EPA
July, 1986

SYLVAN LAKE RESTORATION PROJECT
FINAL REPORT

by

Greg Wierenga
Utility Engineering Corporation
Rapid City, South Dakota 57709

and

Forrest Payne
South Dakota Department of Water and Natural Resources
Pierre, South Dakota 57501

Grant No. S008293-01

Project Officer

Tom Braidech
Water Division, Region VIII
U.S. Environmental Protection Agency
Denver, Colorado 80295

This project was conducted
in cooperation with
U.S. Environmental Protection Agency
South Dakota Department of Water and Natural Resources
South Dakota Department of Game, Fish and Parks
Utility Engineering Corporation

Published by

SOUTH DAKOTA DEPARTMENT OF WATER AND NATURAL RESOURCES
JOE FOSS BUILDING
PIERRE, SOUTH DAKOTA 57501

CONTENTS

Abstract..

Figures...

Tables..

Abbreviations and Symbols...................................

Acknowledgements..

1. Introduction...

2. Objectives...

3. Project Description and Implementation...............

4. Project Financing....................................

5. Water Quality..

6. Summary and Conclusions..............................

References..

ABSTRACT

Sylvan Lake is a small man-made lake of about 7.53 hectares (18.6 acres) located in Custer State Park, approximately 9.7 kilometers north of Custer, South Dakota. The lake, a focal point of intense recreational activity, has been impacted by accelerated sedimentation processes which decreased access to the lake, reduced fish habitat, and degraded aesthetics.

The Sylvan Lake Restoration Project was initiated by the South Dakota Department of Game, Fish and Parks in 1979. Project objectives were to correct watershed and in-lake problems and control activities detrimental to the recreational experience provided by the lake and its surroundings. Application was made and a grant awarded to the South Dakota Department of Water and Natural Resources by the United States Environmental Protection Agency under Public Law 92-500, Section 314. Matching funds were provided by the South Dakota Department of Water and Natural Resources' Lake Protection and Rehabilitation Program and the South Dakota Department of Game, Fish and Parks operational budget. For activities not covered by the "314" grant, supplemental funding was provided by the National Park Service through the Land and Water Conservation Fund, the South Dakota Department of Transportation, and the South Dakota Game, Fish and Parks operational budget.

This final report discusses the following:

1) construction activities that occurred at Sylvan Lake and its watershed; 2) changes in land use practices and park management procedures; and 3) the financing of the project. In addition, the impact of the project on the water quality in Sylvan Lake is discussed in terms of changes in water chemistry and the phytoplankton community. Based upon the results from this project, recommendations are made for similar projects.

DISCLAIMER

ACKNOWLEDGEMENTS

The authors are grateful for the efforts of the South Dakota Department of Game, Fish and Parks and especially various personnel at Custer State Park. Mr. Warren Jackson (Division Director) and Mr. Tom LeFaive (Assistant Director of Operations) were most helpful during the planning phase of the project and participated in project administrative duties. We are also grateful to Mr. Greg Goebel (Natural Resource Analyst) who did much of the water quality and biological sampling at Sylvan Lake and was involved in various other aspects of the project. A number of personnel from the South Dakota Department of Water and Natural Resources participated in the project. Mr. Jim Seyfer gave valuable expertise in the development and management of the project. Mr. Tim Bjork and Ms. Linda Yokum provided additional inputs to project planning and management. Without their enthusiasm and cooperation this project could not have been possible.

FIGURES

Number Page

1 Vicinity map...

2 Sylvan Lake watershed map and hydrologic data summary......................................

3 Sylvan Lake shoreline facilities.....................

4 Sylvan Lake contours..................................

5 Sylvan Lake area sediment profiles....................

6 Sylvan Lake sediment profiles.........................

7 Sylvan Lake Restoration Project organizational chart..

8 Sylvan Lake Restoration Project - sediment removal area map.......................................

9 Parking and access improvements.......................

10 Surface restoration and sediment control.............

11 Type 1 sedimentation structure.......................

12 Type 2 sedimentation structure.......................

13 Shoreline trail system and swimming beach............

14 Water quality sampling sites for the Sylvan Lake Rehabilitation Project...............................

15 Depth-time distribution of isopleths of temperature (°C) at Site SY10 in Sylvan Lake, 1981, 1982, 1983 and 1984...

16 Depth-time distribution of isopleths of temperature (°C) at Site SY11 in Sylvan Lake, 1981, 1982, 1983 and 1984...

17 Depth-time distribution of isopleths of total phosphorus (mg/l) at Site SY10 in Sylvan Lake, 1981, 1982, 1983 and 1984...........................

18 Depth-time distribution of isopleths of total phosphorus (mg/l) at Site SY11 in Sylvan Lake, 1981, 1982, 1983 and 1984...................................

19 Depth-time distribution of isopleths of dissolved orthophosphate (mg/l) at Site SY10 in Sylvan Lake,

1981, 1982, 1983 and 1984............................

20 Depth-time distribution of isopleths of dissolved orthophosphate (mg/l) at Site SY 11 in Sylvan Lake, 1981, 1982, 1983 and 1984............................

21 Depth-time distribution of isopleths of dissolved oxygen (mg/l) at Site SY10 in Sylvan Lake, 1981, 1982, 1983, and 1984...........................

22 Depth-time distribution of isopleths of dissolved oxygen (mg/l) at Site SY11 in Sylvan Lake, 1981, 1982, 1983 and 1984............................

23 Depth-time distribution of isopleths of pH at Site SY10 in Sylvan Lake, 1981, 1982, 1983 and 1984......

24 Depth-time distribution of isopleths of pH at Site SY11 in Sylvan Lake, 1981, 1982, 1983 and 1984......

25 Depth-time distribution of isopleths of suspended solids (mg/l) at Site SY10 in Sylvan Lake in 1981, 1982, 1983 and 1984............................

26 Depth-time distribution of isopleths of suspended solids (mg/l) at Site SY11 in Sylvan Lake, 1981, 1982, 1983 and 1984............................

27 Depth-time distribution of isopleths of ammonia as nitrogen (mg/l) at Site SY10 in Sylvan Lake, 1981, 1982 1983 and 1984.............................

28 Depth-time distribution of isopleths of ammonia as Nitrogen (mg/l) at Site SY11 in Sylvan Lake, 1981, 1982, 1983 and 1984............................

29 Depth-time distribution of isopleths of nitrate as nitrogen (mg/l) at Site SY10 in Sylvan Lake, 1981, 1982, 1983 and 1984............................

30 Depth-time distribution of isopleths of nitrate as nitrogen (mg/l) at Site SY11 in Sylvan Lake, 1981, 1982, 1983 and 1984............................

31 Depth-time distribution of isopleths of organic nitrogen (mg/l) at Site SY10 in Sylvan Lake, 1981, 1982, 1983 and 1984............................

32 Depth-time distribution of isopleths of organic nitrogen (mg/l) at Site SY11 in Sylvan Lake, 1981, 1982, 1983 and 1984............................

33 Secchi disc transparency measurements (m) observed at Site SY10 in Sylvan Lake, 1981, 1982, 1983 and

1984..

34 Secchi disc transparency measurements (m) observed at Site SY11 in Sylvan Lake, 1981, 1982, 1983 and 1984..

35 Box plots of chlorophyll a concentrations (mg/m3) observed in Sylvan Lake, 1982, 1983 and 1984........

36 Chlorophyll a values (mg/m3) observed in Sylvan Lake, 1982, 1983 and 1984................................

37 Inorganic nitrogen to dissolved orthophosphate ratios observed in the surface waters of Sylvan Lake, 1979, 1981, 1982, 1983 and 1984.........................

38 Total nitrogen to total phosphorus ratios observed in the surface waters of Sylvan Lake, 1979, 1981, 1982 1983 and 1984...................................

39 Percent composition by divisions of the phytoplankton (counts/m3) in Sylvan Lake, 1981, 1982, 1983 and 1984..

40 Percent composition by divisions of the phytoplankton (mg/l) in Sylvan Lake, 1981, 1982, 1983 and 1984....

41 Genera that dominated the biomass of phytoplankton and their percent contribution in Sylvan Lake in 1982.......................................

42 Genera that dominated the biomass of phytoplankton and their percent contribution in Sylvan Lake in 1983.......................................

43 Genera that dominated the biomass of phytoplankton their percent contribution in Sylvan Lake in 1984...

44 Annual percent composition of division of phytoplankton based upon cell counts and upon biomass in Sylvan Lake..

TABLES

Number Page

1 Recreational activities in the Sylvan Lake watershed..

2 Water quality problems relative to recreational activities in the Sylvan Lake watershed............

3 Restoration project inventory........................

4 Project cost summary..................................

5 Water quality standards for Sylvan Lake...............

6 Sampling site descriptions for the Sylvan Lake rehabilitation project..............................

7 Mean inorganic and organic nitrogen concentrations observed in Sylvan Lake, 1979, 1981, 1982, 1983 and 1984..

8 Summary statistics for Trophic State Indices calculated from total phosphorus concentrations, chlorophyll a concentrations and Secchi disc measurements......................................

9 Mean chlorophyll a concentrations (mg/m3) in Sylvan Lake, 1982, 1983, and 1984.........................

10 Limiting nutrient determinations based on the 7:1 ratio and the 15:1 Ratio.................................

11 Phytoplankton species and numbers per milliliter observed in Sylvan Lake on June 21, 1979 and August 7, 1979....................................

ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

BOD	- biochemical oxygen demand (5-day)
CSP	- Custer State Park
DO	- dissolved oxygen
EPA	- U.S. Environmental Protection Agency
LWCF	- Land and Water Conservation Fund (National Park Service)
NPS	- National Park Service
SDDGFP	- South Dakota Department of Game, Fish and Parks
SDDOT	- South Dakota Department of Transportation
SDDWNR	- South Dakota Department of Water and Natural Resources
TDS	- total dissolved solids
TKN	- total Kjeldahl nitrogen (as N)
TSI	- trophic state index
TSS	- total suspended solids
USFS	- United States Forest Service

SYMBOLS

C	- temperature in degrees centigrade
cm	- centimeters
c.y.	- cubic yards
ft	- feet
Ha	- hectares
in	- inches
Km	- kilometers
m	- meters

m^3	- cubic meters
mg/l	- milligrams per liter
pH	- standard units (acidity-alkalinity)
s.f.	- square feet

SECTION 1

INTRODUCTION

Sylvan Lake is a small man-made lake located in Custer State Park (CSP), approximately 9.7Km (6 miles) north of Custer, South Dakota via State Highways 87 and 89. The lake is located in one of the most scenic areas of the Black Hills of South Dakota, and is the focal point of intense recreational activity; principally fishing, swimming, camping, and hiking. Figure 1 illustrates the lake's location relative to Black Hills landmarks.

HISTORY

Sylvan Lake was initially constructed by a private landowner, Mr. Theodore Reder, in 1893. A natural dam site existed on Sunday Gulch, a narrow opening between massive granite outcroppings. The original dam, of predominantly timber construction, impounded a lake about one-half its current size. The existing concrete gravity arch dam, approximately 9.75m (32 feet) high, was constructed by the Civilian Conservation Corps in the mid-1930's and impounded the lake to its current size.

With the formation of Custer State Park (CSP) in the 1920's, the lake came under public ownership and is presently managed by the South Dakota Department of Game, Fish and Parks (SDDGFP). The lake has been an extremely popular recreational area since its

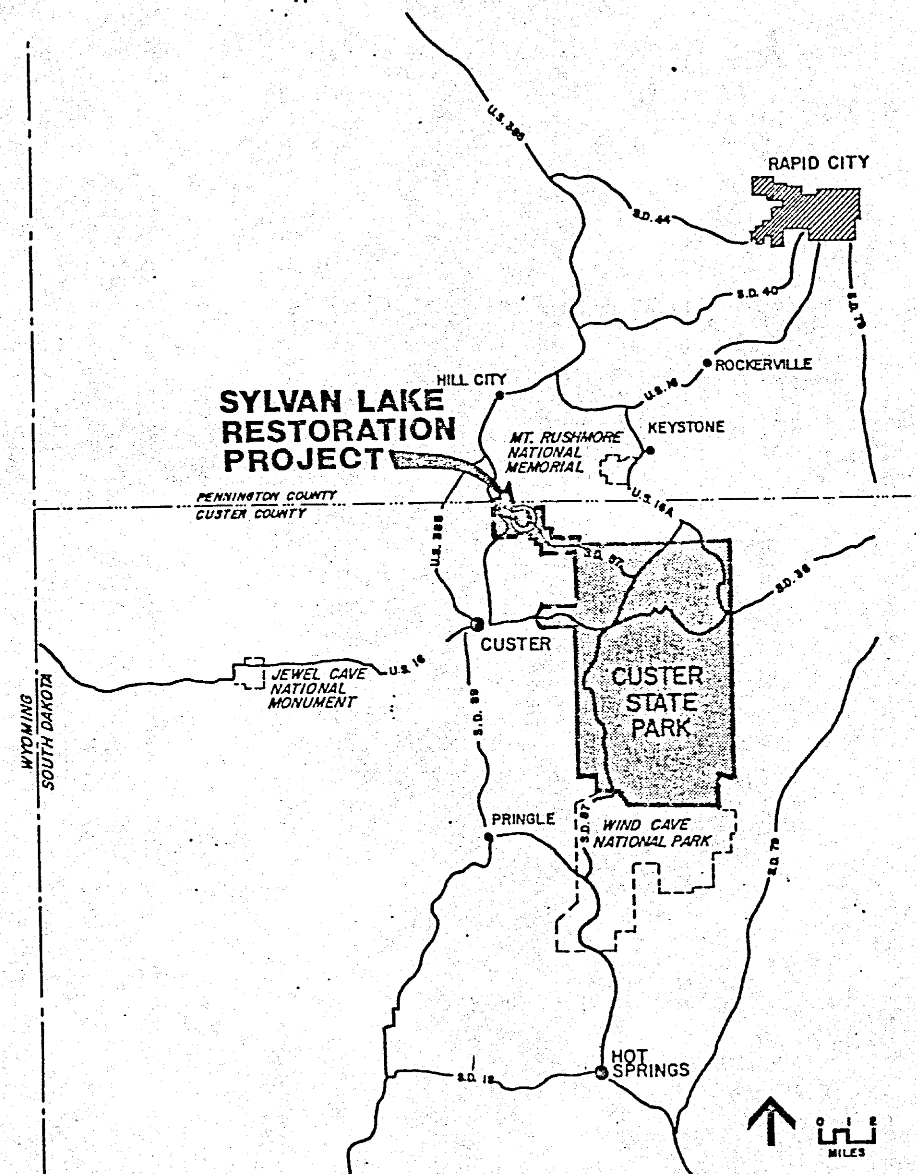


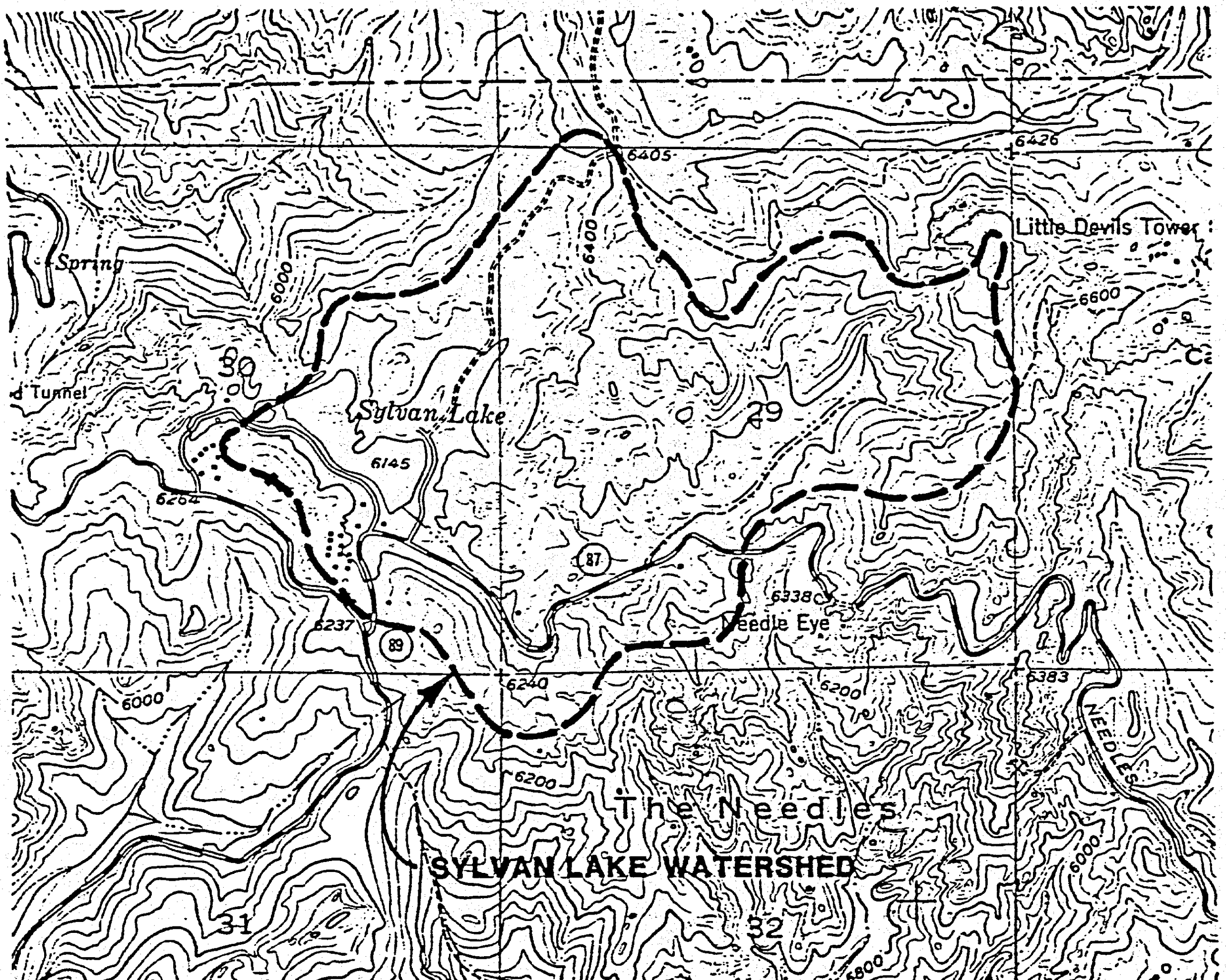
Figure 1. Vicinity Map

initial construction. Until it was destroyed by fire in 1935, the historic Sylvan Lake Hotel operated successfully near the northwest corner of the lake. Sylvan Lake Lodge, with about 30 rooms and 35 individual cabins, now operates on the west side of the lake.

