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TIC AND FEASIBILITY STUDY

LS, AND MANAGEMENT ALTERNATIVES

OR LAKE SALLIE AND DETROIT LAKES

PELICAN RIVER WATERSHED

December, 1993

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PREFACE

A Phase I Clean Lakes Grant was awarded to the Pelican River Watershed District in September 1987. In winter of 1987-88, Monitoring and Quality Assurance plans were approved which outlined data needs and data collection procedures to be undertaken in 1988. The data collection period subsequently was extended to include part of the summer of 1989. In June, 1990, a final report on Phase I activities was submitted. This document was judged insufficient.

In July 1992, a second version was submitted. Although some portions of this document were accepted, and portions implemented, a redraft of the report was deemed necessary.

In the meantime, a public hearing reviewed the main features of the study and its restoration and management alternatives. In addition, numerous presentations concerning findings and plans were made to local service clubs, schools, and lake associations (including Sallie/Melissa Improvement Association, and Lake Detroiters Association).

Notwithstanding the lack of a fully acceptable Phase I report, the Watershed District has preceded with what are, by all accounts, Phase II activities. In this manner, detailed studies of two upper watershed wetland areas have begun. Additional water quality data have been collected in a few key areas. Watershed District personnel have been working closely with State, County and City to identify and implement "best management practices" (BMP's) for residential and other uses of the shoreland zone and other areas of the District. Ordinances which restrict sale and use of phosphorus in fertilizers have been passed by the City of Detroit Lakes and Lakeview Township. One wet detention basin, treating approximately 7 acres of urban storm runoff has been built. The District currently is taking a lead role in the planning for the construction of another wet detention basin to receive storm drainage from about 500 acres of urban area.

This report then is a hybrid document. It aims to satisfy the requirements of a Phase I final report, but also reports on progress that has been made on Phase II activities. It addresses the shortcomings in earlier reports, specifically incorporating the suggestions by various reviewers, including Bruce Paakh, Gary Nansen, Georgia Hecock, and Paul Glander. Comments by Mark Tomasek of the Minnesota Pollution Control Agency were especially helpful.

TABLE OF CONTENTS

INTRODUCTION

Scope and Purpose

This report describes the results of Phase I (Diagnostic/Feasibility Study) of a Clean Lakes Project undertaken by the Pelican River Watershed District (PRWD) with the assistance of the Minnesota Pollution Control Agency (MPCA) and the U.S. Environmental Protection Agency (EPA).

The Area

The Pelican River Watershed District is located in West Central Minnesota, about 50 miles east of the North Dakota border; the Watershed District is almost wholly within Becker County. It includes about 32,500 hectares or 315 square kilometers (76000 acres, 120 square miles).

The Pelican River is a tributary to the Otter Tail River, and ultimately to the Red River of the North. Only the upper portion of the Pelican River is included in the Pelican River Watershed District (Figure 1a, 1b).

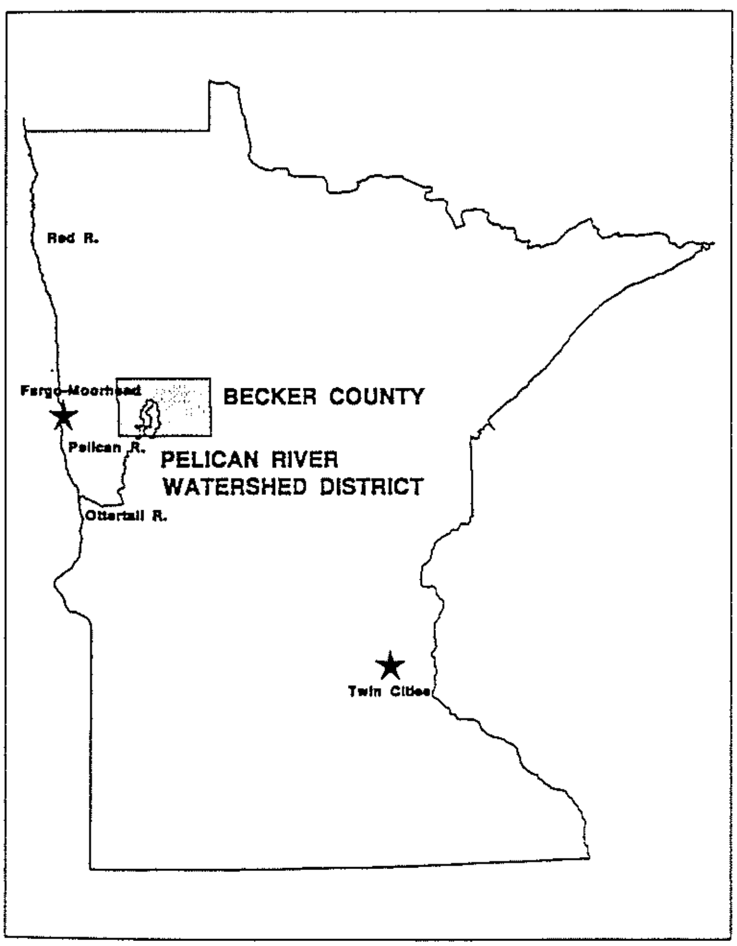

Figure 1a. Location of PRWD

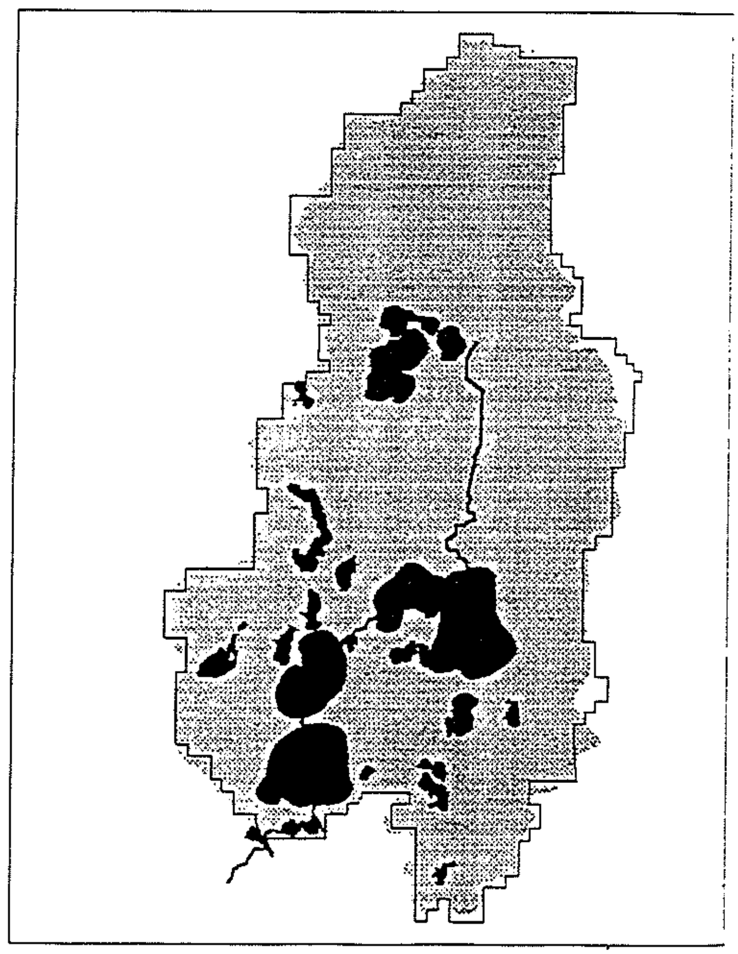

Figure 1b. Hydrologic and Administrative Boundaries

The region owes its landscape to a blanket of glacial moraine and outwash deposited about 10,000 years ago and consisting of thick gravel, sand and clay pitted with numerous "ice-block" lakes and swamps. The District's upland soils range from medium textured, sandy-loams to sandy soils developed from glacial moraine and outwash. Poorly drained organic soils occupy low-lying areas. Overall the relief of the area is about 300 feet, but its local relief rarely exceeds 100 feet; stream gradients in the District are mostly low, and the drainage is naturally poor.

The area's climate has short summers and long cold winters, and is transitional between humid and semi-arid moisture regimes. Accordingly, the area straddles the ecotone between grassland and mixed deciduous and coniferous biomes. In addition to various prairie grasses, natural terrestrial vegetation in the area includes white pine, oak, maple, hemlock, spruce, basswood, and white and yellow poplar.

The Watershed's natural environment has been considerably modified. While numerous Native American groups were found in the area prior to White settlement, their landscape impacts were negligible. Early contact with Europeans came with travelers on the Red River Ox Trail which passed near Detroit and Monson Lakes. A trading post was built in 1854 near the mouth of the Pelican River on Big Detroit Lake. The Northern Pacific Railroad arrived in 1871, and with it permanent settlement, at Tylerville, within the present site of the Detroit Lakes Industrial Park. Much of the Watershed was subsequently cleared of native hardwood and coniferous forest cover, and a considerable amount was brought into agricultural production prior to 1900.

The region's economic base is diverse. Even before major logging operations ended in the area, and modern agriculture took hold, several of the area's lakes became popular destinations for cottage and resort development. The Pelican River was altered to permit navigation in 1889. By 1901 steamships carried 4000 tourists per year along the Pelican River between Detroit Lakes and Sallie. In 1904 a boat-train service connected Fargo with Lake Sallie via Detroit Lakes, and by 1909 there were 3 passenger boats each way from the north shore of Detroit Lakes to Shoreham. Indeed, by 1915 there were reported to be 250 cottages near Shoreham, between lakes Melissa and Sallie. Today, the region's economy is mixed, with agriculture, trade, manufacturing, tourism, and services all playing prominent roles (table 1).

Table 1: 1992 Becker County Sectoral Employment and Wages

	Employment % of Total	Payroll % of Total
Forestry, Fishing, Mining	3.4	2.2
Construction	2.2	2.3
Manufacturing	14.0	16.1
Transportation	6.0	6.9
Wholesale and Retail Trade	23.3	15.5
Finance, Insurance, Real Estate	3.5	3.9
Services	25.3	22.5
Government	21.9	30.2

Data for 8624 employees during 1st quarter of 1992; does not include approximately 1400 self-employed workers, most of whom are farmers.

Source: Research and Statistics Office, Minnesota Department of Jobs and Training

While census data are not separately available for the Watershed District, its population history can be represented by changes which have taken place in the three townships and the city which comprise most of the District's territory (Fig. 2a). After growing steadily since the arrival of the railroad, there was a decline in the 1980's (Fig. 2b).

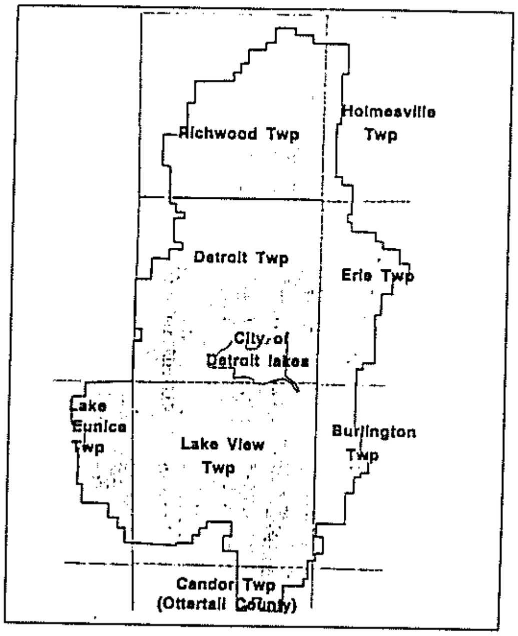

Figure 2a. Census Regions and PRWD

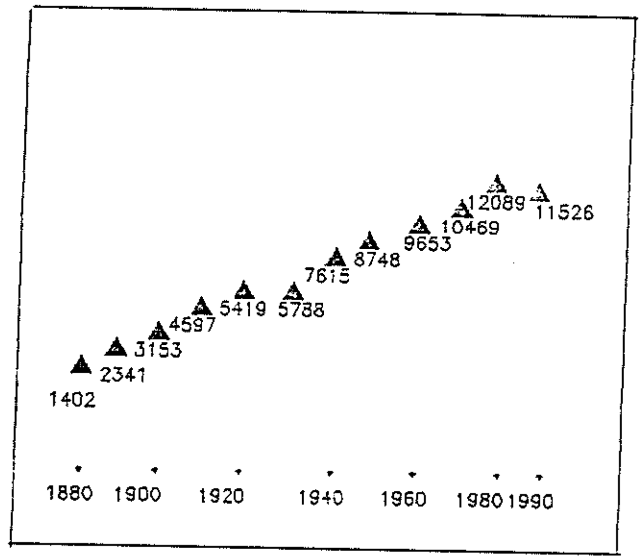

Figure 2b. Population Change, 1890 - 1990
Source: U.S. Census Bureau

Based upon examination of more detailed Bureau of Census files, actual 1990 resident population within the Watershed District is estimated to be 12,120; but the region has a pronounced seasonal shift in population. By inference from data on vacant housing, the occasional resident population adds at least 50%, and perhaps as much as 100%, to populations reported by the Bureau of Census, depending upon housing unit occupancy levels.

The Pelican River Watershed District is predominantly rural (table 2); most of the land is now devoted to agriculture. Residential and other urban developments are heavily concentrated in a few areas - around the area's lakes and in the City of Detroit Lakes.

Table 2: Land Uses in the Pelican River Watershed District

	Hectares	%
Urban, Industrial	889	3
Rural Residences, 2nd Homes Farmsteads	995	3
Cultivated Lands	7,075	23
Grasslands	5,390	17
Forest	10,282	33
Open Water	4,902	16
Wetland	1,437	5
Other, incl. gravel, landfill	154	<1
Totals	31,125	100

Source: DPA International (Based upon 1988 SPOTS Digital Satellite I Imagery)

The Waters of the Watershed District

The principle hydrologic feature of the Watershed District is a chain of lakes connected by the Pelican River (figure 3a). The flow is from north to south with generally low gradients in this system, except in the uppermost portions of the watershed. In addition, the Watershed district includes numerous other small, shallow waterbodies many of which are not directly connected to the Pelican River or its tributaries.

Underlying nearly all of the watershed is the Pelican River Sand-Plain Aquifer. The saturated portions of this aquifer mostly range from 5 to 20 meters, but saturated layers may reach 35 meters. The aquifer receives its water from spring snowmelt and precipitation, as well as from regional aquifers. The Sand-Plain and other regional aquifers are discharged in significant amounts to the Pelican River as well as to local wetlands and lakes (Mann and McBride, Miller).

Mean annual precipitation for the area is about 58 cm., with approximately 70% of that average coming from May to September. Estimated average annual evaporation from area lakes is 67 cm.

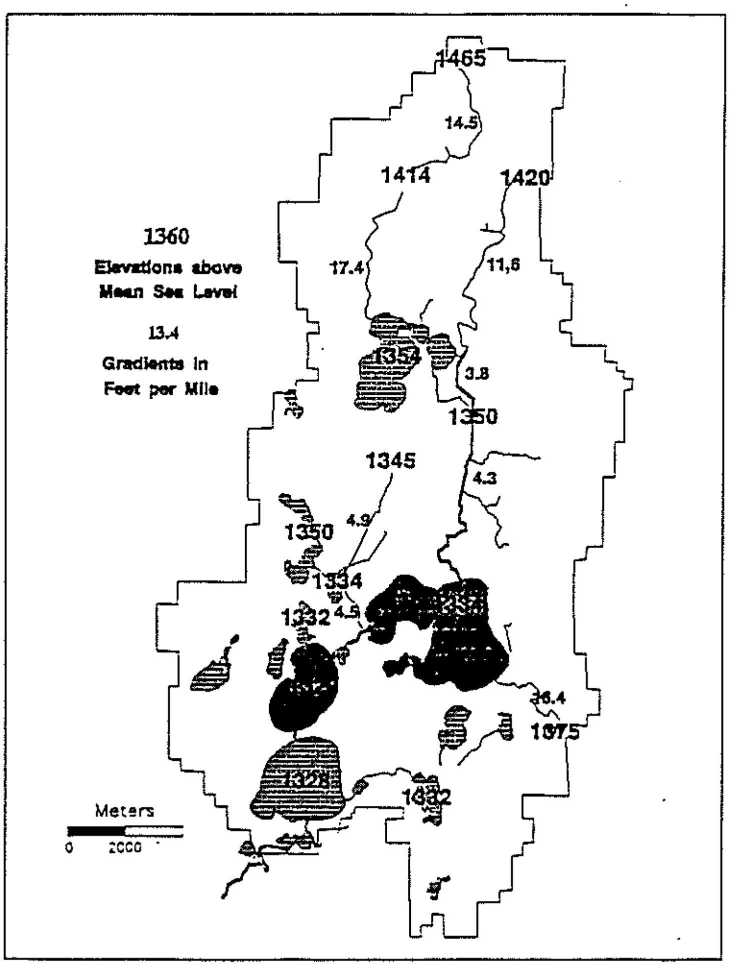

Figure 3a. Elevations and Gradients

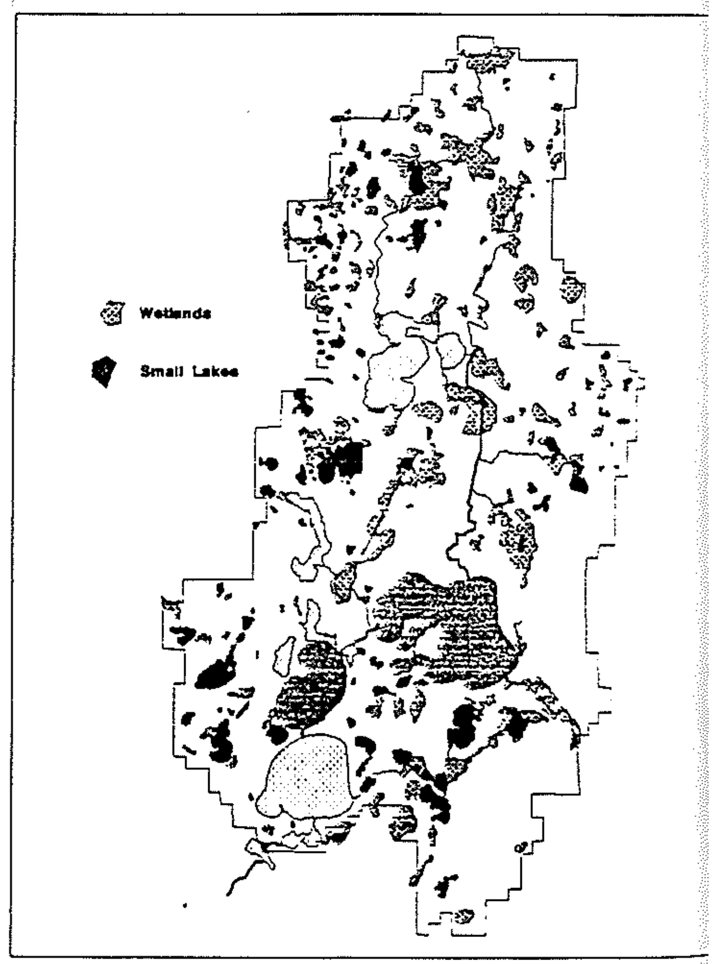

Figure 3b. Small Lakes and Wetlands

An Overview of Water Quality History

During the early stages of the region's development, sanitary wastes were introduced more or less directly into the region's surface and ground waters. Lakes and wetlands were also used as destinations for storm-water runoff from urban and agricultural developments. As the area population grew, it became apparent that these behaviors cause significant deterioration of the water resources.

Of special interest has been the disposal of waste water originating in the City of Detroit Lakes. Near the beginning of this century the first sanitary sewer collectors were constructed; treatment at that time was provided by means of a septic tank, the overflow from which entered St. Clair Lake. In 1929 a facility providing primary and secondary treatment was added; the facility was upgraded in 1942; it's effluent continued to be discharged into a ditch leading to St. Clair.

Following a series of severe algal blooms, the development of dense weed beds which severely restricted recreational use of Lake Sallie, and a lawsuit which identified the City of Detroit Lakes sewage treatment practice as the source of the problems, in 1954 the City undertook a series of upgrades to its system, including aeration and stabilization ponds, some experimentation with spray irrigation, and nutrient removal utilizing peat. After additional legal action, the present system, featuring tertiary treatment, spray irrigation, infiltration basins, and chemical precipitation, was completed in 1977.

In the meantime, the 1950's and 1960's marked declines in water quality of other area lakes too. Algal blooms were frequent, and sometimes severe, especially in the "dog days" (hot, windless) of August. Aquatic weed growth began to limit recreational use of Little Detroit Lake and Melissa. Some thought that property values on area lakes were declining as a result of the water quality situation. Fishermen complained of a decline in game fish and a rise in "rough" fish.

In the early 1970's, Detroit Lakes annexed a substantial part of the north shores of Big and Little Detroit Lakes, and required that residences be serviced by the City's sewer system. At about this time there also began some attempts to restrict urban storm runoff from entering Detroit Lakes; but as of 1988 more than three-quarters of the watershed district residences still depended upon on-site systems to dispose of sanitary wastes (at the present time a sanitary sewer and storm water collection system is being constructed along the south and east shores of Detroit Lakes). The majority of the storm drainage from urban, residential and roadway developments continues to be directed, without treatment, to the Pelican River system.

Two other practices have resulted in major changes in drainage over the years, and have significant water-quality ramifications. Several lakes and large wetland areas were partially or completely drained as a result of drainage enhancement practices which began before 1890. Natural stream channels have been deepened and straightened, natural drainage courses were sometimes re-routed. In the upper parts of the Watershed District these projects were aimed at enhancing agriculture; ditches numbered 13 and 14 were dug in the 1910-1915 period. Lake St. Clair, formerly with no outlet, was drained into the Pelican River in 1915 because it was considered a "smelly nuisance" (Larson, 1971). Around 1889, lake levels were artificially raised about one and one-half feet, and the Pelican River from Detroit Lakes to Melissa was deepened to facilitate steamer transportation between Detroit Lakes and Sallie, and later to Pelican Lake.

In addition, numerous natural wetland areas in both rural and urban areas were filled. Undoubtedly this practice began with permanent European settlement, escalating as farm machinery became more capable; elimination of wetlands continued until relatively recently.

History of the Pelican River Watershed District

The Pelican River Watershed District (PRWD) was formed in 1966 after negotiations with the Minnesota Water Resources Board. It grew out of the concern by local residents that water quality was being substantially degraded. In its earliest "Overall Plan" (1967), water levels, lake eutrophication, pollution, erosion, water supply, and drainage were cited as problems which should be addressed. The Watershed managers quickly realized that in order to make well-advised decisions, a great deal would have to be learned about the watershed, its flows, its nutrient sources and their effects. From its inception the Managers sought expert advice from governmental agencies and universities on these and related issues. Though the specific content of this previous research will be referenced in subsequent discussion, the main Watershed-initiated efforts have included:

- a study, sponsored by Environmental Protection Agency, described nutrient budgets for Lakes' Sallie and Melissa from 1969 to 1971; Dr. Joe Neel of the University of North Dakota was principal investigator; several masters and doctoral theses resulted from these efforts (Neel, 1973);

- extensive hydrologic investigations were conducted by the United States Geological Survey in 1969 and 1970 (USGS);

- another EPA-sponsored study was carried out by Dr. Neel on the efficacy of weed-harvesting in Lake Sallie in 1973 (Neel, 1973);

- In the late 1970's Dr. Neel monitored the impacts of the improvements to Detroit Lakes wastewater treatment system, particularly as they influenced the nutrient balance of Lake Sallie (Neel, 1978, 1981).

- Mr. Del Hogan of Instrumental Research Associates conducted a 1983 study of several Watershed lakes, and made numerous recommendations concerning strategies for remediation (Instrumental Research, 1984);

In addition to its research effort, the Watershed District has undertaken numerous activities in connection with its interest in maintaining the quality of area lakes. Since 1968 Weed Harvesting has been conducted on Lakes Sallie and Melissa. Though originally conceived as a means of nutrient reduction, harvesting has continued on the strength of its perceived improvement of lake aesthetics and enhancement of boating and swimming activities. In 1991 a similar Weed Harvesting program was begun in Detroit Lake. To further assist residents on Melissa, Sallie and Big and Little Detroit Lakes in removing weeds, a weekly roadside weed pickup and disposal service is provided.

For more than 15 years the Watershed Board of Managers has been attempting to deal with Flowering Rush, an exotic species which was first identified in Deadshot Bay, an arm of Big Detroit Lake. Various control measures have been employed, including mechanical harvesting, hand pulling and herbicide applications. The Board also has taken the leadership in securing the addition of Flowering Rush to the State's list of Harmful Exotic Species.

The District has been active in promoting sewers for lake front property. Its work contributed to the decisions which led to provision of sewer and water to the north and west shore areas of Detroit Lakes in the early 1970's and to the current expansion of this system to include the south and east shores of those lakes. Due to a shortage of funds, an effort to provide sewer systems for Lake Sallie and Melissa was abandoned in the early 1980's. The District also has strongly advocated storm runoff control, and in recent years the City of Detroit Lakes has installed a series of dry sedimentation basins, and one wet detention pond as a means of partial control.

Utilizing its rule-making authority, the Managers require permits for various land alteration activities that take place in or near the waters of the District, and seek to prevent those actions that are judged to be detrimental to water quality. Indeed, all construction activities within the District are monitored, and the Managers support strict and consistent enforcement of the County and City Shoreland Ordinances, and Minnesota's Wetland Protection Act, and Federal wetland regulations.

Septic Pumpers are monitored under Watershed rules. Pumpers are issued permits, and required to maintain and submit collection and disposal logs.

Clean Lakes Project History

The Phase I Clean Lakes proposal was originally submitted in March, 1987, and authorized September, 1987. In December, 1987, a Monitoring Plan was approved which delineated data needs and data gathering approach which would accomplish Phase I goals (Larson-Peterson and Associates, 1988a). A Quality Assurance Plan was submitted in February, 1988 (Larson-Peterson and Associates, 1988b). Data collection began in the spring of 1988.

Owing to unfavorable climatic and hydrologic conditions in 1988, the project was amended in January, 1989 to provide more funds and an extension of the data collection program. Additional funds were provided in September, 1992, December, 1992, and April, 1993, and project elements were added, including some Phase II Project Elements.

According to the original Clean Lakes application, Phase I was intended to accomplish the following objectives:

1. identify the parameters that are significantly impacting the water quality and aesthetics of Lakes Detroit and Sallie, and to identify the major sources for these pollutants

2. compile and review existing data relative to the dynamics of the study lakes, including nutrient qualities and flow volumes

3. evaluate the physical characteristics of the watershed to determine areas having the greatest impact on the lakes

4. determine a nutrient-water budget for each lake by developing phosphorus and water input-output models

5. identify major sources of pollution to each lake

6. make recommendations on management practices for lake restoration, including any projects that may have a long-term impact on the water quality of the lakes.

A summary of grants, grant expenditures, and project elements is provided in Appendix A.

SOME GENERAL CHARACTERISTIC OF STUDY LAKES: SALLIE AND DETROIT

The two lakes selected for study in this Phase I project are in the central part of the watershed (Figure 4).

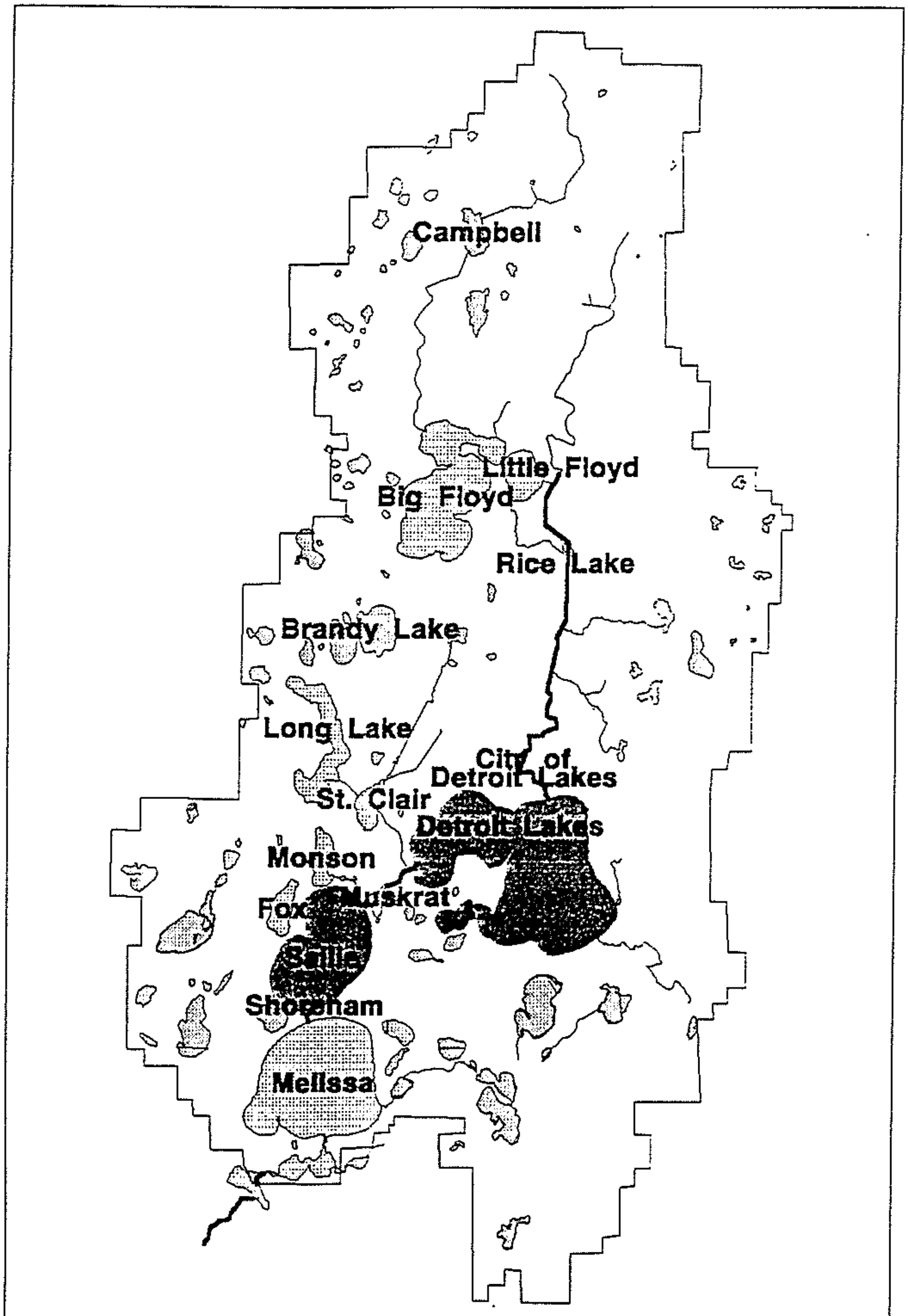

Figure 4. Location of Sallie and Detroit Lakes

There are a number of important similarities. Both have origins that are associated with the retreat of glaciers. Sandy bottoms and shorelines predominate. Both are classified as clear, hard water lakes. Both have small primary watersheds, receiving most of their water from subwatersheds farther upstream on the Pelican River. They are large lakes in comparison to other area lakes. Water levels of both lakes are controlled by man-made structures which were established in the interest of maintaining navigation in the Pelican River Chain between Detroit Lakes and Pelican Lake before 1890. Formerly separate lakes, Big and Little Detroit occupy two separate basins now separated by a shallow sand bar which requires dredging to permit passage of larger boats.

