38	39	40	41	42	43	44	45	46	47	48
Spirogyra							1	1	1			
Hydrodictyon											1	
Rhizoclonium							1	1				4
Vaucheria			1	1		1				1	1	1
Spirodela polyrhiza							1		1			
Lemna minor									1			
Lemna trisulca									1			
Najas flexilis				1z							1z	
Heteranthera dubia		1	1z	1	2z	1		1z	1	2	1z	4
Potamogeton							1z	1z				
Potamogeton filiformis	1z	2z									1z	
Potamogeton pectinatus	1		1z	1z	4z		1	1			1	
Potamogeton crispus			1z							1		2
Ceratophyllum demersum	4z	7z	4z	2z	3z	2z	4z	4z	1	5z	7z	4z
Myriophyllum spicatum		4z		1z		2z	1	1		2		2z
Myriophyllum spp.									1			
Utricularia vulgaris									1			
Elodea canadensis		2z		1z	3z		4z	4z	1			2
Peltandra virginica									1			
Pontederia cordata									1			
Nuphar advena												
Nymphaea odorata									1	2		
Vallisneria americana	4z		1							4		1
Lythrum salicaria									1			
Scirpus validus												
Polygonum spp.												
Sagittaria latifolia												
Sparganium												
Wolffia									1			
Typha									1			
Potamogeton amphifolius								1				
Total number of species	4	5	6	7	4	4	8	9	15	7	7	8

TABLE C6: (cont'd).

z = with zebra mussels on it 1 = at 0-1m depth 2 = at 1-2m depth 3 = at 2-3m depth 4 = at #1 & #2 5 = at #2 & #3 6 = at #1 & #3 7 = at all depths	Main Transects											
	49	50	51	52	53	54	55	56	57	58	59	60
Spirogyra										1		
Hydrodictyon							1	1	1			
Rhizoclonium											1	1
Vaucheria	1	1		1		1	1	1	1	1		
Spirodela polyrhiza												
Lemna minor												
Lemna trisulca												
Najas flexilis		5z		1		2z				1z		1
Heteranthera dubia	4z	4z		2					1z	1	2z	2z
Potamogeton			1z					1		1		
Potamogeton filiformis			1z			2z						
Potamogeton pectinatus	1z		1z	1z	1z		1z	1z	1z	1	1	1
Potamogeton crispus	1z											
Ceratophyllum demersum	4z	7z	5z		1z		1z	4	7z	1	4z	7z
Myriophyllum spicatum	4z						1z	1z	2z	1	4z	4
Myriophyllum spp.		6										
Utricularia vulgaris												
Elodea canadensis		5z				2z			1z		4z	5
Peltandra virginica												
Pontederia cordata												
Nuphar advena												
Nymphaea odorata												
Vallisneria americana	4z						1	1		1	1	
Lythrum salicaria												
Scirpus validus												
Polygonum spp.												
Sagittaria latifolia												
Sparganium												
Wolffia												
Typha												
Total number of species	7	6	4	4	2	4	6	7	7	9	7	7

TABLE C6: (cont'd).

z = with zebra mussels on it 1 = at 0-1m depth 2 = at 1-2m depth 3 = at 2-3m depth 4 = at #1 & #2 5 = at #2 & #3 6 = at #1 & #3 7 = at all depths	Main Transects											Frequency Transect Counts
	61	62	63	64	65	66	67	68	69	70	71	
Spirogyra												7
Hydrodictyon												5
Rhizoclonium	1					4	1					21
Vaucheria						1					1	29
Spirodela polyrhiza												7
Lemna minor												5
Lemna trisulca												2
Najas flexilis							1z					14
Heteranthera dubia		1		1			1					39
Potamogeton												9
Potamogeton filiformis												12
Potamogeton pectinatus	1z	1z						2				41
Potamogeton crispus												18
Ceratophyllum demersum	2	4z		7z		7z	7z	2z	1z	1z		60
Myriophyllum spicatum	1			2z		2	1	2z				40
Myriophyllum spp.		1										11
Utricularia vulgaris												0
Elodea canadensis	1z	1z				4z	4z	2z	2z			37
Peltandra virginica												3
Pontederia cordata												1
Nuphar advena												0
Nymphaea odorata								2				9
Vallisneria americana							1					27
Lythrum salicaria												3
Scirpus validus												1
Polygonum spp.												1
Sagittaria latifolia												0
Sparganium												0
Wolffia												3
Typha												2
Potamogeton amplifolius												1
Total number of species	5	5	0	3	0	5	7	5	2	1	1	27

