DIAGNOSTIC/FEASIBILITY STUDY

MANAGEMENT ALTERNATIVES FOR LAKE SALLIE AND DETROIT LAKE

PELICAN RIVER WATERSHED

June, 1992

By

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I N D E X

I. INTRODUCTION

A. SCOPE AND PURPOSE

This study has been prepared at the direction of the Pelican River Watershed and with the cooperation of the Minnesota Pollution Control Agency (MPCA). The format of the report is consistant with the guidelines of the U.S. Environmental Protection Agency (EPA) Clean Lakes Program (Clean Water Act, Section 314). The Pelican River Watershed and the EPA provided matching funds for this project.

The study began in March, 1988 with sampling of the lakes and surface waters. Prior to the sampling, a Monitoring Plan and Quality Assurance Plan were completed and approved by the MPCA and EPA. Data collection was conducted from March, 1988 to June 1989, a period of 18 months. Sample analysis was completed by Twin City Testing and Engineering Laboratory, Fargo, North Dakota, University of Minnesota Duluth, Life Science Laboratory and the Biology Department of Loras College, Dubuque, Iowa.

Data evaluation was assisted by use of the MinLake modeling program developed by the University of Minnesota, and Lotus 123 computer data formatting.

Restoration alternatives were reviewed and presented to the Pelican River Watershed Board for discussion. Discussions of feasible alternatives were reviewed with the Department of Natural Resources and Soil Conservation Service to obtain local input on the alternatives.

Lake Sallie and Detroit Lake are key elements to the local economy, which is sustained to a significant degree by tourism. The lakes are substantially developed along the shoreline with seasonal and year-round residences which bring visitors to the community, particularly during the summer months. In addition, Detroit Lake is a focal point for the City of Detroit Lakes, which has promoted tourism through development of recreational facilities such as a mile long City beach area. These factors as well as others make it important to take steps necessary to provide protection for the lakes by developing water quality improvement strategies. As a result of these concerns, the Pelican River Watershed Board has authorized this study.

The main objectives of this study are to identify parameters affecting water quality, collect water quality data, review physical characteristics of the watershed, identify sources of pollution and develop recommendations for lake management. Implementation of this plan will assist in improving water quality for recreational opportunities and improved environmental conditions in the area.

B. LOCATION AND DESCRIPTION OF STUDY LAKES

Detroit Lake and Lake Sallie are located in the Pelican River Watershed District, which is in west central Minnesota 50 miles east of the North Dakota border. Lake Sallie and Detroit are part of the Pelican River lake chain in northwestern Minnesota which is a tributary to the Otter Tail River and the Red River of the North. An elevation drop exceeding 20 feet exists from the Pelican River into Detroit Lake. An additional five feet differential exists between Detroit Lake and Lake Sallie. Flow in the watershed is generally from north to south and southwest. The Watershed boundaries are delineated in Figure No. 1.

The climate is characterized by short summers and long, cold winters. The average annual temperature is 39.2°F, and monthly average temperatures of 5°F in January to 70°F in July. Normal annual precipitation is 24 inches with approximately 70% of that precipitation coming between the months of May and September. The average annual lake evaporation for Becker County is 27 inches.

C. PREVIOUS INVESTIGATIONS

Several studies had been conducted regarding water quality and hydrologic factors in the Pelican River Watershed particularly for Lake Sallie. Lake Sallie studies include a groundwater study done by Mann and McBride, 1972, which evaluated the interaction between the lake and the groundwater characteristics, a weed harvest and lake nutrient dynamics study by Neel, Joe K., 1973, and a study by Neel, Joe K., 1981, Upper Pelican River Watershed, Impact of Special Phosphorus Removal Procedures. A study by Instrumental Research, 1984, Watershed-Lake Assessment was completed for Detroit Lake and Lake Sallie in addition to several other lakes in the Pelican River Watershed District.

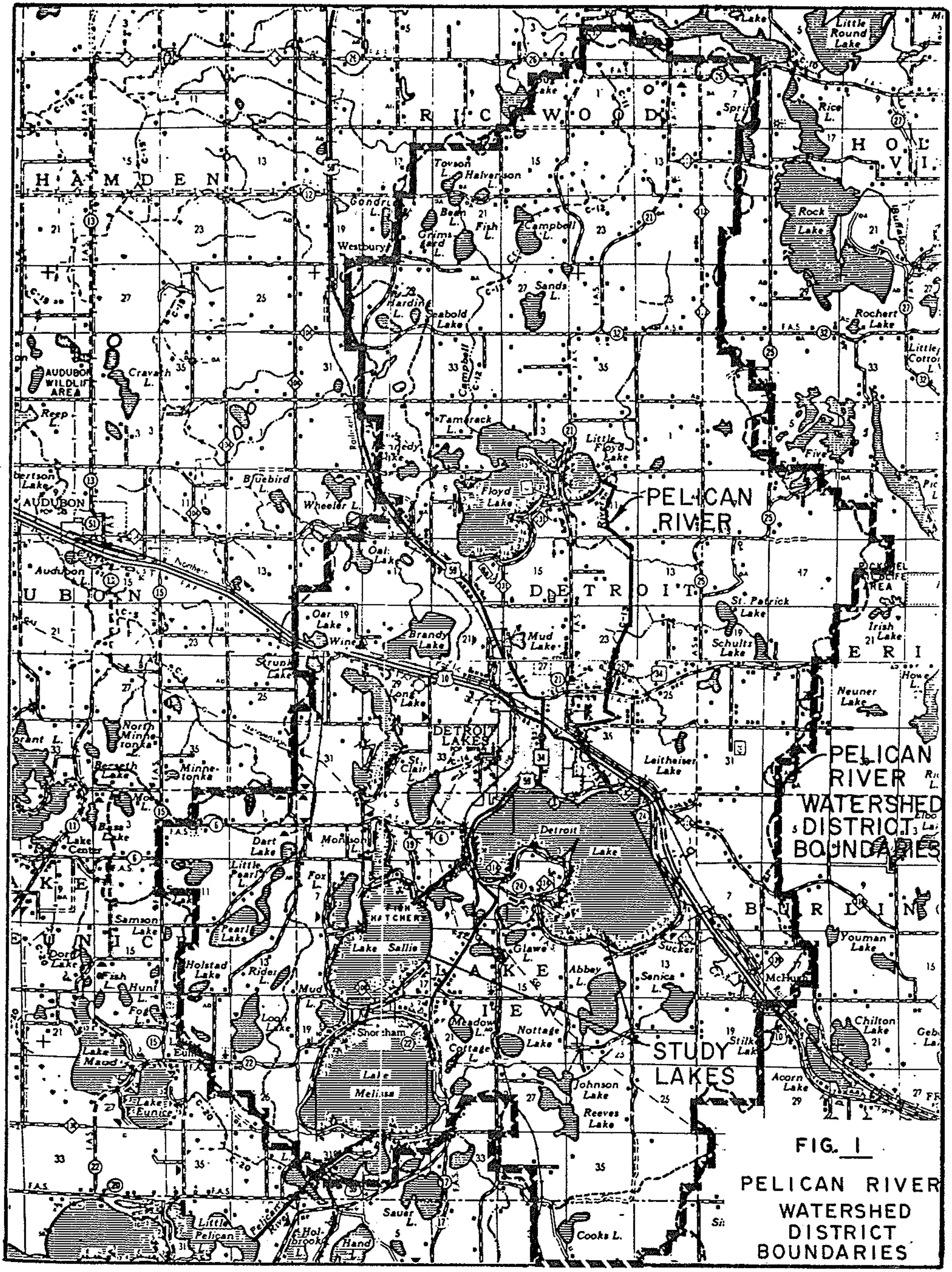


FIG. 1

PELICAN RIVER WATERSHED DISTRICT BOUNDARIES

II. BACKGROUND AND METHODS

A. DESCRIPTION OF STUDY AREA

1. Lake Identification

a. Lake Sallie

Lake Sallie is a 490 hectare (1,211 acre) lake located in Becker County in west central Minnesota. The mid-lake coordinates are T138N, 46°46'18"; R41W, 95°53'43". Primary shoreline land uses for the lake are seasonal and year-round residential development on the north, west, south and southeast sides. A Department of Natural Resources fish hatchery and recreational area is located on much of the east side. A large campground also located on the east side is privately owned and is operated one to two weekends per summer during large music festivals. The lake is kidney shaped with a portion oriented north-south and a portion oriented in a northeast-southwest direction, as shown in Figure No. 2. The mean depth of the lake is 17 feet. The morphological features of the lake are given in Table I.

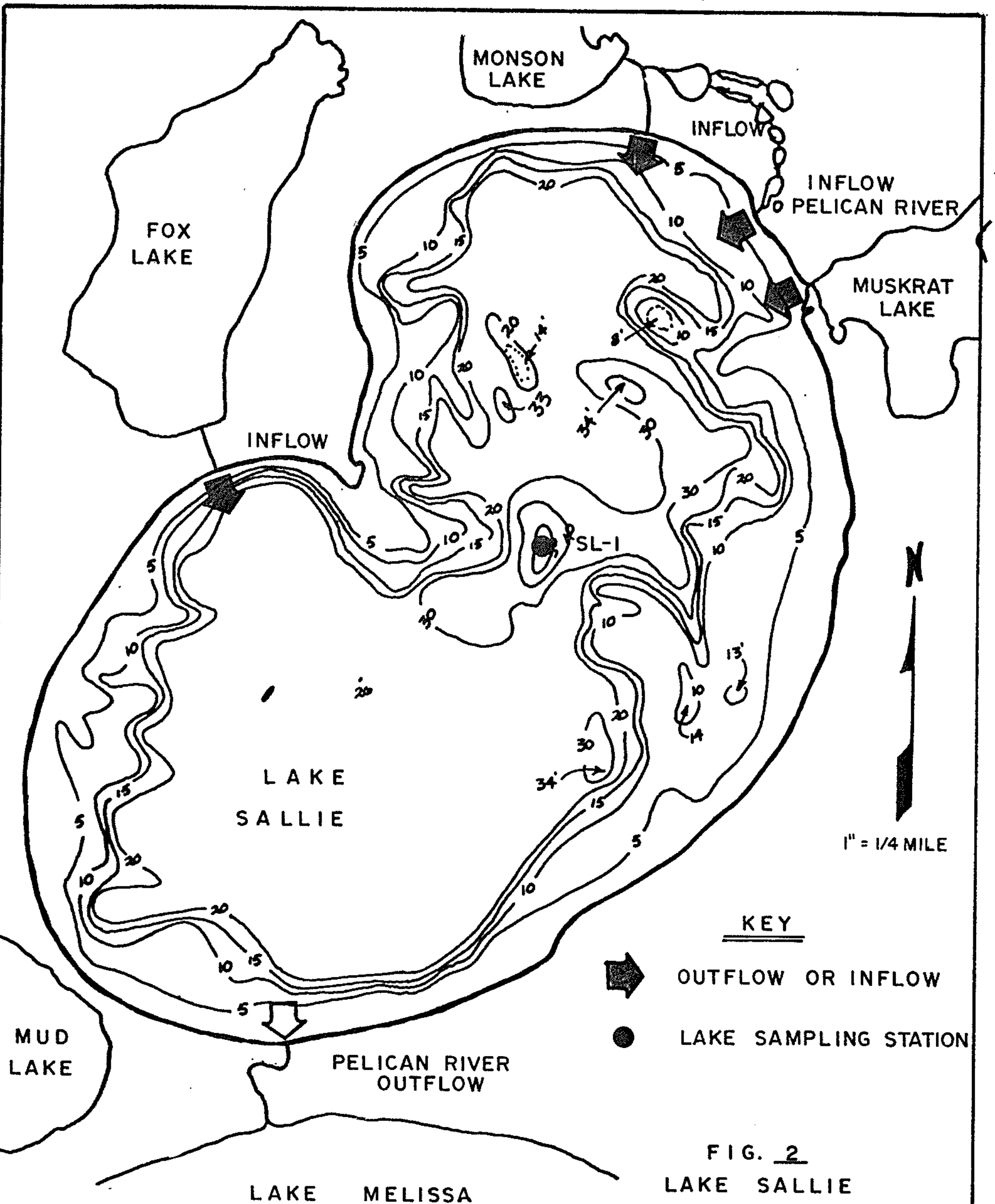


FIG. 2
LAKE SALLIE
CONTOUR & LOCATION MAP
BECKER COUNTY, MINNESOTA

MAP BASED ON D.N.R. DATA
LARSON-PETERSON & ASSOC; INC.

TABLE I MORPHOLOGICAL AND WATERSHED DATA FOR LAKE SALLIE

Surface Area	490 ha	1,211 acres
Maximum Depth.............	16.8 m	55 feet
Mean Depth................	5.2 m	17 feet
Volume....................	$2.55 \times 10^7 m^3$	20,689 acre-feet
Littoral Area[1/]..........	211 ha	520 acres
Shoreline.................	9.4 km	5.9 miles
Maximum Length............	3.3 km	2.1 miles
Maximum Width.............	1.8 km	1.1 miles

[1/]Zone between surface and two meter depths.

The watershed for Lake Sallie includes direct runoff from the lake basin and channelized flows from subwatershed areas. The subwatershed areas as determined from the U.S. Geological Survey mapping are presented in Table II. The location of the areas can be found in Figure 3.

TABLE II LAKE SALLIE SUBWATERSHEDS

Subwatershed No.	Description	Drainage Area (Acres)
6	Lake Sallie (Basin)	2,670
9	Pelican River (St. Clair to Muskrat)	619
Contributing Basins		
7	Fox Lake	765
8	Monson Lake	793
10	St. Clair Lake	663
11	Long Lake	1,974
12	County Ditch No. 14	3,583
13	Brandy Lake	3,213
	Detroit Lake (Pelican River)	43,098
	TOTAL	57,378

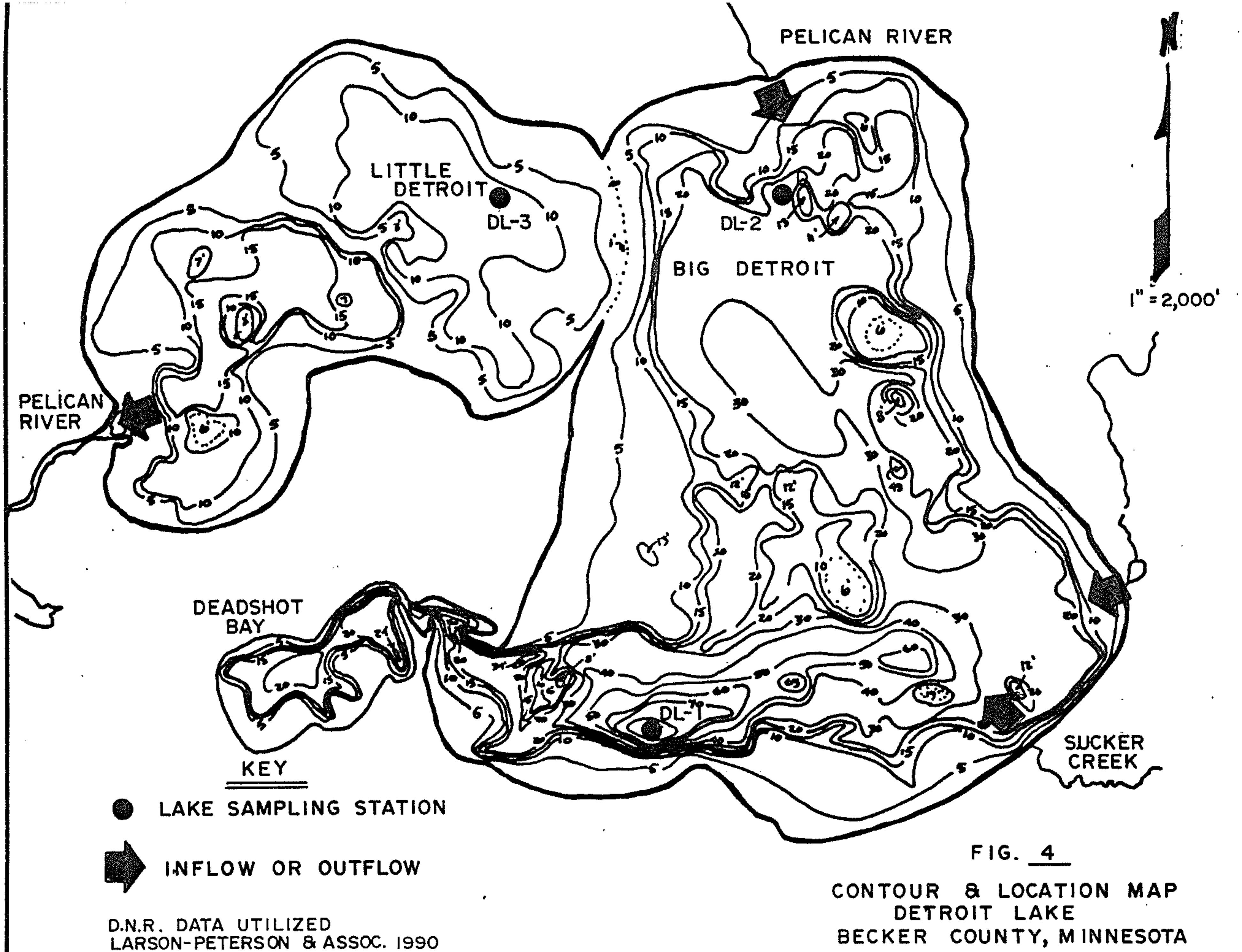


FIG. 4

CONTOUR & LOCATION MAP
DETROIT LAKE
BECKER COUNTY, MINNESOTA

TABLE III MORPHOLOGICAL AND WATERSHED DATA FOR BIG AND LITTLE DETROIT LAKE

	Big Detroit	Little Detroit	Total
Surface Area	875 ha (2,160 ac.)	373 ha (920 ac.)	3,080 ac.
Maximum Depth	25 m (82 ft.)	6.7 m (22 ft.)	82 ft.
Mean Depth	4.9 m (16 ft.)	3.7 m (12 ft.)	14.75 ft.
Volume	$4.26 \times 10^7 m^3$ (34,500 ac-ft.)	$1.36 \times 10^7 m^3$ (11,000 ac-ft.)	45,500 ac-ft.
Littoral Area[1/]	395 ha (975 ac.)	373 ha (920 ac.)	1,895 ac.
Shoreline	12.6 km (7.9 mi.)	7.8 km (4.9 mi.)	12.8 mi.
Maximum Length	3.8 km (2.4 mi.)	2.6 km (1.6 mi.)	N/A

[1/]Zone between surface and two meter depths.

Based upon U.S. Geological Survey information, the drainage to Detroit Lake is presented in Figure No. 5. The predominant drainage area contribution is from the Pelican River, which represents approximately 41% of the total drainage area to Detroit Lake.

TABLE IV DETROIT LAKE SUBWATERSHEDS

Subwatershed No.	Description	Drainage Area (Acres)	
1	Detroit Lake (Basin)	2,728	
2	Sucker Creek	2,577	
3	East Side Drainage	1,718	
4	Pelican River	18,302	
Contributing Basin			
5	Floyd Lakes (Basin)	8,352	
14	Campbell Creek	6,340	
	Total		40,017

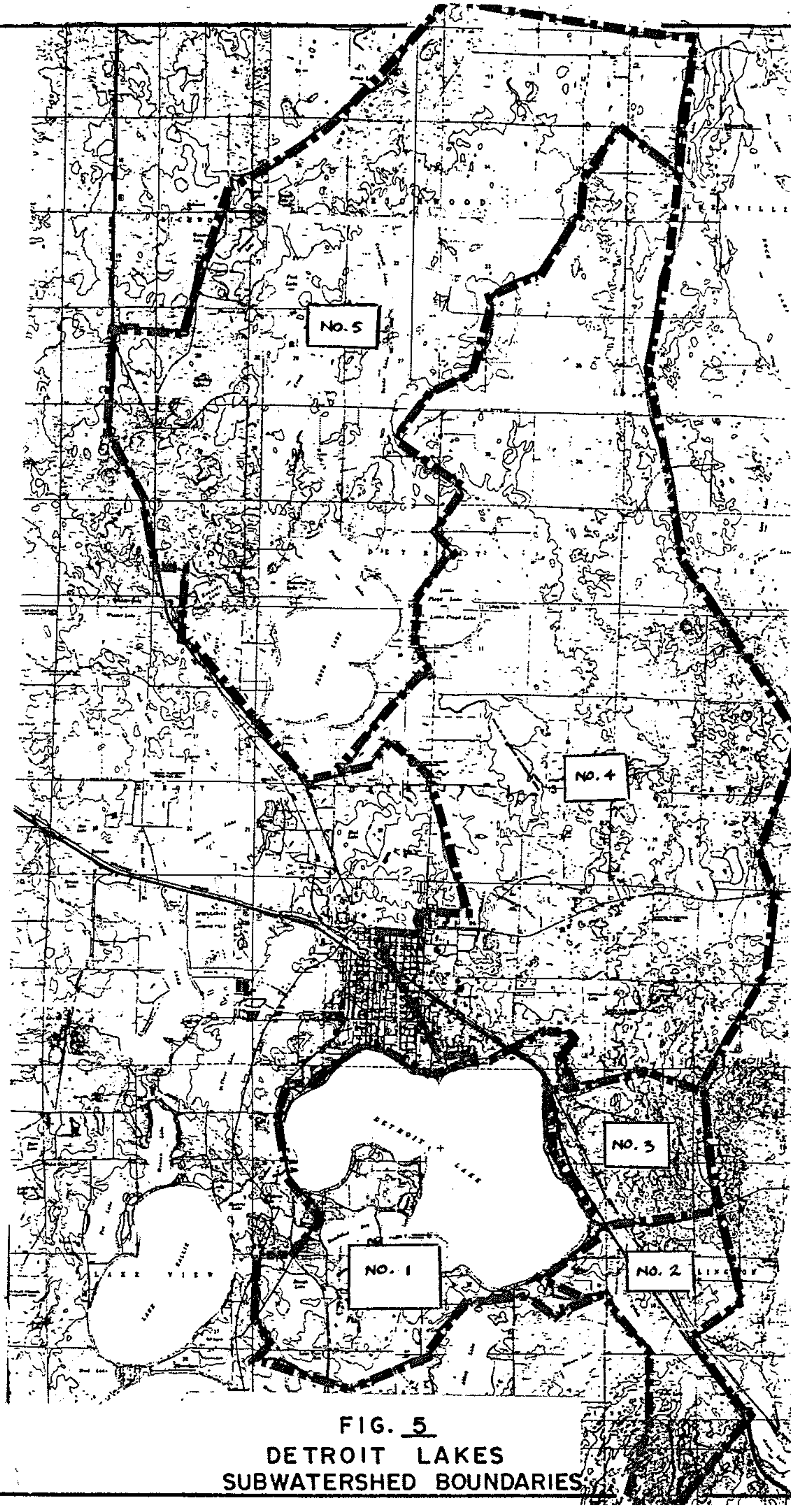


FIG. 5
DETROIT LAKES
SUBWATERSHED BOUNDARIES

2. <u>Geological Description and Watershed Soil Types</u>

The advancement of glaciers from the northwest are primarily responsible for the topography of the Pelican River Watershed, resulting in a thick layer of glacial drift. Watershed soils range from well-drained, medium textured sandy soil developed from calcerous, glacial till on the east to dark colored, coarse to medium textured material formed from outwash near the center, to well drained dark soils produced from calcerous glacial till on the west. (Neel, Joe K., 1973, <u>Weed Harvest and Lake Nutrient Dynamics</u>)

3. <u>Public Access Information</u>

The principle access routes to Lakes Sallie and Detroit are Trunk Highways No. 10 and 59. Public access and boat ramps are available on each lake. Lake Sallie has one access located on the northeast side near the fish hatchery. Detroit Lake has three ramp type accesses. Two are located on Big Detroit on the northeast and southwest sides, and one is located on the north side of Little Detroit Lake.

4. <u>Socio-Economic Data for Nearby Residents</u>

Becker County Population (Estimated 1990)............ 33,386

Median Income - Becker County (1985)................. $15,278

Data for Population Near Lakes:

Detroit Lakes (1990 Estimate)..................	7,500
Detroit Township (1988 Estimate)...............	2,920
Lake View Township Population (1988 Estimate)...	1,929
Total..	12,349

Median Family Size................................	2.51

Statistics show that Becker County ranked second in 1990 among 17 northwest Minnesota counties regarding the economic impact of domestic travel, according to the Minnesota Department of Revenue. Sixty-three million dollars in gross receipts were generated, resulting in 1,250 jobs and $21.5 million dollars in wages.

5. <u>Historical and Current Lake Uses</u>

Tourism is the major industry of the City of Detroit Lakes and has been a significant part of the local economy for many years. Lake Sallie and Detroit Lake are vital components in the tourism industry. Both lakes are highly developed with year-round homes and seasonal cottages. The City of Detroit Lakes has developed a half mile long public beach on Little Detroit. Numerous resorts and tourism related businesses are located along this beach and also along the shoreline of Detroit Lake. A City park including a pavillion, band shell, and playground is located next to the beach and is popular for various recreational activities and events in summer months.

The City of Detroit Lakes impacts the Pelican River and downstream lakes most directly by the discharge of storm sewers and treated wastewater. A brief historical summary of the development of these systems is presented in Table V.

6. Impact of Lake Degradation on User Population

Cottage owners, nearby residents, and visitors have become increasingly concerned over the aesthetic impacts of eutrophication processes in the lake. There are indications that complaints about deteriorating water quality were received as early as 1938 for Lake Sallie. Complaints on Detroit Lake were not received until more recently. Weed growth in the lake has become an increasing nuisance. The harvest of bottom rooted and floating mat types of weeds is required to minimize impacts on swimming, recreational boating, and fishing activities.

Fish kills have been experienced due to oxygen depletion at lower depths.

TABLE V DEVELOPMENT OF SANITARY AND STORM SEWER: CITY OF DETROIT LAKES

Sanitary Sewer

1929	Construction of the first collection system and primary treatment system (Imhoff tank). Discharge was to the east branch of County Ditch No. 14.
1942	Secondary treatment was added, discharge continued to County Ditch No. 14.
1976	Tertiary treatment was added for phosphorus removal from effluent prior to discharge to County Ditch No. 14. Discharge occurs during winter months only with a maximum phosphorus concentration of 1 mg/l. Remainder of effluent is land applied by spray irrigation and rapid infiltration.

TABLE V Continued

Storm Sewer

1935	Records of storm sewer construction date back to this date. Earlier construction may have occurred.
1963	Storm water from the southwest part of town was diverted from discharge to Detroit Lake to discharge to County Ditch No. 14. Much of the northeast part of the City still discharges to the Pelican River.

7. Lake Use Relative to Other Area Lakes

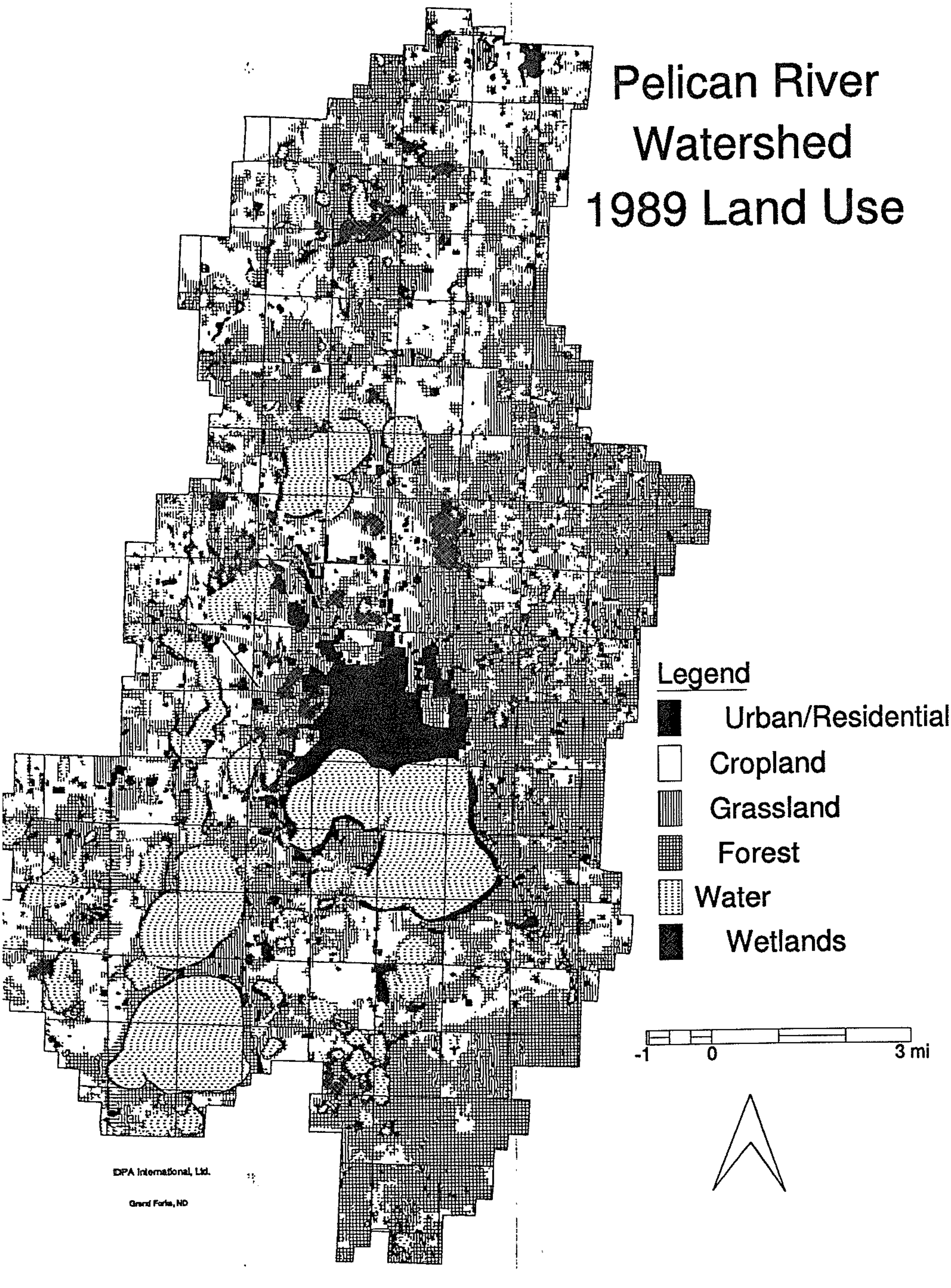
Some of the larger lakes in the study area are Detroit, Sallie, Melissa, Floyd and the Cormorant Lakes. All of these lakes are important recreational lakes and are highly developed with cottages, resorts, and residences. Uses of the lakes are very similar, although Detroit Lake is the most popular due to its developed beach and location near the City of Detroit Lakes.

8. Land Uses in Watershed

The land use in the watershed consists of approximately 41% agriculture (small grains, hay, and pasture), 20% wetlands and water surface, 33% forest, and 6% urban and residential areas. These percentages were derived from a computerized analysis of the watershed by FDPA International LTD from 1989 land cover data.

9. Historical Baseline Limnological Data

Water quality information has been collected on Lakes Sallie and Detroit from previous studies. The average concentrations


Pelican River
Watershed
1989 Land Use
Legend
Urban/Residential
Cropland
Grassland
Forest
Water
Wetlands
-1
0
3 mi
DPA International, Ltd.
Grand Forks, ND

of water quality data are summarized in the following tables:

TABLE VI LAKE SALLIE: HISTORICAL WATER QUALITY DATA

Parameter	n	Summer Average June - September	Annual Average	Range
1969-1970[1/]				
Total Phosphorus (mg/l)	14	0.54	0.40	0.10 - 0.92
Ortho Phosphorus (mg/l)	14	0.118	0.116	0 - 0.25
Alkalinity (mg/l)	14	138	147	124 - 170
Nitrogen-NH_3 (mg/l)	14	0.303	0.297	0.09 - 0.92
1983[2/]				
Total Phosphorus (mg/l)	4	0.046	-	0.02 - 0.107
Ortho Phosphorus (mg/l)	4	0.010	-	0.002 - 0.022
Chlorophyll-a (mg/l)	4	13.49	-	5.16 - 25.90
Secchi-(m)	4	3.35	-	1.45 - 6.33
Alkalinity (mg/l)	4	200	-	195 - 220
Nitrogen, NH_3 (mg/l)	4	0.133	-	0.074 - 0.291

1/Neel, Joe K., 1973, Weed Harvest and Lake Nutrient Dynamics

2/Instrumental Research, Inc., 1983, Watershed-Lake Assessment

Data for Detroit Lake is somewhat more limited than Lake Sallie, although analysis of water quality was derived from available reports. Those results are presented in Table VII.

TABLE VII LAKE DETROIT: HISTORICAL WATER QUALITY DATA 1/

Parameter	n	Summer Average June - September	Annual Average	Range
1968 (October 3)2/ (Sampled at Surface)				
Total Phosphorus	1	N/A	N/A	0.042
Soluble Phosphorus	1	-	-	0.015
Alkalinity	1	-	-	160
Kjeldahl Nitrogen	1	-	-	0.82
1983 Big Detroit3/ (Sample Depth = 6 feet)				
Total Phospnorus	4	0.022	-	0.013 - 0.042
Ortho Phosphorus	4	0.005	-	0.002 - 0.007
Secchi (ft.)	4	8.44	-	4.25 - 15.25
Alkalinity	4	202	-	189 - 211
Nitrogen-TKN	4	0.125	-	0.197 - 0.568
1983 Little Detroit3/ (Sample Depth = 6 feet)				
Total Phosphorus	4	0.029	-	0.013 - 0.046
Ortho Phosphorus	4	0.009	-	0.002 - 0.018
Chlorophyll-a (Mg/M^3)	4	6.43	-	2.83 - 10.66
Secchi (ft.)	4	9.38	-	5.25 - 14.25
Alkalinity	4	192	-	180 - 209
Nitrogen-TKN	4	0.111	-	0.518 - 0.719

1/All values in mg/l unless otherwise noted.
2/Minnesota Department of Conservation - Reedstrom and Carlson, Biological Survey of the Pelican River Watershed - Becker, Clay, and Otter Tail Counties
3/Instrumental Research, Inc., 1983, Watershed Assessment

B. FIELD SAMPLING

1. Lake Sampling

A monitoring plan was developed in March, 1988 to collect water quality information relative to Lake Sallie and Detroit. The plan originally began as a twelve-month collection of data beginning in the spring of 1988. As a result of the unusually dry spring conditions in 1988, the monitoring plan was extended through the spring of 1989 to July 1. The features of the plan can be found in a report by Larson-Peterson & Associates, Inc., 1988, "Monitoring Plan - Lakes Sallie and Detroit".

Lake samples were taken in Lake Sallie and Detroit Lake twice a month during the open water months and monthly during the winter months. The samples were taken by Don Klomstad, executive secretary, and an assistant as necessary to obtain the samples. Equipment obtained by the Pelican River Watershed for these purposes include a temperature and dissolved oxygen meter, Van Doran water sampler and secchi disk.

Water samples were collected, preserved and transported in accordance with the Standard Methods for the Examination of Water and Wastewater, 15th Edition. Samples requiring chemical analysis were sent to Twin City Testing, Fargo, North Dakota. The testing laboratory which was approved by the Minnesota

Pollution Control Agency, provided the chemical analysis results to the watershed district. Results of the chemical analysis are included in a document by Larson-Peterson & Associates, Inc., 1990, "Lakes Sallie and Detroit, Pelican River Watershed, 1988 and 1989 Data Collection Summary".

A description of the testing in accordance with the Quality Assurance Plan is summarized as follows:

TABLE VIII LAKE SAMPLING METHODS

TEST	METHOD	LABORATORY
Total P	Standard Methods	Twin City Testing
Ortho P	Standard Methods	Twin City Testing
TKN	Standard Methods	Twin City Testing
Nitrate, Nitrite	Standard Methods	Twin City Testing
TSS	Standard Methods	Twin City Testing
Coliform	Standard Methods	Twin City Testing
Chlorophyll a	Standard Methods	Twin City Testing
Conductivity	Standard Methods	Twin City Testing
Phytoplankton	Standard Methods	Biology Lab Loras College Dubuque, Iowa
Zooplankton	Microscopic Analysis	U.M.D. Biology Lab Duluth, Minnesota
Dissolved Oxygen (DO)	Field Testing	YSI DO Meter with probe
pH	Standard Methods	pH Meter
Temperature	Field Sampling	YSI Meter
Clarity	Field Sampling	Secchi Disk

2. Stream Sampling

Stream sampling was done in conjunction with the lake sampling during open water periods. The primary location of stream sampling was done at major surface water inflow and outflow points to Lake Sallie and Detroit Lake. The samples taken were analyzed for total suspended solids and phosphorus concentrations. The sample locations were as follows:

TABLE IX STREAM SAMPLE LOCATIONS

NO.	LOCATION
S1	Sallie Outlet: Pelican River
S2	Fox Lake
S3	Monson Lake
S4	Sallie Inlet: Pelican River
D1	Detroit Lake Outlet: Pelican River
D2	Detroit Lake Inlet: Pelican River
D3	East Shore Drive
D4	Sucker Creek
C1	St. Clair Outlet
C2	East St. Clair Inlet
L1	Long Lake Outlet
P1	Pelican River: Highway No. 34
F1	Floyd Lake Outlet
F2	Campbell Creek

The locations are identified on the stream sampling station map.

Flow monitoring was also done at the stream sampling locations to determine flow volumes during the study period. Staff gauges were placed in the stream channels and recorded by volunteers daily or weekly depending upon the location of the staff gauge. Rating curves were developed by measurement of stream velocity and area measurements. The U.S. Geological Survey established rating curves for several of the stream locations for previous studies. Stream flow volumes are determined based upon staff gauge readings. A degree of error must be considered as a result of this type of flow measurement,

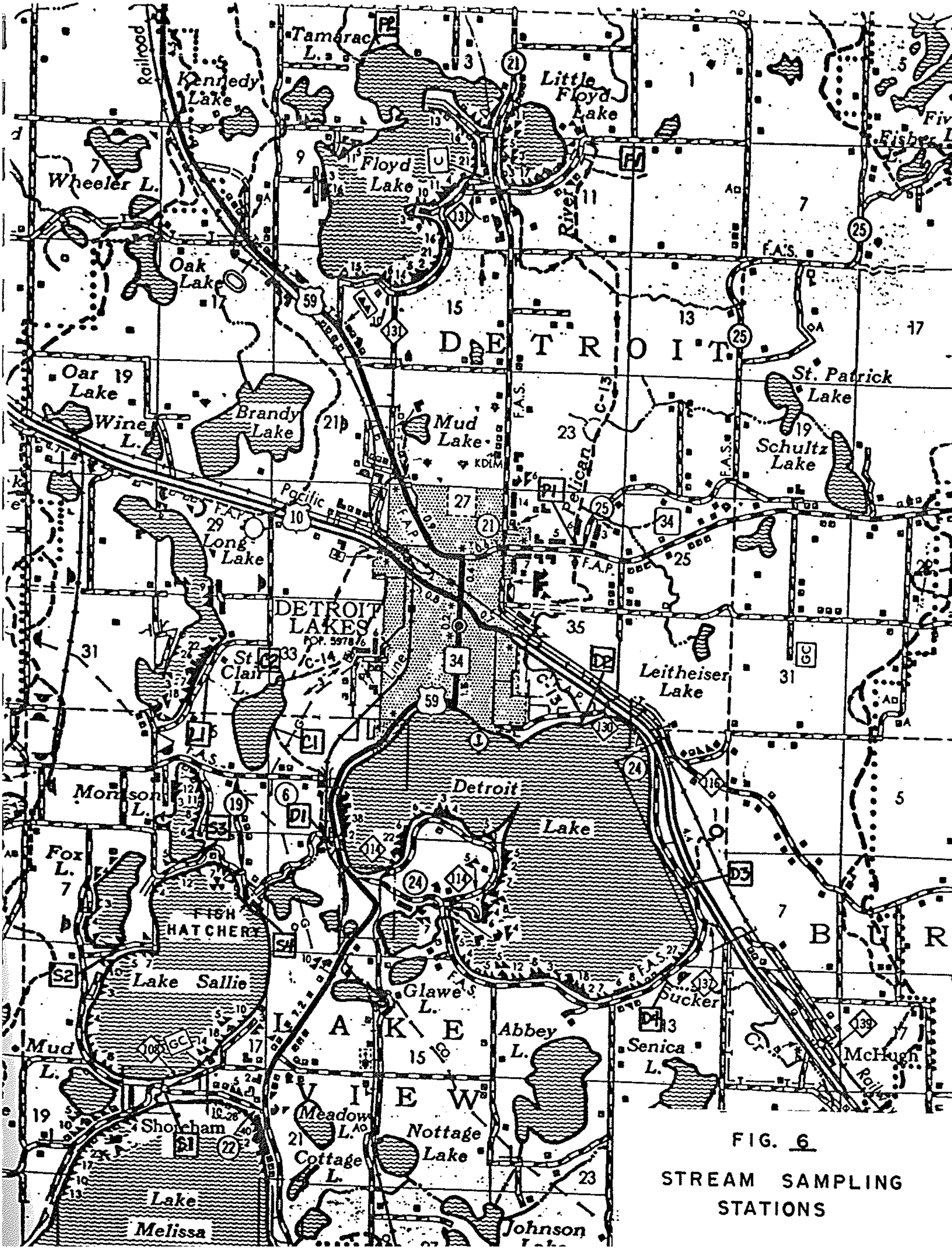


FIG. 6

STREAM SAMPLING STATIONS

especially at locations subject to rapid increases due to precipitation. Therefore, the flow volumes recorded will be less than actual volumes.

