MONITORING PLAN

LAKES SALLIE AND DETROIT

PELICAN RIVER WATERSHED

February 8, 1988

By

LARSON-PETERSON & ASSOCIATES, INC.
Consulting Engineers
Detroit Lakes, Minnesota

MONITORING PLAN

LAKES SALLIE AND DETROIT
PELICAN RIVER WATERSHED

I N D E X

MONITORING PLAN FOR LAKES SALLIE AND DETROIT

Pelican River Watershed

Becker County, Minnesota

February 8, 1988

I. INTRODUCTION

A study of Lake Sallie and Detroit Lakes has been initiated through the U.S. EPA Clean Lakes Assistance Program in cooperation with the Minnesota Pollution Control Agency (MPCA). The Monitoring Plan will collect field data from the study lakes and associated watersheds for evaluation and interpretation. The objectives of this study will be to (1) determine the water quality and condition of each lake by documenting physical, chemical and biological characteristics with in-lake testing, (2) complete a quantitative analysis of hydrologic and limiting nutrient inflows and outflows to each lake by stream flow monitoring and sampling, and (3) obtain hydrologic and nutrient information in the watersheds for assistance in isolation of major nutrient sources.

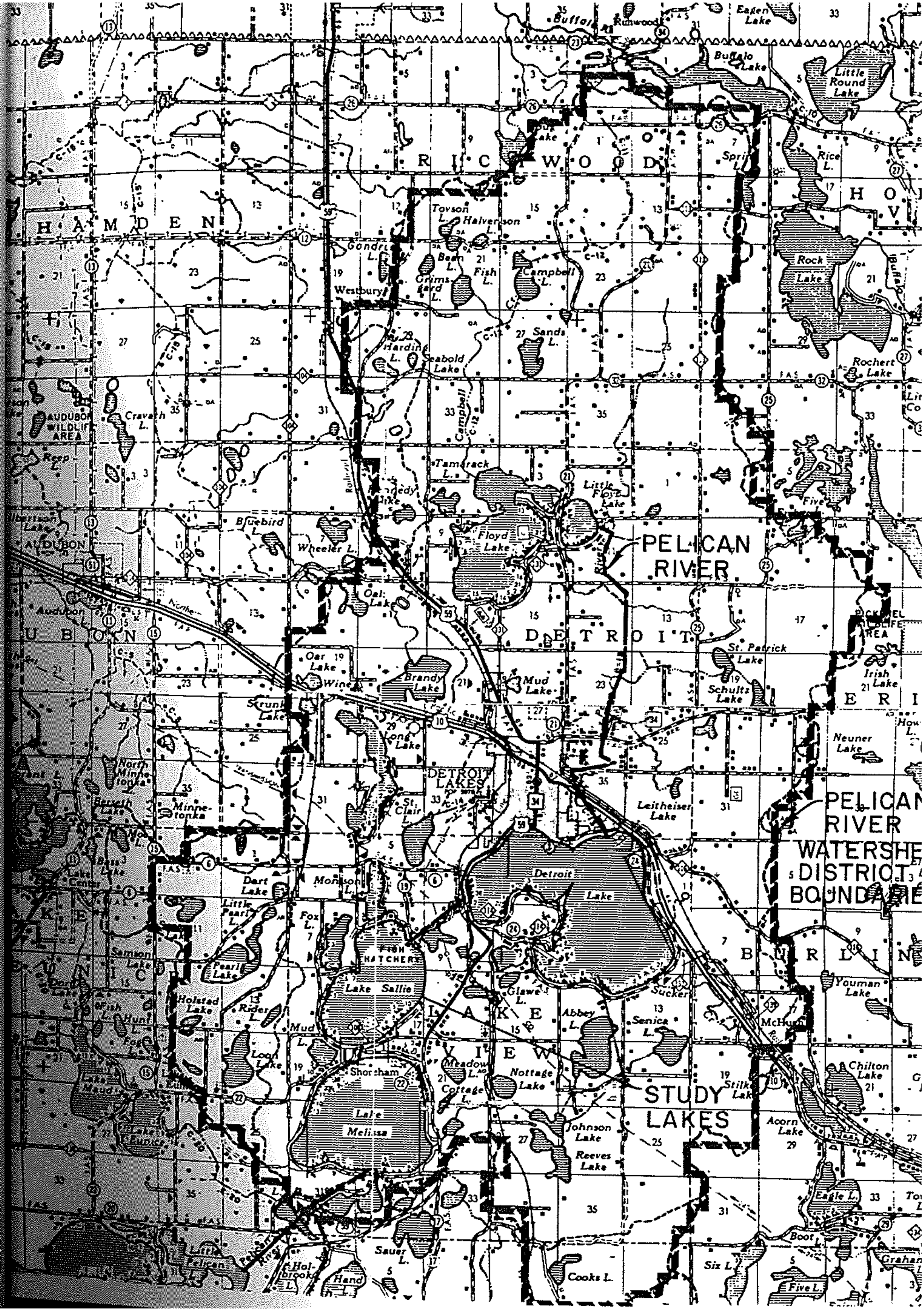
II. LOCATION AND DESCRIPTION OF THE STUDY AREA

Lake Sallie and Detroit are located in the Pelican River Watershed, 50 miles east of Fargo-Moorhead in west central Minnesota. The Pelican River initiates above Detroit lake and flows through Detroit Lake into Lake Sallie as it proceeds southerly to Pelican Lake. An elevation drop exceeding 20 feet exists from the Pelican River into Detroit Lake and an additional five feet differential between Detroit Lake and Lake Sallie.

Annual precipitation is 24 inches, with almost four inches average in June and August. (The average annual lake evaporation for Becker County is 27".) The average annual temperature is 40°F, ranging from a low average monthly temperature of 5°F to 70°F.

III. AVAILABLE STUDIES AND DATA

The Pelican River Watershed has been included in previous reports which include Lakes Sallie and Detroit. A hydrologic study was done by Mann and McBride in 1972 relating to the hydrology of Lake Sallie. A summary of the Study is attached to this Report. Appraisal of the Pelican River Sand-Plain Aquifer, Western Minnesota was completed by the U.S. Geological Survey in 1982 relative to groundwater characteristics. A floor management study by Federal Emergency Management Agency (FEMA) has recently completed an analysis of the Pelican River in regard to flooding frequency. These reports will be used to assist in compiling the necessary data for the monitoring plan.



HAMDEN
DETROIT
LAKE VIEW
PELICAN RIVER
PELICAN RIVER WATERSHE DISTRICT BOUNDARIE
STUDY LAKES
DETROIT LAKES
Detroit Lake
Lake Sallie
Lake Melissa
Shorsham
Floyd Lake
Little Floyd Lake
Rock Lake
Little Round Lake
Buffalo Lake
Eagen Lake
Rice L.
Tovson L.
Halverson L.
Campbell L.
Sands L.
Seabold Lake
Harding L.
Westbury
Tamarack L.
Bluebird L.
Wheeler L.
Oar Lake
Brandy Lake
Mud Lake
Long Lake
St. Clair L.
Dart Lake
Monson L.
Fox L.
Little Pearl L.
Pearl Lake
Holstad Lake
Rider L.
Loon Lake
Glawe L.
Abbey L.
Senica L.
Meadow L.
Nottage Lake
Cottage L.
Johnson Lake
Reeves Lake
Cooks L.
Sauer L.
Hand L.
Holbrook L.
Little Pelican
Lake Maud
Lake Eunice
St. Patrick Lake
Schultz Lake
Irish Lake
Neuner Lake
Leitheiser Lake
Youman Lake
Chilton Lake
Acorn Lake
Stilke L.
Eagle L.
Boot L.
Six L.
Five L.
McHugh
Rochert Lake
Cravath L.
AUDUBON WILDLIFE AREA
AUDUBON
Minnetonka
North Minnetonka
Berseth Lake
Samson
Lake Center
Sucker
FISH HATCHERY

IV. DATA COLLECTION

The Monitoring Plan will be a 12 month study of water quality and quantity as it relates to the study lakes. Data will be collected for the analysis according to the following procedures:

A. Weather Factors

Climatological data which will be necessary for evaluation of lake data will include precipitation, temperature and evaporation information. The Detroit Lakes radio station records daily precipitation and temperature data and compiles the data in a monthly report which is submitted to the National Weather Bureau (NWB). A copy of this information is being made available to the Watershed District (see attached letter). Evaporation studies are currently being done by North Dakota State University and will be used for computation of total annual evaporation. The Soil Conservation Service in Detroit Lakes also has evaporation data which will be of assistance.

B. Lakes

Lake samples in Lake Sallie and Detroit Lake will be taken by a qualified individual employed by the Pelican River Watershed District. The necessary equipment and documentation forms will be supplied by the District.

Samples will be obtained by boat at the deepest point in each lake. The samples will be obtained by a Van Doren water sampler and transferred to samples bottles supplied by the testing laboratory. The date, depth and location of each sample will be documented. The testing laboratory will be Twin City Testing, Fargo, North Dakota, or Pace Laboratories, Minneapolis, Minnesota.

Field data will also be collected for physical characteristics. The data will be taken and recorded in field notes on forms such as the one attached to this Report. (Form PR-1)

C. Surface Water

Flow monitoring will be done on major inflow and outflow streams. Several individuals will be responsible to record stream levels and return the information monthly to the Pelican River Watershed District. Sample recording form PR-2 is attached.