TABLE C7: Aquatic Plant and Algae Frequency Percentages in Spring Lake

Transect Frequency Counts and Percentage	Jerusalem		Stahl		Petty		Smith		Main		Whole Lake	
	C	%	C	%	C	%	C	%	C	%	C	%
<i>Spirogyra</i>	5	71	3	38	6	35	4	33	7	10	25	21
<i>Hydrodictyon</i>	0	0	0	0	0	0	2	17	5	7	7	6
<i>Rhizoclonium</i>	1	14	6	75	15	88	8	67	21	30	51	44
<i>Vaucheria</i>	3	43	0	0	2	12	0	0	29	41	34	30
<i>Spirodela polyrhiza</i>	1	14	6	75	7	41	9	75	7	10	30	26
<i>Lemna minor</i>	1	14	3	38	5	29	8	67	5	7	22	19
<i>Lemna trisulca</i>	0	0	0	0	2	12	7	58	2	3	11	10
<i>Najas flexilis</i>	1	14	3	38	11	65	5	42	14	20	34	30
<i>Heteranthera dubia</i>	5	71	7	88	4	24	7	58	39	55	62	54
<i>Potamogeton Richardsonii</i>	0	0	0	0	6	35	1	8	9	13	16	14
<i>Potamogeton filiformis</i>	1	14	2	25	8	47	3	25	12	17	26	23
<i>Potamogeton pectinatus</i>	5	71	0	0	7	41	7	58	41	58	60	52
<i>Potamogeton crispus</i>	0	0	3	38	5	29	4	33	18	25	30	26
<i>Ceratophyllum</i>	7	100	8	100	17	100	12	100	60	85	104	90
<i>Myriophyllum spicatum</i>	4	57	0	0	9	53	6	50	40	56	59	51
<i>Myriophyllum</i> spp.	0	0	5	62	6	35	3	25	11	15	25	22
<i>Utricularia vulgaris</i>	0	0	0	0	0	0	1	8	0	0	1	.9
<i>Elodea canadensis</i>	3	43	6	75	15	88	12	100	37	52	73	63
<i>Peltandra virginica</i>	0	0	0	0	3	18	6	50	3	4	12	10
<i>Pontederia cordata</i>	0	0	1	12	1	6	3	25	1	1	6	5
<i>Nuphar advena</i>	0	0	0	0	0	0	4	33	0	0	4	3
<i>Nymphaea odorata</i>	5	71	6	75	5	29	7	58	9	13	32	28
<i>Vallisneria americana</i>	0	0	2	25	4	24	2	17	27	38	35	30
<i>Lythrum salicaria</i>	0	0	3	38	2	12	0	0	3	4	8	7
<i>Scirpus validus</i>	0	0	1	12	1	6	0	0	1	1	3	3
<i>Polygonum</i> spp.	0	0	0	0	1	6	0	0	1	1	2	2
<i>Sagittaria latifolia</i>	0	0	0	0	1	6	0	0	0	0	1	.9
<i>Sparganium</i>	0	0	0	0	1	6	0	0	0	0	1	.9
<i>Wolffia</i>	0	0	0	0	0	0	8	67	3	4	11	10
<i>Typha</i>	0	0	0	0	0	0	2	17	2	3	4	3
<i>Potamogeton amplifolius</i>	0	0	0	0	0	0	0	0	1	1	1	.9
Total number of species	13		16		25		24		27		31	

APPENDIX D

WATERSHED USES AND PERSPECTIVES OF THE RESIDENTS

METHODS AND MATERIALS

TABLE D1: 1978 Land Use Acreage in Spring Lake Watershed

	Spring Lake Village	Spring Lake Township	Ferrysburg	Fruitport Village	Fruitport Township	Sullivan Township	Crockery Township	Ravenna Township	Moorland Township	Egelston Township	Norton Shores	Total (acre)	Total (hectare)
Water	140	650	251	51	32	6	0	0	2	0	11	1143	463
Residential	132	1221	307	336	1373	588	118	0	0	40	29	4144	1677
Industry	82	263	89	99	458	33	56	0	0	9	104	1193	483
Cropland	0	328	60	1	2722	2053	175	1582	171	99	0	7191	2910
Open Field	0	279	67	0	1871	1177	260	12	0	97	86	3849	1558
Orchards	0	48	0	0	281	104	23	0	0	0	33	489	198
Forest	0	2342	208	69	5642	4857	1068	156	2	273	136	14753	5971
Wetland	0	55	3	82	92	25	0	0	0	0	0	257	104
Barren	0	9	0	0	17	69	0	0	0	9	0	104	42
Total (acre)	354	5195	985	638	12488	8912	1700	1750	175	527	399	33123	
Total (hectare)	143	2102	399	258	5054	3607	688	708	71	213	161		13405

TABLE D2: 1992-1997 Land Use Acreage in Spring Lake Watershed

	Spring Lake Village	Spring Lake Township	Ferrysburg	Fruitport Village	Fruitport Township	Sullivan Township	Crockery Township	Ravenna Township	Moorland Township	Egelston Township	Norton Shores	Total (acre)	Total (hectare)
Water	140	650	251	51	38	8	0	0	2	0	11	1151	466
Residential	132	1279	338	341	1966	612	144	13	7	61	24	4917	1990
Industry	82	361	98	99	512	74	52	0	0	0	130	1408	570
Cropland	0	170	34	1	1220	1494	87	1503	157	52	0	4718	1909
Open Field	0	324	54	0	1767	1308	252	72	3	174	75	4029	1631
Orchards	0	63	0	0	418	201	106	0	0	0	31	819	331
Forest	0	2283	199	71	6451	5112	1058	162	6	232	128	15702	6355
Wetland	0	55	12	85	89	19	0	0	0	0	0	260	105
Barren	0	9	0	0	30	86	0	0	0	8	0	133	54
Total (acre)	354	5194	986	648	12491	8914	1699	1750	175	527	399	33137	
Total (hectare)	143	2102	399	262	5055	3607	688	708	71	213	161		13418

TABLE D3: Acreage Changes in Land Use from 1978 to 1992-1997 in Spring Lake Watershed

	Spring Lake Village	Spring Lake Township	Ferrysburg	Fruitport Village	Fruitport Township	Sullivan Township	Crockery Township	Ravenna Township	Moorland Township	Egelston Township	Norton Shores	Total (acre)	Percentage lost or gained from 1978
Water	0	0	0	0	6	2	0	0	0	0	0	8	1
Residential	0	58	31	5	593	24	26	13	7	21	-5	773	19
Industry	0	98	9	0	54	41	-4	0	0	-9	26	215	18
Cropland	0	-158	-26	0	-1502	-559	-88	-79	-14	-47	0	-2473	-34
Open Field	0	45	-13	0	-104	131	-8	60	3	77	-11	180	5
Orchards	0	15	0	0	137	97	83	0	0	0	-2	330	67
Forest	0	-59	-9	2	809	255	-10	6	4	-41	-8	949	6
Wetland	0	0	9	3	-3	-6	0	0	0	0	0	3	1
Barren	0	0	0	0	13	17	0	0	0	-1	0	29	28

APPENDIX D

WATERSHED USES AND PERSPECTIVES OF THE RESIDENTS METHODS AND MATERIALS

Watershed Land Uses

Geographical Information System mapping was completed by R. B. Annis Water Resources Institute / Grand Valley State University. All acreage and other components were obtained from their data base. The most recent data base for Ottawa County was from 1992 aerial flights and 1997 flights for Muskegon County. The 1978 land use was obtained from the 1978 aerial flights. Census data was from 1990 (U. S. Department of Commerce 1990).