Both are classified as "General Development" lakes by Becker County and have intensive shoreline development consisting of a mix of seasonal and year-round residential development, of moderate density. There are public access areas and other public use areas on both lakes. Both have some commercial resort development along their shores, and host many summer visitors in addition to summer residents.

Sallie and Detroit Lakes are subject to the Becker County and Detroit Lakes City Shoreland Ordinances, respectively. These have been in effect since 1992, and provide strict control over further development within 1000 feet of the shoreline. In addition, Lake View Township (Lake Sallie) and the City of Detroit Lakes both have adopted ordinances which restrict sale and use of phosphorus fertilizers.

Lakes Sallie and the Detroits both possess strong Lake Associations, with the Melissa and Sallie Lake Improvement Association dating to 1935, and the Lake Detroiters Association originating in 1947.

Nevertheless, the study lakes are different in terms of development history and current use. Though there had been some prior settlement in the area, the railroad's arrival in 1871 marks the real beginning of development on the Detroit Lakes. Tourism was a part of this development from the beginning, as indicated by the presence of several large hotels and resorts near or on the lake, but tourism was by no means the only base for the Detroit Lakes' economy. The city was served by major transportation facilities which lead to the presence of a full-range of retail and wholesale businesses with both local and regional customers. Food processing and ice-harvesting were important industries. But the juxtaposition of the town and the lake has impacted the nature and extent of development, and today the city's character, and to a considerable degree its economic base, is inextricably related to the presence of the Lakes. There are 489 single unit residences on the shores of the lake, as well as several condominium developments, resorts and related commercial developments. Detroit Lakes now lies wholly within the limits of the City of Detroit Lakes.

In Lake View Township, Lake Sallie's shoreline began development a few years later than the Detroits; it consisted of private seasonal residences almost exclusively. Today there are 151 riparian residences along Sallie's shores, and another 49 second tier or backshore residences located very near to the Lake. Though there were once several small hotels and resorts located near Shoreham between Lakes Sallie and Melissa, today only one remains on Sallie itself, and another is found on the river leading from Sallie to Melissa. Seasonal residential development remains more important to Sallie than to Detroit Lakes.

With several small retailing and entertainment establishments, a post office, and a church, Shoreham remains a focal point for both Melissa and Sallie, and many local residents relate more fully to that community than they do to one or the other of the adjacent lakes. Shoreham clearly has mainly seasonal functions, and aside from these and golf, residents depend upon the City of Detroit Lakes for higher order commercial services.

Desired Lake Uses

Neither Detroit Lakes or Lake Sallie serve flood control, drinking water supply, electrical generation, or irrigation functions. Rather, these lakes are considered to be invaluable recreational and aesthetic resources to the local residents as well as to numerous summer residents and other visitors. The most revered attributes are those that one way or another relate to the provision of high quality boating, fishing and swimming. Most of the history of interest in, and the attempts to improve lake quality here, have been directed to specific aesthetic and mechanical impairments to these activities. Concerns often have focussed on buildup of aquatic plants which directly interfere with in- or on-water recreation activities. Similarly the visual and olfactory offenses associated with algae blooms have created great consternation because they are perceived to further degrade the recreational experience.

There is also the matter of fishing quality. These lakes have earned reputations as important game-fishing lakes. Walleyes and Northern Pike are particularly prized, and the City of Detroit Lakes sometimes identifies itself as "The Sunfish Capital of the World". Many fisherman are well-informed about the long-term links between water quality conditions and fishing success as it relates to those species; they are sometimes vocal about the symptoms and the root causes which produce adverse impacts on their sport.

Finally, the aesthetic conditions of the lakes are valued in themselves. Residential and commercial users of lake-front property pay a very heavy premium fo lake shore frontage. This is partly to secure enhanced access to the lake as a recreational opportunity. However, many shoreline residents and customers <u>do not</u> participate in lake-based recreational activities - for these it can be inferred that the way the lake landscape <u>looks</u> is of critical importance. Reductions in water transparency, the presence of large numbers of dead fish, or green scums and foul smells, obviously detract from the preferred aesthetic condition.

WATER QUALITY TRENDS IN THE STUDY LAKES:

Based upon anecdotal evidence, limitations on such desired lake uses in the cases Sallie and the Detroits were already perceived by the late 1930's. While a sing secchi disc reading in August 1949 reported a respectable 165 inches (4.3 meters), in 1948 Lake Sallie residents complained of a "severe algal bloom" to the Departme of Conservation, the Minnesota Department of Health, and the City of Detroit Lakes they linked this unpleasant event to the extraordinary amounts of nutrients in wa flowing from the City's waste treatment plant (Larson). A report by the Departme of Health and Conservation indicated that the effluent from the waste treatment plant, together with sources such as land drainage, septic tanks, adjoining farms all were contributing nutrients to this lake; the report concluded that the lake had been "enriched to the point that regular algal blooms could be anticipated". lawsuit by residents followed, requesting cessation of use of the waste treatmen plant, and damages (Larson).

Though the lawsuit was dismissed on grounds of absence of evidence of the allocal of responsibility together with the lack of an economically or technically feasil method of removing phosphorus and nitrogen from water, the incident demonstrates ... seriousness of the conditions by 1950.

Though systematic observations are missing, reports of symptoms of water quality problems grew during the 1950's in both of the study lakes (Larson). Mention is frequently made that frequent heavy algal blooms were commonplace during July and August; in a recent Sallie/Melissa Improvement Association Directory, long term resident Robert Feder recalls that "in the 50's the lake would become so algae-infested that there would actually be a crust on the top of the water." Heavy infestations of submergent weeds inhibited boating and swimming in most near-shore areas around Sallie, and in several places in Little and Big Detroit Lakes.

The symptoms became even worse in the 1960's. By 1968 Lake Sallie was described in the Minneapolis Star "as the color, if not the consistency of split pea soup". Shoreland residents on both study lakes invested heavily in chemical and mechanical weed removal procedures. At least some residents left the lakes in disgust; property values around Lake Sallie were reputed to be depressed as a result of the deteriorating recreational resource. One news items reveals an instance in which a loan application for property development on Lake Sallie was denied because of the financial risk associated with deteriorating water quality conditions.

These conditions led directly to the creation of the Pelican River Watershed District to address water quality, among other goals.

During the latter years of the 1960's more systematic observation began. A biological survey of the watershed conducted in 1967 and 1968 describes Sallie as follows:

> "submerged aquatic vegetation was moderately abundant, and filamentous algae was present in a dense mat in the shallows along most of the shoreline. There was also a blue-green algal bloom which causes considerable turbidity of the lake."

The same report goes on to note that "submerged aquatic vegetation is dense in Little Detroit Lake, and quite abundant in Big Detroit" (Minnesota Dept of Conservation, now Minnesota Department of Natural Resources).

A single surface sample taken in connection with this survey on October 3, 1968 shows Sallie with a total phosphorus level of 170 parts per billion (ppb) and Detroit at 42 ppb.

DETROIT LAKES PHASE I 1988-1989 DIAGNOSTIC STUDY

The principal morphological and watershed characteristics for Big and Little Detroit Lakes are described in Table 3 and in Figure 5a and 5b. The contributing sub-watersheds were defined by inspection of 1:24,000 USGS topographic maps, together with diagrams of the City of Detroit Lakes storm water diversion system.

Table 3: Morphological and Watershed Characteristics of Big and Little Detroit Lakes

	Big Detroit	Little Detroit	Both
Ordinary Highwater Level (meters)			407
Surface Area (hectares)	875	373	1348
Maximum Depth (meters)	25	7	25
Mean Depth (meters)	4.9	3.7	4.5
Volume (cubic meters)	$43x10^6$	$14x10^6$	$57x10^6$
Av. Annual Inflow(cubic meters)	$21x10^6$		
Littoral Area 1/(hectares)	395	373	768
Shoreline (kilometers)	12.6	7.8	20.4
Fetch (kilometers)	3.8	2.6	-
Inlets (number)	3	0	3
Outlets (number)	1	1	1
Basin Size 2/ (hectares)			2680
Watershed Size 3/ (hectares)			19900

1/ zone between surface and two meter depths
2/ immediate subwatershed
3/ includes 4 subwatersheds directly, plus the Upper Pelican Subwatershed and Floyd Lakes and Campbell Creek.

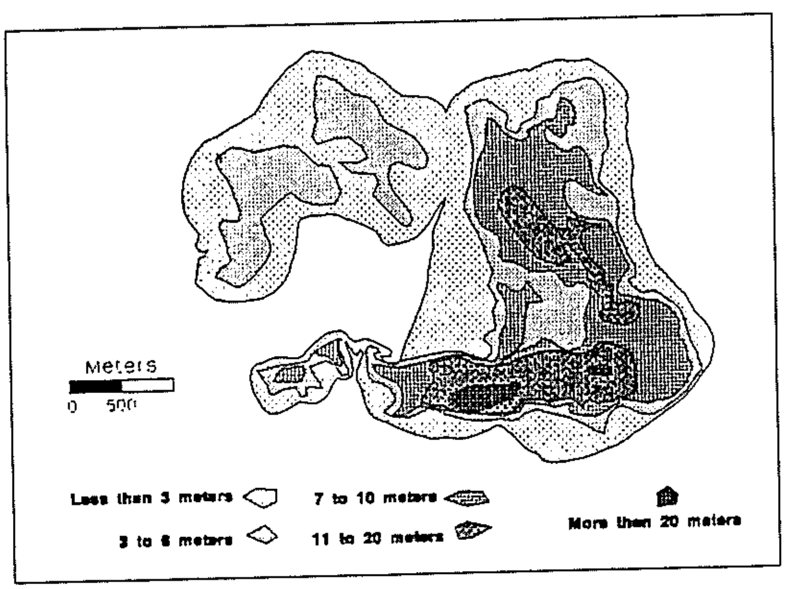

Figure 5a. Detroit Lakes Generalized Depths

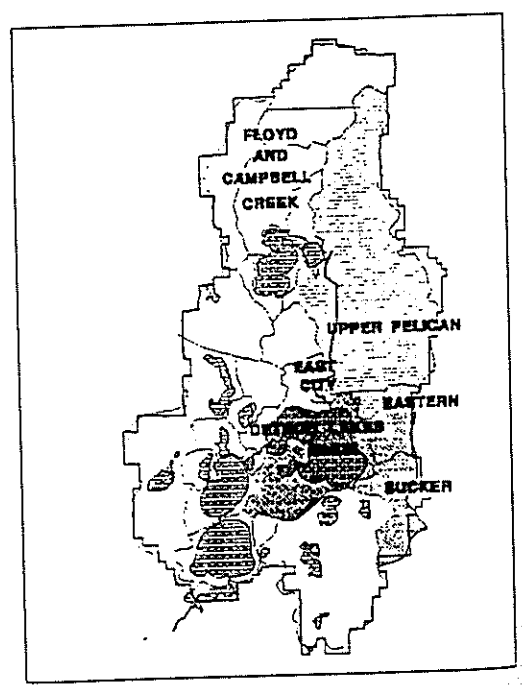

Figure 5b. Detroit Lake Subwatersheds

PREVIOUS STUDIES OF DETROIT LAKES

While there is relatively little previous information on Detroit Lakes water quality, some useful data comes incidentally from the work of Dr. Joe Neel which was aimed at evaluating areas downstream from Detroit Lakes. In the mid-1970's he reported that outflows from Detroit Lake had high concentrations of total phosphorus, with summertime observations ranging from 130 to 430 ug/l and averaging 260 over a three year period. He described "very dense and extensive growths of weeds", especially Chara, and other attached plants, but blue-green phytoplankton were not present (Neel, 1979).

After the City of Detroit Lakes installed tertiary treatment in its waste water treatment facility, Neel carried out a follow-up study on Lake Sallie from 1977 to 1980. He indicated that mean annual total phosphorus concentration in Detroit Lakes outflow was 370 ug/l in 1978, and that in that year phosphorus loads contributed to Sallie from the east side of the upper watershed (above the Detroit outlet) exceeded those from the St.Clair area. He also noted that at the Detroit Lakes outlet, blue-green algae reached greater densities in 1977 than in 1975 or 1979.

In connection with a study on providing a regional sewer system in Lake View township, a consultant, K-V Associates (Falmouth, Mass), conducted a "continuous shoreline septic leachate scan" of part of the shoreline of Big and Little Detroit Lakes in the late summer of 1980. In order to determine the impacts of septic systems, analyses of ground water flows as well as near-shore lake samples and well samples were performed using various techniques, including flouroscopy. K-V Associates reported that in the areas sampled, both in-lake phosphorous and nitrate levels were very low, less than .019 and .015 ppm, respectively. While there were substantial flows towards the Lake along the northeast and southeast shores of the Lake, and while some near-shore wells contained elevated nutrient levels, the research failed to reveal plumes with some movements of phosphorus or nitrogen into the lake. On the other hand, two small streams entering from the eastern part of Big Detroit did bear traces of effluent and higher total phosphorous (42 ug/l).

In 1983 the District retained a consultant to provide additional data on several watershed lakes, including Big and Little Detroit Lakes. In addition to limited sampling of water quality using common measures, he obtained sediment core samples in order to determine sedimentation rates as well as past and present nutrient conditions. As to Big Detroit, Mr. Hogan, of Instrumental Research, Inc. observed:

> "The secchi disk readings collected during the summer of 1983 are not appreciably different from those collected from past years. The lake appears to respond to the influent from the Pelican River. The phosphorous and nitrogen levels are balanced in this lake throughout the season and so the algae populations were not severely limited. The observed chlorophyll-a levels in Big Detroit Lake are expected considering the level of nutrient input."

Hogan further commented that 1983 had been an unusual year, and that results from the sediment core showed extremely high soil loadings.

As to Little Detroit Lake, the report emphasized that it is buffered from upstream nutrient sources by the large volume of Big Detroit Lake. Nevertheless, emphasis was given to the summer-long presence of large amounts of aquatic vegetation which utilize many of the nutrients from the sediments, thereby keeping the algal load relatively low.

Data from past studies of Detroit Lakes are insufficient for comparative or trend analysis purposes.

1988-1989 WATER QUALITY PARAMETERS FOR DETROIT LAKES

The sampling station for Detroit Lake was located in the southwest corner of Big Detroit Lake in the vicinity of the deepest portion of the lake where the depth exceeded 24 meters. Full details of water quality sampling results are reported in a companion volume, "Lakes Sallie and Detroit, Pelican River Watershed, 1988 and 1989 Data Colection Summary" (Larson-Peterson, 1990). In-Lake Sampling results for Detroit Lakes are included in Appendix C. A description of major findings follow.

Temperature. Water remained thoroughly mixed in the 1-4 C^{O} range throughout the full range of depths in the winter months. Open water returned on April 15. By May stratification became noticeable, and in June there was a thermocline below 5 meters. In July and August the thermocline dropped to 10 meters and continued into September when the water began to exhibit more mixing. Temperatures were uniform at all depths by mid-October. The lake was covered with ice from November 22 to April 25. Stratification returned the following May (Fig. 6).

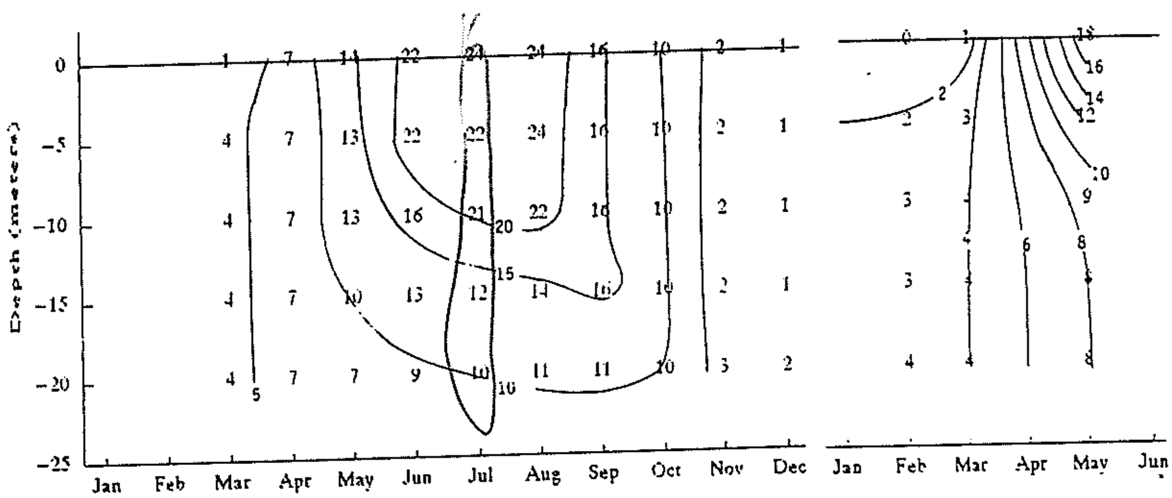

Figure 6. Water Temperature (C^{O})

Dissolved Oxygen. Measurements were taken at five-meter intervals near the deepest location of the Lake from March, 1988 through June, 1989. Figure 7 depicts ample oxygen to a depth of 5 meters, with marked depletion below that depth in the summer months. No oxygen was recorded below 20 meters by June, and below 15 meters by July. Oxygen began returning to deeper waters in September and the lake was well oxygenated at all depths in October and November before freeze-up. Dissolved oxygen levels in depths below light penetration declined from November until March. Apparently oxygen at greater depths (> 20 meters) is absent, or nearly so, by March.

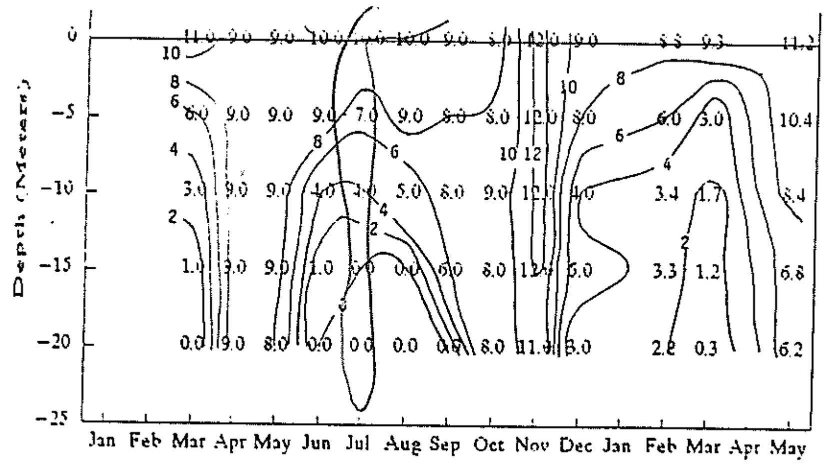

Figure 7. Dissolved Oxygen (ml/l)

Total Phosphorus. Total phosphorus concentrations were sampled at least monthly at the surface, at intermediate depths, and near the bottom of the lake. Eplimnion concentrations in 1988 ranged from 6 ug/l in the spring to maximum levels of 34 ug/l in August, before declining to 9 ug/l in the winter. A spike with a relatively high 39 ug/l reading in March, 1988 was noted, but the pattern did not repeat in spring 1989. The mean of the nine summer observations at the surface was 23 ug/l.

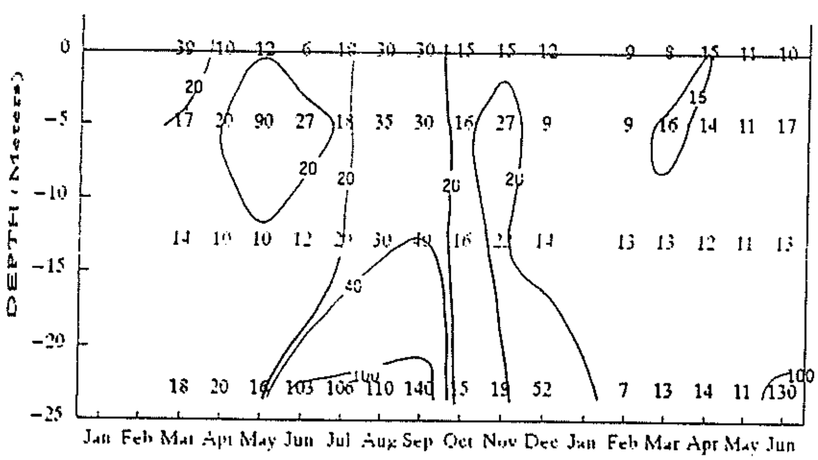

Figure 8. Detroit Lakes Total Phosphorus (ug/l)

In both years phosphorus levels were well mixed at all depths in the spring, and to the 13 meter depth throughout the year. Concentrations in the deeper regions of the lake surpassed 100 ug/l during the stratified anoxic period in 1988, and reached 172 ug/l in mid-September (Fig. 8) before declining rapidly to 15 ug/l in October. Early 1989 samples were comparable and suggest that this pattern would repeat.

A single 90 *ug*/l sample at the 5 meter depth in May is inconsistent with other results, and this spike did not repeat in 1989. It is believed to be the result of either sampling or analytical error.

Orthophosphorus. Orthophosphorus concentrations at surface and 5 meter levels were low (below 10 ug/l), except for a March observation of 27 ug/l t surface and 17 ug/l at 5 meters. At the thirteen meter level orthophosphorous levels were slightly elevated in July and August. In the metalimnion during thermal stratification samples at the 23 meter depth climbed rapidly in May, and reached a peak of 162 ug/l in September. With the return of oxygenated water in October, orthophosphorus dropped quickly to 2 ug/l. There was a secondary, somewhat shallower peak, at 40 ug/l in the December 23 meter sample. The spring 1989 pattern was similar to that of spring, 1988.

Water Clarity. Detroit Lakes' open water season of 1988 began in April with reasonably good transparency reading of 3.7 meters (Fig. 9). It improved to almost 6 meters in late May, but the late June reading was only 1.7 meters. Readings for the rest of the summer ranged from 1.5 to 2.6 meters. There was some improvement, to 3.5 meters, before freeze up.

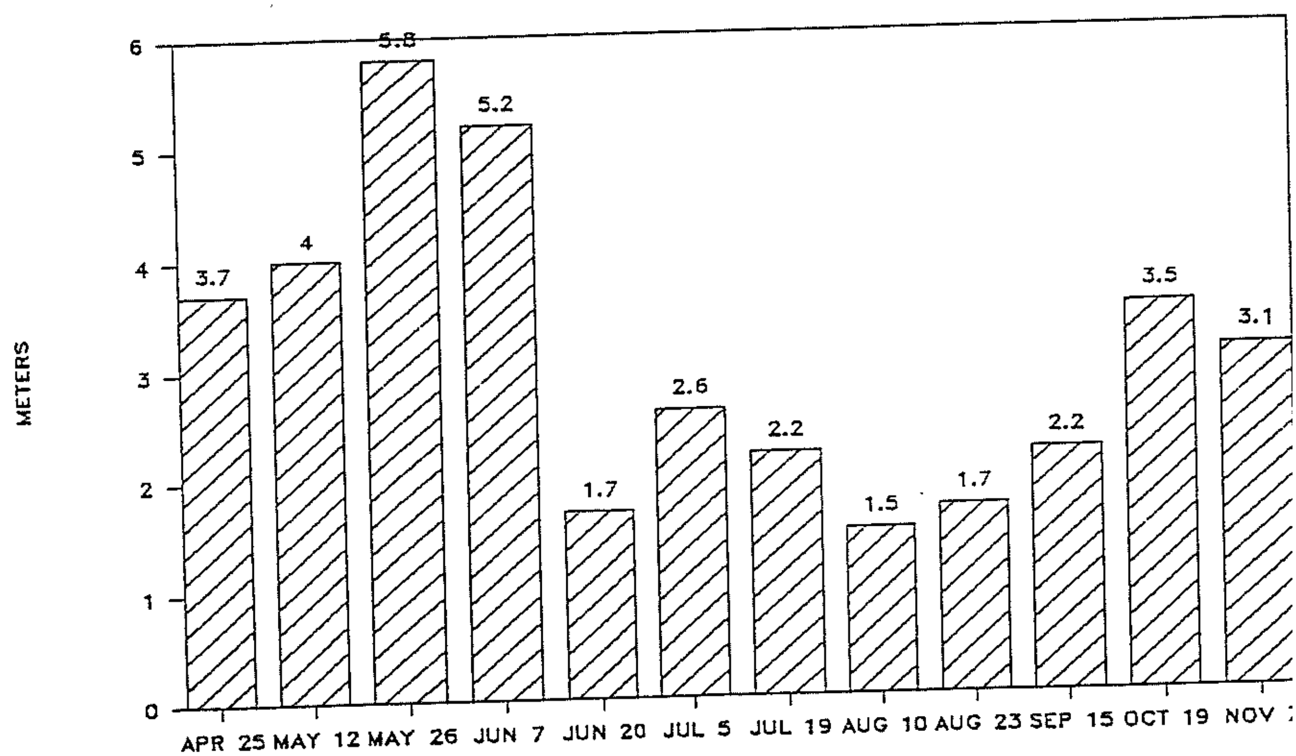

Figure 9. Detroit Lakes Secchi Disc Readings, 1988

Chlorophyll-a. Though an early spring sample showed an elevated Chl-a level, other samples were in the 2 to 5 range until August when this indicator of biological activity jumped to 10 ug/l (Fig. 10). For the remainder of the summer and into the fall, Chl-a levels declined. Two samples in the spring showed moderate Chl-a levels.

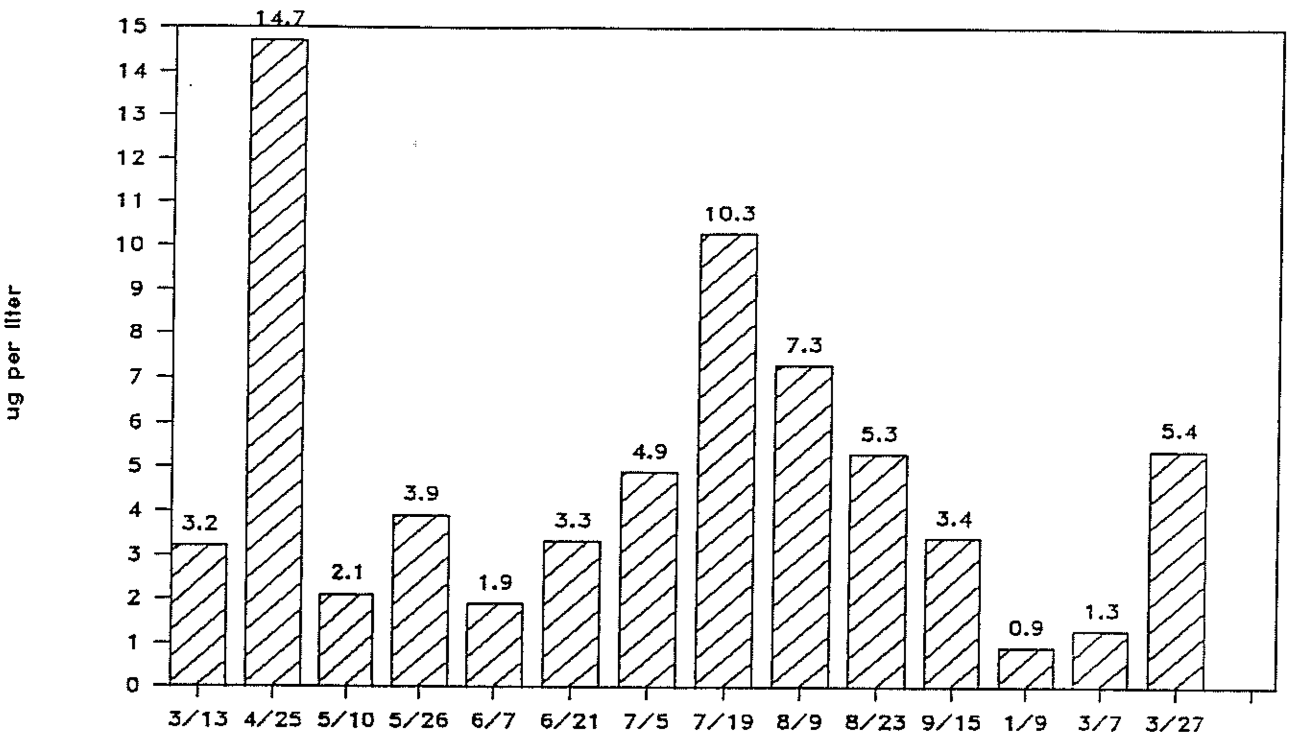

Figure 10. Detroit Lakes Chlorophyll-a (ug/l), 1988, spring 1989.