C. CLIMATE FACTORS

Precipitation records were received from the Detroit Lakes radio station which include daily records of precipitation and temperature as required for a monthly report to the National Weather Bureau. Monthly precipitation amounts were computed from this information. Evaporation data was received from North Dakota State University for computation of total annual evaporation.

III. DATA SUMMARY

A. GENERAL

The data has been compiled in the 1988 and 1989 Data Collection Summary. The information has been filed with the Minnesota Pollution Control Agency for input in the Storet Water Analysis Collection System. The data results are summarized in the following discussion.

B. LAKE SALLIE

The inlake sampling station for Lake Sallie was located at the deepest area of the lakes, which is in the approximate center of the lake. The depth of the sampling was approximately 50 feet.

1. Secchi Disk

Measurements of water transparency were completed with a 20 cm weighted white secchi disk. The measurements were recorded during twice monthly open water periods. The readings ranged from a maximum transparency value of 7.1 meters in June, 1989 to a minimum value of 0.77 meters in August and September, 1988.

2. Temperatures

Lake temperatures were measured twice monthly during the sampling periods. Lake temperatures warmed rapidly from the

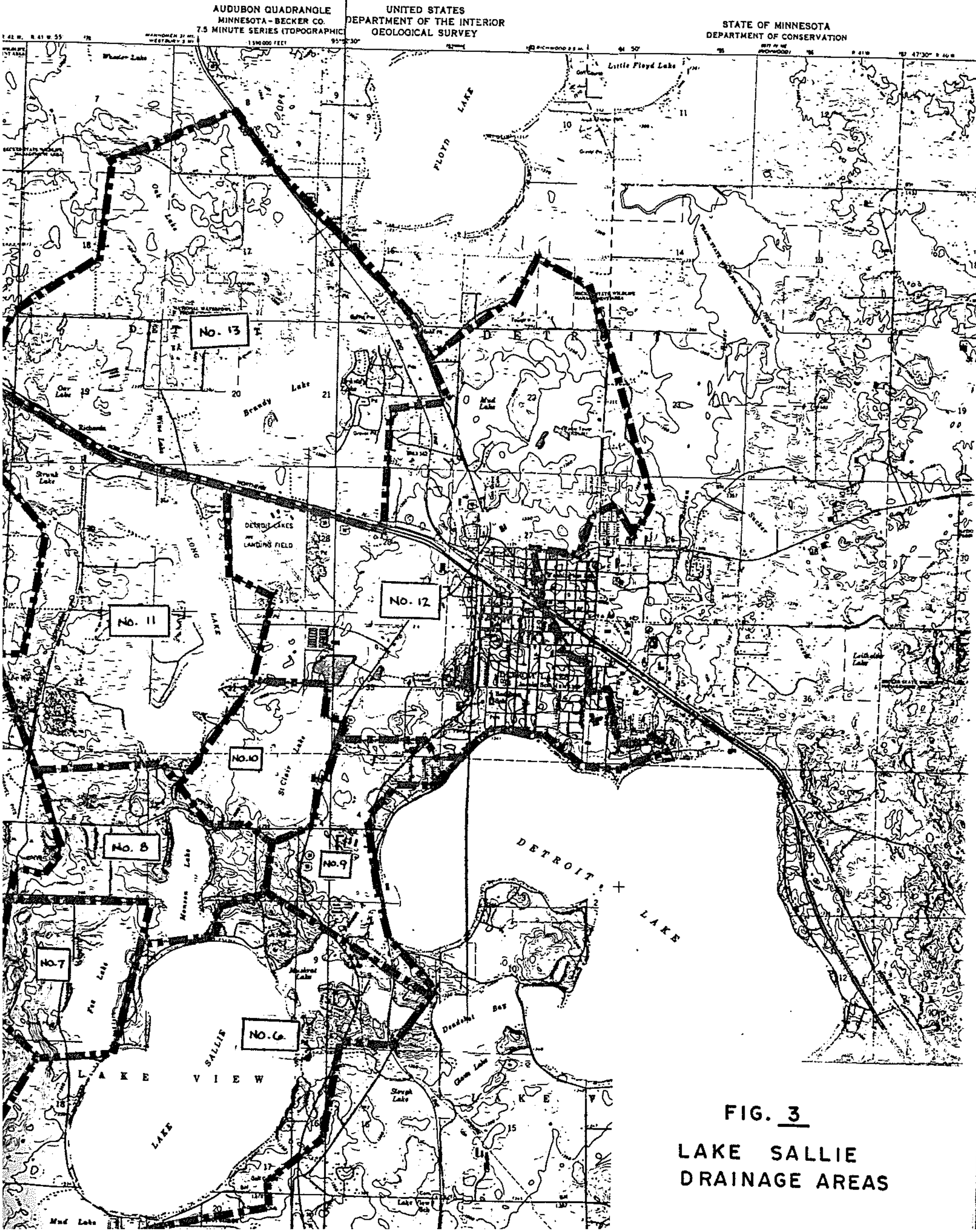


FIG. 3

LAKE SALLIE
DRAINAGE AREAS

Inlets to Lake Sallie include the Pelican River, Monson Lake and Fox Lake, the major inlet being the Pelican River. Lake Sallie has an outlet to Lake Melissa via the Pelican River on the southern end.

b. Detroit Lake (Big Detroit and Little Detroit)

Detroit Lake is located northwest of Lake Sallie in the south central region of the Pelican River Watershed. Primary shoreline uses for the lake are seasonal and year-round residential development, except for approximately one mile of shoreline on the northwest side of Little Detroit. This one mile section consists of one-half mile of public beach on the east end and one-half mile of street right-of-way.

The lake consists of two basins of water that are nearly separated by a sand bar. The larger body is referred to locally as Big Detroit Lake and lies to the east of Little Detroit Lake. The western basin, Little Detroit Lake is shallow, 15 feet deep or less, whereas Big Detroit has a maximum depth of 82 feet. Channel dredging was required through the sand bar to allow passage of larger boats. The layout of Detroit Lake can also be seen on Figure 4.

The morphological features of Big Detroit Lake and Little Detroit Lake can be found in Table III.

winter time lows of 0° to 25° Celsius by mid-summer. Temperatures have been graphically represented versus lake depth for each sampling period from March, 1988 through June, 1989.

3. Dissolved Oxygen

Dissolved oxygen measurements were taken at meter intervals in the deepest location of the lake from March, 1988 through June, 1989. Graphic representations of dissolved oxygen document levels at the surface ranging from 0 mg/l to 11.4 mg/l and 0 mg/l to 9.3 mg/l at the bottom.

4. Phosphorus

Phosphorus concentrations were sampled at least monthly at the surface, intermediate depths and near the bottom of the lake. Phosphorus concentrations in the epilimnion range from 0.02 mg/l in the winter and spring to maximum levels of almost 0.8 mg/l during late summer months. Phosphorus levels in the lower regions of the lake varied from lows of approximately 0.01 mg/l to extreme levels of up to 0.16 mg/l during hypolimnion oxygen depletion periods, as shown in the phosphorus isopleth.

5. Chlorophyll-a

The peak chlorophyll-a concentration was 37.5 mg/l., which occurred on September 15, 1988. The range was from 2.2 mg/l to 37.5 mg/l, with an annual average of 14.1 mg/l. The summer average was 21.6 mg/l.

6. Phytoplankton

Sampling of phytoplankton during the open water months of 1988 identified 39 different species. Concentrations of phytoplankton groups vary from spring to fall, with the blue-green algae dominant during the summer months. Spring concentrations are substantially diatoms, green, and other (non blue-green) which vary in dominance but generally decline in June. Green algae peaks in late May and early June and gives way almost entirely to blue-green throughout the summer, recovering somewhat in the fall. Beginning in June, blue-green algae, particularly Anabaena and Aphanizomenon appear. The blue-greens increase dramatically in concentration in July and August, with Microcystis, Oscillatoria and Coelosphaerium becoming the dominant species. The total concentration of phytoplankton peaks in August, with total concentrations of 37.8×10^6 cells per liter. Phytoplankton growth drops off dramatically in September when the temperature declines. The phytoplankton variation during the sampling period is presented in Figure 11. This figure shows the relative dominance of each type throughout the sampling period. Figure 12 presents the phytoplankton variation in Lake Sallie in 1988 in terms of actual phytoplankton counts by comparing the numbers of blue-green algaes to non blue-green algaes.

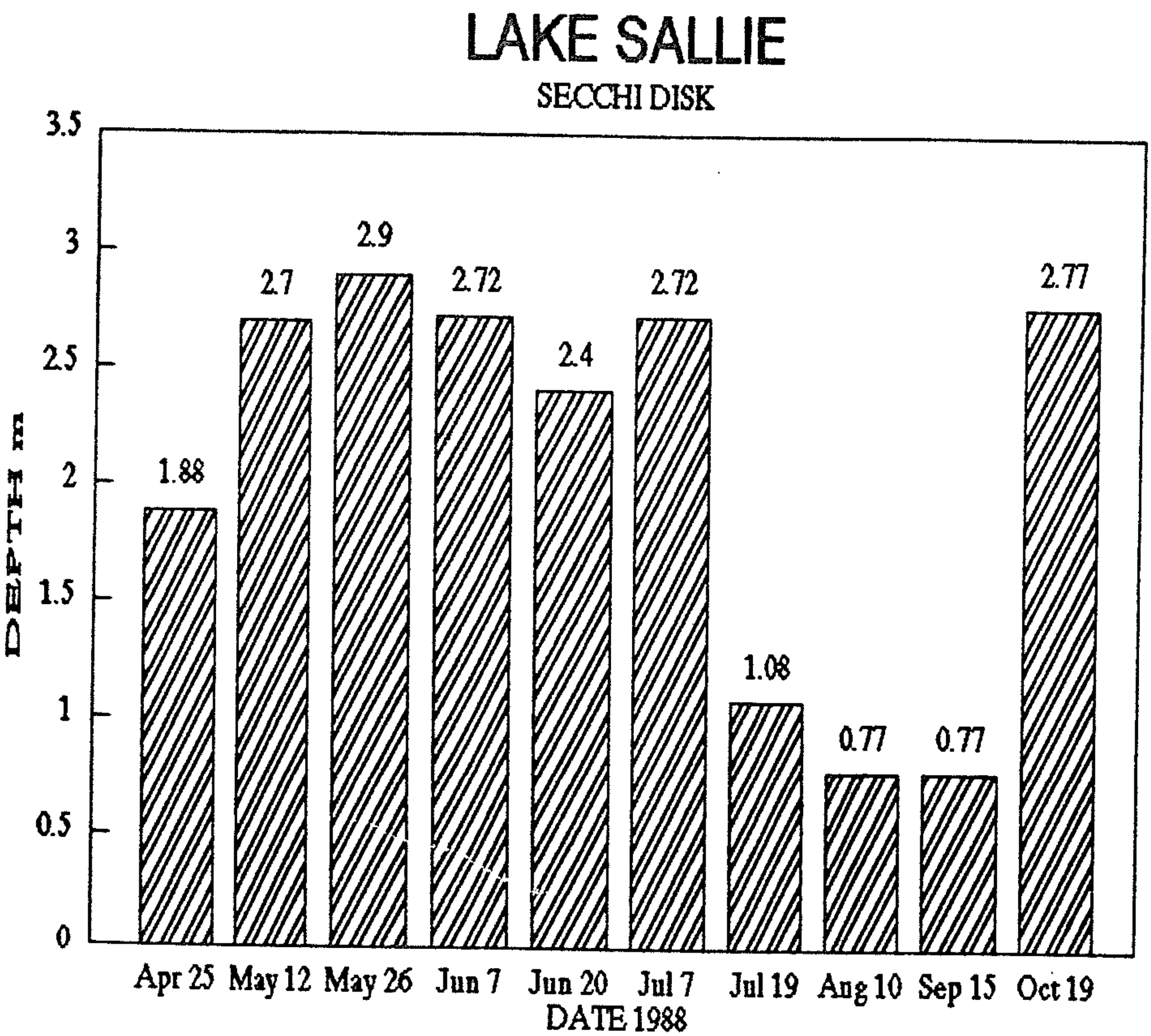


FIG. 7
LAKE SALLIE
1988 SECCHI DISK

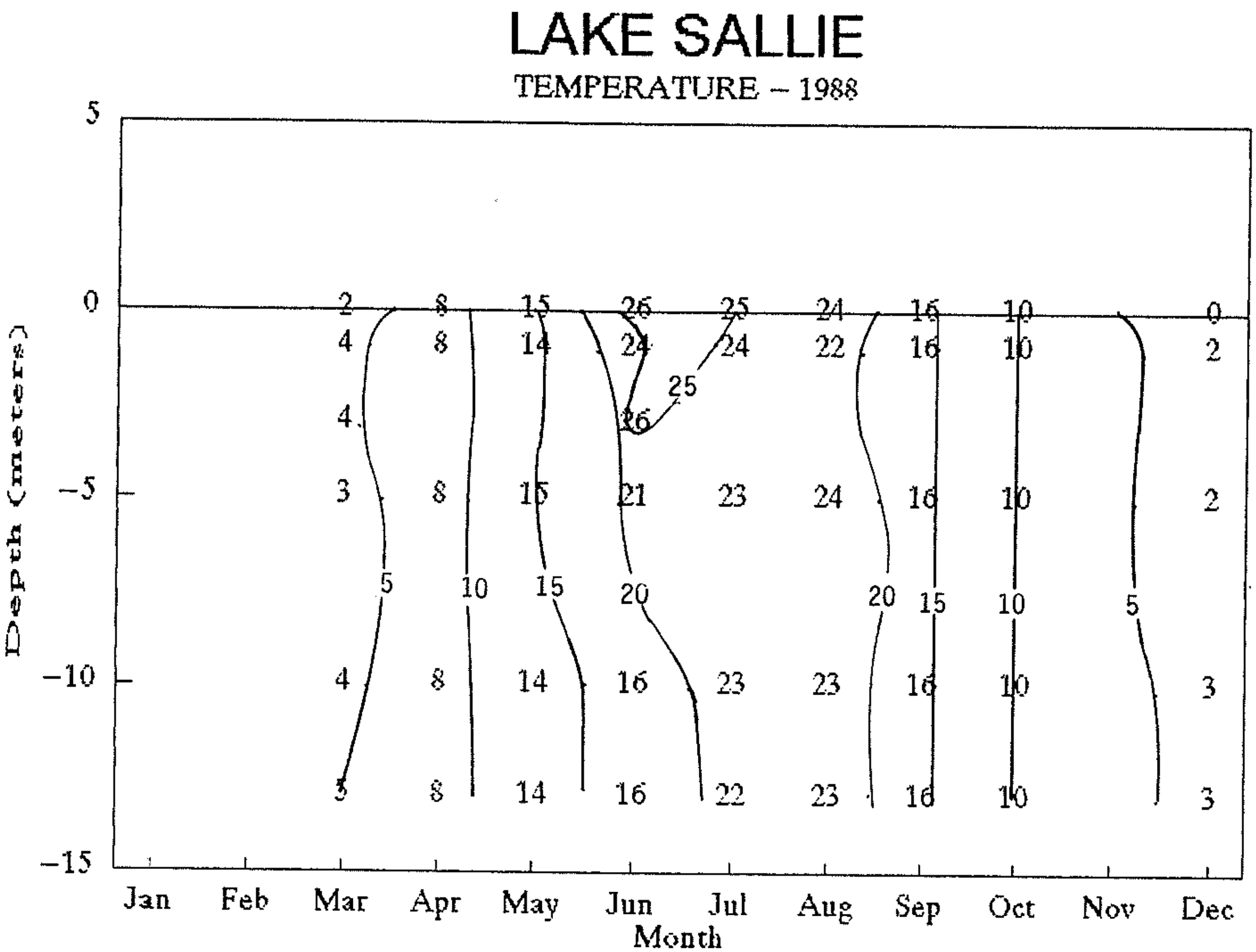
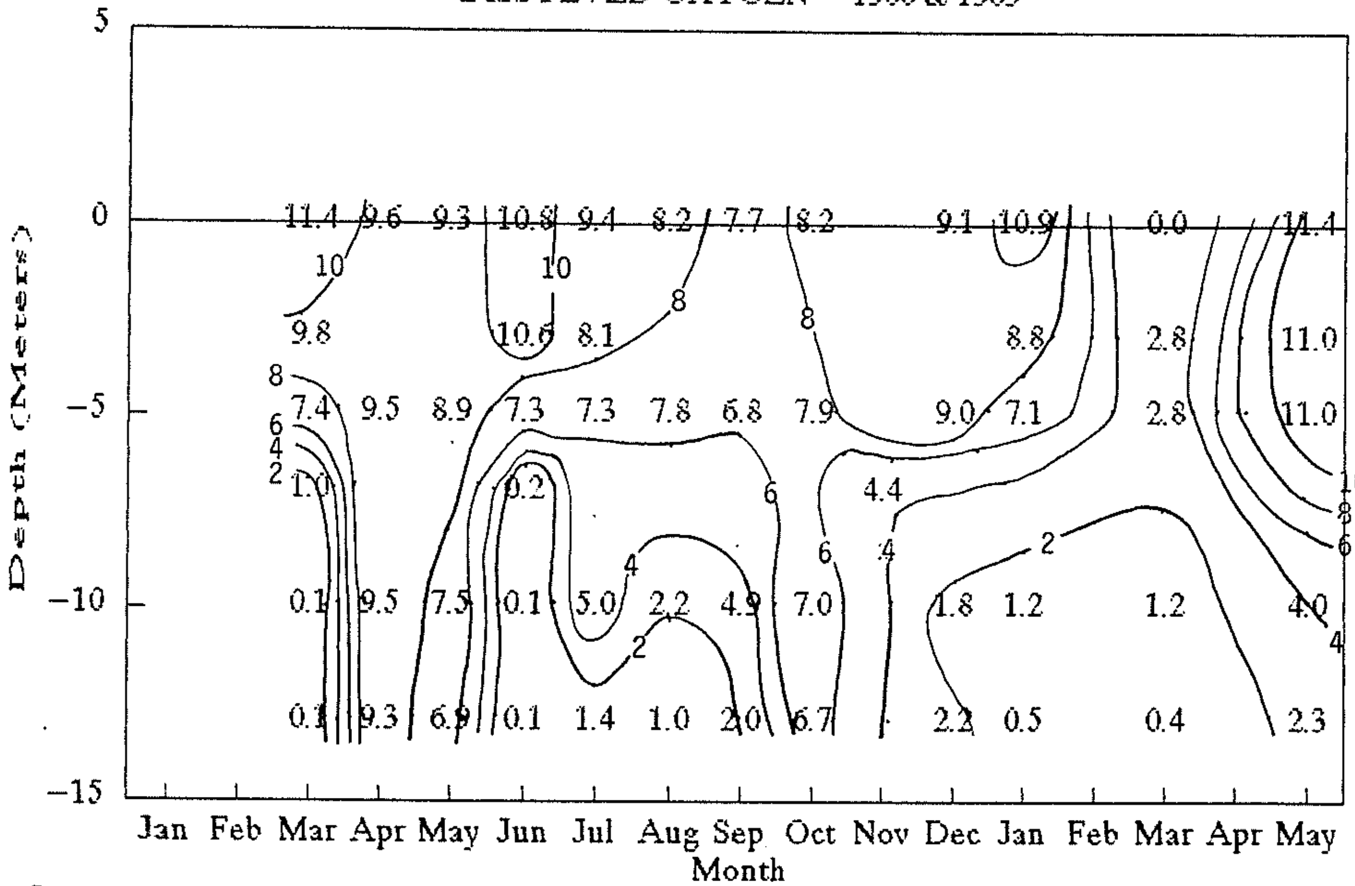


FIG. 8

LAKE SALLIE
1988 TEMPERATURES

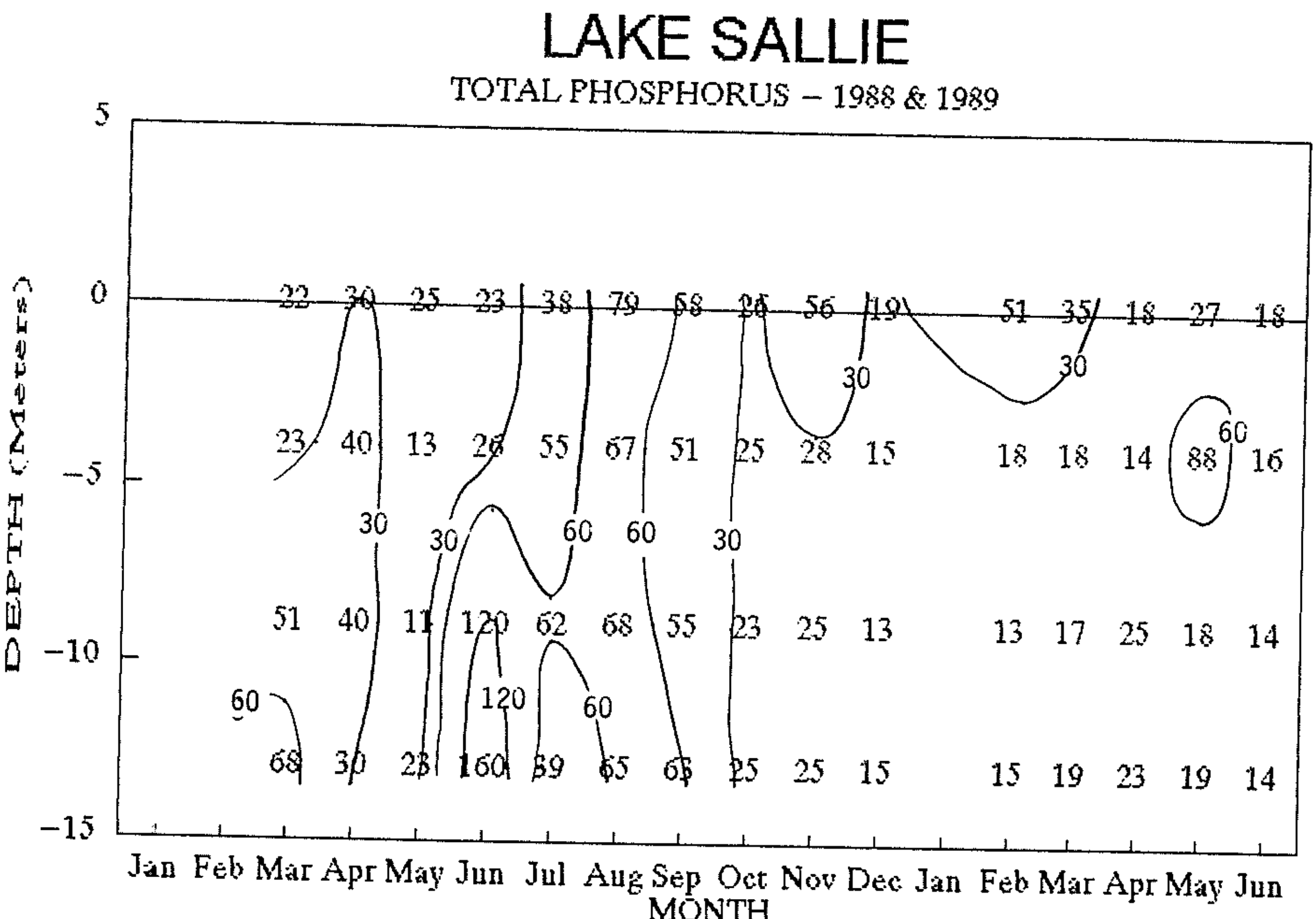
LAKE SALLIE

DISSOLVED OXYGEN – 1988 & 1989



Jan., 1988 to May, 1989

FIG. 9
LAKE SALLIE
1988 DISSOLVED
OXYGEN



January, 1988 to June, 1989
* All concentrations in micrograms/liter

FIG. 10
LAKE SALLIE
TOTAL PHOSPHORUS

7. Zooplankton

Zooplankton analysis for Lake Sallie indicates the most abundant zooplankton are the large bodied herbivores Daphnia Pulex and Daphnia Galeata. Zooplankton identified in Lake Sallie are listed below. Results of the June and July, 1988 sampling are presented in the Appendix.

TABLE X LAKE SALLIE: ZOOPLANKTON

Organism
Cladocera:
Daphnia Pulex
Daphnia Galeata
Daphnia Retrocurva
Unknown Daphnia
Bosmina sp.
Sida Crystallina
Copepod:
Mesocyclops edax
Macrocyclops albidus
Juvenile cyclopoid
Diaptmus oregonensis
Cyclops bisupidatus t.
Epischura lacustris
Juvenile calanoid
Nauplier stages
Ostracods:
Rotifers:

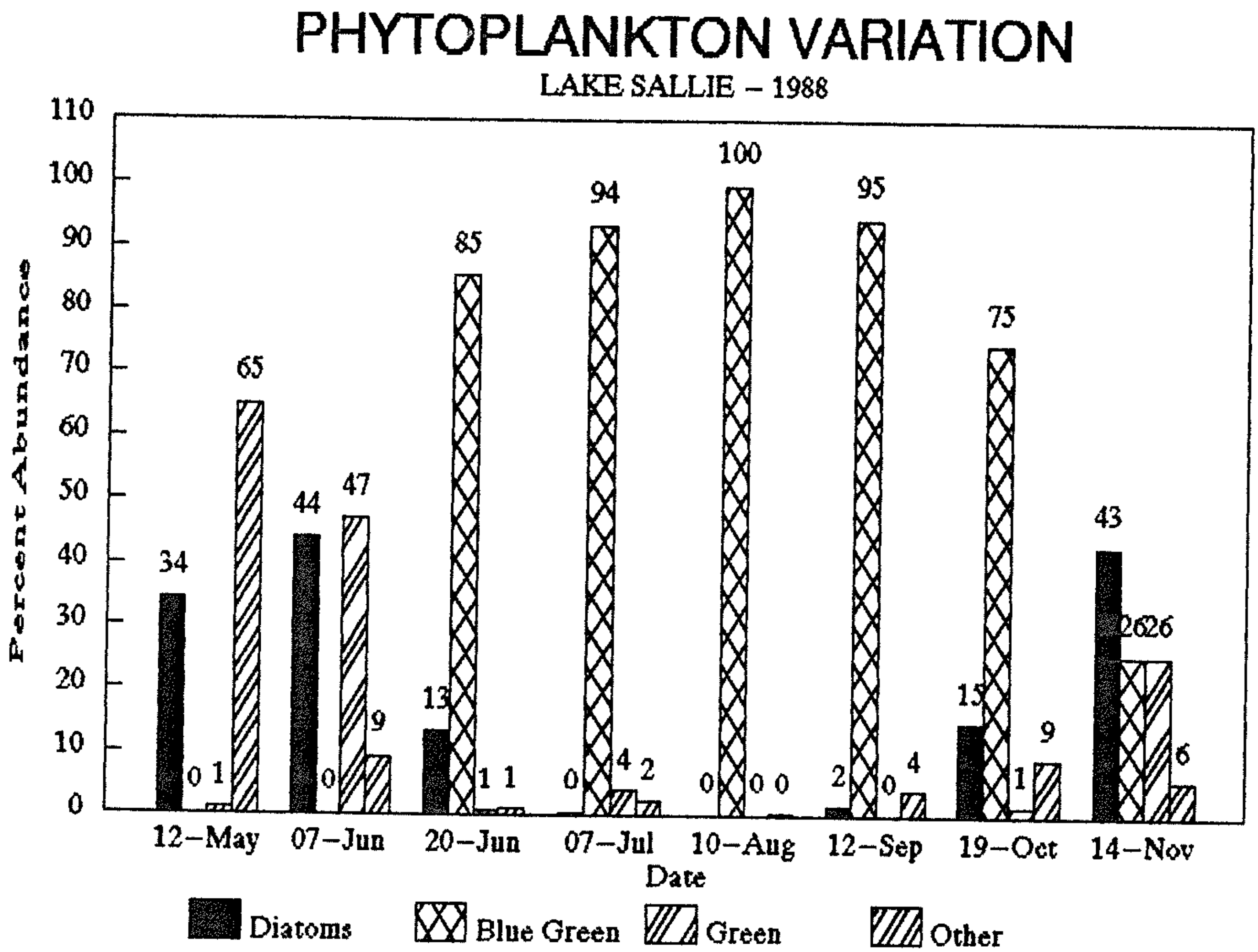


FIG. 11
LAKE SALLIE
PHYTOPLANKTON
DISTRIBUTION

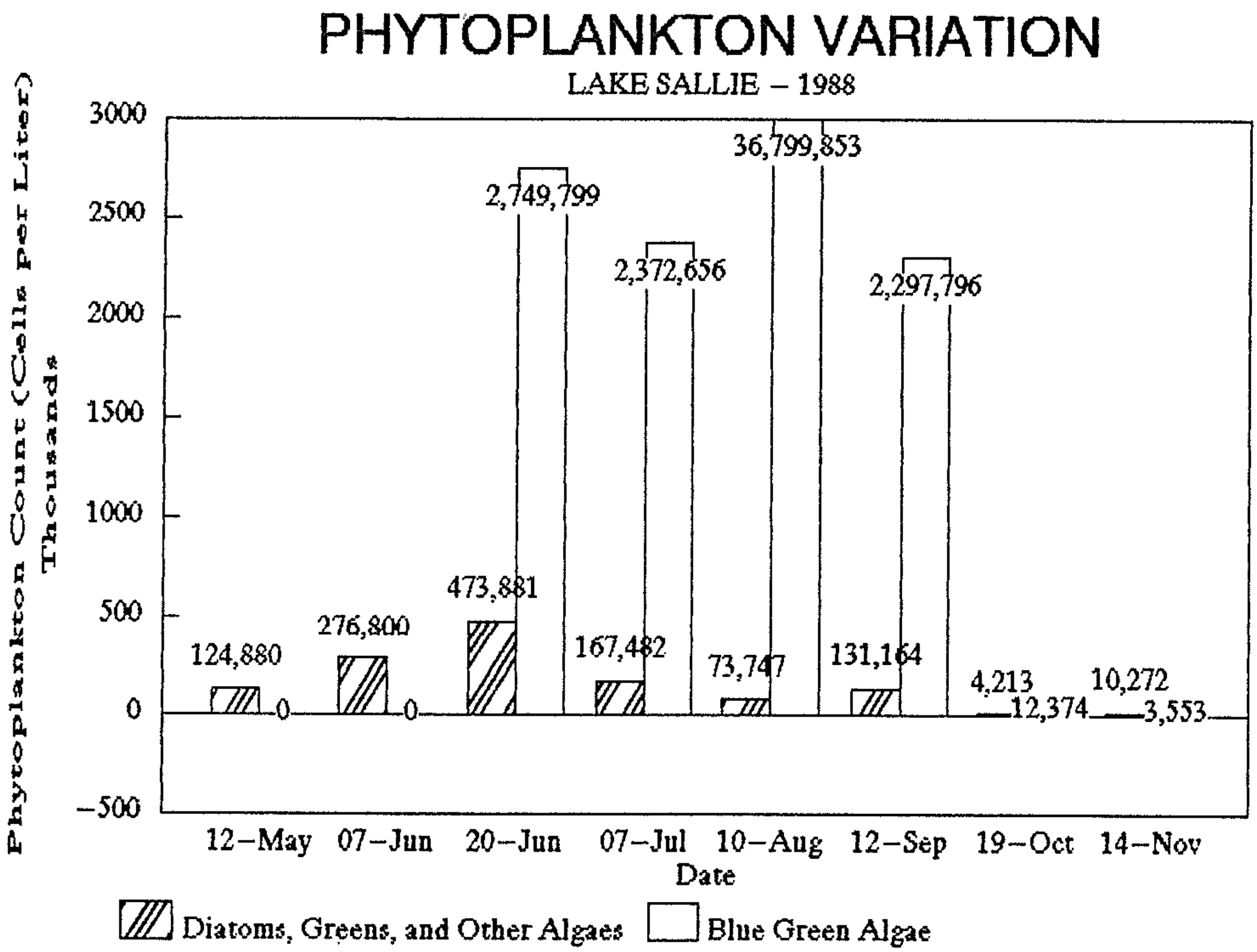


FIG. 12
LAKE SALLIE
I BLUE GREEN ALGAE

8. Macrophytes

A general survey of the macrophytes was completed on Lake Sallie on September 8, 1989. The location of the macrophytes based upon the survey and historical information is shown in Figure 13. The species which have been identified by this study and previous studies are as follows:

Najas flexilis (Willd.) Rostk. & Schmidt.

Potamogeton amplifolius Tuckerm.

P. crispus L.

P. filiformis var. Macounii Marong.

P. pectinatus L.

P. praelongus Wulf.

P. Richardsonii (Benn.) Rydb.

Ruppia maritima L.

Alisma gramineum var. Geyeri (Torr.) Sam.

Scirpus acutus Muhl.

Heteranthera dubia (Jacq.) MacM.

Elodea canadensis Michx.

Vallisneria american Michx.

Ceratophyllum demersum L.

Myriophyllum exalbescens Fern.

Nuphar variegatum Engelm.

Nymphaea tuberosa Paine

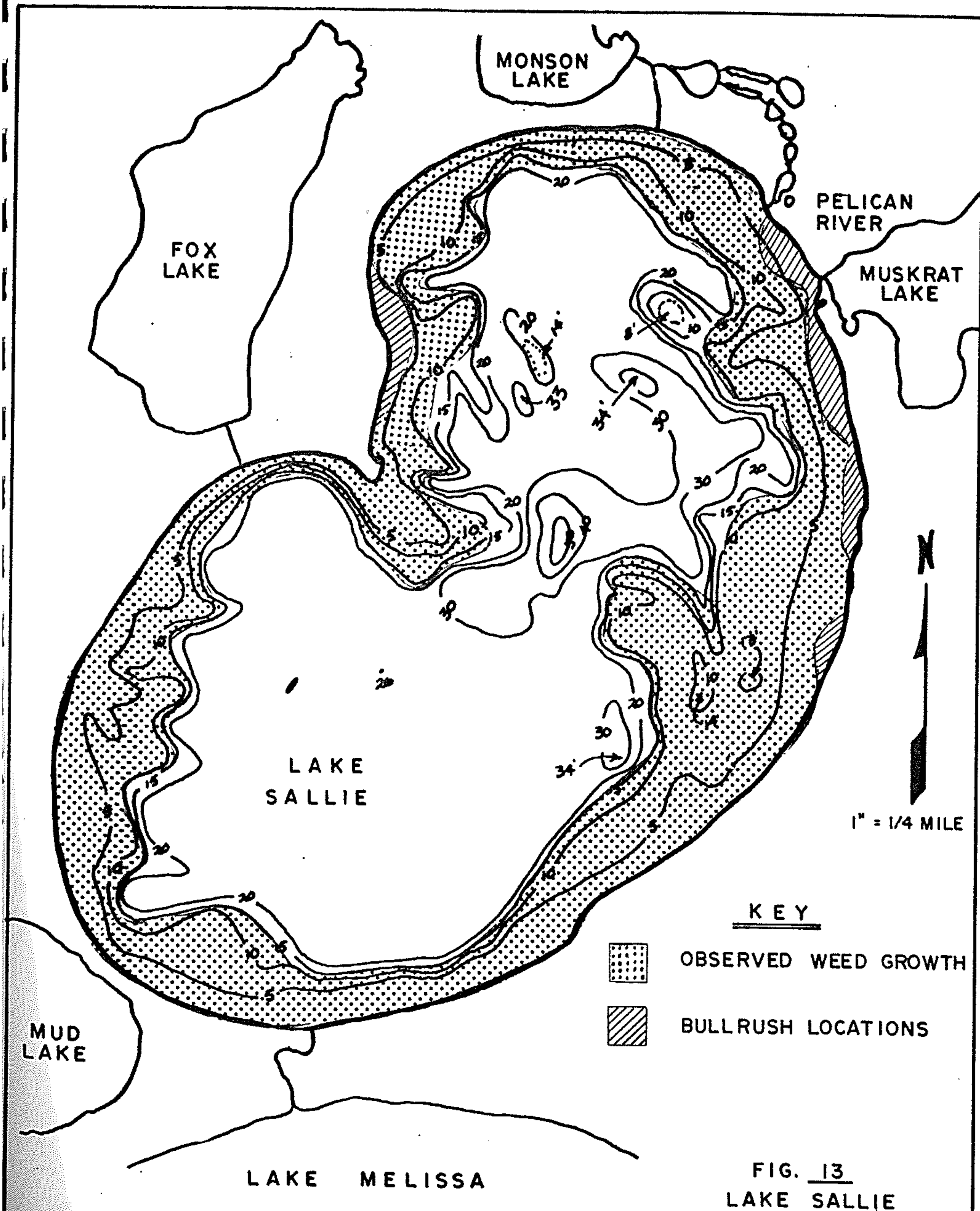


FIG. 13
LAKE SALLIE
MACROPHYTES
LOCATIONS

The most common macrophytes encountered on Lake Sallie are:

Common Name	Scientific Name
Pond Weed	Potamogeton
Mush Grass	Chara
Water Milfoil	Myriophyllum
Flowering Rush	Butomus Umbellatus

The Potamogeton are annuals, reproducing by seed germination. The productivity of these plants can change rapidly with seasonal changes in the lake system. These plants are sensitive to light, occurring in depths up to five meters depending upon light conditions.

Chara are submerged macrophytes and can cover areas in the littoral zone with a dense mat on the bottom sediments. Myriophyllum is a perennial plant. The Flowering Rush plant is extremely hardy and can spread by fragmentation.

C. DETROIT LAKE

The primary sampling station for Detroit Lake was located in the southwest corner of Big Detroit Lake at the deepest portion of the lake. The depth exceeded 80 feet. Secondary sampling was taken near the Pelican River Inlet and in Little Detroit Lake.

1. Secchi Disk Measurements

Transparency readings for Detroit Lake ranged from a maximum of 5.8 meters in May, 1988 to a minimum of 1.5 meters in August of 1988.

2. Temperatures

Temperatures in Detroit Lake range from 0° to 4°C in winter to nearly 25°C in mid to late summer. The lake is thermally mixed until May, when stratification begins to occur. The lake remains in various stages of stratification until October, when uniform and thorough mixing is apparent.

Figure 14 presents temperatures at varying depths for 1988 for Detroit Lake. The 1989 partial temperatures are in the Appendix.

3. Dissolved Oxygen

Monthly dissolved oxygen measurements were taken at one meter intervals at the deepest point of Detroit Lake from March, 1988 through June, 1989. In Detroit Lake dissolved oxygen concentrations beginning in November from a high of 12-13 mg/l decline in direct proportion to depth throughout the winter to levels near zero mg/l at the lower depths in March. Spring turnover yields uniform concentrations near 9 milligrams per liter. Concentrations decline throughout the summer as thermal stratification occurs, with dissolved oxygen levels near zero in the hypolimnion. In August and September the dissolved oxygen begins to move downward with total mixing occuring again in October.

4. Phosphorus

Phosphorus concentrations were sampled at least once per month from March, 1988 through June, 1989 with the exception of February and April, 1989. Samples were taken at 0, 5, 13 and 23 meter (bottom) depths. Phosphorus concentrations in the epilimnion ranged from .01 mg/l in the winter and spring to nearly .04 mg/l in August. Phosphorus concentrations in the hypolimnion ranged from approximately .01 mg/l in the winter and spring to .17 mg/l in late summer.

5. Chlorophyll-a

Chlorophyll-a concentrations ranged from 1.9 mg/l to 14.7 mg/l from April to October of 1988. The average annual concentration was 5.7 mg/l and the summer average was 5.5 mg/l.