Nutrient and sediment loading samples will be taken by the same individual responsible for inplace sampling. The date and location of each sample will be recorded and the samples will be sent to a qualified testing laboratory for analysis. Sample documentation form PR-3 is attached.

D. Groundwater Sampling

Groundwater sampling of designated wells will be accomplished by a field survey team to obtain a sample for nutrient analysis and to record the groundwater elevation. The groundwater samples will be sent to a qualified laboratory for analysis. Groundwater elevations will be obtained from a welldrawdown probe. (Form PR-4)

V. LAKE SAMPLING

Monitoring the lake characteristics of Lakes Sallie and Detroit will require a systematic collection of several physical and water quality parameters. This procedure is described below for each lake.

A. Lake Sallie

Sample Location: Maximum depth near center of the lake. Depth = 55 feet (16.8 meters). (See attached lake map.)

Sampling Schedule: Equal intervals twice each month from May to August. From September to April samples will be taken monthly.

Requirements for Lab Analysis: A sample will be taken near the surface and at depths of 5, 10 and 15 meters (near the bottom) for a total of four at each testing date. The total number of samples taken from Lake Sallie will be:

May - August: 4 months (2)(4 samples) = 32
September - April: 8 months (1)(4 samples) = 32

Total Samples 64

Samples will be analyzed on the basis of the following schedule:

Lab Analysis

Parameter	Frequency	Total
Total P	Each sample	64
Ortho P	Each sample	64
Organic N	Each sample	64
Nitrate, Nitrite	Every other sample	32
TSS	5m depth samples	16
Coliform	Monthly	12
Chlorophyll a	One each test date	16
Conductivity	One test quarterly	4
Phytoplankton	Monthly	12
Zooplankton	Monthly	12

Requirements for Field Analysis: The lake will be samples on 16 separate dates during the one year sampling period. Field analysis will be recorded for each of the following items:

Parameter	Frequency	Testing Method
Dissolved Oxygen	2 meter intervals	DO Meter with probe
pH	2 meter intervals	pH meter
Temperature	2 meter intervals	Thermometer with probe
Clarity	N/A	Secchi Disk

B. Detroit Lake

Sample Location: Maximum depth in southwest corner of Big Detroit. Depth = 82 feet (25.0 meters). (See attached lake map.)

Sampling Schedule: Equal intervals twice each month from May to August. From September to April, samples will be taken monthly.

Requirements for Lab Analysis: A sample will be taken near the surface and at depths of 5, 10, 15, 20 and 25 meters (near the bottom) for a total of six at each testing date. The total number of samples taken from Detroit will be:

May - August: 4 months (2)(6 samples) = 48
September - April: 8 months (1)(6 samples) = 48

Total Samples 96

The testing requirements for the samples will be:

Lab Analysis

Parameter	Frequency	Total
Total P	Each sample	96
Ortho P	Each sample	96
Organic N	Each sample	96
Nitrate, Nitrite	Every other sample	48
TSS	5 meter depth sample	12
Coliform	Monthly	12
Chlorophyll a	One per sample date	16
Conductivity	One test quarterly	4
Phytoplankton	Monthly	12
Zooplankton	Monthly	12

Summary of Field Analysis:

The lake will be sampled on 16 separate dates during the one year sampling period. In addition to the samples for lab analysis, the following field data will be recorded for each sample date:

Field Tests

Parameter	Depth Intervals	Testing Method
Dissolved Oxygen	2 meters	DO meter with probe
pH	2 meter	pH meter
Temperature	2 meter and to define temperature statification depths	Meter with probe
Clarity	N/A	Secchi Disk

VI. STREAM SAMPLING

The purpose of surface water sampling will be to determine the phosphorus and total suspended solids (TSS) loading to Detroit Lakes and Lake Sallie. The Pelican River has been identified as being the major inflow source to each lake. Therefore, samples will be taken twice each month at the inflow and outflow locations to each lake. Scheduled monthly samples will also be taken in the Watershed. The sample locations are shown on the map of the study area. The P and TSS concentrations, combined with the flows, will determine the total annual input of these parameters.

Major inflow of P and TSS are expected during significant rainfall events. As the Soil Conservation Service (SCS) Rainfall Data Map illustrates, a 24-hour, one year rainfall in the study area is two inches. Review of a 1986 Flood Insurance Study done by the Federal Emergency Management Agency (FEMA) and the SCS Hydrology Guide suggest that rainfall events exceeding 1.25 inches will result in substantial increasing in the Pelican River. It is anticipated that up to five storm events during the year may occur. It will be attempted to collect three samples on the Pelican River inflow and outfalow points after these events and one each at the remaining sampling stations. Therefore, the total estimated number of samples taken will be:

Surface Water Sampling

Location	Frequency	Total Samples
Pelican River Stations (4)		
° Scheduled Sampling	Twice a month	48
° 5 Storm Events	3 Per Storm	60
Remaining Sample Locations (10)		
° Scheduled Sampling	Monthly	120
° 5 Storm Events	One Per Storm	50
	Total	278

IN + OUT DETROIT SALLIE

VII. GROUNDWATER SAMPLING

The groundwater sampling to be completed with this Study shall relate to the City of Detroit Lake Wastewater Treatment Facility. The Detroit Lake Wastewater Treatment Facility is located within the groundwater net of Lake Sallie as shown on the attached U.S.G.S. Groundwater Map.

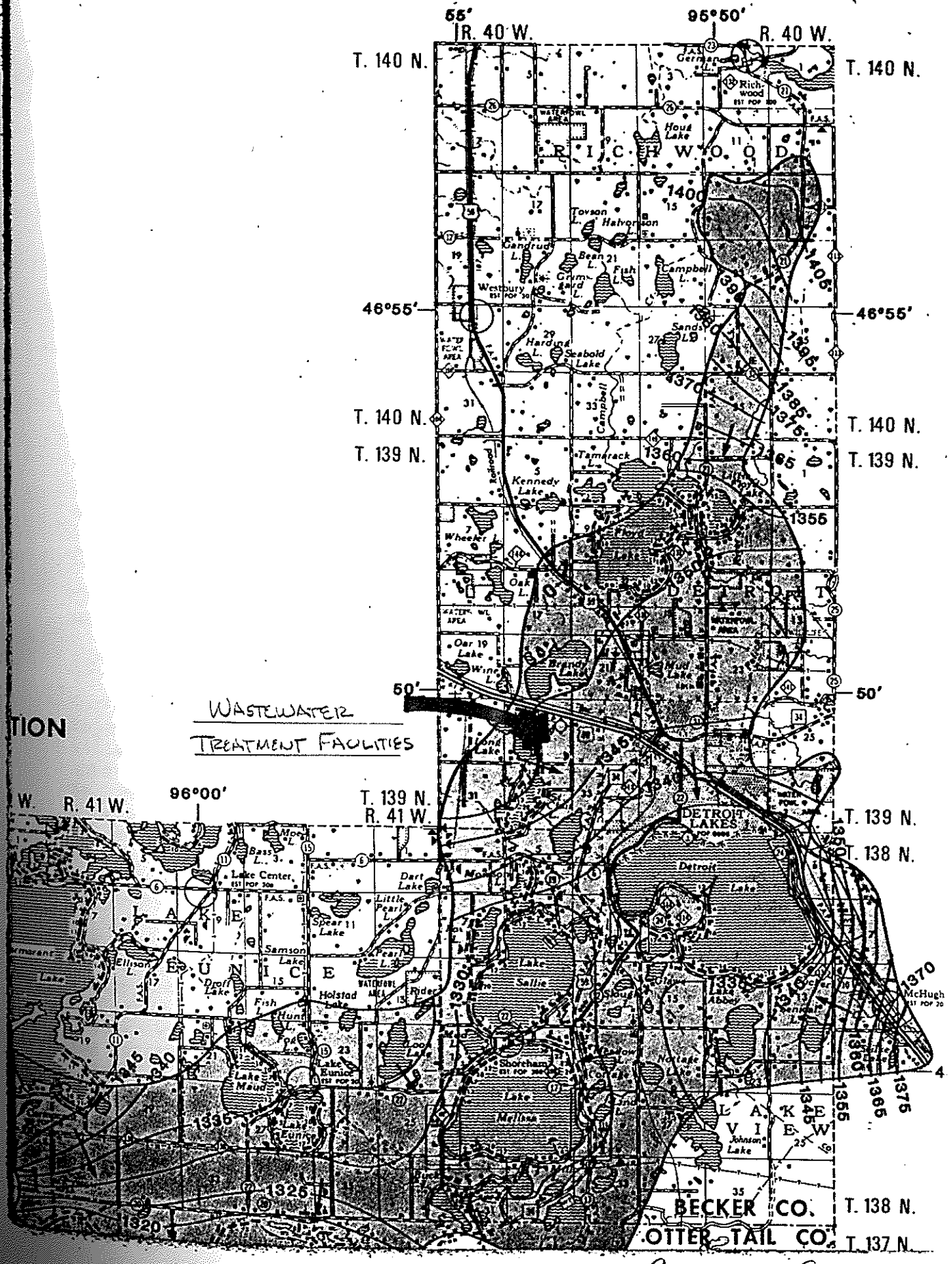
The system consists of spray irrigation and rapid sand infiltration beds which can impact the groundwater. Monitoring wells have been previously installed to monitoring groundwater and the locations are shown on the attached map. Samples will be collected from PC-18, PC-27 and PC-30 (see attached site map) to analyze phosphorus and nitrogen concentrations. The results of PC-18 should provide upstream data which can be compared to samples taken between the facility and the lake. Samples will be taken monthly to compare water quality during the irrigation and non-irrigation periods.