LAKE AND WATERSHED DESCRIPTION

Sylvan Lake has a surface area of about 7.5 Ha (18.6 acres), with an average depth of 4.6 m (15 feet), and a maximum depth of 11 m (36 feet). The lake is recharged solely by natural precipitation from a 275 Ha (1.06 square mile) watershed and is depleted by evaporation and seepage. Excess runoff spills over the concrete dam during periods of high inflow. Figure 2 illustrates the lake and watershed topography and presents descriptive data for the lake and watershed hydrologic characteristics.

The watershed geology is characterized by massive granite outcroppings with thin soil layers of weathered granite and alluvial deposits. Much of the surface topography consists of exposed granite outcroppings, and the lake itself is impounded at its north end by near vertical granite spires which form a natural extension of the concrete arch dam. Watershed topography is moderately to steeply sloped, with nearly vertical exposed granite outcroppings. Vegetation consists principally of Ponderosa Pine forest, with smaller stands of spruce, aspen, and



Hydrologic Data Summary:

$P + Q_1 + Q_2 = E + Q_3 + Q_4$

P = Mean annual precipitation into Lake (19"/yr. over 18.6 ac. = 30 Ac.-Ft.)

E = Mean annual evaporation from Lake (41"/yr. over 18.6 ac. = 64 Ac.-Ft.)

Q_1 = Annual groundwater inflow (assumed negligible)

Q_2 = Annual runoff into Lake (1.6"/yr. over 0.9 sq. miles = 77 Ac. Ft.)

Q_3 = Annual outflow from Lake, or annual recharge rate

Q_4 = Annual groundwater outflow (assumed negligible)

Q_3 Avg. Annual Recharge Rate =(30 ac.-ft. + 77 ac.-ft.) - 64 ac.-ft. = 43 Ac.-Ft.

Hydraulic Residence Time = Lake Volume (217 ac.-ft.) + Annual Inflow (30 ac.-ft./yr. + 77 ac.-ft./yr.) = 2.0 Years

Figure 2. Sylvan Lake watershed and hydrologic data summary

birch. Small meadows of natural grasses and shrubs comprise an estimated 10% of the total watershed area.

Although much of the watershed remains in its natural state, recreational and commercial uses have resulted in significant construction of paved and unpaved roads, parking areas, buildings, campgrounds, trails, and similar man-made features; all of which have altered the lake characteristics over the years. It is estimated that 5% of the total watershed area has been converted to commercial or developed recreational use. Figure 3 illustrates land use in the Sylvan Lake area prior to restoration work. Management of the watershed land area is approximately 90% by the SDDGFP and 10% by the USFS.

PROBLEM STATEMENT

Because of its accessibility and variety of recreational activities available to users, the lake and watershed area are subject to intense usage during the summer months. Table 1 characterizes recreational activities which existed in the Sylvan Lake watershed prior to restoration work and their impact on water quality and Table 2 summarizes the relative severity and nature of water quality problems related to recreational activity.

Traffic studies by CSP indicated total lake visitation in 1979 exceeded 325,000 people for the use period of May through August

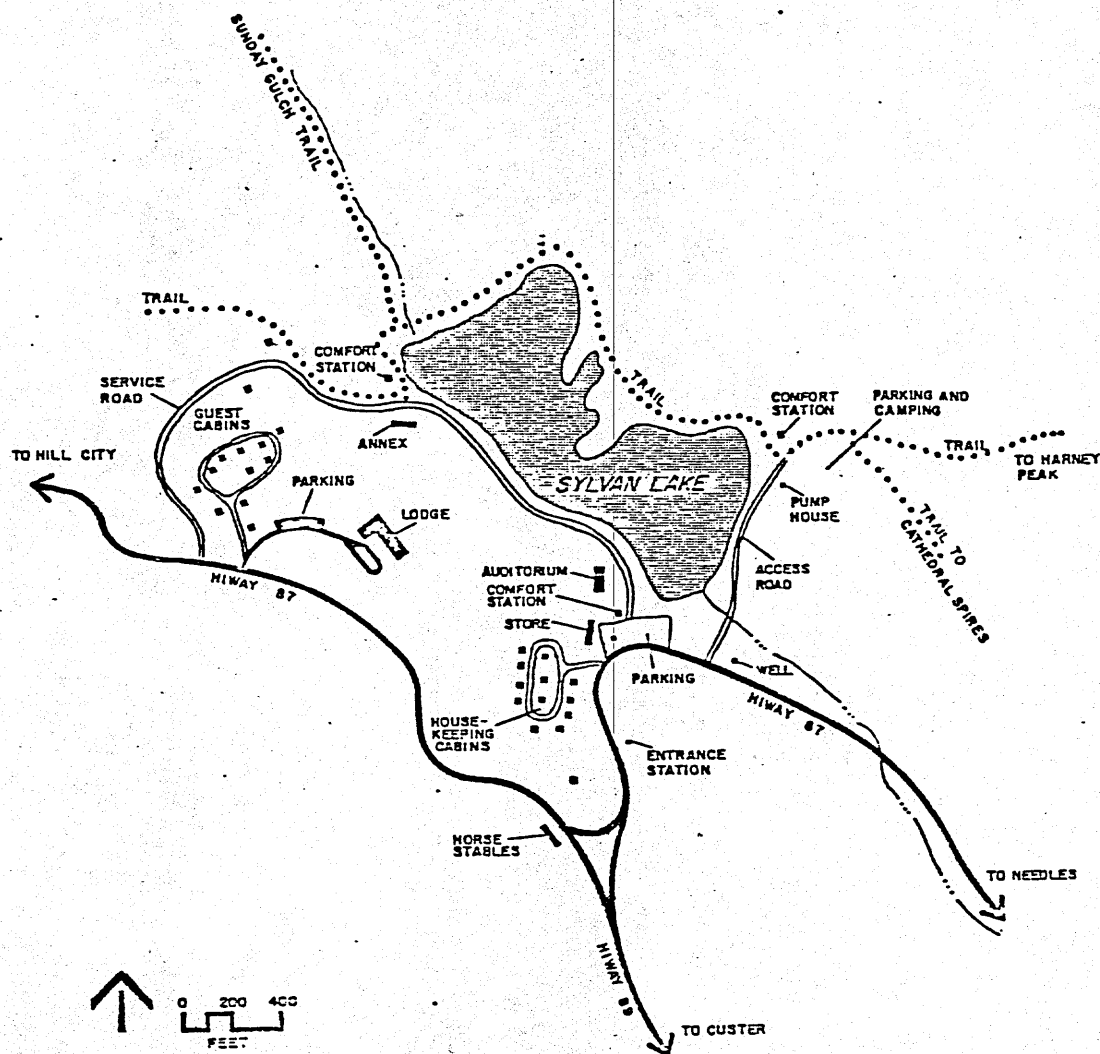


Figure 3. Sylvan Lake shoreline facilities

TABLE 1. RECREATIONAL ACTIVITIES IN THE SYLVAN LAKE WATERSHED

Recreational Activity	Description	Environmental Impact Discussion
Fishing	The Department of Game, Fish and Parks provides regular stocking of catchable size trout in the lake. Approximately 13,500 Rainbow Trout are stocked annually and on occasion several Brown Trout have been stocked. A CEEL survey indicates that 5,854 people fished the Lake during the summer of 1976. No winter data is available, but ice fishing is a popular activity at the Lake.	Summer: Increases shoreline erosion. Limited aesthetic problems with trash. Fishermen desire close access with resulting sediment loads from roads. Domestic waste problems are considered to be minimal because of the availability of adequate toilet facilities. Winter: Normally no impact on shoreline erosion, but late fall and early spring access to the ice may produce limited sedimentation problems. Domestic waste problems are more serious in the winter since toilet facilities are closed.
Camping	The new campground ¼ mile southeast of the Lake is still under construction with areas for recreational vehicles and tent camping. Sanitary facilities are also being provided for year round use.	New camping area is contributing significant sediment loads at the present time due to recent construction. Domestic wastes are transported out of the Sylvan Lake drainage through a central wastewater system. The continued erosion resulting from the new campground operation should be controlled with sediment dams.
	The existing campground doubles as a picnic area and gathering place for fishermen, hikers and rock climbers. The area is badly overused and is presently aesthetically undesirable.	Adjacent: The existing campground located adjacent to the Lake contributes significant quantities of sediment. Domestic wastes are adequately handled in nearby toilets, except for wintertime use. Several aesthetic and soil erosion problems have developed in the campground area due to removal of vegetative cover.

(continued)

TABLE 1. (continued)

Recreational Activity	Description	Environmental Impact Discussion
Hiking	There are several trails which originate at or near Sylvan Lake including the Sunday Gulch Trail, Harney Peak Trails (#9 and #4), the Bismark Lake Trail and the Cathedral Spires Trail.	View Only: Several hiking trails converge near Sylvan Lake. The "view only" trails have negligible impact on Sylvan Lake water quality when trails are maintained in a manner which controls erosion. However, the Harney Peak Trails are seriously eroding and intense hiking activity is contributing to the problem. The trails are presently used for horseback riding and, consequently, have suffered much abuse.
	Many trails have been made by visitors as they find access to the lakeshore for fishing and swimming. These trails are overused and random-sometimes "shortcuts" resulting in double trails connecting two points.	Access: Hiking trails which reach the Sylvan Lake shoreline contribute to the denudation and associated erosion problems adjacent to the Lake. Waste disposal is not a problem because toilet facilities are provided except for wintertime use when toilet facilities are closed.
Horseback Riding	A horseback riding stable is located west of the Lake outside the Lake watershed. This stable is in close proximity to the Lake and shoreline riding is presently practiced. Riders averaged 35 per day during the 1980 summer season. This concession may be eliminated in 1982.	Horseback trails in the Sylvan Lake drainage which overlook the Lake can be expected to contribute sediment during periods of high runoff. Shoed horses loosen soils on the trails with every passing and, typically, trail erosion occurs during runoff periods. The trail to Harney Peak is contributing significant sediment loads and this problem is worsened by horseback riding activity.

(continued)

TABLE 1. (continued)

Recreational Activity	Description	Environmental Impact Discussion
Horseback Riding (continued)		Horseback riding adjacent to the Lake is contributing significant sediment at the present time. Aesthetic and water quality problems are a factor when animals are allowed access to trails being used by hikers, fishermen, swimmers and others.
Swimming/Sunbathing	Although no beach is provided, many visitors to the Lake choose to swim there. GF&P personnel wish to provide a specific site for this activity at Sylvan Lake.	Swimming facilities are not presently provided, but swimming and sunbathing are presently contributing to shoreline denudation and sedimentation problems. Human waste disposal is not considered to be a problem.
Boating-Canoe	Many visitors bring canoes to the Lake to fish out in the Lake or just cruise around the water. There is no concession at the Lake to provide canoes.	Shoreline denudation and associated erosion are the only significant problems associated with boating activities.
Boating-Paddleboats	A concession for renting paddleboats is located at the south end of the Lake. This concession may continue in the future.	Shoreline denudation and associated erosion is a significant problem near the paddleboat concession.
Rock Climbing, Bouldering	Rock formations in the Sylvan Lake watershed are a challenge to may climbers. Facilities at the Lake provide a trail head for climbers.	This activity is not considered to be contributing to any signficant pollution problems other than the general contribution to road and trail erosion.

(continued)

TABLE 1. (continued)

Recreational Activity	Description	Environmental Impact Discussion
Auto Touring	The Lake is readily accessible to tourist traffic. During the 1980-81 year, an average of 688 vehicles per day visited Sylvan Lake. At an average of 3.5 persons per car, the Lake area received 430,000 visitors last year.	Aesthetic problems are caused by the high visibility of the parking lot and highway to the Lake. Wastes from the commercial area frequented by tourists are pumped to a treatment facility outside of the drainage area. Sediment from unpaved roads and parking lots is a serious problem.
Photography	Nearly all visitors to Sylvan Lake desire to photograph the area. Rock outcroppings and the Lake provide good scenery.	This is a miscellaneous use which contributes, generally, to the shoreline denudation and associated sedimentation problems.
Cross-Country Skiing	Hwy. 87 from Sylvan Lake past the Needles and Cathedral Spires is closed during the winter for use by skiers and snowmobile enthusiasts.	No significant problems are associated with cross-country skiing. Snowmobiling is retricted to paved roadways which are groomed for snowmobile usage when adequate snow cover exists. No significant problems with snowmobiling exist, provided that usage is confined to designated areas.

TABLE 2. WATER QUALITY PROBLEMS RELATIVE TO RECREATIONAL ACTIVITY IN THE SYLVAN LAKE WATERSHED

Recreational Activity	Biological	Physical		Chemical
	(Pathogens from Human and Pet Wastes)	Sediment Production	Trash	Nitrogen and Phosphorous
Fishing-Summer	None	Severe	Moderate	Moderate
Fishing-Winter	Slight	Slight	Moderate	None
Camping-Over ¼ mile from Lake	None	Severe	None	Severe
Camping-Adjacent	Slight	Very Severe	Severe	Very Severe
Hiking-View only	None	Severe	Slight	Severe
Hiking-Access	None	Very Severe	Moderate	Very Severe
Horseback Riding-View only	Moderate	Severe	Slight	Severe
Horseback Riding-Access	Severe	Very Severe	Slight	Very Severe
Swimming/Sun Bathing	Moderate	None	Slight	None
Boating-Canoe	None	None	Moderate	None
Boating-Paddleboats	None	None	Moderate	None
Rock Climbing, Bouldering	None	Slight	None	Slight
Auto Touring	None	Moderate	Slight	Moderate
Photography	None	Neg.	None	Negligible
Cross-Country Skiing	None	Neg.	None	Negligible
Snowmobiling	None	Slight	Neg.	Negligible

with mean daily usage at 2700 people. It was estimated that 15,000 people/yr. stayed overnight in available rental units at the lake, with an additional 10,000 people/yr. using overnight camping facilities in the immediate lake vicinity. Usage data indicated a 50% increase in visitation from 1969-1979.

The intense usage summarized above resulted in severe aesthetic and water quality problems at Sylvan Lake. Shoreline areas were denuded of vegetation from shoreline activities, and active erosion of unprotected soils resulted in accelerated sedimentation of the lake bottom. Sediment deposits at the two principal drainage inlets on the south end of the lake reduced approximately one-third of the total shoreline to a marsh environment with littoral aquatic plants and increased water temperatures and algal blooms. The shallowness of the lake, due to sedimentation and nutrient loading related to sedimentation, caused a variety of recreational use problems including undesirable aesthetics, limited access, and reduced fish habitat.

Figures 4, 5, and 6 illustrate the extent to which sediment had intruded into the lake by 1981. Analysis of sediment data indicated that approximately 22,938 m^3 (30,000 C.Y.) of sediment had accumulated in the lake since its initial construction, with recent accumulations averaging about 1,376 m^3 (1,800 C.Y.) per year.