<u>Phytoplankton.</u> Phytoplankton were sampled on Detroit Lakes during the open water months of 1988. The seasonal pattern of phytoplankton counts shows some resemblance to that of Chlorophyll-a (but the high March Chl-a observation is exceptional). May and early June counts were less than 100,000 cells per liter, but began rising in late June to a peak of over 2 million in mid-September before dropping precipitously in October.

Table 4. Phytoplankton in Detroit Lakes, 1988.

	Total Count 1000's cells/l	Phytoplankton Composition Blue Green %	Green %	Diatoms %	Other %
May 12	77	0	0	13	84
Jun 7	52	31	6	30	32
Jun 20	483	55	3	8	34
July 7	1841	87	0	4	9
Aug 10	1768	97	1	1	1
Sep 12	2045	81	18	1	1
Oct 19	10	49	17	34	0
Nov 14	8	0	0	95	5

Thirty-eight species were identified. Different species are dominant at different times of the season (Table 4). Low spring phytoplankton concentrations consisted of diatoms (Fragilaria), and Dinobryon (golden brown); Blue Green Algae (Coeloespherium) appeared in small amounts in early June and increased steadily throughout the summer in numbers and importance as Mycrocystis and Gomphosphaeria became more prominent. Phytoplankton growth declined dramatically in October, and Blue-greens were missing entirely by November.

Macrophytes. Based upon a survey on July 27, 1989, the general location of Detroit Lakes macrophytes is portrayed in Figure 11. Emergent vegetation types, including Hardstem Bullrush, Needle Rush, Common Cattail, and Jewel Weed, are found in several areas, particularly near Dead Shot Bay, and near the outlet of the Pelican River.

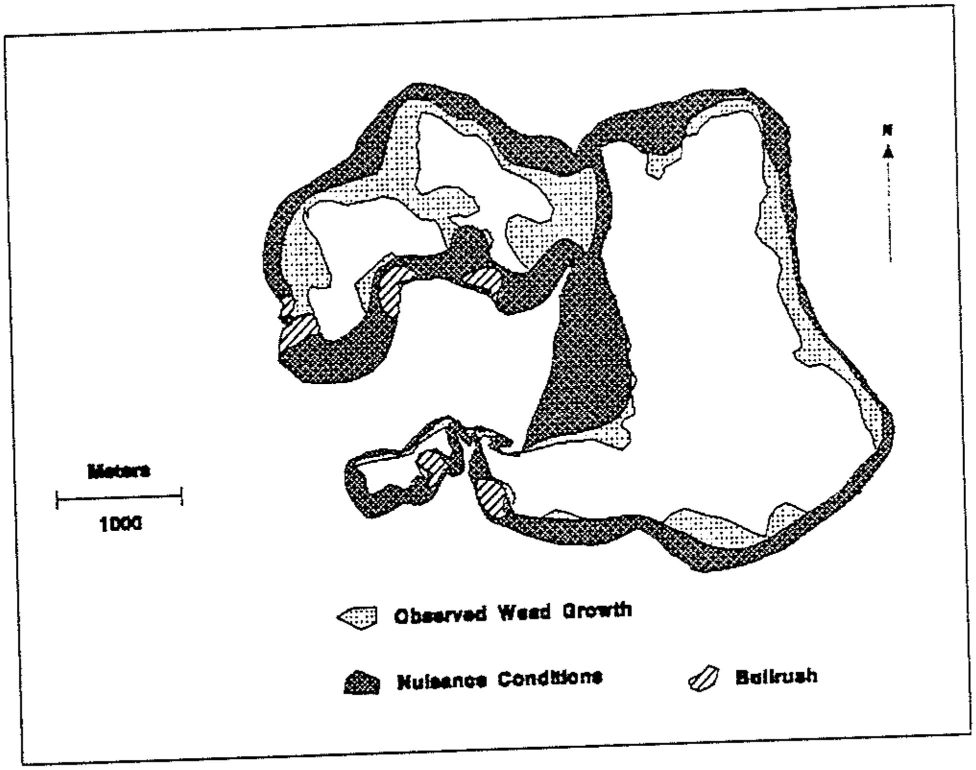

Figure 11. Generalized Macrophyte Locations, and Nuisance Conditions

Submerged and floating leaf aquatic plants found in greatest abundance include Muskgrass (chara spp.) and Northern Water milfoil (Myriophyllum exalbescens). Coontail, Curlyleaf Pondweed, Wild Celery, Sago Pondweed and Flatstem pondweed are common. Of these Muskgrass seems to produce the most serious interference with recreational activities in Detroit Lakes, as it occurs in very dense mats in several areas. The identified species were:

Najas flexilis (willd). rostk. and schmidt
Potamogeton amplifolius tuckerm
P. crispus
P. filiformis var. macounii marong.
P. pectinatus l.
P. praelongus wulf.
P. richardsonii (Benn.) rydb.
Ruppia maritima l.
Alisma gramineum var. geyeri (Torr.)sam.
Scripus acutus (muhl.
Heteranthera dubia (Jacq.) macm.
Elodea canadensis michx.
Vallisneria american michx.
Ceratophyllum dems\ersum L.
Myriophyllum exalbescens fern.
Nuphar variegatum engelm.
Nymphaea tuberosa paine

The exotic Flowering Rush *(Butomus umbellatus)* has diffused from its origin in Deadshot Bay to infest almost all shallow areas (less than 2 meters) around the lake; it is currently spreading downstream in Muskrat Lake as well as Sallie and Melissa (fig. 12).

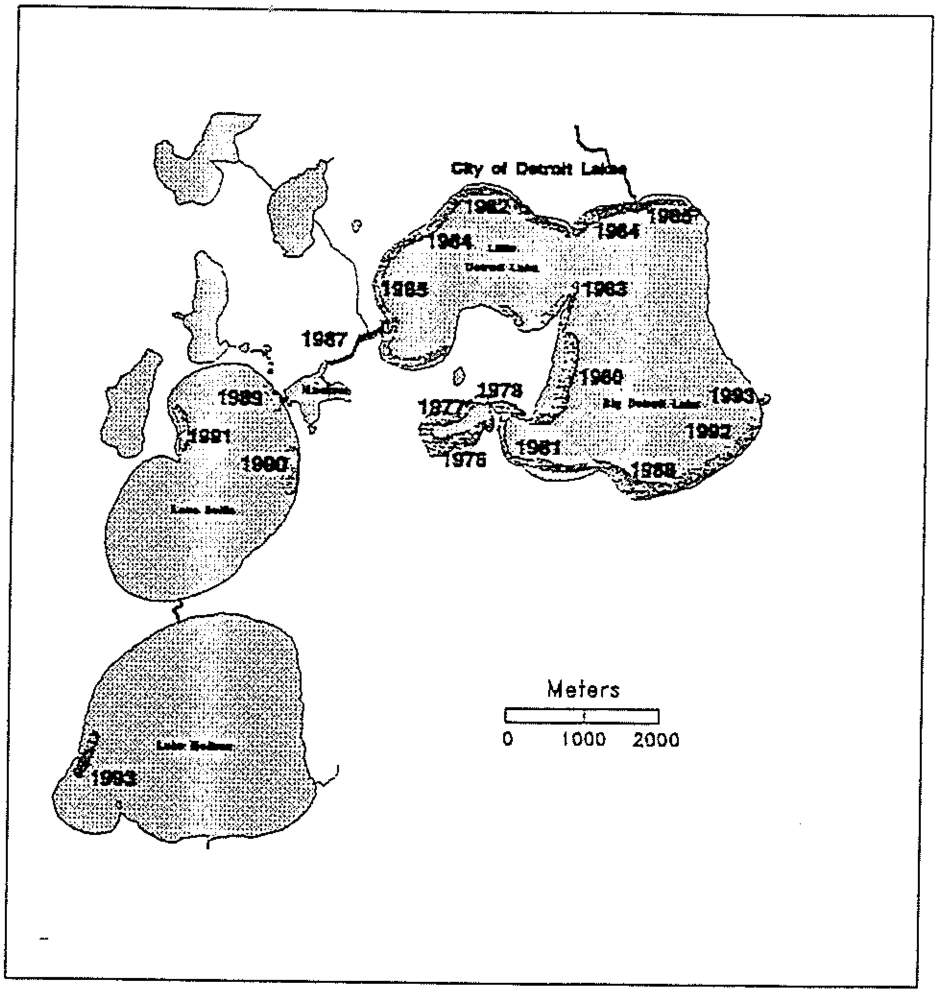

Figure 12. Diffusion of the Exotic Flowering Rush (*Butomus umbellatus*)
(Estimates prepared by Morrie Estenson)

<u>Zooplankton</u>. The most abundant Detroit Lakes zooplankton were the large-bodied herbivores *Daphnia pulex* and *Daphnia galeata*. Zooplankton identified in Detroit Lakes are as follows:

Cladocera, especially,
- *Daphnia pulex, Daphnia galeata*
- *Daphnia retrocurva*, Unknown *Daphnia*
- *Bosmia sp.*

Copepod, especially,
- *Juvinile cyclopoid, diaptmus oregonensis*
- *Cyclops bisupidatus t.*
- Juvenile *calanoid, Nauplier stages*

Ostracods
Rotifers
Diptera

Based upon 6 samples at about one month intervals beginning in May, 1988, counts ranged from 64, 582 per cubic meter in May to 98 per cubic meter in early June. Table 5 portrays the generalized results of the six samples.

Table 5. Zooplankton in Detroit Lakes, 1988.

	Number of Organisms	Density $\#/m^3$	Daphnia Galeata %	Cladocera %	Copepod %	Rotifer %
May 12	126	64585	3.2	11.1	79.4	9.5
Jun 9	154	1973	1.3	7.8	14.3	77.9
Jun 20	110	141	80.0	92.7	3.6	0.0
July 5	78	333	38.5	84.6	15.4	0.0
Aug 9	57	365	7.0	75.4	17.5	0.0
Nov 14	82	1051	39.0	56.1	35.4	8.5

<u>Fishery:</u> Unrelated to the present study, the Minnesota Department of Natural Resources Section of Fisheries conducted a survey of the Detroit Lake fish community in August 1989. Similar sureys or fish community assessments had been conducted in 1952. 1970, 1983, and 1986. Glander summarizes the findings as follows:

> "Bluegill were the most numerous fish collected in the 1989 survey followed by hybrid sunfish, yellow bullhead, pumpkinseed and black bullhead. On the basis of total weight of fish collected, northern pike were first, followe by bluegill, yellow bullhead, walleye and white sucker. Fifteen species of fish were collected during the survey, including largemouth bass, black crappie, and yellow perch in addition to those species mentioned above.
>
> Abundance of bluegill, black crappie, northern pike and walleye was equal or greater than that expected for lakes with similar physical and chemical conditions (Table 6). Yellow perch are not as abundant as normal, perhaps due to predation by northern pike. An experimental expanded daily bag limit of 6 pike is being evaluated at Detroit Lake as a way of reducing pike abundance, improving their growth and size distribution and reducing predation on perch. Other fish management techniques currently used at Detroit Lake include: protection of shoreline and aquatic plant habitats, commercial harvest of bullheads and stocking of muskellunge and walleye fingerlings.
>
> Occasional winterkill of fish in Little Ddetoirt Lake and Curfman Lake ("Deadshot Bay") takes place when dissolved oxygen levels drop. These episodes are not considered to be limiting factors because many fish move out of these areas before oxygen drops to lethal levels. Shoreline development and other land use activities in the watershed have affected habitat and water quality in Detroit Lake with adverse effects on the fish community." (Glander, pers. comm.)

Table 6. Abundance of Selected Fish Species Collected in the 1989 Detroit Lakes Fish Community Assessment

	Number of Fish per Net	
Species	Caught	Normal Range
Bluegill	67	3.3 - 53.0
Black Crappie	.4	.3 - 1.6
Northern Pike	12	3.1 - 8.4
Yellow Perch	0.6	8.2 - 49.3
Walleye	7	3.7 - 9.7

* Normal range indicates typical catches for lakes with similar physical and chemical characteristics

Source: Paul Glander (personal communication)

Trends in Detroit Lakes Water Quality

Lack of previous research makes it difficult to reach conclusions about trends in the water quality of Detroit Lakes. Fisheries data probably offer the most valuable insights:

"As pointed out by Schupp and Wilson (1993), cisco (tullibee) and yellow bullhead are species which are not tolerant of eutrophic conditions. The abundance of cisco has fluctuated in Detroit with none being sampled in 1989. Cisco were collected in the most recent (1993) survey, however. Detroit Lake is open for cisco netting and anecdotal reports from sportsmen indicate that a significant harvest occurs in some years.

Yellow bullheads have been the dominant bullhead species in all fisheries surveys at Detroit Lake back to 1972. Prior to 1972 however, black bullheads were either equal or more abundant than the yellows. As explained further in the Lake Sallie section of this report, black bullheads tend to be more abundant in eutrophic lakes. This provides some evidence that watter quality may have been lessened in 1952 and 1970 and gotten better since then." (Glander, pers. comm.).

Other, mostly anecdotal, evidence is mixed. Many long-term residents are convinced that the project which put the sewer along the north and west shores of Detroit Lakes and redirected some of the City's storm water effluent away from the lakes reversed the declines of 1950's and 1960's in the Lakes' water quality. Mention is usually made of the lack of extensive dense mats of weeds which had previously fouled the northern shore of Little Detroit Lake, and the disappearance of weed patches in other locations. There also seems to be general agreement that recent weed harvesting operations have resulted in improved conditions for boaters and swimmers.

On the other hand, residents along other sections of the lakeshore, and especially those which have seen major infestations of Flowering Rush, are inclined to view the conditions as deteriorating. Nor is there any consistency among water clarity perceptions and fishing success trends.

DETROIT LAKES' NUTRIENT BUDGET

Hydrologic budget.

Based upon stream-flow observations together with lake levels and other sources (Appendix A), Detroit Lakes' Annual Hydrologic Budget for 1988 is reported in Tabl 7a.

Table 7a. 1988 Water Budget for Detroit Lakes

Surface Inflow	$6.7X10^6$ m^3 (5,424 af)
Pelican River = $6.4X10^6 m^3$ (5162af)	
Precipitation	$8.7X10^6$ m^3 (7,069 af)
Surface Outflow	$10.4X10^6$ m^3 (8,450 af)
Evaporation	$14.2X10^6$ m^3 (11,507 af)
Change in Storage	$.2X10^6$ m^3 (– 184 af)
Residual (mainly ground water)	$9.0X10^6$ m^3 (7,280af)

Table 7b. Detroit Lakes Hydrologic Budget, 1988 (10^6 cubic meters)

SOURCE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Surface Inflow	0.10	0.10	1.61	1.95	0.78	0.18	0.17	0.46	0.57	0.57	0.11	0.08	6.69
Precipitation	0.41	0.02	0.46	0.08	0.92	0.60	1.61	2.08	1.45	0.35	0.42	0.32	8.72
Surface Water Outflow	0.62	0.37	1.19	3.32	1.69	0.76	0.15	0.42	0.50	0.30	0.49	0.62	10.43
Evaporation	0.13	0.13	0.16	0.53	2.47	2.87	2.93	2.51	1.40	0.53	0.41	0.14	14.20
Change in Storage	0.00	0.00	1.33	-0.38	-0.11	0.00	-1.22	1.25	0.04	0.30	0.00	0.00	-0.23
Groundwater	0.23	0.38	0.61	1.44	2.34	1.40	0.08	1.64	0.00	0.22	0.37	0.35	8.93

Surface inflows and outflows are summarized from monthly flows monitored at inlet and outlet locations (Table 7b). The values for winter months are based upon base line winter flows from historical' records, as the flow monitoring was not done during the winter season. Evaporation values were adapted from pan evaporation dat provided by North Dakota State University (a correction factor of .7 was used to adjust pan data to lake evaporation rates). The residual value was assigned to th groundwater contributions to the lake.

There is some reason to suspect that 1988 surface water flows were somewhat less than normal. Neel reported surface outflows of more than twice as much in 1973, and 1974, and 30 percent more in 1975. While 1988 precipitation amounts exceeded long-term averages, 1988 springtime conditions were much below normal (See Append C for full climatological details).

In any event, 1988 surface water accounted for less than 30 percent of total flows into the Detroit Lakes. And while this may have been less than usual, the Detro Lakes are known to be important discharge areas for the regional groundwater syste

(USGS). In 1988 the Pelican River accounted for about 95 percent of the total surface inflow, and about 26% of the total water that was added. Other surface sources include the Sucker Creek, an unnamed flowage along the east shore, and some overland flow from roadways, parking lots, boat ramps. Groundwater was the largest contributor to the inflow of water, representing more than one-third of the total.

Phosphorus, the limiting nutrient

Phosphorus is usually the major limiting factor on plant growth, including algal productivity, in lakes. Reducing phosphorus generally results in lowered Chlorophyll-a levels, and fewer nuisance phytoplankton types, as well as improved transparency. Contemporary lake management strategies are heavily based upon research evidence which suggests that phosphorus management is the key to improving water quality in lakes (EPA,1990).

Accordingly, a fuller description of the nature and origins of Detroit Lakes phosphorus is offered.

External Phosphorus Loading

Phosphorus entering Detroit Lakes was estimated by sampling concentrations in the main inflowing streams. Consideration was also given to phosphorus in ground water, as measured near the Detroit Lakes Waste Water treatment plant, and atmospheric sources. In order to evaluate loadings under extreme conditions, phosphorus concentrations in runoff from an 8 cm rainfall event were measured. This led to adjustments in phosphorus loadings for 1988 storms in excess of 1 cm.

The export of phosphorus from Detroit Lakes was derived from data on phosphorus concentrations taken at the Detroit lakes outflow. A factor to account for phosphorus removal as a result of the fish harvest also was added. A summary is provided in Table 8.

Table 8. External Phosphorus Loadings for Detroit Lakes

	Phosphorus kg	%
Input		
surface inflow		
Pelican River	302	36%
Sucker Creek	67	8
East side inlet	19	2
ground water	201	24
atmospheric sources	279	33
Total	847	100
Output		
surface outflow		
Pelican River	137	
fish harvest	125	
Total	262	

Note: The excess of inputs over outputs, equal to 585 Kg, is assumed to be incorporated into lake biomass and sediments.

Available Phosphorus

The total phosphorus mass in Detroit Lakes was determined for 1988 based upon sampled concentrations. Amounts varied considerably (Figure 13), ranging from about 575 to just over 2000 kilograms. Springtime peaks in phosphorus appears to correspond to phosphorus inflow into the lake associated by snowmelt. Since it coincides with very low inflow rates, a surge in mid August may be associated with the recycling of phosphorus from sediments during the period of stratification and low oxygen availability in mid to late summer.

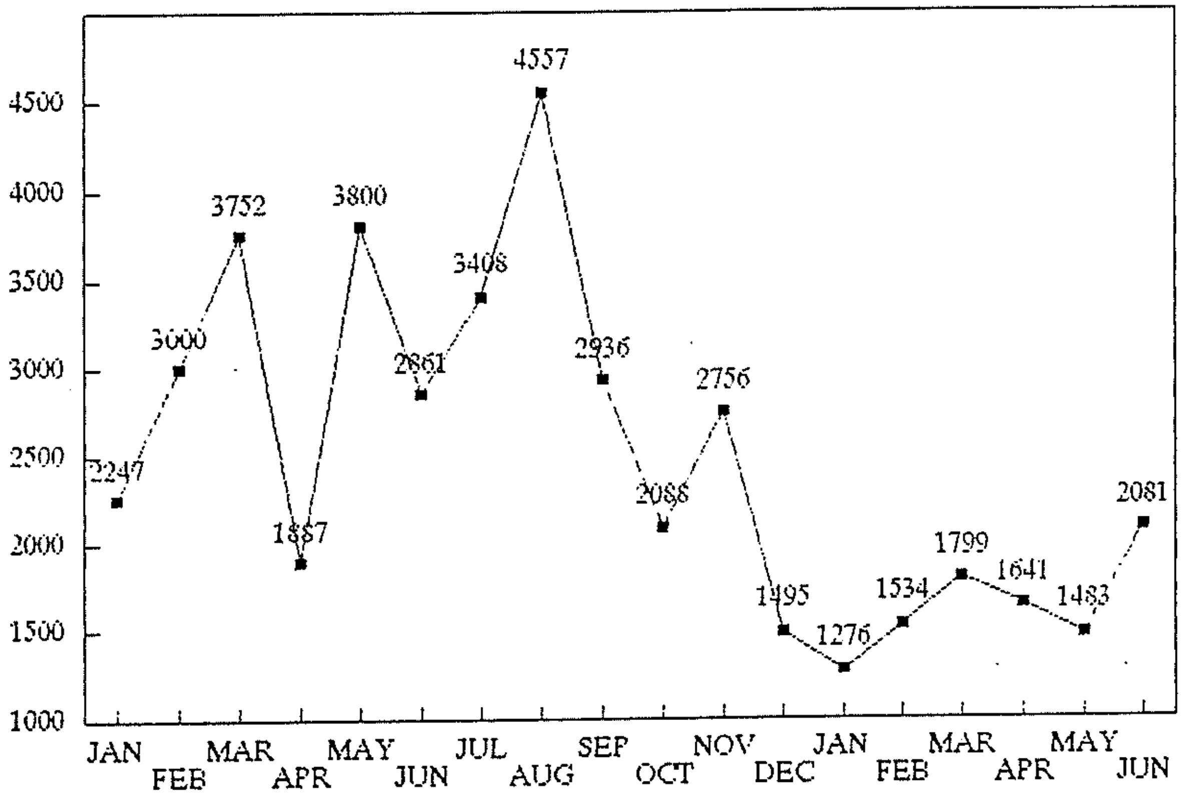

Figure 11. Available Phosphorus (Total Phosphorus Mass in Pounds)

Internal Phosphorus Loading. While specific data from this study are not available, it is known that a substantial amount of phosphorus becomes available from internal sources to Detroit Lakes. In particular, phosphorus is released from bottom sediments as a result of chemical processes during times when anoxic conditions exist.

Hogan (1983) reported phosphorus levels in at .6 grams and .67 grams per kilogram of dry sediment in the upper levels of Big and Little Detroit' bottom sediments, respectively.

In the present study internal phosphorus loadings were estimated from a model developed by Dillon-Rigler. The model permits a comparison between actual lake phosphorus concentrations and theoretical concentrations which take into account lake size, depth, detention times, and observed phosphorus loads. In the case of Detroit Lakes the model produces an estimate of the annual internal loading of just over 1000 kilograms, or 1.2 times the amount from external sources. (Appendix C includes the calculations for this estimate).

Watershed Origins of Detroit Lakes Phosphorus

According to the 1988 data, approximately 46% of the external phosphorus loading derives from surface drainage into the lake. Another 24% derives from ground water. Improvement of Detroit Lakes quality is dependent upon careful management of the phosphorus which enters the lake from various subwatersheds which contribute to the flows (Fig. 12). These subwatersheds differ in terms of physical attributes as well as land developments (estimates of land uses and predicted phosphorus loadings by subwatershed are provided in Appendix C).

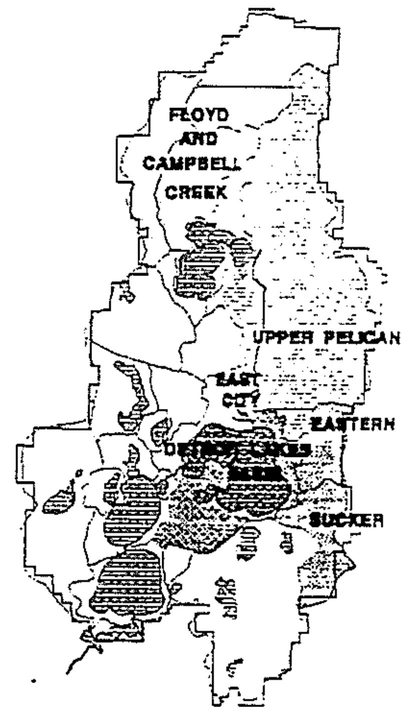

Figure 12. Detroit Lakes Subwatersheds

The Detroit Lakes Basin (Detroit Lakes Subwatershed)

It is not known just how much of the external phosphorus load enters Detroit Lakes from the Detroit Lakes Basin itself. Precipitation is one source, runoff and ground water sources are others.

The land areas immediately adjacent to the Detroit Lakes are heavily developed, with a mixture of commercial and residential uses. Southwesterly from the lakes, most of the land is devoted to agriculture. Land use in the Subwatershed is summarized in Table 9.

Table 9. Land Usage in Detroit Lakes Basin Subwatershed

	hectares	% of Total
Urban, rural residential	209	17
Agriculture	378	31
Pasture/Grass	216	18
Wooded	339	27
Water*	53	4
Wetland	45	3
Total	1238	

* excludes surface area of Big and Little Detroit Lakes

Residential development is predominantly year-round, though as road distance from the City of Detroit Lakes increases, residences used seasonally are more common. There are 489 riparian housing units along the shoreline of Detroit Lakes, and about as many more in "second tier" or backshore residential development (Fig. 13).

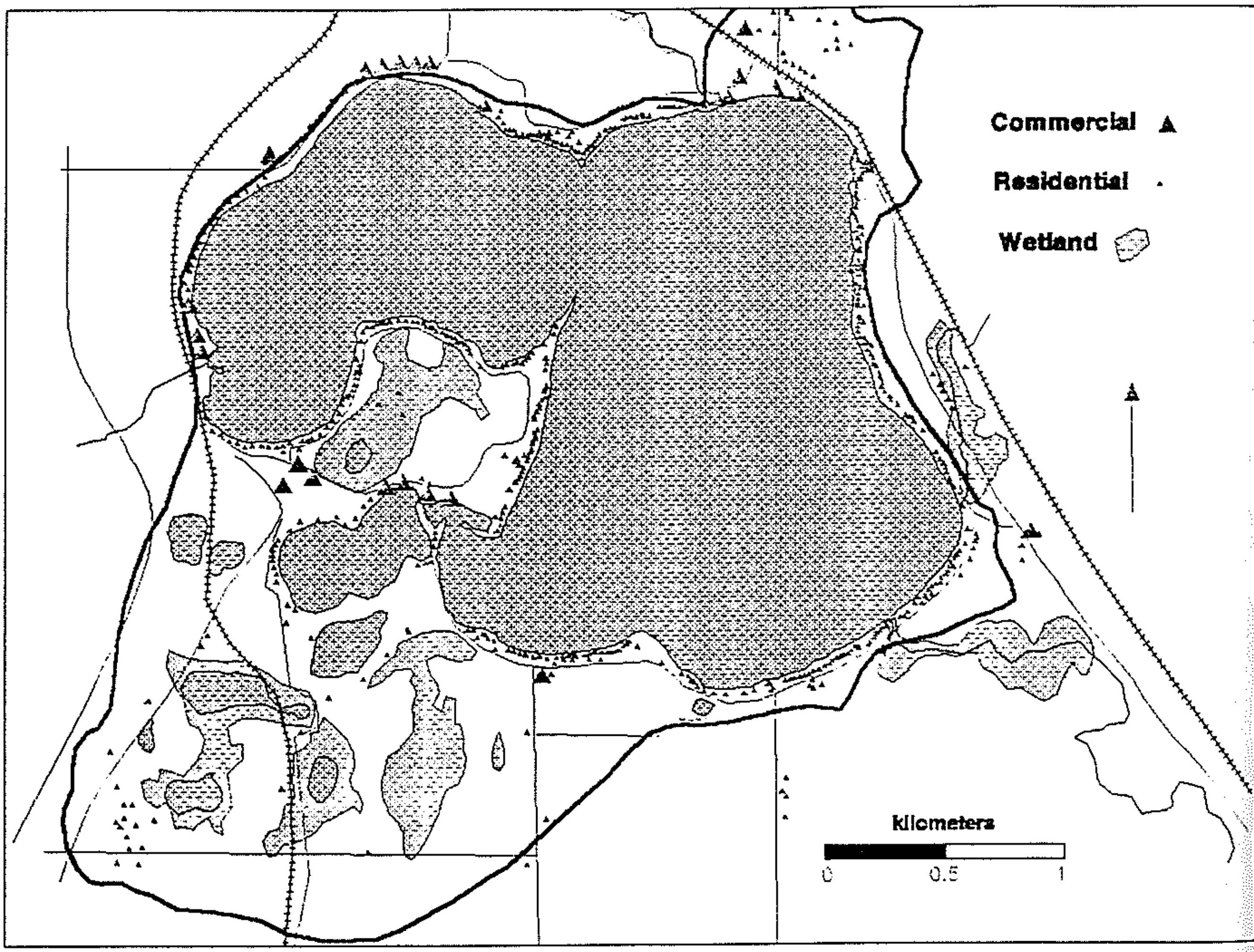

Figure 13. General Development Characteristics of the Detroit Lakes Basin

Though most of the riparian fringe of the lakes has already been developed, land use has intensified as a result of some in-filling (construction on previously undeveloped lots), upgrading of housing from seasonal to year-round, splitting of larger lots into multiple family housing, as in the case of condominiums, and backshore (second tier) development (Table 10). There are 108 developable parcels (assuming platted lot or 150 foot frontage if unplatted).

Table 10. Some characteristics of Detroit Lakes Residences

Riparian Residences	489
Total Residential Frontage	15,128 meters
Average shoreline frontage	31 meters
Developable parcels	108
Public Frontage	1310 meters
Backshore Residences	412

Some other elements of the basin's land development warrant attention (Fig. 13). For about 1300 meters along the north shore of Little Detroit Lake there is public beach, heavily used for swimming, sunbathing, fishing, waterskiing and other boating. On the opposite side of the road from this beach is a strip of commercial development which includes motels, a campground, restaurants, and other tourist facilities. In other parts of the Detroit Lakes basin, commercial development, including restaurants, resorts, motels and mobile home parks, is scattered.

At times the lakes receive rather heavy pressure from fishermen and other boaters who launch boats at one of the three public launch sites. There are also three boat rental enterprises which provide various types of watercraft to non-resident pleasure-seekers. The lake is heavily fished during the winter, and its frozen surface has occasionally been the site of wintertime races of automobiles and snowmobiles.