Groundwater Sampling

Location	Parameter	Frequency	Total
PC-18	P, N	Monthly	12
PC-27	P, N	Monthly	12
PC-30	P, N	Monthly	12
		Total	36

The City of Detroit Lakes records water analysis and flow data daily at the Treatment Plant. These records will be evaluated to determine a relationship between nutrient loading and impacts on groundwater.

PREPARED IN C
WESMIN RESOURCE CONSERVATION AND
MINNESOTA DEPARTMENT OF NATURAL RESOU



GROUNDWATER CONTOURS

VIII. HYDROLOGIC BUDGET

The hydrologic budget is a summary of changes in the water volume of each lake as a result of precipitation, streamflow, changes in surface storage, groundwater flow and evaporation. The equation for such a budget can be written as follows:

$$LV_f - LV_i = P_T + (I_T - O_T) \pm GW - E$$

where:

LV_i = Initial lake volume
LV_v = Final lake volume
P_T = Total precipitation
I_T = Surface inflow
O_T = Surface outflow
GW = Groundwater input
E = Evaporation

A. Lake Volume

The change in lake volume can be determined by the initial and final lake elevations. Daily lake elevations will be recorded for each lake. The location of those readings will be at the Detroit Lake outlet and at the Lake Sallie DNR Fish Hatchery.

B. Precipitation and Evaporation

Collection of precipitation and evaporation as previously noted will be totaled for annual values.

C. Surface Inflow/Outflow

Surface water will be monitored for one year by collection of data at major inflows and outflows to each lake. Previous studies have identified the Pelican River as by far the largest contributor to each lake. Therefore, the Pelican River inflow and outflow locations will be considered primary monitoring locations. The remaining inflow points to each lake will be designated secondary monitoring locations. The monitoring locations are shown on the lake maps attached. Stations at upstream locations are supplemental locations to be used for evaluation of low and nutrient sources. U.S.G.S. contour maps identifying each monitoring station are attached.

The flow monitoring will be done by installation of staff gauges. Rating curves will be developed by measuring the cross-sectional stream area and determining velocities at variable stream depths. Available data from the U.S.G.S. office from previous flow analysis studies will be of assistance in calibration and flow monitoring of the streams. A survey team will be used to measure stream flow velocities.

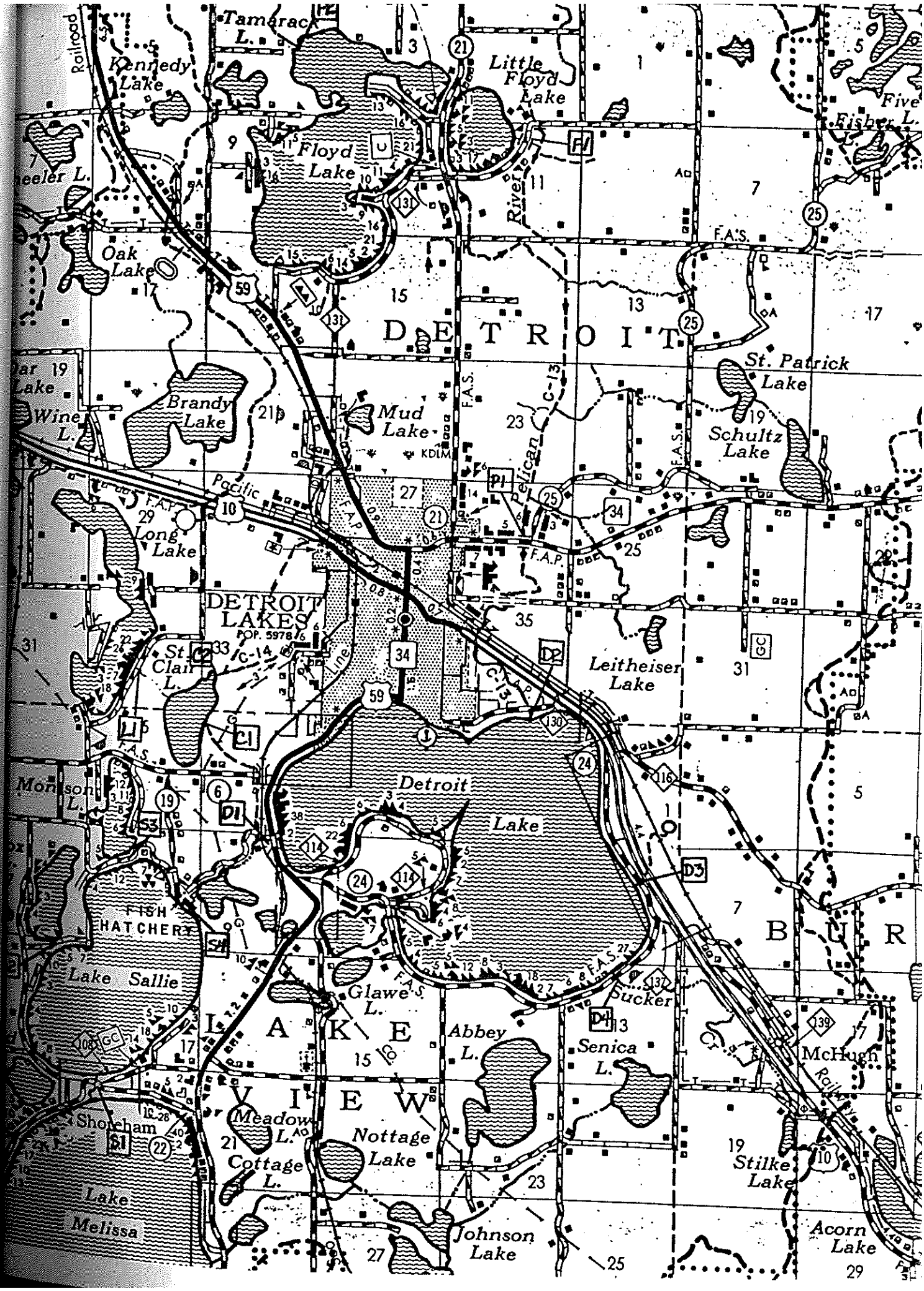
The monitoring locations as identified on the study area map will be as follows:

Flow Montoring Stations

No.	Location	Type	Frequency of Measurement
S1	Sallie Outlet: Pelican River	Primary	Daily
S2	Fox Lake	Primary	Twice a Week
S3	Monson Lake	Secondary	Twice a Week
S3A	Rearing Ponds	Secondary	Twice a Week
S4	Sallie Inlet: Pelican River	Primary	Daily
D1	Detroit Lake Outlet: Pelican River	Primary	Daily
D2	Detroit Lake Inlet: Pelican River	Primary	Daily
D3	East Shore Drive	Secondary	Twice a Week
D4	Sucker Creek	Secondary	Twice a Week
C1	St. Clair Outlet	Supplemental	Twice a Week
L1	Long Lake Outlet	Supplemental	Twice a Week
P1	Pelican River: Highway 34	Supplemental	Twice a Week
F1	Floyd Lake Outlet	Supplemental	Twice a Week
F2	Campbell Creek	Supplemental	Twice a Week

A summary of each station and Form PR-5 for describing a rating curve are included with this Report.

In addition to the scheduled flow monitor readings, major storm events may require more frequent readings for inflow points to each lake. As a guideline for the monitoring frequency, if the major inflow points vary by more than 10% between readings, additional readings will be taken on the primary inflow and outflow points. The SCS Report Hydrology Guide for Minnesota offers some assistance in predicting significant runoff events including the 1 year - 24 hour rainfall map. Based upon soil complex factors, the Watershed of the Pelican River above Detroit Lake can be expected to respond according to the following theoretical values:


Tamarac L.
Kennedy Lake
Little Floyd Lake
Five Fisher L.
Floyd Lake
Oak Lake
Wheeler L.
Brandy Lake
Wine L.
Mud Lake
St. Patrick Lake
Schultz Lake
Pacific
Long Lake
DETROIT LAKES
POP. 5978
St. Clair L.
Leitheiser Lake
Detroit Lake
FISH HATCHERY
Lake Sallie
Glawe L.
LAKE VIEW
Abbey L.
Senica L.
Tucker
McHugh
Meadow L.
Shoreham
Cottage L.
Nottage Lake
Stilke Lake
Johnson Lake
Acorn Lake
Melissa Lake
Monson L.
Pelican
C-13
C-14
F.A.S.
F.A.P.
Railroad

Projected Runoff: Pelican River Watershed

Precipitation (in) 24 Hours	Direct Runoff (inches)
0.50	0.00
0.75	0.02
1.00	0.04
1.25	0.12
1.50	0.20
1.75	0.29
2.00	0.38

A significant increase in runoff occurs as the rainfall reaches 1.25 inches. For preliminary purposes, it is assumed that up to five events of this magnitude may occur annually. Therefore, storms of this magnitude may require more frequent monitoring.