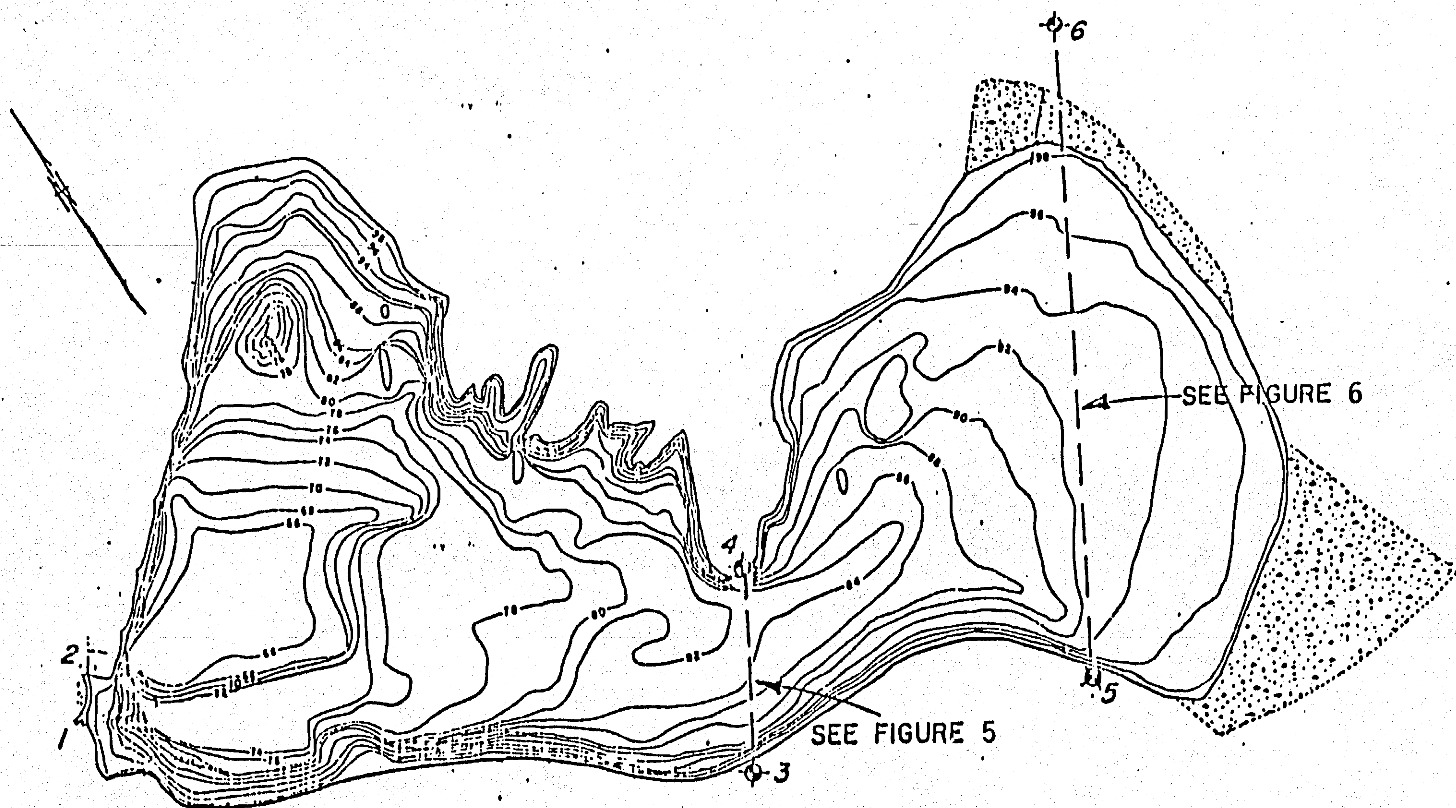


Figure 4. Sylvan Lake sediment contours

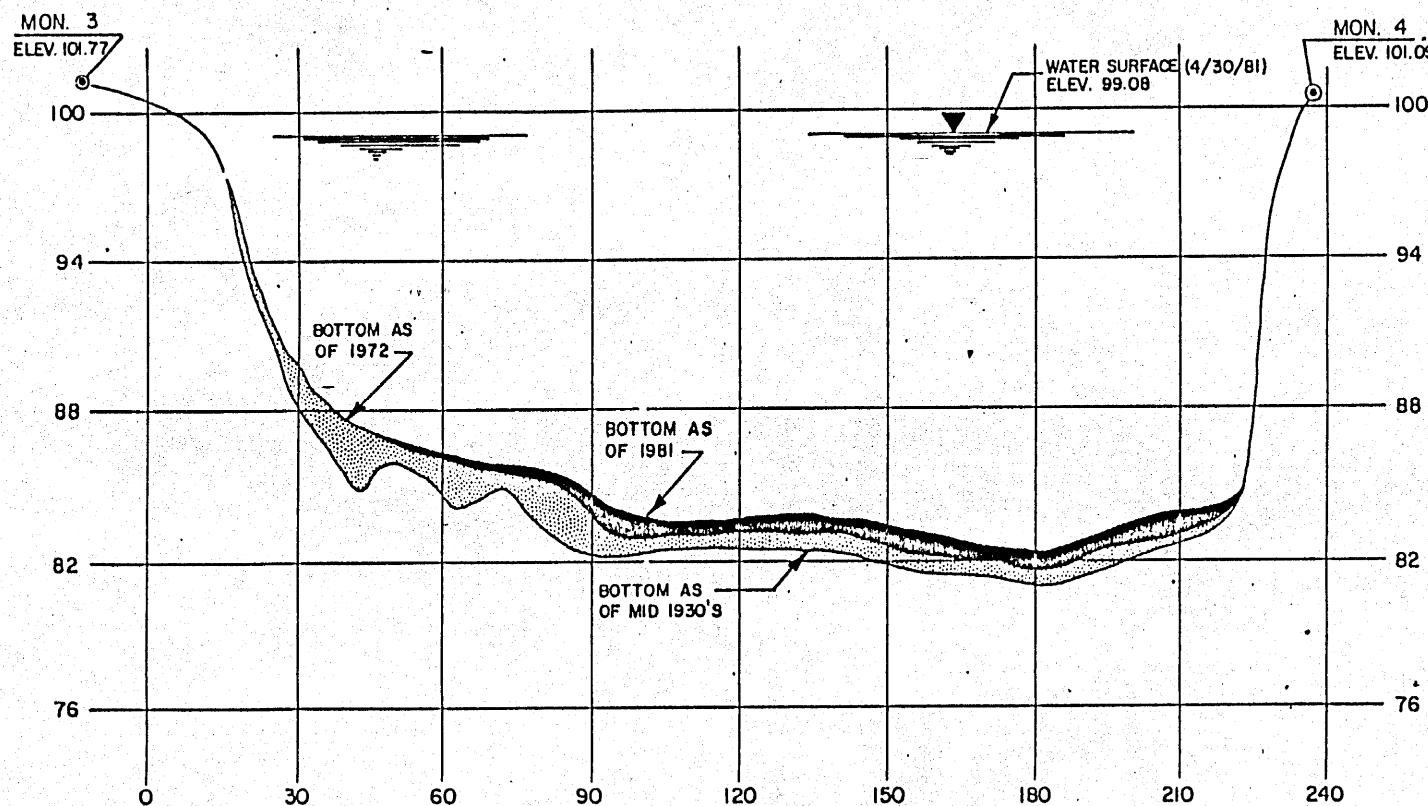


Figure 5. Sylvan Lake sediment range profile No. 1

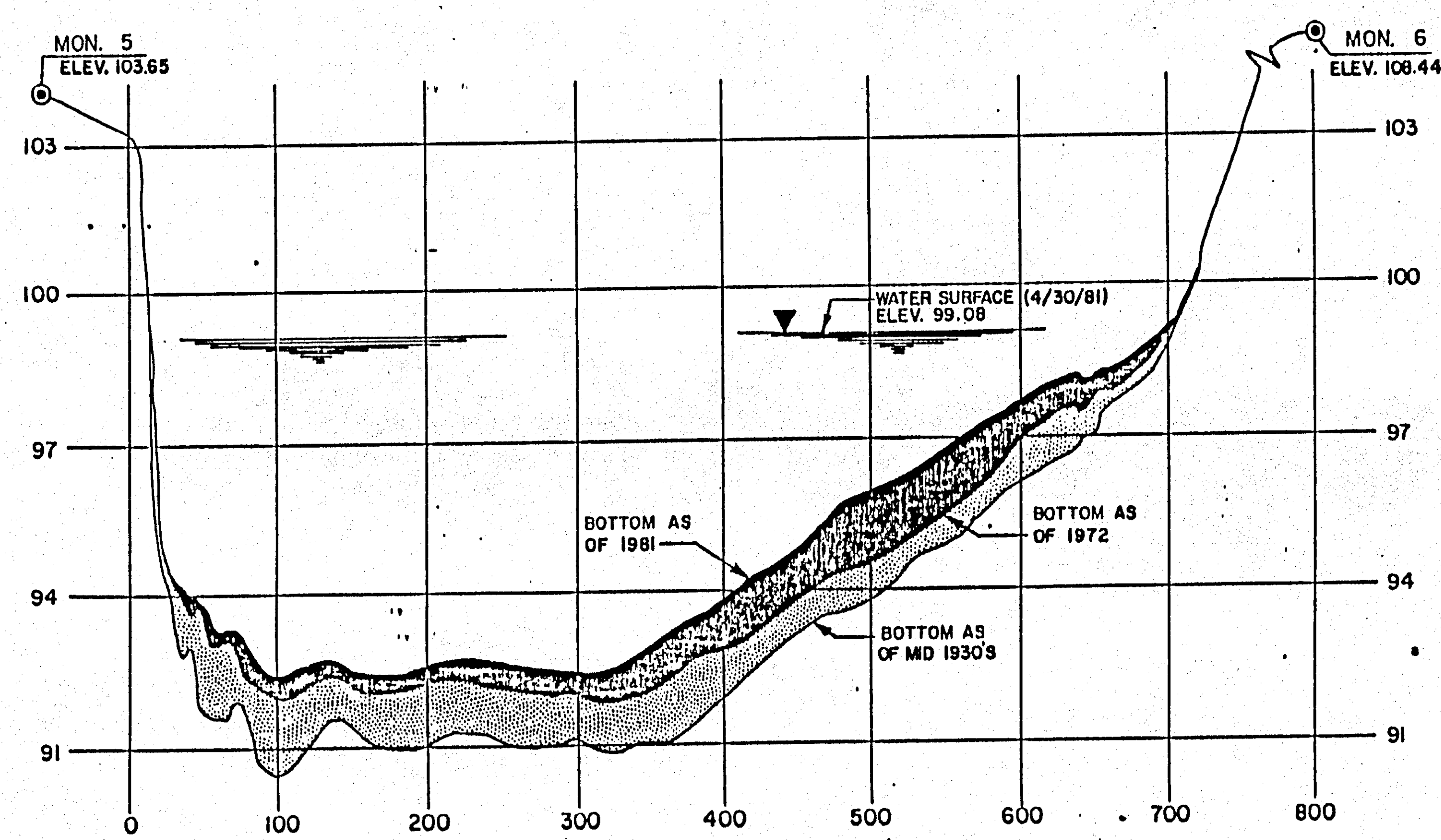


Figure 6. Sylvan Lake sediment range profile No. 2

Water quality analyses by several entities (Black Hills Conservancy Subdistrict, 1971 and 1972; South Dakota Department of Water and Natural Resources, 1980; Bauman, 1980; Utility Engineering Corporation, 1981) determined that moderate eutrophic conditions existed in the lake, with detrimental effects on recreational use. (See Section 5 for water quality background and analyses.)

SECTION 2

OBJECTIVES

GENERAL

The Sylvan Lake Restoration Project was initiated by the SDDGFP in 1979 with the general objective of correcting problems and controlling activities which were detrimental to the recreational experience provided by the lake and its surroundings. The water quality, aesthetic and recreational use of the lake were the principal concerns of the restoration effort.

A master planning document for CSP (Wirth Associates, 1976) provided general direction and objectives for the Park as a whole, with specific recommendations for improvements to the various facilities and attractions, including Sylvan Lake. Restoration efforts, including those related directly to water quality, were coordinated with the Park Master Plan.

WATER QUALITY

As the focal point of the Sylvan Lake recreational area, the water quality of the lake was a prime concern in developing restoration plans. Application was made, and a grant was awarded to the SDDWNR from the Environmental Protection Agency (EPA) for restoration work at Sylvan Lake for "lake protection and rehabilitation" purposes under Public Law 92-500, Section 314 (as defined in 40 CFR 35, subpart H) on the basis of the document, "A Proposal for the Restoration of Sylvan Lake," SDDWNR, 1979. SDDWNR delegated the grant implementation responsibility for the grant funds to the SDDGFP via a contractual agreement.

SECTION 3

PROJECT DESCRIPTION AND IMPLEMENTATION

PROJECT ORGANIZATION

The SDDGFP developed and implemented the Sylvan Lake Restoration Project through the combined efforts of its own staff, private consultants, other State agencies, and private construction contractors and their subcontractors. An organizational chart of principal participants in project development and implementation is presented in Figure 7.

Major funding for Sylvan Lake restoration work was provided through the EPA Clean Lakes Grant program. Matching funds were provided by the SDDWNR Lake Protection and Rehabilitation funds and SDDGFP operational budget. Supplemental funding was provided by the National Park Service via the Land and Water Conservation Fund (LWCF), South Dakota Department of Transportation (SDDOT), and SDGFP operational budgets.

Elements of the restoration work which were not funded by the EPA Clean Lakes Grant were constructed simultaneously under the same construction contract with EPA grant funded work. Because of the combined effort, project descriptions in this report refer in part to work which was not constructed with Clean Lakes Grant funding. (See Section 4, Project Financing, of this report for

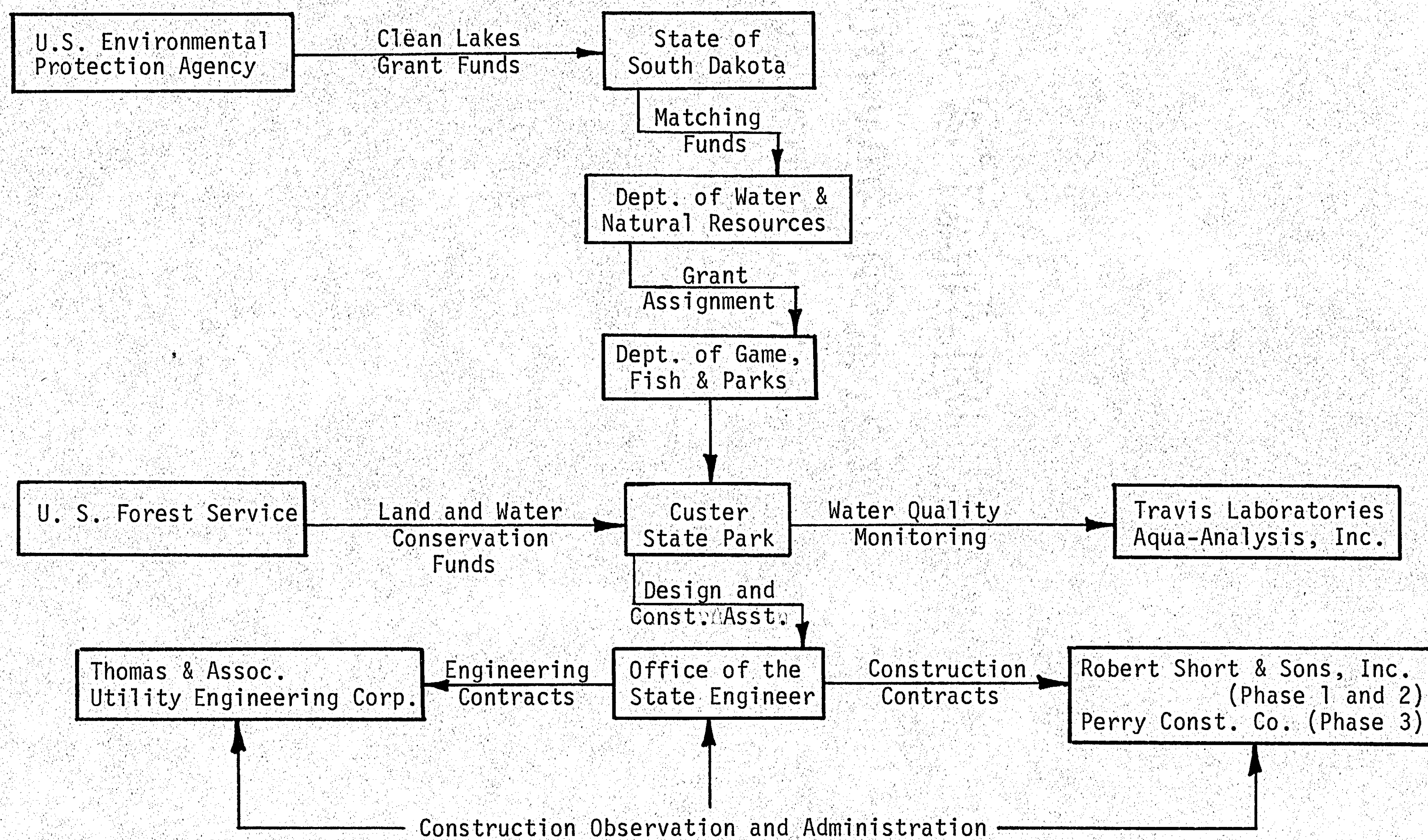


Figure 7. Project organization chart

further discussion of project funding sources and utilization of Clean Lakes Grant funds.)

PROJECT DESCRIPTION

Based on preliminary engineering work by private consultants (Thomas and Associates, 1979; Utility Engineering Corporation, 1981), a restoration and protection project scope was developed for Sylvan Lake which included three major construction phases.

Phase 1. Partial removal of lake sediment deposits.

Phase 2. Paving of existing gravel surfaced access roads and parking areas and construction of new hard surfaced access roads and parking areas.

Phase 3. Surface restoration and revegetation, and construction of sediment controls.

A fourth project phase included changes in management practices and land uses by CSP to enhance and accommodate the objectives of the restoration plan. Work accomplished under this project phase, although essential to the restoration effort, did not involve expenditure of EPA Clean Lakes Grant Funds.

Table 3 presents an inventory of restoration project components completed under each major construction phase of the Sylvan Lake

TABLE 3. RESTORATION PROJECT INVENTORY

Project Phase	Component	Purpose	Funding Source
1.	Sediment Removal From Lake.	Improve aesthetic values in high visibility and high use areas or lake, improve fishing access, enhance fishery potential, prepare shoreline for hiking trail system and swimming beach.	Combined EPA and Local
2.	Parking Access Improvements.		
	A. Main Parking Lot Paving	All paving projects intended to minimize erosion from gravel roadways and parking areas and confine vehicular travel to paved surfaces. Adequate parking facilities needed to accommodate visitors and discourage off-road travel and parking.	SDDOT
	B. Eastside Access Road Paving		SDDOT
	C. Eastside Parking Lot Construction and Paving		EPA
	D. Cathedral Spires Parking Lot Construction and Paving		Local
3.	Surface Restoration and Sediment Controls.		
	A. Eastside and South Shoreline Surface Restoration	Topsoil and Seeding of denuded soils intended to stabilize erosive conditions, reduce sediment loading to lake and improve aesthetics.	EPA
	B. Sedimentation Basins.		
	1. South Drainage at New Campground.	On-stream sedimentation basins to provide temporary detention and storage and allow quiescent settling of sediment laden runoff and filtering of organic debris during period of high inflow. Base flows enter lake relatively unaffected by detention and storage facilities.	EPA
	2. South Drainage at Eastside Access Road.		
	3. South Shoreline from Cabin and Commercial Area.		
	4. West Shoreline.		
	5. West Shoreline from Lodge Area.		