Some of the nutrient load and other water quality problems confronting Detroit Lakes most certainly originate in the riparian zone which surrounds the lake. Using standard runoff coefficients, this land use mix would yield about 676 kilograms of phosphorus on an annual basis. However, given the high infiltration rates of the predominantly sandy soils, surface runoff cannot be much of a factor, except in those cases where storm drainage is carried directly into the Lake by hardened surfaces. The several boat launching sites are noteworthy in this regard as is the highway overlook along US Highway 10, the parking lots of the Holiday Inn, and several locations where highways are routed close to the lake. Trash left on the ice by winter visitors is considered by some to be a problem.

Contamination of ground water by surface waters, as well as that from septic systems, and other sources, including lawn fertilization by riparian landowners, may be locally important.

Approximately one-half of the riparian parcels were served by septic tanks in 1988-89. If average annual waste disposal yields about 1 kilogram of phosphorus per person, with about 270 unsewered residences and an average of 2.1 persons per residence, about 800 kilograms of phosphorus were introduced into drainfields each year. Nitrogen and other elements also enter septic tanks, and given the high water table near the lake, it would seem reasonable to expect some transmission of nutrients into the lake. However, many of the remaining on-site treatment systems are on the south edges of the lake, and ground water along these shores may flow away from the lake, not towards it (KV Associates). Moreover, the City of Detroit Lakes will have extended its sewer and water services to all of the lakeshore and backshore developments by the spring of 1995.

So it seems reasonable to conclude that with completion of the sewer system, which should eliminate whatever nutrients now entering the lake from septic sources, the major nutrient sources originating within the basin are susceptible to better management practices. Thus, the control of runoff from hard surfaces and those sources that are related to large numbers of visitors remain as important problems.

Sucker Creek and other small tributaries.

Flowing to Detroit Lakes are two relatively small streams, Sucker Creek and an unnamed flowage which drains the Eastern Subwatershed (Fig. 14). Taken together, in 1988 they accounted for about 10% of Detroit Lakes total external phosphorus loading, about 86 kilograms (Table 8).

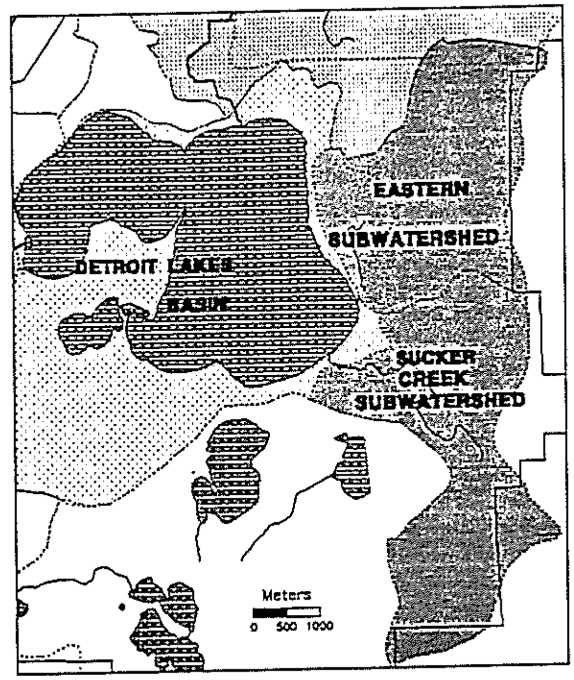

Figure 14. Eastern and Sucker Creek Subwatersheds

The land uses in these areas are provided in Table 11. Applying standard runoff coefficients to this land use mix, it is to be expected that these watersheds would generate almost 600 kilograms of phosphorus per year. The discrepancy between expected and measured amounts may have to do with low runoff during 1988, so that even with high concentrations, many of the nutrients carried by the low flows were retained by the wetlands through which the drainage from these areas passes immediately before reaching Detroit Lakes.

Table 11. Combined Land Usage in Sucker Creek and Eastern Subwatersheds

	hectares	% of Total
Urban, rural residential	110	6
Agriculture	216	11
Pasture/Grass	341	18
Wooded	1247	64
Water	20	1
Wetland	24	1
Total	1949	

While data are incomplete, it seems likely that these subwatersheds contribute heavily to the phosphorus load of Detroit Lakes during periods of high runoff, as during spring thaws or during episodes of heavy summer rains.

But in 1988 three-quarters of the nutrients entering Detroit Lakes via surface waters did so through the Pelican River inlet on the North shore of Big Detroit Lake. Given that the various contributing subwatersheds upstream of that inlet are sufficiently distinctive in terms of the nature and amounts of nutrient supply, it is reasonable to look at them separately.

The East Detroit Lakes City Subwatershed District.

A large part of the phosphorus flowing to Detroit Lakes via the Pelican River originates as storm runoff in the City of Detroit Lakes (fig. 15).

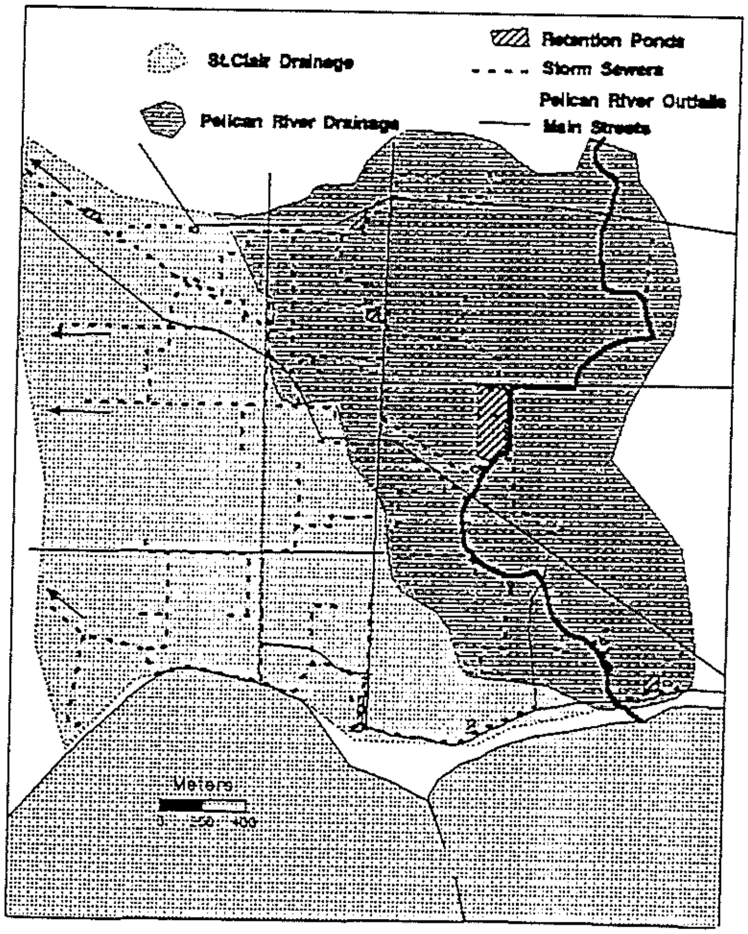

Figure 15. East Detroit Lakes City Subwatershed

Surface water from approximately one-half of the urbanized area of the City of Detroit Lakes, representing approximately 370 hectares, is discharged to the Pelican River at 12 points within 2 kilometers of the lake. Rudimentary treatment, in the form of shallow, dry sedimentation basins, has been provided for four of the collecting areas. Two small wet detention basins, involving drainage from less than 10 hectares have been added to the system since 1988.

Such a heavily urbanized area would be expected to produce about 1 kilogram of phosphorus per hectare annually, or about 370 kilograms. While actual data are not available, it can be inferred that such amounts were not generated by this watershed in 1988 since only about 300 kilograms came from all sources upstream from Big Detroit. However, it does seem reasonable to expect that episodes of heavy runoff would produce greater amounts than were measured in 1988.

In fact in April and May of 1989 the flow from the Pelican River into Big Detroit far exceeded the total flows of 1988. Accompanied by relatively higher phosphorus concentrations, this condition suggests a phosphorus input into Big Detroit Lake of almost 400 kilograms in those two months alone ($8.2\ 10^6 m^3$ x 50 ug/l phosphorus). Similarly, after record storms in 1993, one flow-weighted sample in mid-summer of 1993 indicated that the Pelican River was discharging phosphorus to Detroit Lakes at the rate 0.6 kilograms per hour. Flows of this magnitude continued for several weeks (though concentrations were not measured again).

Since the study was not designed to apportion sources of nutrients, it is not possible to say for sure that these loadings originate from within the City of Detroit Lakes.

<u>Upper Pelican Subwatershed</u>

In fact, those data which are available suggest that significant loadings come from farther upstream than the corporate limits of Detroit Lakes. An April 1989 phosphorus concentration was 200 ug/l at 2.5 m^3/second at the Highway 34 crossing of the Pelican River.

In general the Upper Pelican River Subwatershed is rural, with generally low gradients, channelized streams, and drained wetlands (Table 12).

Table 12. Land Usage in Upper Pelican Subwatershed

	hectares	% of Total
Urban, rural residential	249	3
Agriculture	2040	27
Pasture/Grass	1798	23
Wooded	3234	42
Water	47	1
Wetland	312	4
Total	7680	

This is an area where urban spillover from the City, based upon low land values, has attracted a fair amount of residential development in the last twenty years. While residential development is scattered throughout the area, it does occur in clusters on the fringe of the City and along highway 34 which cuts through the southern portion of the subwatershed (Figure 16).

Agriculture is marginal, mostly given to dairy operations, and scattered throughout the subwatershed. There are 14 livestock operations, five beef, four turkey, four dairy, one mink. Though there is some reason to believe that the major nutrient management issue in this subwatershed has to do with livestock operation, preliminary investigation has revealed that all of these operations have adopted reasonable management plans for the treatment of waste and prevention of erosion.

A prominent subwatershed feature is Rice Lake, a meandered lake drained in about 1913 to provide crop and pastureland to several nearby farmers. To accomplish this purpose the Pelican River was channelized throughout its whole length as it passes through this subwatershed, from its outlet at Little Floyd Lake to its entry into the City of Detroit Lakes. The drainageway has suffered from neglect over the years; the drained areas now are not ordinarily used for agriculture.

In addition to the meandered area, the State of Minnesota manages substantial land adjacent to the drained Rice Lake as a Wildlife Management Area. The City of Detroit Lakes has recently acquired land along Rice Lake's western shore for purposes of developing an industrial park.

The northern-most reaches of this subwatershed are mostly given over to livestock-based agricultural enterprises. These are connected to the Pelican River with low-gradient tributaries, most of which also have been ditched.

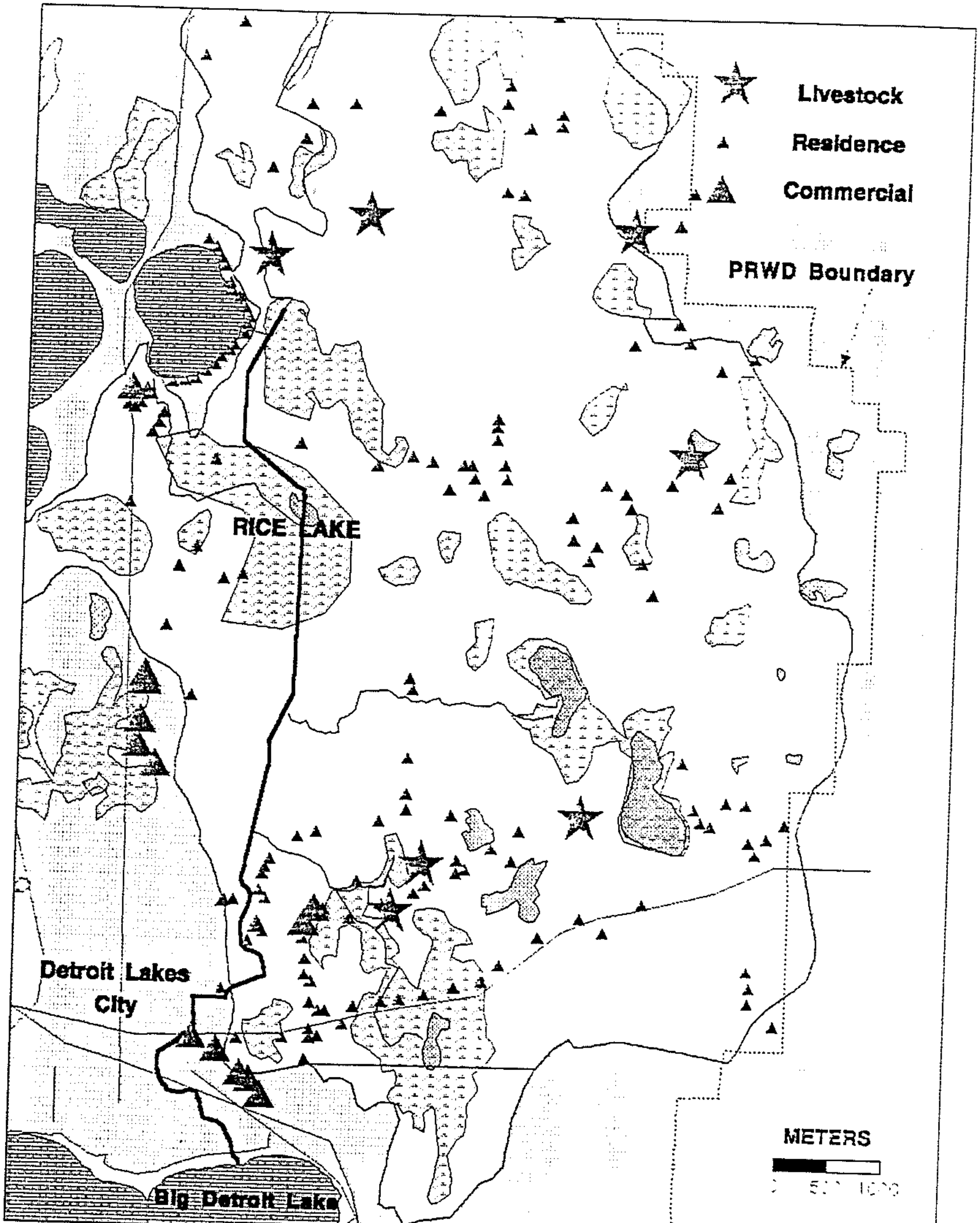

Figure 16. Upper Pelican River Subwatershed

Flows into and from this subwatershed are buffered by wetlands, including the former Rice Lake. It is believed that these sediment and nutrient traps do release nutrients routinely during spring snowmelt, and occasionally during episodes of high precipitation.

Floyd Lake and Campbell Creek Subwatersheds

The Pelican River originates at the outlet dam at Little Floyd Lake. Water reaching this dam originates in the 6800 hectares that comprise the Campbell Creek and Big Floyd Lake subwatersheds (Figure 12).

Big and Little Floyd Lakes are the most prominent physical features in the subwatershed. Campbell Creek, which extends to the northern limits of the subwatershed, has been channelized throughout most of its course. Nevertheless, there are several large wetland areas which remain in this subwatershed (Figure 3b). Gradients are relatively high with a fall of 55 meters in about ten kilometers. Aside from the residential and commercial development in the immediate vicinity of Big and Little Floyd Lakes, this subwatershed is relatively rural (Table 13).

Table 13. Land Usage in the Floyd-Campbell Subwatershed

	hectares	% of Total
Urban, rural residential	198	3
Agriculture	2157	32
Pasture/Grass	1182	17
Wooded	1965	29
Water	878	13
Wetland	422	6
Total	6802	

Indeed, agricultural land uses are relatively more important here, with almost one-third of the total land in crops. There are 13 livestock operations in this subwatershed, split almost equally among producers of dairy, beef and turkey.

While Big Floyd Lake now enjoys better water quality than any of the major lakes in the Pelican Chain, it is vulnerable to management decisions made by landowners in the upper reaches of the subwatershed. The situation is exacerbated by the high gradients which increase the erosion potential. The problem manifests itself during spring snowmelt and other episodes of high runoff.

Some samples taken from Campbell Creek during the spring of 1989 indicated phosphorus concentrations in excess of 400 ug/l with suspended solids over 100 mg/l. On the other hand, it appears likely that Floyd Lakes in general, and Little Floyd Lake in particular serve to utilize nutrients or trap them before they leave the subwatershed. A single sample at the Little Floyd outlet to the Pelican River in the early spring snowmelt of 1989 showed negligible suspended solids, and a phosphorus concentration of 10 ug/l (a phosphorus concentration of 100 ug/l was measured after record storms of summer, 1993, but this was low compared to other readings taken in watershed streams at the same time.) Based upon available evidence, it appears that the Floyd Lake, Campbell Creek subwatershed does not offer a serious nutrient threat to downstream areas at this time.

SUMMARY

Using Carlson's equation (EPA, 1990), Trophic State Indices were calculated using several parameters of the Chloraphyll-a, Total Phosphorus and Transparency data obtained from 1988 and 1989 (Table 14). Taken together these indicate a Detroit Lakes condition that is, on average, within the mesoeutrophic limits, but only barely.

Table 14. Detroit Lakes Trophic State Indices

	TSI Summer average	TSI Annual average	TSI Worst 1988-89 Observation
Secchi Disk	44	*	53 (Aug 9)
Chlorphyll-a	47	45	56 (Apr 25)
Phosphorus	48	46	55 (Aug 9)

* no transparency measures taken during ice-cover

It is noteworthy that the worst observations did not greatly distort the averages, nor did they lower water quality too far into the eutrophic category.

Data are insufficient to pinpoint sources of Detroit Lakes water quality problems. Nevertheless, by piecing together those data that are available, it is possible to obtain a reasonably complete picture. It seems likely that a significant part of the problem arises in those parts of the Detroit Lakes' urbanized area which drain largely untreated to the Pelican River and thence to the lakes. A similar source is runoff from hard surfaces which drain directly to the lake, as in the case of boat-launching sites, parking lot and highway drains. Whether or not ground water infiltration from septic sources from riparian landowners is contributory is moot, as a sewer around the lake will be completed soon. There is no reason to believe that other ground water sources of nutrients are significant.

Nutrients and sediments, most likely resulting from agricultural practices, and introduced to Detroit Lakes from the Sucker, East Side, and Upper Pelican subwatersheds seems to be a contributor, particularly during periods of high runoff when those materials stored in wetlands and upstream lakes are released to Detroit Lakes. At the present time, evidence is insufficient to link the Floyd Lake-Campbell Creek subwatershed to Detroit lakes water quality problems.

Finally, there is the matter of internal loading of nutrients from sediments in the bottom of the lakes. It is known that the release of such nutrients during periods of anoxia, does significantly add to the available phosphorus supply, and is largely responsible for the mid-summer algae blooms and transparency problems.

LAKE SALLIE PHASE I 1988-1989 DIAGNOSTIC STUDY

The principal morphological and watershed characteristics for Lake Sallie are described in Table 15 and in Figure 16a and 16b. The contributing sub-watersheds were defined by inspection of 1:24,000 USGS topographic maps, together with diagrams of the City of Detroit Lakes storm water diversion system.

Table 15: Morphological and Watershed Characteristics of Lake Sallie

Ordinary High Water Level	405 meters (1329 feet) above MSL
Surface Area	484 hectares (1211 acres)
Maximum Depth	17 meters (55 feet)
Mean Depth	5 meters (17 feet)
Volume	$25x10^6m^3$ (20,689ac.ft)
Av. Annual Inflow	$27x10^6m^3$ (22,000 ac.ft)
Littoral Area 1/	208 hectares (520 acres)
Shoreline	9.5 km(5.9 miles)
Maximum Length	3.38 km (2.1 miles)
Maximum Width	1.77 km (1.1 miles)
Inlets (number)	5
Outlets (number)	1
Basin Size 2/	1,058hectares (2,670 acres)
Watershed Size	23,350 hectares(58,378 acres)

1/ zone between surface and two meter depths
2/ immediate subwatershed
3/ includes 11 subwatersheds to Sallie plus those that drain to Detroit Lakes

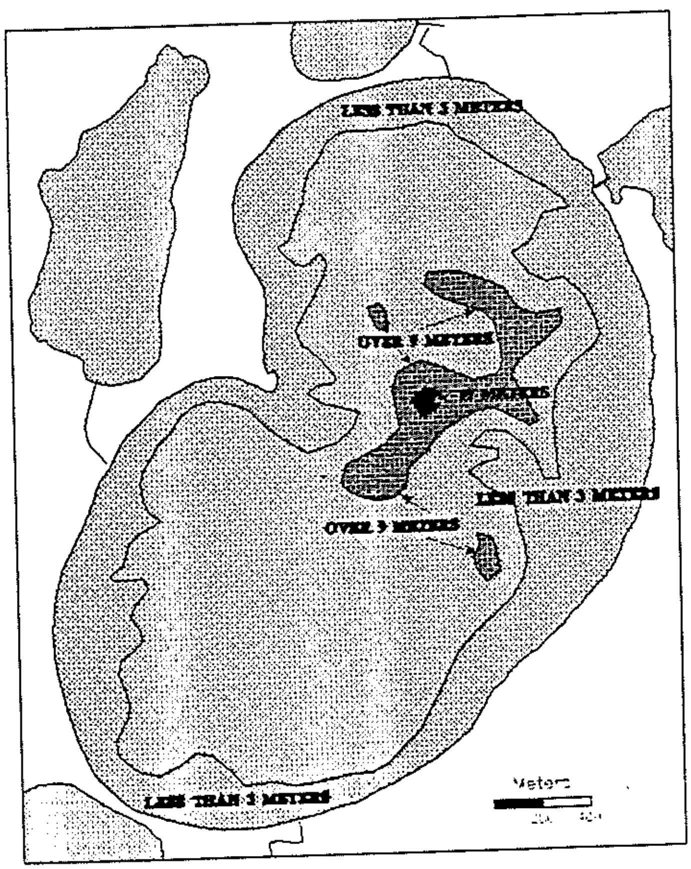

Figure 17a Lake Sallie Generalized Depths

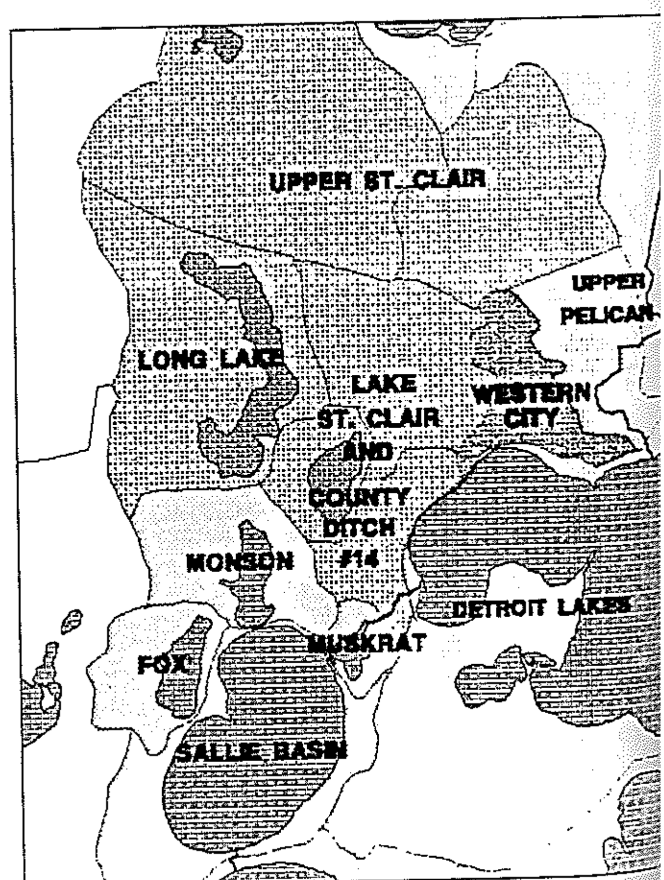

Figure 17b Lake Sallie Subwatersheds

PREVIOUS STUDIES OF LAKE SALLIE

Comprehensive qualitative and quantitative information on Lake Sallie's water quality first became available in connection with the Environmental Protection Agency supported research by Dr. Joe Neel in 1969-1971. In work that nominally was aimed at evaluating the efficacy of nutrient reduction through the mechanical harvesting of aquatic weeds, he observed Lake Sallie as a "highly photosynthetic lake, rich in phytoplankton and attached vegetation", noting further "that luxuriant summer growths of rooted aquatic plants extended out to depths of 10 feet and patches of *Potamogeton praelongus* extending to depths of 18 feet."

Based upon many observations, at numerous sampling stations, and at several depths, Dr. Neel and his doctoral students made observations of Lake Sallie's water chemistry and biology. For example, conditions of Lake Sallie are described as follows:

> "Available phosphorus generally was most concentrated in deeper waters of the limnetic zone, especially during periods of stratification (a 9.2mg/l maximum was in the hypolimnion in 1969), but it tended to disappear from surface waters during the growing season, although this occurred infrequently in 1969. It varied markedly in surface water at Station 1, where maximum values 4.8 mg/l occurred, but it reached comparable levels in other littoral areas... under ice cover. Its maximum for the limnetic zone surface 1.4 mg/l occurred in September 1969. Surface values there were usually less than 1.4 mg/l. Orthophosphate was consistently higher in the inlet than in outflowing water, declining to zero in the latter for about 30 consecutive days in July and August 1971. Surface water concentrations were higher in 1969 than in 1970 and 1971.
>
> Total phosphorus occurrence and variations generally paralleled those of PO_4, but its concentration was substantially higher. It increased with depth, declined from winter maxima during the growing season, and was almost always more concentrated in inflowing than in outflowing water. Its level was also greater in 1969 than in 1970 and 1971."

Information on other chemical and biological conditions of the lake were similarly described. Neel summarized by writing that "the major nutrient source is the Pelican River which receives the waste water effluents from Detroit Lakes (City)", and that "the bulk of nitrogen and phosphorus is contained in the water mass with relatively minor amounts in sediments and bodies of organisms". He also reached the important conclusion that removal of organisms from Lake Sallie would decrease annual nutrient increments by a very small fraction and "would alone contribute little or nothing toward's the lake's recovery."

In 1973-75 Dr. Neel expanded his work to consider the areas of the watershed upstream from Lake Sallie, and especially in the area of the City of Detroit Lakes' St. Clair Waste Water Treatment site. In this effort, both ground water and surface waters were studied, and an attempt was made to apportion sources of Lake Sallie enrichment to various origins. He discovered that "in 1973 and 1974 the major share of P load discharged by the Pelican River to Lake Sallie was in the wastewater effluent from the City of Detroit Lakes." But he also noted that in 1975, a larger amount of the load entering Lake Sallie came from non-point sources in the drainage area above Detroit Lake, including that carried in ground water but originating at the surface. In this connection he mentioned that summer rain contributions in the upper watershed account for about 40 percent of the annual P load from Detroit Lake. As to Lake Sallie's condition, he said that "most noxious conditions in surface waters have been occasioned by *heterocystous* blue-green phytoplankters, but the greatest plant mass has been produced by rooted and attached vegetation." He also mentioned that groundwater seepage into lakes directly contributed more nutrients than precipitation, though the latter served as an important indirect source (through watershed soils). He noted in passing that mechanical weed harvesting had "markedly reduced the growth of aquatic weeds" in Lake Sallie, and had caused qualitative changes in their mix.

In 1976 the City of Detroit Lakes installed a tertiary treatment system to remove phosphorus from effluent prior to discharge. Treatment included chemical precipitation, spray irrigation, and intermittent application to grassed absorption galleries. Discharge of effluent to surface waters occurs during winter months only with a maximum of 1 mg/l of total phosphorus. The remainder of effluent is land applied by spray irrigation and rapid infiltration.

In a follow-up study from 1977 to 1980, Dr. Neel reported a significant improvement in the condition of Lake Sallie (in particular a reduction in the occurrence of blue-green algae) which he attributed to the special phosphorus removal procedures implemented in 1976. However, using research procedures similar to those previously employed, he discovered that while waste water effluent itself ceased to be a significant contributor, phosphorous availability actually had increased in Lake Sallie. He suggested that this was partly due to phosphorus imports from the upper portions of the watershed via Detroit Lakes. He also pointed to the possibility that nitrogen, which continued to enter Sallie through St. Clair sources (including the new wastewater treatment facilities) might be a factor. Among other recommendations, he suggested that more information should be gathered on the matte of ground water response to land application of wastewater influent.

In connection with a proposal to provide a regional sewer system in Lake View township, a consultant, K-V Associates (Falmouth, Mass), conducted a "continuous shoreline leachate scan" of Lake Sallie in late summer of 1980. Analyses of ground water flows as well as near-shore lake samples and well samples were performed usin various techniques, including tracer elements. They reported that total phosphorus and orthophosphate levels in Lake Sallie surface water are significantly higher (average = 75 ug/l) than other nearby lakes. They noted that while the eutrophic condition of this lake has long been known...,

> "only a handful of groundwater plumes could be confirmed. At least seven of these did show signs of (septic system) effluent content by lab analysis.... While the lake bottom sediments appear to be leaching nutrients as a result of the past years of receiving effluent-charged Pelican River inflows (likely traceable to St. Clair Lake) the actual frequency of shoreline currently emergent effluent plumes is quite low. The Pelican River issuing from Muskrat Lake had a higher intensity of effluent and bog components than any other Lake Sallie surface water sample, however, its total phosphorus concentration at (29 ug/l) was one-third the lake body (average) of (75 ug/l)."

The K-V report went on to note that existing plumes in the Lake reflected the movement of ground water towards Lake Sallie from north to south in general, and from Monson to Sallie and Fox Lake to Sallie in particular. There were no plumes along the south side of the Lake, consistent with the measured lakewater "exfiltration" through the Shoreham area (though wells in that area did show effluent imprints).