IX. SUMMARY OF SAMPLING

The total number of samples that will be taken is presented below:

Sampling

Source	Parameters	Number
Inlake		
° Sallie	P, N, TSS, Coliform	64
° Detroit	Chlorophyll a, Conductivity, Zooplankton, Phytoplankton	96
Groundwater	P, N	48
Surface Water	P, TSS	278
	Total	486

Pace Laboratories, Minneapolis, Minnesota or Twin City Testing, Fargo, North Dakota, will be used for the sample analysis.

X. SUMMARY OF COSTS

The costs associated with the Monitoring Plan will include sample collection, field analysis equipment, lab analysis costs, flow monitoring and data analysis requirements. Those costs are summarized as follows:

A. Sample Collection

May - August: 6 days/month (4 months) ($200/day) = $4,800
September - April: 2 days/month (8 months) ($200/day) = $3,200

Total $8,000

B. Field Analysis Equipment

Lake Sampling

° DO Meter, pH, Temperature $1,500
° Van Doren Sampler 300
° Boat and Equipment 200

Stream Sampling

° Pygmy Meter 800
° Staff Gauges 400

Total $3,200

C. Laboratory Analysis

Parameter	Tests	Unit Price	Total
Total P	486	$ 15	$ 7,290
Ortho P	160	10	1,600
Organic N	208	32	6,656
Nitrate, Nitrite	80	15	1,200
TSS	318	10	3,180
Coliform	24	12	288
Chlorophyll a	32	30	960
Phytoplankton	24	100	2,400
Zooplankton	24	100	2,400
Conductivity	8	10	80
Total			$26,054

Total Laboratory Analysis $26,054
Sample Mailing and Transporting 2,000

Total $28,054

D. Flow Monitoring

° Stream Calibration ..... $ 3,600

E. Data Collection and Administration 5,000

The Total Estimated Monitoring Costs are $47,854

XI. PROJECT SCHEDULE

Monitoring is scheduled to begin in April, 1988 and be completed in March, 1989.

ATTACHMENTS

1. Hydrologic Balance of Lake Sallie
2. Correspondence
3. In-Lake Sampling, Form PR-1
4. Observations of Gauge Height, Form PR-2
5. Stream Sampling, Form PR-3
6. Groundwater Monitoring, Form PR-4
7. Lake Sallie Contour Map
8. Detroit Lake Contour Map
9. Groundwater Monitoring Locations
10. U.S.G.S. Map - Lake Sallie
11. U.S.G.S. Map - Detroit Lake
12. S.C.S. 1-Year 24-Hour Rainfall
13. Gauging Station Descriptions, Form PR-5

THE HYDROLOGIC BALANCE OF LAKE SALLIE, BECKER COUNTY, MINNESOTA

By WILLIAM B. MANN IV and MARK S. McBRIDE,
St. Paul, Minn.

Abstract.—The hydrologic balance of Lake Sallie was determined for the 1969 and 1970 water years. The hydrologic balance for the 1969 water year shows that surface-water flow accounted for 77 percent of the inflow, precipitation 10 percent, and ground-water flow 13 percent; 86 percent of the outflow was surface water and 14 percent evaporation. Percentages for the 1970 water year were comparable with those for 1969; ground water accounted for 3 percent more of the inflow, 3 percent more of the outflow was by evaporation, and surface inflow and outflow were correspondingly less. To check the ground-water flows computed in the hydrologic balance, flow nets were constructed to determine the ground-water flow. The ground-water inflows determined using the flow nets were 1,730 acre-feet during a period of low ground-water levels and 1,810 acre-feet during a period of high ground-water levels. The estimated range of error for elements of the water balance is: surface-water inflow and outflow, precipitation, and change in lake storage, ±5 percent; evaporation, ±10 percent. The estimated range of error for the ground-water inflow as determined from the flow-net analysis is ±30 percent.

Lake Sallie, Minn., has been a popular recreational lake since the 1870's. Since about 1915, however, eutrophication has increased at an accelerating rate. Large increases in the growth of aquatic vegetation became apparent in the late 1940's, and objectionable growths were very apparent 10 years later. In 1968 the Water Quality Office (formerly Federal Water Quality Adm.), Environmental Protection Agency, through its research grant program, provided funds for an extensive study of the effects of aquatic-plant removal on the level of eutrophication in Lake Sallie. As part of the study, the U.S. Geological Survey was asked to determine the hydrologic budget for the lake so that nutrient budgets could be determined before and after removal of the aquatic plants. The purpose of this report is to present the hydrologic budget for the 1969 and 1970 water years.

Lake Sallie is 2 miles southwest of Detroit Lakes, Minn. (fig. 1). It lies within the Alexandria moraine complex, a broad belt of hilly country that trends north and south through west-central Minnesota. This moraine complex was formed at the western margin of the Wadena ice lobe during its Hewitt phase, the earliest Wisconsin glacial advance recognized in Minnesota

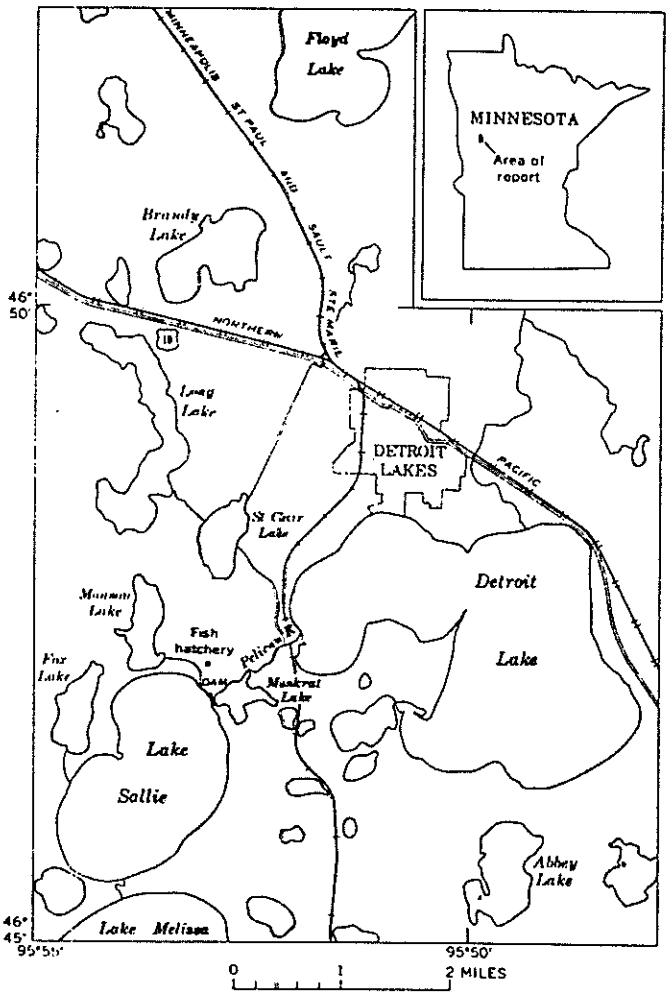


Figure 1.—Location map of Lake Sallie and Detroit Lakes, Minn., vicinity.

(Wright and Ruhe, 1965). Later, ice of the Des Moines lobe overrode the moraine from the west. Together, the two ice lobes deposited about 400 feet of silty to clayey gray till of very low permeability. As the Des Moines lobe retreated,

coarse permeable outwash as much as 100 feet in thickness mantled the Lake Sallie area. The outwash buried many isolated ice blocks, one of which formed the Lake Sallie basin upon melting.

Acknowledgment.—Funds for this study were provided by the Water Quality Office, Environmental Protection Agency.

HYDROLOGIC SETTING

Lake Sallie is one of a chain of lakes along the course of the Pelican River. The lake is kidney shaped, approximately 2 miles long and 1 mile wide. The maximum depth of the lake is 55 feet, and the average depth is 18 feet. The surface area is 1.9 square miles, and the capacity is 22,000 acre-ft (acre-feet) at an elevation of 1,329 feet above mean sea level. In addition to the Pelican River, several small streams draining nearby lakes flow into Lake Sallie.

The Pelican River valley, including Lake Sallie, is characterized in part as an area of ground-water discharge. Regional ground-water systems within the drift are recharged in the higher parts of the moraine and discharge to the river valley and Lake Sallie. Most of the ground-water contribution comes, however, from local flow systems within the surficial outwash. Interlake ground-water flow is an important component of these systems.

THE HYDROLOGIC BUDGET

The hydrologic budget is derived by equating the water gains to the water losses, plus or minus the changes in storage. The measurement of water gains, water losses, and storage changes in a hydrologic basin involves several important factors. These are: (1) precipitation, (2) streamflow, (3) changes in surface storage, (4) ground-water flow, and (5) evaporation. These items, in relation to the Lake Sallie study area, are described in the following paragraphs. The data used to develop the hydrologic budget were collected during the 1969 and 1970 water years.

The hydrologic budget of the lake is expressed mathematically as follows:

$$\Delta S = S_I + P \pm GW - S_O - E,$$

where

ΔS = change in surface-water storage,
S_I = surface-water inflow,
P = precipitation,
GW = net ground-water flow,
S_O = surface-water outflow, and
E = evaporation.

Because of the nature of hydrologic phenomena, the components of the above equation could not be evaluated with equal accuracy.