(continued)

TABLE 3. (continued)

Project Phase	Component	Purpose	Funding Source
	B. Sedimentation Basins (continued)		
	6. East Shoreline from Eastside Parking and Day Use Area.		
	7. South Drainage at Cathedral Spire Parking Access Road.		
	C. Reconstruct and Revegetate West Shoreline.	Obliterates former gravel roadway, restore stable slopes to eroding cut and fill slopes, topsoil and seeding to restore natural appearance and stable non-erosive soil conditions.	EPA
	D. Shoreline Trail Construction.	Provides gravel surfaced shoreline access with proper definition and continuity. Helps confine foot traffic to designated areas and minimizes adverse effect of heavy use on revegetation work.	Local
	E. Swimming Beach Construction.	Confines previously uncontrolled swimming activity to a designated location, away from conflicting uses such as fishing and sightseeing. Provides stable, non-erosive sand surface for intense swimming usage.	Local
	F. Revegetate Sediment Disposal Areas.	Provides finish grading and seeding of sediment disposal sites from Phase I work to provide stable non-erosive surface.	EPA
4.	Changes in Management Practices and Land Uses.		
	A. Timber Thinning	Agressive understory thinning to promote light penetration and development of	Local

(continued)

TABLE 3. (continued)

Project Phase	Component	Purpose	Funding Source
	A. Timber Thinning (continued)	surface vegetation.	
	B. Land Use Changes.		
	1. Eliminate horseback riding from watershed.	Reduce surface disturbance and erosion.	
	2. Eliminate gasoline sales in lake area.	Prevent oil and grease spillage.	
	3. Move camping facilities away from lakeshore.	Reduce surface disturbance at lakeshore.	
	C. Trail Rehabilitation and Hardening.	Improve hiking trail definition to confine traffic to stable surfaces and promote surface vegetation.	

Restoration Project, along with a general rationale for the work and the source of funding for each. (See Section 4 for further discussion of project funding.)

DISCUSSION OF PROJECT COMPONENTS

Phase 1. Sediment Removal

Sediment removal was included as a component of the restoration effort based on the following factors:

1. Sediment deposits prevented shoreline access to nearly one-third of the total shoreline for several major recreational activities, primarily fishing.

2. Removal of sediment would enhance the fishery potential as a result of improvement in several water quality parameters required for a cold water fishery (principally temperature and dissolved oxygen).

3. Aesthetic values would be improved by removal of emergent vegetation and restoration of the lake to its original size and shoreline location.

Alternatives for no sediment removal work, or minimal sediment removal work, with "sacrificing" the lost lake area and volume, were considered. These were discarded in favor of extensive, but not total, removal of sediment. Shoreline access, improvement of fish habitat, and aesthetic considerations were the principal factors in justifying the sediment removal work.

Sediment deposits were removed only from the east and southeast shoreline areas to a distance of about 31 to 61 m (100 ft. to 200 ft.) from the shore as illustrated in Figure 8. Extensive excavation was performed on the south shoreline at the entry of the principal tributary to the lake to restore the shoreline to its original historical location.

To minimize interruption of lake use during the summer months, sediment removal work was performed during the winter. The lake water level was lowered by approximately 2.7 m (9 ft.) in September, 1981 by siphoning over the dam, and the exposed lake bottom deposits allowed to dry naturally until removal work began in January, 1982.

Sediment removal was accomplished under a competitively-bid unit-price contract, by a private contractor. The contractor elected to employ conventional earth-moving equipment for the work: wheeled and tracked loaders and excavators, with hauling by dump truck. Removed sediment was disposed of by dumping at two predetermined disposal sites: 1) a borrow pit from a previous highway construction project located approximately 0.8 km southwest of the lake, and 2) an older borrow pit and dump site located about 1.2 km south of the lake. The sediment deposits

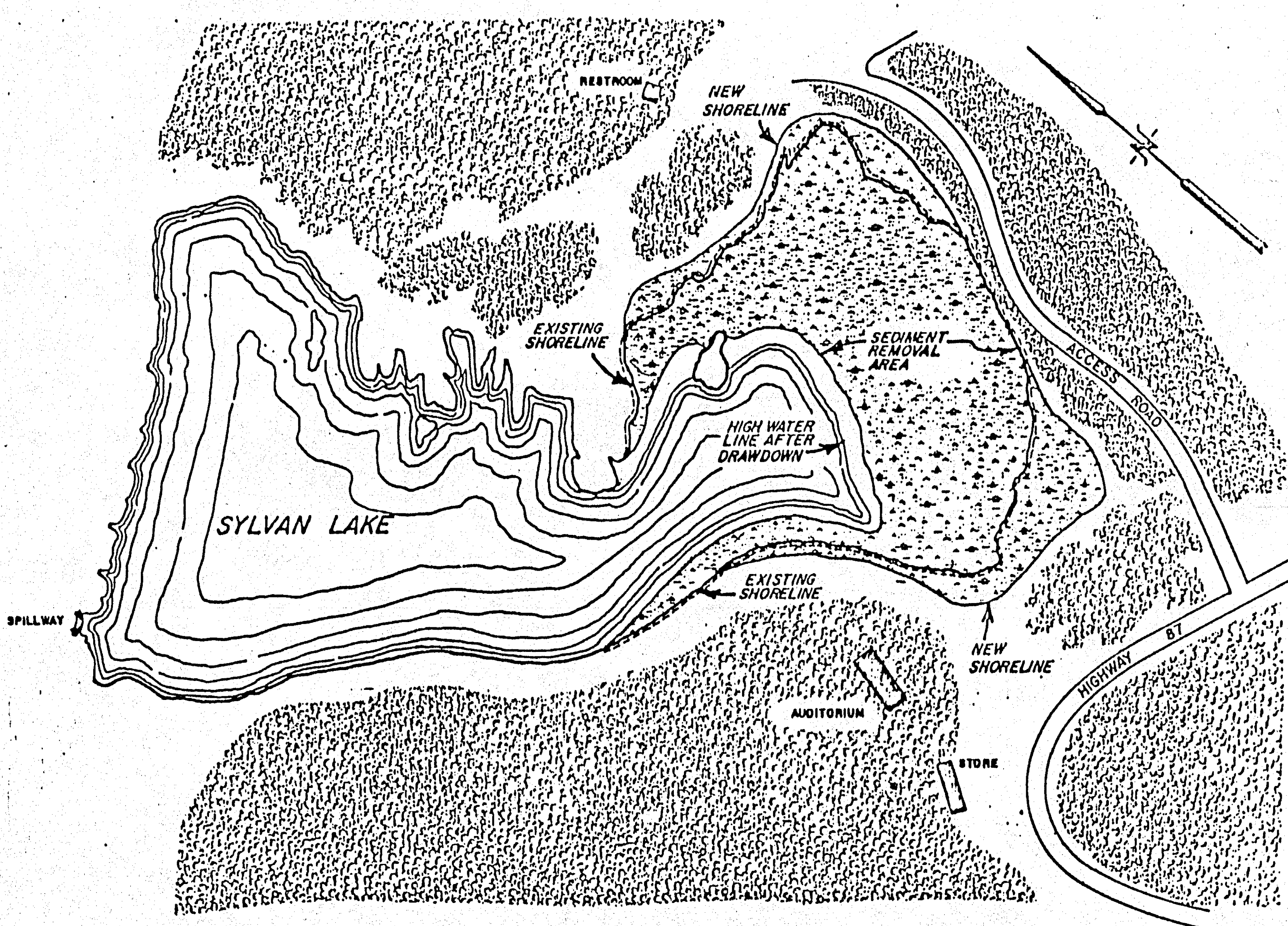


Figure 8. Sediment removal area map

were generally in a frozen condition during removal, and the contractor had little difficulty in removing the frozen material or operating on the frozen lake bed in most areas.

The only significant problem encountered with the sediment removal project was controlling the contractor's removal work and limiting work to specified lines and grades. The final measured volume of sediment removal was 60% more than anticipated (18,580 m^3 or 24,300 C.Y. vs. 11,469 m^3 or 15,000 C.Y.), and was attributed to inadvertent removal of non-sediment soils which existed in the lake prior to lake construction. The contractor was unable to visually distinguish between sediments and some native soils. Excavation was generally performed to expose a uniform granular substrate of weathered granite which is the typical subsoil in the area. Depths of excavating ranged from 0.3 m to 1.8 m in depth vs. an estimated 0.3 m to 0.9 m depth in the original contract quantity estimates.

Control of the contractor's work was further hampered by the absence of a full-time on-site technician or an effective method of monitoring the contractor's progress or the status of the volume of material removed.

Because it was determined that his performance was within the scope of the contract and was to the benefit of the project, the contractor was ultimately paid for the entire volume of material removed from the lake area. However, use of EPA funds for this effort was limited to the amount set forth in original project budgets, with the balance provided by the SDDGFP. (See Section 4 for further discussion and cost analysis.)

Phase 2. Access Road and Parking Improvements

Work under this project phase was conducted through two independent construction contracts; one of which did not include expenditure of EPA grant funds. When taken together, these projects provided for the construction or reconstruction of 118 paved parking spaces and 0.6 km (0.4 miles) of paved access roadway.

The paving projects were completed for the following principal reasons:

1. Erosion of unpaved roadways and parking was a significant source of sediment.

2. The lack of controlled and adequate parking was promoting the off-road use of vehicles which lead to surface disturbance and erosion.

The SDDOT designed, administered, and funded an improvement project for State Highway 87 near the south shoreline. The project included reconstruction and paving of the west side parking area and paving the access road to the east side parking area (former campground) along the south shoreline of the lake. This work was completed in October, 1981.

A second project, which included partial funding through the EPA Clean Lakes Grant, was completed to provide new paved parking facilities for the new east side day use area at Sylvan Lake. It also provided new paved parking facilities at the Cathedral Spires Trailhead about one mile south of the lake (along Highway 87) but within the Sylvan Lake watershed. Figure 9 illustrates the parking and access facilities constructed under restoration Phase 2.

The east side parking construction included the obliteration and removal of about 1858 m^2 (20,000 s.f.) of unpaved or denuded driving and parking surfaces from the former lake shore campground and construction of 43 new paved parking spaces. The paved access road to the east side parking area was constructed as part of the SDDOT project for State Highway 87.

The Cathedral Spires Trailhead parking lot construction included the obliteration and surface restoration of approximately 465 m^2 (5,000 s.f.) of denuded soils resulting from off-road vehicle use and unauthorized parking, and construction of 21 new paved parking spaces. The approach road to the parking area was utilized as part of a sedimentation structure built as part of of Phase 3 restoration work at Sylvan Lake.

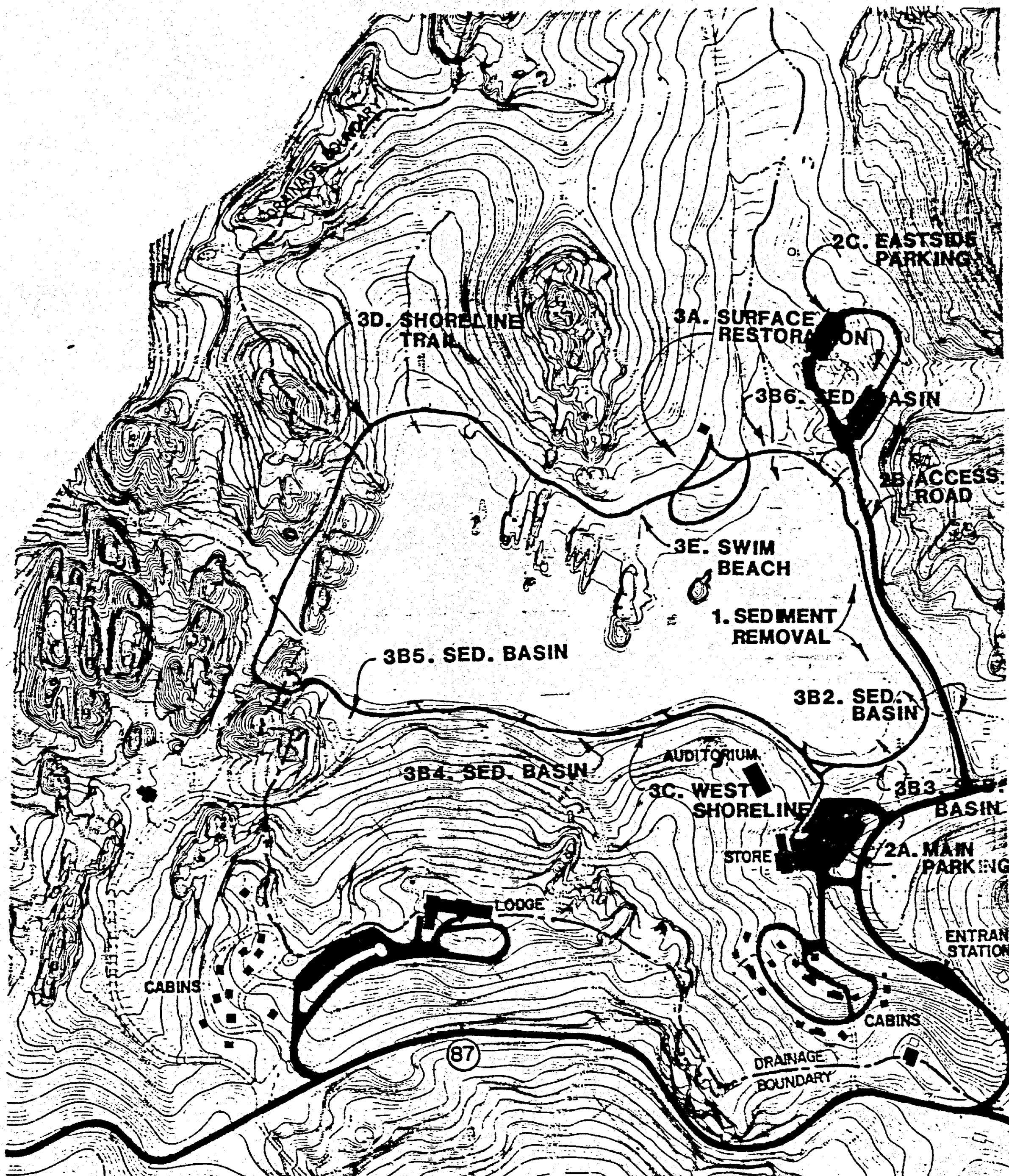


Figure 9. Sylvan Lake restoration Phase II & Phase III components - North 1/2

Parking facility construction was initiated in April, 1982 under a competitively-bid unit-price contract, with completion scheduled for June 15, 1982. Unusually heavy spring rains in April, May, and June of 1982 resulted in delay of project completion until October, 1982. Subgrade soils were in an unworkable condition during much of this period, and spring water at both parking facilities necessitated construction of unplanned subsurface drainage systems, which delayed construction completion and increased project costs by 23%.

Phase 3. Surface Restoration and Sediment Controls.

Phase 3 restoration work was accomplished under a competitively-bid unit-price construction contract and consisted of the following major components:

1. Topsoiling and seeding (or sodding) of approximately 2 hectares (5 acres) of denuded or disturbed surfaces.

2. Minor grading and excavation to correct steep eroding slopes unsuitable for revegatation work and to stabilize eroding shoreline areas.

3. Construction of a gravel surfaced lakeshore hiking trail system.

4. Construction of eight sediment control structures or devices in the watershed.

5. Finish grading and seeding of sediment disposal sites from Phase 1 work.

6. Construction of a small swimming beach area.

Objectives of Phase 3 work were as follows:

1. Stabilize and revegetate principal sources of soil erosion and sediment in the immediate lake shore area.

2. Contain sediment from uncontrolled or natural erosion sources in upstream entrapments to retard future lake sedimentation.

3. "Harden" and improve definition of lake shore facilities to control recreational use and encourage revegetation efforts.

Figure 10 illustrates the principal components of the Phase 3 restoration work. A discussion of major Phase 3 restoration components follows.

Figure 10. Sylvan Lake restoration Phase II & Phase III components - South 1/2

Slope Stabilization and Roadway Obliteration --

Steep cut slopes existed along the west shoreline where a gravel access road connected the dam area with the main parking area at the south end of the lake. Active erosion of roadway surfaces and construction cut slopes was evident in many areas.

The gravel roadway was obliterated and converted to hiking use only, and eroding cuts were backsloped and/or filled to a stable slope capable of supporting vegetation. Approximately 0.4 km of roadway was obliterated and approximately 0.2 Ha of erodible cut slopes were stabilized.

Surface Revegetation --

Approximately 3.2 Ha (8 acres) of denuded soils in the shoreline areas were covered with topsoil material and seeded with native grasses. The sediment disposal areas from Phase 1 work was also revegetated.

Topsoil material was obtained from stripping construction sites from other project components (principally parking areas) and from salvage of suitable material from sediment deposits removed under Phase 1 work. Lake sediments were found to be variable in character and suitable for topsoil. Most required fertilizer enhancement. Topsoil was placed from 10 to 15 cm in thickness in all denuded areas, except those where non-erodible rock was exposed.

Seed material consisted of native grass varieties indigenous to the vicinity. Seed was placed by hand broadcasting methods due to the inaccessibility of most areas for mechanical seeding equipment.

Revegetation of certain project areas with other plant materials (native trees, shrubs, etc.) was considered in detail but was ultimately eliminated from the project as funds for plantings of this type could not be obtained from available funding sources. Tree and shrub planting is a key element of Phase 4 restoration work performed by CSP forces as an on-going element of improved forestry and management practices.

Sediment Control Structures --

Sediment control devices were located in the streams at principal drainage courses entering the lake. Sediment controls were of two types: 1) previous gravel dikes contained within treated timber cribbing and 2) perforated pipe riser. Typical construction details for sediment control devices are illustrated in Figures 11 and 12. Gravel dikes were used in all locations except at the Cathedral Spires Parking area due to less objectionable aesthetics, and multiple use possibilities discussed hereinafter.