6. Phytoplankton

Phytoplankton was sampled on Detroit Lake during the open water months of 1988. There were 38 different species identified. Different species dominate during different times of the year and with varying water conditions. On Detroit Lake algal growth begins in May and begins to decline in September. Similar to Lake Sallie, algal growth in spring consists largely of

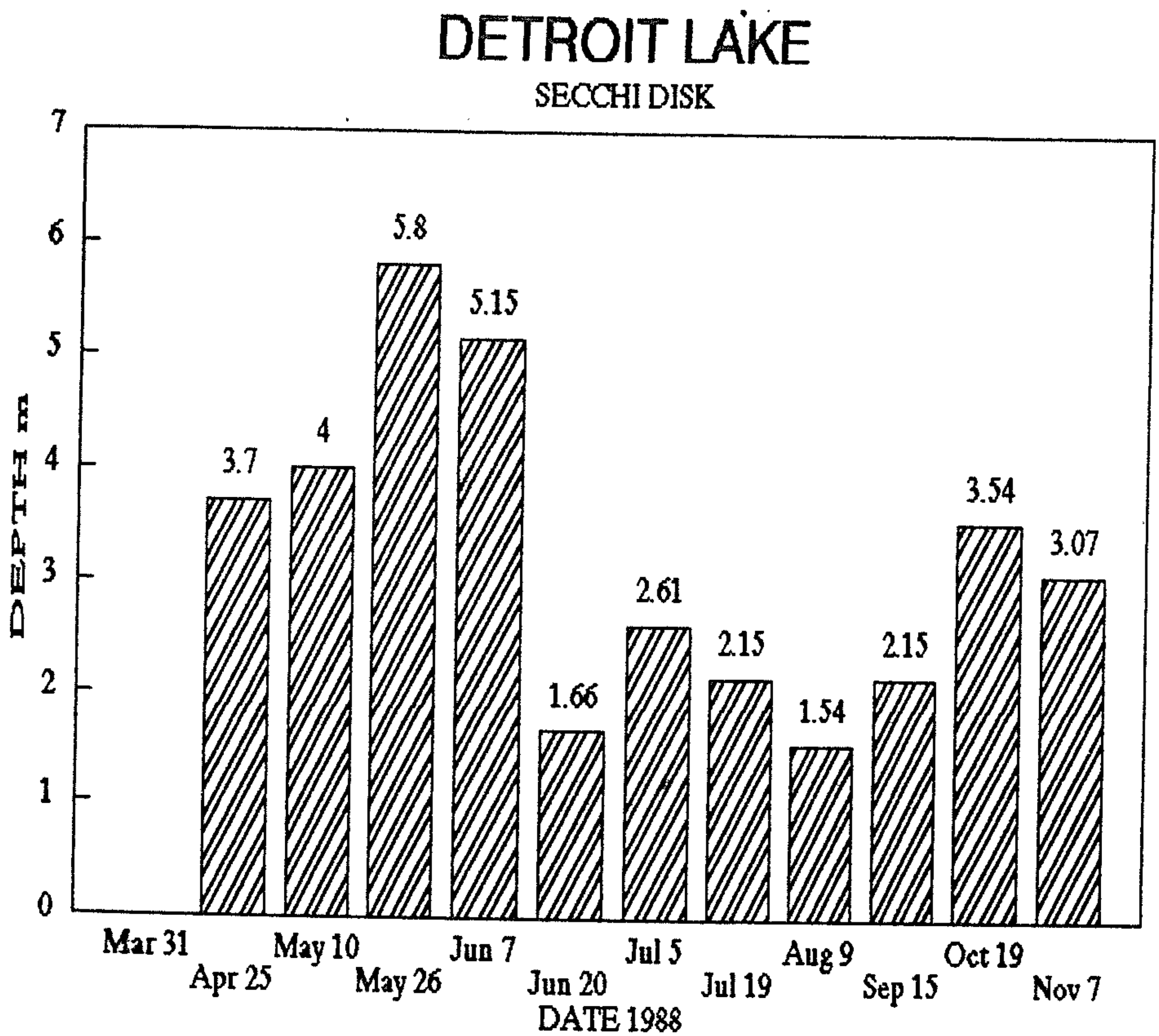


FIG. 14
DETROIT LAKE
1988 SECCHI DISK

#12

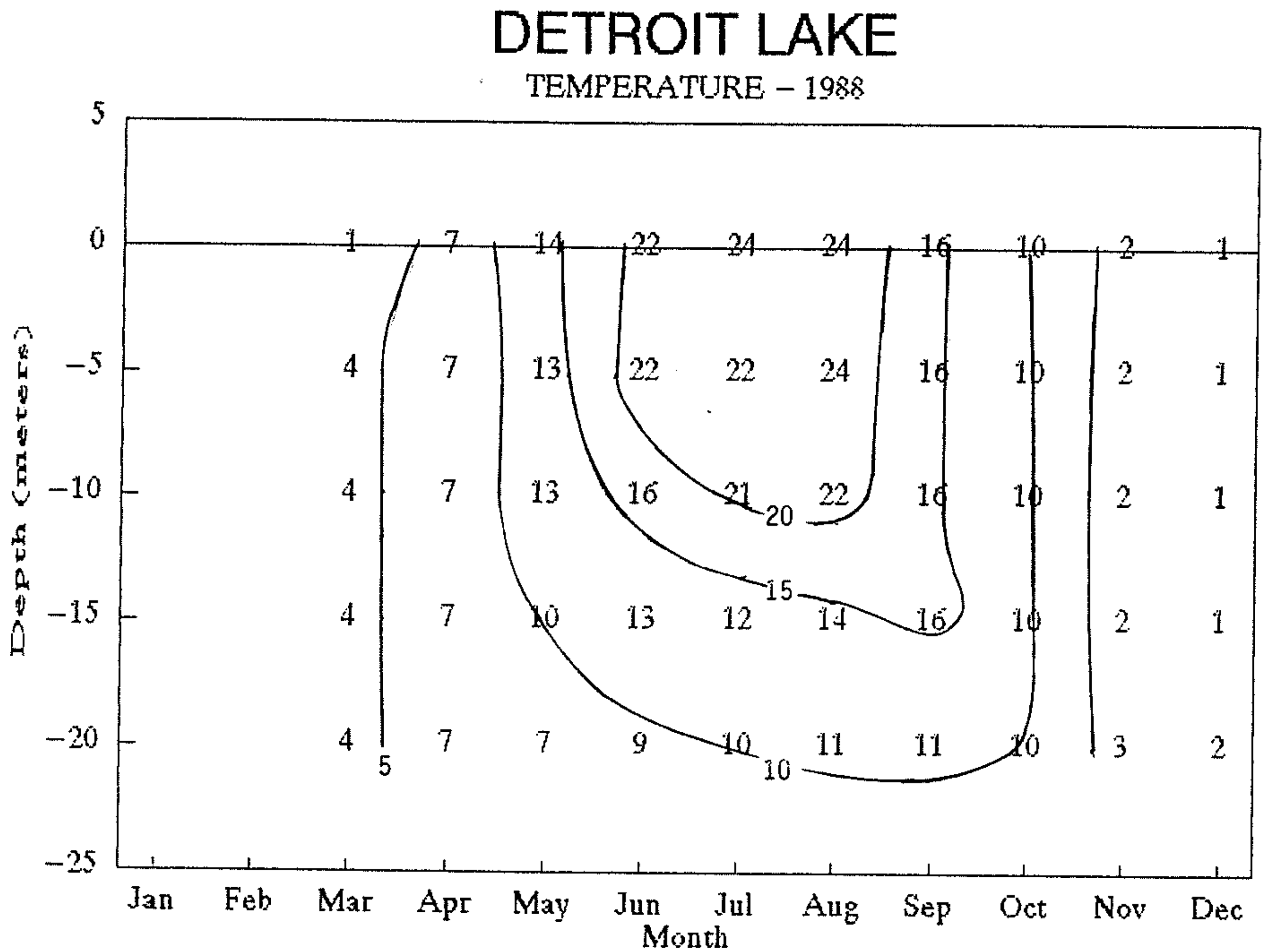


FIG. 15
DETROIT LAKE
TEMPERATURE

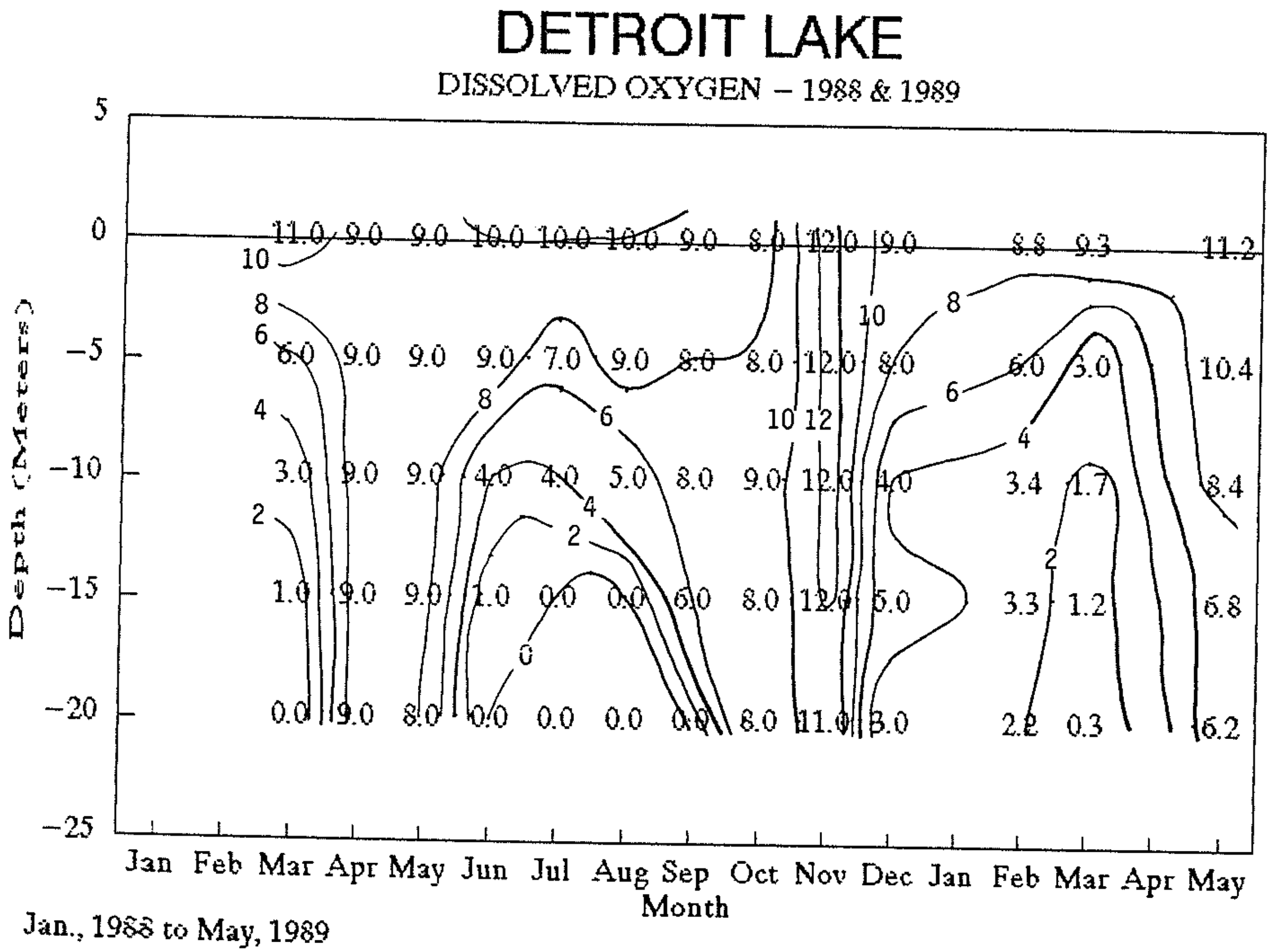
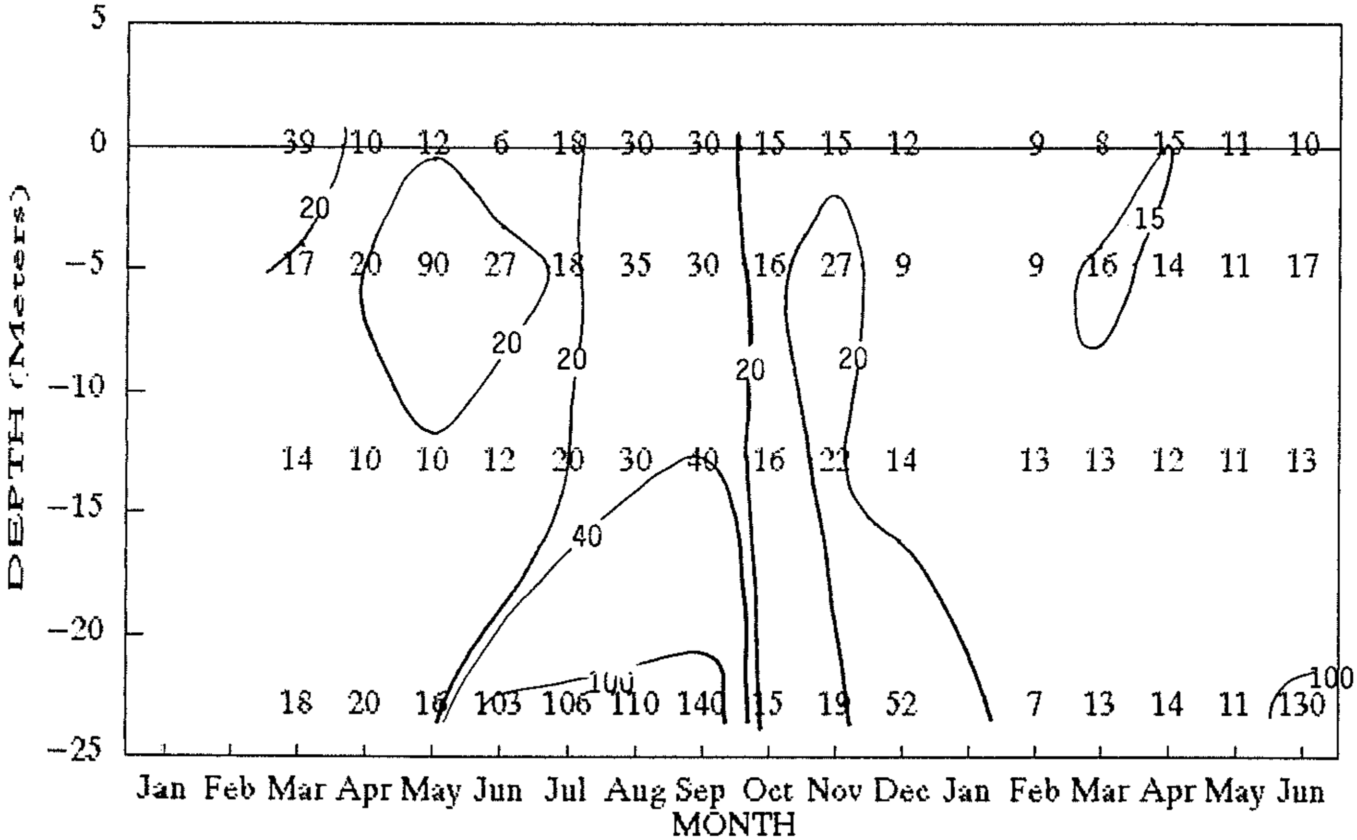


FIG. 16
DETROIT LAKE
DISSOLVED OXYGEN

DETROIT LAKE

TOTAL PHOSPHORUS – 1988 & 1989



January, 1988 to June, 1989

* All concentrations in micrograms/liter

FIG. 17

DETROIT LAKE

TOTAL PHOSPHORUS

types other than green or blue-green and diatoms, which decline in June. As diatoms and other types decline, blue-green algae begin to appear, particularly Anabaena and Aphanizomenon.

In July these species begin to give way to Microcystis and in August and September to Coelosphaerium and Oscillotoria. In fall the diatoms resume dominance.

The progression of phytoplankton in Detroit Lake for 1988 identified the most numerous species as follows:

Month	Peak Productivity
May	Dinobryon (Golden Brown)
June	Dinobryon (Golden Brown) Fragilaria (Diatoms)
July	Microcystis (Blue-Green)
August	Coelosphaerium (Blue-Green) Mycrocystis (Blue-Green)
September	Gomphosphaeria (Blue-Green) Mycrocystis (Blue-Green)

The peak measurement of phytoplankton occurred in September with a total cell measurement of 2.045×10^6 cells/l. In contrast, the August productivity level for Lake Sallie was 37.8×10^6 cells/l in August of 1988.

7. <u>Zooplankton</u>

The analysis of zooplankton in Detroit Lake indicates a substantially lower concentration than identified in Lake

Sallie. The Daphia Pulex and Daphnia Galeata are common in the sampling, identified species are listed in Table XI. A summary of zooplankton sampling for Detroit Lake is in the Appendix.

TABLE XI DETROIT LAKE: ZOOPLANKTON

Organism
Cladocerans:
Daphnia Pulex
Daphnia Galeata
Daphnia Retrocurva
Unknown Daphnia
Bosmina sp.
Copepods:
Mesocyclops edax
Macrocyclops albidus
Juvenile cyclopoid
Diaptmus oregonensis
Cyclops bicuspidatus t.
Epischura lacustris
Juvenile calanoid
Naupliar stages
Rotifera:
Ostracods:
Diptera:

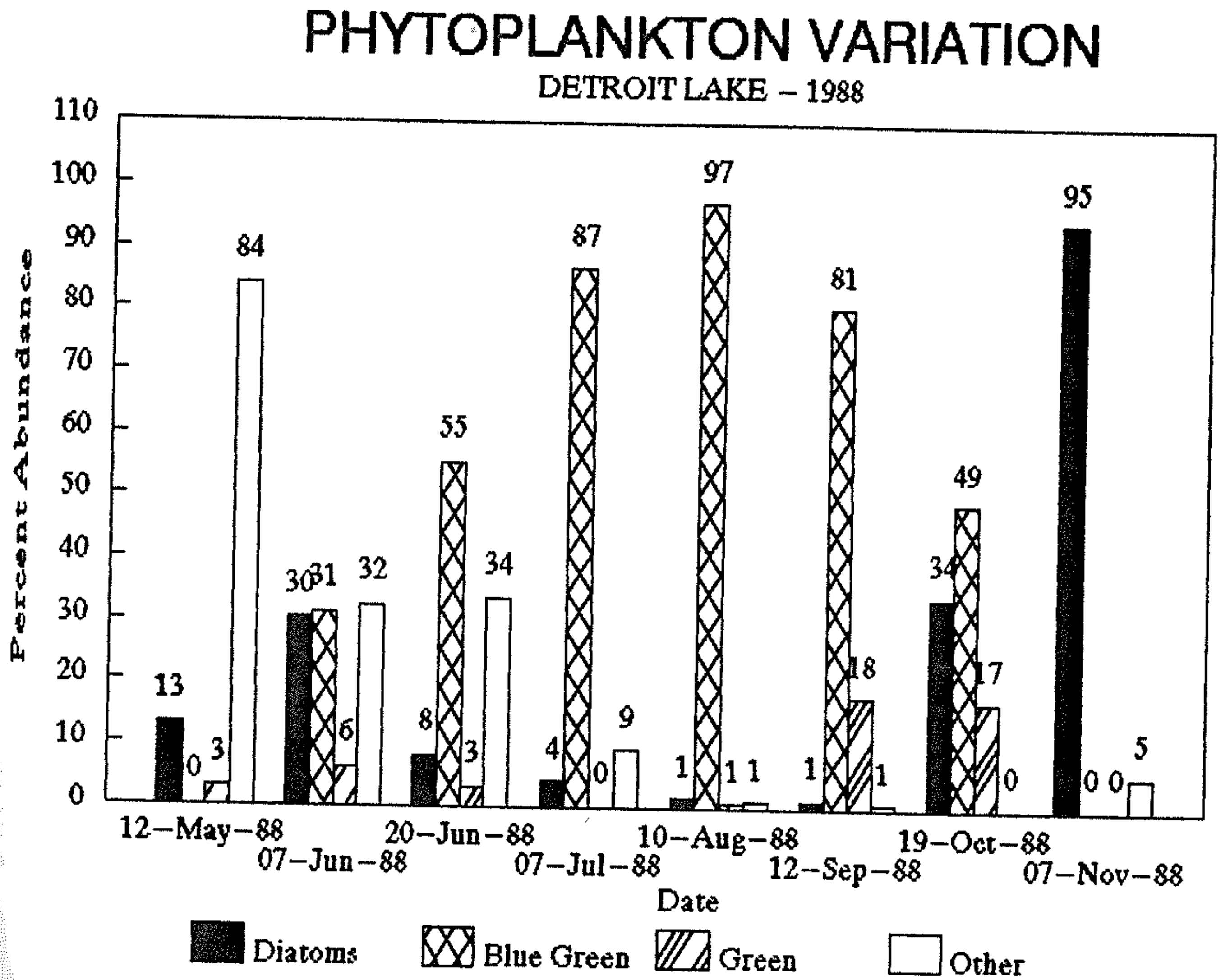


FIG. 18
DETROIT LAKE
PHYTOPLANKTON

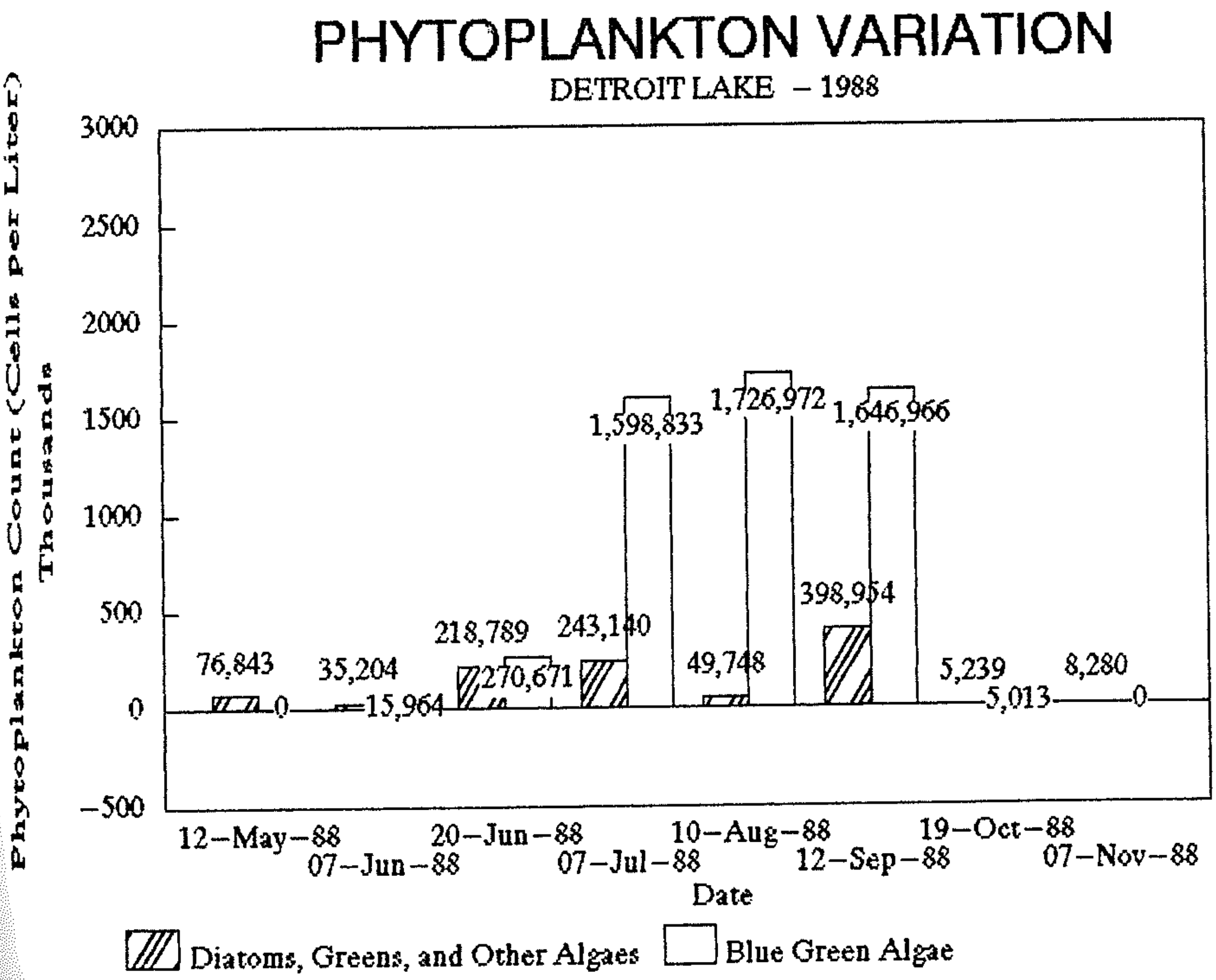


FIG. 19
DETROIT LAKE
BLUE GREEN ALGAE

8. Macrophytes

On July 27, 1989, the aquatic macrophytes were surveyed in Detroit Lake. Growths of Chara were predominate in several areas and numerous patches of the nuisance plant Flowering Rush were identified scattered along the shallow areas. The general vegetative growth areas of macrophytes in Detroit Lake are shown in Figure 20.

The most common macrophytes and other identified species are similar to those discussed for Lake Sallie.

D. STREAM SAMPLING

The stream sampling was accomplished by grab samples taken at selected intervals and high flow conditions in 1988 and 1989. Analysis of the samples included total phosphorus and total suspended solids concentrations. A summary of the stream sampling test results are included in the Appendix.

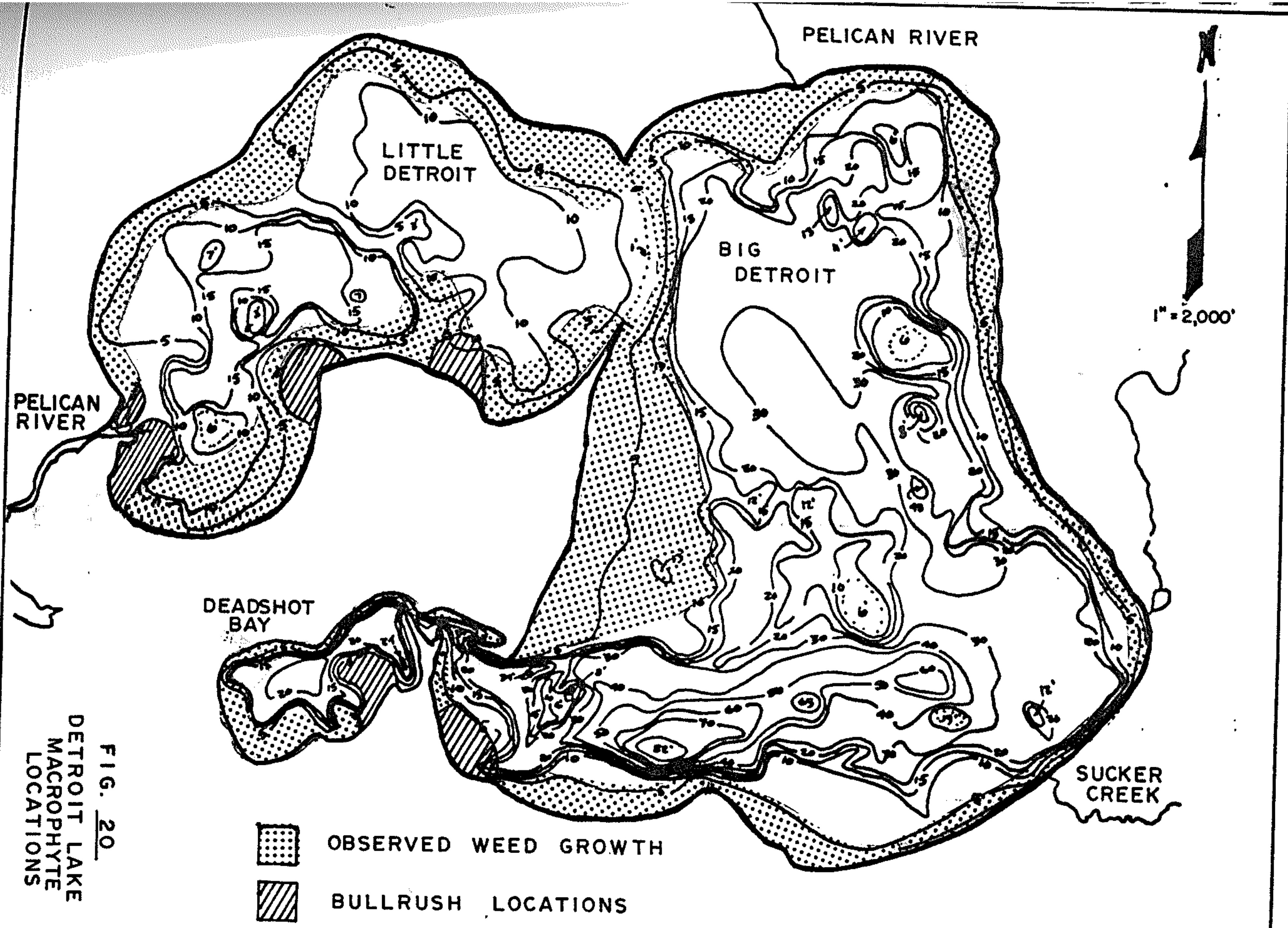


FIG. 20
DETROIT LAKE MACROPHYTE LOCATIONS

IV. WATER NUTRIENT BUDGETS

A. HYDROLOGIC BUDGET

A hydrologic budget was developed for each lake based upon surface water monitoring, lake elevations and climate data.

Climatological information obtained for precipitation and evaporation data are applied to the total hydrologic budget. Pan evaporation values received from North Dakota State University were corrected for estimated lake evaporation rates. The correction factor based upon values received, pan evaporation testing was 0.7.

The annual hydrologic budget was calculated according to the following equation:

$$S = S_I + P \pm R - S_O - E$$

where S = Change in Surface Water Storage

S_I = Surface Water Inflow
P = Precipitation
R = Residual (Assumed Groundwater)
S_O = Surface Water Outflow
E = Evaporation

Surface inflow and outflow are summaries of monthly flows monitored at inlet and outlet locations. The value for the winter months are based upon base line winter flows from historical records, as the flow monitoring was not done during the winter season. The residual value is assigned to the groundwater contributions to the lake.

1. Lake Sallie

Historical records of flow monitoring for the Muskrat Lake inlet and the Lake Sallie outlet are presented in the Appendix. It is apparent that flows in 1988 represent levels at least 50% less than some years as a result of the warm, dry spring and summer. Monthly comparisons of the 1988 Pelican River inlet and outlet flows are compared to 1969 and 1970 are also included in the Appendix.

A graphic comparison was made for the precipitation and flows in Lake Sallie in 1988. The inflow and outflow conditions as they correspond to precipitation are presented in Figure 21. A comparison of historical flows and precipitation as they relate to Lake Sallie are included in the Appendix.

The Pelican River is the major contributor to the hydrologic budget for Lake Sallie. The total inflow from surface water sources in 1988 represented 65 percent of the total inflow to the lake. The Pelican River recorded flows represented almost 97 percent of the total annual surface water flow to Lake Sallie.

Previous studies have presented up to 70 percent contribution from the Pelican River. Therefore, the Pelican River represents the most significant hydrologic contributor to Lake Sallie based upon 1988 historical data.

TABLE XII

HYDROLOGIC BUDGET (Ac-ft)

LAKE SALLIE, 1988

SOURCE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Surface Inflow	500	500	1,634	3,374	1,980	619	-	602	895	150	525	500	11,279
Precipitation	125	1	139	21	281	183	490	633	441	105	128	98	2,645
Surface Outflow	800	800	1,390	2,898	2,017	964	252	491	1,071	1,064	779	614	13,140
Evaporation	40	40	50	170	786	913	933	801	446	170	130	45	4,524
Change in Storage	-	-	+302	-61	-194	-497	-170	+412	+121	-	-	-	-87
Residual	+215	+339	-31	-388	+348	+578	+525	+469	+302	+979	+256	+61	+3,653

Table VIII presents the 1988 hydrologic budget for Lake Sallie.

2. Detroit Lake

The hydrologic budget for Detroit Lake varies from Lake Sallie as a result of the lake size and watershed characteristics. In 1988, surface water represented approximately 30 percent of total hydrologic inflow contributions to the lake. It is expected that normal surface water contribution would comprise a more significant volume of the average hydrologic budget.

A monthly comparison was prepared in Figure 22 for precipitation and flows for Lake Detroit. There is no available information to historically compare previous runoff and precipitation.

The inflow into Detroit Lake from the Pelican River is sensitive to storm runoff from the City of Detroit Lakes. Storm flows from events of approximately one inch or more comprised three to four percent of the total inflow to the lake for 1988. The duration of the runoff was usually less than one day. A hydrograph was prepared to estimate the quantity of water from each event due to the short durations.

Under normal conditions Detroit Lake is a discharge area for groundwater (Miller, 1982, USGS). The data for the hydrologic budget for Detroit Lake supports this in that the contribution of water to the lake from groundwater exceeded that of the surface water inflow.

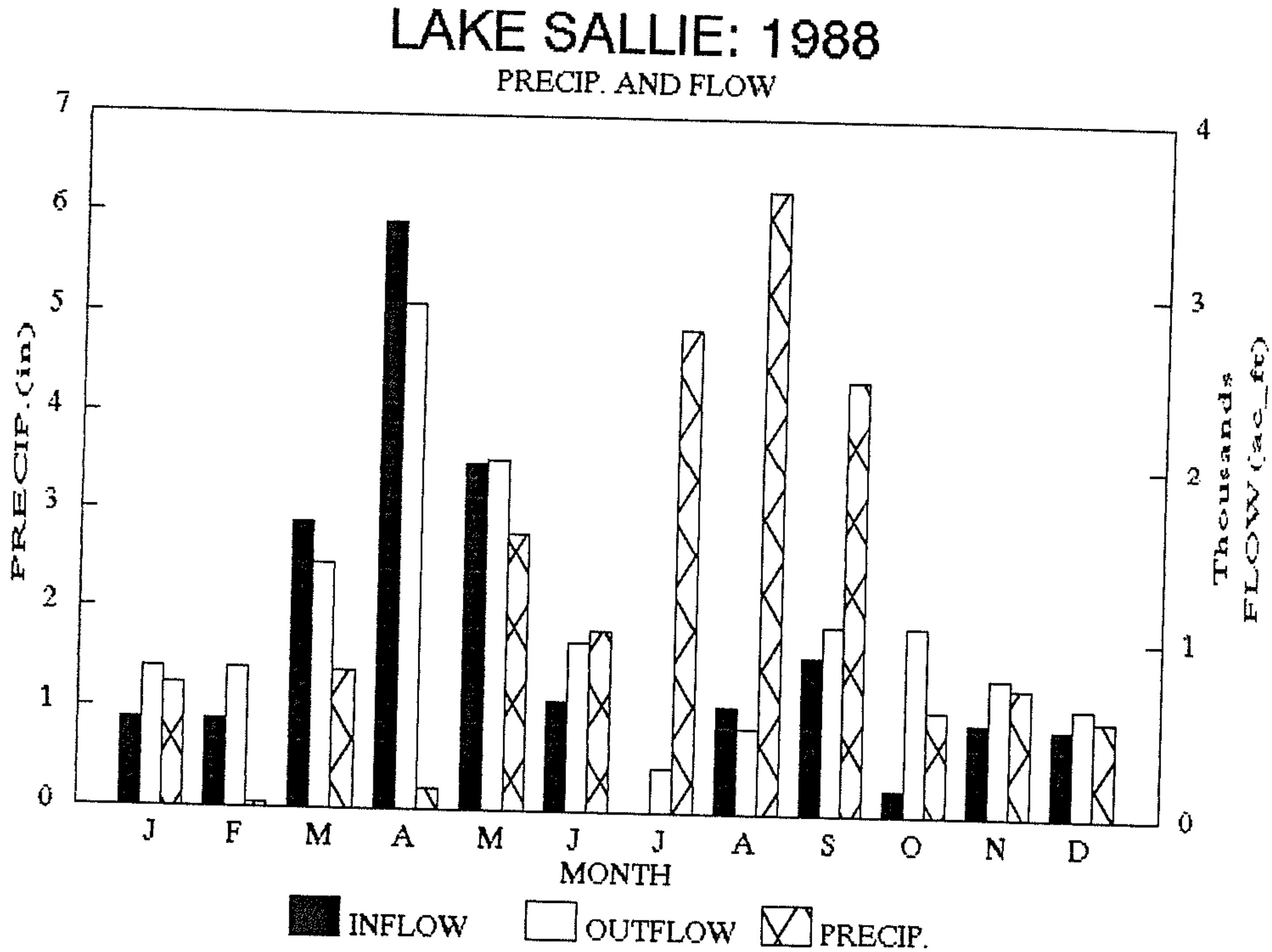


FIG. 21
LAKE SALLIE
PRECIPITATION
AND FLOWS

TABLE XIII

HYDROLOGIC BUDGET

DETROIT LAKE, 1988

SOURCE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Surface Water Inflow	84	84	1,304	1,582	634	143	137	375	461	465	89	66	5,424
Precipitation	334	13	371	62	748	487	1,308	1,687	1,176	280	342	261	7,069
Surface Water Outflow	500	300	965	2,690	1,371	613	123	338	404	246	400	500	8,450
Evaporation	102	102	127	432	2,000	2,322	2,374	2,038	1,133	432	331	114	11,507
Change in Storage	-	-	1,078	-308	-92	-1,170	-985	1,016	31	246	-	-	-184
Groundwater	184	305	495	1,170	1,897	1,135	67	1,330	-69	179	300	287	7,280

The hydrologic budget for Detroit Lake in 1988 can be seen in Table XIII.

B. PHOSPHORUS LOADING

1. Lake Sallie

Phosphorus loadings were calculated based upon grab samples of stream flow projected to flow monitoring of the streams. The measured phosphorus conentrations were applied to the monthly flows based upon averaged phosphorus concentrations.

Inflow to Lake Sallie is primarily from lake overflows which buffer storm runoff peaks. Therefore, inflows to Lake Sallie did not include instantaneous storm event monitoring.

Phosphorus concentrations in the groundwater were included as a consideration in the study area. Total phosphorus concentrations were analyzed by the City of Detroit Lakes and as a part of this study to determine localized phosphorus concentrations adjacent to the City of Detroit Lakes wastewater treatment facilities. The monitoring wells are shallow and constructed of PVC casings and screens. A summary of the analysis is as follows:

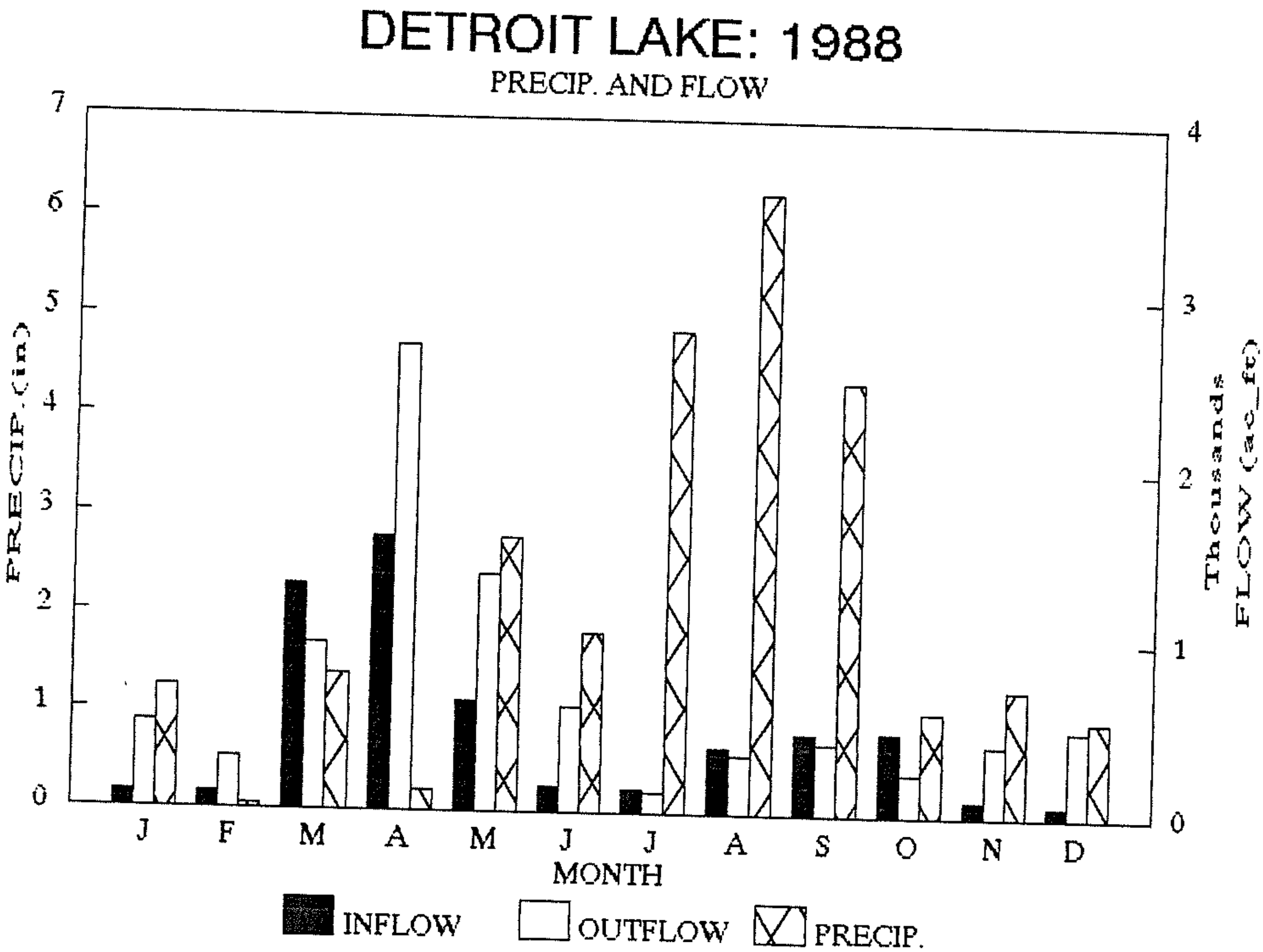


FIG. 22
DETROIT LAKE
PRECIPITATION
AND FLOWS

TABLE XIV PHOSPHORUS CONCENTRATIONS (mg/l), MONITORING WELLS, DETROIT LAKES WASTEWATER TREATMENT FACILITIES

Date	Well No. 2	4	6	9	10	11	12	14	15	16	18	20	23
1988													
July					.13	.16	.10			2.14		.12	
August					0.0	.18	.03					.04	
September					.04	.20	.07					.06	
October	.14	.23	.11	.12	.11		.03	.09	.13	2.12	.08	.12	.03
1989													
April		.70	.70	.43	.64		.43					.50	
May					.14		.04					.13	
June					.03		.06					.14	
July					.13		.51			2.99		.17	
August					.17		.11					.12	
September					.08		.06					.09	
October					.08		.04					.07	
November					.16		.18					.08	

The well locations are shown in Figure 23.