Lake Shoreline Type

While completing the aquatic plant survey, shoreline types of natural, rip rap or solid seawalls were counted and recorded for residential parcels. When residential boundaries were indistinguishable, such as for undeveloped areas, about 50 meters of shoreline was considered a parcel. Approximately 226 shoreline parcels remain natural, 179 parcels with rip rap shores, and 361 parcels with solid seawalls around the lake.

Resident Survey

With the approval of MSU's University Committee on Research Involving Human Subjects, the watershed residents' survey was developed to characterize the human community by their lake/watershed knowledge, concerns, management priorities, and their

suggestions addressing watershed issues. The surveys (see the following pages) were printed by Johnston Boiler Company and mailed to 600 random taxpayer households within the watershed. Addresses were obtained from tax lists within the municipalities of City of Ferrysburg, Spring Lake Village, Spring Lake Township, Fruitport Township, Fruitport Village, Sullivan Township, Ravenna Township, and Crockery Township. The addresses were checked by house number and street for confirmation of placement within the watershed and duplicates were eliminated. The entire compiled list of approximately 5666 addresses were numbered and 600 addresses were randomly picked by using a random number list generated by SAS statistical program with the starter number of 11330. The surveys were mailed in June 1998 along with an introduction letter (see following page) explaining the study and the resident's anonymity. The residents' consent to participate in the study was implied by their completion of the survey. Since a modified Total Design Method (Dillman 1978) was utilized, postcards were mailed a few weeks later to remind residents to complete the survey and to thank them for their time. Overall results are described in Chapter 4, whereas detailed counts are given in Table D4 by cross analyzing the answers of those that live on the water and those that do not. Survey statistics were analyzed by using SYSTAT 8. Of the 600 surveys sent, 169 surveys were returned for a response rate of 28%. In the results, each no response is listed for each part of the question. To obtain total no response for each question, add up the responses and subtract from 169 (Table D4). In questions concerning rankings, only the first highest rankings are listed.

Resident Survey Cover Letter

June 15, 1998

Dear Spring Lake Watershed Property Owner,

This survey is part of a project called the Spring Lake Watershed Aquatic Assessment. Studying the water quality of the lake and its streams, the assessment study will provide management suggestions to the local governments and the newly-formed lake board. This survey will be used to determine your beliefs about your lake and watershed which will be incorporated into the study's results and suggestions.

Your opinions and ideas are important! Your household was randomly chosen from all who own property in the Spring Lake Watershed, so this survey should not be given to another household. **The adult (18 years or older) who has had the most recent birthday should be the person who answers the survey.** Completing and returning the survey is your consent to participate in this confidential survey. All survey mailing lists will be destroyed after the completion of the survey.

Upon the study's completion in the spring of 1999, the survey results will be written in the Spring Lake Watershed Aquatic Assessment Report. The study will be given to all local governmental units, Ottawa Conservation District, Muskegon Conservation District, Spring Lake Board, local libraries, and other supporting groups. In addition a public information meeting will be held during the spring of 1999. The survey results will be available to you free of charge. If you would like a copy of the survey results, print your name and address on the enclosed postcard. Please return the postcard separately from the survey.

Please call with any questions (_____). I am most happy to answer them. The best times to call are Tuesdays or Thursdays between 7:00 a.m. - 10:00 p.m. Thank you very much for your time and assistance!

Sincerely,

Theresa Lauber
Michigan State University Graduate Student

Resident Survey Questionnaire

**PLEASE RETURN THE COMPLETED SURVEY IN
THE ENCLOSED STAMPED ENVELOPE BY JULY
30, 1998.**

WATER QUALITY OF SPRING LAKE

*The survey will begin with some questions about your
perceptions of the water quality of Spring Lake.*

1. How would you rate the water quality of Spring Lake
this past year? **(CIRCLE ONE)**

- 1 UNACCEPTABLE (go to Question 2)
- 2 ACCEPTABLE (skip to Question 4)
- 3 SUPERIOR (skip to Question 4)
- 4 I DON'T KNOW / I'M NOT SURE
(skip to question 4)

SPRING LAKE WATERSHED A STUDY OF ITS RESIDENTS

June - July 1998

Sponsors of the Spring Lake Aquatic Watershed Study:

- Community Foundation of Muskegon County
- Fruitport Township
- Grand Haven Area Community Foundation
- GVSU - R. B. Annis Water Resource Institute
- Michigan State University
- Muskegon Conservation District
- North Bank Community Fund
- Ottawa Soil & Water Conservation District
- Spring Lake Township
- Village of Fruitport
- Village of Spring Lake
- Spring Lake Area Resident Association

*Johnston Boiler Company provided the printing services for
this survey.*

2. If you answered UNACCEPTABLE in
question #1, what characteristic(s) do you
feel are a problem? **(CIRCLE ALL THAT
APPLY)**

- 1 WATER COLOR
- 2 WATER SMELL
- 3 INCREASED AQUATIC PLANT
AND ALGAE GROWTH
- 4 LITTER PRESENT
- 5 SEWAGE PRESENT
- 6 I DON'T KNOW / I'M NOT SURE
- 7 OTHER (PLEASE
SPECIFY) _____

(CONTINUE WITH QUESTION 3)

3. What lake uses or benefits do you feel are impaired because of UNACCEPTABLE water quality?
(CIRCLE ALL THAT APPLY)

- 1 FISHING
- 2 SWIMMING
- 3 BOATING
- 4 AESTHETICS
- 5 OTHER (PLEASE SPECIFY) _____

4. Do you feel that the water quality of the lake in the past 5 - 10 years has (CIRCLE ONE)

- 1 DECLINED (go to question 5) → → → →
- 2 IMPROVED (skip to question 6)
- 3 REMAINED THE SAME (skip to question 6)
- 4 I DON'T KNOW (skip to question 6) ▼

5. If you feel the water quality of Spring Lake has DECLINED in the past 5-10 years, what do you believe has changed? (CIRCLE ALL THAT APPLY)

- 1 WATER COLOR
- 2 WATER SMELL
- 3 INCREASED AQUATIC PLANT AND ALGAE GROWTH
- 4 LITTER PRESENT
- 5 TEMPERATURE CHANGE
- 6 SEWAGE PRESENT
- 7 I DON'T KNOW / I'M NOT SURE
- 8 OTHER (PLEASE SPECIFY) _____

WATER QUALITY OF NORRIS CREEK

Although Spring Lake has many small streams or tributaries flowing into it, Norris Creek is the largest tributary which enters the lake near Coop's Party Store in Fruitport.