In 1983 the District retained a consultant to provide additional data on several [illegible] lakes. In addition to limited sampling of water quality using common measures, he obtained sediment core samples in order to determine sedimentation rates as well as past and present nutrient conditions. Regarding Lake Sallie Mr. Del Hogan, of Instrumental Research, Inc. observed:

> "the large aquatic vegetation in Lake Sallie is growing on the accumulated nutrients in waters more than twenty feet deep and supplying these waters with a large amount of oxygen. It is only later in the season when the turbidity prevents photosynthesis by the large aquatic plants, that there is a significant increase in released nutrients from the sediments....the algae populations take all of their nutrients from the free water..., the four sources are: the waters from the Pelican River, input from the watershed, the nutrients released to the free water as macrophytes decay, and recycled nutrients from the sediments.... blue-green algae dominated the population in Lake Sallie from August through September and probably through October. The September population (of blue-green algae) was about one-quarter of what it was in 1979."

Hogan further commented that if established harvesting and beach removal practices continue for a sufficient time period, the deposition of a "low nutrient cap" will prevent large quantities of macrophytes from c. This idea has been challenged (Tomasek, pers. communication).

Finally, Glander notes that there have been major changes in the Lake Sallie fish community during the 40 years between 1949 and 1989 (Table 16). "Abundance of walleye, yellow perch, bluegill and white sucker generally declined until 1975. Subsequent to the diversion of the (City of Detroit Lakes) sewage effluent, there were additional changes in the fish community." He goes on to say that "by the 1980's, walleye, perch, bluegill and sucker populations showed evidence of recovery from the 1975 lows". (Paul Glander, pers. comm.).

Table 16. Historical Abundance of selected fish species in Lake Sallie between 1949 and 1989.

	Number of Fish Per Net					
Species	1949	1968	1975	1981	1984	1989
White Sucker	3.8	3.5	2.5	4.2	2.9	3.4
Black Bullhead	3.7	101.2	11.0	22.5	1.6	7.6
Yellow Bullhead	0.2	0.1	0	1.7	0.3	2.0
Brown Bullhead	1.0	2.3	0.9	0.7	0.4	1.6
Bluegill	-	4.1	1.6	4.5	5.2	30.4
Yellow Perch	42.0	38.8	25.0	48.0	70.4	52.5
Walleye	16.3	5.8	3.0	9.3	3.8	3.3

Source: Paul Glander, personal communication

Though lack of consistency in sampling and analytical procedures makes quantitative comparisons inconclusive, existing research seems to support the generalization that Lake Sallie has experienced some improvement in overall water quality since the 1960's.

1988-1989 WATER QUALITY PARAMETERS FOR LAKE SALLIE

Full details of water quality sampling results are reported in a companion volume, "Lakes Sallie and Detroit, Pelican River Watershed, 1988 and 1989 Data Collection Summary" (Larson-Peterson, 1990). In-Lake sampling data, and other relevant results from Lake Sallie data collection efforts are included in Appendix D. A summary and interpretation of the major findings follow.

Temperature. Lake temperatures warmed rapidly at all depths in May and June of 1988, reaching 26 degrees C. near the surface. Waters were thermally mixed until June, at which time a thermocline developed between 3 and 6 meters. Thermal mixing between 21 and 24 C° returned in early July, and temperatures remained consistent at all depths for each sampling period through June, 1989 (fig. 18).

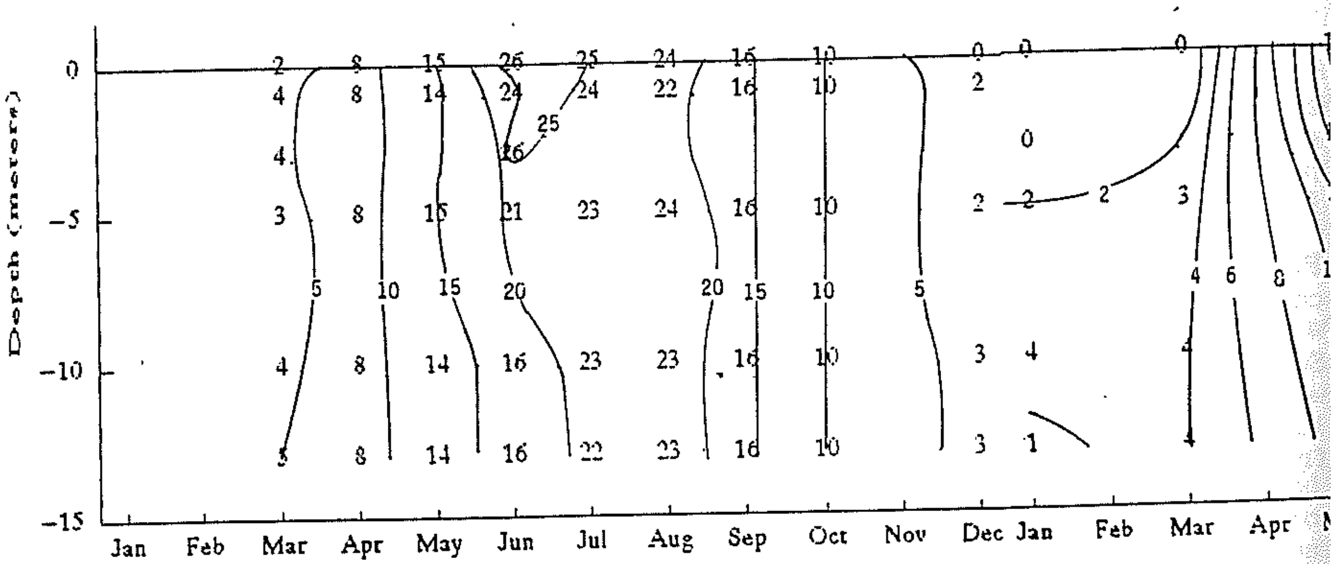

Figure 18. Lake Sallie Temperatures (C°), 1988

Dissolved Oxygen. Measurements were taken at one-meter intervals near the deepest location of the Lake. Figure 19 depicts ample surface oxygen to a depth of 5 meters, with depletion below that depth in the summer months, and at all depths during the winter. Dissolved oxygen levels in depths below light penetration declined from November until March with lower depth oxygen concentrations at almost zero. Spring turnover produced dissolved oxygen concentrations uniformly through the lake strata, but these declined at lower depths as temperature stratification occurred. The condition improved at lower levels in the fall, before freeze-up. During the early spring dissolved oxygen levels remained perilously low, though no fish skills were reported.

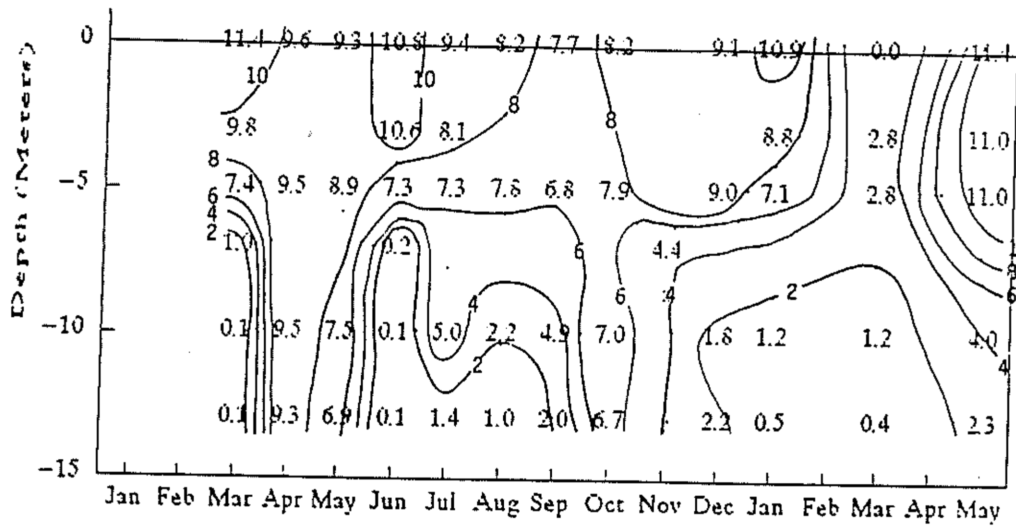

Figure 19. Lake Sallie Dissolved Oxygen (mg/l), 1988, spring, 1989

<u>Total Phosphorus</u>. Total phosphorus concentrations were sampled at least monthly at the surface, at intermediate depths, and near the bottom of the lake. Eplimnion concentrations in 1988 ranged from 22 ug/l in the winter and spring to maximum levels of 79 ug/l in July, before returning to 15 ug/l at the end of the year. The mean of the nine summer observations at the surface was 36 ug/l. Mixing in July and August, which seems to correlate with temperature mixing at the same time, may be related to unsettled weather conditions.

1989 started with somewhat higher readings, but quickly dropped to levels that were comparable with 1988. Concentrations in the deeper regions of the lake varied from lows of approximately 15 ug/l to amounts up to 160ug/l during hypolimnion oxygen depletion periods in 1988 (figure 20). Early 1989 samples were comparable. The 88 ug/l reading in May is considered to be a sampling or processing error.

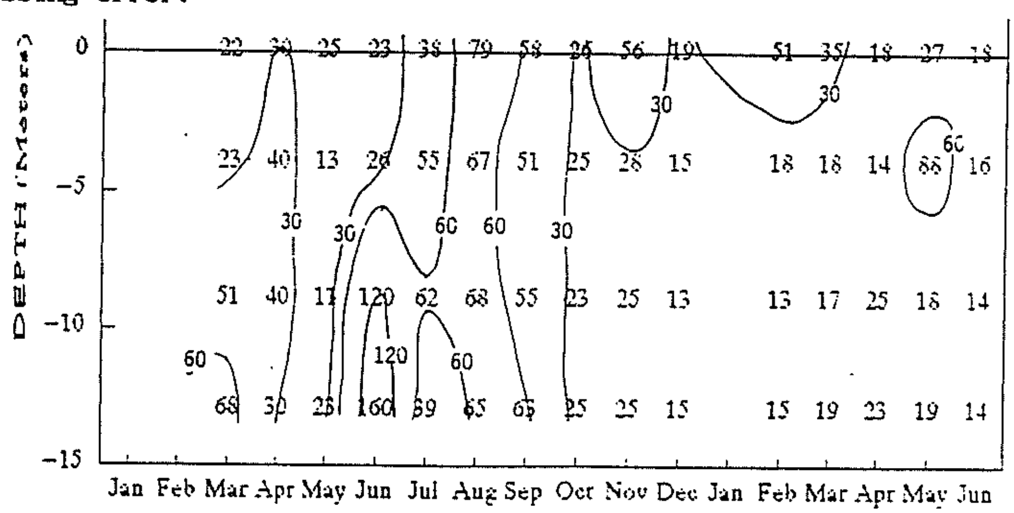

Figure 20 Lake Sallie. Total Phosphorus (ug/l), 1988, spring, 1989.

Orthophosphorus. Orthophosphorus concentrations in 1988 were generally low (below 14 ug/l), except in the hypolimnion during thermal stratification when observations from the nine and thirteen meter levels showed 72 and 80 ug/l, respectively (Appendix D). At the nine meter level, orthophosphorus returned to a low level (6 ug/l) by August 10, but dropped more gradually and somewhat erratically in the bottom samples (13 meters), finally reaching levels below 10 ug/l in October. Sampling in winter and early spring, 1989, indicated low orthophosphorus at all depths in all five samples.

Water Clarity. Lake Sallie's open water season of 1988 began in April with fairly poor transparency readings of slightly less than 2 meters. After some improvement in early summer, conditions deteriorated, so that by the end of August, and into September, readings were less than 1 meter. In October conditions improved somewhat. Interestingly, 1989 transparencies were better at least through mid-July (Fig. 21). Open Water Season was from April 15 to November 22 in 1988, and began on April 25 in 1989.

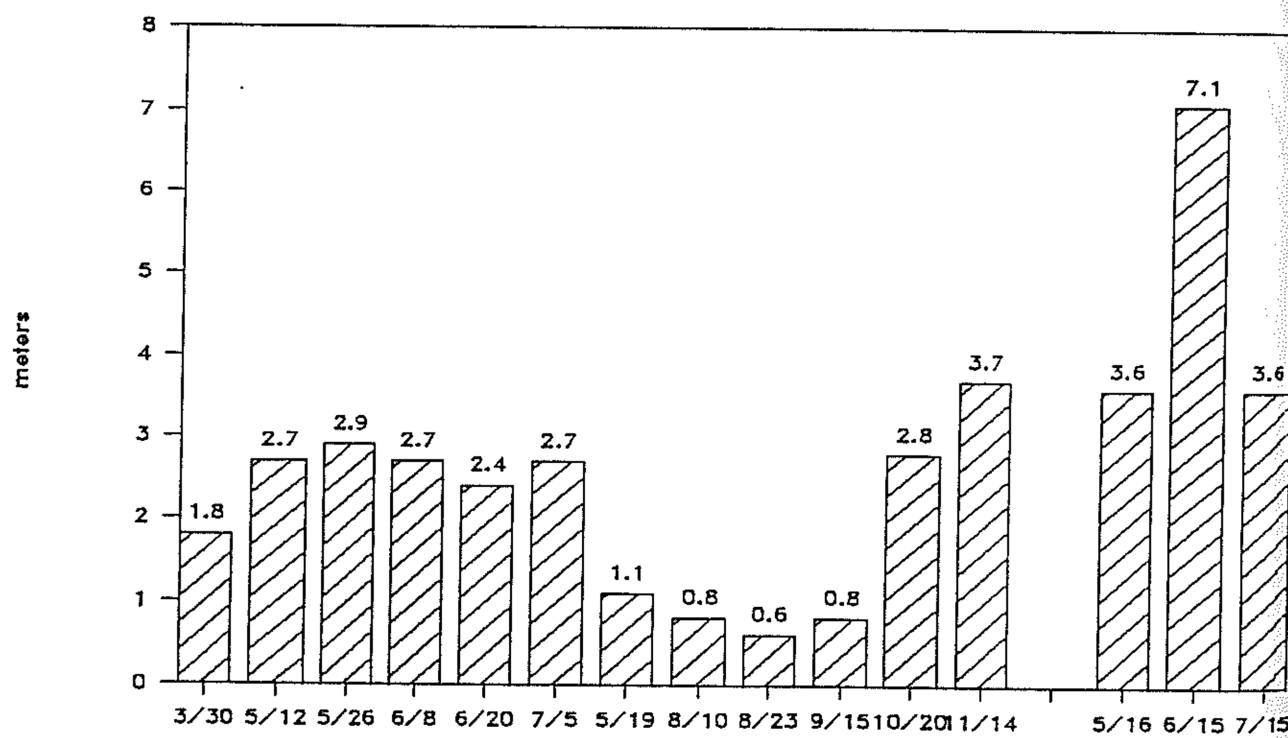

Figure 21. Lake Sallie, 1988, 1989 Secchi Depths (meters)

Chlorophyll-a. This indicator of biological activity started the open water season with levels in the 3-4 ug/l range (Fig. 22). After dropping slightly in the early summer, the readings rose dramatically in July, and reached a peak of 37.5 ug/l on September 15. The last sample in 1988 (October 20) was 10.7 ug/l. The early spring samples in 1989 (before open water returned) were less than 1 ug/l.

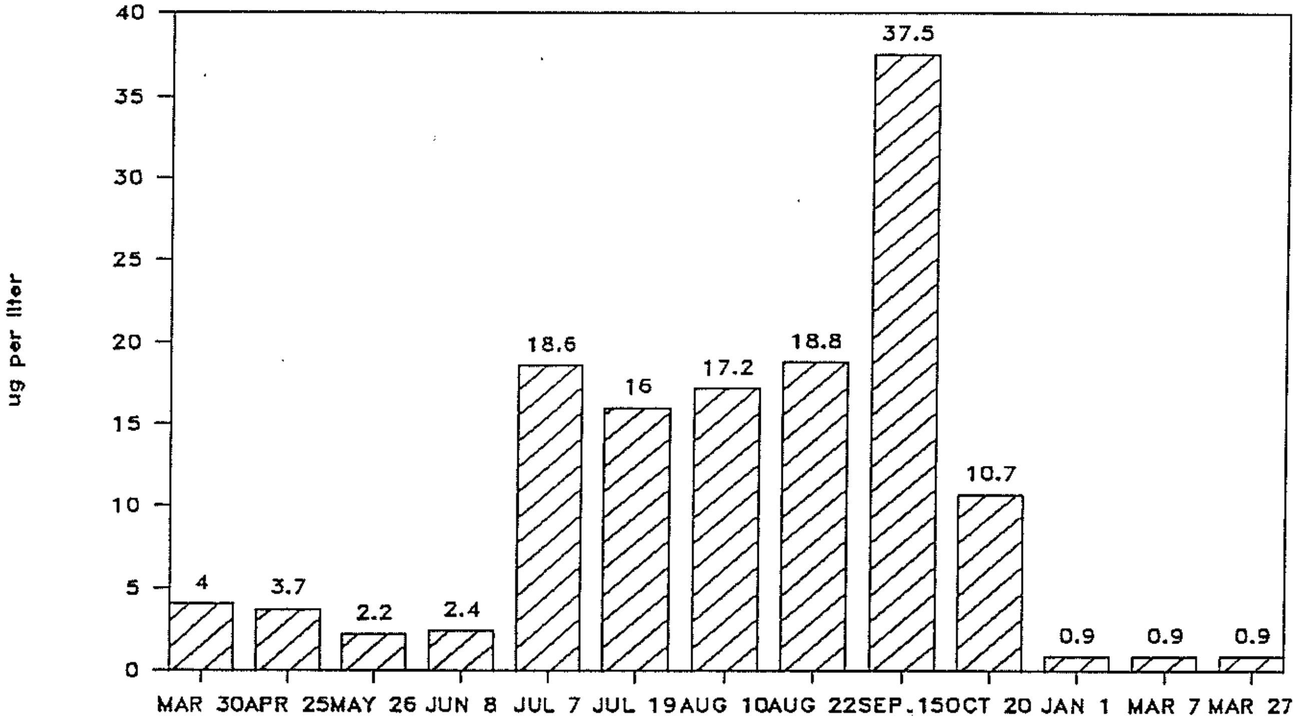

Figure 22. Lake Sallie Chlorophyll-a (ug/l), 1988,

<u>Phytoplankton.</u> Phytoplankton counts resemble those of Chlorophyll-a: in 1988, May and early June counts were less than 300,000 (cells/liter), rising to almost 38 million in August before dropping back to under 20,000 in the fall (Figure 22). Nearly all of the variation in Chl-a can be explained by the growth and decline of blue-green algae. Low spring phytoplankton concentrations consisted mainly of diatoms, and green algaes; the later peaked in June, and then declined as the season progressed. In contrast, blue green varieties made an appearance in June in the form of anabaena and aphanizomenon. Blue-green algaes increased dramatically in concentrations in July and August with *Microcystis*, *Oscillatoria* and *Coelosphaerium* becoming the dominant species. Phytoplankton growth declined dramatically in September with temperature decreases (Table 19).

Table 19. Phytoplankton in Lake Sallie, 1988.

	Total Count 1000's cells/l	Phytoplankton Composition Blue Green %	Green %	Diatoms %	Other %
May 12	126	0	1	34	65
Jun 7	277	0	47	44	9
Jun 20	2640	85	1	13	1
July 7	2225	94	4	0	2
Aug 10	37769	100	0	0	0
Sep 12	2428	95	0	2	4
Oct 19	16	75	1	15	9
Nov 14	13	26	26	43	6

Macrophytes. The general location of Lake Sallie's macrophytes is portrayed in Figure 23. Macrophytes are found throughout the littoral zone. The identified species were very similar to those found in Detroit Lakes (see preceding section). The most common macrophytes were:

Common Name	Scientific Name
Curlyleaf Pond Weed	*Potamogeton crispus*
Muskgrass	*Chara spp.*
Northern watermilfoil	*Myriophyllum exalbescens*
Wild Celery	*Vallisneria americana*
Flowering rush*	*Butomus umbellatus*

*exotic, recently added to Minnesota's Harmful Exotic Species list.

A full report on Lake Sallie macrophytes is included in Appendix D.

The distribution of Lake Sallie's macrophytic vegetation is difficult to describe because of the long-standing practice of weed harvesting in depths to two meters. This is particularly true with respect to submerged and floating species. Emergent species have not been harvested, so that in shallower waters, bullrush and some common cattail populations are found in scattered locations where riparian development is not intensive (Figure 23). Flowering Rush which recently has spread to Lake Sallie is found in depths to 2.5 meters, and is increasing its area of infestation rapidly. Because it too is harvested, it is usually seen in depths less than 1 meter.

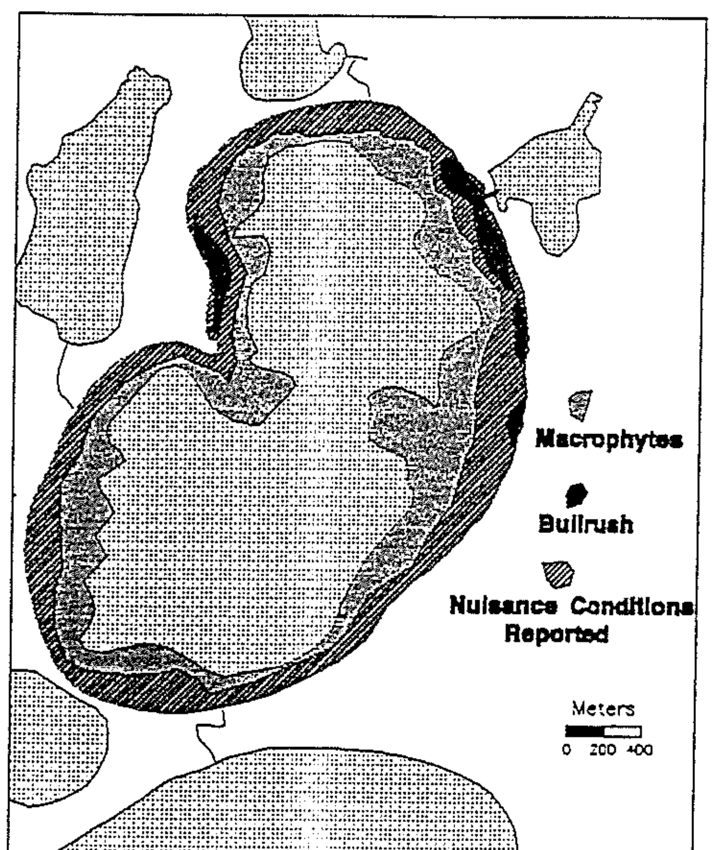

Figure 23 Lake Sallie Macrophyte Distribution

Zooplankton. The most abundant Lake Sallie zooplankton were the large-bodied herbivores *Daphnia pulex* and *Daphnia galeata*. Based upon 6 samples at about one month intervals beginning in April, 1988, counts ranged from 176,837 per cubic meter in May to 2778 per cubic meter in early June (table 20). Zooplankon identified in Lake Sallie are as follows:

Cladocera, especially,
Daphnia pulex, Daphnia galeata
Daphnia retrocurva, Unknown Daphnia
Bosmia sp. sida crystallina
Copepod, especially,
Mesocyclops edax, macrocyclos albidus
Juvinile cyclopoid, diaptmus oregonensis
Cyclops bisupidatus t. Epischura lacustris
Juvenile calanoid, Nauplier stages
Ostracods, and *Rotifers*

Table 20. Zooplankton in Lake Sallie, 1988

Sample Date	Total Organisms	Density $\#/m^3$	*Daphnia galeata* %	*Cladocera* %	*Copepod* %	*Rotifer* %
May 12	210	176,838	0.9	7.6	62.9	29.5
Jun 9	161	3,389	34.8	36	16.2	45.3
Jun 20	88	3,705	59.1	95.5	4.6	0.0
Jul 7	116	17,210	12.1	98.3	1.7	0.0
Aug 10	109	4,589	7.3	52.3	25.7	18.4
Nov 14	140	14,737	32.9	87.1	11.4	1.4

Fishery. Unrelated to the present study, in July 1989 the Section of Fisheries of Minnesota's Department of Natural Resources conducted regular a "Fisheries Lake Survey" in order to update the DNR's lake management plan for Sallie. (As noted previously, similar assessments had been conducted in 1949, 1968, 1981 and 1984.) Paul Glander summarizes the 1989 results as follows:

"Bluegill were the most numerous fish collected in the 1989 assessment, followed by yellow perch, hybrid sunfish, black bullheads and northern pike. When ranked by total weight of fish collected, northern pike were first, followed by yellow perch, bluegill, walleye and white sucker. A total of 16 species of fish were collected including other popular game fish such as largemouth bass, black crappie and tullibee (cisco).

Table 21 show the number of popular sport fish captured per net in the 1989 assessment of Lake Sallie in comparison to the normal range for that fish species in lakes with similar physical and chemical characteristics. Bluegills were as abundant as expected for lakes like Sallie as they were in the middle of the normal range. Both black crappie and yellow perch were slightly above the normal range but not enough to adversely affect fish community structure. Northern pike abundance, however, was high enough to impact the fish community.... Walleye numbers were just below the normal range. Walleye fry and fingerlings are stocked annually.

Table 21. Abundance of some fish collected in the 1989 Lake Sallie Fish Community Assessment

	Number of Fish per Net	
	Caught	Normal Range*
Species		
Bluegill	30	3.3 - 53.0
Black Crappie	2	0.3 - 1.6
Northern Pike	18	3.1 - 8.4
Yellow Perch	53	8.2 - 49.3
Walleye	3	3.7 - 9.7

*Normal ranges represent typical catches for lakes with similar physical a chemical characteristics

Source: Data supplied by Paul Glander

Trends based upon previous studies

There can be no doubt that there has been general improvement in the Water Quality of Lake Sallie.

In particular, total phosphorus concentration in Lake Sallie apparently has declin by a factor of almost ten from the 1968-1970 testing period (Table 22). The chang in orthophosphorus is similar. While transparency data are not comparable, Neel reported in 1971 that light penetration during open water seasons was commonly restricted by turbidity due to plankton growth, especially blue-green algae near t surface. It appears that there has been some improvement in that condition, especially when taking into account early summer conditions in 1989.

Table 22. Historical Phosphorus Data, Lake Sallie

	Phosphorus in ug/l		
	Samples	Summer Mean	Summer Range
1968 (Mn DC)	1	170	-
1968 (Neel, 1973)	12		50 - 230
1969 (Neel, 1973)	31		30 - 750
1970 (Neel, 1973)	32		60 - 1440
1971 (Neel, 1973)	14	400	10 - 920
1973 (Neel, 1978)	14	150	90 - 250
1974 (Neel, 1978)	14	160	130 - 200
1975 (Neel, 1978)	14	350	230 - 480
1978 (Neel, 1981)	14	502	320 - 750
1980 (KV, 1980)	8	60	30 - 93
1983 (Hogan, 1983)	4	46	20 - 107
1988 Present Study	10	54	23 - 79
1989 Present Study	2	52	18 - 27

Fisheries data strongly support the conclusion of improved water quality conditions. Glander says that the "changes in the Lake Sallie bullhead community (Table 23) are a classic example of the effects of eutrophication on fish" (Glander, pers. comm.). He refers to a recent article by Schupp and Wilson (1993) who summarize the situation as follows:

> "Perhaps the best fish indicators of water quality are two of the three bullhead species.... Yellow bullheads are found in the highest numbers in lakes with clear water. In contrast, black bullheads reach their greatest abundance in very turbid, eutrophic waters. "In lakes where both species are present, the ratio of black bullheads to yellow bullheads can serve as an additional indicator of water quality. A ratio of two black bullheads to one yellow is about normal for a mesotrophic lake. As water clarity increases, the ratio decreases. And, in very clear water, yellow bullheads usually outnumber blacks. Conversely, as water clarity declines, the ratio increases. In moderately eutrophic lakes, a ratio of five blacks to one yellow is typical. As lakes become more eutrophic, the ratio increases rapidly."
>
> "The ratio of black to yellow bullheads changed dramatically at Lake Sallie before and after diversion of Detroit Lakes wastewater treatment facility's effluent. In a 1953 lake survey, the ratio was 22 blacks to one yellow, which indicated degraded conditions at that time. By 1961 and 1972, before the effluent was diverted, the ratio had climbed to 1,265 and 3,437 blacks to one yellow, respectively. Since diversion, the ratio has declined with each survey and by 1989 it was four blacks to one yellow."

Anecdotal data support the science. Long-time residents and visitors point to substantial improvements in the situation during the last 20 years. A 50 year resident writes a typical sentiment..." with the introduction of the tertiary treatment system at Detroit Lakes [1976], the Lakes [Sallie and Melissa] became much cleaner." Residents often cite improved boating and swimming conditions. Many believe that Sallie has regained its reputation as an above-average local fishing resource (each winter several hundred fish houses now can be found on Lake Sallie ice).

Inferential evidence also supports these views. Lake Sallie property is no longer unsalable or unmortgageable, as indicated by recent upgrades in the housing stock, and additional development is currently underway. Local Realtors consider Lake Sallie offerings of to be "prime" listings.

SOURCES OF LAKE SALLIE NUTRIENTS

Hydrologic budget.

Based upon stream-flow observations together with lake levels and other sources (See Appendix A), Lake Sallie's Annual and Monthly Hydrologic Budgets for 1988 are reported in Table 24a and Table 24b, respectively.

Table 24a. 1988 Water Budget for Lake Sallie

Surface Inflow	13.7 10^6 m^3 (11,279 af)
Pelican River = 13.3 $10^6 m^3$ (10940 af)	
Precipitation	3.2 10^6 m^3 (2,645 af)
Surface Outflow	15.8 10^6 m^3 (13,140 af)
Evaporation	5.5 10^6 m^3 (4,524 af)
Change in Storage	.01 10^6 m^3 (- 87 af)
Residual (mainly ground water)	4.4 10^6 m^3 (+3,653af)

Table 24b. 1988 Monthly Water Budget for Lake Sallie (flows in 10^6 m^3)

SOURCE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Surface Inflow	0.62	0.62	2.02	4.16	2.44	0.76	0.00	0.74	1.10	0.19	0.65	0.62	13.92
Precipitation	0.15	0.00	0.17	0.03	0.35	0.23	0.60	0.78	0.54	0.13	0.16	0.12	3.26
Surface Outflow	0.99	0.99	1.72	3.58	2.49	1.19	0.31	0.61	1.32	1.31	0.96	0.76	16.21
Evaporation	0.05	0.05	0.06	0.21	0.97	1.13	1.15	0.99	0.55	0.21	0.16	0.06	5.58
Change in Storage	0.00	0.00	0.37	-0.08	-0.24	-0.61	-0.21	0.51	0.15	0.00	0.00	0.00	-0.11
Residual (Ground)	0.27	0.42	-0.04	-0.48	0.43	0.71	0.65	0.58	0.37	1.21	0.32	0.08	4.51

The Pelican River is the major contributor to the hydrologic budget for Lake Sallie. In 1988, the river accounted for about 97% of the total surface inflow, and about 65% of the water that is added to Lake Sallie. Other sources include the outlets from Monson and Fox lakes, and the Fish Hatchery.