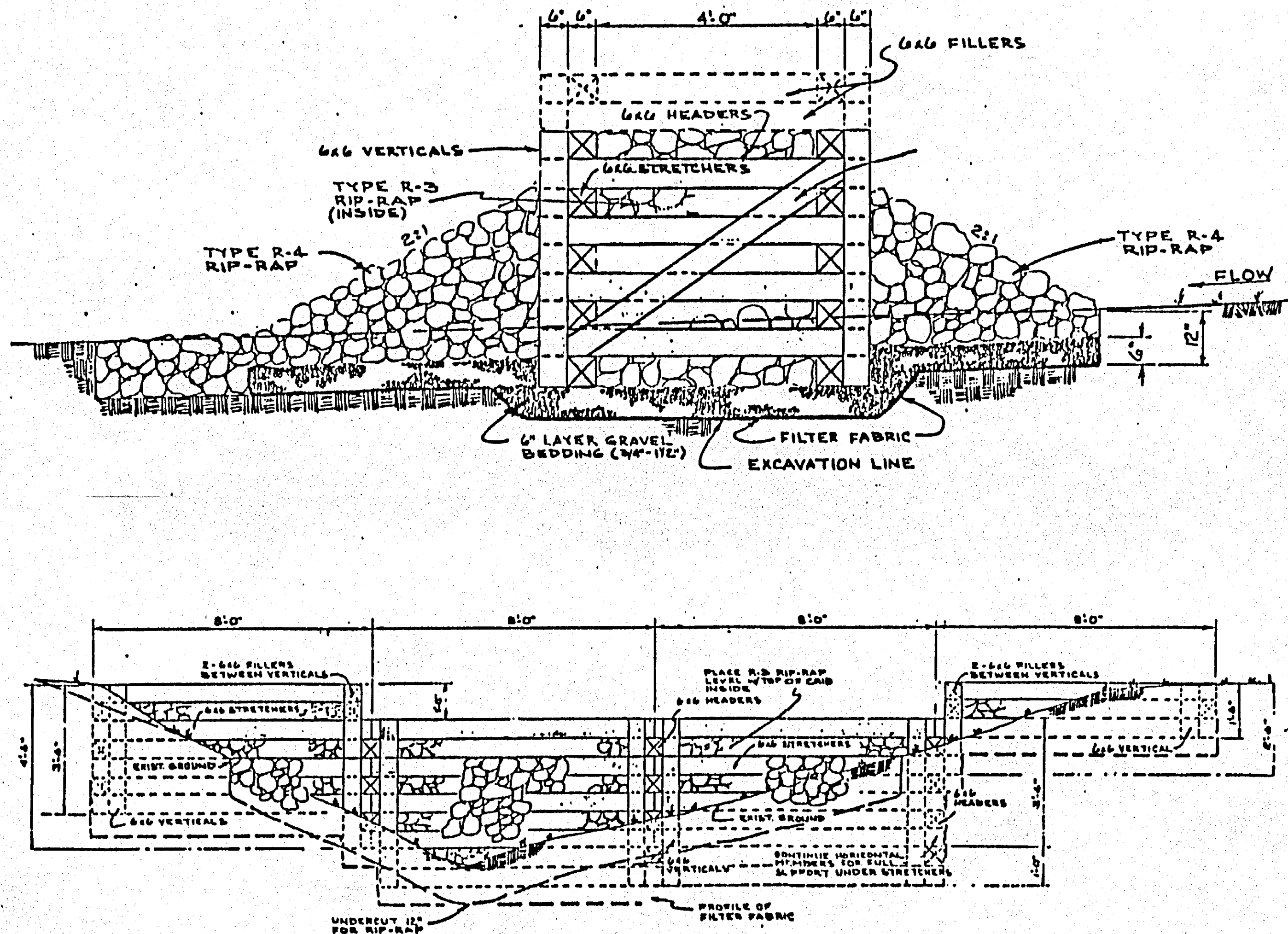


Figure 11. Type 1 sedimentation structure

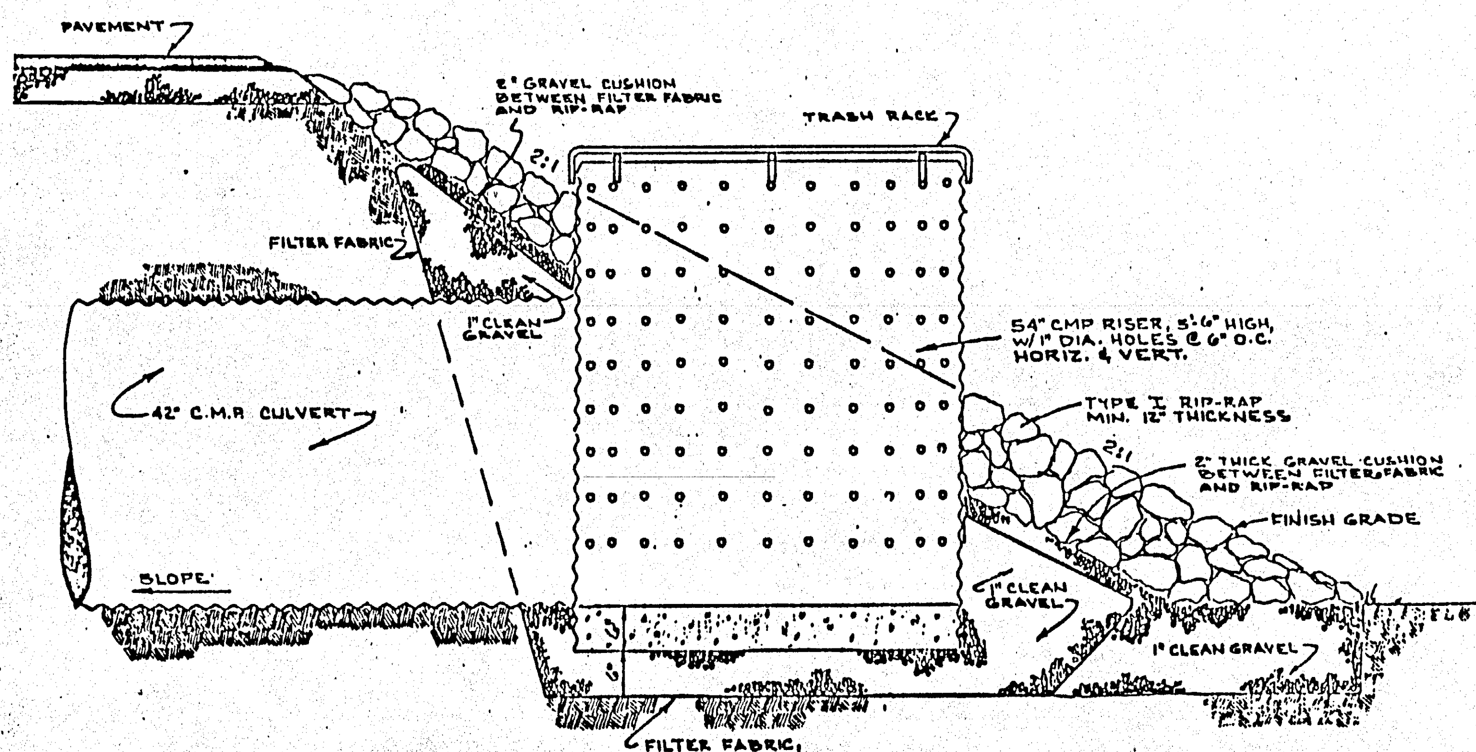


Figure 12. Type 2 sedimentation structure

Shoreline Trail System and Swimming Beach --

A shoreline hiking trail system and swimming beach area were constructed as part of Phase 3 surface restoration work. No well defined trail system or swimming area existed at Sylvan Lake prior to restoration work, and hiking and swimming activities were unrestricted and uncontrolled over virtually all accessible shoreline areas. As a result, surface vegetation had been virtually eliminated in many shoreline areas.

The principal objective of the trail and beach construction work was to provide well defined and easily accessible facilities, to confine usage to facilities capable of handling this use without degradation, and to enhance surface revegetation efforts. The alternative of eliminating swimming activities entirely was considered. However, swimming was a traditionally popular activity, and no reasonable methods of enforcing swimming restrictions were available.

Hiking trail construction consisted principally of hand excavation and leveling of a 1.2 to 1.5 m wide path with gravel surfacing 10.0 cm to 15.1 cm depth. Trails were constructed with treated timber step, 15.0 cm high and they were embedded and anchored to surrounding soil where trail slopes exceeded about 0.3 m in 3.0 m (a 10% grade). Raised embankments for trails were constructed in low lying areas for drainage and also where trails were incorporated as dikes for sedimentation basin containment

Both types of sediment controls were intended for temporary detention of runoff to facilitate settling of sediments. No filtering action was intended or designed for, except to the extent that floating organic debris would be removed by either type of structure. Sedimentation areas or basins upstream from structures were natural basins, and no excavation, grading or surface disturbance was conducted to attempt to enhance sedimentation characteristics or storage volumes. The mountainous terrain and desire to keep structures as unobtrusive as possible dictated that sedimentation structures be located only where natural topographic conditions were favorable and construction access and future maintenance was practical. Structural components were sized to pass natural base flows and frequent storm flows relatively unobstructed, with impoundment of storm flows beginning at about a 1-year return frequency rainfall or greater. All structures were designed to safely pass up to 100-year frequency storm flows by overtopping without damage to structures, roadways, or other facilities.

Various alternatives were considered in sedimentation structure location and design, including more effective designs for off-stream storage and relatively long term detention before release to the lake. Topographic conditions did not favor off-stream detention, and on-stream sites were limited to relatively small storage volumes which precluded long-term detention without major excavation work and displacement of recreational facilities.

areas. In such cases, trails served a dual purpose of providing a well drained walking surface along with providing containment of runoff for sedimentation.

The hiking trail system crossed the gravel filled sedimentation structures. Treated timber decking, 15.2 x 15.2 cm (6 in. x 6 in.), was added to the top of timber cribbing and incorporated into the trail system as a walking surface in these locations. Crib type structures were also used at several additional locations where minor drainageways crossed trails. These structures were not specifically intended to provide sedimentation functions.

Gravel trail surfacing was treated with an ammonium liquid sulfonate stabilizing material in an effort to bind gravel materials to form a non-erodible and well bonded surface. Trail paving with asphalt concrete or asphalt chip seal surface treatment was considered but rejected due to negative comments from SDGFP staff concerning objectionable aesthetics.

The swimming beach was located in a small natural cove on the east shoreline in an area which was relatively well removed from prime viewing and fishing areas and was already one of the more popular spots for swimming. Beach areas were prepared by removing sediment, rocks and debris from a 3716 m^2 (40,000 s.f.) area from about 1.5 m (5 ft.) below normal high water to about 0.9 m (3 ft.) above high water. Beach sand was spread over the entire prepared area to a depth of 30.00 cm (12 in.). Slopes were limited to about a 15% grade or flatter.

The hiking trail system and beach location are illustrated in Figure 13.

Phase 4. Land Use and Management Practices

To enhance revegetation and soil stabilization efforts, CSP instituted several changes in management practices and land uses. Principal changes were as follows:

1. Lakeshore camping was eliminated entirely. Lakeshore facilities are day-use type only.

2. Horseback riding was eliminated from the Sylvan Lake watershed. A horseback riding concession remains in the vicinity but all horseback use is limited to areas where soil disturbance will not affect runoff to the lake.

3. An extensive timber thinning and management program was instituted in the lake watershed to remove excess understory material and enhance light penetration and development of ground cover vegetation.

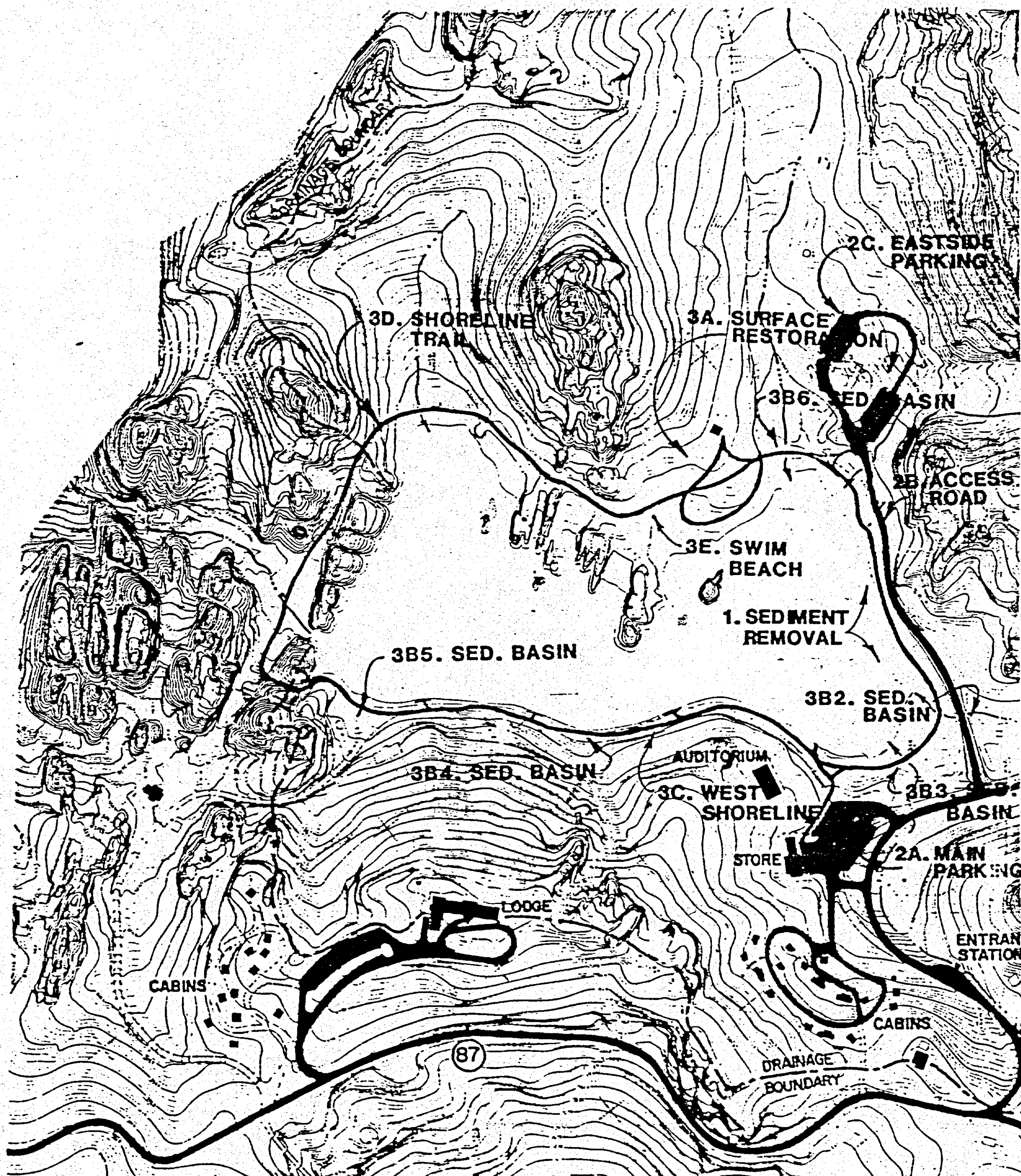


Figure 13. Sylvan Lake Hiking Trail and Beach location.

4. A gasoline sales operation near the main parking area was eliminated to reduce potential oil and grease spills from motor vehicles and to provide additional parking space.

5. A tree and shrub planting program was instituted to aid soil stabilization with native vegetation, provide natural foot traffic controls in high use areas, and to improve aesthetics and privacy for lake users.

Elimination or modification of a number of other activities and uses such as boating, commercial use near the main parking area, and tourist and employee residences in shoreline areas have been considered and may be included in future efforts to reduce unnecessary activities in the lake area and enable vegetation to stabilize in erodible soils.

SECTION 4

PROJECT FINANCING

FUNDING SOURCES

Funding for Sylvan Lake restoration work was provided by the EPA (Clean Lakes Grant), SDDWNR (Lake Protection and Rehabilitation Program Grant), National Park Service (NPS) (Land and Water Conservation Fund), SDDOT, and the SDDGFP (Custer State Park Division).

The principal source of funds, and the impetus for the overall restoration effort was a grant from EPA (Section 314 of the Clean Water Act per 40 CFR 35, subpart H) of $155,194. Matching funds of $146,100 in accordance with SDDWNR's Lake Protection and Rehabilitation Program (SDCL 34A-2-92-3) and $9,094 of SDDGFP funds resulted in a total project budget of $310,388. This budget amount was established solely for restoration work eligible for funding under the 314 Clean Lakes program. Other funding sources were utilized on restoration project elements which were determined to be outside the scope of the Clean Lakes program.

ALLOCATION OF FUNDS

The budgeted Clean Lakes program funding of $310,388 was utilized for significant portions of the three construction phases described in Section 3 of this report, as well as for engineering and consulting services, and water quality monitoring as required by the grant conditions. The final allocation of 314 funds to the various project components is set forth in Table 4 along with a summary of other funding and total costs.

Many project components, determined to be outside the scope of 314 funding during final work plan and budget reviews by EPA, were necessary to achieve overall project objectives. Related, but non-EPA funded work was, in some cases, a prerequisite for concurrent construction effort with EPA grant eligible work. Construction projects were bid with both grant eligible and non-eligible work included in the scope of work and were often included together in individual line items of unit price construction contracts. Although there was a clear understanding regarding allocation of EPA funds to contract work at the time of bidding, actual allocation of funding to as-built construction quantities and change order work was not always as clear.

A considerable amount of administrative and technical effort was expended to allocate grant funds properly to final project components and costs. Although the intent of grant eligibility was generally clear, the lack of full-time inspection effort left

TABLE 4. FINANCIAL SUMMARY - SYLVAN LAKE RESTORATION PROJECT

Item	EPA Grant Eligible	Other Funds	Total Cost
Pre. Engineering Studies:			
Thomas & Assoc.		$ 7,000.00	$ 7,000.00
Utility Engineering Corp.	$ 5,000.00	15,390.00	20,390.00
Engineering Service:			
Utility Engineering Corp.	22,572.00	10,378.81	32,950.82
Phase I Construction,			
Siphon for Lake Drawdown	1,780.00	---	1,780.00
Sediment Removal	60,000.00	9,681.00	69,681.27
Phase II Construction:			
Main Parking Lot and Eastside Access Road *	---	---	---
Eastside Parking Lot and Cathedral Spires Parking Lot	75,786.48	13,650.37	89,436.85
Phase III Construction:			
Surface Restoration and Sediment Controls +	105,655.20	84,741.31	190,396.51
Other Construction:			
Miscellaneous Erosion Control Projects ±	---	---	---
Water Quality Monitoring Program	31,851.37	---	31,851.37
Administrative Services	7,742.94	---	7,742.94
PROJECT TOTALS	$310,388.00	$140,841.76	$451,229.16

* Construction and funding through South Dakota Department of Transportation. Actual costs are undetermined as work was included within the scope of a highway construction project which was not solely related to the Sylvan Lake area.