6. How would you rate the water quality of the major tributary, Norris Creek, this past year? (CIRCLE ONE)

- 1 UNACCEPTABLE (go to question 7) ▼
- 2 ACCEPTABLE (skip to question 8)
- 3 SUPERIOR (skip to question 8)
- 4 I DON'T KNOW / I'M NOT SURE (skip to question 8) ▼

7. If you answered UNACCEPTABLE in question 6, what characteristic(s) do you feel are a problem? (CIRCLE ALL THAT APPLY)

- 1 WATER COLOR
- 2 WATER SMELL
- 3 INCREASED AQUATIC PLANT AND ALGAE GROWTH
- 4 LITTER PRESENT
- 5 INCREASED SEDIMENTS
- 6 TEMPERATURE CHANGE
- 7 SEWAGE PRESENT
- 8 I DON'T KNOW / I'M NOT SURE
- 9 OTHER (PLEASE SPECIFY) _____

WATER QUALITY OF GRAND RIVER

The Spring Lake watershed is part of the Grand River Watershed. A watershed is the entire land area that contributes to the water in a lake or basin.

8. How would you rate the water quality of Grand River this past year? (**CIRCLE ONE**)

- 1 UNACCEPTABLE (go to question 9) →
2 ACCEPTABLE (skip to question 10)
3 SUPERIOR (skip to question 10)
4 I DON'T KNOW / I'M NOT SURE
(skip to question 10) ▾

9. If you answered unacceptable in question 8 what characteristic(s) do you feel are a problem? (**CIRCLE ALL THAT APPLY**)

- 1 WATER COLOR
2 WATER SMELL
3 INCREASED AQUATIC PLANT AND ALGAE GROWTH
4 LITTER PRESENT
5 INCREASED SEDIMENT
6 TEMPERATURE CHANGE
7 SEWAGE PRESENT
8 I DON'T KNOW / I'M NOT SURE
9 OTHER (PLEASE SPECIFY) _____

YOUR WATERSHED PRIORITIES AND MANAGEMENT SUGGESTIONS

Your opinions and priorities will guide the writing of the watershed management suggestions. Most of the following issues were identified in a survey completed by the Spring Lake Area Residents Association in 1993. The following questions involve a list of items that will need to be prioritized. PLEASE RANK THEM BY NUMBERING YOUR HIGHEST PRIORITY WITH 1 AND SO ON TO YOUR LOWEST PRIORITY. DO NOT INCLUDE "OTHER" IN YOUR RANKING UNLESS YOU WRITE SOMETHING IN THE PROVIDED BLANK. FOR EXAMPLE:

What activities should children complete first after school?

- | | | |
|---|---|----------|
| 2 | 1 | CHORES |
| 3 | 2 | PLAY |
| 1 | 3 | HOMEWORK |

10. Which do you feel are the most important issues for the Spring Lake Watershed? (**PLEASE RANK**

YOUR TOP 5 CHOICES

- | | | |
|---|----|---|
| — | 1 | PROPERTY TAXES |
| — | 2 | POLLUTION (ANY TYPE) |
| — | 3 | WATER QUALITY |
| — | 4 | TOO MANY LAKE USERS |
| — | 5 | WETLAND LOSS |
| — | 6 | EXCESS AQUATIC PLANTS |
| — | 7 | INVADING SPECIES, SUCH AS ZEBRA MUSSELS |
| — | 8 | TRESPASSING |
| — | 9 | FISHING |
| — | 10 | SOIL EROSION |
| — | 11 | OTHER _____ |

11. Which suggestions do you believe would be most effective in managing boating ? **(PLEASE RANK FROM 1 TO 6)**
- 1 REQUIRING DRIVER TRAINING
- 2 REQUIRING SAFETY EDUCATION
- 3 REQUIRING ENVIRONMENTAL EDUCATION
- 4 LIMITING NUMBER OF BOAT SLIPS AND USE OF BOAT RAMPS
- 5 LIMITING ENGINE NOISES
- 6 ADDRESSING SPEED AND CONGESTION
- 7 OTHER _____
12. Which suggestions do you believe would be most effective in managing swimmers? **(PLEASE RANK FROM 1 TO 3)**
- 1 PROVIDING SAFETY EDUCATION
- 2 PROVIDING ENVIRONMENTAL EDUCATION
- 3 BANNING BRIDGE JUMPING
- 4 OTHER _____
13. What suggestions do you believe would be most effective in improving businesses' & industries' treatment of the lake ? **(PLEASE RANK 1 TO 4)**
- 1 REQUIRING ENVIRONMENTAL EDUCATION
- 2 LIMITING LAND USE CHANGES
- 3 PARTICIPATING IN LAKE AND COMMUNITY EVENTS
- 4 REDUCING WASTE
- 5 OTHER _____

14. What suggestions do you feel would be the most effective in improving Spring Lake Watershed residents' treatment of the lake and its waterways? **(PLEASE RANK ONLY YOUR TOP 5 CHOICES)**
- 1 PROVIDING ENVIRONMENTAL EDUCATION
- 2 LIMITING FERTILIZER USE
- 3 LIMITING CHANGES IN LAND USE (e.g. WETLANDS, FARMLANDS, INDUSTRIAL LAND)
- 4 LOWERING PROPERTY TAXES
- 5 TAXING TO IMPROVE WATER QUALITY
- 6 CONNECTING TO CITY SEWER
- 7 PRESERVING WILDLIFE HABITATS
- 8 PROTECTING AND RESTORING OF WETLANDS
- 9 REDUCING STORMWATER RUNOFF
- 10 OTHER _____

CHARACTERISTICS OF YOUR WATERSHED

The following are some questions about the ecology of Spring Lake. What do you believe are true for Spring Lake?