It is noteworthy that 1988 water budget components were somewhat different than those identified in other studies. Neel reported surface inflows in 1968-70 in th range of 30 to 50 percent more than were observed in 1988. On the other hand, at 26 percent, the role of groundwater seems consistent with previous findings. (Mann and McBride and Neel, 1979).

Phosphorus. The limiting nutrient

Phosphorus and nitrogen are usually associated with limits of algae growth in lakes with phosphorus being of greater importance unless extremely high concentrations of phosphorus are present, reducing the total nitrogen to phosphorus ratio to less tha 12. In Sallie's case, the average NT:PT ratio was 47.5 which suggests that phosphorus _is_ the limiting nutrient. Ratios ranged from 33 to 90. The ratios wer especially consistent during the spring and summer, ranging from 33 to 50. It appears that the affect of storm water runoff in otherwise droughty 1988 did not significantly alter the ratio.

Research evidence strongly suggests that phosphorus management is the key to improving water quality in lakes. Reducing phosphorus generally results in lower Chlorophyll-a levels, and related nuisance phytoplankton species. Conversely, as phosphorus concentrations exceed 40 ug/l, chlorophyll-a levels increase to approximately 20 ug/l, a level which is generally considered to yield a nuisance condition. Lake Sallie phosphorus levels exceeding 40 ug/l occurred in August and early September of 1988.

Available phosphorus in Lake Sallie is strongly affected by the amounts stored in bottom sediments from previous high nutrient loadings. Some of these are released during the anaerobic conditions which occur in hypolimnion in summer months. These releases appear to be sufficient to cause Lake Sallie to export phosphorus (to Lake Melissa) in 1988.

External Phosphorus Loading.

From inlet and outlet sampling, ground water concentrations as revealed in the City of Detroit Lakes Waste Water Treatment Plant, data on phosphorus in the annual spring Fish Hatchery discharges, and an evaluation of atmospheric phosphorus deposition, Lake Sallie's 1988 phosphorus loadings were estimated (table 22). In this calculation, the contributions of waterfowl, direct runoff, and riparian septic tanks were not considered. Phosphorous sedimentation rates were not calculated.

Overall it is clear that the major source of external phosphores input to the lake is from the Pelican River. It also is noteworthy that in 1988, Sallie exported phosphorus to Lake Melissa.

Table 25. 1988 External Phosphorus Budget

	kilograms
surface inflow	
Pelican River	371
Monson Lake	2
Fox Lake	5
Fish Hatchery	t.
precipitation	110
ground water	116
Total	604 kg. of phosphorus per year
removal	
outflow via Pelican River	506
harvest	
weeds	171
fish	100
Total	777 kg. of phosphorus per year

Available Phosphorus

However, external sources of phosphorus seem to be inadequate to the task of explaining phosphorous availability in Lake Sallie. In-lake phosphorous amounts varied considerably over time (Figure 24), ranging from about 500 to almost 2000 kilograms with a 1988 average of a little more than 800 kilograms. While the springtime rise in phosphorus appears to correspond to phosphorus inflow into the lake, a secondary, and much greater surge in phosphorus seems to be associated with the recycling of phosphorus from sediments during the period of stratification and low oxygen availability in mid to late summer. This latter event coincided with very low inflow rates during June and July. A lesser peak in November followed restoration of surface inflows in late summer and early fall.

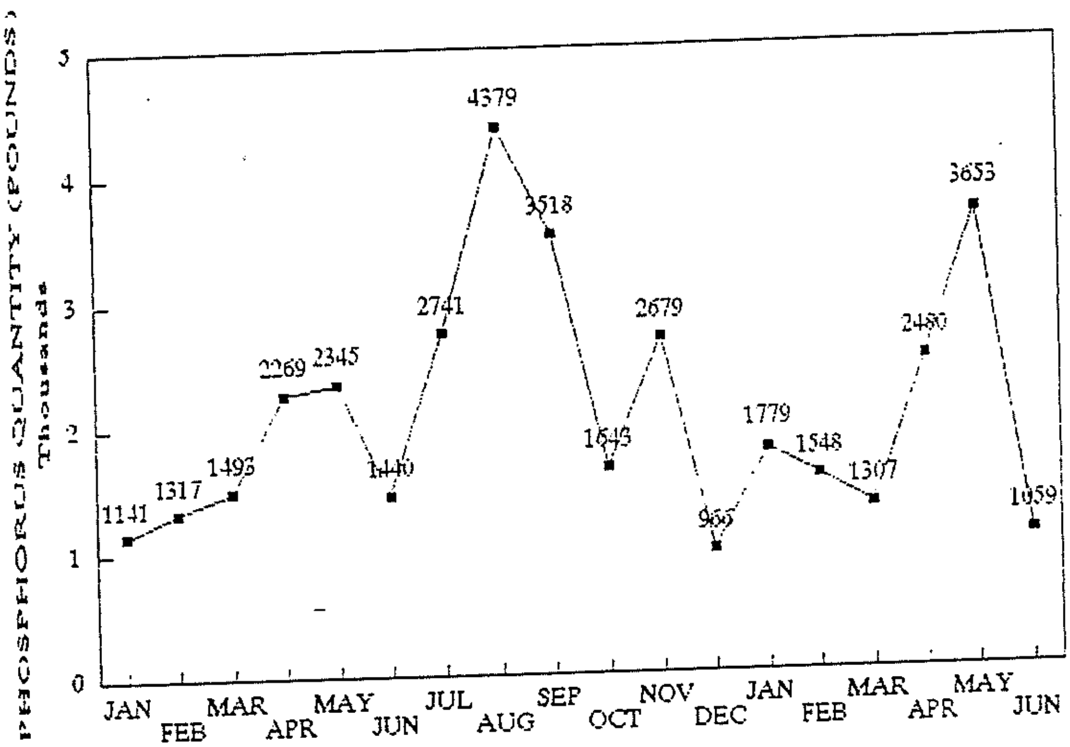

Figure 24. Lake Sallie: Available Phosphorus, 1988 and 1989

<u>Internal Phosphorus Loading</u>. While specific data from this study are not available, it is known that a substantial amount of phosphorus becomes available from sources internal to Lake Sallie (Neel, Hogan). In particular, phosphorus is released from bottom sediments as a result of chemical processes during times of anoxic conditions. In 1968-1969 the potential amounts were variously estimated in the range of .3 o 1.43 grams of total phosphorus per kilogram of sediment (Neel, 1973); Neel later reported that orthophosphorus levels in 1970 and 1971 were 1.75 grams per kilogram. Hogan (1983) reported phosphorus at just under 1.3 grams per kilogram of dry sediment in the upper levels of Lake Sallie's sediments.

In the present study internal phosphorus loadings were estimated from a model developed by Dillon-Rigler (Appendix D). The model permits a comparison between actual outflow concentrations and theoretical concentrations which take into account lake size, depth, detention times, and observed phosphorus loads. In the Lake Sallie case the model produces an estimate of the estimated annual internal loading of 1700 kilograms.

<u>Sources of Lake Sallie's Phosphorus</u>

The origins of Lake Sallie's nutrients, as represented by the limiting nutrient phosphorus, are described in Table 26.

Table 26: Lake Sallie: Sources of Phosphorus Loads

	Annual Loading kg	%
Pelican River (Upstream watersheds)	371	16
Monson and Fox Lakes Subwatersheds	7	<1
Ground Water	116	5
Atmosphere	110	5
Internal Loading	1700	74
Total	2304	100+

To more fully understand the nature of the contributors of nutrients to Lake Sallie, the various contributing subwatersheds will be examined in turn.

The Lake Sallie Basin (Lake Sallie Subwatershed)

The land areas immediately adjacent to Lake Sallie are heavily developed, predominantly with residential development. Overall land use in the Subwatershed is summarized in table 27.

Table 27. Land Usage in Lake Sallie Subwatershed

	hectares	% of Total
Urban, rural residential	25	3.7
Agriculture	108	10.1
Pasture/Grass	116	10.9
Wooded	210	19.7
Water	582	54.5
Wetland	1	1.2
Total	1068	100

Some of the nutrient load and other water quality problems confronting Lake Sallie originate in the riparian zone which surrounds the lake.

Most of the agricultural land in the subwatershed lies westward and southeasterly from the Lake itself. Moreover, much of this land is separated from Sallie by wetlands, including Mud Lake, which act to intercept inflowing nutrients. Land use is mixed, with few hard surfaces near the lake. Given the high infiltration rates of the predominantly sandy soils, surface runoff does not seem to be much of a factor in nutrient loading in the Sallie Basin.

On the other hand, contamination of ground water by infiltrating surface waters, as well as that from septic systems, and other sources, including lawn fertilization by residents and the nearby golf course, may be locally important (Figure 25). There are 218 riparian housing units along the shoreline of Lake Sallie, and almost 100 more in "second tier" or backshore residential developments, particularly in the vicinity of Shoreham.

see next page

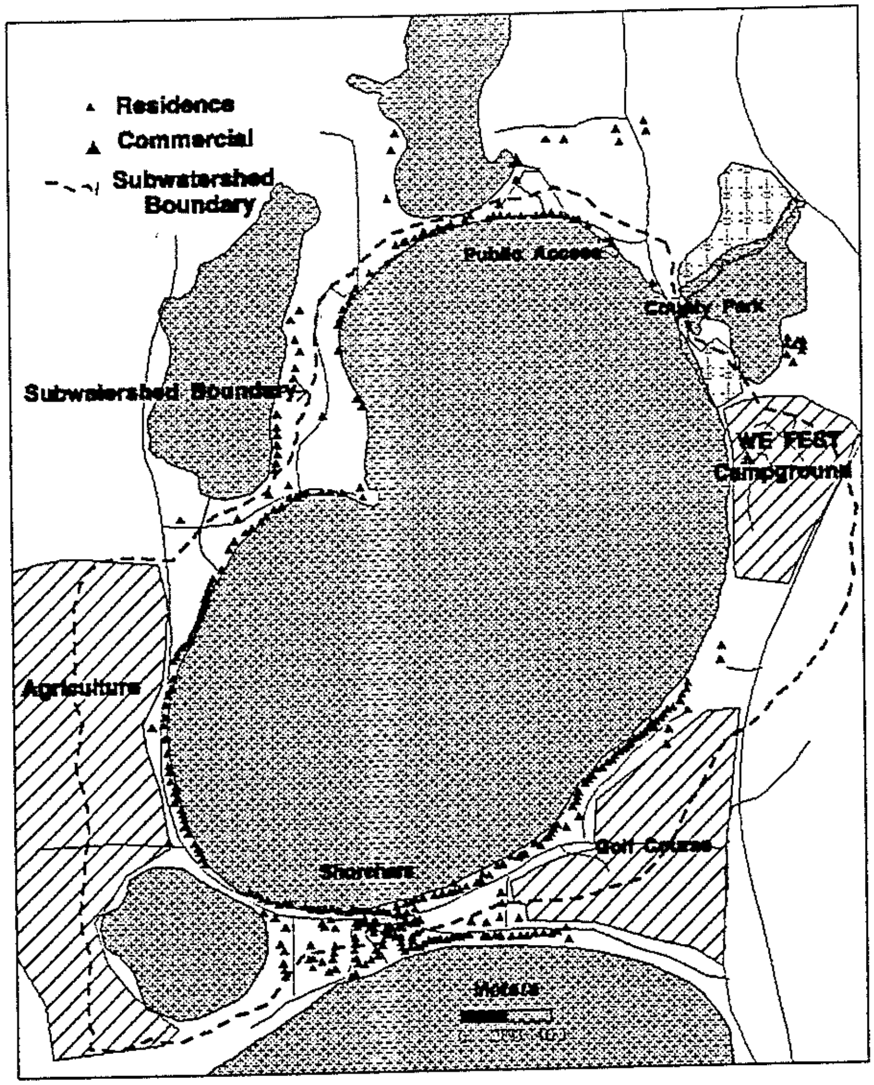

Figure 25. Lake Sallie Basin Development

Though residential development retains its predominantly seasonal character, there is considerable observable evidence that the normative use pattern is no longer confined to the summer months. Indeed, "occasional use" may be a more appropriate descriptor. Certainly housing units are now rarely the stereotypical summer cabins – more and more of these units have been expanded and modernized, and many carry high market valuations (Table 28). Many now are capable of year-round use. Moreover, 30 percent are now owned by "homesteaded" residents, a taxation designation, which if not conclusive evidence of year-round residency, at least indicates presence during a substantial portion of the year. And this proportion is probably growing, as is indicated by the fact that Lake View township is one of the few in Becker County to gain population in the 1980's.

Table 28. Some characteristics of Lake Sallie Residences

Riparian Residences = 151
average shoreline frontage = 31.1 meters
Backshore Residences = 61
Permanent Residence = [illegible].1% (based upon address)
Maximum Vacant Parcels suitable for future
Residential Development = 89
(includes 18 possible sites in the We-Fest Campground, in addition to other undeveloped shoreline)

Some other elements of the basin's development warrant attention. A 36 hole golf course and driving range is located in a hilly area towards the southeast of Lake Sallie, along the subwatershed divide. On the east shore of the lake, about 600 meters of the remaining undeveloped lakeshore recently has modified to accommodate camping associated with the Soo-Pass Ranch, which hosts the annual We-Fest and other summer music events. The project involves the removal of some woodland, and construction of numerous trails and roads in the remaining wooded areas. Unrelated to the We-Fest campground, but adjacent to it, a small subdivision of permanent homes is being developed, and a parcel along the southwest shore has recently been developed. There is some in-filling along developed shores, and some back-shore (second tier development), especially along the west and north sides of the Lake.

If average annual waste disposal is 1 kilogram per person, and there is an average occupancy of 1.5 persons per year for 200 residences, about 300 kilograms of phosphorus is generated annually. If 20 percent reaches the lake, this would result in about 60 kilograms entering Lake Sallie, or about half the estimated ground water loading. More nutrients may be added in connection with the management of the golf course. Other nutrients may reach the Sallie subwatershed as a result of the very large ground water flows thought to move through the areas which receive large amounts of nutrients from the City of Detroit Lakes Waste Water Treatment Plant.

Indeed, because of the sandy soil, and generally low slopes, it seems reasonable to characterize the major inflow nutrient problem in this subwatershed as ground-water related. And while regional groundwater flows are from northeast to southwest, it seems likely that the greatest opportunity for directly reducing nutrients loadings in this subwatershed stems from better management of septic systems, and the control of fertilizers in the riparian and backshore zones around the lake.

As previously reported, the largest part of the available phosphorus in Lake Sallie comes from internal loadings of phosphorus released from bottom sediments during periods of anoxia, particularly in the mid-summer. Variously estimated at amounts up to 1.75 grams per kilogram of bottom sediment, this represents a particularly intractable problem with respect to the restoration of Lake Sallie. It seems reasonable to conclude that the bulk of these amounts arrived during the period of massive exports of nutrients from the Lake St. Clair subwatershed prior to the upgrade of the City of Detroit Lakes Waste Water Treatment facility; nevertheless, there is some reason to believe that accumulations are continuing, albeit at a lower rate, as upstream accumulations are carried out of Lake St. Clair in sediments or in solution. Obviously, it is essential that further accumulations of phosphorus be stopped, and that existing amounts be prevented from becoming available to vegetation.

<u>Fox and Monson Lake subwatersheds</u>

As mentioned previously, flows from these subwatersheds are relatively small, less than 3% of the total surface inflow of water to Lake Sallie in 1988, and probably much less than 1% of the surface inflow of phosphorus.

Taken together they comprise 623 hectares, of which about 18% is in water. In both cases these subwatersheds are about one-third in agriculture, and there is some rural residential development. Residential development has increased substantially in the 1980's as a result of suburbanization of permanent residents from the City of Detroit Lakes especially along the Fox and Monson Lake shorelines.

Both of these subwatersheds contain signifcant amounts of wetlands, and lakes Monson and Fox themselves lie close to Lake Sallie (Fig. 17b). It seems logical that many of the surface nutrients produced in these subwatersheds are intercepted before they reach Lake Sallie.

On the other hand, both Neel and K-V Associates have noted the probable movement of nutrients from these areas to Lake Sallie via ground water flows. The presence of some agriculture, together with dependence on on-site sewage disposal systems, suggests that special care must be given to sound management practices with respect to ground water in these subwatersheds.

Long-Lake, St Clair, Muskrat, City of Detroit Lakes (West) Subwatersheds

There is much evidence to support the conclusion that a large part of the external phosphorus loading to Sallie originates in the St. Clair and its tributary areas. While only about one-quarter of the total surface flow into Lake Sallie was attributable to these areas in 1988, this subwatershed was responsible for a majority of the external phosphorus loading to the Pelican River below this confluence.

Based upon in-stream sampling in 1988, about 213 kilograms (470 pounds), or about 57 percent of the total phosphorus input into the Lake, came from these subwatersheds. Possibly because 1988 was a dry year, this rate of inflow of phosphorus to Lake Sallie was substantially below previous assessments (Table 29), but the proportional contribution to the total phosphorus inflow is not out of line with historical patterns.

Table 29 Historical Phosphorus Loading from St. Clair Outlet

years	St. Clair Outlet (pounds)	St. Clair Phosphorus as % of Total Inflow to Sallie
1968-70	11,071	
1973	12,770	82.4%
1974	9,648	61.0%
1975	9,533	62.6%
1978-79	9,385	43.2%
1979-80	2,543	64.5%
1988	213	57.3%

Source: Neel (1971, 1973, 1978, 1982) 1988 data from Stream samples

Loadings from the first half of 1989 ranged from 1.9 to 2.9 times the phosphorus loading from the first half of 1988. Phosphorus from St. Clair Lake showed the largest increase.

Though these subwatersheds account for only 25% of the total watershed acreage which contributes to Lake Sallie, they contribute a disproportionate amount of the urban land uses in the contributing watersheds (table 30).

Table 30. St. Clair Subwatershed Land Usage and Proportion of total Watershed Land by category

	hectares	% of land use category in all contributing subwatersheds
Urban, Rural Res.	628	37
Agriculture	955	17
Pasture/Grass	918	22
Wooded	729	10
Water	484	14
Wetland	195	19
Total	3909	

More importantly, effluent from the entire City of Detroit Lakes sanitary, and most of the collected and untreated storm water runoff, have been introduced to these subwatersheds since 1926 (Figure 26).

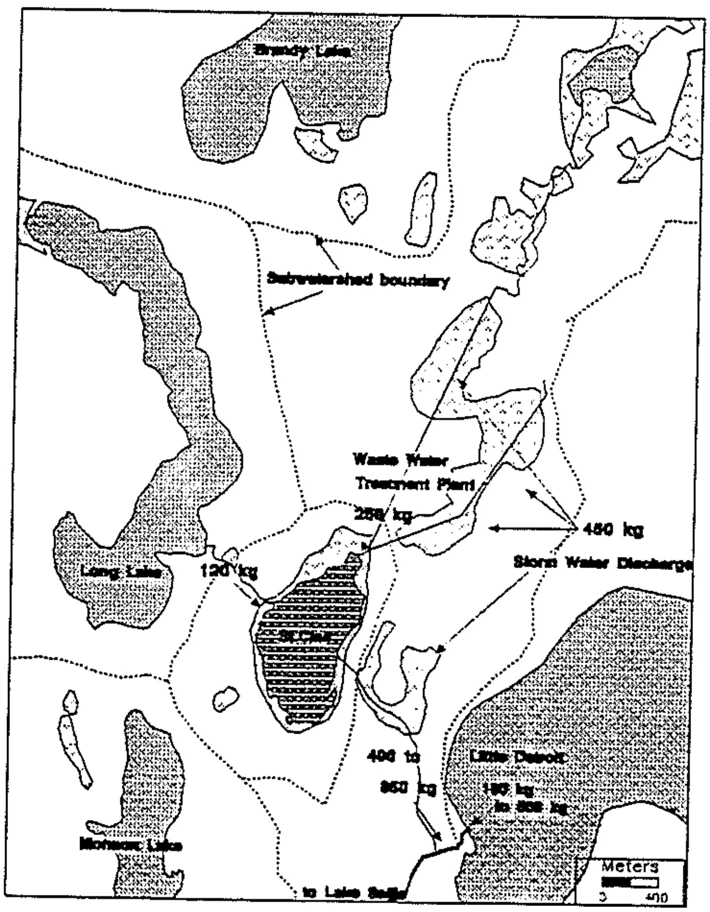

Figure 26 St. Clair, Long Lake, Western City Phosphorus Loadings

Prior to 1976, phosphorus discharges from the City's Waste Water Treatment facility exceeded 4500 kilograms annually. Current waste water treatment practices of the City are well within acceptable EPA and MPCA standards. Nevertheless, based upon reports from the Treatment facility in 1988, the surface discharge was 530,552 m^3 of water, containing 278 kilograms of phosphorus (flow weighted mean concentration of

The quantity of phosphorus contributed to the river by storm water runoff from the City's storm water runoff system is more difficult to determine since some of the flow is buffered by wetland areas. Based upon standard urban runoff coefficients (1 kg/acre), under normal surface flow years, 360 to 400 kilograms of phosphorus would be expected in storm runoff from the portion of the city serviced by storm water collectors which drain to County Ditch #14.

Note that Lake St. Clair, together with the wetlands through which County Ditch #1 passes after it leaves Lake St. Clair, and Muskrat Lake are thought to contain high residual nutrient levels left from the days of the City's high phosphorus discharge practice. Based upon core samples and analysis in 1983, the upper 1.3 meters of sediment in Lake St. Clair contains 19,000 kilograms of phosphorus (Instrumental Research). The 1988 data suggest that some of this phosphorus is released to the Pelican River through County Ditch #14 during heavy rainfall events and during the annual spring snowmelt.

The situation may be similar in Muskrat Lake, a shallow lake in which phosphorus amounting to more than 26,000 kilograms were estimated to exist in the upper 1.3 meters of sediments (Instrumental Research).

There are several additional development matters that relate to these subwatersheds (fig. 27). There is a large turkey production facility in the subwatershed, near County Ditch #14. It is a fully-roofed operation, and apparently operates to a high standard of management of its manure.

Real estate development along the Highway 10 corridor west of Detroit Lakes is significant. A new K-Mart, a lumber yard, and several smaller commercial establishments, along with attendant parking lots and service roads, recently have been added. Likewise, there is rapid commercialization following state trunk highway 59 along the western flank of the City, and southward towards Lakes Sallie and Melissa. In addition to the new We-Fest facilities, there are restaurants, a State Highway Department District Office, a large car dealership, a metal fabricating plant, and several tourist-related businesses.

Finally, Long and Brandy lakes are both lakes which now are relatively free of wate quality problems. Both discharge flows, largely low in nutrients, through the St Clair subwatershed basin. However, these lakes are experiencing rapid urban development, mostly housing oriented to Detroit Lakes. Located well beyond the City limits, these areas are served by on-site sewage treatment facilities, and are vulnerable to degradation of their water quality; they may contribute to future problems in management of water quality emanating from the St. Clair outlet.

Though waste-water treatment is no longer the key issue, further remedial and preventive measures in this subwatershed are necessary as a part of any plan to improve Lake Sallie's water quality.

Detroit Lakes, and the Upper Pelican Subwatersheds

The Detroit Lakes basin receives drainage from about 17,400 hectares from various subwatersheds; its conditions, and its nutrient situation are described in previou sections.

What is important here is that Detroit Lakes is a contributor to Lake Sallie's water quality problems. Professor Neel noted this before (1978, 1981). Based upon in-stream sampling in 1988, about one-third of Sallie's external phosphorus load originates from Little Detroit Lake.

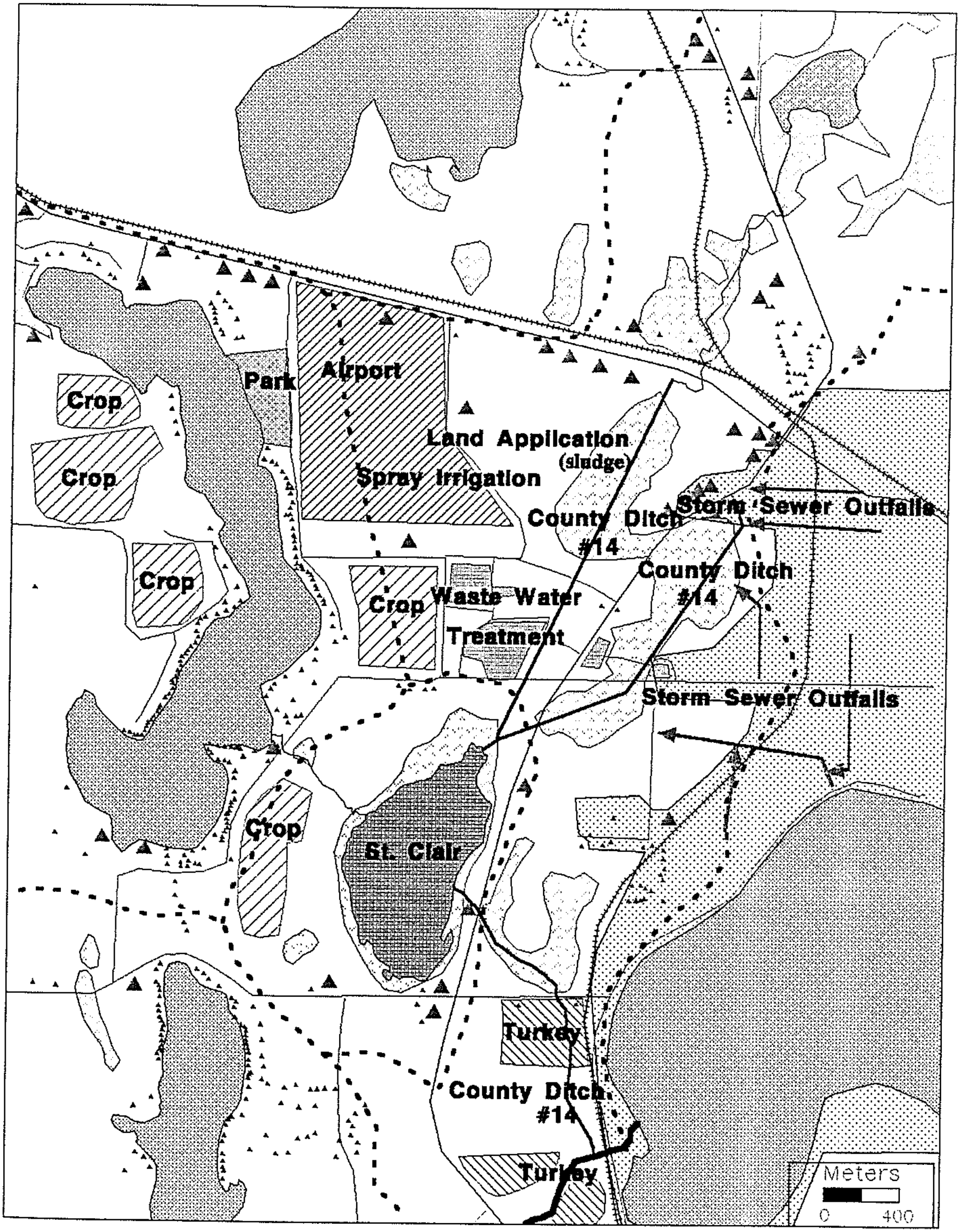

Figure 27. St. Clair, Long Lake, Western City Land Development

SUMMARY

Lake Sallie's condition can be summarized by employing Carlson's Trophic State Index (TSI) using several parameters (see Table 31).

Table 28. Lake Sallie's Trophic Status

	TSI Summer Mean	TSI Annual Mean	TSI Worst Condition	TSI Best Condition
Secchi Disc	53	51	68 (Aug)	32 (Jun)
Chlorophyll-a	58	55	68 (Sept)	31 (Jan-Mar)
Phosphorus	60	56	67 (Aug)	44 (Dec)

It is clear that on average, Sallie is well within the limits for a eutrophic lake. However, it is noteworthy that the variances in the means are high, and that a great range of water quality conditions tend to undermine the value of averages. Lake Sallie is best characterized as a Lake whose water quality is extremely variable, and that under the worst conditions it is quite unsuitable to many desired uses.

The causes of this situation are well known. At least some part of the problem arises in the Sallie basin as a result of septic tanks and other nutrient sources which enter Lake Sallie via groundwater. However, Sallie has received, and continues to receive, excessive amounts of nutrients from upstream subwatersheds, in particular, from Detroit Lakes and its contributing subwatersheds, and the St.Clair, Western City and Long Lake subwatersheds. Previous discussion concerning sources of these nutrients focuses on the City of Detroit Lakes waste water treatment facilities, untreated storm runoff, and various land use practices which tend to provide nutrient loadings. A prominent source of loading also is the nutrients which are stored in sediments in upstream wetlands and lakes, including Muskrat and St. Clair. However, the major ingredient in the Lake Sallie problem seems to be the enormous amounts of nutrients released from storage in bottom sediments during summer periods of anoxia. It is these which produce the worst water quality conditions, and greatly exaggerate the water quality difficulties facing the lake.