\+ Includes non-EPA grant eligible work for shoreline trail system and swimming beach.

± Miscellaneous work by Custer State Park forces on minor erosion sources in the Sylvan Lake watershed, but not within Phase II and III construction areas.

** Not available at time of printing.

much doubt as to the correct proportions of work effort required for grant eligible and non-eligible work items. Principal problems were encountered with items such as paving and earthwork costs, since construction records provided totals only, with no means of proportioning to eligible and non-eligible items. In addition, no clear understanding was reached before construction as to allocation costs, overruns and change orders resulting from unknown site conditions or inaccurate quantity estimates. This problem was manifested primarily on Phase I - Sediment Removal work where as-built sediment removal quantities exceeded contract estimates by some 60%.

Final allocation of funds was accomplished by supplemental field measurements and office computations to proportion completed work to the various funding sources. Although funding allocation was successfully accomplished to the mutual satisfaction of all parties, the magnitude of this effort was not fully anticipated at project inception and caused much confusion and delay in funds distribution. There is no question that a total segregation of EPA grant eligible and non-eligible work into separate construction contracts would have eliminated the administrative problems. It is likely, however, that overlapping construction responsibilities among two or more contractors would have been equally difficult to manage. In retrospect, it is believed that a more careful selection of contract items, units of measurement, and definition of payment methods may have helped. Full-time inspection is probably the most important factor missing from the project work which would have streamlined the entire fund allocation process.

SECTION 5

WATER QUALITY

As discussed in Section 1, the Sylvan Lake restoration project was undertaken to correct watershed problems affecting water quality in Sylvan Lake and to remove sediments from the lake. Recreational activities had denuded several areas in the watershed and along the shoreline resulting in active erosion of unprotected soils which accumulated in the lake.

The SDDWNR has assigned the following beneficial uses to Sylvan Lake:

*Cold water permanent fish life propagation;

*Immersion recreation;

*Limited contact recreation; and

*Wildlife propagation and stock watering.

Table 5 lists the numerical water quality standards assigned by the SDDWNR to protect these beneficial uses.

The sampling site locations and descriptions are described in Table 6. The first seven sites (SY01 through SY07) were sampled

TABLE 5. WATER QUALITY STANDARDS FOR SYLVAN LAKE

Parameter	Concentration
Dissolved Oxygen	6.0 mg/l
Dissolved Oxygen (Spawning areas during spawning season)	7.0 mg/l
pH	>6.6 <8.6
Temperature	18.3°c
Conductivity	4000 microhms/cm(25°c)
Fecal Coliform (1 May to 30 September)	200/100 ml
Total Chlorine Residual	0.02 mg/l
Total Cyanide	0.02 mg/l
Free Cyanide	0.005 mg/l
Total Alkalinity	750 mg/l
Hydrogen Sulfide	0.002 mg/l
Total Dissolved Solids	2500 mg/l
Total Suspended Solids	30 mg/l
Un-ionized Ammonia as N	0.02 mg/l
Nitrate as N	50 mg/l
Polychlorinated Biphenyls	.000001 mg/l
Chlorides	100 mg/l

TABLE 6. SAMPLING SITE DESCPRIPTIONS FOR THE SYLVAN LAKE REHABILITATION PROJECT

Site SY01 is located at a longitude of 103°33'37" W and a latitude of 43°50'37"N in township 2S range 5E, and Section 30. This site is on the southeast tributary 15.2 m upstream from the stone bridge accessing the east parking lot.

Site SY02 is located at a longitude of 103°33'38"W and a latitude of 43°50'49"N in township 2S, range 5E and section 30. This site is on the northeast tributary 18.3m upstream from the lake's shoreline at full pool.

Site SY03 is located at a longitude of 103°33'34"W and a latitude of 43°50'51"N in township 2S, range 5E and section 30. This site is on the northeast tributary 168m upstream from the shoreline at full pool.

Site SY04 is located at a longitude of 103°33'21"W and a latitude of 43°50'28"N in township 2S, range 5E and section 29. Above site SY01, SY01 is on the southeast tributary 162m upstream from the wood bridge accessing the new campground.

Site SY05 is located at a longitude of 103°33'21"W and a latitude of 43°50'40"N in township 2S, range 5E and section 30. This site is in the lake by the paddleboat dock on the east side of the lake.

Site SY06 is located at a longitude of 103°33'54"W and a latitude of 43°50'47"N in township 2S, range 5E and section 30. This is an in-lake site off the south shore of the lake.

Site SY07 is located at a longitude of 103°33'54" and a latitude of 43°50'47" in township 2S, range 5E and section 30. This site is on the outlet from Sylvan Lake, 61m below the dam.

Site SY08 is located at a longitude of 103°33'43" and a latitude of 43°50'47" in township 2S, range 5E and section 30. This site is at the downstream end of a drainage culvert that receives runoff from that parking lot serving the Sylvan Lake Store. The runoff drains into Sylvan Lake.

Site SY09 is located at a longitude of 103°33'43" and a latitude of 43°50'47" in township 2S, range 5E and section 30. This site is in the Sylvan Lake outlet 6.1m below the dam.

TABLE 6. CONTINUED

Site SY10 is located at a longitude of 103°33'05" and a latitude of 43°50'51" in township 2S, range 5E and section 30. This site is in north portion of the lake.

Site SY11 is located at a longitude of 103°33'0" and a latitude of 43°50'44" in township 2S, range 5E and section 30. This site is off the southwest shore in the lake.

Site SY12 is located at a longitude of 103°33'39" and a latitude of 43°50'38" in township 2S, range 5E. This site is on the southeast tributary, at the upstream edge of a pool above a sediment collection structure. Paired with site number SY13, these sites were selected to determine the effectiveness of sediment collection structures.

Site SY13 is located at a longitude of 103°33'40"W and a latitude of 43°50'39"N in township 2S, range 5E and section 30. This site is on the downstream edge of a sediment collection structure. Paired with site SY12, these sites were selected to determine the effectiveness of sediment collection structures.

Site SY14 is located at a longitude of 103°33'03"W and a latitude of 43°50'37"N in township 2S, range 5E and section 29. This site is on the southwest tributary 55m northwest of the Cathedral Spires parking lot on trail number four.

Site SY15 is located at a longitude of 103°33'38"W and a latitude of 43°50'49"N in township 2S, range 5E and section 30. This site is on the northeast tributary at the upstream edge of a pool above a sediment collection structure. Paired with site SY16, these sites were selected to determine the effectiveness of sediment control structures.

Site SY16 is located at a longitude of 103°33'37"W and a latitude of 43°50'46"N in township 2S, range 5E and section 30. This site is on the northeast tributary 6.1m below the downstream end of the sediment collection structure. Paired with site SY15, these sites were selected to determine the effectiveness of sediment control structures.

Site SY17 is located at a longitude of 103°33'28"W and a latitude of 43°50'45"N in township 2S, range 5E and section 30. This site was on an intermittent tributary 47.2m upstream of the east parking lot.

from May 1979 through September 1979. All the samples collected during this time period were surface grab samples. Sites SY01 and SY04 were located on the southeast inlet with SY04 above SY01. Sites SY02 and SY03 were located on the northeast inlet of the lake with SY03 above SY02. In the lake, just offshore, sites SY05 and SY06 were established. Site SY07 was located on the outlet from Sylvan Lake. Figure 14 shows these sampling and sites.

After September 1979, sampling was discontinued until October, 1981, immediately prior to restoration activities. At this time new sampling sites were established in addition to the 1979 sites (Figure 14). Site SY04 was relocated on the southeast tributary 162 meters upstream from a wood bridge accessing the new camp ground (longitude 103' 33'21" W; latitude 43' to 5' 28" T2S, R5E, Sec. 30). Site SY05 was located on an intermittent tributary downstream of a culvert in the eastern part of the East Parking Lot. (longitude 103' 33' 22"; latitude 43' 50' 47" T2S, R5E, Sec. 30).

In 1981 and throughout the rest of the study, the in-lake sites were designated SY10 and SY11. The samples were collected at depth intervals. Parameters monitored from the lake included ammonia as nitrogen, nitrate as nitrogen, total Kjeldahl nitrogen as nitrogen, total phosphorus, dissolved orthophosphate, total solids, total dissolved solids, suspended solids, chlorophyll a, algal identification and enumeration, algal cell volume, algal

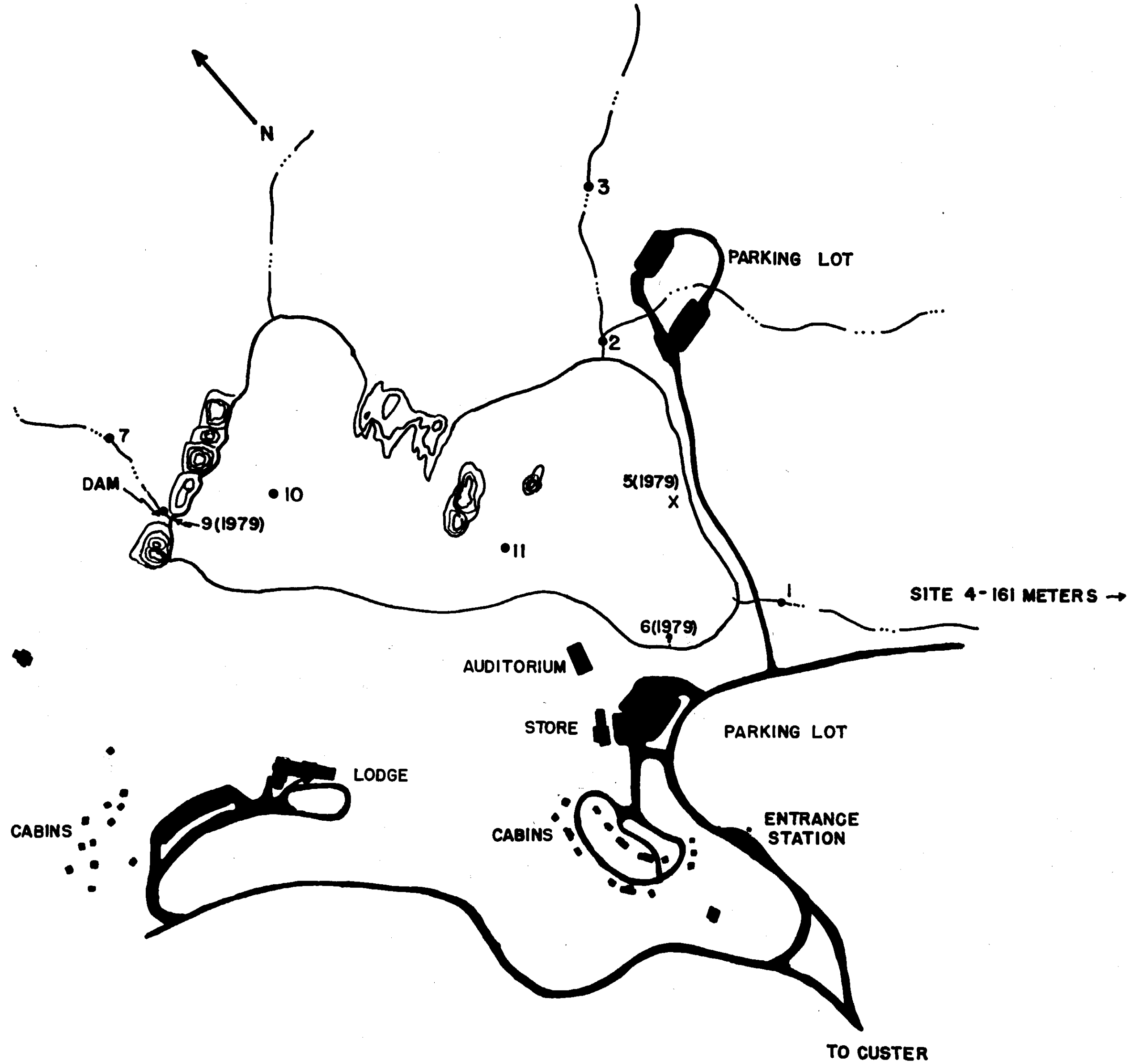


FIGURE 14. SCHEMATIC OF SYLVAN LAKE AND CERTAIN SAMPLING SITES

biomass, Secchi transparency, air and water temperature, pH and dissolved oxygen. Except for the biological samples and Secchi transparency these same parameters were monitored in the inflows and outflows.

All samples were collected following the procedures described in the field sampling manual prepared by SDDWNR's quality assurance coordinator (Lutter, 1981). Chemical anaylses were conducted by Travis Laboratory, Rapid City; and the methods used are described in standard Methods for Chemical Analysis of Water and Wastes (EPA, 1979). Biological samples for algal enumeration and identification were preserved in Lugol's solution and were processed by Aquanalysis, Inc., Sioux Falls, South Dakota. Membrane filtration was used to concentrate the samples. The volume biomass procedure used was that described by Wetzel and Likens (1979), and chlorophyll a analyses were done with the trichromatic method (Strickland and Parson, 1972). The water chemistry data are available through EPA's STORET system or SDDWNR and the biological data are available from SDDWNR.

The primary emphasis of this water quality section is on the parameters observed in the lake during and after restoration work. Where appropriate, the water quality observed in 1981 through 1984 was statistically compared to the water quality observed in 1979. However, all comparisons were between surface water samples, as samples were not collected throughout the water column in 1979.

Water quality comparisons within and between tributaries were limited because samples were not collected during comparable intervals and because storm events were not monitored. The reasons why only limited sampling occurred were; inadequate funding for chemical analysis and manpower limitations.

TEMPERATURE

Figures 15 and 16 are depth-time diagrams of temperature isotherms observed in Sylvan Lake at sites SY10 and SY11. The lake is dimictic with spring turnover occurring when ice cover thaws about mid-April. The fall overturn occurred in October. Stratification occurred in the summer and in the winter, inverse stratification occurred with the colder waters overlying the warmer waters. These trends were more obvious in the deeper in-lake site (SY10) than in the shallow in-lake site (SY11). When the lake was being drawn down for sediment removal all trends were disrupted.

Before and after lake rehabilitation work, lake temperatures periodically exceeded the State's water quality standard of 18.3^{o}C (65^{o}F). As far as it can be determined these high temperatures were the result of natural ambient environmental factors rather than non-related influences.

TOTAL PHOSPHORUS

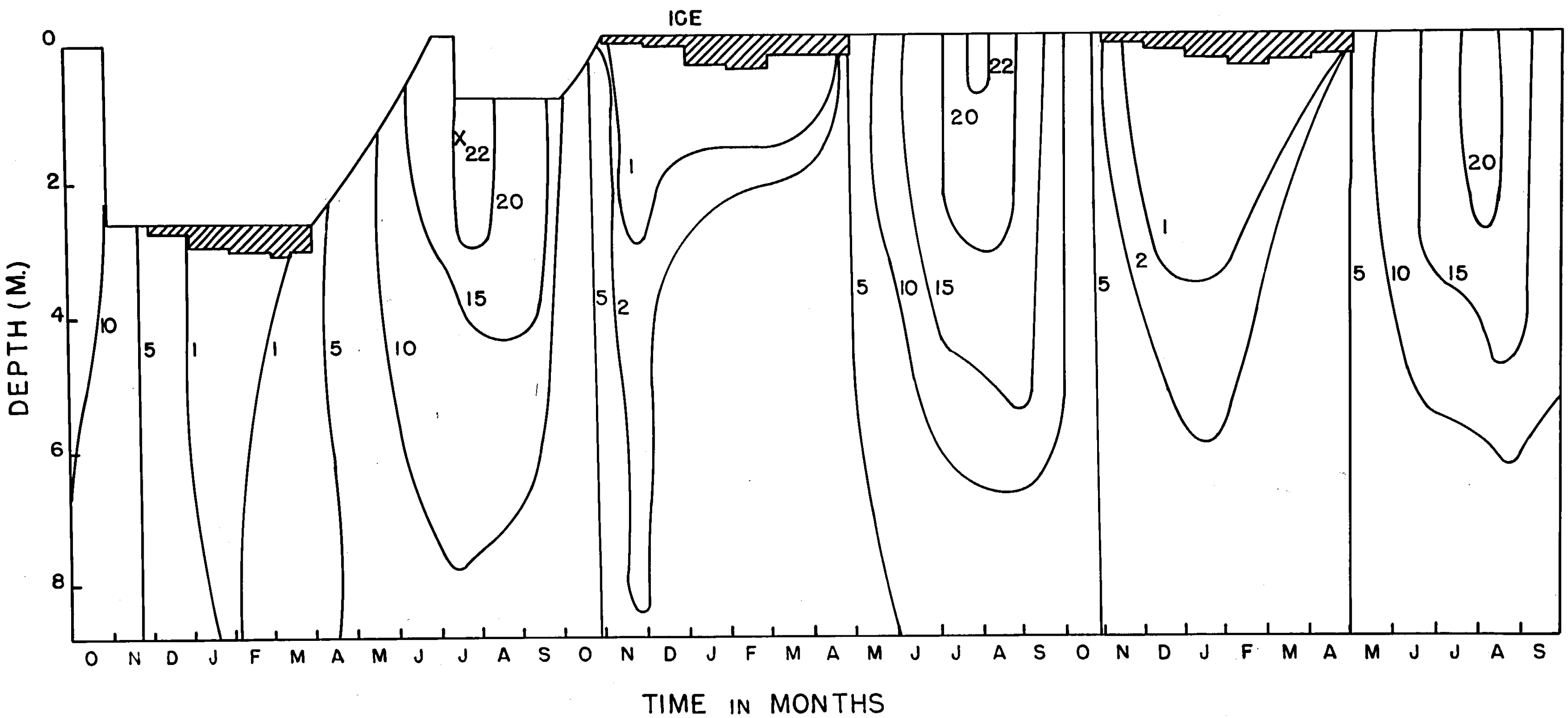


FIGURE 15. DEPTH-TIME DISTRIBUTION OF ISOPLETHS OF TEMPERATURE (C°) AT SITE SY10 IN SYLVAN LAKE, 1981, 1982, 1983 AND 1984.