Precipitation was measured by a National Weather Service (U.S. Weather Bureau) observer using a standard nonrecording gage 3 miles northeast of Lake Sallie. Because there was no precipitation gage at Lake Sallie, the precipitation recorded at this station was assumed to apply to Lake Sallie. Precipitation for the 1969 and 1970 water years (U.S. Dept. of Commerce, 1968–70) amounted to 21.28 and 20.26 inches, respectively. The total precipitation for the 1969 water year showed a −2.29-inch departure from the normal, and that for the 1970 water year showed a −3.31-inch departure (Baker and others, 1967).

Gaging stations to measure the surface-water inflows and outflows of Lake Sallie were installed in July 1968. The principal inflow station is on the Pelican River at the dam between Muskrat Lake and Lake Sallie adjacent to the Minnesota Department of Natural Resources fish hatchery. The outflow station is on the Pelican River channel between Lake Sallie and Lake Melissa, approximately 250 feet downstream from the outlet of Lake Sallie. Staff gages were also installed on the outlets of Fox Lake, Monson Lake, and the rearing ponds at the fish hatchery. Monthly measurements during winter and biweekly measurements during open-water periods were used to estimate the monthly mean discharges to Lake Sallie. These outlet streams contribute only a very small percentage of the total surface-water inflow to Lake Sallie; the Pelican River supplies the major part.

Direct runoff to the lake from the drainage area surrounding it is considered to be very small. This area is approximately 520 acres, or less than half the size of the lake surface. The soil is very sandy, and any direct runoff probably occurs only during the spring snowmelt. Therefore, direct runoff is considered to be insignificant.

Changes in Lake Sallie storage were determined from lake elevations obtained from a staff gage on the Lake Sallie side of the dam at the fish hatchery. A bathymetric map of the lake was furnished by the Minnesota Department of Natural Resources and was used to develop the area-capacity curves for the lake.

The estimated annual evaporation for the Lake Sallie area as reported by Meyers (1962) was 28 inches. Class A pan evaporation measurements (U.S. Dept. of Commerce, 1968–70) at Fargo, N. Dak., 43 miles northwest of Lake Sallie, were available for the 2-year period for the months May through October, except for May 1970. These data show the estimated value for evaporation to be reasonable, but accurate only to ±1 inch.

The hydrologic budget for Lake Sallie for the 1969 and 1970 water years is shown in table 1. The percentage contribution by each component of the water budget for the 2 years is shown below:

	1969	*1970*
Inflow:		
Surface water	76.9	73.3
Precipitation	10.4	10.9
Net ground-water flow	12.6	15.8
Outflow:		
Surface water	86.1	82.7
Evaporation	13.9	17.3

Table 1.—*The water budget of Lake Sallie, Minn., 1969 and 1970 water years*

[All data in acre-feet]

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	The year
1969 water year[1]													
Surface-water inflow	314	853	976	1,001	1,941	1,058	4,041	2,856	791	535	179	24	16,170
Precipitation	280	51	175	171	82	12	112	230	294	455	86	244	2,192
Surface-water outflow	218	796	1,170	1,420	2,270	1,960	4,270	4,100	821	834	250	7	18,416
Evaporation	179	130	45	40	40	51	170	495	390	497	609	337	2,983
Change in storage	+490	−130	0	+100	−290	−190	+1,310	−800	−210	+120	−510	−270	−380
Residual	+293	−108	+64	+388	−6	+151	+697	+1,009	−84	+363	+84	−194	+2,657
1970 water year[2]													
Surface-water inflow	25	531	708	697	529	689	2,015	4,192	3,199	1,336	149	116	14,192
Precipitation	304	33	110	17	27	96	299	190	560	161	28	282	2,107
Surface-water outflow	6	109	622	762	617	998	2,310	4,670	4,180	1,290	80	17	15,661
Evaporation	178	130	55	50	55	63	170	475	515	665	532	391	3,277
Change in storage	+120	+480	+230	0	0	+100	+440	−220	−70	−450	−430	+220	+420
Residual	−25	+155	+89	+96	+116	+376	+606	+537	+866	+6	+5	+230	+3,059

[1]October 1968–September 1969.

[2]October 1969–September 1970.

The components of the water budget vary throughout the year (see table 1). Streamflow is greatest in spring and early summer. Precipitation is greatest in spring and fall. Evaporation is greatest during the summer months. Two-thirds of the ground-water inflow occurred in the months of April to June.

In most hydrologic budget studies, the residual obtained when the total outflow is subtracted from the total inflow is assumed to represent net ground-water flow. For this study, however, direct measurement of the ground-water flow was desirable because of possible differences in nutrient concentrations between the inflow and the outflow. In addition, if ground water could be calculated directly, it would lead to better understanding of the magnitude of error in the other elements of the water budget.

Ground-water levels were measured weekly in 32 observation wells within the Lake Sallie watershed. The data showed that ground water moved into Lake Sallie everywhere except the southern end, where at certain times water moves as underflow from Lake Sallie to the next lake downstream, Lake Melissa. This underflow from the lake occurs only in the spring of the year in a very small area with low gradients and is considered to be negligible. The geometry of the saturated zone, the results of computer modeling studies, and the small differences between water levels in adjacent wells screened at different depths indicated that ground-water flow was horizontal. Thus, to calculate ground-water contribution to the lake, two flow nets were constructed using water-level data. One flow net was constructed for the winter period when levels were low, and the second was constructed for the late spring period when levels were high. The respective ground-water inflow rates calculated were 1,730 and 1,810 acre-ft per year.

The mean of these inflow rates is 1,090 acre-ft per year less than the mean residuals. The discrepancy results from errors in the flow net and in evaluating the terms of the hydrologic balance. Estimates of the percentages and magnitudes of error were made for each component individually, on the basis of the precision and adequacy of the data used. They are as follows:

Term	*Percentage error*	*Magnitude of error (acre-ft per year)*
Surface-water inflow	±5	±760
Precipitation	±5	±110
Surface-water outflow	±5	±850
Evaporation	±10	±310
Change in storage	±5	±20
Ground-water inflow from flow nets	±30	±530

It is evident that the residual, as calculated from the hydrologic budget equation, cannot be expected to agree exactly with the ground-water inflow calculated using the flow-net analysis. The results obtained in this study indicate that in this or similar hydrologic settings the flow-net analysis may give results comparable to those from the hydrologic budget equation. However, additional work is necessary before a meaningful comparison can be made between the two methods.

REFERENCES

Baker, D. G., Haines, D. A., and Strub, J. H., Jr., 1967, Precipitation facts, normals and extremes: Climate of Minnesota, Pt. V, Minnesota Univ. Agr. Expt. Sta., Tech. Bull. 254, 42 p.

Meyers, J. S., 1962, Evaporation from the 17 Western States: U.S. Geol. Survey Prof. Paper 272-D, p. 71–100, pl. 3.

U.S. Department of Commerce, Environmental Sciences Service Administration, 1968, Climatological data: Minnesota, v. 74.

——1969, Climatological data: Minnesota, v. 75.

——1970, Climatological data: Minnesota, v. 76.

——1968, Climatological data: North Dakota, v. 77.

——1969, Climatological data: North Dakota, v. 78.

——1970, Climatological data: North Dakota, v. 79.

Wright, H. E., Jr., and Ruhe, R. V., 1965, Glaciation of Minnesota and Iowa, *in* The Quaternary of the United States: Princeton, N.J., Princeton Univ. Press, p. 29–41.

LARSON-PETERSON & ASSOCIATES, INC.

CONSULTING MUNICIPAL ENGINEERS

REG. PROFESSIONAL ENGINEERS:
IRVING D. BAKKEN
THOMAS V. AUGUSTIN
GARY L. NANSEN
DAVID F. GRINAKER

522 W. MAIN STREET - BOX 150
DETROIT LAKES, MINN. 56501
OFFICE PHONE: 218-847-5607

February 4, 1988

Mr. Wayne Edwards
KDLM Radio
1340 Richwood Road
Detroit Lakes, Minnesota 56501

Re: Weather Data

Dear Wayne:

Enclosed please find 16 stamped, self-addressed envelopes from our office. As we discussed, I would like the monthly weather information including precipitation and temperatures that you record for the National Weather Bureau (NWB).

If you have any questions, please contact me.

Sincerely,

LARSON-PETERSON & ASSOCIATES, INC.

By Gary L. Nansen
Gary L. Nansen, P.E.

GLN:br
Encs.

FORM PR-1

PELICAN RIVER WATERSHED

IN-LAKE SAMPLING FOR LAKE _____

LOCATION: _____

DATE: _____

WEATHER: _____

DEPTH (m)	DO	pH	Temp.
Surface			
2			
4			
6			
8			
10			
12			
14			
16			
18			
20			
22			
24			
26			

SECCHI DISK READING _____ ft.