WATER QUALITY GOALS

Lakes are temporary features in the landscape. Ordinarily it takes thousands or even tens of thousands of years for the processes of natural eutrophication to accomplish the filling of lakes and their transformation to dry land. Lakes ordinarily proceed through several stages from oligotrophy to hypereutrophy as follows:

Oligotrophy - nutrient poor, biologically unproductive; crystal clear water.

Mesotrophy - intermediate nutrient availability and biological productivity; good game fish populations, moderately clear water; some macrophyte growth.

Eutrophy - nutrient-rich, highly productive; occasional algal blooms, and/or dense macrophyte growth, widespread summer and winter anoxia, frequent fish kills.

Hypereutrophy - pea-soup conditions, constant algal blooms and/or dense macrophyte populations, thick sediments, decreasing depth and shoreline length, long periods of anoxia, few fish survive; at late stages, lake disappears altogether.

As a general rule progression through these stages occurs at an increasing rate. Thus, lakes may remain oligotrophic or mesotrophic for many thousands of years, but the elapsed time between eutrophy and hypereutrophy may only take a few hundreds of years, or less. In Minnesota there is a very strong relationship between oligotrophic or mesotrophic lakes and lakes that are generally perceived to be of good quality by visitors and residents. Such lakes are generally thought to impose no restrictions on in- or on-lake recreational activities, and are generally regarded as aesthetically pleasing. Conversely, lakes in the eutrophic and hypereutrophic stages usually are seen by Minnesotans to be unsuitable as recreational or aesthetic resources.

The Lakes in the Pelican River Chain have been here for about 10,000 years; for most of these years natural processes of eutrophication moved quite slowly. Unfortunately the last 100 years since European settlement arrived have produced in area lakes an advancement of the eutrophication process as a result of causes such as those enumerated in the preceding section (see box). Most of the area lakes now are in the early or middle stages of mesotrophy. In this condition they are vulnerable to the greatly accelerated deterioration that is associated with the beginning of eutrophy.

With respect to water quality, the general goal of Watershed District is to retard the eutrophic processes for purposes of enhancing recreational and aesthetic attributes of all watershed lakes. This general goal subsumes improved water clarity, control of aquatic plants which interfere with swimming, boating and fishing, reduction in algal blooms, especially the blue-green variety which detract from the aesthetic experience, and improvement of game fish populations.

A REVIEW OF CONDITIONS WHICH PRODUCE
LAKES SALLIE AND DETROIT WATER QUALITY PROBLEMS

past and present sanitary waste treatment effluent by Detroit Lakes City

previously enriched wetlands and lake-bottom sediments wherein nutrients are released under conditions of excessive runoff or anoxia.

inadequately treated storm water effluent from the City of Detroit Lakes

miscellaneous storm discharge from other sources near lakes and streams

nutrient-rich, sediment-laden runoff from agricultural and other practices

ground waters charged by nutrients from residential and other activities in shoreland and upstream locations, including septic systems

land application of septage, treated sewage, and livestock wastes

elimination of wetlands serving as natural sediment and nutrient buffers

channelization of drainageways which increases ability to transfer sediments and nutrients to lake basins.

Specific Goal for Detroit Lakes

It seems reasonable to characterize Detroit Lake as a borderline lake, a mesoeutrophic lake that is approaching the condition of eutrophy which, when reached, would be accompanied by further rapid deterioration (Figure 28). During the dry 1988 study period, most data suggest a sub-eutrophic condition. However, during spring snowmelt and again during the lake stratification period of mid-summer, transparency worsened as a result of increased presence of phosphorus and small plant life, and trophic state indices for these events showed mildly eutrophic conditions. Moreover concentrations of aquatic plants, in sufficient quantities to be considered detrimental to recreational use of the lake, are often found in mid- and late-summer.

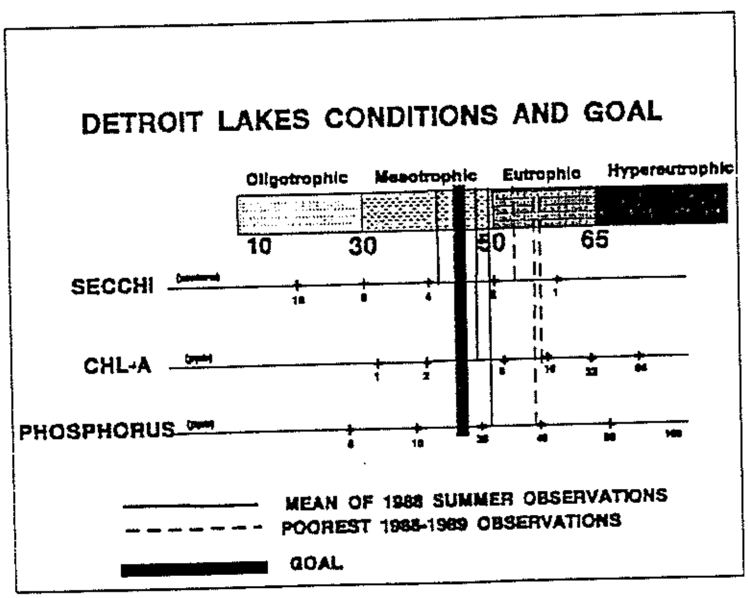

Figure 28. Detroit Lakes Generalized Trophic State Conditions and Goal

With the absence of solid data on past conditions, it is difficult to discern trends in the lake, though most knowledgeable observers believe that conditions have worsened during the last 40 years.

Using transparency as an indicator of lake condition, it can be seen that Detroit Lakes is similar to many other lakes of comparable size in the region (Table 28). Location of Reference lakes is depicted in Figure 29.

Table 28. Trophic State Indexes (transparency); Study Lakes and Reference Lakes

	SUMMER AVERAGES	MINIMUM TRANSPARENCY
SALLIE	54	64
DETROIT LAKES	46	54
Reference Lakes in PRWD		
Floyd	48	54
Melissa (1990)	46	53
Long	38	51
Fox	46	51
AVERAGE =	45	= 53
Other Nearby Reference Lakes		
Boot	38	44
Buffalo	48	53
Island	46	53
Middle Cormorant	43	46
Bad Medicene (1989)	39	43
White Earth (1987)	42	50
Eunice (1990)	43	42
Little Cormorant (1987)	55	59
Maud	42	46
Pelican	42	47
AVERAGE =	44	= 48

Source: MPCA, Reports on Transparency of Minnesota Lakes, 1988, 1990
Lake Sallie and Detroit values from Phase I study (1988)

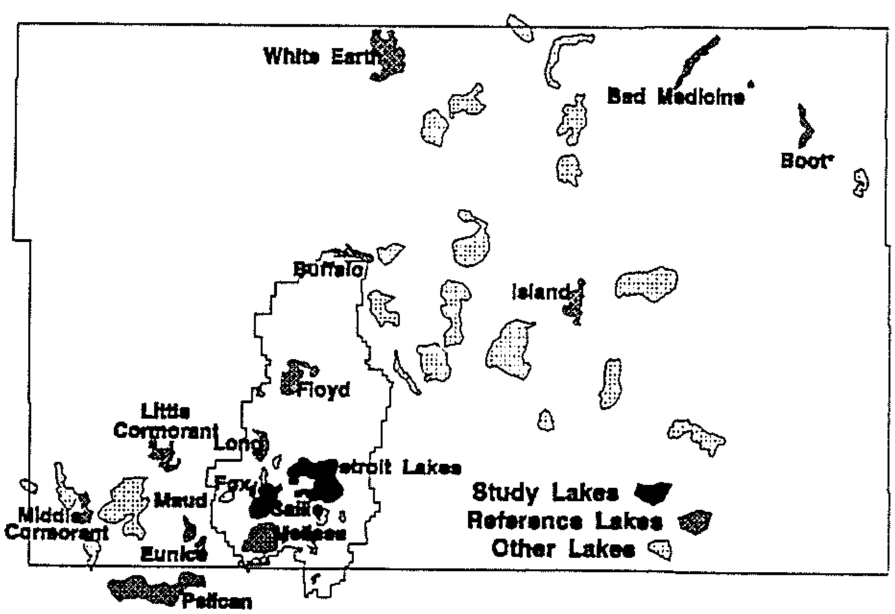

Figure 29. Reference Lakes for Lakes Detroit and Sallie (* denotes lakes in Northern Forest and Lake Ecological Zone)

The Pelican River Watershed District, recognizing that the study data indicates that Detroit Lakes are poised for rapid future declines in their recreational and aesthetic conditions, adopts as a goal that...

> DETROIT LAKES WATER QUALITY SHOULD NOT
>
> BE DEGRADED FURTHER.

As an operational guideline, Phase II programs will be aimed at maintaining average and maximum trophic state indices below the arbitrary mesotrophic–eutrophic boundary of 50.

Some will feel that this goal is not sufficiently ambitious given recent trends in Detroit Lakes water quality. However, simply maintaining the *status quo* or reversing water quality trends in the face of continuing intensification of development in riparian and watershed areas would be a major undertaking. Moreover, it is believed that a lake management program aimed at accomplishing this goal will, in fact, have water quality *improvements* as a practical result. This is so because in order to prevent further water quality declines, it is necessary to adopt certain measures which can do no less than improve the water quality condition of the lake. Such measures fall broadly into these three categories:

1. Adoption of a full range of management practices to ensure that water entering Detroit Lakes is as free from sediments and nutrients as possible.

2. Control periodic releases from upstream sediment and nutrient storage areas

3. Control in-lake macrophyte populations to prevent nuisance condition, giving special attention to control of the exotic, Flowering Rush.

It is our further understanding of the situation, that the accomplishment of the Watershed District's goal may result in a reduction in the extreme conditions which are sometimes associated with both spring runoff events and mid-summer releases of phosphorus from bottom sediments. The latter is expected because it is thought that reduction of external phosphorus loadings over time will result in the depletion of the sediment phosphorus which is the source of internal phosphorus loading.

Water Quality Goal for Lake Sallie

Unlike Detroit Lakes, Sallie seems to have water quality conditions that are substantially inferior to other comparable lakes in the area (Table 28).

While significant progress has been made in improving the quality of Lake Sallie's waters since 1976, the lake still experiences nuisance conditions, including extensive weed growth and algae blooms which detract from the Lake as a recreational and aesthetic resource. This evidence together with that offered by the Trophic State Indices, suggest that Sallie remains in the early stages of Eutrophy (Figure 30). Moreover, these are symptoms that in spite of recent improvements, suggest that the lake may rapidly deteriorate further; the legacy of inaction now could be severe, perhaps irreparable, damage.

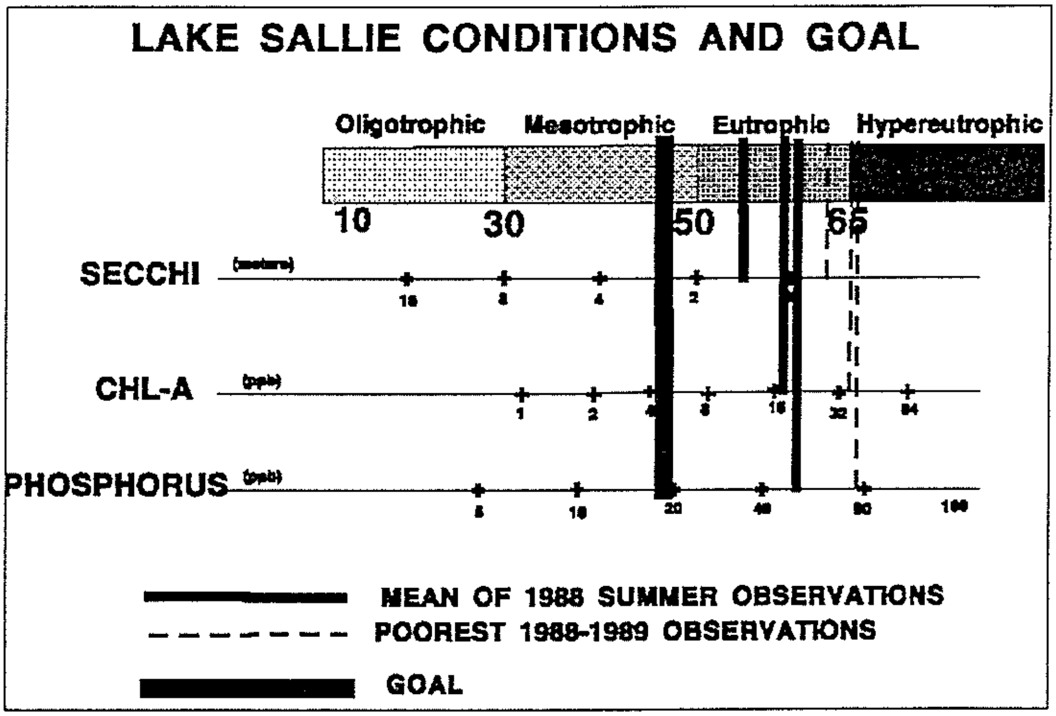

Figure 30. Lake Sallie Generalized Trophic State Conditions and Goal

Lake Sallie's water quality is subject to wide swings, apparently in response to relatively large releases of nutrients during summer periods of hypolimnion anoxia. These recurrent mid-summer episodes of extremely poor conditions, which fall statistically in the *hypereutrophic* range, play a large role in defining Sallie's overall water quality problem. Thus the aesthetic and recreational conditions desired by residents and other lake users are annually compromised by the mid-summer smell, look and feel of large algal blooms and rapid weed growth.

Having fully considered these issues, and given that there are still some things which we do not fully understand about the mechanisms which depress Lake Sallie's water quality, The Pelican River Watershed District hereby establishes the following goal for Lake Sallie:

LAKE SALLIE'S WATER QUALITY SHOULD BE

IMPROVED TO THAT OF OTHER NEARBY LAKES.

As an operational guideline, programs will be aimed at lowering average trophic state indices below the arbitrary mesotrophic-eutrophic boundary of 50, and eliminating mid-summer episodes of high loadings of phosphorus from internal sources.

This goal is purposely broad, and, given the current condition of Lake Sallie, unquestionably ambitious. It is intended to apply to both average conditions and extreme events. Yet under the circumstances of the long-standing root causes of Sallie's problem, and the matter of equity of resource allocations by the Pelican River Watershed District, as well as those of Becker County and the State of Minnesota, the District believes that this goal is appropriate.

And it is thought to be reasonable as well. To lower Sallie's extreme events to the average of other nearby lakes will require an increase in minimum transparency by about one meter and would require a reduction of extreme event Chlorophyll-a or phosphorus level observations of about 50 percent (figure 30).

Here it is noteworthy that a reduction in the severity of Lake Sallie's extreme events to the average of nearby lakes would alone improve the summer average trophic state index to levels that would approach the summer averages for other nearby lakes. Another way of putting this is that Lake Sallie's current underlying nutrient situation is not greatly different from that of other lakes in the general area. Rather it is extremely high release of phosphorus from bottom sediments during episodes of mid-summer anoxia, that are most influential in defining Sallie's water quality.

The strategy for achieving the goal is complicated by the fact that the lake's internal loading problems cannot be solved without first eliminating the in-flow of nutrients (especially phosphorus). This in turn is further complicated by the fact there is a strong suspicion that some nutrients entering Sallie are released from stored sediments in lakes and wetlands upstream from Lake Sallie.

Accordingly the following general steps are required to achieve the goal:

1. Adopt a full range of best management practices to ensure that water entering Sallie from all sources, is as free from sediments and nutrients as we can make it.

2. Control the releases from residual nutrient build-up in several key upstream locations, most notably in the St. Clair subwatershed.

3. Undertake measures that will reduce internal loading from residual nutrients stored in Lake Sallie's bottom sediments.

The order of these steps is purposeful, and reflects in a general way the order in which various corrective actions should be taken.

The Lake Sallie - Detroit Lakes Connection

It is hard, and perhaps unwise, to treat these lakes as separate water quality entities. Obviously, Detroit Lakes contributes nutrients to Lake Sallie. Not so obviously, many of the general conditions which cause problems in Lake Sallie, are conditions facing Detroit Lakes as well. A careful reader also will notice that in offering general strategies to achieve the respective water quality goals, the three approaches suggested for each lake are parallel. Accordingly, as we consider lake restoration measures, the lakes are treated together, along with appropriate notations as to how a particular measure may affect each lake.

WATER QUALITY ENHANCEMENT AND PROTECTION PLANS

In the preceding sections the general water quality problems facing Lake Sallie and Detroit Lakes were described and their causes identified; improvement goals were specified and some general approaches to obtaining the goals were enumerated. In this section the various elements of a plan to enhance and further protect water quality is provided, together with cost and phosphorus reduction estimates, and a timetable.

While the nature and specific causes of water quality problems in the two lakes are different, it has been noted that in fact the two lakes are interacting systems; moreover, many of the conditions that produce their respective problems are common to both. It follows that many of the solutions will be common ones too.

In the preceding section it was suggested that three general approaches will be employed as part of the overall strategy for achieving water quality improvement goals. The first of these deals with general watershed practices and can be considered the "Best management Practice" approach. The second approach addresses the need for control of sediments and nutrients which are stored in upstream settings; their release, often in association with high runoff events, may cause episodes of poor water quality, and may contribute to long-term problems by carrying nutrient-enriched sediments to the bottoms of recreational lakes. The third approach deals with measures that are to applied within the lakes themselves. There follows a full discussion of the three approaches and the specific measures which will be implemented or considered further.

1. "Best Management Practices" and related measures

Lake management experts believe that a large part of lake water quality problems are associated with nutrients which enter the system from "non-point" sources. The present study suggests that over 300 kilograms of phosphorus entered Detroit Lakes from the Pelican River and its tributaries, and another 200 kilograms entered the lakes from ground water in 1988; amounts may be higher during years in which runoff is greater.

While underlying water quality problems in Lake Sallie are not principally the result of current riparian or upstream non-point sources, these sources must be controlled in order to satisfactorily solve Sallie's problems.

The District is confident that much of this nutrient enrichment can be controlled by application of "Best Management Practices" and related activities in watershed areas upstream from Lakes Sallie and Detroit. The District will give its fullest attention to promoting the following measures.

a. Detroit Lakes storm water runoff treatment.

It is believed that a substantial part of the nutrient load which reaches Detroit Lake is introduced in the urban areas which drain to the Pelican River. Similarly, storm drainage to County Ditch #14 which leads to Lake St. Clair and eventually to the Pelican River is believed to contribute to residual nutrients found in Lake St. Clair and nearby wetlands (fig. 31).

Several boat-launching ramps, parking lot drainage systems, and highway rights of way are known to introduce runoff directly to Detroit Lakes. Similarly, storage sites for sand, salt and snow, will be evaluated regarding their potential involvement with waterways. Watershed personnel will work with responsible private and public organizations to alleviate these problems.

As a highest priority, properly designed storm treatment systems (wet sedimentation basins or the equivalent) should be installed to intercept each storm water outfall. No storm water should be directed to the Pelican River or County Ditch #14 without such treatment. There are now at least 13 outfalls requiring enhanced treatment or further study. In several cases, effective treatment can be accomplished by converting existing dry sedimentation basins into wet basins.

A wet detention basin offering sediment and nutrient storm water runoff protection from several apartment parking lots, and a large housing subdivision was built in 1991.

A Phase II wet-type retention basin on Lori Avenue was placed near the Pelican River in 1993 to capture sediment and nutrients draining three hectares of residential area. The City will assume responsibility for management of this facility after landscaping is complete in spring, 1994.

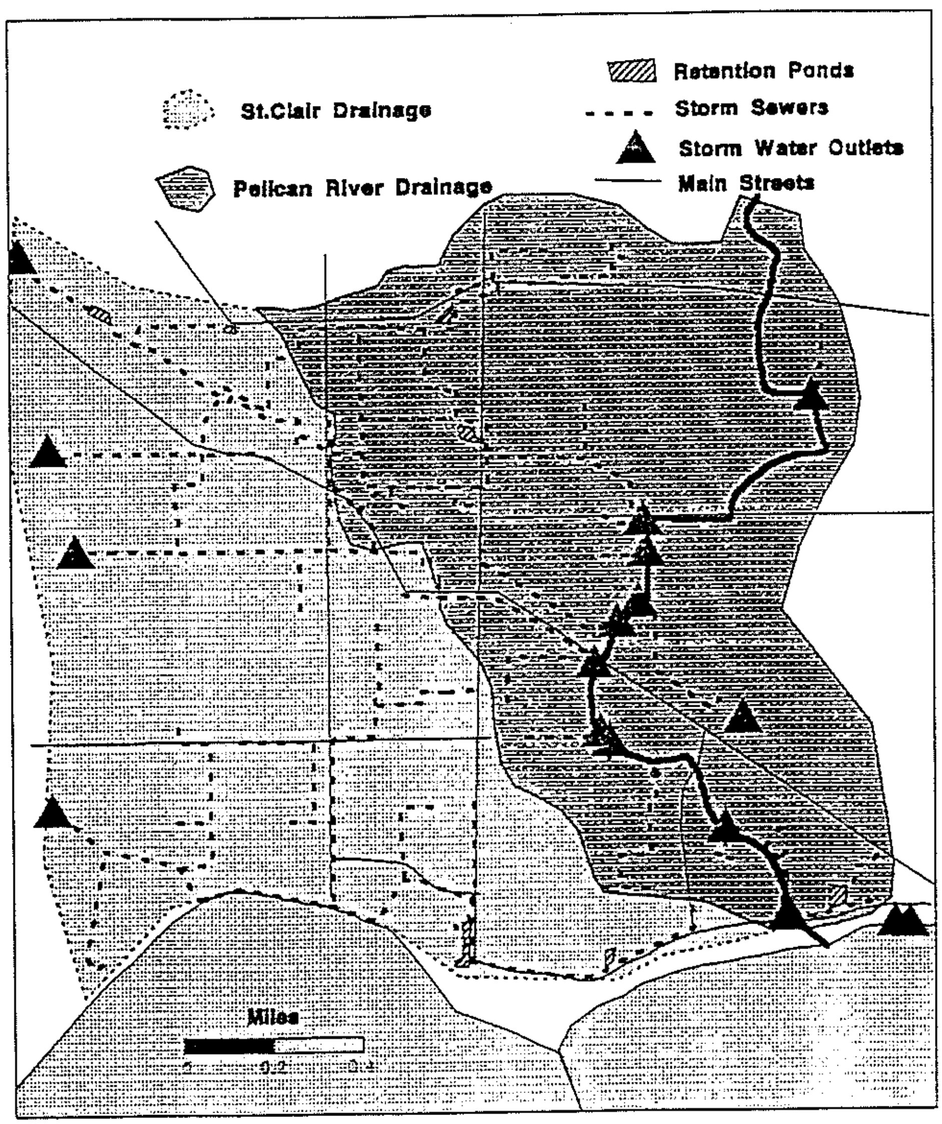

Figure 31. Storm Drainage and Related Structures, City of Detroit Lakes

The highest priority is now to be assigned to converting the existing Softball Park site in the Detroit Lakes Industrial Park to a two-cell wet detention basin for purposes of treating storm water runoff. Originally a wetland through which the Pelican River flowed, the area was filled in 1971 and the river channelized and detoured around the site in order to provide sediment control for storm water from the adjacent Industrial Park, and the northeast part of the City of Detroit Lakes. Over the years the site elevation was increased by the addition of an unknown quantity of fill in order to make it more suitable for softball play, but this reduced its value for sediment and nutrient control.

At present about 240 hectares are drained by storm sewer collectors which empty into this 4 hectare area (Figure 32). It is estimated that less than one meter of fill will have to be removed; the proper weirs and outlet structures will have to be added to provide two-cell treatment facility. The project is estimated to cost approximately $470,000, including site preparation and land value. The City has begun plans to move the site's present recreational facilities to a new location.

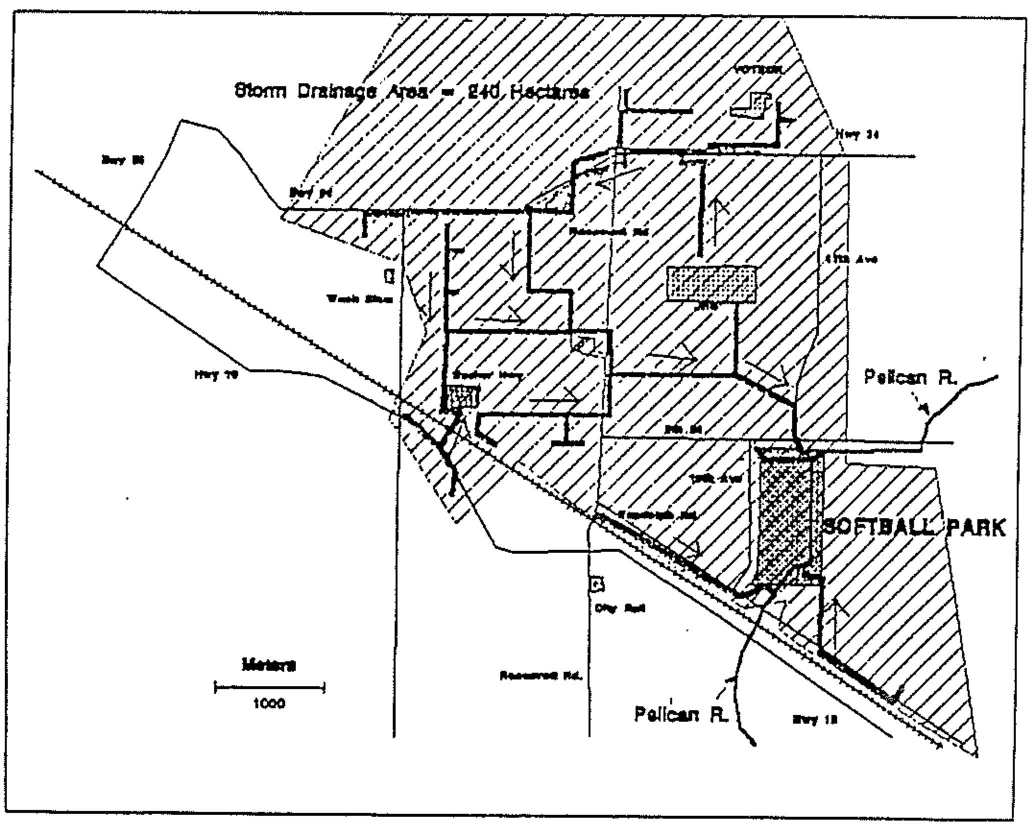

Figure 32. Storm water catchment area, softball site detention basin

There are seven other dry sedimentation or slow-release basins located in the storm collector system of the City of Detroit Lakes. These should be converted to wet-type detention basins in order to obtain maximum removal of nutrients prior to discharge into the Pelican River or its tributaries (Figure 31). Such conversions are known to produce phosphorus reduction from as little as 15% to as much as 95%, depending upon catchment areas, structure design and other factors.

At least three major storm-water collecting systems bring untreated runoff from approximately 425 hectares of urban land to the northeast arm of ditch #14 or into wetlands which drain to the ditch (figure 33). It is believed that, taken together, these carry about 300 kilograms of phosphorus. Another system drains to ditch #14 through a sediment detention pond. Additional data are required to precisely ascertain the loadings to wetlands, to ditch #14, and thence to Lake St. Clair; information is also required to ascertain the conditions under which these nutrients are subsequently released to the Pelican River above Muskrat Lake and Sallie.

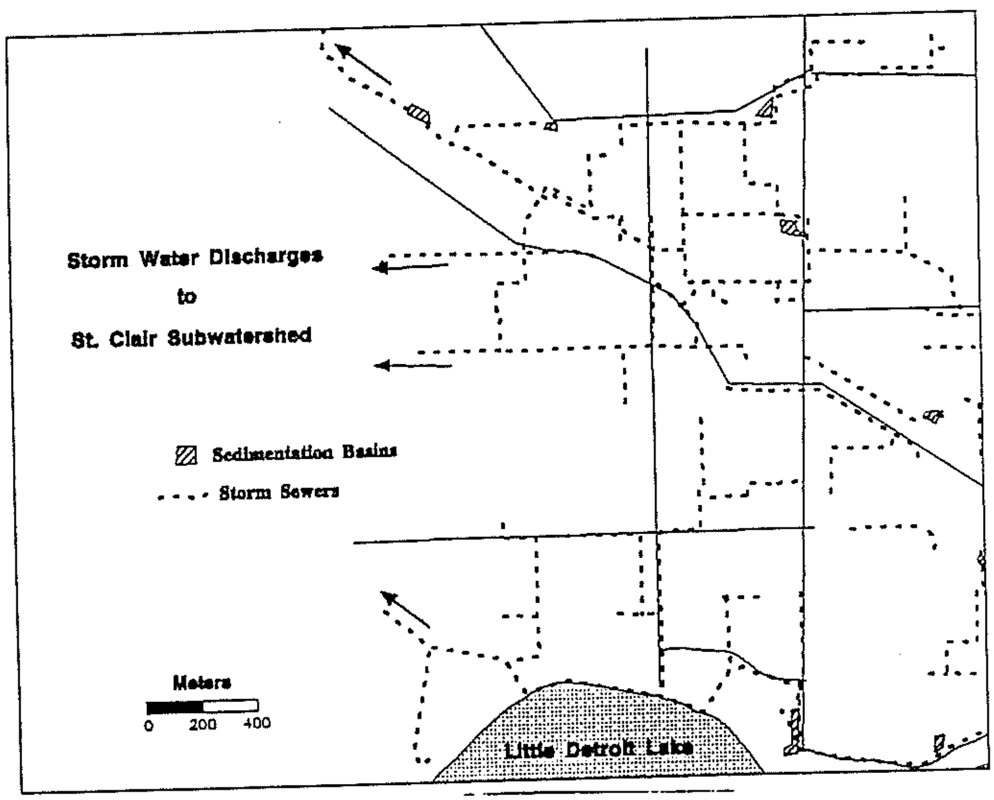

Figure 33. Storm water discharges to St. Clair Subwatershed

One possible method to control storm water impacts is to re-route the two branches of County Ditch #14 to bypass Lake St. Clair; this could be coupled with construction of sedimentation basins or even alum treatment of the stormwater effluent to reduce nutrients (Figure 34). ... would be available to tie up additional phosphorus in downstream wetland and streambed sediments. A primary reason for considering this approach would be to reduce flows through Lake St. Clair in order to control export of phosphorus from that source (this measure is discussed more fully later in Approach #2).