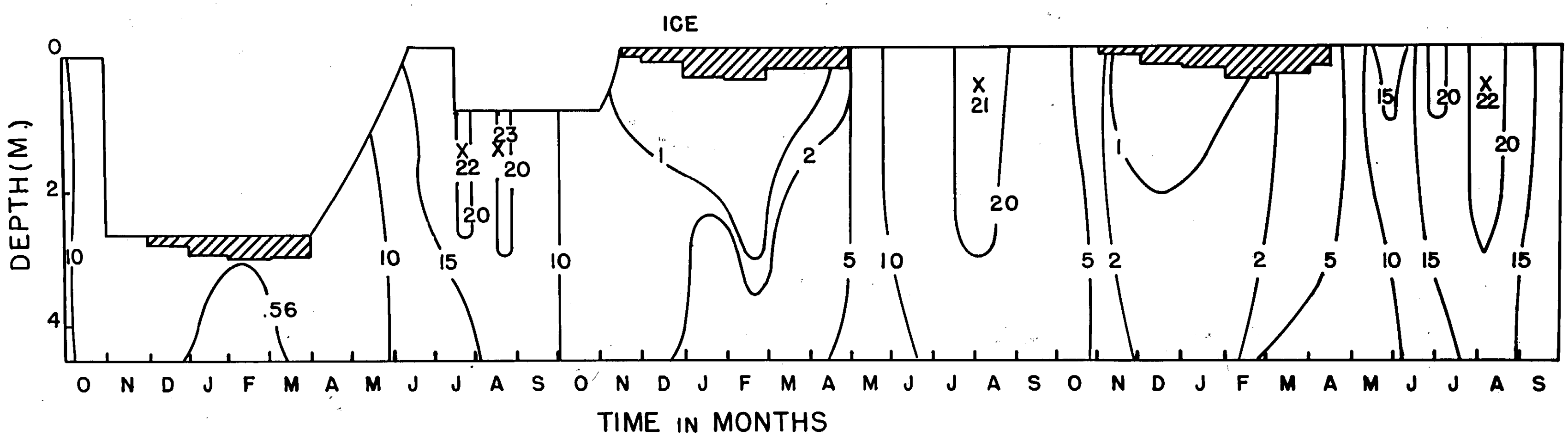


FIGURE 16. DEPTH-TIME DISTRIBUTION OF ISOPLETHS OF TEMPERATURE (C°) AT SITE SITE SYII IN SYLVAN LAKE, 1981, 1982, 1983 AND 1984.

The total phosphorus concentrations observed in Sylvan Lake during 1979 ranged from .034 mg/l to .090 mg/l. The mean concentration at site SY05 was .047 mg/l and at site SY06 it was .051 mg/l. These mean concentrations were based upon samples collected between May and September.

In order to determine whether the lake project had a positive or negative effect on the in-lake phosphorus concentrations by the removal of sediments, the means and standard deviations for surface data between May and September were calculated for 1979, 1982 and 1983. All in-lake surface water data were pooled by year. After the means and standard deviations were calculated, the hypothesis of equal variances between years was tested. Depending upon whether the variances were equal or unequal, the appropriate test was conducted. At an alpha level of .05, the results revealed that the mean in-lake surface water phosphorus concentration was significantly greater in 1982, than in 1979 or 1983. A probable explanation for higher concentrations in 1982 is the release of nutrients as the sediments were disturbed because of construction activities. Based on the statistics, phosphorus concentrations were not ultimately affected by the rehabilitation project.

Figures 17 and 18 demonstrate the reason for the lack of a decrease in phosphorus concentrations in Sylvan Lake with the removal of sediment. During summer and winter stratification periods low dissolved oxygen concentrations occurred in the

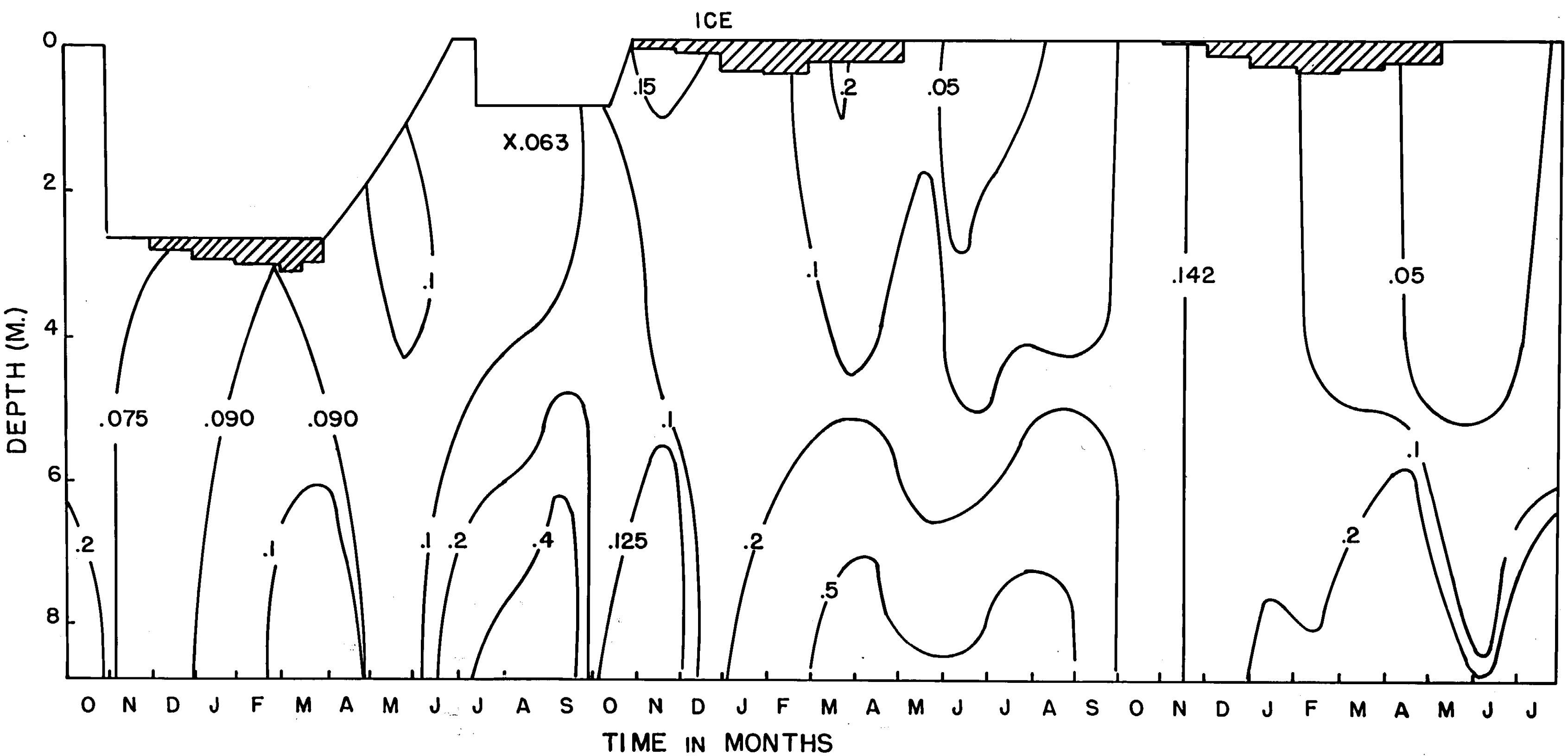


FIGURE 17. DEPTH-TIME DISTRIBUTION OF ISOPLETHS OF TOTAL PHOSPHORUS(MG/L) AT SITE SY10 IN SYLVAN LAKE, 1981, 1982, 1983 AND 1984.

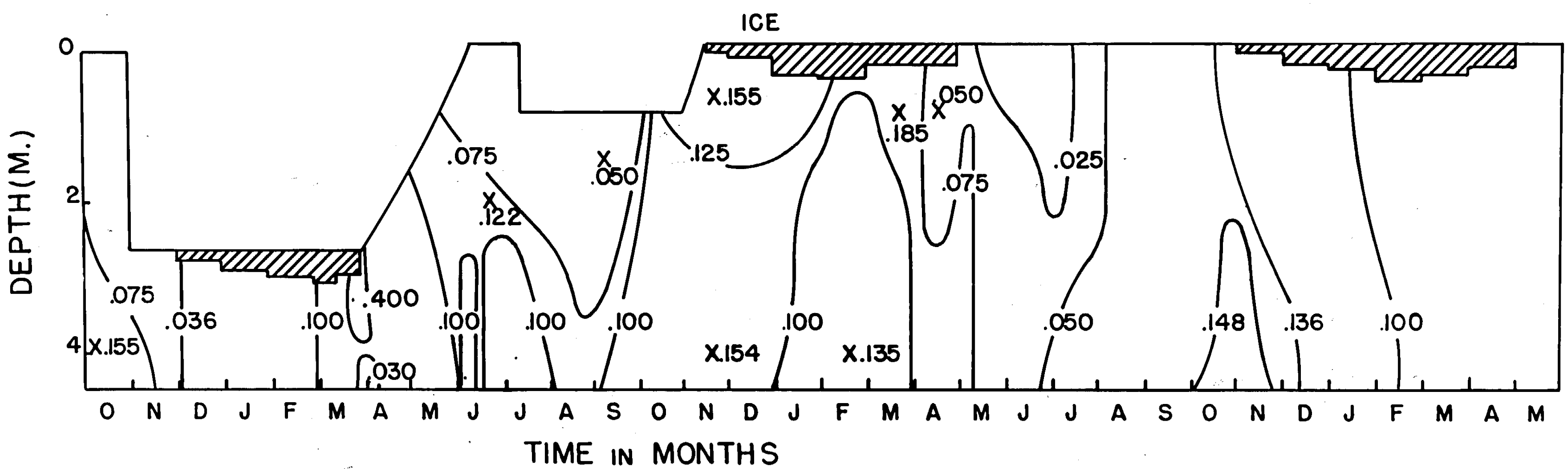


FIGURE 18. DEPTH-TIME DISTRIBUTION OF ISOPLETHS OF TOTAL PHOSPHORUS(MG/L) AT SITE SYII IN SYLVAN LAKE, 1981, 1982, 1983 AND 1984.

deeper waters (See the discussion on dissolved oxygen) with an accompanying increase in phosphorus. These high phosphorus concentrations in the upper lake levels during spring and fall overturn were apparently due to recirculation. Therefore, the phosphorus concentrations before and after the project are approximately the same. Aeration to maintain oxygen levels in the hypolimnion may be a method to reduce total phosphorus concentration in the lake.

The mean total phosphorus concentrations at sites SY05 and SY06 (.047 mg/l and .051 mg/l) indicate Sylvan Lake is eutrophic (Reckhow et al., 1980). When sediment was being removed the trophic status degenerated, becoming hypereutrophic. Once the sediment removal operations ceased, the trophic status returned to eutrophic. These comments on trophic status are based only on surface water data.

Mean total phosphorus concentrations in the tributaries ranged from .077 to .563 mg/l. Because the number of data points per year ranged from two to ten and because storm events that occurred at night or on weekends, were not sampled, conclusions from the data were limited. Of the data available, the total phosphorus concentrations indicated euthrophic to hypereutrophic conditions in the streams. How these values relate to lake loadings is not known because flow data was not collected.

The mean total phosphorus concentration in the outlet ranged from .025 to .107 mg/l. Again, these waters would be considered to range from eutrophic to hypereutrophic.

ORTHOPHOSPHATE (DISSOLVED)

Figure 19 and 20 are depth-time isopleths of dissolved orthophosphate concentrations observed in Sylvan Lake. As was observed with total phosphorus, dissolved orthophosphate accumulated at the lower depth during the winter and summer, becoming available to the upper levels during overturn events.

Statistical comparisons of means calculated from surface water data between May and September showed that the mean concentration observed in 1982 was significantly greater ($P<.05$) than in 1979. Also, the 1983 mean concentration was significantly greater ($P<.05$) than in 1979. The indication is that orthophosphate concentrations increased after the project.

Because sediments were being removed from the lake, it was not unrealistic to expect increases in total phosphorus and orthophosphate during the actual work phase of the project. However, the overall increase in dissolved orthophosphate was unexpected.

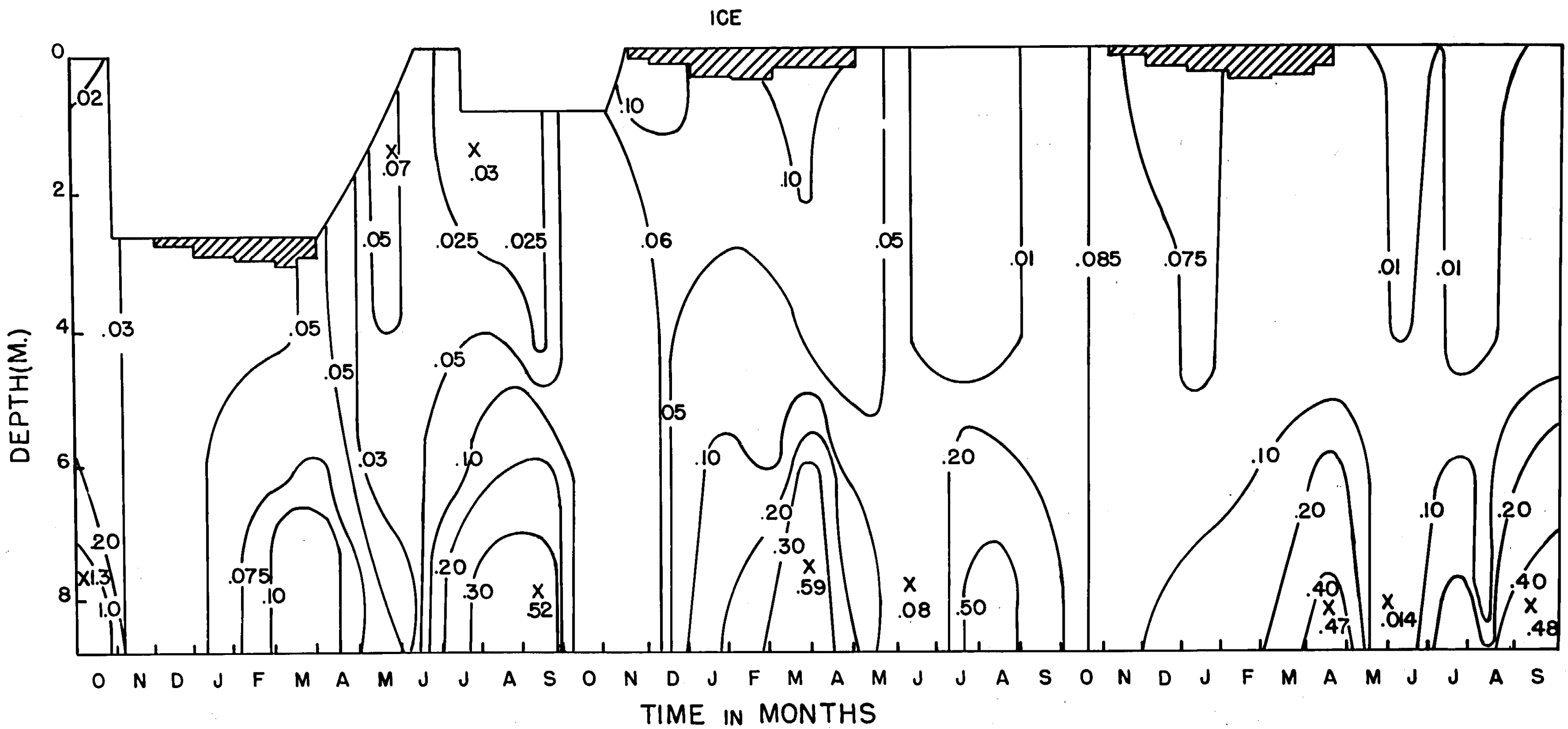


FIGURE 19. DEPTH-TIME DISTRIBUTION OF ISOPLETHS OF DISSOLVED ORTHOPHOSPHATE (MG/L) AT SITE SY10 IN SYLVAN LAKE, 1981, 1982, 1983 AND 1984

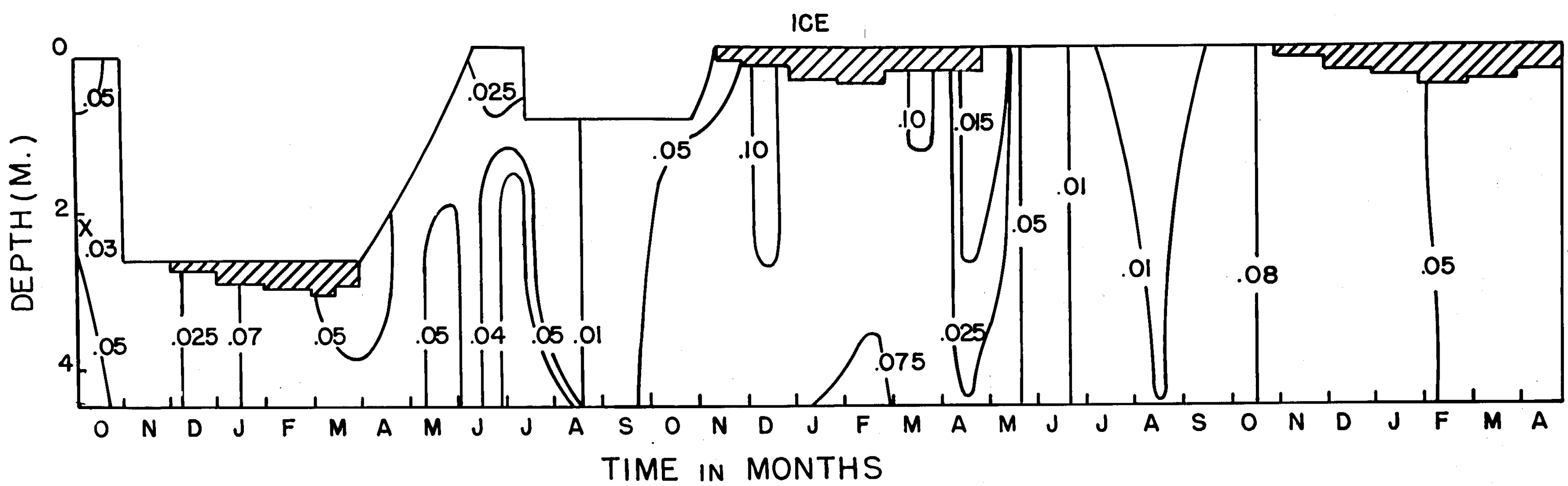


FIGURE 20. DEPTH-TIME DISTRIBUTION OF DISSOLVED ORTHOPHOSPHATE (MG/L) AT SITE SY11 IN SYLVAN LAKE, 1981, 1982, 1983 AND 1984.