Total phosphorus load to Lake Sallie was estimated, including groundwater and atmospheric contributions. A concentration of 0.04 mg/l is estimated to be representative of the concentration of P_T in groundwater adjacent to the study lakes. The actual groundwater phosphorus concentrations flowing into the lakes has not been sampled, but is based upon estimates.

The atmospheric annual loading rate to Lake Sallie was estimated to be 0.2 lbs/acre (22kg/km^2/yr.). This rate was estimated based on surface sampling of snow and dust accumulations on the ice in January of 1989. The total phosphorus concentration from a three square area was projected for the

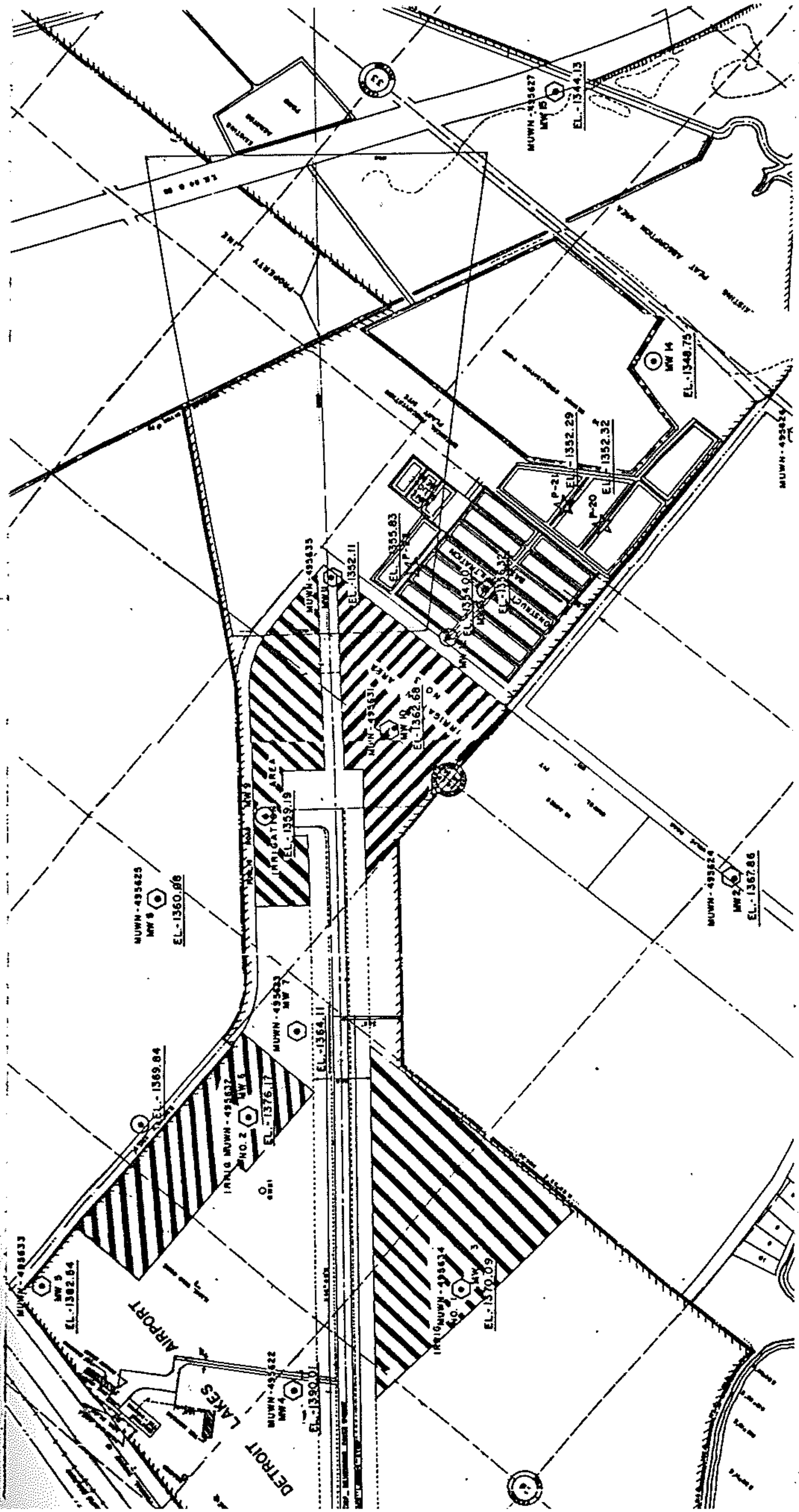


FIG. 23

MONITORING WELL LOCATION

entire lake surface. The loading rate was assumed constant for the entire year.

The DNR fish hatchery discharges water from the fisheries operation for a limited period each spring. The discharge is approximately 20 gpm for 10 days. An analysis of the discharge shows a 0.06 mg/l total phosphorus content. The result of this discharge was considered negligible in the phosphorus budget.

The phosphorus budget for Lake Sallie for 1988 can be found in Table XV.

TABLE XV LAKE SALLIE: 1988 PHOSPHORUS BUDGET

Source	Total Phosphorus (lbs.)
a. Input	
1) Inflow	
Pelican River	817
Monson Lake	4
Fox Lake	12
2) Groundwater	256
3) Atmosphere	242
Total	1,331
b. Output	
1) Outflow	
Pelican River	1,116
2) Harvest	
Weeds	377
Fish	220[1]
Total	1,713

[1] Estimated

2. Detroit Lake

Phosphorus loadings to Detroit Lake were calculated similar to Lake Sallie. In addition, the loadings from individual storm events must be considered since there is no buffer to even storm flows from the City. Phosphorus loadings from the inflow of the Pelican River was estimated at 560 pounds for 1988, not including City storm water contributions. The loading represents the non-storm phosphorus concentrations based upon grab samples in the streams. Contributions from short-term individual storms resulted in rapid run-off of short duration which became difficult to quantify with the grab sample method.

The contribution of phosphorus from storm events is based on a hydrograph and phosphorus sampling for a 3.5 inch storm event on August 31, 1989. The estimated contributions from that event was 51 pounds of phosphorus. The loadings were estimated from the hydrograph prepared for the runoff to the Pelican River from the City and factors for anticipated phosphorus contributions from urban areas. Loadings from additional events were estimated based on the August 31, 1988 event.

Further analysis of the storm sewer contributions to the Detroit Lake inlet are included in the watershed analysis.

The phosphorus budget for Detroit Lake for 1988 can be found in Table XVI. The phosphorus budget includes estimated phosphorus loadings from City runoff during storm events greater than ½" for 1988.

TABLE XVI DETROIT LAKE: 1988 PHOSPHORUS BUDGET

Source	Total Phosphorus (lbs.)
a. Input	
1) Inflow	
Pelican River (STA.D2)	677
Sucker Creek (STA.D4)	149
East Side (STA.D3)	41
2) Groundwater	442
3) Atmosphere	616
Total	1,925
b. Output	
1) Outflow	
Pelican River	302
2) Harvest	
Weeds	0
Fish	275[1]
Total	577

[1] Estimated

V. ANALYSIS AND SUMMARY

A. LAKE SALLIE

1. Phosphorus

A general relationship between lake productivity and total phosphorus concentrations in the epilimnion based upon studies done by Vollenweider, 1968, is as follows:

General Level of Lake Productivity	Total Phosphorus (mg/l)
Ultra-oligotroph	< .005
Oligo-mesotrophic	.005 to .01
Meso-eutrophic	.01 to .03
Eutrophic	.03 to .1
Hypereutrophic	> .1

Application of this table to the data derived from Lake Sallie would clearly put Lake Sallie in the middle range of the eutrophic lake condition.

Ortho-phosphorus sampling was done in conjunction with the total phosphorus testing. Ortho-phosphorus concentrations were generally substantially less than the total phosphorus concentrations except in the hypolimnion where concentrations of ortho-phosphorus increased substantially during thermal stratification.

Surface phosphorus concentration can be summarized as follows:

TABLE XVII LAKE SALLIE: HISTORICAL PHOSPHORUS CONCENTRATION COMPARISON

Parameter	n	Average June - September	Annual Average	Range
1969-1970				
Total Phosphorus	14	0.54	0.40	0.10 - 0.92
Ortho Phosphorus	14	0.118	0.116	0 - 0.25
1983				
Total Phosphorus	4	0.046	-	0.02 - 0.107
Ortho Phosphorus	4	0.010	-	0.002 - 0.022
1988				
Phosphorus Total	14	0.047	0.038	0.015 - 0.079
Phosphorus Ortho	14	0.008	0.008	0.002 - 0.014

From a historical prospective, phosphorus concentration has declined by a factor of almost 10 from the 1969-1970 testing period. The 1983 and 1988 tests are very similar.

A general overview of phosphorus testing in 1983 of local lakes, including Floyd Lake and Detroit Lake, indicate current summer phosphorus concentrations are two to three times higher on the average in Lake Sallie than the other lakes sampled.

Based upon weighted volume concentrations, the total suspended phosphorus concentrations in Lake Sallie were determined for

1988. The phosphorus quantities expressed in pounds range from 1,100 to almost 4,400 pounds of phosphorus during the late summer. The initial rise in phosphorus in the lake appears to correspond at least in part to phosphorus inflow into the lake. There was virtually no inflow of phosphorus into the lake which is evident by the drop in inlake phosphorus during the initial stage of that month. However, as the lake began to destratify in late June, the phosphorus in the lake increased rapidly to a peak of 4,400 pounds in August. This concentration is apparently at least in part the result of recycling of phosphorus sediments. A direct relationship between the types of phyto-plankton and phosphorus concentrations in the lake is apparent and will be discussed in greater detail in this study.

In 1989, the phosphorus levels in the lake increased during April and May from 1,300 pounds to 3,650 pounds. This increase is more dramatic than 1988 due to the increased surface runoff and factors associated with that runoff.

Several models are available to predict phosphorus concentrations based on annual loadings and lake characteristics. (Cooke, Welch, Peterson and Neuroth, 1984). The Model used in this study was reported by Dillon - Rigler, 1974. Application of this model to Lake Sallie yields the following:

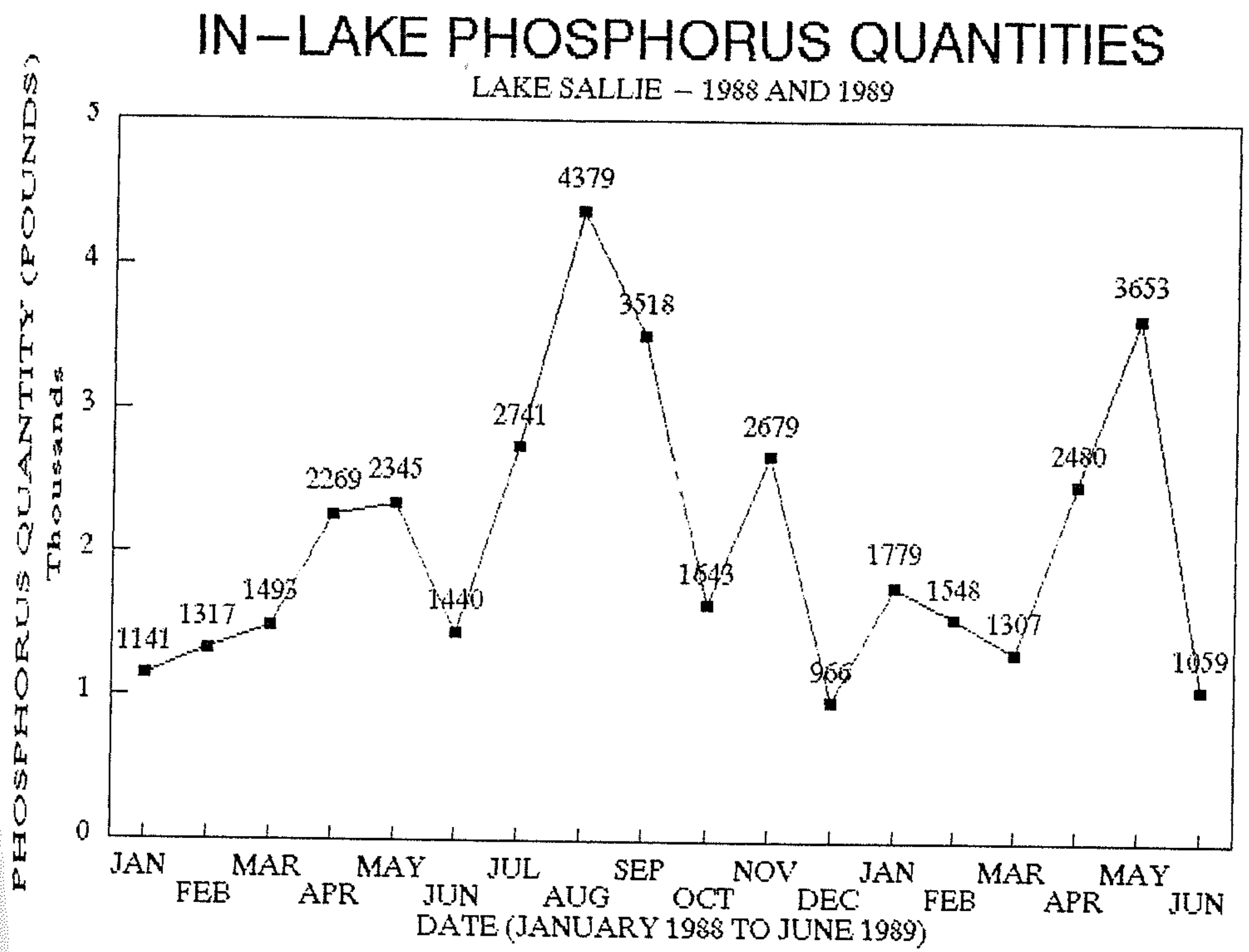


FIG. 24
LAKE SALLIE
IN-LAKE PHOSPHORUS
CONCENTRATION

$$[P] = \frac{L(1 - R_p)}{\bar{z}p}$$

where [P] = Total phosphorus concentration (average in-lake) after spring turnover and runoff (mg/l)

L = Areal phosphorus loading (external and internal loads) (g/m^2year)

$R_p = 0.426e^{(-.271A)} + .574e^{(-.00949A)}$ (Kirchener and Dillon, 1975)

$A = \frac{\text{Annual Outflow}}{\text{Lake Area}}$ (meters)

$\bar{z}$ = Mean Depth (5.2 meters)

p = Mean Detention Time $\frac{\text{Annual Outflow}}{\text{Volume}}$ ($Year^{-1}$)

Data from June 1, 1988 to June 1, 1989 led to a predicted [P] of 0.044 mg/l after spring runoff and turnover. The measured [P] was 0.042 mg/l (by interpolation). For application in predictions all variables should be calculated for the conditions being modeled. The estimated annual internal loading from Lake Sallie is 3,752 lb/year based on calibration with 1988 data. Sample calculations can be found in the Appendix.

2. Chlorophyll-a

For predictive purposes a relationship between total phosphorus levels and chlorophyll-a was established based on the 1988 data. The equation derived from analysis of the field data is as follows:

$$[\text{Chlorophyll-a}] = .0156[Pt]^{1.755}$$

where [Chlorophyll-a] = Chlorophyll-a concentration (g/l)

[P] = Total phosphorus concentration (g/l)

The correlation coefficient was 0.67. This relationship compares to the relationship between chlorophyll-a and total phosphorus reported by Carlson (1977):

$$[\text{Chlorophyll-a}] = .0870[P_t]^{1.449}$$

Both equations were based on summer data. A plot of the measured summer data, the regression line of the data, and the theoretical chlorophyll-a based on Carlson's equation can be found in Figure 25.

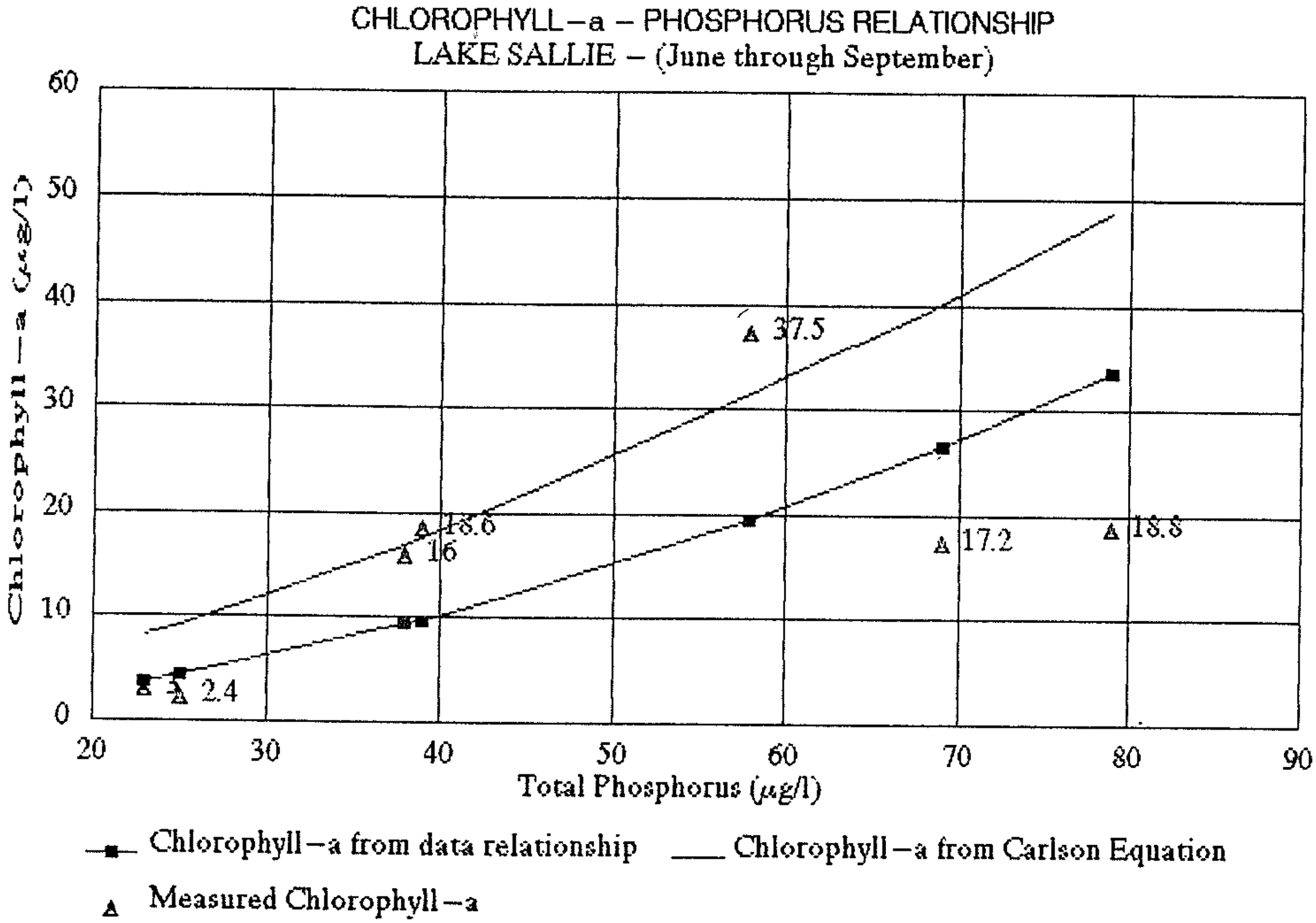
3. Transparency

A relationship exists between the transparency of water to light and the measurement of algal biomass concentrations. Therefore, the secchi disk measurements were plotted against chlorophyl-a measurements on a logarithmic basis, Figure 26, yielding the following relationship:

$$\text{Secchi Depth} = 4.06 \div (\text{Chl-a}^{0.4})$$

The correlation coefficient for the regression line was 0.54.

The relationship indicated by the data compares favorably to the relationship between transparency and chlorophyll-a reported by Carlson, (1977). This relationship is as follows:



Data Eq'n: $\ln[Chl]=1.755*\ln[P]-4.160$ ($r^2=.67$)
Carlson Eq'n: $\ln[Chl] = 1.449*\ln[P]-2.442$

FIG. 25
LAKE SALLIE
CHLOROPHYLL-a-PHOSPHORUS RELATIONSHIP

$$\text{Secchi Depth} = 7.7 \div \text{Chl a}^{0.68}$$

The 1988 measured transparency readings were also plotted against chlorophyll-a concentrations on a linear scale. The regression of the data yielded a correlation coefficient (r^2) of 0.45.

For predictive purposes the relationship established on a logarithmic basis will be used since it has the highest correlation coefficient. Based upon this relationship, chlorophyll-a levels would have to be reduced to approximately 10 mg/l or less to achieve desirable Secchi Disk readings.

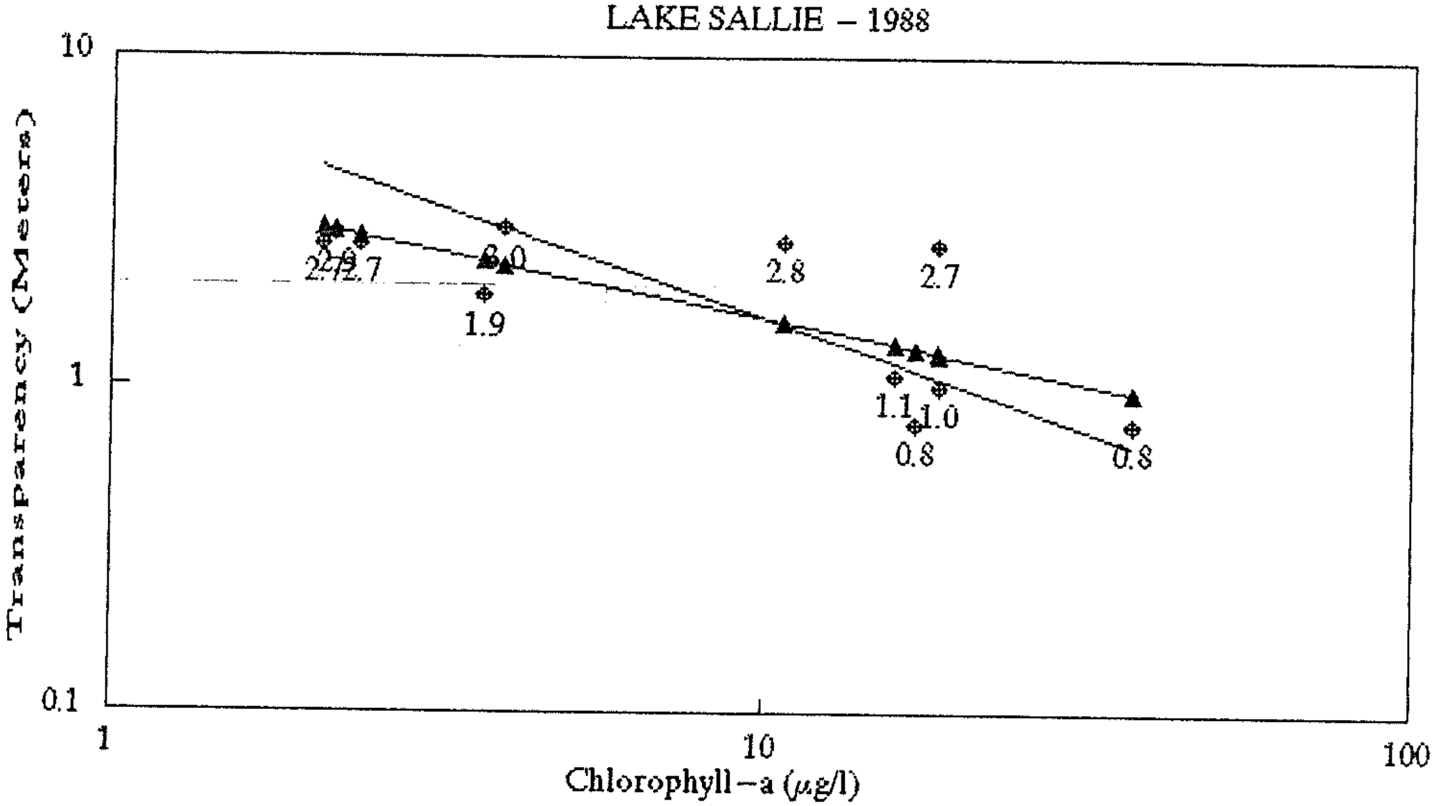
4. Temperature and Dissolved Oxygen

Lake Sallie was thermally mixed in 1988 until May, when thermal stratification begins to take place. On June 7, 1988 a well defined thermocline was present from 3 to 6 meters in depth. By July 7, 1988 testing date, the thermocline had completely dissipated and lake temperatures were uniformly between 21° and 24° Celsius. Uniform thorough mixing was apparent throughout the fall and winter months of 1988.

Graphic representations of dissolved oxygen versus depth build a predictable pattern of oxygen depletion and restoration. Dissolved oxygen levels in depths below light transparency during winter months continue to decline from November until March, when lower depth oxygen concentrations are nearly zero.

TRANSPARENCY AND CHLOROPHYLL-a

LAKE SALLIE – 1988



—— Theoretical Transparency

⊕ Measured Transparency

—▲— Logarithmic Regression of Measured Trans

Theoretical Transparency = 7.7/(Chlor-a ^ .68)
Regression of Meas'd Trans. = 4.06/(Chlor-a ^ .4)

FIG. 26
LAKE SALLIE
TRANSPARENCY
AND

Spring turnover yielded dissolved oxygen concentrations uniformly through the lake strata of approximately 9 milligrams per liter, then declining at lower depths as thermal stratification began to occur. In June, 1988, oxygen levels in the hypolimnion rapidly were depleted in conjunction with the development of the thermocline. August and September yielded almost linear depletions of oxygen from 8 milligrams per liter at the surface to almost zero at the bottom.

A method of comparing oxygen depletion from lakes was developed by Strom in 1931. The term relative oxygen deficit compares the difference between the oxygen content of the hypolimnion and the oxygen content at the end of spring turnover. A review of Lake Sallie determined that the hypolimnion oxygen deficit from April 25 to June 7, 1988 was 46.84 metric tons. Conversion of this factor to the hypolimnion area resulted in a value of difference in oxygen during this period of approximately 1.15 milligrams per square centimeter per month. This value would indicate a meso-eutrophic lake (Wetzel, 1975). The relative areal oxygen deficit may not be a good indicator of the productivity of Lake Sallie since the hypolimniom is anaerobic or nearly anaerobic during a portion of the stratification period.

A significant effect of the depletion of dissolved oxygen in the hypolimneum strata during June, 1988 was the increase in phosphorus release from the sediments. As oxygen depletion occured phosphorus levels increased several times over, indicating nutrient rich sediments in the lake.

5. Nutrient Limitation

The primary element in the examination of lake dynamics is an evaluation of the limiting nutrient. The common nutrients that limit algae growth in a lake system are phosphorus and nitrogen. Phosphorus is commonly the first limiting nutrient in a vast majority of lake systems. The phosphorus limitation is usually only overcome in systems that contain extremely high phosphorus concentrations, thereby reducing the total nitrogen to total phosphorus ratios to less than 12.

A comparison of the total nitrogen to total phosphorus for surface water samples in Lake Sallie was analyzed. The average $N_T:P_T$ ratio was 47.5, which suggests that phosphorus is the limiting nutrient. The values ranged from 33 to 90. The ratio was very consistent during the spring and summer, ranging from 33 to 50. It appears that the affect of storm water runoff in 1988 did not significantly alter the ratio, although the runoff in 1988 was well below average.

The relationship between total phosphorus and chlorophyll-a for 1988 is compared in Figure 10. In general, as phosphorus concentrations exceed 0.04 mg/l, chlorophyll-a levels increase to approximately 20 which is generally considered a nuisance condition. Phosphorus levels exceeding 0.04 mg/l were exceeded in August and early September of 1988.

Lake phosphorus average concentrations of 0.04 mg/l correspond to approximately 2,300 pounds of inlake phosphorus. If the net phosphorus loading to Lake Sallie was 2,300 pounds, the phosphorus loading to the area would be 0.22 grams/square meter. By comparison, Vollenweider estimated that the permissible phosphorus loading of a total of these characteristics is 0.07 g/m^2 or 755 pounds and dangerous loadings are 0.13 g/m^2 or 1,400 pounds. A reduction in the phosphorus loadings to Lake Sallie therefore, should be beneficial in reducing algal growth and nuisance conditions. Models established in previous sections can be used to predict the effects of reduced phosphorus loadings.

6. <u>Trophic State</u>

A Trophic State Index (TSI) was computed for the minimum transparency readings based upon the following equation as presented by Carlson, 1979. The equation is as follows:

TSI = 60 - (14.41)(ln secchi disk in meters).

The calculated measurement for a secchi disk reading of 0.77 meters = a TSI of 64.

Values ranging from 50 to 100 would define various stages of a eutrophic lake. To attain a summer transparency value of 50 or less, the secchi disk reading would have to be increased to approximately 1.6 meters. The secchi disk readings have been plotted against time and are presented in the Appendix.

The trophic state index for the annual average chlorophyll-a and summer average was computed for the following equation:

$$TSI = 9.8 \ln \text{Chlorophyll } (mgm^{-3}) + 30.6$$

The values were 56.5 and 60.7, respectively.

The Carlson Trophic State Index (TSI) for the phosphorus concentrations was completed according to the following equation:

$$TSI = 14.42 \ln P_T(mgm^{-3}) + 4.15$$

The summer and annual average phosphorus TSI in 1988 was 60 and 56, respectively. These values fit the lake classification for a eutrophic lake, characterized by decreased transparency and increased macrophyte problems.

A summary of the trophic state indexes previously presented are as follows:

TABLE XVIII LAKE SALLIE: TROPHIC STATE INDEX (TSI)

Parameter	TSI Summer	TSI Annual	Classification
Secchi Disk	64	-	Eutrophic
Chlorophyll-a	61	57	Eutrophic
Phosphorus	60	56	Eutrophic

The lower range of a eutrophic category is 50. As stated previously, secchi disk readings must be greater than approximately two meters to consider the TSI less than 50.

The general relationship between total phosphorus, chlorophyll-a and secchi depths determined in 1988 are:

TABLE XIX LAKE SALLIE: P_T, CHLOROPHYLL-a, SECCHI DISK RELATIONSHIP

P_T (mg/l)	Chlorophyll-a (mg/l) (By Carlson Eqn)	Secchi Disk (m) (By Data)
0.02	6.7	1.9
0.04	18.2	1.3
0.06	32.8	1.0

7. <u>Water Quality Goals</u>

Based upon the preceding analysis of water quality characteristics, interrelationships have been developed between the major parameters that are indicators of water quality. In order to establish water quality goals for Lake Sallie, it is important to begin with the most important element, the limiting nutrient which is phosphorus.

The Dillon-Rigler model used for evaluation of in-lake phosphorus concentration compared favorably with field data information and will be used to evaluate change in lake characteristics. A summary of the reduction in phosphorus loading to achieve lower levels of phosphorus concentrations and changes in chlorophyll-a and secchi disk readings in presented in Table XX.

TABLE XX - LAKE SALLIE WATER QUALITY CHARACTERISTICS FROM DILLON-RIGLER MODEL

P_T (mg/l) From Model	$L(g/m^2/yr.)$ Area P Load
0.015	0.196
0.02	0.216
0.025	0.326
0.03	0.391
0.035	0.457
0.04	0.522
0.045	0.587

The 1988 early summer conditions based upon data are characterized by average total in-lake phosphorus concentrations of approximately 0.04 mg/l.

Limited water quality testing of local lakes suggest that, on the average, the summer phosphorus levels of Lake Sallie are above levels of most area lakes. By comparison, Detroit Lake average in-lake levels can be expected to be 0.03 mg/l and Floyd Lake levels of 0.01 mg/l. The public perception of lake quality has a correlation to the phosphorus levels. Lake Sallie is generally characterized as experiencing significant improvements since the 1970's, but still exhibits nuisance conditions including extensive weed growth and algae blooms. Detroit Lake has begun a notable decline in water quality in the last 50 years, but is generally regarded as experiencing less nuisance conditions than Lake Sallie. Floyd Lake is considered to be of superior water quality to both Detroit Lake and Lake Sallie.

The goal for Lake Sallie is to reduce in-lake phosphorus concentrations to attain improved water quality characteristics. The following relationships have been developed, based upon evaluation of the data:

TABLE XXI - WATER QUALITY RELATIONSHIPS

P_T (mg/l) From Model	Chlorophyll-a 1/ (mg/l)	Secchi 2/ Disk (m)
0.015	4.4	2.25
0.02	6.7	1.90
0.025	9.2	1.67
0.03	12.0	1.50
0.035	15.0	1.37
0.04	18.2	1.27
0.045	21.6	1.19

1/Carlson Equation
2/From Data

In order to attain water quality characteristics similar to Detroit Lake, the desirable minimum water quality characteristics for summer values of chlorophyll-a and secchi disk readings of 12.0 mg/l and 1.5 meters, respectively.

B. LAKE DETROIT

1. Phosphorus

Based on the relationship between lake productivity and total phosphorus concentrations in the epilimnion as discussed for Lake Sallie, Detroit Lake would be considered meso-eutrophic to eutrophic.

Ortho phosphorus sampling performed in conjunction with total phosphorus sampling indicates that ortho phosphorus concentrations are generally much lower than total phosphorus concentrations. Similar to lake Sallie, ortho phosphorus concentrations do increase substantially during summer thermal stratification.

Surface phosphorus concentrations are summarized as follows:

TABLE XXII DETROIT LAKE: SURFACE PHOSPHORUS
March, 1988 - May, 1989

Parameter	n	Average June - September	Annual Average March, 1989 - February, 1990	Range
Total Phosphorus	19	.026	.020	.008 - .039
Ortho Phosphorus	19	.006	.007	ND - .027

Average 1988 phosphorus levels from June to September at five to six meters are slightly lower than phosphorus levels at this depth in 1982 during the same time of year.

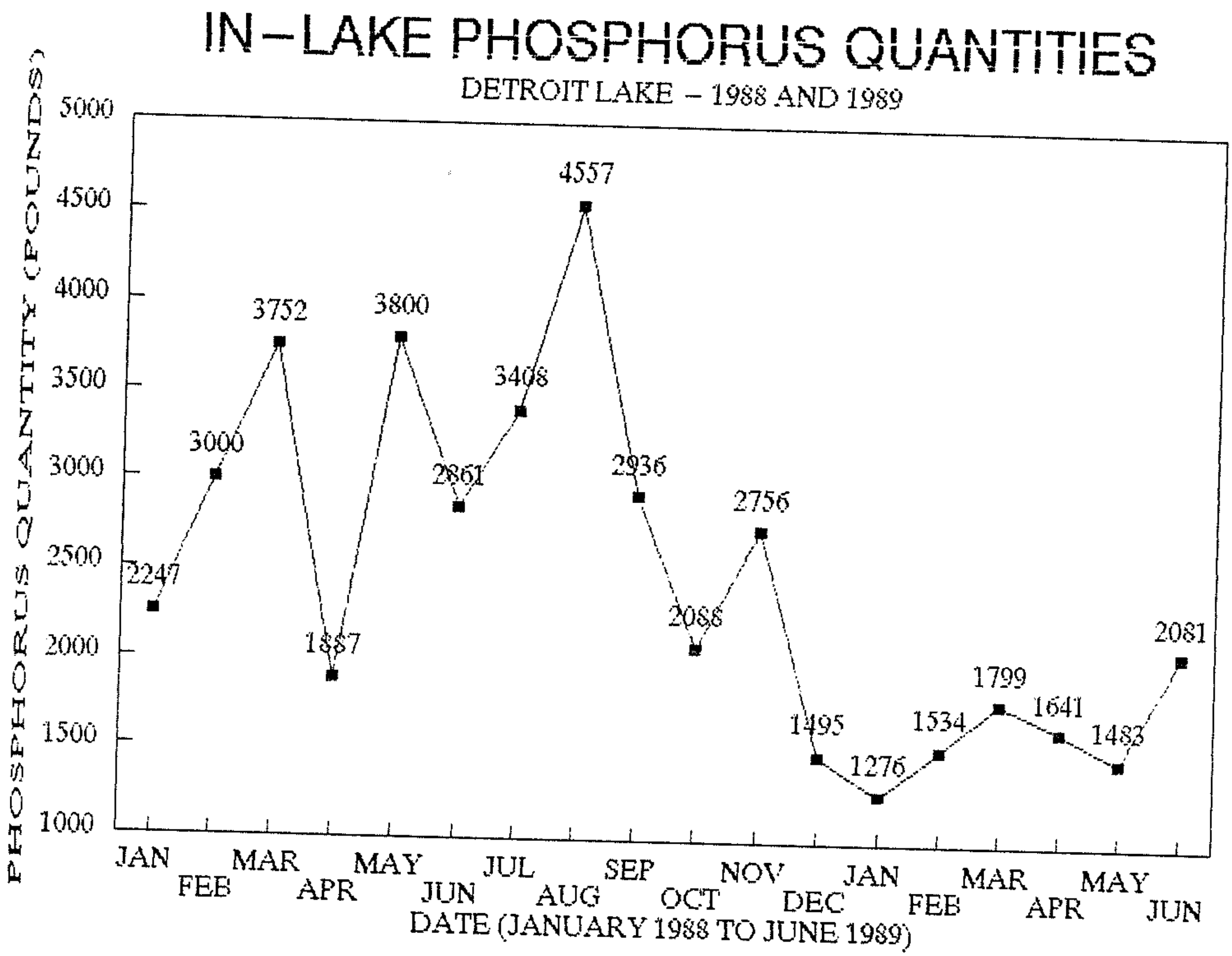


FIG. 27
DETROIT LAKE
IN-LAKE PHOSPHORUS
QUANTITIES

The total phosphorus quantity in Detroit Lake was determined for each month from January, 1988 through June, 1989. The in lake phosphorus quantity ranged from 1,268 pounds in January, 1989 to 4,557 pounds in August of 1988. The peak suspended phosphorus appears to coincide with the maximum thermal stratification in the lake. This would be expected due to the release of phosphorus from bottom sediments. The initial peak of suspended phosphorus seems to be largely due to the inflow of phosphorus to the lake during spring runoff.