15. From what source do you believe that Spring Lake receives most of its water? **(CIRCLE ONE)**

1 CREEKS / STREAMS
2 SPRINGS / SEEPAGE
3 RAIN OR SNOW, FALLING DIRECTLY INTO WATER
4 GRAND RIVER
5 OTHER (PLEASE SPECIFY) _____

16. Which of the following items do the fish in Spring Lake need in order to survive? **(CIRCLE ALL THAT APPLY)**

1 ALGAE (TINY GREEN PLANTS)
2 ZOOPLANKTON (VERY SMALL ANIMALS IN THE WATER)
3 AQUATIC PLANTS
4 GOOD WATER QUALITY
5 DISSOLVED OXYGEN
6 OTHER (PLEASE SPECIFY) _____

17. What kinds of benefits do you believe wetlands provide for the Spring Lake Watershed? **(CIRCLE ALL THAT APPLY)**

1 NURSERY FOR WILDLIFE
2 FLOOD CONTROL
3 IMPROVES WATER QUALITY
4 SEDIMENTATION AREA
5 OTHER (PLEASE SPECIFY) _____

1. Do you agree or disagree with the following statement? An ecologically healthy watershed is necessary for economic prosperity. Do you agree? **(CIRCLE ONE)**

1 NO, I DISAGREE
2 YES, I AGREE
3 UNDECIDED

19. Do you agree or disagree with the following statement? My health and my family's health can be harmed by the land, air, and water quality of our watershed. Do you agree? **(CIRCLE ONE)**

1 NO, I DISAGREE
2 YES, I AGREE
3 UNDECIDED

20. What do you believe may cause the most significant problems to the lake? **(PLEASE RANK YOUR TOP FIVE CHOICES)**

1 DISCHARGE FROM INDUSTRIES / BUSINESSES
2 FAILING SEPTIC TANKS
3 RUNOFF FROM FARMS/ FIELDS
4 RUNOFF FROM LAWN FERTILIZER
5 AIR POLLUTION
6 RUNOFF FROM STORM DRAINS
7 ACID RAIN
8 GRAND RIVER
9 DROPPINGS FROM DUCKS / ANIMALS
10 OTHER (PLEASE SPECIFY) _____

21. Do you feel that you personally contribute to the pollution of Spring Lake Watershed? (**CIRCLE ONE**)
- 1 NO, DEFINITELY NOT
 - 2 YES, PROBABLY DO
 - 3 YES, BUT I DO EVERYTHING I CAN TO LESSEN IT.
 - 4 I DON'T KNOW/ I'M NOT SURE

22. A workbook, Home-A-Syst, is now available to homeowners and can be completed to determine if your household practices are "environmentally sound". Would you like a copy of this workbook?
- 1 NO
 - 2 YES (please see enclosed postcard)

Hang in there, you are almost finished!! *



RECREATION

The following questions will ask you about your recreation interests in the Spring Lake Watershed.

23. Please indicate how many times you visited Spring Lake or its streams during 1997 specifically for each of the activities listed below. (**PLEASE CIRCLE EACH APPROPRIATE LETTER FOR EACH ACTIVITY**):

	No Visits	1 - 5 Visits	6 - 10 Visits	More than 10 Visits
USED ONLY FOR ACCESS TO LAKE MI OR GRAND RIVER	A	B	C	D
BOATING	A	B	C	D
RAFTING	A	B	C	D
SAILING	A	B	C	D
CANOEING	A	B	C	D
SWIMMING	A	B	C	D
WATER SKIING	A	B	C	D
FISHING	A	B	C	D
ICE FISHING	A	B	C	D
ICE SKATING	A	B	C	D
BIRDING	A	B	C	D
PICNICING	A	B	C	D
OTHER(SPECIFY)	A	B	C	D

24. Would you consider 1997 a typical recreation year for you? **(CIRCLE ONE ANSWER)**
- 1 NO, POOR WATER QUALITY
 - 2 NO, HEALTH OR FAMILY PROBLEMS
 - 3 NO, NO TIME
 - 4 NO, OTHER REASONS
 - 5 YES (PLEASE SKIP TO QUESTION 26)
25. In a typical year, how often do you engage in the following activities on Spring Lake or its streams? **(PLEASE CIRCLE EACH APPROPRIATE LETTER FOR EACH ACTIVITY):**

	No Visits	1 - 5 Visits	6 - 10 Visits	More than 10 Visits
USED ONLY FOR ACCESS TO LAKE MI OR GRAND RIVER	A	B	C	D
BOATING	A	B	C	D
RAFTING	A	B	C	D
SAILING	A	B	C	D
CANOEING	A	B	C	D
SWIMMING	A	B	C	D
WATER SKIING	A	B	C	D
FISHING	A	B	C	D
ICE FISHING	A	B	C	D
ICE SKATING	A	B	C	D
BIRDING	A	B	C	D
PICNICING	A	B	C	D
OTHER (PLEASE SPECIFY)	A	B	C	D

Now we would like to know some things about you so that we can compare your opinions across other groups of people in the watershed. Remember your answers are completely confidential.

26. Did you know that your residence or property(s) was in the Spring Lake Watershed prior to receiving this survey? **(A Map of the Spring Lake Watershed is outlined on the cover, CIRCLE ONE)**
- 1 NO
 - 2 YES
 - 3 I DON'T KNOW
27. Is your property or residence directly on the lake, its bayou, or one of its streams? **(CIRCLE ONE)**
- 1 NO
 - 2 YES, ON THE LAKE OR A BAYOU
 - 3 YES, ON A STREAM OR DRAINAGE
28. Do you live on a Spring Lake Watershed property?
- 1 NO **(SKIP TO QUESTION 38)**
 - 2 YES **(GO TO QUESTION 29)**
29. How long have you lived in the Spring Lake Watershed? **(CIRCLE ONE)**
- 1 LESS THAN 1 YEAR
 - 2 1-5 YEARS
 - 3 6-15 YEARS
 - 4 16-25 YEARS
 - 5 MORE THAN 25 YEARS