REMARKS:

PR-2

PELICAN RIVER WATERSHED

OBSERVATIONS OF GAUGE HEIGHT

Sta. No. _____

Month _____ 198__

Gauging For _____

DATE	TIME	GAUGE HEIGHT	REMARKS
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
27			
28			
29			
30			
31			

PR-3

PELICAN RIVER WATERSHED

STREAM SAMPLING

Date: _____

Time: _____

STATION NO.	SAMPLE TAKEN	REMARKS
S1		
S2		
S3		
S4		
D1		
D2		
D3		
D4		
C1		
C2		
L1		
P1		
F1		
F2		

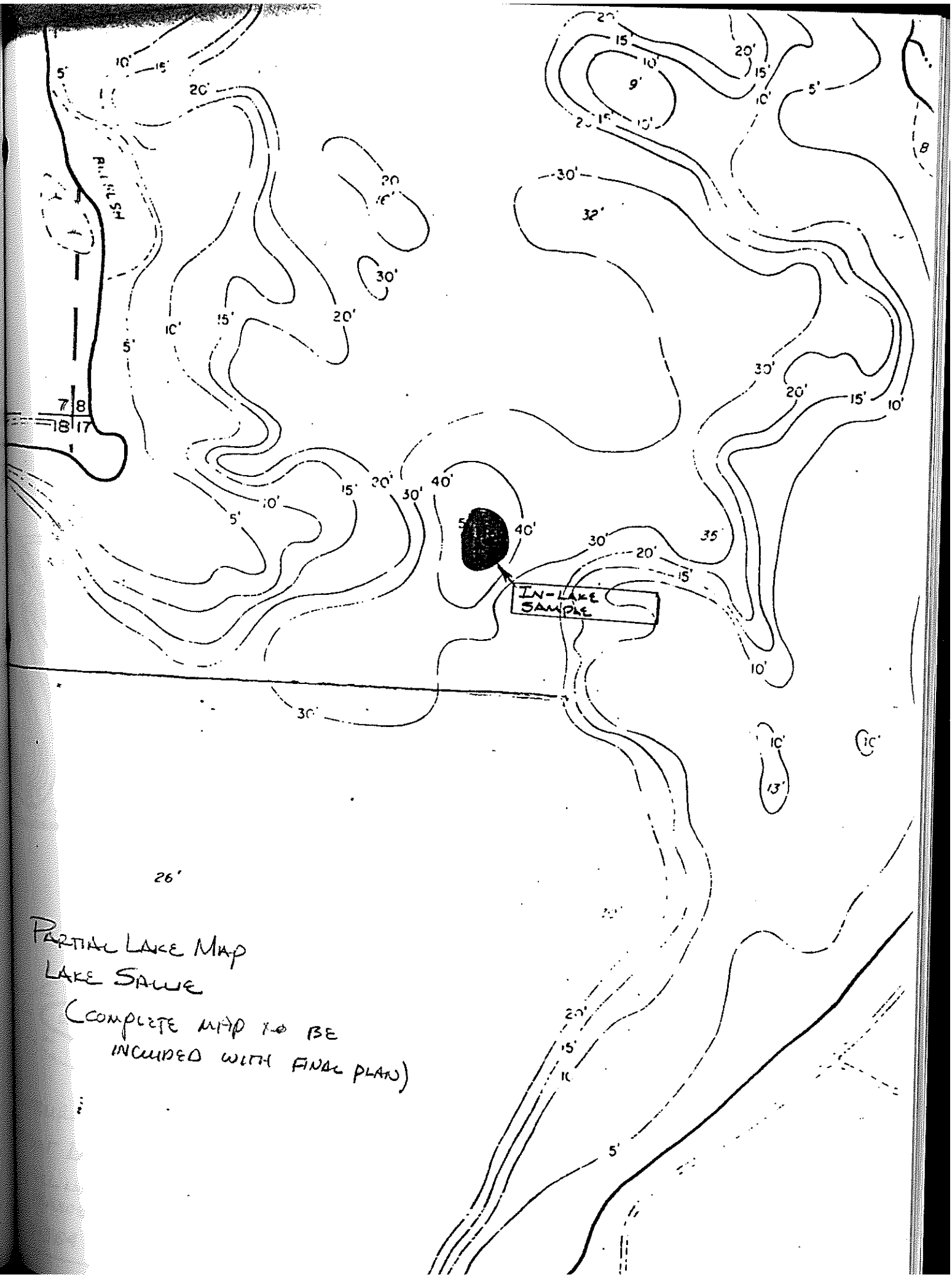
FORM PR-4

Date: _____

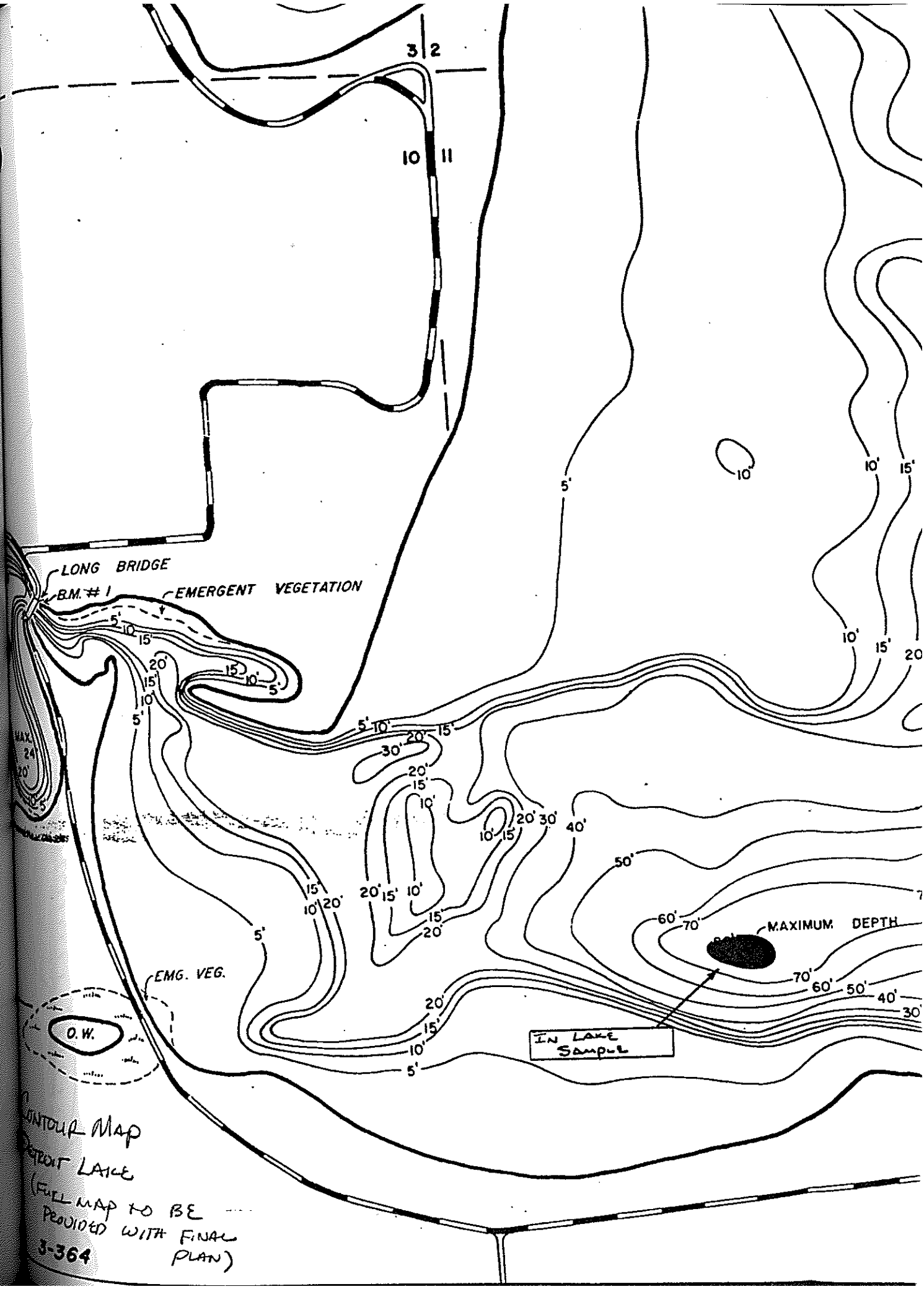
PELICAN RIVER WATERSHED

GROUNDWATER MONITORING