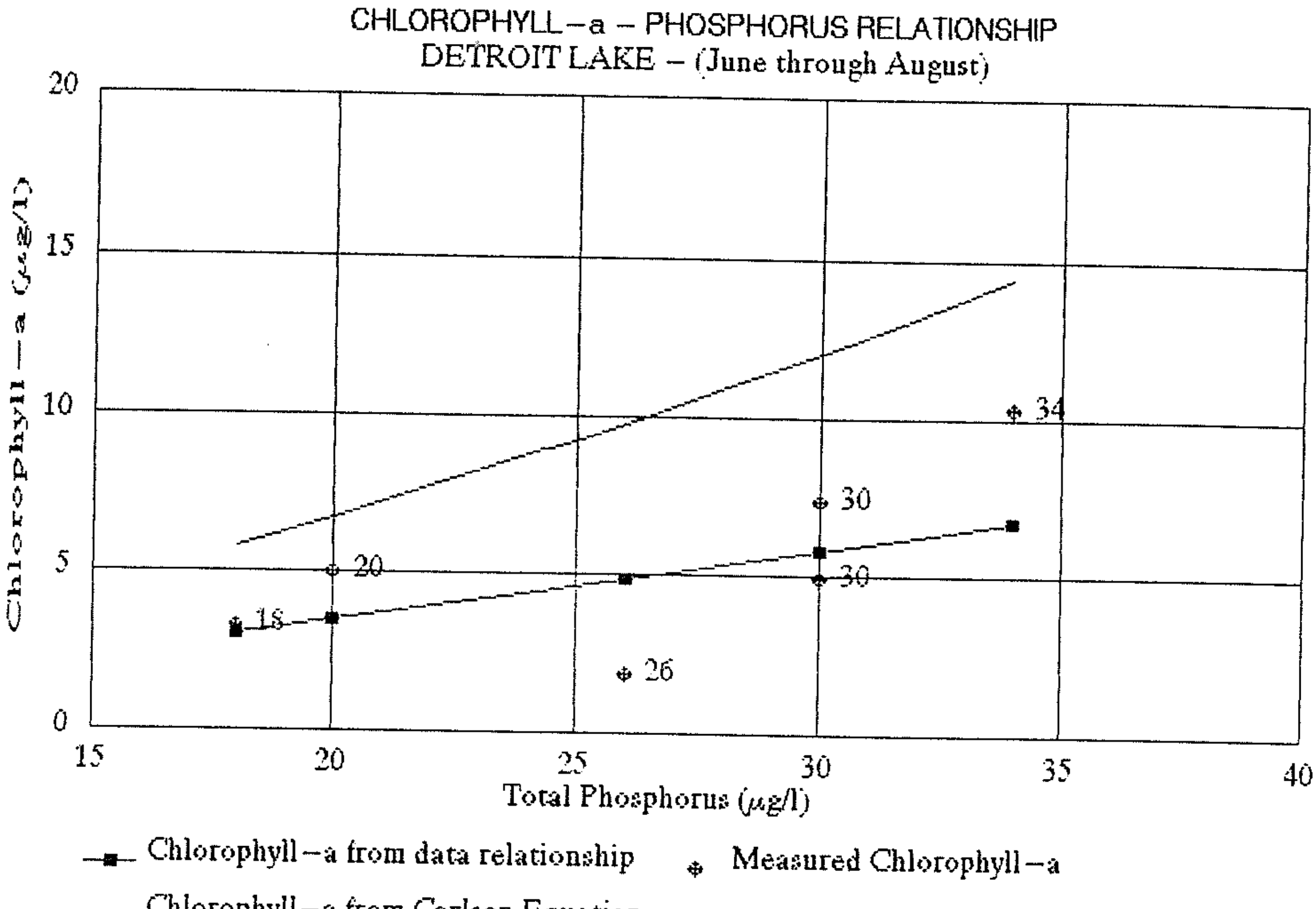
As discussed for Lake Sallie, the Dillon and Rigler model was also applied to Detroit Lake. Using data from June 1, 1988 to June 1, 1989, the model predicted an average total phosphorus concentration of .0.016 mg/l for June 1, 1989. This compares to a measured concentration of .0142 mg/l (by interpolation). The estimated annual internal loading is 2,250 lb/year. Sample calculations can be found in the Appendix.

2. <u>Chlorophyll-a</u>

As discussed for Lake Sallie, a relationship between chlorophyll-a and total phosphorus levels was established. The equation derived from analysis of field data is:

$$[\text{Chlorophyll-a}] = .0830[P_t]^{1.247}$$

where all variables are as defined for Lake Sallie.



Data Equation: $\ln[Chl]=1.247*\ln[P]-2.489$ ($r^2=.28$)
Carlson Equation: $\ln[Chl]=1.449*\ln[P]-2.442$

FIG. 28
DETROIT LAKE
CHLOROPHYLL-a-PHOSPHORUS
RELATIONSHIP

The correlation coefficient was $r^2 = .28$. This compares to the relationship reported by Carlson (1977).

$$[\text{Chlorophyll-a}] = .0870[P_t]^{1.449}$$

Both equations are based on summer data. A plot of the measured summer data, the regression line of the data, and the theoretical chlorophyll-a based on the Carlson equation can be found in Figure 28.

3. Transparency

A plot of secchi disk measurements versus chlorophyll-a measurements is presented in Figure 14. Regression analysis of the natural logarithms of the data yielded the following relationship:

$$\text{Transparency} = 5.2/[\text{Chlor-a}]^{.36}$$

The correlation coefficient was $r^2 = .29$.

The relationship indicated by the data compares to the theoretical relationship reported by Carlson (1977) as discussed for Lake Sallie:

$$\text{Transparency} = 7.7/[\text{Chlor-a}]^{.68}$$

Examination of the plot of the measured data and its regression line in Figure 14 and the low correlation coefficient indicates a weak relationship from the field data. If two of the

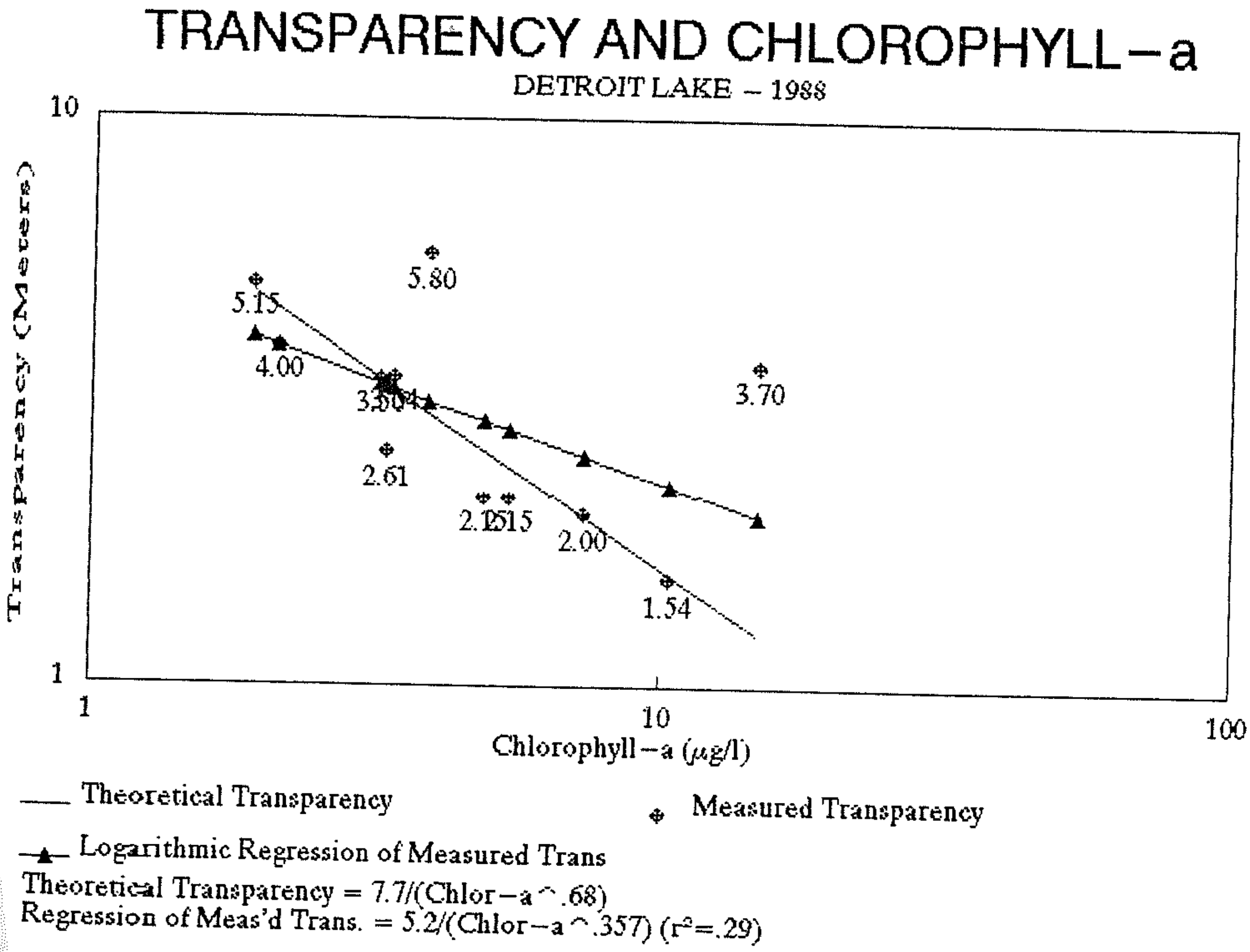


FIG. 29

DETROIT LAKE
TRANSPARENCY
AND

readings are thrown out, the data appears to more closely fit the transparency readings predicted by the Carlson equation presented above.

Regression analysis of the field data on a linear basis yielded a correlation coefficient of $r^2 = .19$.

For Detroit Lake it appears that a reduction of chlorophyll-a to 7-8 mg/l or less will result in desirable transparency readings of two meters or greater.

4. Temperature and Dissolved Oxygen

As with Lake Sallie, oxygen depletion and restoration can be predicted based upon a graphical representation of dissolved oxygen versus depth. In Detroit Lake dissolved oxygen concentrations beginning in November from a high of 12-13 mg/l decline in direct proportion to depth throughout the winter to levels near zero mg/l at the lower depths in March. Spring turnover yields uniform concentrations near 9 milligrams per liter. Concentrations decline throughout the summer as thermal stratification occurs, with dissolved oxygen levels near zero in the hypolimnion. In August and September the dissolved oxygen begins to move downward with total mixing occuring again in October.

The relative areal oxygen deficit as discussed for Lake Sallie was also calculated for Detroit Lake in 1988. The value was 1.06 milligrams per square centimeter per month which indicates the lake is in the mesotrophic production stage. The relative oxygen deficit may be a poor indicator of productivity for Detroit Lake since the hypolimnion was anaerobic or near anaerobic for a large part of the stratification period (April 25 to August 9). (Wetzel, 1975.)

As observed in Lake Sallie in 1988, phosphorus was released from the sediments into the hypolimnion during thermal stratification, indicating nutrient rich sediments in Detroit Lake as well as Lake Sallie.

5. Nutrient Limitation

The nutrient limitations are generally determined by nitrogen and phosphorus. The ratio of nitrogen to phosphorus generally only becomes nitrogen limiting when the ratio is less than 12.

The N:P ratio based upon Kjeldahl nitrogen and total phosphorus concentrations ranged from 38 to 120. The annual average N:P ratio for 1988 was 73 and the summer average declined to 50. However, based upon this information, phosphorus is considered the limiting nutrient throughout the growth season in Detroit Lake.

A graph was developed to determine the total phosphorus and chlorophyll-a relationships for 1988 (Figure 19). In most comparisons, increases in total phosphorus levels result in increased chlorophyll-a concentrations. Although this relationship is not as evident as Lake Sallie's from this relationship, reduction in phosphorus levels to 0.025 mg/l or less would likely reduce chlorophyll-a concentrations to levels consistently below 10 mg/l. Phosphorus concentrations exceeded 0.25 mg/l in August and September of 1988.

If a concentration of 0.025 mg/l of phosphorus was attained in Detroit Lake, the inlake phosphorus would equal 3,100 pounds. An annual loading rate of 3,100 pounds to Detroit Lake would equal 0.11 grams per square meter. This value is above the permissible loading rate of 0.07 grams/square meter as proposed by Vollenweider and is approaching the 0.13 g/m^2 level, which is considered dangerous. Models developed in previous sections can be used to predict effects on water quality if phosphorus levels are reduced.

6. Trophic State

The Trophic State Index (TSI) for the minimum readings was computed to be 54. Values of TSI ranging from 50 to 100 would define various stages of an eutrophic lake. To achieve a TSI of less than 50, the minimum secchi disk reading would have to be greater than two meters.

The trophic state index for the annual average and summer average chlorophyll-a based upon the following equation derived by Carlson are:

$$TSI = 9.8 \ln \text{chlorophyll} + 30.6$$

The values are 47.7 and 47.3, respectively.

The trophic state indices for Detroit Lakes based upon summer and annual surface phosphorus concentrations are 51 and 47.

The trophic state indexes for Detroit Lake are summarized below:

TABLE XXIII DETROIT LAKE: TROPHIC STATE INDEX

Parameter	TSI Summer	TSI Annual	Classification
Secchi Disk	54	-	Eutrophic
Chlorphyll-a	47	48	Meso-eutrophic
Phosphorus	51	47	Meso-eutrophic

The approximate upper level of meso-eutrophic conditions is 50. Therefore, the trophic state characterization of Detroit Läke would likely be borderline between meso-eutrophic and eutrophic.

The general relationship between total phosphorus, chlorophyll-a and secchi depths as compared in 1988 would be:

TABLE XXIV DETROIT LAKE: P_T, CHOROPHYLL-a, SECCHI DISK RELATIONSHIP

P_T(mg/l)	Chlorophyll-a (g/l) (By Data)	Secchi Disk (m) (By Carlson)
0.01	1.47	5.92
0.015	2.43	4.52
0.02	3.48	3.30
0.025	4.60	2.73
0.03	5.77	2.34
0.035	6.99	2.05
0.04	8.30	1.80

7. Water Quality Goals

The water quality goal for Detroit Lake is improving lake conditions to levels considered generally acceptable for area lakes. This requires reducing nuisance conditions including reducing weed growth and reduction of the concentrations of algae growth.

The anticipated water quality characteristics for Detroit Lake, based upon the Dillon-Rigler model are as follows:

TABLE XXV DETROIT LAKE WATER QUALITY CHARACTERISTICS FROM DILLON-RIGLER MODEL

P_T (mg/l) From Model	$L(g/m^2/yr.)$ Area P Load
0.01	0.10
0.015	0.14
0.02	0.19
0.025	0.24
0.030	0.29
0.035	0.34

The data from 1988 conditions during the summer period after spring runoff approaches conditions in the 0.025 mg/l to 0.030 mg/l total in-lake phosphorus concentration. The water quality goal is to reduce the late summer phosphorus concentrations to 0.020 mg/l or less. The desired secchi disk would be approximately 3.5 meters, an improvement of between 0.5 to 1.0 meters for average spring and summer readings.

C. SUMMARY AND CONCLUSIONS

Conclusions from historical data, monitoring and analysis are evidence that Lake Sallie and Detroit Lake are experiencing declines in water quality conditions as a result of nutrient levels in the lake. The consequences of the nutrient levels, particularly phosphorus are resulting in nuisance conditions including reduced transparency and high algae growth conditions.

Lake Sallie has rebounded significantly from the high loads of phosphorus prior to 1976 as a result of improvements to the City of Detroit Lakes Wastewater Treatment Facility. A consequence of the previous high nutrient loading appears to be internal loading of phosphorus as identified in August and September, 1988. The result was the export of phosphorus from Lake Sallie in 1988. Lake Sallie responded to the nutrients associated with surface runoff in the spring of 1988.

Detroit Lake exhibited responses to nutrient loading, but of a different magnitude. Phosphorus level increases during spring snowmelt and runoff is evident from in-lake phosphorus levels in the spring. Oxygen depletion of the hypolimnion beginning in June, 1988 was followed by internal loading of phosphorus in August and September, resulting in increased algae production. In contrast to Lake Sallie, Detroit Lake retained phosphorus in 1988, based upon inflow/outflow monitoring.

The initial phase of lake restoration, based upon this study, indicates that nutrient inputs to Lake Sallie and Detroit Lake must be controlled. The specific characteristics of each watershed and uses within the drainage areas must be evaluated to determine approaches to nutrient management to each lake.

VI. WATERSHED ASSESSMENT

A. LAKE SALLIE

The watershed assessment for Lake Sallie considers the contributions of runoff and nutrients to the lake and the characteristics of the lake watershed.

1. Watershed Description

The watershed contributing to Lake Sallie was reviewed to evaluate hydraulic and nutrient contributions to the lake.

a. Shoreline

Lake Sallie is predominately developed along the shoreline with seasonal and year-round residences. The total number of residences is approximately 200. The Department of Natural Resources operates a fish hatchery on the northeast shoreline of this lake.

b. Wastewater Treatment Facility

Operation records indicate that the City wastewater treatment facility is currently discharging 1,120 to 1,460 acre-feet of wastewater per year. The plant disposes of the treated wastewater in summer by spray irrigation on the airport site and by the use of rapid infiltration basins. This discharge does not impact surface flows.

During winter the effluent is treated by chemical precipitation and discharged to County Ditch Number 14. This effluent must be treated to contain less than 1 mg/l of phosphorus. The amount discharged by each disposal method in 1988 is presented in Table XIV.

TABLE XXVI - 1988 TOTAL WASTEWATER FLOWS

Disposal Method	Time of Use	Acre-Feet Discharged	Percent of Total
Spray Irrigation	May-October	484	37.7
Rapid Infiltration	April-December	362	28.2
Chemical Precipitation	December-April	437	34.1
TOTAL		1,283	

Surface water contribution from the chemical precipitation process represented four percent of the flow entering Lake Sallie in 1988, based upon 437 acre-feet.

c. Feed Lots

2. Surface Flows

Surface water flows to Lake Sallie include the Pelican River, Monson Lake, Fox Lake and the direct unchannelized surface flow. The measurement of surface flow to Lake Sallie confirms that the Pelican River from Detroit Lake and Lake St. Clair is the major hydrologic contributor to the lake, comprising greater than 95 percent of the channelized surface flow in 1988. The measured flows to Lake Sallie in 1988 were:

TABLE XXVII SURFACE WATER INFLOW TO LAKE SALLIE (1988)

Source	Flow (cfs)	% of Total
Lake St. Clair	2,635	23
Pelican River (Detroit Lake)	8,450	74
Monson Lake	109	1
Fox Lake	173	2
TOTAL	11,367	100

Historically, the flow in the Pelican River inlet to Lake Sallie should be approximately 20,000 acre-feet. In 1988, climate conditions limited the flow to slightly more than 11,000 acre-feet.

The Pelican River inlet to Lake Sallie receives its flow contribution from Detroit Lake and County Ditch No. 14. During the flow monitoring, 75 to 80 percent of the flow was contributed from the Detroit Lake outlet.

County Ditch No. 14 collects surface water from the north watershed of the ditch, the City of Detroit Lakes urban runoff and treated effluent from the wastewater treatment facility prior to entering Lake St. Clair.

Adding the flows from the Long Lake outlet, the St. Clair outlet connects with the Pelican River.

Flow volumes for 1988 and 1989 at selected monitoring locations are shown in Figure 30 and Figure 30 and the following table:

TABLE XXVIII RUNOFF: SPRING 1988 VS SPRING 1989 (ac-ft)

Source	1988	1989
Long Lake	247	-
County Ditch #14	150	304
Lake St. Clair	1,781	2,824
Pelican River (Detroit Lake Outlet)	6,439	10,887
Lake Sallie Inlet	8,436	12,636
Lake Sallie Outlet	8,869	11,888

The land uses within the Lake Sallie Watershed areas range from agricultural to urban types. A summary of the approximate uses are as follows:

TABLE XXIX LAKE SALLIE WATERSHED: LAND USES (%)

Land Use	Acres	% of Total
Urban	1,072	8
Agricultural	3,821	26
Pasture	2,816	20
Wooded	2,802	19
Open Water	2,929	21
Wetland	838	6
TOTAL	14,278	100

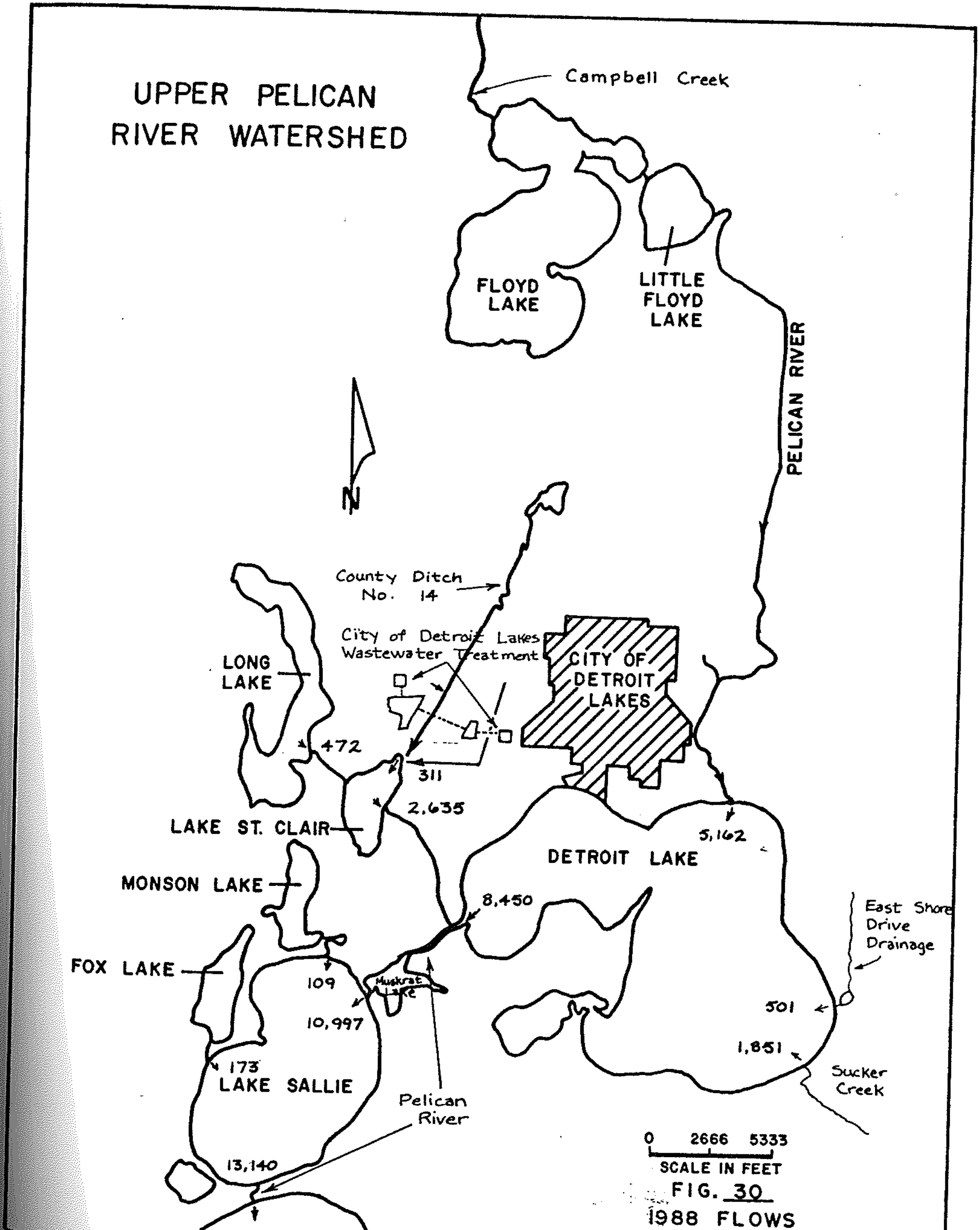


FIG. 30
1988 FLOWS
PELICAN RIVER WATERSHED

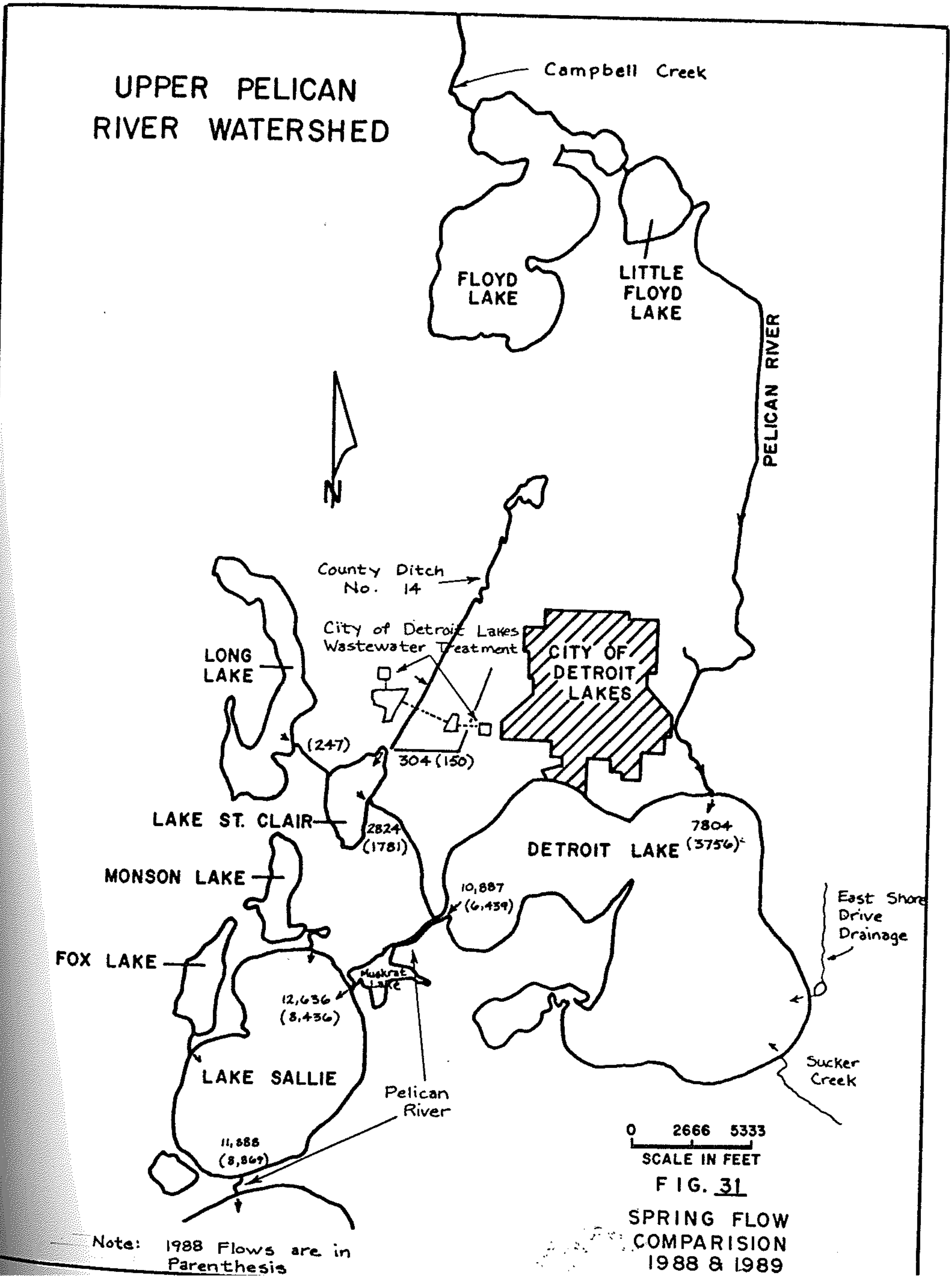


FIG. 31

SPRING FLOW
COMPARISION
1988 & 1989

3. Phosphorus Contributions

For Lake Sallie the primary source of phosphorus inflow is the Pelican River from Detroit Lake and Lake St. Clair. Data from 1988 indicates that approximately 820 pounds of phosphorus was contributed to Lake Sallie from the Pelican River. This represents about 52 percent of the total 1988 phosphorus input into the Lake. Approximately 470 pounds or 57 percent of this phosphorus loading was from Lake St. Clair. The inflow of phosphorus to Lake Sallie in 1988 from the Pelican River was below historical measurements and the result of dry weather conditions.

A review of historical phosphorus loadings to Lake Sallie and from St. Clair indicates the following:

TABLE XXX LAKE ST. CLAIR: PHOSPHORUS LOADING

Year(s)	Inflow to Lake Sallie Annual	St. Clair Outlet
1968-1970	24,440	-
1973	27,998	23,060
1974	21,252	12,963
1975	20,988	13,139
1978-1979	20,672	8,921
1979-1980	5,602	3,612

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.

The watershed for the portion of the Pelican River between Lakes Sallie and Detroit is dominated by urban, wetland, and open water land uses. Of these, the only significant contributor of phosphorus is the urban. Lake St. Clair provides an outlet for two branches of County Ditch Number 14. The north branch of this ditch receives effluent from the City of Detroit Lakes wastewater treatment facilities. The east branch receives storm water runoff from the west side of the City.

Modifications to the wastewater treatment facilities in 1976 have reduced the amount of phosphorus discharged to County Ditch Number 14. Prior to those improvements, phosphorus discharges from the facility exceeded 10,000 pounds annually. Based upon reports from the treatment facility, the surface water discharge in 1988 was 437 acre-feet, with a total phosphorus discharge of 614 pounds.

The quantity of phosphorus contributed to the river by storm water runoff from the west side of the City is more difficult to determine since the flow is buffered by wetland areas. The phosphorus in the storm water may not actually reach the river.

It appears the marsh areas on this branch of County Ditch Number 14 may buffer phosphorus loadings from the City to St. Clair Lake and the Pelican River to a degree. Based on area and urban runoff coefficients, under normal surface flow years, 900 to 1,000 pounds of phosphorus would be expected in runoff from the west side of the City.

The highest level of phosphorus concentration measurements in the Lake Sallie Watershed were monitored at Lake St. Clair. Based upon the 1983 Watershed - Lake Assessment Report, sediment buildup in the lake has occurred in the last 40 to 50 years. The result is a release of nutrients to the County Ditch, particularly in the spring. Based upon core samples and analysis in 1983, the upper four feet of sediment in lake St. Claire contains 19,000 kilograms of phosphorus which has a potential release to the drainage system.

As previously discussed in this report, Lake Sallie is substantially surrounded by residential development. The residences are served by individual septic systems, which total approximately 200 units. The average daily flow per residence is estimated to be 150 gallons per day maximum, as a result of seasonal residences. If the total flow is, therefore, 30,000 gallons per day, the phosphorus generated is 920 pounds per year, according to the Environmental Protection Agency estimates of 10 mg/l phosphorus concentrations in domestic wastewater. The phosphorus removal rate for septic tanks is approximately 30%. Therefore, the annual discharge to drainfields on Lake Sallie is estimated in the range of 500 to 600 pounds per year. It is beyond the scope of this project to determine the movement of phosphorus to Lake Sallie or to quantify the amount by measurement.

TABLE XXXI LAKE SALLIE WATERSHED: PHOSPHORUS SOURCES

Source	1988	Estimated Theoretical Annual Average
Surface		
Lake St. Clair	470	1,150 - 1,700
Detroit Lake Outlet	350	850 - 1,300
Wastewater Treatment Facilities	614	615
Septic Systems*	275	275

*Assuming 70% Efficient

B. DETROIT LAKE

Detroit Lake is dominated by the Pelican River and the characteristics of its Watershed. Minor contributing areas include Sucker Creek and contributing areas along East Shore Drive. The evaluation of the Detroit Lake Watershed includes land use characteristics and results of monitoring.

1. Watershed Description

The Watershed for Detroit Lake was evaluated to include the factors which may have an impact on the lake.

a. Inlet Channels

The Pelican River channel to Detroit Lake is part of the Becker County ditch system. The channel has been modified to increase the rate of runoff within the corporate limits of the City of Detroit Lakes and into the area north of T.H. No. 34 known as Rice Lake. An inspection report of the channel is in the Appendix. The channel is subject to some bank erosion.

b. Shoreline

According to the County Shoreline Ordinance, limitations on development activities should be considered within 1,000 feet of a lake and 300 feet of a river. Detroit Lake is highly developed along the lake perimeter. Adjacent properties are served by sanitary sewer with the exception of the east and south areas of Big Detroit Lake. The Pelican River is developed to the banks from the Lake to Highway No. 34. Agricultural use and wetlands are the shoreline characteristics of the Pelican River proceeding north from Highway No. 34.

c. Point Discharge

The major point discharges in the Watershed are the storm sewers from the City of Detroit Lakes. Figure 32 identifies the storm sewer inlets and the drainage areas for those inlets. The direct discharge to the river from the urban areas has a noticable impact on the river. A significant sediment load was observed on August 31, 1989 as a result of storm sewer contributions to the Pelican River. The urban phosphorus loading on the basis of an average of

1.12 lbs/acre/year is shown in Table XXXII.

TABLE XXXII DETROIT LAKE: STORM SEWER INLETS TO PELICAN RIVER

Runoff Area	Acres	Phosphorus (lbs)
1	335	375
2	23	25
3	12.3	14
4	12.3	14
5	9.3	10
6	9.3	10
7	5.2	6
8	8.3	9
9	30.7	35
10	43	48
11	46	52
13	26	29
14	21	24
15	18.5	21
16	24.6	30
TOTAL	624.5	702

2. Surface Flows

Surface flow contributors to Detroit Lake include the Pelican River, Sucker Creek and East Shore Drive. In 1988, the Pelican River contributed 69 percent of the surface to Detroit Lake. During the spring flows in 1989, the runoff from the Pelican

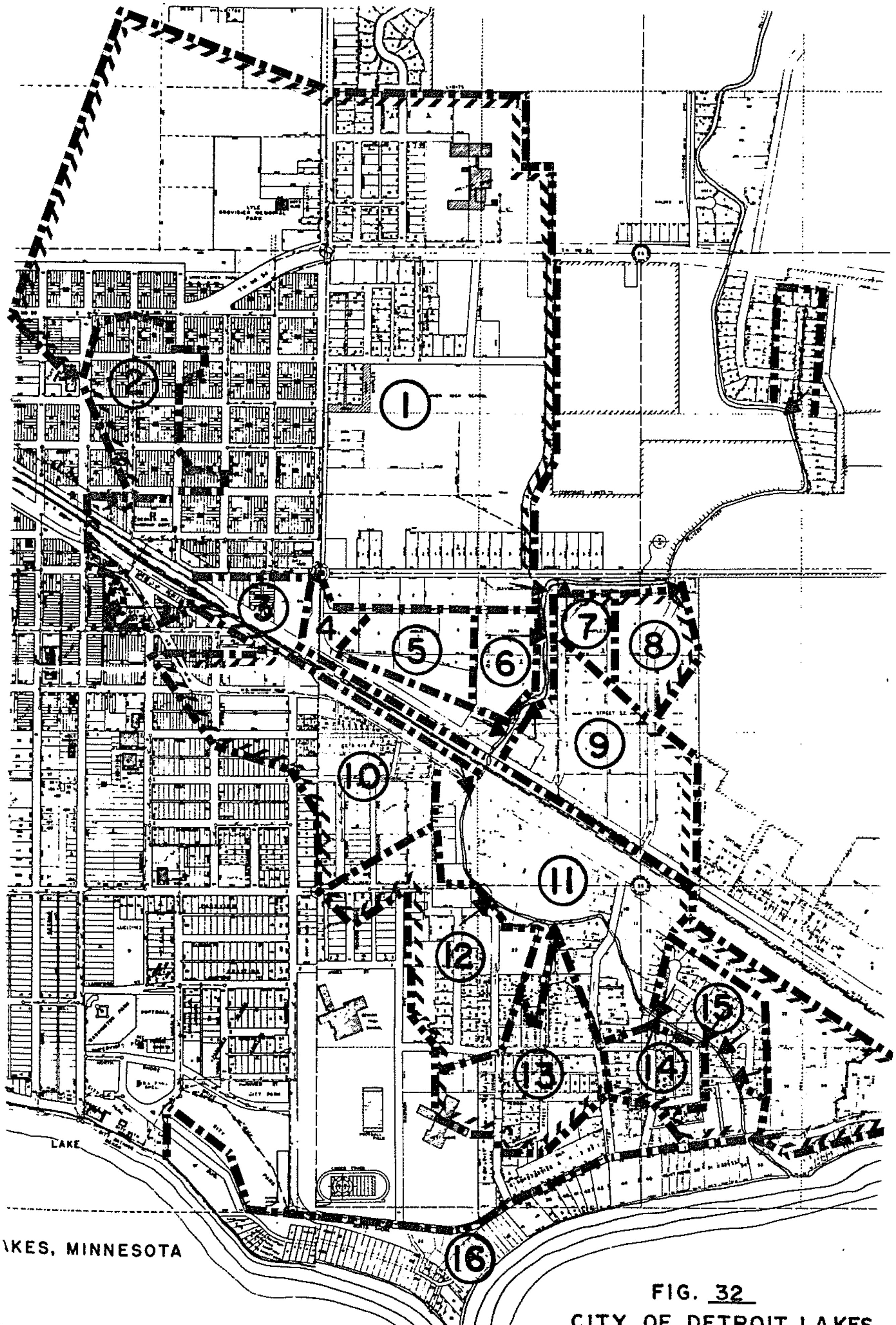


FIG. 32
CITY OF DETROIT LAKES
STORM SEWER

River exceeded the total flows of 1988. The flow from the Pelican River in Detroit Lake in 1988 was approximately a third of the volume that would be anticipated in a typical year.

3. Phosphorus Contributions

For Detroit Lake the area of concern is the river north of the lake and runoff from the City of Detroit Lakes into the river. Data from 1988 indicates that approximately 680 pounds of phosphorus were contributed to Detroit Lake from the Pelican River. This is about 35% of the total 1988 estimated phosphorus input. Phosphorus loading to the lake from the Pelican River would be expected to be higher during years with normal surface flows. Phosphorus loadings for the first six months of 1989 were 2.9 times the phosphorus loadings for the same period in 1988 at the Pelican River inlet to Detroit Lake.

The watershed for the reach of the Pelican River which flows into Detroit Lake consists of various land uses; urban, open water, marsh, forest, cropland, and pasture/open areas. Phosphorus exports from these different land uses are quite variable. Table XXXII presents an estimate of the phosphorus exports that could be expected from the various land uses in the watershed during a normal year. The values are based on available land use data and published phosphorus export values. Rechow, K.H., Simpson, J.T. 1980.

TABLE XXXIII ESTIMATED PHOSPHORUS EXPORTS

Pelican River North of Detroit Lake

Land Use	Size Acres	Phosphorus Export Coefficient (Lb/Ac/Yr)	Phosphorus Quantity (Lb/Yr)
Open Water	546	0	0
Forest	7,124	0.13	926
Farmstead	485	0.80	388
Agricultural	4,493	0.89	3,998
Pature/Open	3,962	0.36	1,426
Urban	1,002	1.12	1,122
Wetland	689	0.04	27
Total			7,887

Of the phosphorus exported from these areas annually, only a portion would be expected to reach the lake. The estimated 680 pounds of phosphorus that was contributed to Detroit Lake in 1988 is much less than the above table estimates. A possible explanation is that much of this phosphorus may be retained in wetlands or low areas and would not reach the river. Wetlands discharging to the river would release phosphorus to the lake, but only in small amounts. It is expected that nearly all phosphorous in runoff from the City of Detroit Lakes would reach the Pelican River and Detroit Lake.

It is evident that a contributor of phosphorus to the river is the phosphorus contributed by runoff from the City of Detroit Lakes. The average annual loading from the City would be expected to be approximately 1,000 to 1,200 pounds per year. Loading from other areas would be expected to be about 1,000 pounds per year or more based on 1988 observed loadings and estimation of normal surface flows. The total expected phosphorus loading from the City and remaining watershed could be 2,000 to 3,000 or more pounds annually.

There are approximately 270 residences along Big Detroit Lake which utilize individual treatment systems. The estimated daily flow from these systems is 70,000 gallons per day, based upon previous reports. The annual phosphorus input to those systems, using 10 mg/l phosphorus concentrations according to the U.S. Environmental Protection Agency estimates, is 2,130 pounds per year. This is approximately 1.2 kilograms per capita per day. The removal efficiency of phosphorus in a septic tank is estimated to be approximately 30% (Tyler, Converse and Parker, 1985). The reduction in the septic tank is the result of the phosphorus content of solids retained in the unit. Therefore, approximately 70% of the loading can be anticipated to discharge from the drainfield to the soils. For Detroit Lake, the annual estimated discharge to the soils is 1,490 pounds. The impact of this loading to the lake would be significant if the phosphorus is being released to the lake system. The efficiency of the treatment systems along Big Detroit Lake was not determined in the scope of this report.

C. AGRICULTURAL LIVESTOCK OPERATIONS

The livestock operations in the Pelican River Watershed District are dairy, beef, turkey and mink. The facilities in operation as of January, 1992 are as follows:

TABLE XXXIV LIVESTOCK OPERATIONS

TYPE	NO. OF ANIMALS	LOCATION TOWNSHIP	LOCATION SECTION	OWNER
Beef	75	Erie	6	Shafer
Beef	75	Erie	8	Triebenback
Turkeys	-	Erie	19	Disse
Turkeys	-	Detroit	12	Disse
Dairy	40	Detroit	23	Cleveland
Mink	-	Detroit	25	Hillcrest Mink
Beef	30	Detroit	25	Stall
Dairy	40	Burlington	19	Willie
Beef	25	Burlington	19	Bentley
Turkeys	-	Lake View	4	Taves
Turkeys	-	Lake View	15,26	Chelmo Bros.

The location map for these operations is included in the report. The Taves facility is located in the Lake Sallie Watershed and the remaining operations are in the Detroit Lake Subwatershed.

According to a publication by the Minnesota Pollution Control Agency, Running Your Feedlot, the daily elemental phosphorus generated by poultry is estimated to be 0.001 pounds and for beef 0.11 pounds.