30. What type of housing do you live in? (CIRCLE ONE)

- 1 SINGLE FAMILY HOUSE
- 2 DUPLEX
- 3 CONDOMINIUM
- 4 APARTMENT

31. When do you live in this residence? (CIRCLE ONE)

- 1 WEEKENDS ONLY
- 2 PART OF THE SUMMER
- 3 THE ENTIRE SUMMER
- 4 YEAR ROUND
- 5 OTHER (PLEASE SPECIFY)

32. Is your residence connected ...? (CIRCLE ONE)

- 1 PARTIALLY TO A SEPTIC TANK & FIELD
- 2 COMPLETELY TO A SEPTIC TANK & FIELD
- 3 TO THE CITY SEWER
- 4 TO OTHER (PLEASE SPECIFY) _____

33. Do you normally use an automatic dishwasher at this residence? (CIRCLE ONE)

- 1 NO
- 2 YES, LESS THAN TWICE A MONTH
- 3 YES, ABOUT TWICE A MONTH
- 4 YES, ABOUT TWICE A WEEK
- 5 YES, ABOUT ONCE A DAY

34. On a regular basis, how many people live in your household? (CIRCLE ONE)

- 1 1 - 2 PERSON(S)
- 2 3 - 4 PERSONS
- 3 5 - 6 PERSONS
- 4 7 - 8 PERSONS
- 5 MORE THAN 8 PERSONS

35. Do you own a watercraft? (CIRCLE ALL THAT APPLY)

- 1 NO,
- 2 YES, WATERCRAFT
- 3 YES, PERSONAL WATERCRAFT
- 4 YES, CANOE
- 5 YES, OTHER SPECIFY _____

36. Where do you normally wash your car? (CIRCLE ONE)

- 1 I DON'T OWN A CAR
- 2 CAR WASH
- 3 ON THE LAWN / GRASS
- 4 ON PAVEMENT
- 5 ON GRAVEL

37. Does anyone fertilize your lawn or garden? (CIRCLE ONE)

- 1 NO
- 2 YES, ABOUT ONCE A YEAR
- 3 YES, ABOUT TWICE A YEAR
- 4 YES, MORE THAN TWICE A YEAR

38. What is your gender? (CIRCLE ONE)

- 1 FEMALE
- 2 MALE

39. What is your current age? (CIRCLE ONE)

- 1 18 - 25 YEARS OLD
- 2 26 - 35 YEARS OLD
- 3 36 - 45 YEARS OLD
- 4 46 - 55 YEARS OLD
- 5 56 - 66 YEARS OLD
- 6 67 YEARS OLD OR OLDER

40. What level of education have you received?
(CIRCLE ONE)

- 1 SOME HIGH SCHOOL
- 2 HIGH SCHOOL DIPLOMA
- 3 SOME COLLEGE
- 4 COLLEGE, BACHELOR'S DEGREE
- 5 COLLEGE, MASTER'S DEGREE
- 6 COLLEGE, DOCTORATE'S DEGREE

41. What is your approximate 1997 annual household income before taxes? (CIRCLE ONE)

- 1 LESS THAN \$20,000
- 2 \$20,000 - \$49,999
- 3 \$50,000 - \$79,999
- 4 \$80,000 - \$150,000
- 5 MORE THAN \$150,000

YOU ARE FINISHED!!

THANK YOU VERY MUCH.

PLEASE MAIL THIS SURVEY IN THE ENCLOSED STAMPED ENVELOPE BY JULY 30, 1998.

IF YOU ARE INTERESTED IN THE RESULTS OF THIS SURVEY OR A COPY OF THE HOME-A-SYST WORKBOOK, PLEASE COMPLETE AND RETURN THE ENCLOSED POSTCARD SEPARATELY FROM THE SURVEY.

IF YOU HAVE ADDITIONAL COMMENTS, PLEASE WRITE THEM IN THE FOLLOWING SPACE OR ADD ADDITIONAL PAGES IF NECESSARY.

**PLEASE RETURN THE COMPLETED SURVEY IN THE ENCLOSED STAMPED ENVELOPE BY JULY 30, 1998.
ENCLOSED STAMPED ENVELOPE BY JULY 30, 1998.**

TABLE D4: Resident Answer Frequencies for the Spring Lake Watershed Survey

Question #	Answers	Question 28	No Response	No, I don't live in the watershed			Yes, I live in the watershed			Number of Responses
		Question 27		Property in Watershed	Property on Lake	Property on Stream	Property in Watershed	Property on Lake	Property on Stream	
1	Unacceptable		8	6	5	1	37	41	6	104
1	Acceptable		3	2	0	1	14	6	3	29
1	Superior		0	0	0	0	0	0	0	0
1	I don't know		1	7	2	1	11	0	5	27
2	Water Color		83	4	5	0	30	35	6	86
2	Water Smell		114	3	2	0	22	18	3	54
2	↑ Algae & plants		72	5	5	1	31	42	5	97
2	Litter		139	2	3	1	9	11	2	30
2	Sewage		140	3	1	0	13	8	2	29
2	I don't know		167	0	0	0	0	1	0	2
2	Other		16	1	1	0	2	4	2	11
3	Fishing		89	6	4	0	28	29	6	80
3	Swimming		62	5	5	1	38	43	7	107
3	Boating		127	2	2	0	15	17	2	42
3	Aesthetics		96	3	5	0	26	33	3	73
3	Other		166	0	0	0	2	1	0	3
4	Declined		5	5	3	0	39	34	7	93
4	Improved		2	1	1	1	3	2	0	10
4	Same		1	3	1	1	12	8	5	31
4	I don't know		2	6	2	1	10	3	2	26
5	Water color		95	4	3	0	31	27	6	73
5	Water smell		122	4	2	0	21	15	2	46
5	↑ Algae & plats		89	2	3	1	30	33	6	80
5	Litter		140	2	2	1	10	11	0	29
5	Temperature		162	0	0	0	5	1	1	7
5	Sewage		137	3	1	0	16	8	2	32
5	I don't know		167	2	0	0	0	0	0	2
5	Other		162	0	0	0	2	3	2	7
6	Unacceptable		0	4	1	0	18	8	3	34
6	Acceptable		2	0	0	2	7	7	4	22

TABLE D4: (cont'd).