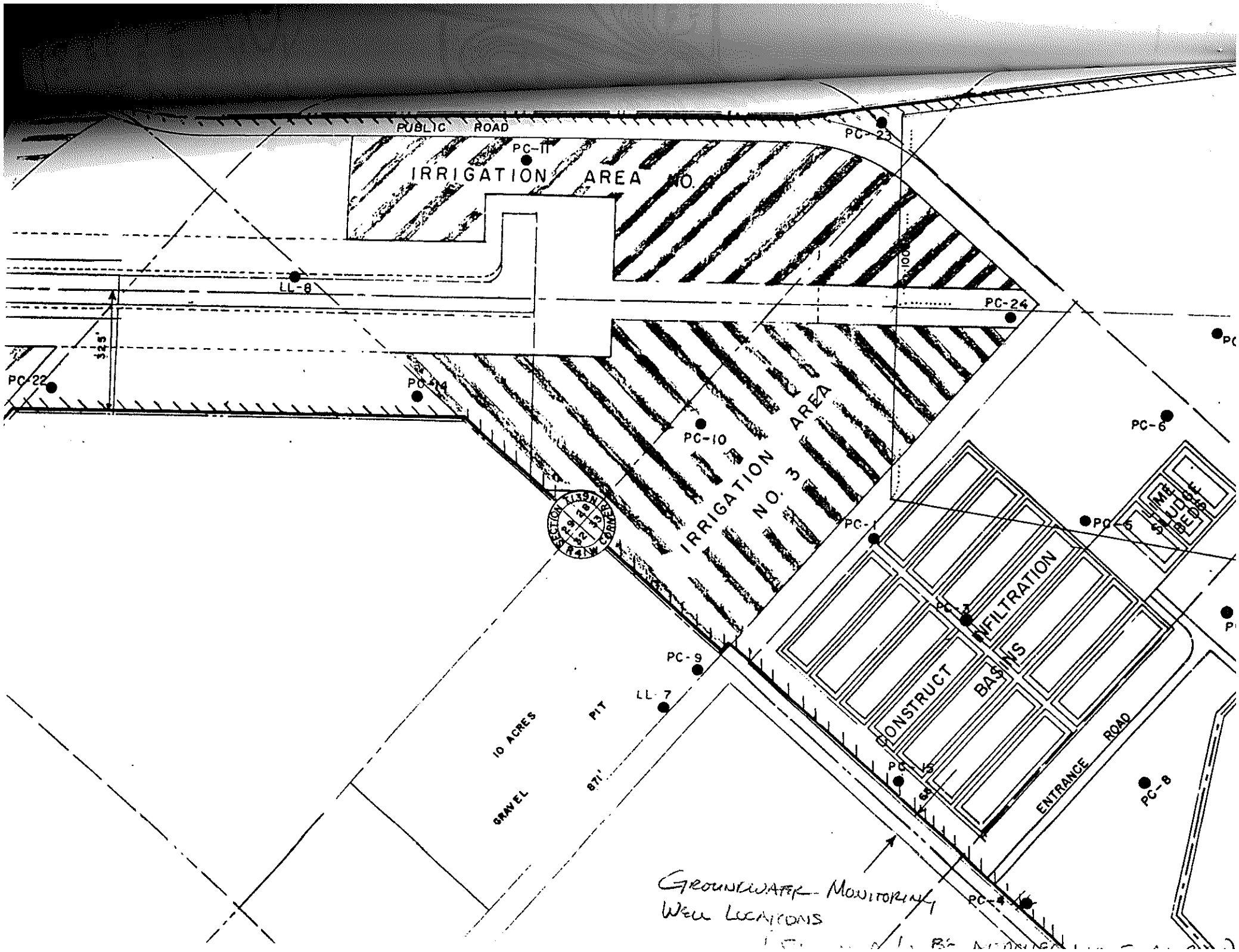
SAMPLE LOCATION	SAMPLE TAKEN	DEPTH TO GROUNDWATER	REMARKS
PC-18			
PC-27			
PC-30			

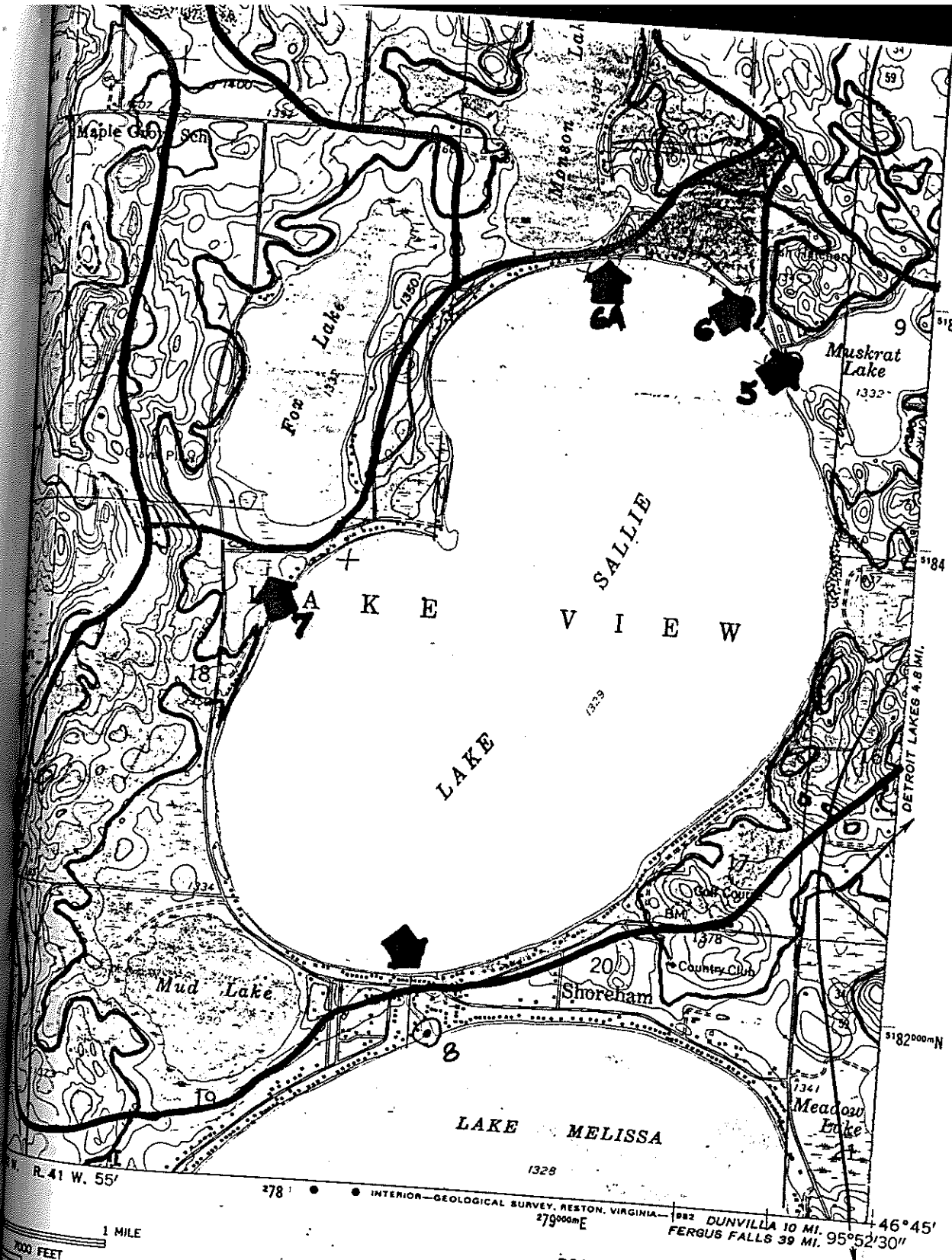


PARTIAL LAKE MAP
LAKE SAWYER
(COMPLETE MAP TO BE INCLUDED WITH FINAL PLAN)



CONTOUR MAP
DETROIT LAKE
(FULL MAP TO BE PROVIDED WITH FINAL PLAN)


PUBLIC ROAD
PC-11
IRRIGATION AREA NO.
PC-23
LL-8
PC-24
325'
PC-22
PC-14
PC-10
IRRIGATION AREA NO. 3
PC-6
PC-1
PC-5
LIME SLUDGE BED
INFILTRATION BASINS
CONSTRUCT
PC-9
LL-7
10 ACRES
PIT
GRAVEL
871'
ENTRANCE ROAD
PC-8
PC-4
GROUNDWATER MONITORING WELL LOCATIONS