LIVESTOCK OPERATIONS WITHIN THE WATERSHEDS OF DETROIT LAKE AND LAKE SALLIE

Key

Beef ★

Turkeys ●

Dairy ✱

Mink ■

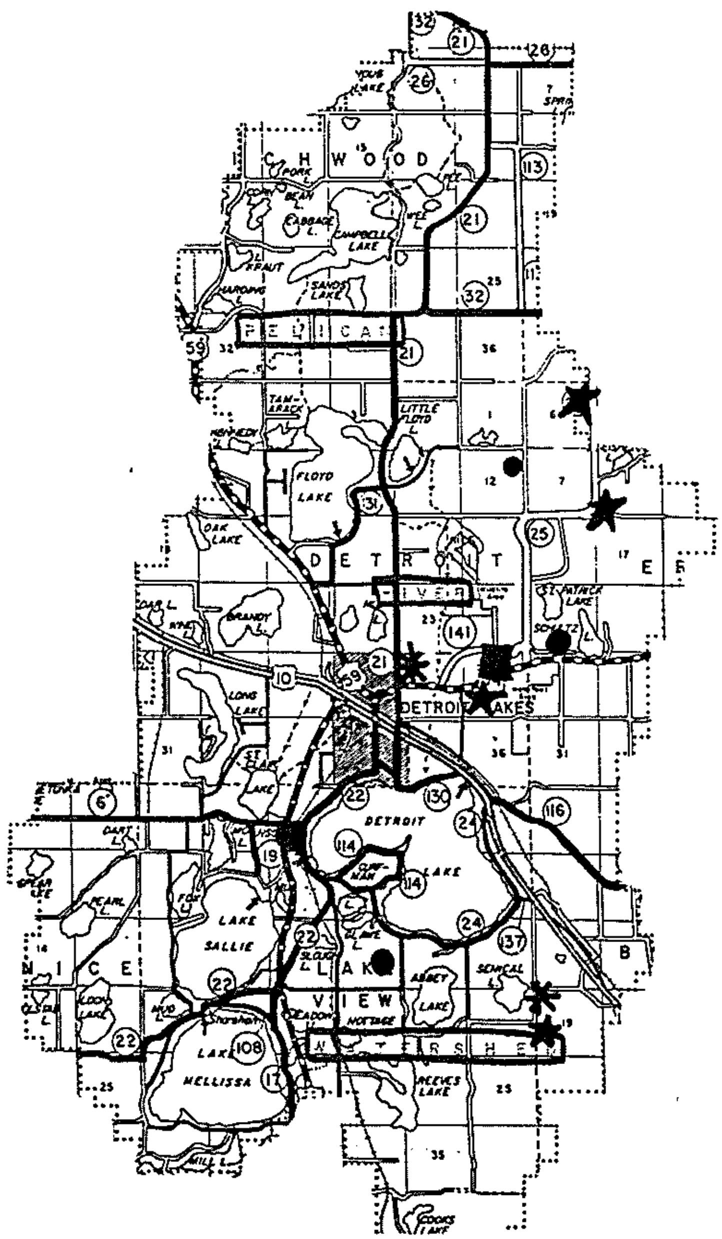


Fig 32

The annual phosphorus for the livestock operations within the District can be expected to range from 1,000 to 3,000 pounds per year. Based upon an average of 1,500 pounds per operation, the total phosphorus annually generated would be 16,500 pounds. This represents a significant quantity of phosphorus in relation to the annual nutrient contributions to Lakes Sallie and Detroit. Therefore, it is important that handling and disposal methods for the wastes are accomplished with an absolute minimum potential for movement in the surface waters. Best Management Practices (BMP's) for agricultural properties must include management of livestock operation.

D. CONCLUSIONS OF ANALYSIS

Conclusions from this study based upon historical data, monitoring and analysis are the evidence that Lake Sallie and Detroit Lake have declined in water quality as a result of modifications and urbanization of sensitive areas in the watershed of each lake. The consequences of these changes have been increased inputs of nutrients, particularly phosphorus, resulting in algal growth and internal recycling of phosphorus from the sediments.

Lake Sallie has rebounded significantly from the high loads of phosphorus prior to 1976 as a result of improvements to the City of Detroit Lakes Wastewater Treatment Facility. The residual of this loading of nutrients is an internal loading of phosphorus as identified in August and September of 1988 during a period of low inflow. Lake Sallie exported phosphorus in 1988 as a result of the internal cycling. Lake Sallie also demonstrated a phosphorus increase resulting from surface inflows. The response to spring snowmelt and runoff resulted in higher inlake phophorus levels in 1989 due to increased runoff compared to 1988.

Detroit Lake exhibited responses to nutrient loading, but of a different magnitude. Phosphorus level increases during spring snowmelt and runoff is evident from in-lake phosphorus levels in the spring. Oxygen depletion of the hypolimnion beginning in June, 1988 was followed by internal loading of phosphorus in August and September, resulting in increased algae production during these months. In contrast to Lake Sallie, Detroit Lake retained phosphorus in 1988, based upon inflow/outflow monitoring.

VII. RECOMMENDATIONS

A. GENERAL

The analysis of water quality and conditions of Lake Sallie and Detroit Lake provide evidence that improvemtns in lake conditions are necessary. The nutrient loadings are the rpimary cause of declines in water transparency and increased algae levels. The reduction of phophorus levels in each lake will be a major factor in lake restoration.

A summary of the goals for phosphorus reduction as compiled for data collection and analysis is as follows:

	LAKE SALLIE	DETROIT LAKE
1988 P_T Measured (lbs.)	817	1925
Total Estimated	2,000 - 5,000	2,500 - 3,500
Reduction Goal (lbs./yr.)	1,000	1,300

The goal reductions are based upon the Dillion-Rigler evaluations for water quality improvements based upon the previously stated goals.

B. LAKE RESTORATION ALTERNATIVES

The following are the restoration alternatives that were considered in view of the need to reduce the phosphorus concentrations of each study lake:

RESTORATION ALTERNATIVES

Technique	Method
1. External Nutrient Loading Reduction	
a. Diversion/Treatment of Runoff	Reduction of external phosphorus loading by removal of direct inputs or treatment of those sources.
b. Diversion/Treatment of Wastewater	Diversion of wastewater from the lake systems or improved treatment.
c. Management Practices	Voluntary and mandatory method of watershed management to reduce nutrient sources to the study lakes.
2. Inlake Nutrient Control	
a. Sediment Removal	Dredging of sediment deposits to reduce internal loading of nutrients.
b. Hypolimetic Aeration or Withdrawal	Aeration of the hypolimnion to eliminate oxygen depletion and subsequent internal nutrient loading or withdrawal and discharge of the hypolimnion to remove nutrient rich water.
c. Phosphorus Precipitation	Addition of a chemical such as alum to precipitate phosphorus.
d. Dilution and Flushing	Substantial increases in the volume of inflow to reduce residence time and flush phosphorus and algae from the lake.

Technique	Method
3. Biomass Control	
a. Artificial Circulation	Destratification of the lake by circulation to reduce internal loading and subsequent algal production.
b. Harvesting	Mechanical harvesting of aquatic vegetation to remove nuisance plants in the littoral zone and biomass nutrient removal.
c. Biological Controls	Control of biological growth through manipulation of biological interactions.

C. RECOMMENDED IMPROVEMENTS

The alternatives presented below represent major alternatives recommended for the reduction of phosphorus inflow:

1. LAKE ST. CLAIR BYPASS (Lake Sallie)

This study and previous testing identify County Ditch No. 14 as the largest single contributor of phosphorus to Lake Sallie. The sources of phosphorus upstream on County Ditch No. 14 are the Detroit Lakes Wastewater Treatment Facility, agricultural and urban runoff and phosphorus export from Lake St. Clair. Consideration was given to the effective use of Lake St. Clair to retain existing phosphorus and control future runoff and sediment.

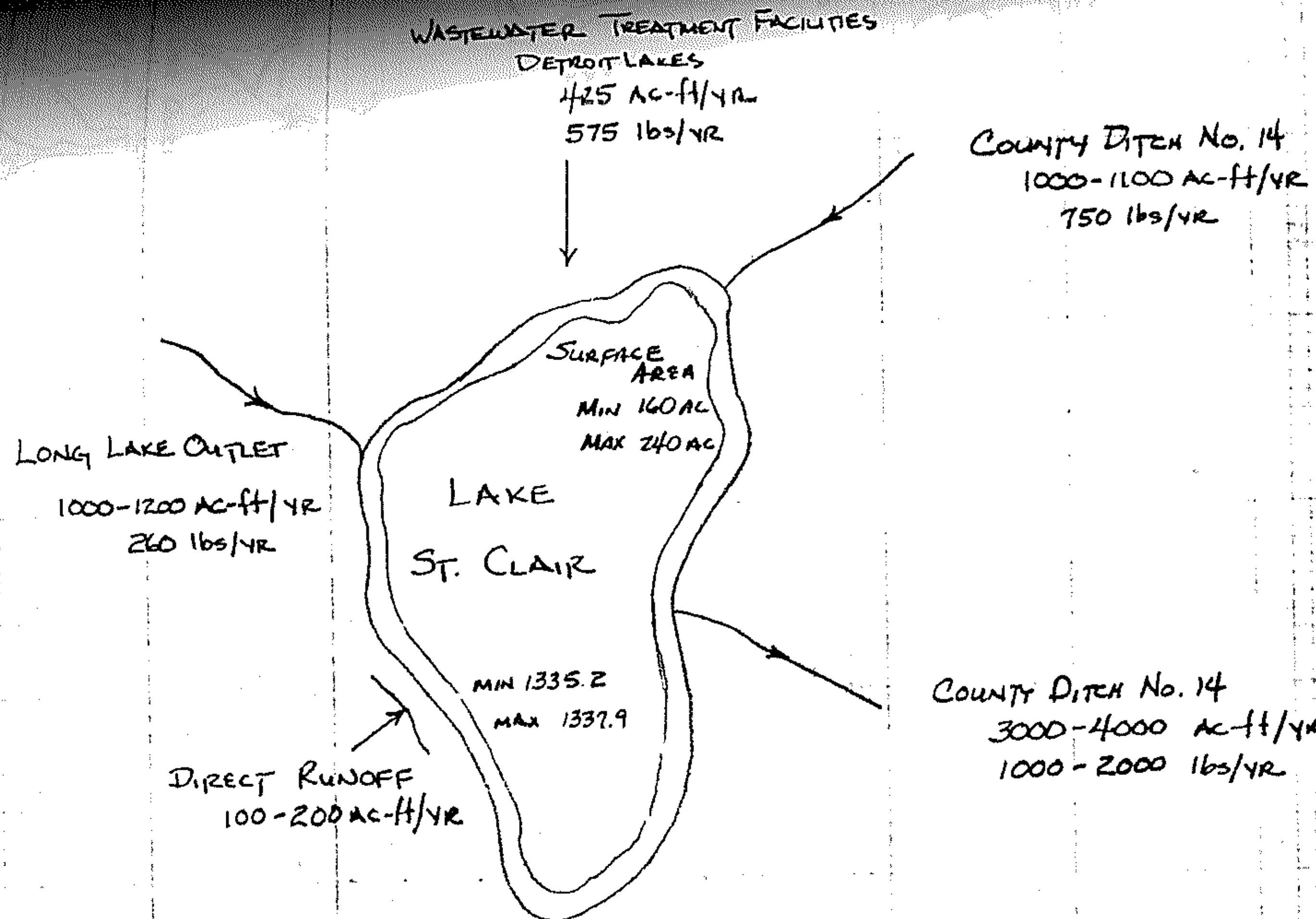


FIG. 33
LAKE ST. CLAIR
FLOW & PHOSPHORUS-TOTAL

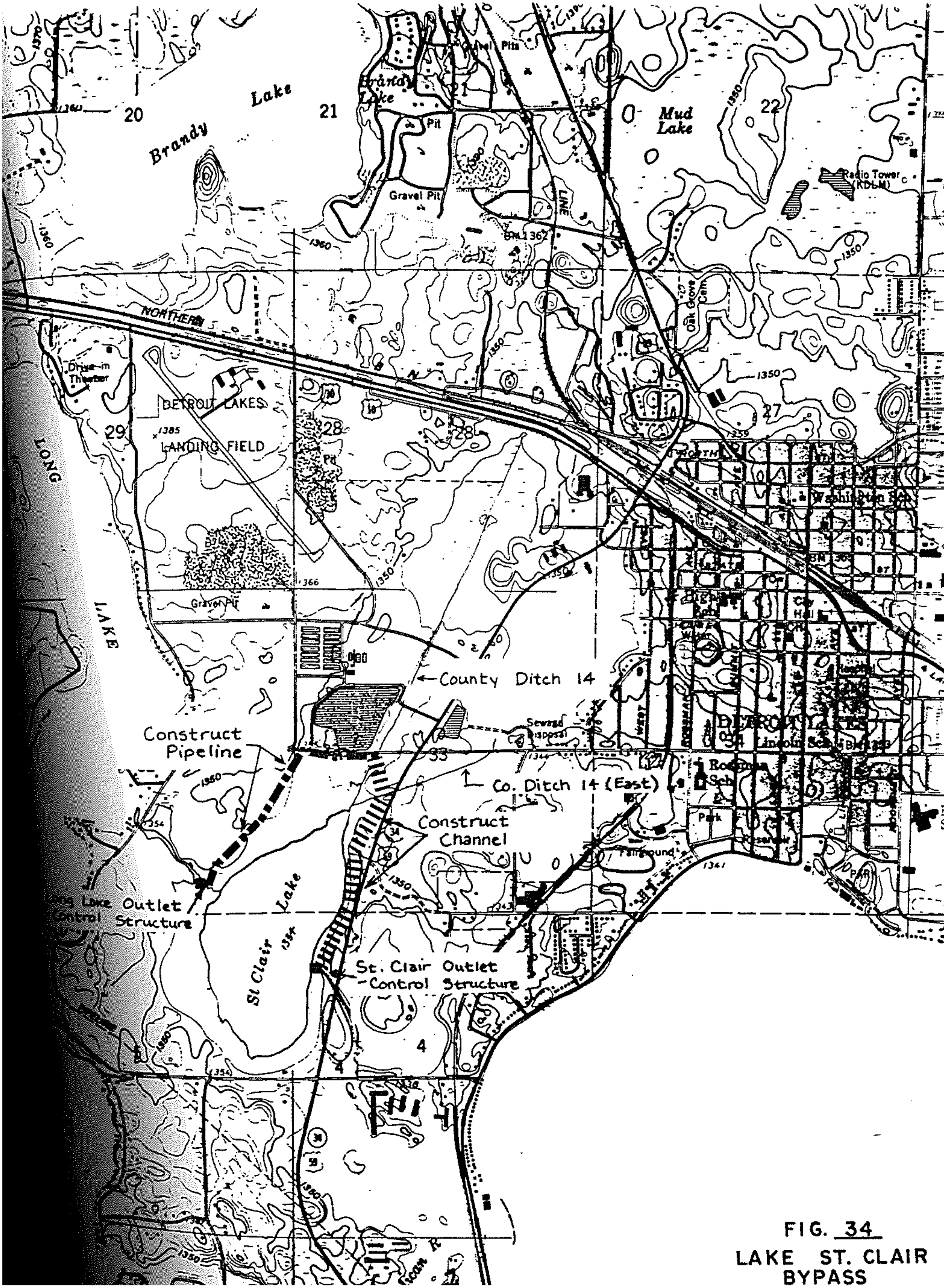


FIG. 34
LAKE ST. CLAIR BYPASS

A review of the hydraulic and nutrient budget for Lake St. Clair based upon available information is as follows:

TABLE XXXV LAKE ST. CLAIR: HYDRAULIC AND NUTRIENT BUDGET

Source	Flow (Ac-ft.)	P_T (lbs.)
Long Lake	1,000 - 1,200	260
County Ditch No. 14 (Inlet)	1,000 - 1,100	750
Wastewater Treatment Plant	425	575
Outlet*	3,000 - 4,000	1,000 - 2,000

*Includes lake contributions.

There are several considerations which have been evaluated for construction or modification of facilities relative to Lake St. Clair. They are as follows:

- Lake St. Clair Bypass
- Storm Sewer Diversion and Instream Alum Treatment
- Inlake Alum Treatment
- Wastewater Treatment Facilities Relocation

a. LAKE ST. CLAIR BYPASS

The water level fluctuation between minimum and maximum levels within Lake St. Clair allows for the storage of approximately 590 acre-feet. The bypassing of the Long Lake discharge and a control structure for outlet monitoring will allow for retention of nutrients and suspended solids in Lake St. Clair. The goal from this controlled outlet is reduction of phosphorus contributions of 30 to 40%, or 400 to 500 pounds per year.

b. STORM SEWER DIVERSION AND INSTREAM ALUM TREATMENT

The second alternative consists of diversion of the storm sewer flows to bypass Lake St. Clair and instream alum treatment of outlet flows from Lake St. Clair during periods of phosphorus export. The alum treatment would occur during the warmer months of the year and vary with the outlet flow volumes. The ditch for storm sewer entering Lake St. Clair would be bypassed to reduce the inlet flows to the lake. The storm water bypass would include a desiltation area prior to entering the Lake St. Clair outlet. A mixing and alum injection station would be installed at the outlet from Lake St. Clair. The injection of alum would result in tieing up the phosphorus discharged from the lake and residual aluminum from the application would be available to tie up phosphorus in the downstream sediments. The advantage of this alternative is the flexibility of alum addition at variable outlet phosphorus levels. The disadvantage is the annual alum costs, which are estimated at $10,000 to $20,000 annually. This project could be considered in two phases, beginning with the instream alum addition. The efficiency of this procedure could be considered prior to the storm sewer diversion.

c. INLAKE ALUM TREATMENT

A third alternative is the one time application of alum to the lake sediments, resulting in the reduction of phosphorus release from the sediments. If successful, this treatment may last for 10 years. Critical elements to the alum treatment are lake stratification and minimal mixing.

Lake St. Clair is a shallow lake which averages approximately 200 acres in surface area. As a result of the depth and lake configuration, mixing by wind action and the lack of thermal stratification are likely. In addition, alum treatment is not effective in depths less than four feet. The success of alum treatment in this manner is difficult to predict, but Lake St. Clair does not appear to be a good canidate for this procedure.

d. WASTEWATER TREATMENT FACILITIES RELOCATION

The relocation of the Detroit Lakes Wastewater Treatment Facilities is not within the scope of this report. However, the City of Detroit Lakes is considering major improvements to the Treatment Facilities in the next five to ten years. Alternatives are being considered for relocation of the discharge to a waterway that does not affect recreation lakes. The removal of 575 pounds of phosphorus as a result will have a significant positive impact on Lake Sallie.

In summary, the alternative that allows the greatest flexibility is the storm sewer bypass and instream alum treatment.

2. URBAN STORM WATER DIVERSION - DETROIT LAKE

Detroit Lake is significantly impacted by the urban runoff from the City of Detroit Lakes into the Pelican River. As indicated in the Watershed Assessment, the annual nutrient contribution to Detroit Lake from the Pelican River is approximately 1,100 pounds of phosphorus. It is not feasible to treat or divert all the storm water runoff entering the Pelican River. Best Management practices are needed to minimize phosphorus contributions. However, Subarea No. 14 is proposed to be diverted to an existing wetland east of the Detroit Lakes Industrial Park. The diversion will include construction of a storm water pumping station, forcemain and sedimentation basin prior to discharge into the wetland area. The phosphorus reduction in the wetland is anticipated to be 90%, or a total anticipated reduction of 495 pounds annually.

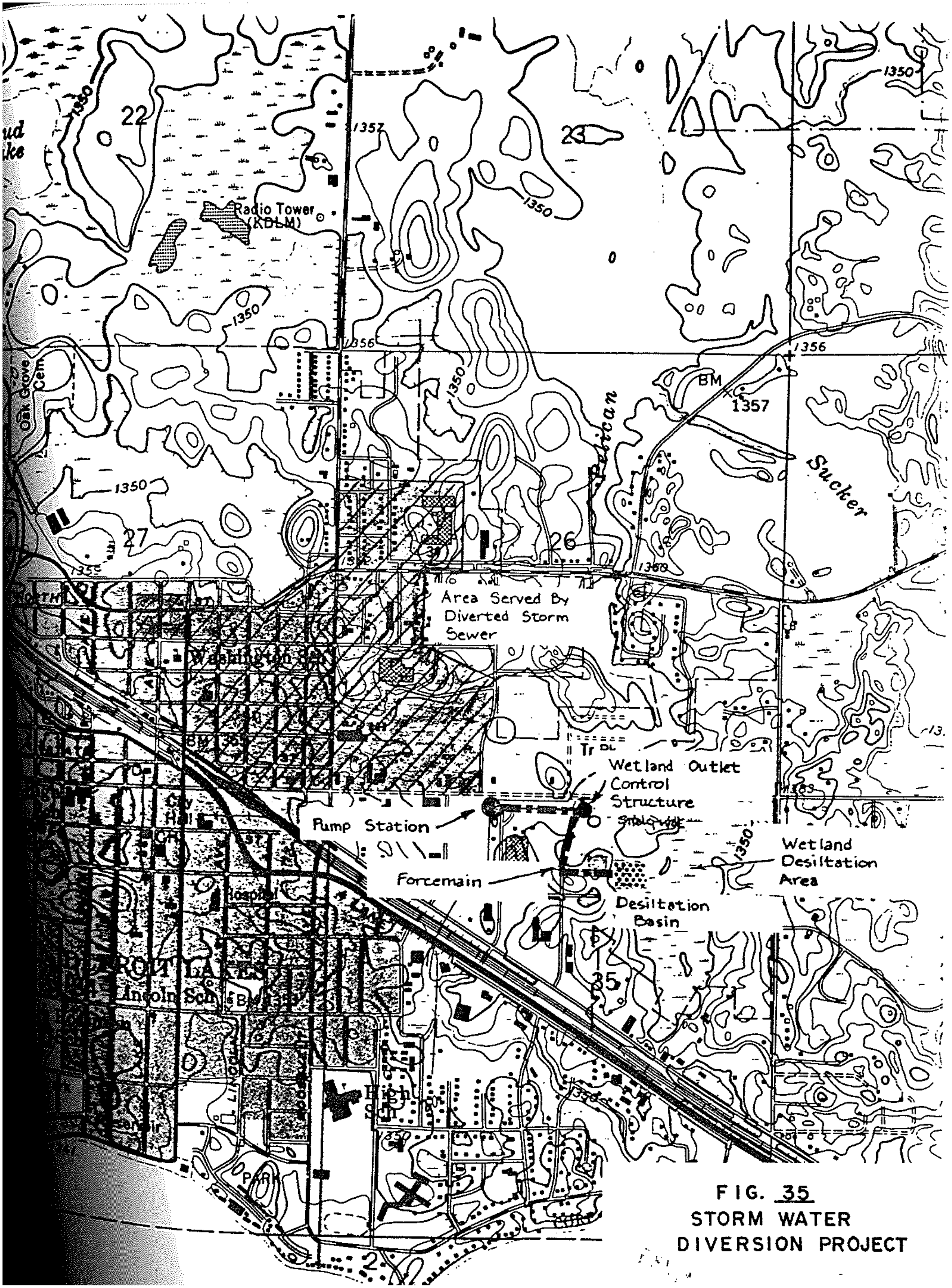


FIG. 35
STORM WATER
DIVERSION PROJECT

3. RICE LAKE RETENTION AREA - DETROIT LAKES

The annual contribution of nutrients along the Pelican River north of the City of Detroit Lakes flows through the Rice Lake wetland area. As previously stated, the large wetland area has been channelized and reduced the effectiveness of the wetland area as a buffer for containing nutrients and suspended solids. There is a significant potential in the wetland to reduce stream velocities and utilize the natural capacity of a wetland to retain and utilize nutrients. Based upon information from the monitoring and Watershed Assessment, approximately 2,000 - 3,000 pounds will annually enter the Rice Lake area from the Pelican River and adjacent runoff. Placement of a control structure for retention of runoff combined with dispersion of flow for nutrient uptake and sedimentation facilities are projected to reduce phosphorus levels by 30%, or 600 - 1,000 pounds annually. Additional evaluation of the potential of the Rice Lake wetland area will be conducted after receipt of the necessary field data. This information will be included in Addendum No. 1 to this report.

D. Biomass Control: Aquatic Vegetation Harvesting

The Pelican River Watershed has managed and encouraged an aggressive aquatic harvesting program in Lake Sallie since 1968. The project, which is funded by special assessments on lakeshore properties, has resulted in improved lake conditions for recreational use and removal of nutrients contained in the vegetation. The process includes mechanical cutting and harvesting of vegetation, beach cleaning and roadside pickup of vegetation. The project is an ongoing one.

Initial studies of the aquatic harvesting noted the relatively high cost of phosphorus removal. The percentage of removal of phosphorus was considered small in comparison to the major nutrient source which was the Detroit Lakes Wastewater Treatment Plant. However, reduction of that source of phosphorus has increased the impact that harvesting can have on the lake. Considering the alternatives for in-lake controls to reduce internal phosphorus loading, the use of harvesting is recommmended to continue because the remaining alternatives are either expensive or difficult to predict. Aquatic harvesting also has the advantage of being an inplace program.

Consideration has been given to establishing a mechanical harvesting project on Detroit Lakes. This project would be operated similar to Lake Sallie's project and would be funded by adjacent lakeshore owners. The purpose of the harvesting would be to aesthetically improve the lake for recreational uses, remove phosphorus and assist in the control of the Flowering Rush plant. The development of an aquatic vegetation harvesting project in Detroit Lake in conjunction with the current project in Lake Sallie would be an improvement to the lake conditions.

E. Management Practices

Efforts should be made to promote management practices which minimize the introduction and movement of nutrient and sediment within the areas that impact Lake Sallie and Detroit Lake.

As previously discussed, the urbanization of the shorelines of Lake Sallie and Detroit Lake result in individual treatment systems in the environmentally sensitive area adjacent to the lakes. Efforts to install sanitary sewer and/or combined treatment systems for environmental and health reasons have been considered by the City and Lake View Township.

Individual treatment systems adjacent to a lake are potential sources of phosphorus, especially if the systems are not installed properly. It is recommended that an orderly method of record keeping and monitoring of the individual treatment units to assure that they are properly installed and maintained. Each system should be inventoried and inspected on a regular basis. Septic tank pumpage should also be monitored to assure disposal on sites approved for sludge disposal. Septic tank pumpers should be required to identify the sites used for disposal and maintain a record of the location and quantity of waste disposed.

The Detroit Lakes Wastewater Treatment Facility utilizes on-land treatment and chemical precipitation for effluent disposal. Reduction in surface discharge by utilization of on-land treatment should be encouraged. Future expansion of the system should maximize on-land disposal or methods to reduce the surface discharge of phosphorus to the watershed. The result of the chemical precipitation process is a lime sludge. The current disposal site for the lime sludge is north of the wastewater treatment facilities. The proximity of the site to County Ditch No. 14 presents a potential for phosphorus contributions to the watershed. It is recommended that the lime sludge drying beds at the treatment plant be utilized and alternative sites be pursued for use as sludge disposal sites. Approved sites should be selected to minimize runoff in the Watershed.

DIRECT CONTRIBUTION AREAS

Zone	Management Practice	Implementation
Lakeshore (1,000')	Restrict use of lawn fertilizers.	Ordinances by City and Township
	Treatment or diversion of future storm runoff facilities.	
	Efforts to sweep streets urban areas to minimize sediment and nutrient discharge.	Watershed development of a plan with City of Detroit Lakes.
	Compliance with Shoreland Ordinance for development and building.	City of Detroit Lakes
Urban Areas	Restrict fertilizer using phosphates.	City ordinance.
Pelican River Shoreline	Inspection and stabilization of channel banks utilizing riprap and willow waddles in accordance with the Department of Natural Resources recommendations.	Joint cooperation with DNR
	Maintenance of a 20 foot buffer zone in the urban area and 50 feet buffer zone in the non-urbanized area.	Pelican River Watershed
	Compliance with Shoreland Ordinances.	

INDIRECT CONTRIBUTION AREAS	Implementation
Establishment of a plan with the Soil Conservation Service for the best management practices on the agricultural properties.	Pelican River Watershed in cooperation with the Soil Conservation Service.
Notification of agricultural property owners within the watershed of methods and practices which will reduce the impact of agriculture on the watershed.	
Feedlot monitoring.	Pelican River Watershed
Septic System Pumping.	Monitoring plan by the Pelican River Watershed.

F. Non-Feasible Lake Restoration Alternatives

Several of the restoration alternatives were reviewed and eliminated.

1. Sediment Removal

Removal of sediment by dredging either Lake Sallie or Detroit Lake adequately to reduce the volume of sediments would not be feasible. The Pelican River Watershed funded a minor dredging project on each lake in 1983 for channel improvements. The high cost of dredging and problems with dredged material disposal clearly illustrate the non-feasibility of this method of restoration.

2. <u>Hypolimnetic Withdrawal and Aeration</u>

The requirement to dispose of several thousand acre-feet of nutrient rich water or aeration of that volume makes this alternative prohibitive.

3. <u>Phosphorus Precipitation</u>

Chemical costs and the short-term benefits eliminate this alternative.

4. <u>Artificial Circulation</u>

It is not feasible to consider circulation of either Lake Sallie or Detroit Lake in a magnitude adequate to eliminate oxygen deficit.

5. <u>Biological Controls</u>

There is not enough information on biological controls to consider this method in recreational lakes the size of Lake Sallie and Detroit Lake.

G. SUMMARY OF RECOMMENDED ALTERNATIVES

1. Lake Sallie

Action	Method
Storm Sewer Bypass and Instream Alum Addition	Reduction of phosphorus from Lake St. Clair outlet.
Phosphorus Reduction from Wastewater Treatment Facilities	Modifications in lime sludge disposal procedures to abandon site north of treatment facilities.
	Inventory and update all individual treatment systems adjacent to Lake Sallie.
Management Procedures	Restrict phosphate containing fertilizers from shoreline zones.
	Recommend reduction of phosphate fertilizer use in the urban runoff areas to Lake Sallie.
	Monitoring septic tank effluent disposal by identifying volumes and locations of disposal.
	Promote street sweeping procedures that reduce sediment runoff.
Biomass Control	Maintain the current aquatic vegetation harvesting program.

The goals for phopshorus reduction include 600 - 800 lbs/yr by the Lake St. Clair bypass and 200 lbs/yr as a result of best management practices.

2. Detroit Lake

	Result
Urban Stormwater Diversion/ Treatment	Divert urban stormwater runoff to sediment and treatment areas.
Pelican River Nutrient Sediment Control	Construct settling and detention areas to remove sediment.
Phosphorus Reduction from Individual Treatment Systems	Inventory, update and monitor all individual treatment systems in the shoreline zone.
Management Procedures	Restrict all fertilizers containing phosphorus from shoreline zones and urban areas with runoff to the Pelican River.
	Promote street sweeping practices that reduce sediment runoff.
	Develop and distribute practices to agricultural owners that promote erosion and nutrient control.
	Maintain buffer zones and minimize channel bank erosion along the Pelican River.
Biomass Control	Establish an aquatic vegetation harvest program.

The reduction goals for these projects includes 495 lbs/yr from the storm sewer diversion, 600 - 1,000 lbs/yr from the Rice Lake wetland project and 200 - 300 lbs/yr from best management practices. The total reduction goal is 1,300 - 1,800 lbs/yr.

VIII. IMPLEMENTATION PLANS AND COSTS

The recommended improvements and estimated project costs are considered as follows:

A. ST. CLAIR STORM SEWER BYPASS AND INSTREAM ALUM ADDITION

St. Clair Lake contains a high nutrient load, based upon monitoring and previous documented studies. The sediments of the lake are being recycled and contributing a nutrient load to the downstream channel. Treating the Lake St. Clair outlet will reduce the phosphorus loading to Lake Sallie and improve the quality of the lake.

It is estimated that construction of the St. Clair Lake bypass and alum treatment project will reduce phosphorus loading to Lake Sallie by 600 - 800 pounds per year. Application of predictive models established in previous sections indicate long term improvements in water quality if phosphorus removal from a system of this magnitude can be achieved. Reduction in the nutrient load to Lake Sallie will become more evident as the internal phosphorus loading continues a natural flushing process which is apparently occurring in response to previous high nutrient loadings.

The surface flows from County Ditch No. 14 will be diverted around Lake St. Clair. Discharge from the lake would be controlled by a controlled structure to raise and lower the lake as desired to control phosphorus discharge from the lake.

The bypass would be achieved by diverting the storm sewer flows around Lake St. Clair. A control structure would be installed at County Ditch No. 14 to permit flow regulation during high or low flow conditions. County Ditch No. 14, which normally flows through Lake St. Clair, would be diverted around the east side of the lake by construction of a ditch or pipeline from the north end of St. Clair to its current outlet on the east side. A control structure at the outlet of Lake St. Clair would be for injection of alum and mixing. The layout plan is presented in Figure 34.

The area of Lake St. Clair is approximately 180 acres. The estimated watershed runoff to the lake is estimated to range from 100-200 acre-feet per year. The winter month's average contribution from the City Wastewater Facility is 425 acre-feet per year. Flow records indicate total flows from Lake St. Clair from all sources can be expected to be 2,000-3,000 acre-feet. Therefore, surface flows to Lake St. Clair would be reduced.

The estimated costs for the three alternatives for Lake St. Clair are as follows:

1. Lake St. Clair Bypass.................... $536,100
2. Storm Sewer Bypass and Alum Treatment.... $335,250
3. Inlake Alum Treatment.................... $139,000

Approvals for this project would be required from State and Federal Agencies. Easements would also be necessary for construction of the ditch and pipeline.

COST ESTIMATE - STORM SEWER BYPASS AND INLINE ALUM TREATMENT

1. STORM SEWER BYPASS

ITEM	AMOUNT	UNIT	UNIT PRICE	TOTAL
42" RCP....................	1,500	L.F.	75.00	112,500.00
Manholes.................	40	L.F.	300.00	12,000.00
Aprons....................	2	Each	1,000.00	2,000.00
Control Structure-Inlet..	1	L.S.	12,000.00	12,000.00
Control Structure-Outlet.	1	L.S.	15,000.00	15,000.00
Ditch Construction.......	1	L.S.	9,000.00	9,000.00

SUBTOTAL...	$162,500.00
Construction Contingencies............................	16,000.00
Engineering, Legal and Administrative..................	32,000.00
TOTAL STORM SEWER BYPASS...............................	$210,500.00

2. INSTREAM ALUM TREATMENT

General and Site Work..................................	$ 26,800.00
Concrete..	12,900.00
Equipment...	2,000.00
Mechanical..	30,250.00
SUBTOTAL..	$ 71,950.00
Construction Contingencies............................	10,800.00
Engineering, Legal and Administrative..................	17,000.00
TOTAL INSTREAM ALUM TREATMENT..........................	$ 99,750.00
3. LAND..	$ 25,000.00
TOTAL PROJECT COST.....................................	$335,250.00

The annual chemical costs for alum are estimated to be $10,000 to $20,000.

B. STORM SEWER DIVERSION

Storm sewer runoff has long been recognized as a contributor of suspended solids and nutrients to lakes. In 1970, the City of

Detroit Lakes implemented a major storm sewer diversion project to reduce urban runoff to Detroit Lake. As discussed previously, there are several storm sewers that presently discharge into the Pelican River upstream from Detroit Lake. Short term treatment of storm sewer discharge for nutrient removal by filtration through sand filters has not proven effective. Treatment requires storage and filtration, which has been accomplished with varied degrees of succes in wetlands.

The alternative considered for storm sewer diversion consists of diverting 230 acres of urban runoff in the northeast corner of the City of Detroit Lakes into an existing isolated wetland. The ratio of urban runoff to wetland area would be 3.2.

Discharge from an existing 42 inch storm sewer would be diverted by pumping easterly to a sedimentation basin located adjacent to the wetland area east of the Industrial Park. Removal of sediment would be achieved in this basin. The basin would be constructed to permit periodic maintenance and cleaning.

After initial sedimentation, the water would overflow to the wetland area for retention and filtration. A control structure located at the discharge from the wetland would be required to control outflow from the basin. A proposed layout plan for this alternative is presented in Figure 35.

This project will result in a reduction in sediment and nutrients currently discharging to Detroit Lakes. It is anticipated that

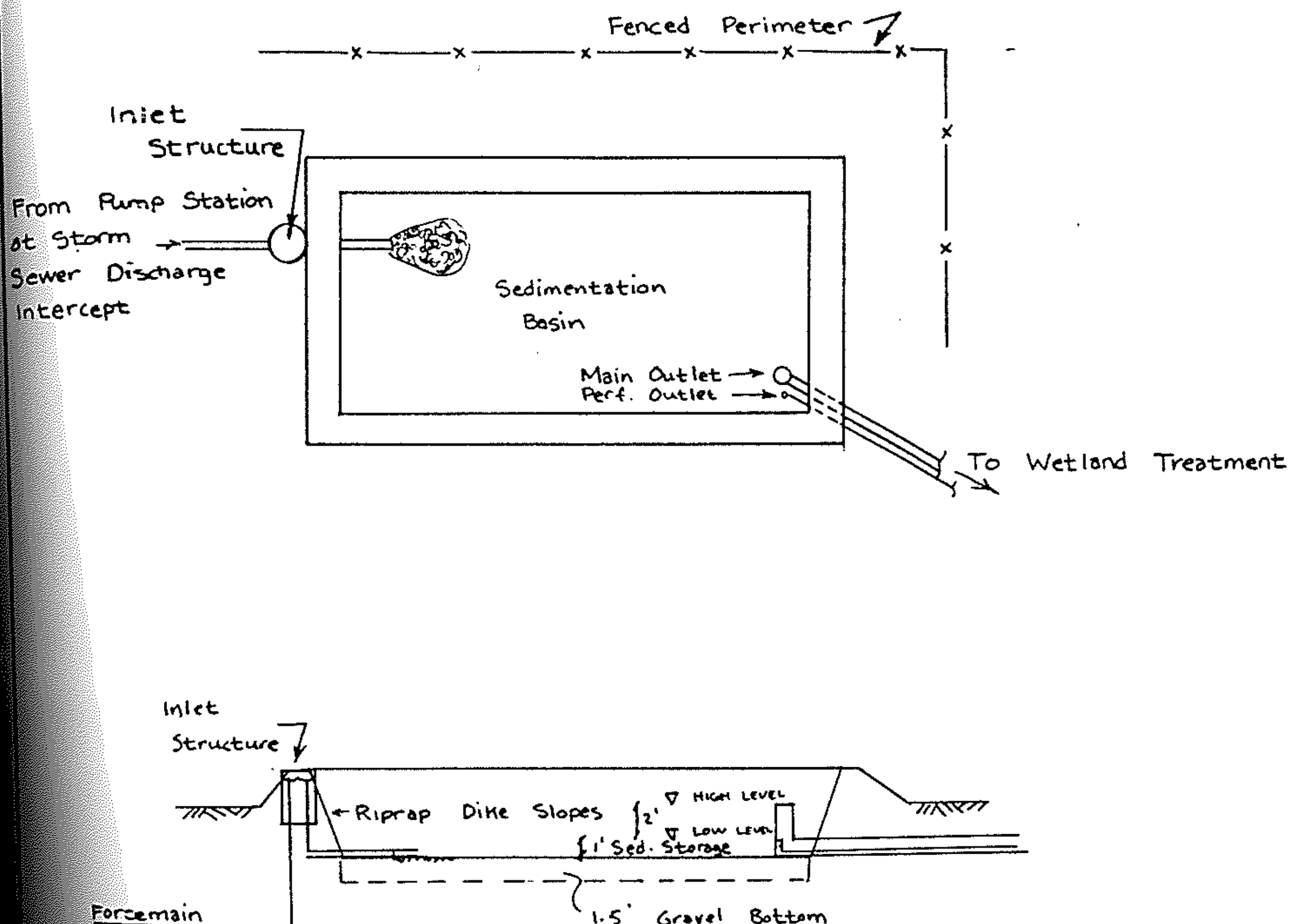


FIG. 36
STORM WATER DIVERSION PROJECT
SEDIMENTATION BASINS

sediment removals will exceed 90 percent and phosphorus reductions by 70 to 80 percent from use of the wetland.

The total estimated project cost is $535,930.

COST ESTIMATE - STORM SEWER DIVERSION

ITEM	AMOUNT	UNIT	UNIT PRICE	TOTAL
30" RCP..................	2,500	L.F.	75.00	187,500.00
Storm Sewer Pumping Station................	1	L.S.	180,000.00	180,000.00
Sedimentation Basin......	1	L.S.	15,000.00	15,000.00
Control Structure........	1	L.S.	15,000.00	15,000.00
Restoration..............	1	L.S.	8,000.00	8,000.00
SUBTOTAL..				$405,500.00
Construction Contingencies............................				20,280.00
TOTAL CONSTRUCTION....................................				$425,780.00
Engineering, Legal and Administrative..................				85,150.00
Land Acquisition Costs................................				25,000.00
TOTAL PROJECT COST....................................				$535,930.00

C. STORMWATER TREATMENT

There are several inlets to the Pelican River between Detroit Lake and U.S. Highway No. 10. Land space and economic considerations limit the alternatives which may be considered for the inlets.

It is proposed to connect three storm sewer outlets along Lori Avenue and use a sedimenation basin for removal of suspended solids. Phosphorus removal will be limited to the particulate material collected in the sediments.