6	Superior	0	0	0	0	0	0	0	0
6	I don't know	8	11	6	1	38	33	7	104
7	Water color	147	2	0	0	12	5	2	22
7	Water smell	152	1	0	0	12	2	1	17
7	↑ Algae & plants	142	3	1	0	15	6	2	27
7	Litter	158	1	0	0	5	2	2	11
7	Sediments	147	4	1	0	9	5	2	22
7	Temperature	165	0	0	0	4	0	0	4
7	Sewage	162	0	0	0	6	1	0	7
7	I don't know	168	0	0	0	0	1	0	1
7	Other	167	0	0	0	1	1	0	2
8	Unacceptable	4	10	4	1	44	35	9	107
8	Acceptable	2	0	1	2	5	3	1	14
8	Superior	0	0	0	0	0	0	0	0
8	I don't know	5	3	2	0	12	8	4	34
9	Water color	99	4	3	0	26	26	7	70
9	Water smell	103	7	4	0	23	24	5	66
9	↑ Algae & plants	123	5	3	1	17	12	5	46
9	Litter	128	6	4	1	10	14	3	41
9	Sediments	119	6	3	0	18	17	3	50
9	Temperature	160	0	1	0	5	2	1	9
9	Sewage	74	10	3	0	37	31	8	95
9	I don't know	169	0	0	0	0	0	0	0
9	Other	164	0	0	0	0	2	2	4
10	Taxes	120	1	1	1	1	5	1	10
10	Pollution	34	3	1	0	28	16	10	60
10	Water quality	39	1	2	0	13	18	1	39
10	Too many users	122	1	0	0	2	4	0	7
10	Wetland loss	99	1	1	0	5	2	0	9
10	Excessive plants	71	0	0	0	3	2	0	7
10	Invading species	83	2	0	0	2	1	0	5
10	Trespassing	165	0	0	0	0	0	0	0
10	Fishing	145	1	0	0	2	0	2	5
10	Soil erosion	130	0	0	0	0	0	0	0
10	Other	160	1	0	1	1	2	0	5
11	Training	40	1	0	0	19	4	0	26
11	Education	39	4	2	0	11	8	4	33
11	Envir. Education	48	1	1	0	1	1	0	4
11	Limit boats	51	0	0	1	6	9	2	18

TABLE D4: (cont'd).

11	Limit noise	39	1	0	1	4	12	1	20
11	Address speed	33	2	2	0	17	11	6	39
11	Other	155	0	0	0	1	2	1	4
12	Education	42	6	3	1	32	19	10	75
12	Envir. Education	51	2	0	0	7	4	1	14
12	Ban jumping	52	3	3	0	14	14	2	38
12	Other	143	0	0	1	4	7	1	15
13	Education	41	3	2	0	5	5	2	21
13	Limit land changes	42	3	1	1	15	8	1	29
13	Lake events	49	0	1	1	2	2	0	7
13	Reduce waste	33	3	2	0	33	29	11	82
13	Other	161	0	0	0	2	1	0	3
14	Envir. education	91	3	1	0	8	4	2	19
14	Limit fertilizer	58	0	2	1	11	12	4	32
14	Limit land changes	69	2	0	1	9	1	3	17
14	Lower taxes	140	0	0	0	1	2	1	4
14	Tax for water quality	153	0	0	0	0	1	0	1
14	Connect to sewer	67	3	1	0	11	20	1	38
14	Preserve habitats	103	0	0	0	3	0	0	3
14	Protect wetlands	73	1	2	0	7	3	3	17
14	Reduce runoff	82	0	0	0	5	4	0	9
14	Other	158	0	0	0	4	1	0	5
15	Streams	4	5	2	0	28	14	6	59
15	Springs	2	4	4	2	16	22	4	54
15	Precipitation	0	1	0	0	0	0	0	1
15	Grand River	4	2	0	0	17	9	3	35
15	Other	1	2	0	0	1	0	0	4
16	Algae	114	5	1	1	27	12	6	52
16	Zooplankton	75	5	3	1	38	32	11	94
16	Aquatic plants	77	6	2	1	40	30	10	92
16	Good water	26	13	5	3	57	44	12	143
16	Oxygen	78	4	4	2	38	29	12	91
16	Other	161	1	0	0	5	1	1	8
17	Nursery	37	11	7	2	52	40	11	132
17	Flood control	69	8	5	2	38	32	9	100
17	Improves water	66	8	5	1	40	33	12	103
17	Sedimentation	77	4	4	1	37	31	11	92
17	Other	156	2	0	0	4	5	2	13

TABLE D4: (cont'd).

18	Disagree	1	0	1	0	5	8	0	15
18	Agree	9	11	4	2	46	38	9	119
18	Undecided	2	3	2	1	12	2	4	26
19	Disagree	0	1	1	0	0	1	0	3
19	Agree	12	11	5	3	60	48	14	153
19	Undecided	0	3	1	0	3	0	0	7
20	Discharge	57	3	1	0	11	6	2	26
20	Septic tanks	56	3	1	1	12	11	3	33
20	Farm runoff	72	0	1	0	4	5	2	12
20	Lawn runoff	51	2	1	1	13	9	4	31
20	Air pollution	152	0	0	0	1	0	0	1
20	Drain runoff	82	0	0	0	3	1	0	4
20	Acid rain	148	1	0	0	0	0	0	1
20	Grand River	87	2	0	0	14	11	3	30
20	Duck dropping	132	0	0	0	0	2	0	3
20	Other	159	0	0	0	2	1	0	3
21	No	3	6	5	1	16	11	4	46
21	Yes	4	2	0	1	10	5	1	23
21	Yes, I do	4	2	0	0	20	24	7	57
21	I don't know	1	5	2	1	13	6	2	30
22	No	5	9	3	3	17	6	3	46
22	Yes	7	3	2	0	42	37	10	101
23	Access only	47	5	4	2	26	5	9	55a
23	Boating	27	1	2	1	10	36	3	57d
23	Rafting	123	10	4	2	43	21	11	98a
23	Sailing	60	10	5	1	43	19	11	97a
23	Canoeing	58	9	5	2	43	15	11	91a
23	Swimming	42	7	3	1	28	8	9	60a
23	Water skiing	53	6	4	1	40	14	10	81a
23	Fishing	38	7	3	0	26	3	6	47a
23	Ice fishing	59	10	4	2	40	19	8	88a
23	Ice skating	58	10	5	2	44	23	11	103a
23	Birding	58	8	4	2	37	15	9	82a
23	Picnic	45	7	4	2	28	12	7	66a
23	Other	134	2	2	0	13	2	0	20a
24	No, water	1	0	2	0	4	11	1	19
24	No, health	0	2	0	1	4	1	1	9
24	No, time	2	4	2	0	7	5	1	21
24	No, other reasons	2	2	1	0	7	3	3	18

TABLE D4: (cont'd).