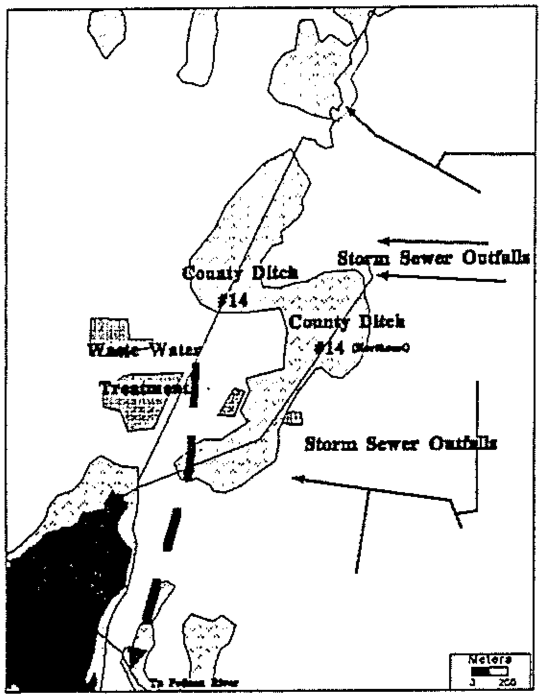

Figure 34. Situation of possible storm water by-pass

In order to more precisely evaluate the nature of the storm-water effluent problem in the St. Clair subwatershed, a Phase II monitoring study, employing automatic sampling equipment, will begin in the spring of 1994.

In considering these measures, it is noteworthy that the Watershed District enjoys the full cooperation and support of the City of Detroit Lakes. Indeed, the City has specified storm water management as a top priority goal in its current 10 year plan.

b. Septic System monitoring and modernization

It is generally accepted that septic upgrades should be emphasized throughout the District, but particularly in those areas adjacent to District lakes and streams. An initiative to review all septic systems is part of the Becker County's Comprehensive Water Plan, and is already underway. Experience in this program already has shown that about 20 percent of riparian septic systems do not comply with existing standards (Minnesota Rule Chapter 7080). The County requires upgrade of deficient systems, and monitors compliance.

The Watershed District requires permits of septic pumpers, and has monitored their collection and land disposal of septage since 1992.

Special attention is paid to collection patterns associated with lakeshore residences and commercial establishments, as well as land application sites that have potential of providing nutrients to ground waters entering area lakes. As of this time, there is no evidence that septage disposal practices contribute to water quality problems in Lakes Sallie or Detroit. Nevertheless, the District will continue to monitor these patterns and practices, and, if necessary, will adopt rules and procedures to ameliorate septage disposal problems.

c. Sanitary sewer conversions.

It is widely believed that central waste-water treatment systems must eventually replace on-site sewage disposal, and that such conversions will reduce nutrient loads in District lakes. The District will continue its encouragement of development of centralized systems, such as the one that is currently being constructed around the south and east shores of Detroit Lakes. Based upon widely-held perceptions of the dramatic reduction of aquatic vegetation associated with previous construction of sewers around north and west shores of Detroit Lakes, it is expected that considerable water quality benefits will be obtained by the present project.

The District will help other high density areas to pursue centralized sewage treatment facilities. At the present time, Floyd Shores Lake Association is examining citizen support levels for a central system around Big and Little Floyd Lakes. The prospects for such systems are enhanced by the closing of a Swift turkey processing plant within the City of Detroit Lakes. While this event has been unfortunate for the economic health of the community, it has made available considerable surplus capacity in the City's waste water treatment facility.

d. Shoreland zone management practices.

The City of Detroit Lakes prohibits the sale and use of fertilizer containing more than 1% phosphorus (by weight). Lake View Township, which includes the non-annexed areas near Detroit Lakes as well as the whole of the Sallie Basin, has a zero phosphorus requirement. It is generally thought

that education is the key to a successful result from these ordinances. The Watershed District has begun a campaign to ensure that all residents and merchants are aware of the provisions of the ordinances. It is believed that reductions in fertilizer phosphorus will reduce phosphorus entering ground water in and near the District's lakes and streams.

The Watershed District has promoted the strict enforcement of shoreland protection regulations adopted in 1992 by Becker County and the City of Detroit Lakes. Vigorous enforcement of provisions of the Wetland Conservation Act (1991) also is encouraged. The District monitors building and other permits, and requires its own permits for certain land development activities within its boundaries. Special attention is given to ensuring that best management practices accompany construction activities in shoreland areas (and upstream subwatershed areas too).

Such measures will not result in water quality enhancement, but they are intended to avoid further deterioration in water quality as a result of inappropriate near-shore and stream-side development activities.

In 1994 the District will attempt to initiate a joint powers agreement or some similar instrument to ensure that proposed development projects are fully considered in the context of best management plans by all interested local parties, including township, county and city.

e. Improve feedlot and other agricultural practices.

Working with Soil and Water Conservation District personnel and the USDA, as well as representatives of the Minnesota Pollution Control Agency (MCPA), and the Minnesota Department of Natural Resources (DNR), the District will work to encourage landowners to continue to upgrade their cropping and livestock practices. Most land owners are aware of the consequences of poor stewardship. Indeed, it is believed that some of the barriers to improving management in the subwatersheds in which active agriculture is present can be traced to institutional problems.

With a view to speeding adoption of "best management practices", a prototype for coordinating multi-jurisdictional land-management responsibilities in Becker County is currently being tested with MPCA as the lead agency. Special attention will be given to livestock operations and cropping areas near tributaries within the district.

Here too, strict enforcement of wetland regulations will be encouraged as it is recognized that active, healthy wetlands can be beneficial in preventing nutrients and sediments from entering streams and lakes.

f. Streambank protection and stabilization.

A full inventory of streambank conditions will be completed for the entire length of the Pelican River and its tributaries; streambank buffer zones will be planned; sites of bank erosion will be identified, and remedial measures will be undertaken. Of special interest here is the Campbell Creek area where gradients are high, and high runoff events have been accompanied by very high sediment and nutrient loads. Any land utilization practices that seem incompatible with the highest standards of stream protection will be targeted for remedial actions.

g. Continue water quality monitoring efforts.

It is essential that systematic observations of lake and stream water quality are maintained. Such a program is necessary in order to evaluate the efficacy of the best management plans measures, and to identify any possible trouble spots that may subsequently develop. A formal program of measuring residents' and lake users' <u>perceptions</u> of water quality will also be implemented.

h. Relocation, redesign of Detroit Lakes Wastewater Treatment Plant.

The City's waste water treatment plant is a modern, efficient operation. Nevertheless, it contributes a significant amount of phosphorous to ditch #14 above Lake St. Clair.

For disposal of effluent the system currently employs on-land treatment during the months from April to November and chemical precipitation of phosphorus prior to discharge from December to March. Continued reduction in surface discharge by utilization of on-land treatment should be encouraged. Any future expansion of the system should emphasize on-land disposal or other methods to reduce the surface discharge of nutrients to the watershed (figure 27).

Also, the chemical precipitation process used during winter months produces a lime sludge which is disposed on land sites north of the wastewater treatment facilities. The proximity of the site to Ditch #14 is problematic from the standpoint of the potential for phosphorus entering St. Clair drainage.

The City is considering renovations to the treatment facilities in the next five years. Primary treatment facilities will be modernized and upgraded. Consideration is being given to reduction of chemical treatment (chemical precipitation), and the identification of alternative land-application sites. It is believed that this would positively impact the phosphorus loadings to Lake Sallie.

The District strongly supports the use of a wastewater treatment system which eliminate point-source discharges to the St. Clair drainage.

i. Education.

The Watershed District accepts the premise that maintenance of water-quality in area lakes requires a citizenry that is well informed. Education in the Watershed District will continue to take two forms: First, efforts will continue to inform citizens about actions that they themselves can take to maintain and enhance water quality. In this connection, the District is heavily involved with the Becker County Coalition of Lake Associations, and other local organizations. A second, and possibly a more important thrust, involves continued effort with the Detroit Lakes School District to incorporate basic learning activities concerning water, lakes, and lake management, into the formal curriculum. Accordingly, the Waterwatch program of Detroit Lakes Junior High School will continue to have a high priority for the Watershed District.

For many of these preceding measures it is not possible to make direct and specific estimates of water quality improvement through reduction of nutrients entering Lakes Detroit and Sallie. Nevertheless, experience obtained in other lakes suggest that reductions of current nutrient loadings in the 25% to 50% range can be expected (EPA, 1991). Moreover, it is believed that such measures can lessen future water quality problems by reducing phosphorus sedimentation on lake bottoms. These measures, together with estimates of their relative impacts in the Lakes Sallie and Detroit cases, and projected costs and estimated completion dates are summarized in Table 29. A priority rating is also assigned.

Table 29. Watershed Management Practices, Costs, Impacts, Timetable

ACTION	COST TO PROGRAM	ESTIMATE OF REDUCED KG OF ANNUAL PHOS REACHING... DETROIT	SALLIE	COMPLETION DATE
a. Stormwater Treatment	$320,000	270	a/	1996
Softball Project (120,000)				
Convert dry to wet (200,000)				
b Septic Tank Upgrade	0	0	40	continuing
b Septage Monitoring	$500/year	0	0	continuing
c Conversion to Sewer	0	400		1994
d Shoreland Mangement				
Implement Fertilizer Ord	$500	10	10	1994
Parking runoff control	$10,000	?	?	1996
Enforce Shoreland Ord	0	?	?	continuing
e Ag, Feedlot BMPS's	0	?	?	1996
f Stream zone Inventory	$4000	?	?	1994
g Monitoring	2000/year	0	0	continuing
h City Sewer Plant	0	?	?	1998
i Education	4000/year	?	?	continuing

a/ stormwater treatment for the Western City subwatershed is considered in connection with Lake St. Clair, under Approach #2.

2. Control stored nutrient releases from upstream areas.

The present study, as well as previous studies, indicated that some upstream lakes and wetlands serve as storage areas from which nutrients, received from various sources in the past and present, are released during periods of oxygen depletion or during spring thaws or other high runoff events. Lake St. Clair in particular, is known to perform this function to the detriment of Lake Sallie. It is believe that much of St Clair's stored nutrients originated from the City's sewage treatment practices before 1976 (though it is believed that St. Clair still receives some nutrients from various sources). Nutrients stored in wetlands associated with ditch #14 both upstream and downstream from Lake St. Clair, as well as Muskrat Lake, are also suspected of sporadically contributing high nutrient loadings to Lake Sallie.

In the case of Detroit Lakes, it has been noticed that significant amounts of nutrients and sediments are being released into the Pelican River from the Rice Lake area during high runoff situations. It is believed that ditches that have been dug through this area exacerbate nutrient release by permitting more rapid flushing of this wetland.

These situations require special attention because they contribute to episodes of high nutrient loadings which contribute to degraded water quality conditions evidenced in Lakes Sallie and Detroit. They may also contribute to the accumulation of nutrient-rich bottom sediments which in turn are related to the problem of internal loadings associated with summer hypolimnetic oxygen depletion which occur in these lakes.

Several measures for addressing these conditions are considered here.

a. By-pass Lake St. Clair

Evidence from this and previous studies points at the two branches of County Ditch # 14 above Lake St. Clair as focal points for phosphorus problems in Lake Sallie. The ditch receives Detroit Lakes Wastewater Treatment effluent, urban runoff from Detroit Lakes, and some agricultural runoff in its upper reaches. Lake St. Clair itself is a phosphorus exporter. Isolating Lake St. Clair would return it to its natural state, and prevent its phosphorus from entering the Pelican River system as it flows into Lake Sallie. It is anticipated that full isolation of Lake St. Clair would reduce surface phosphorus contributions to Lake Sallie by 30 to 40% (200-280 kilograms per year).

In the previous section ("best management practices" and related measures) a partial measure to isolate St. Clair was described in connection with bypassing and treating the City's storm water effluent which now is received by Ditch #14 (Figure 33).

Another possibility is to construct a by-pass to carry Long Lake discharge, which is relatively free of nutrients, directly to County Ditch #14 below St. Clair or directly to the Pelican River (Figure 35). It is important to stress that while both of these measures would reduce nutrients flowing <u>into</u> St. Clair, their importance is tied to reducing flow volumes <u>out</u> of St. Clair, thereby decreasing the movement of residual nutrients downstream to the Pelican River.

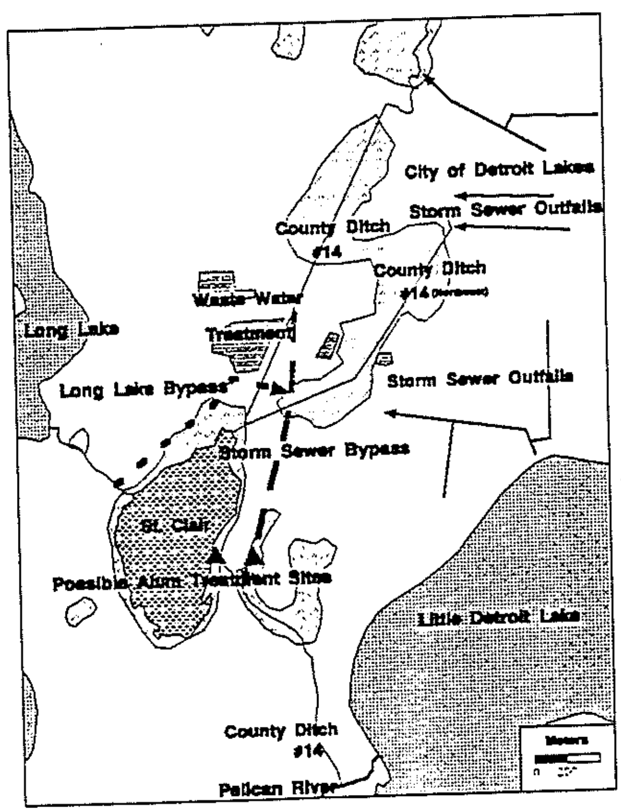

Figure 35. Possible Alterations to St. Clair Drainage

Given the configuration of the St. Clair basin, a small outlet control structure would permit the storage of approximately 0.7 10^6 m^3 (590 acre feet) of water, more than enough to handle the annual effluent discharged by the City's waste water treatment (about 0.5 10^6 m^3), which now could be placed directly into Lake St. Clair.

b. Alum treatment of outlet flows from Lake St.Clair

As a possible alternative to by-passing St. Clair, or possibly in concert with the diversion of City storm water effluent, a mixing and alum injection station would be installed at the outlet from Lake St. Clair (fig. 35). The alum treatment, aimed at tying phosphorus to aluminum salts thereby rendering it unavailable as a plant nutrient, would occur during the warmer months of the year and would vary with outlet flow volumes and phosphorus concentrations.

c. In-lake alum treatment of Muskrat and St. Clair lakes.

Alum treatment has been shown to achieve long-term control of phosphorus release from lake sediments. Phosphorus binds tightly to salts of aluminum under a wide range of conditions, including oxygen depletion. An application of alum tends to produce a layer of sediment which acts as a chemical barrier to further phosphorus release from deeper sediments.

Alum treatments of St. Clair and Muskrat would be intended to neutralize these water bodies as nutrient sources for Lake Sallie. Treatment of St. Clair would be unnecessary if Long Lake and City storm sewer discharges by-passed the Lake.

There is concern about the efficacy of this technique in these two relatively small shallow lakes.

d. Restoration of Rice Lake area

Shallow Rice Lake was drained about 80 years ago in order to enhance grazing and cropland opportunities for adjacent and upstream landowners. Various configurations of the project are being considered, including one that would involve nearly 400 hectares of wetland. In any case, restoring meandered Rice Lake is intended to reduce sediment flows to Detroit Lakes by reducing stream velocities, and to enhance the capacity of the enhanced wetland development to utilize residual nutrients as well as those introduced upstream from, the site (Figure 36). Various configurations are possible, involving up to 500 hectares. Much of the adjacent land is now owned by the City of Detroit Lakes or the DNR.

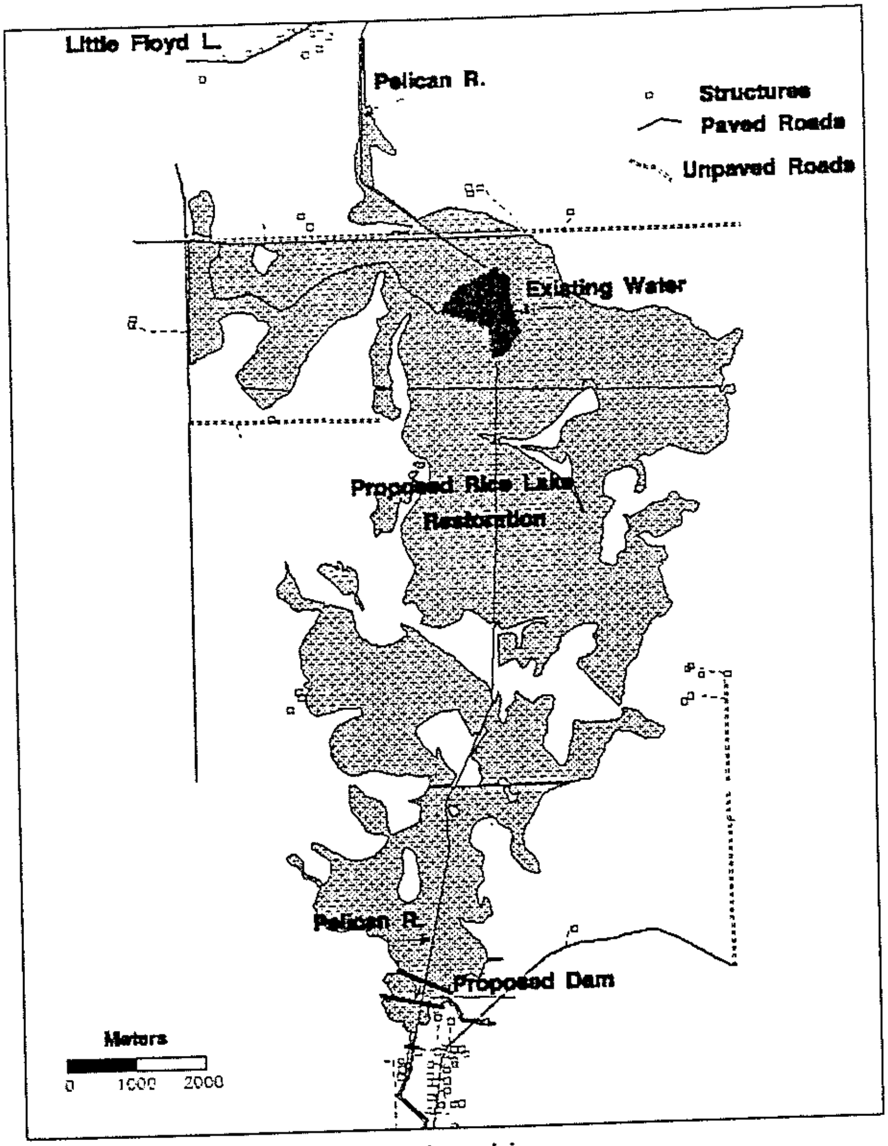

Figure 36. Rice Lake Restoration

Measures that could serve to control nutrient releases from upstream storage areas are summarized in Table 30. While it is believed that these represent the practical alternatives for addressing stored nutrient releases, at this time there is insufficient detailed information concerning the suitability and feasibility of these specific measures. Therefore, a Phase II monitoring program involving the detailed examination of variable conditions which characterize these situations, (and previously discussed in connection with evaluation of storm-water flows into Ditch #14), is underway, and is expected to shed light on a preferable course of action. Also underway in connection with Phase II, is a detailed evaluation of the Rice Lake situation. Large-scale topographic maps have been prepared from new aerial photography, water levels and phosphorus concentrations were measured during the record rainfall episodes of summer, 1993, a hydrologic model to test various design alternatives is being developed, and biological and cadastral surveys are nearing completion. Further evaluation of the Lake St. Clair and Muskrat alum treatment measures, as well as the by-pass approach also will be undertaken as a part of Phase II.

Table 30. Alternate Measures to Control Sediment and Nutrient Releases from Upstream Storage Areas.

ACTION	COST TO PROGRAM	ESTIMATE OF REDUCED KG OF ANNUAL PHOS REACHING... DETROIT	SALLIE	DATE OF COMPLETION
a Bypass Lake St. Clair				
Long-Lake Bypass	$200,000	0	50	1996
Storm Sewer Bypass	$210,000	0	100	1996
Storm Sewer Bypass w/alum	$335,000		200	1996
b St.Clair outflow treatment	$50,000	0	200	1996
	$20,000/year	0		continuing
c In-Lake Alum Treatments				
Lake St. Clair	$140,000	0	200	1995
Muskrat Lake	$140,000	0	?	1995
d Rice Lake Restoration	$500,000	200	0	1997
e Assessment	$20,000		0	1994
Monitoring	2000/year		0	continuing

3. In-lake treatments

The final approach involves several in-lake treatment measures.

a. Weed harvesting

The Watershed District has maintained an aggressive program of aquatic harvesting in Lake Sallie since 1968. The program includes mechanical cutting and harvesting of vegetation, beach cleaning and roadside pickup of vegetation. While the initial aim was to reduce nutrients by removal of vegetation, research (Neel, 1971) indicated that this was not a cost-effective procedure. Nevertheless, while nutrient removal is marginal, the project, funded by special assessments on lakeshore properties, is perceived by residents to have resulted in improved lake conditions for recreational use. For this reason, and because of difficulties encountered with controlling Flowering Rush, a similar project was begun on Detroit Lakes in 1991. These projects will continue as part of an effort to address the internal nutrient and recreational quality problems of both the study lakes.

b. Control of Flowering Rush

In Minnesota this exotic is found exclusively in District Lakes. The District accepts a special responsibility in connection with the prevention of its spread to other lakes in the state and region. The plant has had deleterious impacts on aesthetics and recreational activities in Detroit Lakes; it also is reported to have long-term adverse affects on fish habitat and sedimentation patterns. Since its introduction in the mid-1970's, Flowering Rush has spread through those lakes in spite of vigorous District attempts of control. It appears that it is moving downstream through the Pelican River system. The plant is now established in many places in Lake Sallie and in 1993 was found in Lake Melissa.

The District is working closely with scientists from the DNR in order to assess the extent of the damage, to understand the causes of its spread, and to develop a plan for control of this noxious plant. Preliminary reports suggest that repeated cutting may be an effective control in the submergent form of the plant.

c. In-lake alum treatment of Lake Sallie

As stressed before, there is abundant evidence that the most serious of Lake Sallie's water quality problems are attributable to large internal loadings of phosphorus during summer periods of hypolimnetic oxygen depletion. While a similar pattern of internal releases in noticeable in Detroit Lakes, the severity is less and internal loadings are not considered to be a major factor in shaping water quality there.

While other methods of dealing with this problem, such as sediment removal (dredging) or artificial circulation, are possible, it seems likely that the approach with the greatest chance of success is in-lake alum treatment.

The basic strategy which involves removing in-lake phosphorus and causing a barrier to the release of sediment phosphorus has been previously described. The technique has been widely used to treat lakes of this type, and Sallie appears to be a very good candidate for this technique.

However, the success of this technique is predicated upon the condition that further in-flows of phosphorus to Sallie are insufficient to cause subsequent creation of new phosphorus-enriched sediments on top of the sediment phosphorus barrier. This means that in-lake alum treatment must await demonstrated success in reducing flows of nutrients from upstream areas, and from the basin itself.

d. Resumption of monitoring activities in Lakes Detroit and Sallie

Phase II will incorporate resumption of water quality monitoring for Detroit Lakes and Sallie. This is necessary in order to measure the effectiveness of various lake management and restoration techniques, but also will be required to signal the proper time to undertake the in-lake alum treatment of Lake Sallie.

A review of these in-lake plans, together with cost estimates, phosphorus reduction estimates and a timetable, is provided in Table 31.

Table 31. In Lake Measures

ACTION	COST TO PROGRAM	ESTIMATE OF REDUCED KG OF ANNUAL PHOS REACHING...		DATE OF COMPLETION
		DETROIT	SALLIE	
a Weed Harvesting	0	0	0	continuing
b Control of Flowering Rush	0	0	0	continuing
c Alum Treatment, L. Sallie	$400,000	0	2700	1997-98
d Monitoring	2000/year	0	0	continuing

ADMINISTRATION OF THE PROJECT

The District is cognizant of the fact that various permits and environmental review evaluations are associated with these proposed restoration measures. The successful completion of this program will require numerous proposals, applications, analyses, and evaluations, as well as numerous liaisons with cooperating and supervisory agencies. It is estimated that implementation of the key elements in this plan over the next five years will result in direct administrative costs as indicated in Table 32.

Table 32. Administrative Costs of Phase II Activities

Salary of Project Manager		
1/2 time @ $36,000 x 5 years	=	90,000
Travel	=	5,000
Communications	=	2,000
Reporting	=	10,000
Total Administrative Costs	=	$107,000

PROJECT SUMMARY

Water quality has been defined here in terms of desired lake uses including boating, fishing, swimming and aesthetics. We believe that better watershed management, treatments of known upstream nutrient sources, and in-lake measures for obtaining water quality goals for Lakes Sallie and Detroit can be implemented within five years. Moreover, these measures will result in obtaining District goals for Lakes

The various measures to be considered in reaching project goals are reviewed in Table 33 together with a time plan and cost estimates.

Table 33. Summary of Program's Management Alternatives

ACTION	FIVE YEAR PROGRAM COSTS (1993-1998)	DATE OF COMPLETION
GENERAL WATERSHED MEASURES		
Stormwater treatment	$320,000	1996
Septic Tank Upgrade	$0	continuing
Septage Monitor	$2,500	continuing
Conversion to Sewer	$0	1994
Shoreland Management	$10,500	continuing
Ag, Feedlot BMPS	$0	1996
Stream Inventory	$4,000	1994
Monitoring	$10,000	continuing
Sewer Plant Upgrade	$0	1998
Education	$20,000	continuing
UPSTREAM NUTRIENT TREATMENTS		
Long Lake Bypass	$200,000 a/	1996
Storm Sewer Bypass and Treatment	$335,000 a/	1995
St.Clair Outflow Treatment	$150,000 a/	1996
St. Clair Alum Treatment	$140,000 a/	1995
Muskrat Alum Treatment	$140.000	1995
Rice Lake Restoration	$500,000	1997
Assessment/Monitoring	$30,000	continuing
IN-LAKE TREATMENTS		
Weed Harvesting	$0	continuing
Control of Flowering Rush	$0	continuing
L. Sallie Alum Treatment	$400,000	1997-98
Monitoring	$10,000	continuing
ADMINISTRATION	$107,000	1998

a/ alternative measures

U.S. Department of Interior, Geological Survey (1972), Water Resources Data for the Pelican River Watershed District, July 1968 to September 1971.

U.S. Environmental Protection Agency (1990), The Lake and Reservoir Restoration Guidance Manual. 2nd edition, Washington, EPA Office of Water.

U.S. Environmental Protection Agency (1990) Monitoring Lake and Reservoir Restoration. Washington, EPA Office of Water.

APPENDICES

APPENDIX A - Data Collection Procedures

APPENDIX B - Clean Lakes Project Elements, Budgets and Expenditures

APPENDIX C - Detroit Lakes Data

APPENDIX D - Lake Sallie Data

APPENDIX A

DATA COLLECTION PROCEDURES

APPENDIX A - Data Collection Procedures

A water quality monitoring plan for Lakes Sallie and Big and Little Detroit was developed in March, 1988. Data collection originally was proposed over a 12-month period, beginning in the spring of 1988; however, unusually dry 1988 conditions required that the monitoring plan be extended through July 1, 1989. The plan's features are fully described in "Monitoring Plan - Lakes Sallie and Detroit" (Larson-Peterson & Associates, Inc., 1988). A companion volume, entitled Quality Assurance Plan (Larson-Peterson $ Associates) further describes sampling and testing procedures (Larson-Peterson and Associates, Inc., 1988).

In brief, lake samples were taken in Sallie and Detroit Lakes twice during the open water months and monthly during winter months. Stream sampling of water quality and flows was done in at major surface water inflow and outflow points to Lakes Sallie and Detroit. Samples of Department of Natural Resources Fish Hatchery discharges were also taken.

The atmospheric loading rate of phosphorus was estimated based on surface sampling of snow and dust accumulations on test sites on the ice in January of 1989.

Samples were obtained, collected, preserved and transported in accordance with Standard Methods for the Examination of Water and Wastewater, 15th Edition. Water clarity, pH, dissolved oxygen, and temperature were obtained by trained observers using recommended methods and equipment. Samples requiring chemical analysis were sent to Twin City Testing, Fargo, north Dakota, a lab approved by the Minnesota Pollution Control Agency. Phytoplankton and Zooplankton inventories were conducted by the Biology Lab of Loras College (Iowa) and University of Minnesota, Duluth, Biology Lab, respectively.

Some rating curves to establish stream flows were deveoped by the U.S. Geological Survey in connection with previous studies. Others were determined by District staff using standard procedures.

Full results of the chemical and other analyses are included in "Lakes Sallie and Detroit, Pelican River Watershed, 1988 and 1989 Data Collection Summary (Larson-Peterson & Associates, Inc., 1990). This report has been filed with the Minnesota Pollution Control Agency for input in the Storet Water Analysis Collection System.

Precipitation records were obtained from the KDLM radio station which is the City of Detroit Lakes' official reporting station to the National Weather Service. Hourly reports and standard reporting formats are used as is equipment consistent with U.S. Weather Service standards. Evaporation data was obtained from the North Dakota State University.

Data on transparency of "Reference Lakes" were obtained from reports of the Citizen Lake Monitoring Program administered by the Minnesota Pollution Control Agency.

A model developed by Dillon/Rigler was employed to predict internal phosphorus loadings.

The maps were prepared from data stored in a Geographical Information System (GIS).