AUDUBON, MINN.
N4645—W9552.5/7.5

1959
PHOTOREVISED 1982
DMA 6877 IV SW—SERIES V878

Lake Sallie
U.S.G.S. Contour Map

Detroit Lake
USGS. Contour Map

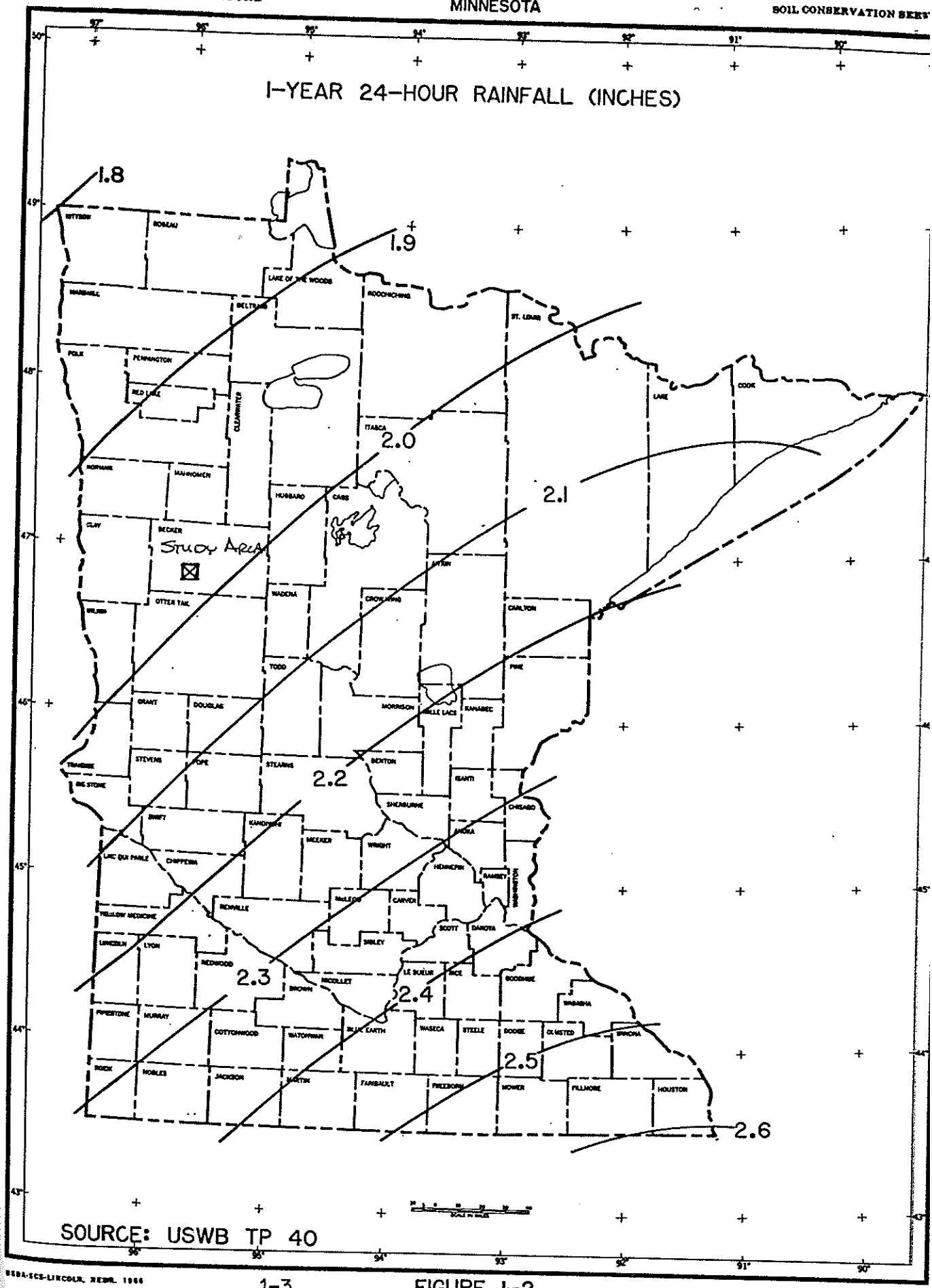

1-YEAR 24-HOUR RAINFALL (INCHES)
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
Study Area
SOURCE: USWB TP 40

FIGURE I-2

PR-5

PELICAN RIVER WATERSHED

STREAM FLOW MONITORING

GAUGING STATION

IDENTIFICATION NO.: F1

LOCATION: Floyd Lake outlet.

DESCRIPTION: Dam structure at the outlet of Little Floyd Lake.

GAUGE: Staff gauge located on the headwall of the dam.

CHANNEL AND CONTROL: Channel downstream from the dam.

METHOD OF FLOW DETERMINATION: Rating curve from channel measurements. Staff gauge readings taken twice a week.

VERTICAL CONTROL:

OBSERVER: Don Klomstad

PR-5

PELICAN RIVER WATERSHED

STREAM FLOW MONITORING

GAUGING STATION

IDENTIFICATION NO.:	F2
LOCATION:	Campbell Creek north of Floyd Lake.
DESCRIPTION:	Metal culvert at road crossing of gravel road north of Floyd Lake.
GAUGE:	Staff gauge downstream from the culvert.
CHANNEL AND CONTROL:	Channel.
METHOD OF FLOW DETERMINATION:	Rating curve of the channel. Flow measurements taken twice a week.
VERTICAL CONTROL:	
OBSERVER:	Don Klomstad

PR-5

PELICAN RIVER WATERSHED

STREAM FLOW MONITORING

GAUGING STATION

IDENTIFICATION NO.:	S1
LOCATION:	Pelican River at Lake Sallie Outlet.
DESCRIPTION:	Bridge on Becker County Road No. 22 approximately 250 feet south of Lake Sallie outlet.
GAUGE:	Staff gauge at downstream from bridge wing wall.
CHANNEL AND CONTROL:	Dam at inlet to Lake Melissa. Stop-log changes must be noted.
METHOD OF FLOW DETERMINATION:	Rating curve based upon channel. Cross-section and velocity measurements with a pygmy meter. Staff gauge measurements recorded daily.
VERTICAL CONTROL:	
OBSERVER:	Morrie Estenson

PR-5

PELICAN RIVER WATERSHED

STREAM FLOW MONITORING

GAUGING STATION

IDENTIFICATION NO.:	S2
LOCATION:	Outlet from Fox Lake.
DESCRIPTION:	South of township road approximately 50 feet.
GAUGE:	Staff gauge in center of stream.
CHANNEL AND CONTROL:	Narrow channel downstream from staff gauge.
METHOD OF FLOW DETERMINATION:	Rating curve based upon channel. Cross-section and velocity measurements with a pygmy meter. Staff gauge measurements recorded twice a week.
VERTICAL CONTROL:	
OBSERVER:	Morrie Estenson

PR-5

PELICAN RIVER WATERSHED

STREAM FLOW MONITORING

GAUGING STATION

IDENTIFICATION NO.:	S3
LOCATION:	Monson Lake outlet to Lake Sallie.
DESCRIPTION:	Fifty feet upstream from culvert or 100 feet downstream from Monson Lake.
GAUGE:	Staff gauge located near pumphouse.
CHANNEL AND CONTROL:	Culvert is highwater level control and channel may be low level control if weed growth is significant in the channel.
METHOD OF FLOW DETERMINATION:	Rating curve by discharge measurements of the channel and culvert. Rating curve may need adjustment for low level flows. Staff gauge read at least twice a week.
VERTICAL CONTROL:	_____
OBSERVER:	Morrie Estenson

PELICAN RIVER WATERSHED

STREAM FLOW MONITORING

GAUGING STATION

IFICATION NO.:	S4
ON:	Pelican River at Muskrat Lake outlet to Lake Sallie (Fish Hatchery).
PTION:	Boat lock channel between Muskrat Lake and Lake Sallie. Staff gauge on boat lock channel.
L AND CONTROL:	Muskrat Lake.
OF FLOW DETERMINATION:	Rating curve has been developed by the U.S. Geological Survey office. A record of stop-log changes must be recorded.
AL CONTROL:	
ER:	Department of Natural Resources

PR-5

PELICAN RIVER WATERSHED

STREAM FLOW MONITORING

GAUGING STATION

IDENTIFICATION NO.:	D1
LOCATION:	Pelican River at Detroit Lake outlet.
DESCRIPTION:	Bridge on County Road No. 22 crossing the Pelican River at the outlet of Detroit Lake.
GAUGE:	Staff gauge on wing wall of bridge structure.
CHANNEL AND CONTROL:	The channel of the Pelican River or the dam at Muskrat Lake.
METHOD OF FLOW DETERMINATION:	Flow rating curve from channel measurements downstream from the bridge. Daily staff gauge readings.
VERTICAL CONTROL:	
OBSERVER:	Larson-Peterson & Associates, Inc.

PR-5

PELICAN RIVER WATERSHED

STREAM FLOW MONITORING

GAUGING STATION

IDENTIFICATION NO.:	D2
LOCATION:	Pelican River inlet to Detroit Lakes.
DESCRIPTION:	Bridge across Pelican River on North Shore Drive.
GAUGE:	Staff gauge upstream from bridge.
CHANNEL AND CONTROL:	Bridge at North Shore Drive during high flow conditions and Detroit Lake during normal flows.
METHOD OF FLOW DETERMINATION:	Rating curve from channel measurements. Daily staff gauge readings.
VERTICAL CONTROL:	_____
OBSERVER:	Roger Hesby

PR-5

PELICAN RIVER WATERSHED

STREAM FLOW MONITORING

GAUGING STATION

IDENTIFICATION NO.:	D3
LOCATION:	Culvert across East Shore Drive in Section 12 Township 138N Range 41W, 2½ miles southeast of Detroit Lakes.
DESCRIPTION:	Channel from culvert on East Shore Drive to Detroit Lake.
GAUGE:	Staff gauge downstream from the culvert.
CHANNEL AND CONTROL:	Detroit Lake during normal flows. Possible weed obstruction during low flows.
METHOD OF FLOW DETERMINATION:	Stream measurements for a rating curve near inlet to lake. Twice a week staff gauge readings.
VERTICAL CONTROL:	
OBSERVER:	Jim Ramstad

PR-5

PELICAN RIVER WATERSHED

STREAM FLOW MONITORING

GAUGING STATION

IDENTIFICATION NO.:	D4
LOCATION:	Sucker Creek near Detroit Lakes.
DESCRIPTION:	Culvert located on Becker County No. 24 with channel to Detroit Lakes.
GAUGE:	Staff gauge downstream from culvert near bank of the stream.
CHANNEL AND CONTROL:	Detroit Lake and possible sand bar deposition at the inlet to the lake.
METHOD OF FLOW DETERMINATION:	Rating curve for channel prior to entering Detroit Lake. Twice a Week staff gauge readings.
VERTICAL CONTROL:	
OBSERVER:	Dr. John Emery

PR-5

PELICAN RIVER WATERSHED

STREAM FLOW MONITORING

GAUGING STATION

IDENTIFICATION NO.:	C1
LOCATION:	St. Clair Lake outlet.
DESCRIPTION:	Upstream of culvert on Highway No. 59 in channel outlet from St. Clair Lake.
GAUGE:	Staff gauge in channel bed upstream of the culvert.
CHANNEL AND CONTROL:	Culvert during high flow. Channel during low flows.
METHOD OF FLOW DETERMINATION:	Rating curve in channel compared to U.S. Geological Survey rating curves previously done. Twice a week staff gauge readings as a minimum.
VERTICAL CONTROL:	
OBSERVER:	To Be Determined