24	Yes	3	7	1	2	38	28	8	87
25	Access only	122	2	3	0	9	1	2	18a
25	Boating	106	1	2	0	5	16	3	29d
25	Rafting	123	5	4	0	19	8	4	41a
25	Sailing	121	5	5	0	19	7	4	41a
25	Canoeing	122	5	5	0	18	8	3	40a
25	Swimming	115	3	3	0	6	2	2	17a
25	Water skiing	120	4	4	0	17	6	4	36a
25	Fishing	112	2	1	0	5	7	1	17d
25	Ice fishing	122	5	4	0	16	8	2	36a
25	Ice skating	123	5	5	0	17	10	4	42a
25	Birding	120	4	4	0	13	6	2	30a
25	Picnic	114	2	4	0	9	7	2	25a
25	Other	152	3	2	0	5	1	0	11a
26	No	5	11	2	1	26	3	3	51
26	Yes	4	4	5	2	37	46	11	109
26	I don't know	0	0	0	0	1	0	0	1
27	No								85
27	Yes, lake								59
27	Yes, stream								17
28	No, live elsewhere								25
28	Yes, in watershed								127
29	Less than year	2	0	0	0	2	1	0	5
29	1 - 5 years	1	1	0	1	13	9	4	29
29	6-15 years	3	0	1	0	18	14	4	40
29	16-25 years	0	0	1	0	9	9	2	21
29	More than 25 years	2	1	0	1	22	16	4	46
30	Single	12	2	2	2	62	42	14	136
30	Duplex	0	0	0	0	0	1	0	1
30	Condominium	0	0	0	0	1	3	0	4
30	Apartment	0	0	0	0	0	0	0	0
31	Weekends	0	0	0	0	1	1	0	2
31	Part of summer	0	0	0	1	0	2	0	3
31	Summer	2	0	1	0	1	3	0	7
31	Year round	9	2	1	0	60	39	14	125
31	Other	0	0	0	0	0	0	0	0
32	Partial septic	0	0	0	0	2	0	0	2
32	Complete septic	4	2	0	1	31	12	13	63
32	City sewer	8	0	2	1	29	33	1	74

TABLE D4: (cont'd).

32	Other	0	0	0	0	0	2	0	2
33	No	3	1	0	1	21	10	5	41
33	Yes, < 2 month	0	0	0	0	1	0	1	2
33	Yes, twice a month	0	0	0	0	2	3	0	5
33	Yes, twice a week	6	1	1	0	22	24	4	58
33	Yes, once a day	2	0	1	1	17	11	4	36
34	1-2 persons	8	2	1	2	30	31	4	78
34	3-4 persons	4	0	1	0	26	13	6	50
34	5-6 persons	0	0	0	0	7	3	3	13
34	7-8 persons	0	0	0	0	0	1	1	2
34	> 8 persons	0	0	0	0	0	0	0	0
35	No	128	2	1	1	25	4	3	41
35	Yes, watercraft	91	0	1	1	25	35	10	78
35	Yes, per. watercraft	143	0	1	1	9	12	2	26
35	Yes, canoe	149	0	0	0	7	9	2	20
35	Yes, other	162	0	0	0	2	5	0	7
36	No car	0	1	0	0	0	0	0	1
36	Car wash	5	1	1	0	40	34	10	91
36	On grass	1	0	0	2	6	2	3	14
36	On pavement	5	0	1	0	12	11	0	29
36	On gravel	0	0	0	0	4	1	1	6
37	No	1	1	1	0	17	12	4	36
37	Yes, once a year	4	0	0	0	13	8	6	31
37	Yes, twice a year	5	1	1	1	18	12	1	39
37	Yes, > 2 a year	2	0	0	1	15	16	3	37
38	Female	3	10	4	0	27	10	4	58
38	Male	9	5	3	3	36	38	10	104
39	18-25 years	0	0	0	0	2	0	0	2
39	26-35 years	0	2	0	0	6	1	0	9
39	36-45 years	4	0	0	0	21	6	4	35
39	46-55 years	2	5	3	2	13	15	6	46
39	56-66 years	1	2	3	0	12	14	3	35
39	67 years and older	5	5	1	1	10	12	1	35
40	Some high school	1	2	0	0	1	0	0	4
40	High school	2	4	1	0	10	5	3	25
40	Some college	7	2	4	1	28	15	4	61
40	Bachelor	1	5	2	0	17	14	5	44
40	Master	1	0	0	1	4	9	2	17
40	Doctorate	0	1	0	1	3	3	0	8

TABLE D4: (cont'd).

41	Less than \$20000	1	3	0	0	13	1	0	18
41	\$20000-49999	6	4	1	1	19	4	4	39
41	\$50000-\$79999	0	3	1	0	16	15	6	41
41	\$80000-\$150000	2	1	2	2	7	9	2	25
41	> \$150,000	1	1	2	0	1	8	0	13

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 - July 27, 1954b. S. L. weed control meeting called.
 - August 4, 1954c. Spring Lake residents proceed with program to control weeds.
 - August 17, 1954d. Weed control spraying to be done this week.
 - August 20, 1954e. Weed spraying in Spring Lake is completed.
 - May 10, 1955f. First S. L. treatment needed before June 1.
 - June 1, 1955g. 5 Days needed for full effect of algacide.
 - June 6, 1956h. Spring Lake improvement group meets.
 - July 25, 1955i. Second spraying for algae starts.
 - June 28, 1956j. Weed treatment is underway on Spring Lake.
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