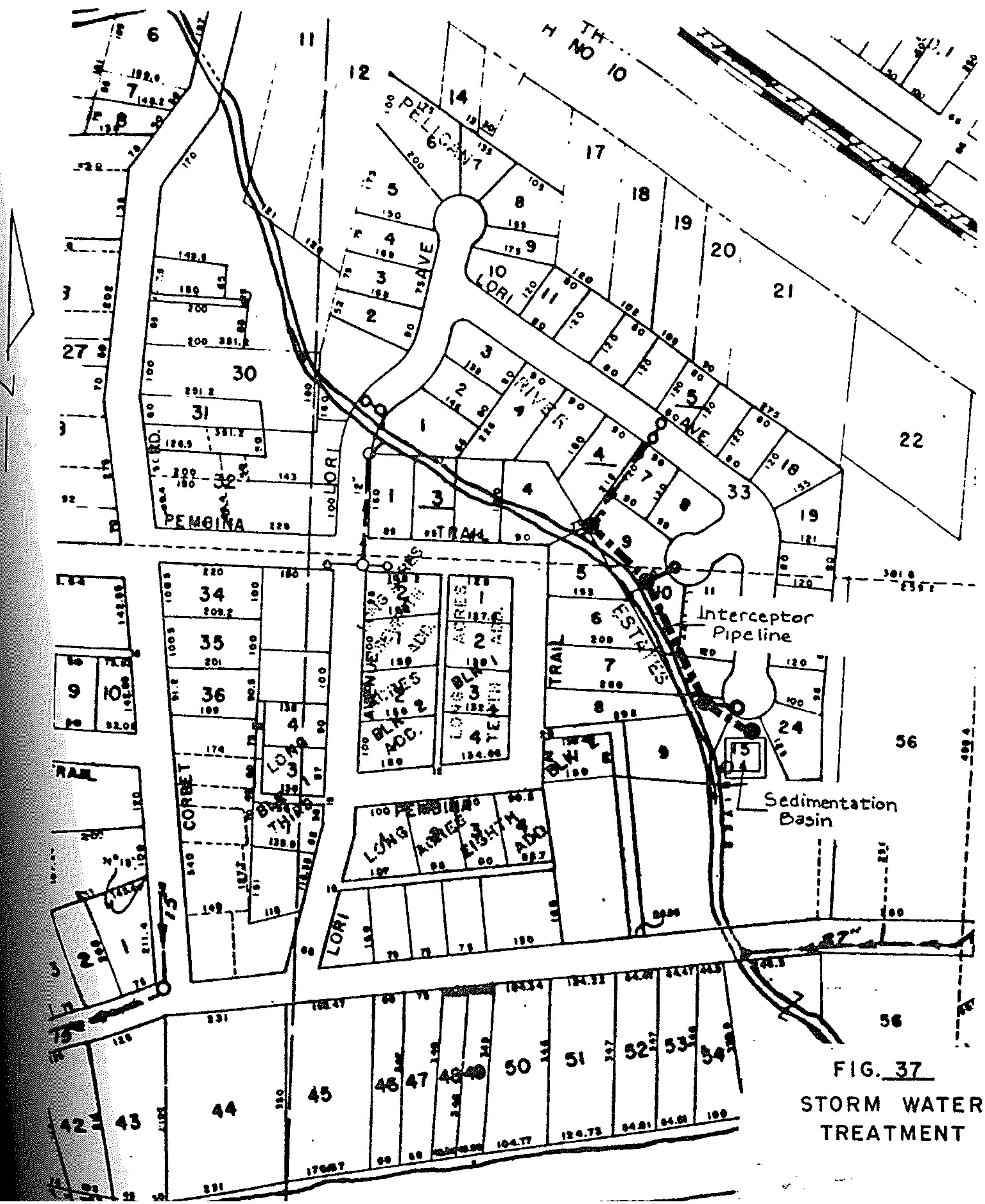
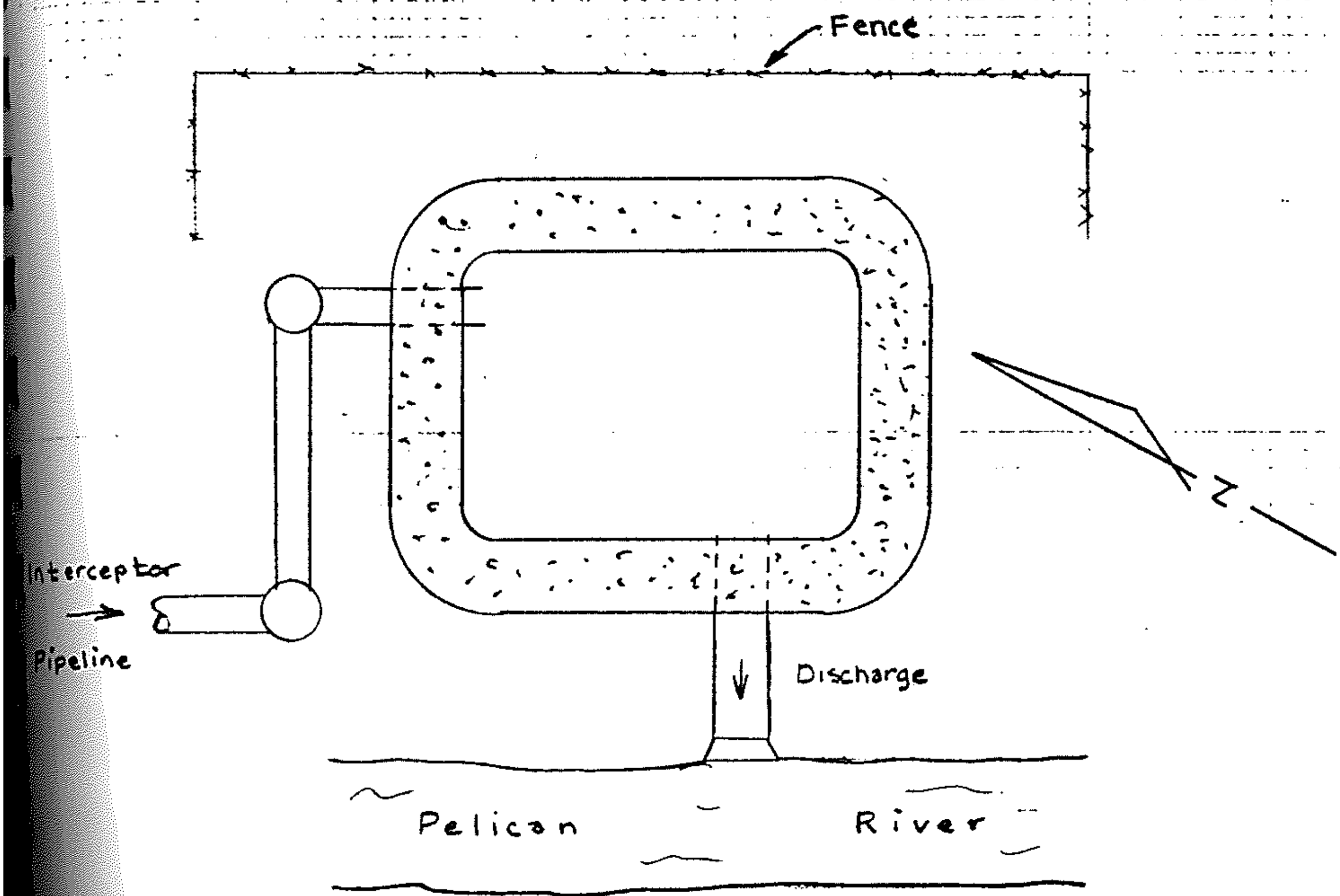


FIG. 37

STORM WATER TREATMENT



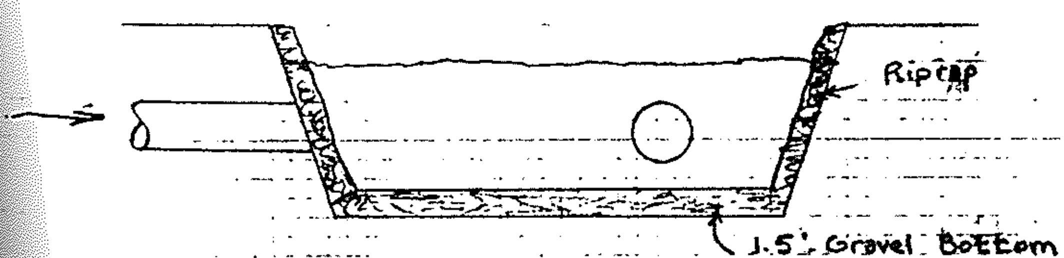


FIGURE 38

Sedimentation Basin

Stormwater Treatment

COST ESTIMATE - STORM SEWER SEDIMENT BASIN

ITEM	AMOUNT	UNIT	UNIT PRICE	TOTAL
18" RCP..................	400	L.F.	30.00	12,000.00
Manholes.................	21	L.F.	150.00	3,150.00
Sediment Basin...........	1	L.S.	10,000.00	10,000.00
Fence....................	1	L.S.	5,000.00	5,000.00
Restoration..............	1	L.S.	2,000.00	2,000.00

SUBTOTAL..	$ 32,150.00
Construction Contingencies......................	3,200.00
TOTAL CONSTRUCTION..............................	$ 35,350.00
Engineering, Legal and Administrative...........	7,070.00
Land Acquisition Costs..........................	10,000.00
TOTAL PROJECT COST..............................	$ 52,420.00

D. PELICAN RIVER: DETROIT LAKES INLET

The Pelican River inlet to Detroit Lake has been channelized by County Ditch construction and urban development, increasing the rate and volume of runoff entering Detroit Lake.

Based upon an average slope and ditch channel typical section, estimated velocities in the river channel were determined:

$$V = \underline{1.49}\ R^{2/3} S^{1/2}$$

$R = 11.4$

$S = 0.000227$

$= 0.023$

$V = 4.9$ fps

Velocities exceeding five feet per second during flows of 25 cfs or greater would not be unusual in the moderate slope regions of the channel, such as the Rice Lake area. At channel velocities of this magnitude, silt and sediment transport will be easily maintained.

The settling velocities of fine sediments such as a 0.05 mm particle will be as slow as 0.006 feet per second. Based upon average spring flows of 50 to 60 acre-feet per day, a large retention area would be necessary to reduce velocities to settle this material.

Consideration for the development of three different areas along the Pelican River are considered in this report for use as sedimentation, desiltation and retention areas.

Area No. 1 - Rice Lake Wetland Area: The Rice Lake Wetland area is a large open area north of Highway No. 34 that contains wetlands and open water areas. The area was channelized by County Ditch No. 14 in the early part of the century. The development of the Rice Lake area to reduce velocities, retain sediments and utilize phosphorus through uptake is being evaluated as part of Addendum No. 1 to this report. The work is anticipated to include, but not be limited to, the construction of the control structure for retention of water in the basin, acquisition or obtaining easements for control of water elevations, construction of channels, piping and basins to utilize the wetlands to its maximum extent for nutrient uptake. The actual estimated cost of this work cannot be finalized until additional information is obtained and will be presented in Addendum No. 1. For budgetary purposes, an estimated project cost of $500,000 is included for the work involved with the Rice Lake area.

Area No. 2 - Sedimentation Basin South of T.H. No. 34: The Pelican River Watershed has purchased a parcel of property south of Highway No. 34 adjacent to the Pelican River channel. The area is an open space that can be utilized as a buffer zone for the river channel to control development. The area can also be utilized for construction of a sedimentation basin to assist in reduction of river channel velocities and removal of silt and sediments. Reduction would include excavation of the property to construct a basin, piping, and riprap to control erosion of the banks. A summary of the estimated costs for these improvements are as follows:

COST ESTIMATE - DESILTATION BASIN

ITEM	AMOUNT	UNIT	UNIT PRICE	TOTAL
Common Excavation............	7,800	C.Y.	3.50	27,300.00
Riprap.......................	300	Ton	10.00	3,000.00
Filter Cloth.................	800	S.Y.	1.25	1,000.00
27" RCP Bypass...............	500	L.F.	35.00	17,500.00
Control Structure............	1	L.S.	2,000.00	2,000.00
Restoration..................	1	L.S.	1,600.00	1,600.00
SUBTOTAL...				$52,400.00
Construction Contingencies.........................				5,240.00
TOTAL CONSTRUCTION.................................				$57,640.00
Engineering, Legal and Administrative..............				11,500.00
Land Acquisition Costs.............................				12,000.00
TOTAL PROJECT COST.................................				$81,140.00

The development of this project will be dependent upon potential improvements to the Rice Lake area.

Area No. 3 - Retention Pond North of 8th Street: A naturally existing low confined area located adjacent and north of 8th Street is proposed to be utilized for storm water retention of the Pelican River. The work required to develop this area would include construction of a control structure to confine water surface elevations during low flow periods and also during high flow periods to allow for retention of storm water in the Pelican River Channel Basin. A control structure would include an overflow for high intensity storm events, but allow for retention and reduction of channel velocities. The estimated cost for the storm water retention is as follows:

COST ESTIMATE - RETENTION PONDING

ITEM	AMOUNT	UNIT	UNIT PRICE	TOTAL
Control Structure............	1	L.S.	10,000.00	10,000.00
21" RCP Discharge............	40	L.F.	30.00	1,200.00
21" RCP Apron................	2	Each	350.00	700.00
Riprap.......................	125	Ton	10.00	1,250.00
Filter Cloth.................	360	S.Y.	2.00	720.00
Restoration..................	1	L.S.	1,500.00	1,500.00
SUBTOTAL..				$15,370.00
Construction Contingencies............................				3,070.00
TOTAL CONSTRUCTION....................................				$18,440.00
Engineering, Legal and Administrative.................				3,690.00
Land Acquisition Costs................................				10,000.00
TOTAL PROJECT COST....................................				$32,130.00

The implementation and economic feasibilty of this retention ponding area is dependent upon the Rice Lake area potential development plans.

E. EDUCATION OF THE PUBLIC

Education of the public within the Watershed will be important to obtain the goals and success of lake restoration of Detroit Lake and Lake Sallie. The residents must be aware of the importance of lake protection and to be better stewards of the land and water. A newsletter will be used extensively for this purpose. The newsletter will discuss best management practices and promote compliance with the new local ordinances. Specifically, management practices such as restricting or eliminating the use of phosphorus fertilizer within the environmentally critical areas adjacent to the lake will be presented. The estimated cost of this project is $2,000.

F. BEST MANAGEMENT PRACTICES

The areas of Best Management Practices (BMP's) which will be concentrated on will be construction and agricultural related practices.

In regard to construction, efforts will be made to improve construction practices for erosion control and lake protection, and to provide recommendations and assistance in the development of design procedures that are not harmful to the Watershed's waterways. Requirements for erosion control during construction can be regulated through the permitting process of the Watershed. Proposed street and storm sewer improvements adjacent to Detroit Lake will be evaluated to provide a method of controlling and discharging storm water runoff in a manner that is environmentally sound.

Improved agricultural BMP's, such as Animal Waste Management Systems (AWMS), nutrient management, terraces, and buffer strips are also needed to compliment the other projects in Phase II. The Watershed District proposes to identify fields which have been highlighted adjacent to waterways as potential sites which may be adversely impacting the water quality of the District. The identification of these areas was completed by the local conservation district. The Watershed District proposes to contact the landowners of these parcels and work individually with each owner on BMP's that will reduce nutrient and erosion to the waterways. The estimated cost of construction and agricultural BMP's are $150,000 and $50,000, respectively.

The organizations that would be requested to assist in management practices would include Becker County, the City of Detroit Lakes, the Department of Natural Resources, Soil Conservation Service, Becker Soil and Water Conservation District and the U.S. Fish and Wildlife Service. The services would include monitoring of individual wastewater treatment systems, recommendations on agricultural erosion control procedures and channel erosion control.

The total of these improvements as presented above is $200,000.

G. LOCAL ORDINANCES

In 1991 the Pelican River Watershed District adopted a comprehensive set of rules and regulations for the Watershed District. Implementation of the rules and regulations give the Watershed District the authority to regulate land use activities and enforce policies and practices which are necessary for lake protection. The enforcement of these rules and regulations will require District time to provide the enforcement necessary. The City of Detroit Lakes is considering an ordinance banning the use of phosphorus fertilizer and Becker County is rewriting its shoreland ordinances for lake protection. Implementing these ordinances by the City and County will cost an estimated $5,000.

H. WATER QUALITY MONITORING

Water quality monitoring will be necessary during the implementation of projects to determine the impact on the lake system. The monitoring will include water quality monitoring of the lake systems and the inlet sources during construction. After completion of the projects, documentation will be necessary to determine the impact the improvements have had on Detroit Lake and Lake Sallie. The estimated cost for the construction monitoring plan is $25,000, and the estimated cost for a one-year post construction testing period is $20,000. The total estimated project cost for water quality monitoring is $45,000.

I. SALARY

It will be important to the success of this project to have one individual for coordination of the improvements and assistance in developing and implementing BMP's. The position of executive secretary for the Pelican River Watershed District is currently a part-time position and it is proposed to expand the responsibilities and duties to a full-time position. The responsibilities which apply directly to this project are implementation and enforcement of the rules and regulations of the Pelican River Watershed District. It will include identifying sites which are affecting the study lakes and preparing and implementing BMP's on those properties. Efforts would also include working with the City of Detroit Lakes regarding the wastewater treatment facility and any other point nutrient sources. Work with the City of Detroit Lakes would include improving operation practices to minimize the discharge of nutrients into the Watershed. In addition, evaluation of non-point sources will be considered and recommendations for corrective action made for those sources. The time required by the executive secretary to administer the Phase II project and implement the proposals and recommendations of the project are anticipated to require approximately 80% of his time. Based upon a full-time salary of $31,250 per year, the estimated annual cost for administration of the project by the executive secretary is $25,000. This corresponds to a cost of $125,000 based upon a five-year project.

J. ADMINISTRATIVE EXPENSE

The cost for administrative expense including the office for the executive secretary, equipment necessary for the administration of this project, including telephone, and office supplies is estimated to be $2,500 per year. Based upon a five-year project, the total value of these costs is estimated to be $12,500.

K. AQUATIC PLANT HARVESTING

The Pelican River Watershed participates in an aquatic plant harvesting program for both Lake Sallie and Detroit Lake. The harvesting equipment is owned and operated by the Watershed District and the costs for the harvesting are assessed to property owners adjacent to the lake. This is an ongoing project which is funded locally and not included in the proposed costs for this project.

IX. PROJECT SUMMARY

A. GENERAL

The most significant impact of this project will be reduction in the external phosphorus loading to Lake Sallie and Detroit Lake by diversion and treatment of inflows and watershed management. External phosphorus loading has been shown to be above levels considered permissable for these lake systems.

The goal for reduction of phosphorus inflow to Lake Sallie is between 800 and 1,000 pounds per year. The goal for reduction of phosphorus inflow to Detroit Lake is between 1,300 and 1,800 pounds per year.

In addition, aquatic vegetation harvesting is recommended as an inlake procedure for improving the recreational aesthetics of the lakes in conjunction with minimal nutrient removal. Review of the other methods of inlake restoration from a cost and implementation prospective indicate that the methods are costly or highly unpredictable in results. Although harvesting is labor intensive and involves an ongoing operation capital outlay, the implementation of harvesting on Detroit Lake in conjunction with Lake Sallie is the best alternative for inlake improvements and provides for increased use of the lake systems.

B. PROJECT GOALS

The project goals are to reduce phosphorus loadings to improve the lake conditions by reductions in algal problems and improvements in transparency.

The 1988 phosphorus inflow to Lake Sallie was substantially below expected average levels. The most significant source of that loading was identified from Lake St. Clair. Containment of phosphorus loading that is currently being discharged from the outlet of Lake St. Clair may result in reducing the total phosphorus load to the Pelican River upstream from Lake Sallie. The long term benefits of this reduction will be significant. As stated previously, the goal for Lake Sallie is to improve water quality characteristics to be reflected in chlorophyll-a and secchi disk reading measurements. Due to the internal phosphorus loading concentrations, response to these changes will be slow, but a necessary initial step in improving lake conditions.

Detroit Lake demonstrated a pronounced response to phosphorus inflow by increases in inlake phosphorus concentrations. Control of nutrient loadings from surface inflow sources will have a long-term beneficial impact in the lake. Reduction of phosphorus loadings of 1,000 pounds or more from surface water improvements and management practices can be achieved by the methods indicated in this report and will slow lake eutrophication. Improvements in water quality will be based upon reductions in algae population as measured by chlorophyll-a and transparency measures as indicated by secchi disk readings.

C. PROJECT COSTS

A summary of the proposed project capital costs is as follows:

1.	Storm Sewer Bypass and Alum Treatment...........	$ 335,250
2.	Storm Sewer Diversion...........................	535,930
3.	Storm Water Treatment - Lori Avenue............	52,420
4.	Pelican River, Detroit Lakes Inlet	
	a. Rice Lake Wetland Restoration.............	500,000
	b. Desiltation Basin.........................	81,140
	c. Retention Pond............................	32,130
5.	Education..	2,000
6.	Best Management Practices.......................	200,000
7.	Local Ordinances................................	5,000
8.	Water Quality Monitoring........................	45,000
9.	Salary...	125,000
10.	Administrative Expense..........................	12,500
	TOTAL..	$1,926,370

*Rice Lake restoration wetland costs are subject to the evaluation which will be included in Addendum No. 1.

D. PROJECT FINANCING

Application will be made for 50% funding from the U.S. Environmental Protection Agency. State cost sharing funds will be requested from the Board of Water and Soil Resources and the Comprehensive Local Work Plan. The Pelican River Watershed will act as the local agency assisting in obtaining funding for the local matching share. The City of Detroit Lakes, the Minnesota Department of Natural Resources and Becker County will be contacted for potential cost sharing.

E. PUBLIC PARTICIPATION

An informational public meeting will be held to review the information included in this study. As the project proceeds, additional informational meetings will be held.

The recommended management practice as presented in this report will require notification of property owners. Informational mailings will be sent to property owners to inform them of the plans and goals of the watershed management and the requirements of each property owner.

F. MAINTENANCE

The maintenance repsonsibilities msut be determined for each of the recommended facilities. The Pelican River Watershed will be responsible to maintain or develop agreements for maintenance.

G. PERMITS

Agencies which must approve the permits include the Department of Natural Resources, Army Corps of Engineers, Becker County, Minnesota Department of Transportation and the City of Detroit Lakes.

APPENDIX

NO.	DESCRIPTION
1.	Detroit Lake: 1988 In-Lake Sampling
2.	Detroit Lake: 1989 In-Lake Sampling
3.	Lake Sallie: 1988 In-Lake Sampling
4.	Lake Sallie: 1989 In-Lake Sampling
5.	Detroit Lake: 1988 Inflow Sampling
6.	Detroit Lake: 1989 Inflow Sampling
7.	Lake Sallie: 1988 Inflow Sampling
8.	Lake Sallie: 1989 Inflow Sampling
9.	1989 Stream Sampling Results
10.	Detroit Lake: 1988 Phytoplankton Sampling
11.	Lake Sallie: 1988 Phytoplankton Sampling
12.	Detroit Lake: 1989 Secchi Disk
13.	Detroit Lake: 1989 Temperature Isopleth
14.	Lake Sallie: 1989 Temperature Isopleth
15.	Detroit Lake: In-Lake Suspended Phosphorus
16.	Lake Sallie: In-Lake Suspended Phosphorus
17.	Lake Sallie: Historical Hydrologic Budget
18.	Lake Sallie: Historical Inflows
19.	Lake Sallie: Historical Outlet Flows
20.	Pelican River Inlet: August 31, 1989 Flows
21.	Pelican River Inlet: August 31, 1989 Phosphorus
22.	Detroit Lake: Zooplankton Summary
23.	Lake Sallie: Zooplankton Summary
24.	Dillon - Rigler Model Calculations

DETROIT LAKE

1988 IN-LAKE SAMPLING RESULTS

	3/31/88	4/25/88	5/10/88	5/26/88	6/7/88	6/21/88	7/5/88	7/19/88	8/9/88	8/23/88	9/15/88	10/19/88	11/7/88	12/15/88
Surface														
Po	0.027	<0.01	0.004	0.002	0.006	0.008	0.004	ND	0.008	0.008	0.006	0.002	0.008	0.002
P_T	0.039	0.01	0.012	0.015	0.026	0.020	0.018	0.030	0.034	0.030	0.024	0.015	0.015	0.012
Kjl-N	0.78	1.2	1.4	1.03	1.2	1.08	0.68	2.08	1.8	1.48	0.92	1.72	1.40	1.12
Org-N	0.57													
NH_3-N	0.21	0.02	0.23		0.09	0.001	<0.01	ND	<0.01	0.06	0.04	0.02	0.05	0.04
NO_2-N+	0.20													
Chlor-a	3.20	14.7	2.1	3.9	1.9		3.3	4.9	10.3	7.3	5.4	3.4		
TSS	4.0													
PH	8.3													8.0
Conduct	320.0													
Alk.	150													
Secchi Disk(m)		3.7	4.0	5.8	5.15	1.66	2.61	2.15	1.54	1.69	2.15	3.54	3.07	
Fecal Coli		2.0	4.0		<2.0				<2.0			4.0		
Five Meter Sample														
Po	0.017	<0.01	0.004	0.008	0.004	0.004	0.005	ND	0.004	0.006	0.002	0.002	0.008	0.002
PT	0.017	0.02	0.09	0.011	0.027	0.012	0.018	0.035	0.039	0.030	0.019	0.016	0.027	0.009
TSS	0.8	1.5	1.1	1.7	1.0	1.2	2.1	1.0	4.9	4.8	5.4	4.3	4.0	0.5
Thirteen Meter Sample														
Po	0.008	<0.01	0.008	0.008	0.004	0.004	0.005	0.002	0.016	0.012	0.004	0.002	0.008	0.005
PT	0.014	0.01	0.010	0.015	0.012	0.023	0.020	0.030	0.036	0.040	0.018	0.016	0.022	0.014
N-NO_2+NO_3	0.06	0.01	0.01		0.04	0.01	<0.01	ND	<0.01	0.06	0.04	0.02	0.02	0.04
Twenty-Three Meter Sample (Bottom)														
Po	0.011	<0.01	0.005	0.056	0.088	0.056	0.081	0.082	0.106	0.116	0.162	0.002	0.008	0.040
PT	0.018	0.02	0.016	0.067	0.103	0.065	0.106	0.110	0.135	0.140	0.172	0.015	0.019	0.052
Kjl-N	0.68	1.1	1.4	1.76	1.4	1.48	1.48	2.38	2.12	2.48	3.00	1.40	1.04	1.52

DETROIT LAKE

1989 IN-LAKE SAMPLING RESULTS

	1/31/89	3/07/89	3/27/89	5/18/89	6/15/89
Surface					
Po	0.007	0.005	0.004	0.002	0.004
P_T	0.009	0.008	0.015	0.011	0.010
Kjl-N	1.2	1.28	1.32	0.64	1.28
Org-N					
NH_3-N	<0.01	0.04	0.06	0.01	0.01
NO_2-N+					
Chlor-a	<1.0	1.3	5.4		
TSS					
PH					
Conduct					
Alk.					
Secchi Disk(m)					
Fecal Coli					
Five Meter Sample					
Po	0.007	0.008	0.006	0.002	0.005
PT	0.009	0.016	0.014	0.011	0.017
TSS	0.5	0.3	0.5	0.6	2.0
Thirteen Meter Sample					
Po	0.008	0.012	0.010	0.002	0.004
PT	0.013	0.013	0.012	0.011	0.013
N-NO_2+NO_3	0.06	0.10	0.12	0.01	0.01
Twenty-Three Meter Sample (Bottom)					
Po	0.007	0.010	0.008	0.002	0.050
PT	0.007	0.013	0.014	0.011	0.130
Kjl-N	1.12	1.28	0.96	0.68	1.40

LAKE SALLIE

1988 IN-LAKE SAMPLING RESULTS

	3/30/88	4/25/88	5/12/88	5/26/88	6/8/88	6/20/88	7/7/88	7/19/88	8/10/88	8/22/88	9/15/88	10/20/88	11/14/88	12/13/88
Surface														
Po	0.012	<0.01	0.002	0.010	0.008	0.006	0.002	0.008	0.008	0.014	0.008	0.002	0.006	0.008
P_T	0.022	0.03	0.025	0.041	0.025	0.023	0.039	0.038	0.069	0.079	0.058	0.026	0.056	0.015
Kjl-N	0.98	1.5	1.2	1.43	1.4	1.2	1.6	2.0	3.0	2.68	2.0	1.6	1.08	1.36
Org-N	0.78													
NH_3-N	0.20	0.02	0.01		0.02	0.008	<0.01	0.01	<0.01	0.06	0.05	0.03	0.04	0.04
NO_2-N+	0.18													
Chlor-a	4.01	3.74		2.2	2.4		18.6	16.0	17.2	18.8	37.5	10.7		
TSS	4.0													
PH	8.3													
Conduct	370.0													
Alk.														
Secchi Disk(m)	1.8		2.7	2.9	2.72	2.4	2.72	1.08	0.77	0.62	0.77	2.77	3.69	
Fecal Coli.	<2.0		35.0		<2.0		2.0		<2.0			<2.0		
Four Meter Sample														
Po	0.010	0.01	0.01	0.003	0.004	0.004	0.002	0.008	0.006	0.014	0.008	0.008	0.004	0.005
PT	0.023	0.04	0.013	0.065	0.011	0.026	0.037	0.055	0.057	0.067	0.051	0.025	0.028	0.015
TSS	2.4	5.80	4.67	3.84	1.8	3.5	7.41	7.0	10.9	11.6	11.0	9.7	2.9	1.1
Nine Meter Sample														
Po	0.020	0.01	<0.01	0.006	0.010	0.072	0.004	0.024	0.006	0.012	0.012	0.004	0.004	0.005
PT	0.051	0.04	0.011	0.080	0.027	0.120	0.035	0.062	0.055	0.068	0.055	0.023	0.025	0.013
N-NO_2+NO_3	0.84		0.01		0.01	0.001	<0.01	0.02	<0.01	0.05	0.06	0.05	0.02	0.08
Thirteen Meter Sample (Bottom)														
Po	0.0270	<0.01	0.002	0.004	0.006	0.080	0.058	0.036	0.012	0.018	0.024	0.002	0.004	0.005
PT	0.068	0.03	0.023	0.140	0.014	0.160	0.096	0.039	0.069	0.065	0.063	0.025	0.025	0.015
Kjl-N	1.91	0.8	1.20	1.40	1.76	1.80	1.28	2.28	2.88	2.28	1.88	1.76	1.48	1.36

#3

LAKE SALLIE

1989 IN-LAKE SAMPLING RESULTS

	1/31/89	3/07/89	3/27/89	5/15/89	6/15/89
Surface					
Po	0.007	0.008	0.008	0.002	0.006
P_T	0.051	0.035	0.018	0.027	0.018
Kjl-N	1.00	1.72	1.44	0.72	1.24
Org-N					
NH_3-N	<0.01	0.04	0.06	0.05	0.01
NO_2-N+					
Chlor-a	<1.0	<1.0	<1.0		
TSS					
PH	7.90				
Conduct					
Alk.					
Secchi Disk(m)				3.55	7.10
Fecal Coli.					
Four Meter Sample					
Po	0.013	0.008	0.008	0.003	0.008
PT	0.018	0.018	0.014	0.088	0.016
TSS	1.0	0.6	1.3	4.7	2.2
Nine Meter Sample					
Po	0.008	0.011	0.024	0.002	0.006
PT	0.013	0.017	0.025	0.018	0.014
N-NO_2+NO_3	<0.01	0.04	0.07	0.03	0.01
Thirteen Meter Sample (Bottom)					
Po	0.011	0.011	0.016	0.002	0.010
PT	0.015	0.019	0.023	0.019	0.014
Kjl-N	0.88	2.32	2.50	0.68	1.20

DETROIT LAKE

1988 INFLOW SAMPLING

	3/30/88	4/21/88	5/9/88	5/26/88	6/8/88	6/20/88	7/7/88	7/21/88	8/3/88	8/21/88	8/22/88	9/12/88	9/20/88
Phosphorus													
D-1 Detroit Lake Outlet		<0.01	0.011	0.018	0.018	0.027	0.015	0.031	0.017	0.027	0.021	0.018	0.018
D-2 Detroit Lake Inlet	0.05	0.03	0.025	0.037	0.048	0.020		0.031		0.105	0.059	0.019	0.053
D-3 Inlet: East Shore Dr.		0.03	0.058								0.081		
D-4 Sucker Creek		0.02	0.032		0.072		0.044		0.036				
Total Suspended Solids													
D-1 Detroit Lake Outlet		1.67	2.6	0.6	1.1	2.0	1.0	2.0	1.9	5.7	2.0	2.2	3.3
D-2 Detroit Lake Inlet	5.3	2.25	4.2	2.8	5.2	1.8		10.0		27.7	3.0	1.1	2.5
D-3 Inlet: East Shore Dr.		1.54	4.3								4.1		
D-4 Sucker Creek		2.04	4.9		6.5		7.4		2.6				

DETROIT LAKE

1989 INFLOW SAMPLING

	3/28/89	4/5/89	4/19/89	5/9/89	5/25/89	6/14/89
Phosphorus						
D-1 Detroit Lake Outlet	.017	.014	.018	.013	.011	.009
D-2 Detroit Lake Inlet	.084	.093	.039	.024	.042	.037
D-3 Inlet: East Shore Dr.	-	.057	-	-	-	-
D-4 Sucker Creek	.028	.024	-	.022	-	-
Total Suspended Solids						
D-1 Detroit Lake Outlet	1.1	.6	2.9	2.0	2.5	4.0
D-2 Detroit Lake Inlet	8.8	40.3	6.9	4.7	10	6.5
D-3 Inlet: East Shore Dr.	-	3.3	-	-	-	-
D-4 Sucker Creek	4.0	2.3	-	4.3	-	-

LAKE SALLIE

1988 INFLOW SAMPLING

Phosphorus	3/30/88	4/21/88	5/9/88	5/26/88	6/8/88	6/20/88	7/7/88	7/21/88	8/3/88	8/21/88	8/22/88	9/12/88	9/20/88
S-1 Sallie Outlet		0.03	0.004	0.130	0.022	0.027	0.031	0.035	0.076	0.053	0.060	0.051	0.045
S-2 Fox Lake Outlet		0.01	0.027		0.038						0.029		
S-3 Monson Lake		0.01	0.010		0.023						0.032	0.026	0.036
S-3A Rearing Ponds		0.02	0.043										
S-4 Sallie Lake Inlet		0.03	0.022	0.082	0.040	0.020	0.019	0.030	0.030	0.047	0.048	0.038	
Total Suspended Solids													
S-1 Sallie Outlet		4.05	9.5	3.2	3.7	2.0	3.6	6.0	26.7	7.8	8.2	7.3	7.6
S-2 Fox Lake Outlet		3.19	1.8		0.6						1.4		
S-3 Monson Lake		2.01	0.6		0.9						5.3	4.0	
S-3A Rearing Ponds		0.55	1.6										
S-4 Sallie Lake Inlet		1.83	2.6	2.4	3.8	1.8	0.6	3.0	1.1	13.5	10.7	7.8	6.7

#7

LAKE SALLIE

1989 INFLOW SAMPLING

	3/28/89	4/5/89	4/19/89	5/9/89	5/25/89	6/14/89
Phosphorus						
S-1 Sallie Outlet	0.018	0.018	0.006	0.020	0.007	0.015
S-2 Fox Lake Outlet	0.018	0.008		0.012		
S-3 Monson Lake		0.017				
S-3A Rearing Ponds						
S-4 Sallie Lake Inlet	0.065	0.057	0.025	0.024	0.037	0.030
Total Suspended Solids						
S-1 Sallie Outlet	1.1	0.4	1.4	2.5	0.7	3.7
S-2 Fox Lake Outlet	18.7	0.6		3.6		
S-3 Monson Lake		2.3				
S-3A Rearing Ponds						
S-4 Sallie Lake Inlet	2.7	2.7	2.3	2.0	3.3	1.5

PELICAN RIVER WATERSHED

1989 STREAM SAMPLING RESULTS

	3/28/89	4/05/89	4/11/89	4/19/89	5/09/89	5/25/89	6/14/89
Phosphorus							
C-1 St. Clair Outlet	0.205	0.160			0.043		
C-2 St. Clair Inlet E. Ditch	0.092	0.145			0.079		
C-3 St. Clair Inlet N. Ditch							
L-1 Long Lake Outlet	0.015				0.010		
P-1 Pelican River and Highway No. 34	0.097	0.200			0.024	0.034	0.035
F-1 Floyd Lake Outlet					0.010		0.011
F-2 Campell Creek	0.490	0.475	0.161	0.062	0.020		
Total Suspended Solids							
C-1 St. Clair Outlet	4.8	5.5			6.8		
C-2 St. Clair Inlet E. Ditch	6.4	3.8			6.7		
C-3 St. Clair Inlet N. Ditch							
L-1 Long Lake Outlet	1.6				2.6		
P-1 Pelican River and Highway No. 34	8.9	33.2			4.7	4.8	5.6
F-1 Floyd Lake Outlet			100.6	38.3	1.4		2.7
F-2 Campell Creek	15.7	70.3			11.5		

DETROIT LAKE
1988 PHYTOPLANKTON SAMPLING
DATA ANALYSIS

June 23, 1989

	5-12-88	6-7-88	6-20-88	7-7-88	8-10-88	9-12-88	10-19-88	11-07-88
Achnanthes								
microcephala	587	-	-	-	-	-	-	-
Anabaena								
circinalis	-	-	191,540	244,800	229,680	-	-	-
flos-aquae	-	-	-	-	63,360	42,560	-	-
Ankistrodesmus								
falcatus	-	-	-	533	-	-	-	-
Aphanizomenon								
flos-aquae	-	-	79,040	-	89,760	48,640	-	-
Aphanothece								
nidulans	-	-	-	-	-	72,960	-	-
Asterionella								
formosa	1,173	-	-	-	-	-	484	4,590
Aulacosira								
spp.	-	-	-	13,600	10,560	-	-	-
Botryococcus								
braunii	-	-	-	-	-	364,800	1,760	-
Ceratium								
hirundinella	-	-	3,040	2,720	5,280	-	-	-
Chroomonas								
acuta	15,838	-	3,040	-	-	-	-	-
Coelastrum								
microporum	-	-	-	43,520	-	-	-	-
Coelosphaerium								
naegelianum	-	15,990	-	-	660,000	-	-	-
Cosmarium								
protuberoms	-	-	3,040	-	-	-	-	-
Cryptomonas								
erosa	-	-	-	2,720	-	3,040	-	-
Cyclotella								
bodanica	-	1,599	3,040	-	-	-	-	-
meneghiniana	-	-	3,040	-	-	-	-	-
spp.	-	-	-	-	2,640	-	44	90
Dictyosphaerium								
pulchellum	6,159	16,523	-	40,800	-	-	-	-
Dinobryon								
bavaricum	-	-	-	2,720	-	-	-	180
sertularia	37,249	-	148,960	100,640	-	-	-	270
Fragilaria								
crotonensis	6,159	13,858	27,360	65,280	-	18,240	2,904	2,430
Gloeothece								
rupestris	-	-	-	-	21,120	-	-	-
Golenkinia								
radiata	293	-	-	-	-	-	-	-
Gomphosphaeria								
aponina	-	-	-	65,280	-	85,120	-	-
lacustris	-	-	-	320,960	79,200	638,400	-	-
Mallomonas								
pseudocoronata	-	-	-	2,720	-	6,080	-	-
sp.	-	-	3,040	-	-	-	-	-
Merismopedia								
glauca	-	-	-	-	253,440	-	-	-
tenuissima	-	-	-	-	-	-	2,816	-
Microcystis								
aeruginosa	-	-	-	924,800	330,000	608,000	2,200	-
Navicula								
sp.	-	-	-	-	-	-	-	90
Nitzschia								
spp.	-	-	-	-	10,560	3,040	-	360
Oocystis								
sp.	2,053	-	-	-	-	-	-	-
Oscillatoria								
tenuis	-	-	-	-	-	152,000	-	-
Quadrigula								
chodatii	5,279	-	6,080	-	-	-	-	-
Scenedesmus								
bijuga	-	3,198	12,160	-	10,560	-	-	-
Synedra								
spp.	2,053	-	6,080	10,880	10,560	3,040	44	270
Total (Cells/l)	76,845	51,701	483,360	1,841,440	1,768,800	2,045,920	10,252	8,280
Total Taxa (S)	10	6	13	1.57462	1.80388	1.71887	1.53338	1.24219
Diversity (H'= bits)	1.10	0.971	1.094	2.63906	2.63906	2.56495	1.94591	2.07944
Diversity (H-max)	1.60	1.241	1.777	14	14	13	0.788001	0.597368
Evenness (J)	0.6878	0.7820	0.6157	0.596659	0.683533	0.670139	7	8

#10

LAKE SALLIE
1988 PHYTOPLANKTON SAMPLING
DATA ANALYSIS

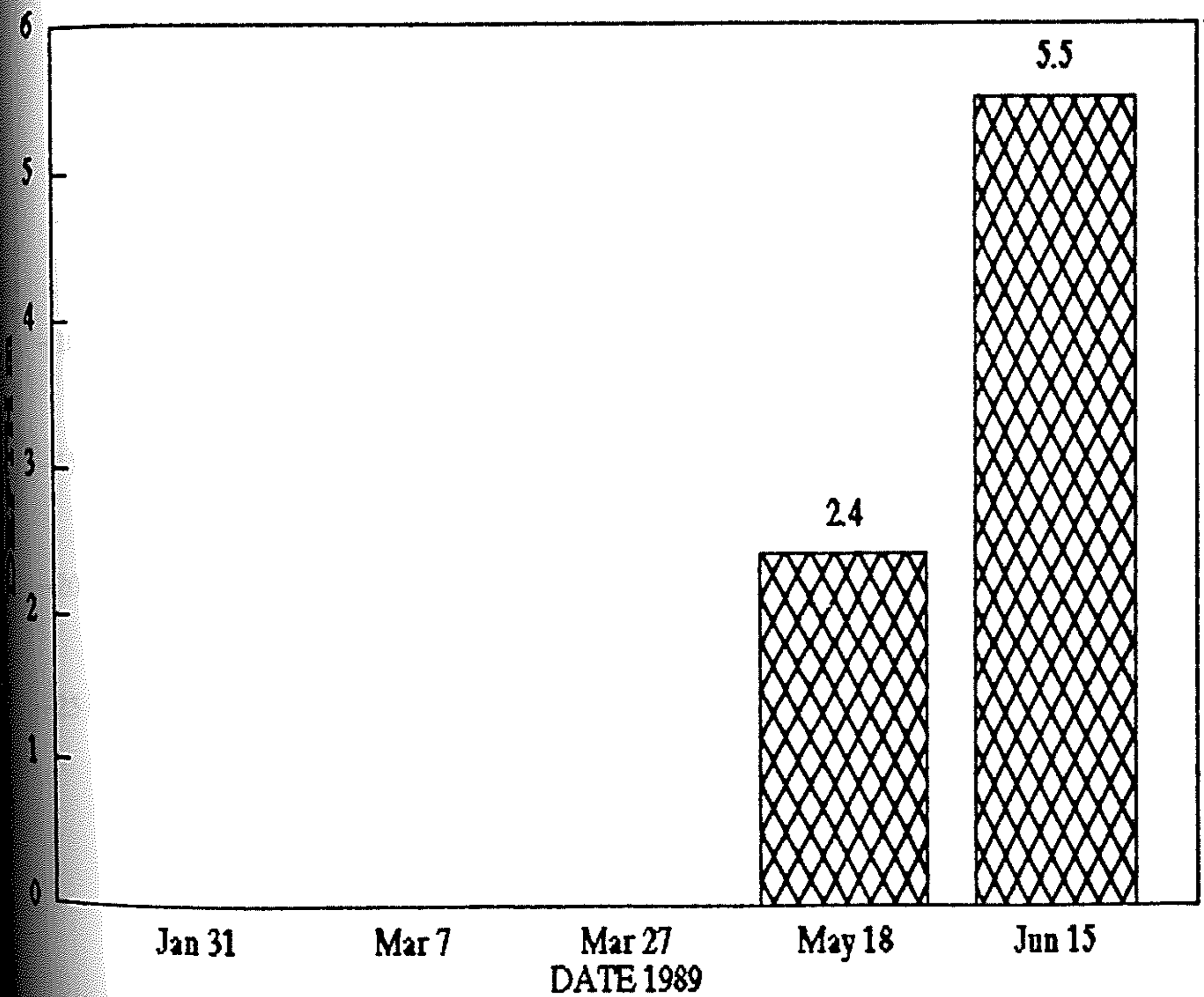
June 23, 1989

	5-12-88	6-7-88	6-20-88	7-7-88	8-10-88	9-12-88	10-19-88	11-14-88
Anabaena								
circinalis	-	-	1,684,800	416,480	448,000	-	-	-
flos-aquae	-	-	-	-	608,000	-	-	-
macrospora	-	-	-	425,600	1,200,000	18,240	-	-
Aphanizomenon								
flos-aquae	-	-	320,000	635,360	5,440,000	72,960	2,109	3,555
Aphanothece								
nidulans	-	-	-	-	320,000	-	-	-
Asterionella								
formosa	26,320	-	-	-	-	-	-	158
Aulacosira								
spp.	-	-	-	-	32,000	79,040	798	553
Botryococcus								
braunii	-	96,000	-	-	-	-	-	3,555
Ceratium								
hirundinella	-	1,600	-	-	3,200	-	-	-
Chroomonas								
acuta	17,360	-	-	6,080	-	-	57	-
Coelosphaerium								
naegelianum	-	-	-	-	1,920,000	942,400	10,260	-
Cosmarium								
protuberans	-	1,600	-	3,040	-	-	-	-
Cryptomonas								
erosa	560	3,200	9,600	6,080	16,000	12,160	399	237
Dictyosphaerium								
pulchellum	40,880	-	-	-	-	-	171	-
Dinobryon								
sertularia	22,400	19,200	8,000	3,040	-	-	-	-
Elakatothrix								
viridis	-	-	-	-	-	-	114	-
Fragilaria								
capucina	1,680	-	-	-	-	-	-	3,397
Fragilaria								
crotonensis	4,480	121,600	425,600	9,120	-	-	-	553
Gloeocapsa								
spp.	-	-	18,240	-	-	-	-	-
Gomphosphaeria								
aponina	-	-	565,440	800,000	-	-	-	-
lacustris	-	-	-	96,000	-	-	-	-
Lyngbya								
bergii	-	-	-	36,480	-	-	-	-
Mallomonas								
pseudocoronata	-	-	-	-	-	3,040	-	-
sp.	-	1,600	3,200	-	-	-	-	-
Microcystis								
aeruginosa	-	-	160,000	-	9,920,000	-	-	-
Nitzschia								
sp.	1,680	-	-	-	-	-	-	-
Oocystis								
parva	-	-	-	-	-	-	228	-
sp.	-	6,400	16,000	-	-	-	-	-
Oscillatoria								
princeps	-	-	-	-	-	18,240	-	-
tenuis	-	-	-	-	16,960,000	1,246,400	-	-
Pandorina								
morum	-	25,600	-	97,280	-	-	-	-
Peridinium								
inconspicuum	-	-	-	-	6,400	-	-	-
Pinnularia								
spp.	-	-	-	3,040	-	-	-	-
Quadrigula								
chodatii	-	-	12,800	-	-	-	-	-
Scenedesmus								
bijuga	1,120	-	-	-	-	-	-	-
Stephanodiscus								
alpinus	3,360	-	-	-	-	-	-	-
niagarae	-	-	-	-	-	-	2,451	1,738
spp.	-	-	-	-	-	36,480	-	-
Synedra								
spp.	5,040	-	-	-	-	-	-	79
Total (Cells/l)	125,860	276,800	2,640,000	2,225,280	37,769,600	2,428,960	16,587	13,825
Total taxa (S)	11	9	9	1.65358	1.51364	1.10213	1.23498	1.7114
Diversity (H', bits)	1.26	0.935	0.768	2.56495	2.63906	2.19722	2.19722	2.19722
Diversity (H-max)	1.66	1.522	1.522	13	14	9	0.562063	0.778912
Evenness (J)	0.7628	0.6140	0.5046	0.644682	0.573554	0.501602	•	•

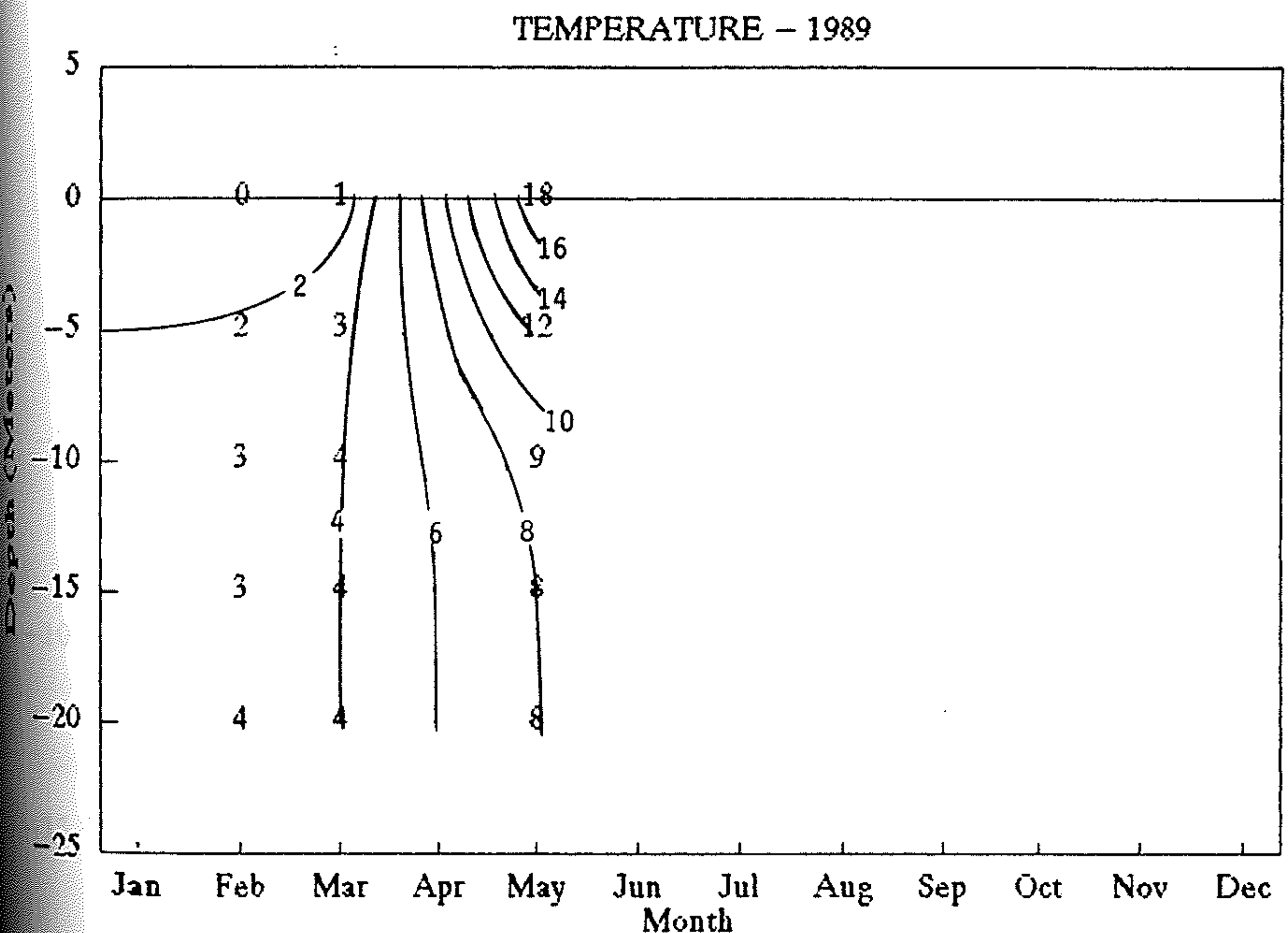
#11

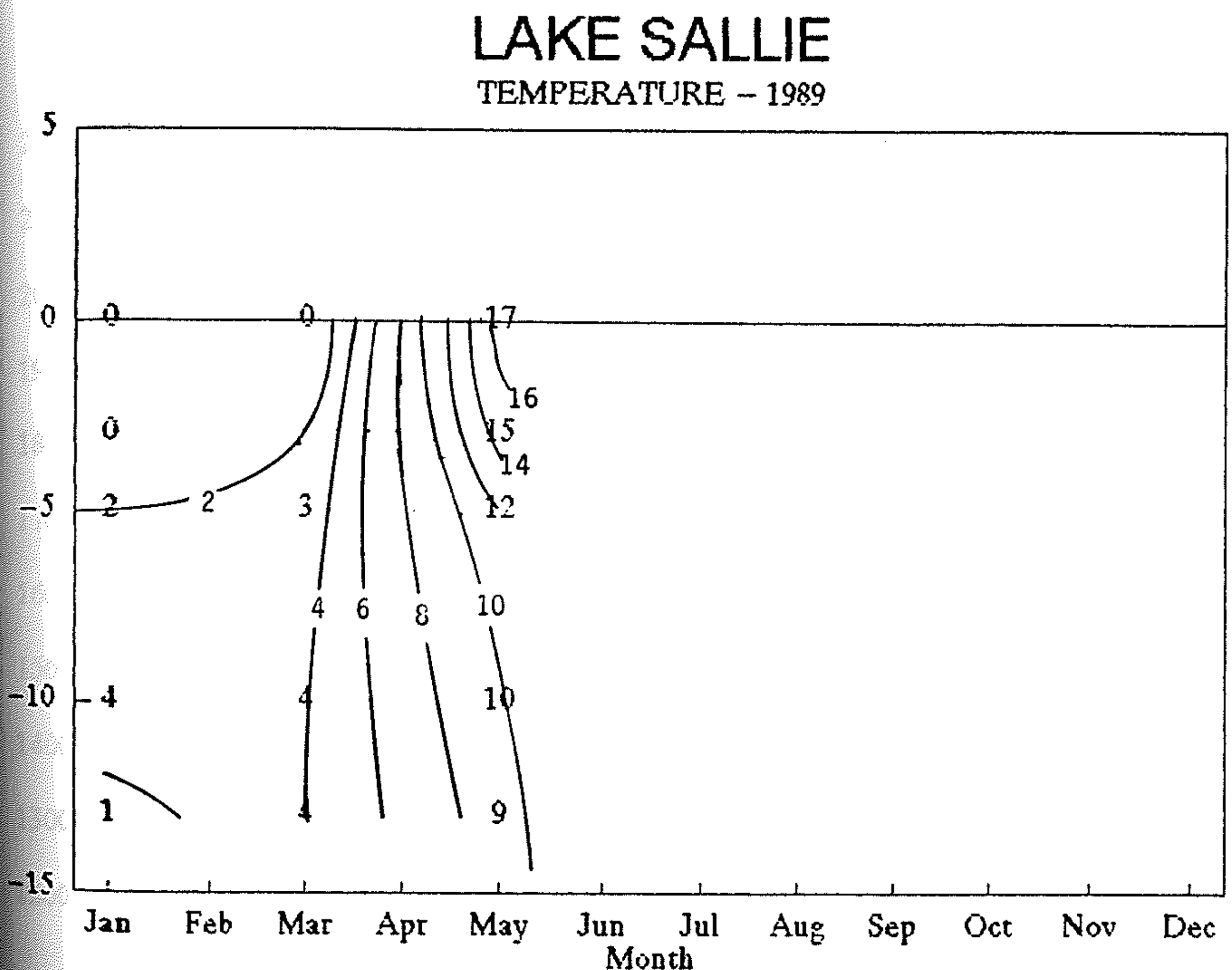
DETROIT LAKE

SECCHI DISK



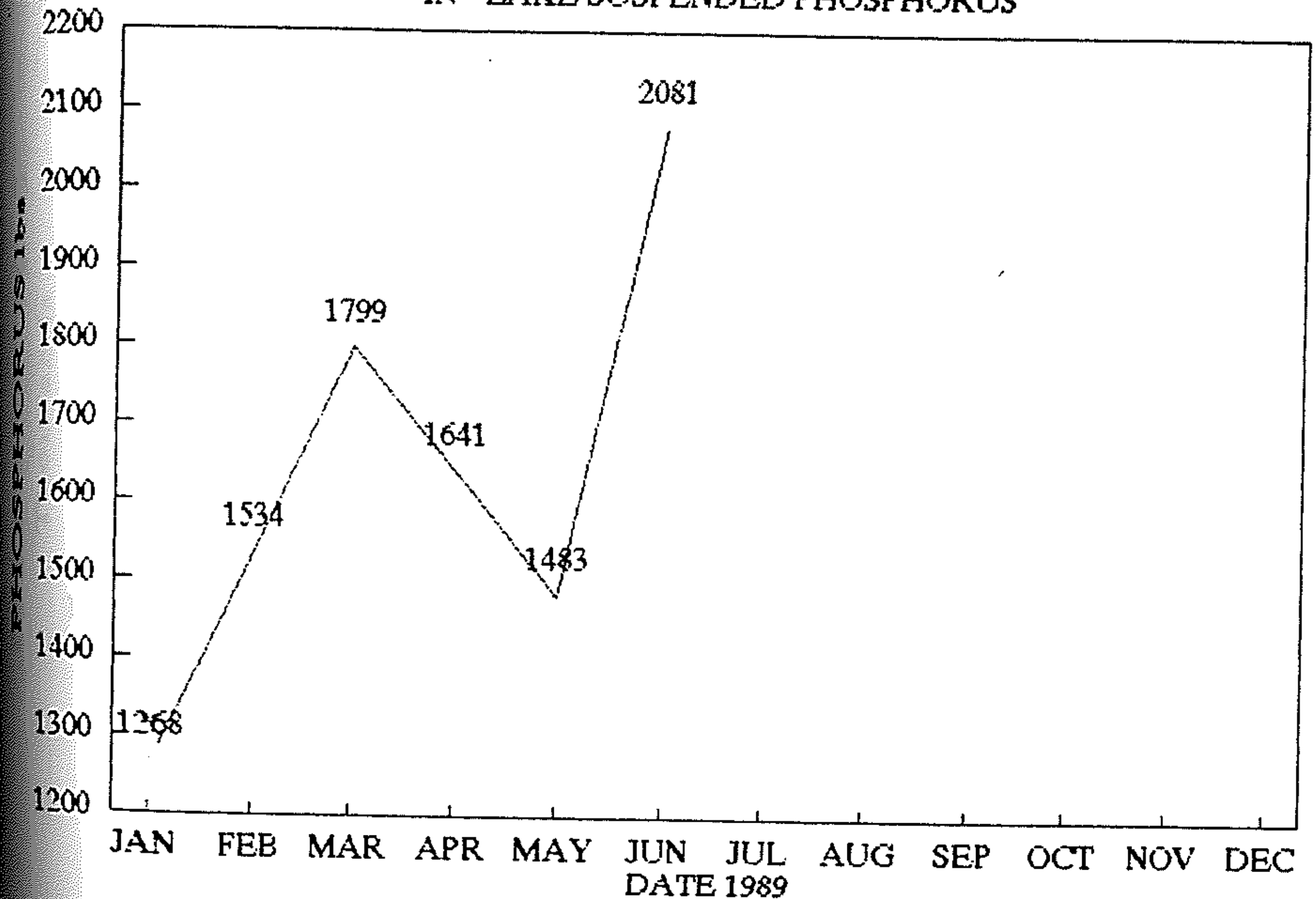
DETROIT LAKE

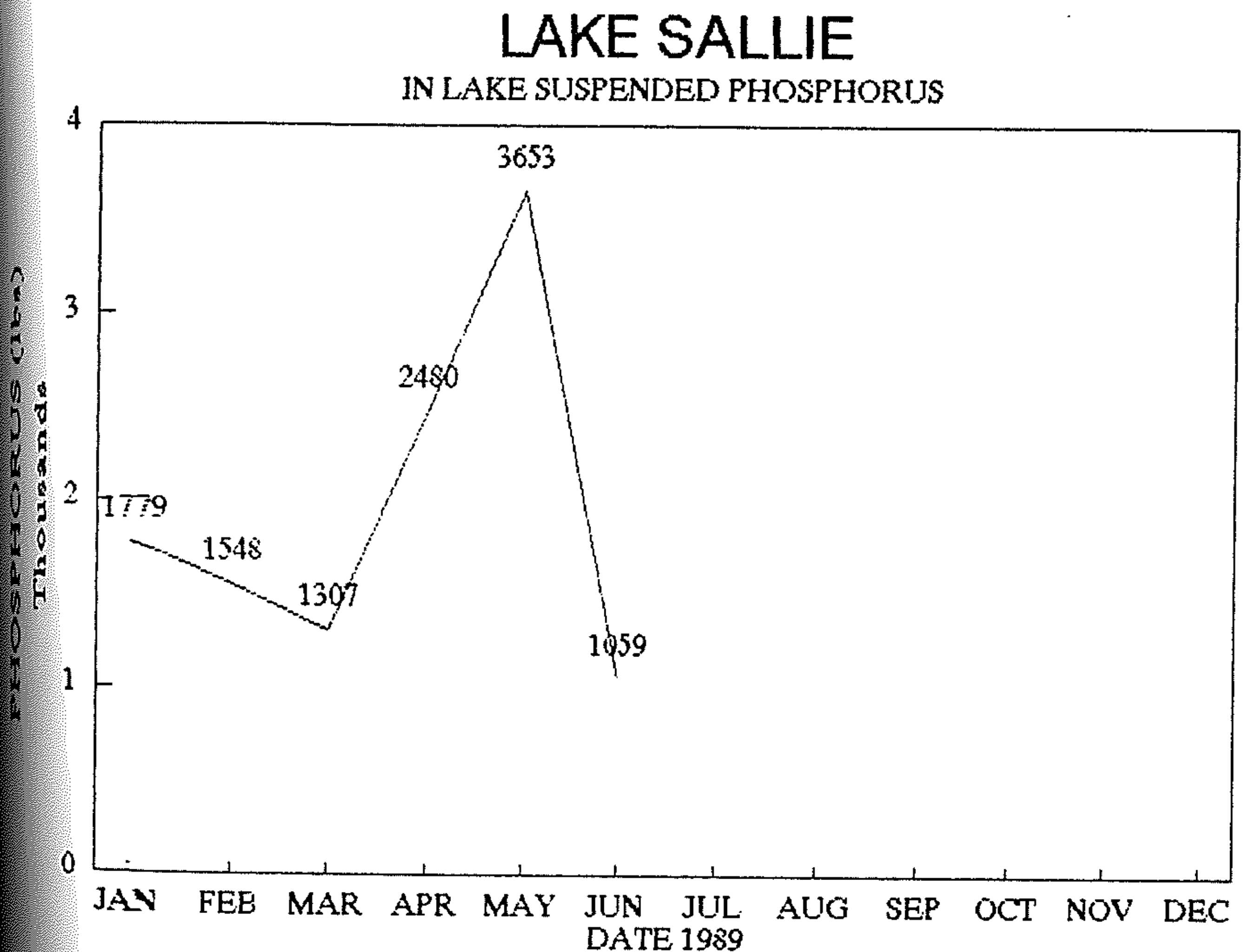



LAKE SALLIE
TEMPERATURE – 1989
5
0
-5
-10
-15
0
0
2
2
0
3
4
1
4
4
4
6
8
10
17
16
15
14
12
10
10
9
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

DETROIT LAKE

IN-LAKE SUSPENDED PHOSPHORUS




LAKE SALLIE
IN LAKE SUSPENDED PHOSPHORUS
PHOSPHORUS (lbs)
Thousands
4
3
2
1
0
1779
1548
1307
2480
3653
1059
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
DATE 1989

HYDROLOGIC BUDGET

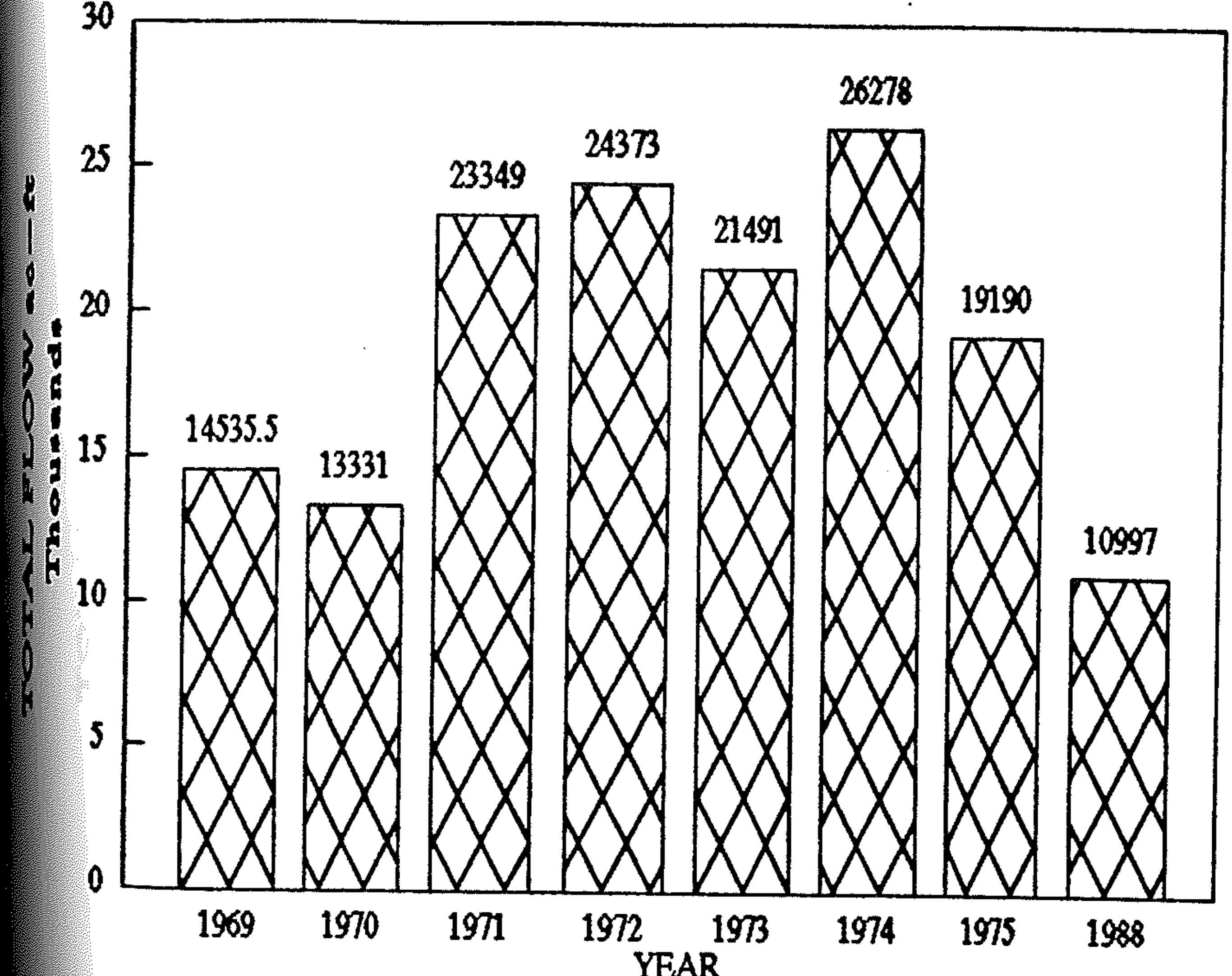
LAKE SALLIE

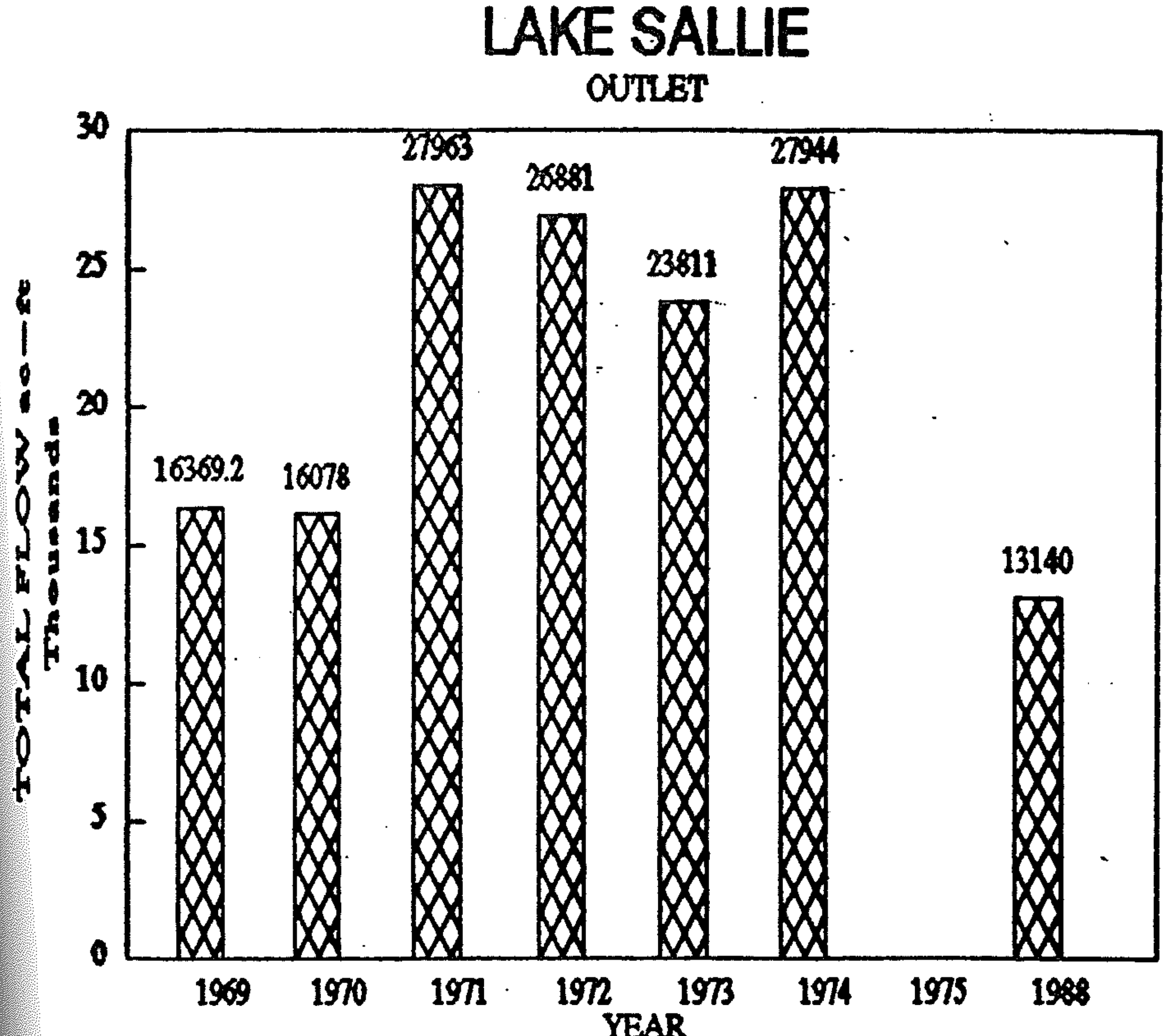
	1969	1970	1988
Surface Inflow	16,170	14,192	11,279
Precipitation	2,192	2,107	2,645
Surface Outflow	18,416	15,661	13,140
Evaporation	2,983	3,277	4,524
Change in Storage	-380	+420	-87
Residual	2,657	3,059	3,767

#17

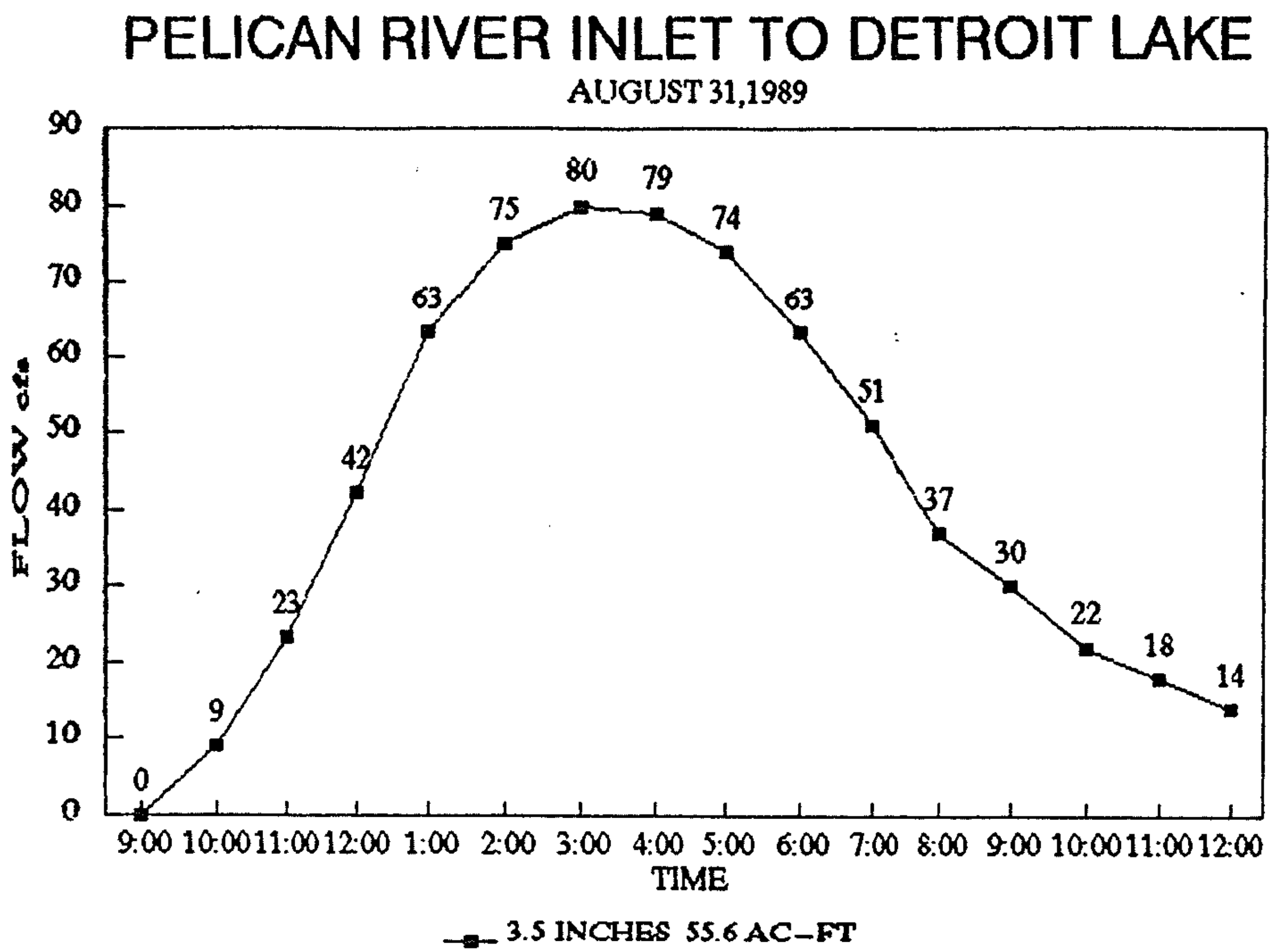
LAKE SALLIE

MUSKRAT LAKE OUTLET

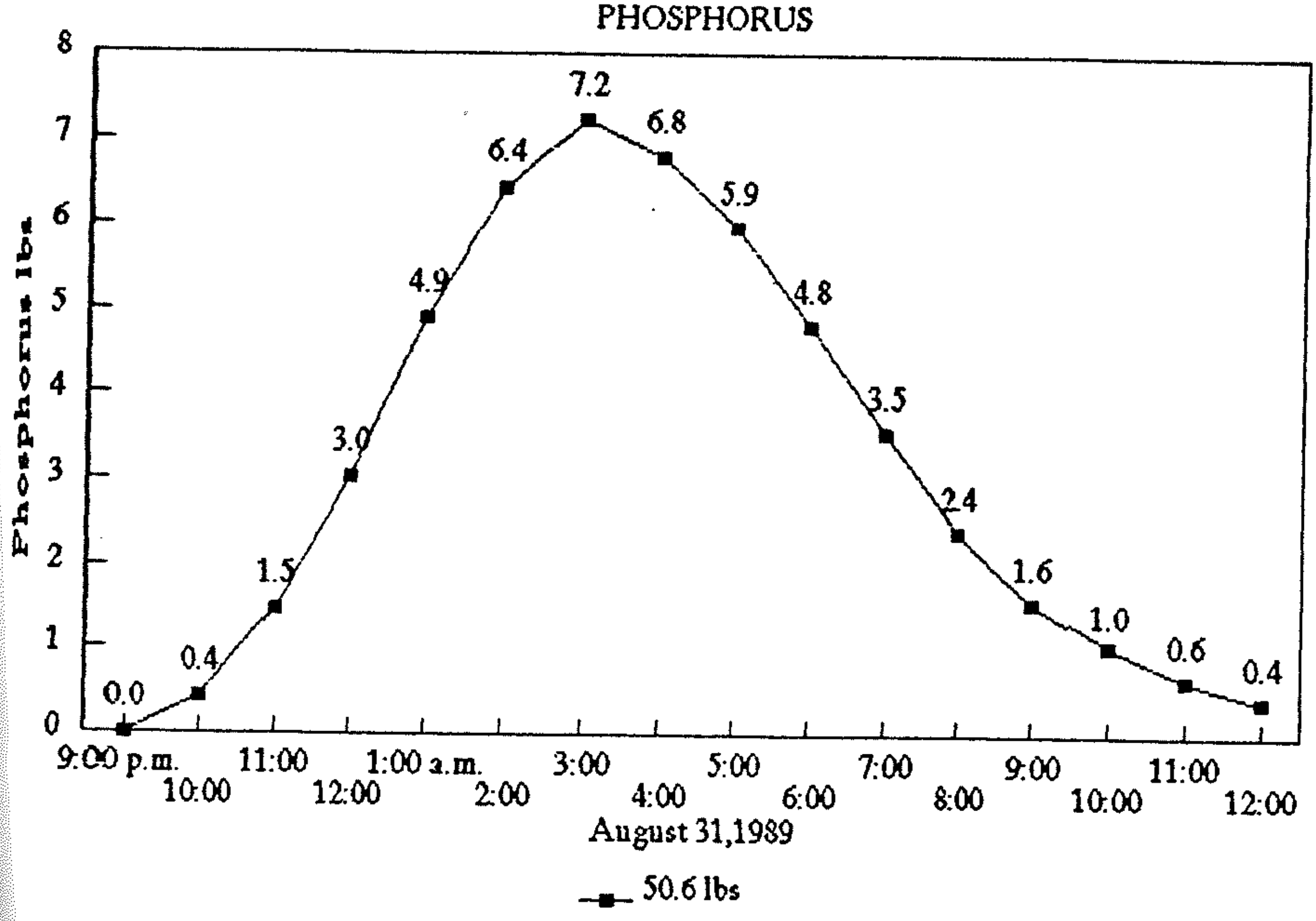




LAKE SALLIE
OUTLET
TOTAL FLOW ac-ft
Thousands
30
25
20
15
10
5
0
16369.2
16078
27963
26881
23811
27944
13140
1969
1970
1971
1972
1973
1974
1975
1988
YEAR


PELICAN RIVER INLET TO DETROIT LAKE
AUGUST 31,1989
FLOW cfs
90
80
70
60
50
40
30
20
10
0
0
9
23
42
63
75
80
79
74
63
51
37
30
22
18
14
9:00
10:00
11:00
12:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
12:00
TIME
3.5 INCHES 55.6 AC-FT

PELICAN RIVER INLET TO DETROIT LAKE



ZOOPLANKTON: DETROIT LAKE (No. Per M^3)

Organism	5/12/88	6/9/88	6/20/88	7/5/88	8/9/88	11/14/88
Daphnia Pulex	2,050	23	8	43	-	26
Daphnia Galeata	2,050	41	113	128	26	410
Daphnia Retrocurva	-	-	-	43	250	-
Chydorus sphaericus	1,025	-	-	-	-	128
Unknown Daphnia	-	-	10	68	-	-
Bosmina sp.	2,050	3	-	-	-	26
Sida crystallina	-	-	-	-	-	-
Total Cladocera	7,175	67	131	282	276	590
Mesocyclops edax	-	-	-	-	13	-
Macrocyclops albidus	-	3	3	-	26	-
Juvenile cyclopoid	26,653	5	-	17	-	128
Diaptmus oregonensis		3	-	-	-	192
Cyclops bicuspidatus t.	-	-	-	-	-	26
Epischura lacustris	-	3	-	-	-	-
Juvenile calanoid	2,050	8	3	34	26	26
Naupliar stages	22,553	3	-	-	-	-
Total Copepod	51,256	25	6	51	65	372
Rotifera	6,151	3	-	-	-	90
Ostracods	-	-	5	-	-	-
Diptera	-	3	-	-	-	-
Total Organisms	64,582	98	142	333	341	1,052

ZOO PLANKTON: LAKE SALLIE (No. per M^3)

Organism	5/12/88	6/9/88	6/20/88	7/5/88	8/9/88	11/14/88
Daphnia Pulex	6,736	547	168	9,684	1,810	7,789
Daphnia Galeata	1,684	758	2,189	-	-	4,842
Daphnia Retrocurva	-	253	674	1,474	337	-
Unknown Daphnia	-	463	505	842	168	-
Bosmina sp.	5,052	-	-	-	-	210
Sida Crystallina	-	-	-	-	84	-
TOTAL CLADOCERA	13,472	2,021	3,536	12,000	2,399	12,841
Mesocyclops edax	-	168	-	-	421	-
Macrocyclops albidus	-	42	-	-	-	-
Juvenile cyclopoid	63,157	-	-	-	84	632
Diaptmus oregonensis	-	211	84	211	168	211
Cyclops bisupidatus t.	6,737	-	-	-	-	-
Epischura lacustris	-	42	-	-	-	-
Juvenile calanoid	5,052	42	84	-	253	632
Nauplier stages	36,210	168	-	-	253	211
TOTAL COPEPOD	111,156	673	168	211	1,179	1,686
Ostracods	-	84	-	-	84	-
Rotifers	52,209	-	-	-	842	211
TOTAL ORGANISMS	176,837	2,778	3,704	12,211	4,504	14,738