DISSOLVED OXYGEN

The depth-time isopleths for dissolved oxygen are presented in Figures 21 and 22. Figure 21, station SY10, illustrates dissolved oxygen levels of 0.0 mg/l at the bottom in June, 1982. As the summer progressed, this anoxic water increased in volume. In the fall, coinciding with turnover, the anoxic layer broke down and the water column became oxygenated (i.e. 7 mg/l). During the winter of 1983 the dissolved oxygen concentration was low throughout much of the water column (i.e. 3 mg/l), and between 7 meters and the bottom, the dissolved oxygen concentrations were zero. These anoxic conditions persisted into the summer although a partial turnover occurred in May, 1983. The extension of anoxic conditions from the winter into the summer possibly explains the greater levels of dissolved orthophosphate observed in 1983.

Although dissolved oxygen concentrations at the shallow site (SY11) never reached 0.0 mg/l, a low value of 0.4 mg/l was observed in June, 1982 while rehabilitation activities were occurring (Figure 22). In general, low dissolved oxygen concentrations were observed at the lower depths during the summer and the winter months of 1982 and 1983. By 1984 the overall dissolved oxygen concentrations increased. It is believed that the lower dissolved oxygen concentrations in 1982 and 1983 were related to wastewater activities occurring in the lake and in the watershed.

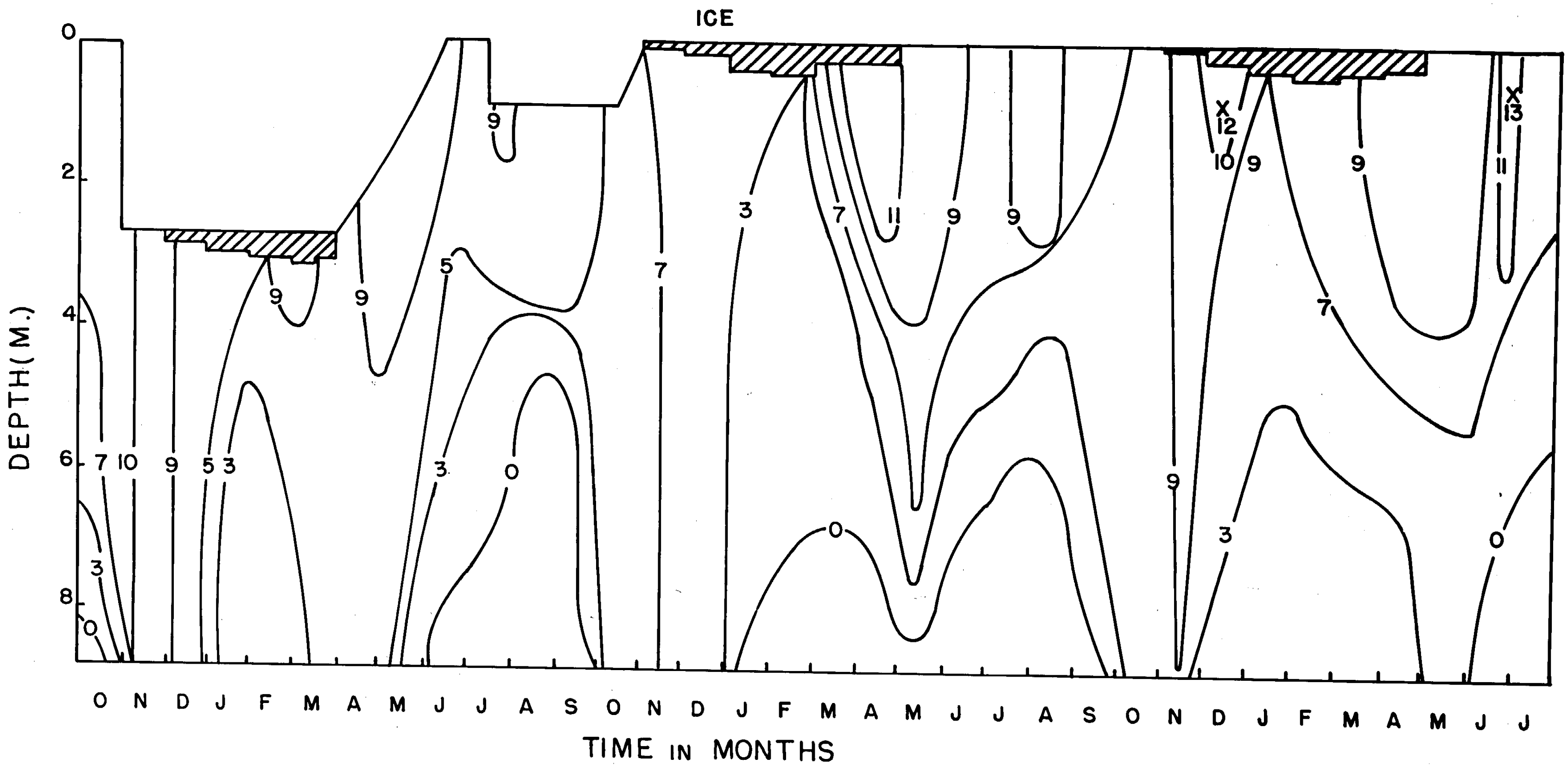


FIGURE 21. DEPTH-TIME DISTRIBUTION OF ISOPLETHS OF DISSOLVED OXYGEN (MG/L) AT SITE SY10 IN SYLVAN LAKE 1981, 1982, 1983 AND 1984.

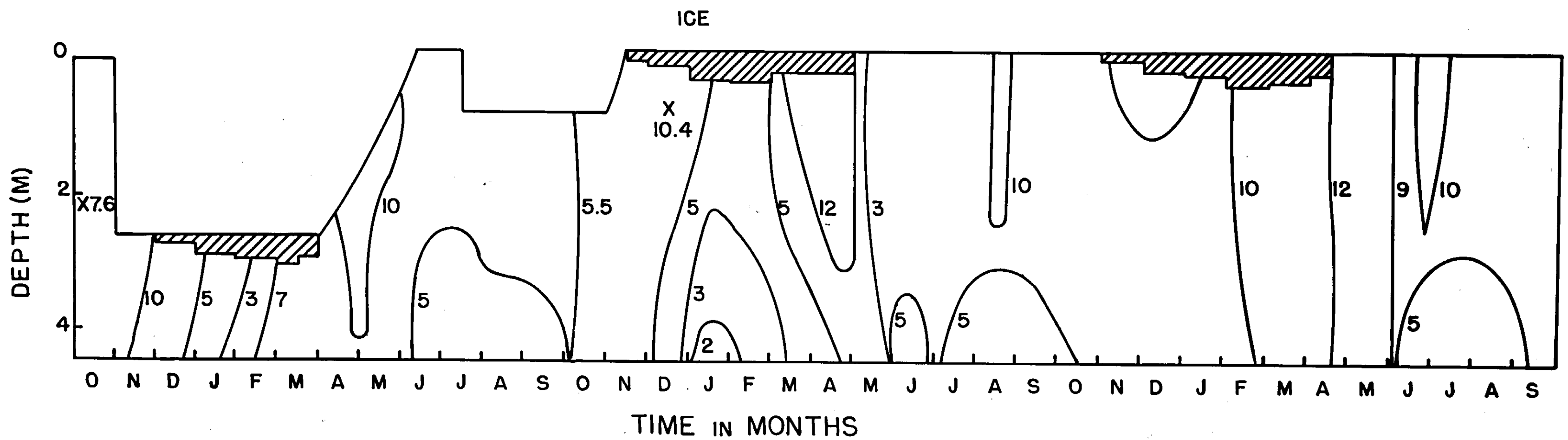


FIGURE 22. DEPTH - TIME DISTRIBUTION OF ISOPLETHS OF DISSOLVED OXYGEN (MG/L) AT SITE SY11 IN SYLVAN LAKE, 1981, 1982, 1983 AND 1984.

At the tributary sites SY01 through SY04 mean concentrations of dissolved oxygen ranged from 7.6 to 9.3 mg/l and the observed values ranged from 5.5 to 8.6 mg/l. In the outlet, 61 meters downstream from the dam, values ranged from 3.5 to 7.6 mg/l with a mean concentration of 6.2 mg/l in 1979 (only one sample was collected in 1982.) Mean dissolved oxygen concentrations were 7.2 and 8.6 mg/l in 1983 and 1984, but these means were based on only two data points.

pH

Figures 23 and 24 are time depth isopleths for pH in Sylvan Lake. Over a record period of 1982 to 1984 at site SY10, pH values ranged from 6.4 to 10.1 and at site SY11 from 6.6 to 10.1. Generally, acidic pH values occurred in the lower depths except in the winter when values less than 7.0 were observed from top to bottom. The explanation for lower pH values in the summer is probably heterotrophic degradation of organic matter, microbial methane fermentation, nitrification of ammonia, and sulfide oxidation, generating CO_2 and reducing pH (Wetzel, 1983). These processes typically occur in eutrophic waters. The higher pH values observed in the upper waters reflect photosynthetic utilization of CO2 concentrations and increasing pH.

The pH values in the tributaries ranged from 6.1 to 7.6. These low pH values are best explained by the watershed's characteristics. The terrain is characterized by Precambrian

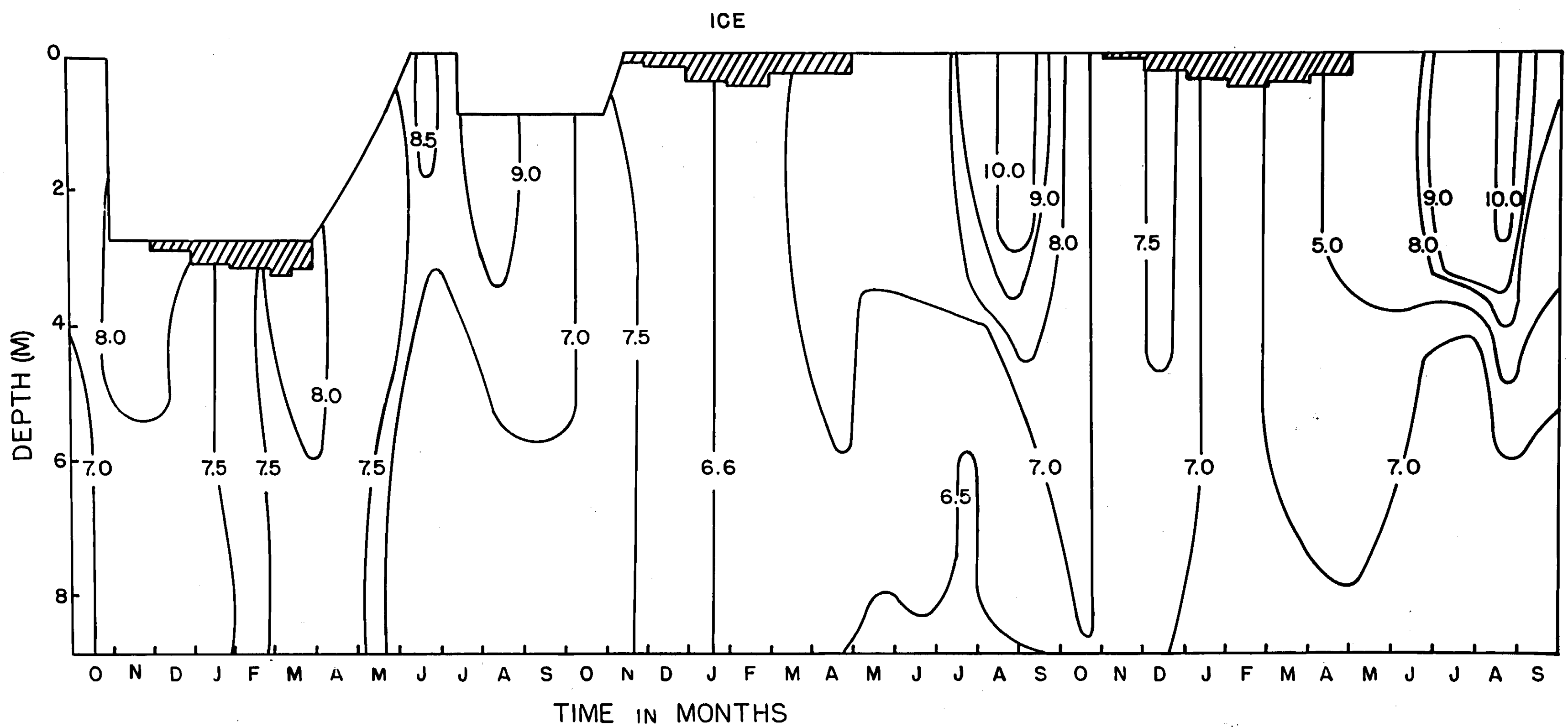


FIGURE 23. DEPTH-TIME DISTRIBUTION OF ISOPLETHS OF pH AT SITE SY10 IN SYLVAN LAKE, 1981, 1982, 1983 AND 1984.

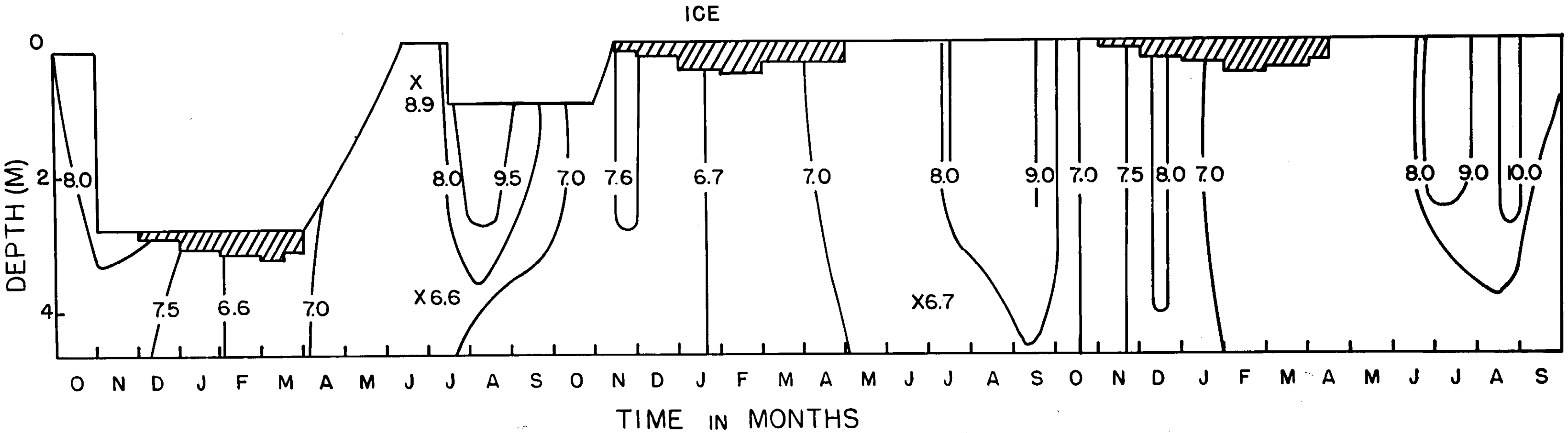


FIGURE 24. DEPTH-TIME DISTRIBUTION OF ISOPLETHS OF pH AT SITE SYII IN SYLVAN LAKE, 1981, 1982, 1983 AND 1984.

granite formations with pine trees being the most abundant plants. A combination of decomposition of pine needles and poorly buffered soils probably resulted in pH values less than 7.0.

In the outlet, pH values reflected lake conditions with pH values ranging from 6.9 to 9.1. The mean pH values ranged from 7.4 to 8.7.

ALKALINITY

In 1979, alkalinity values ranged from 21 to 25 mg $CaCO_3$/l. Between October 1981 and January 1982, alkalinity values ranged between 36 and 72 mg $CaCO_3$/l. These data indicate that Sylvan Lake is a poorly buffered lake.

Tributary alkalinities tended to be lower than in-lake alkalinities. At the four inflow sites mean alkalinity concentrations ranged from 13.3 to 21.0 mg $CaCO_3$/l in 1979. The outflow site had higher alkalinities, with a mean concentration of 32.4 mg $CaCO_3$/l and a range of 22 to 40 mg $CaCO_3$/l.

SUSPENDED SOLIDS

Suspended solids in the surface waters of Sylvan Lake ranged from less than 1 mg/l to 38 mg/l with mean concentrations of 7.6 and 6.7 mg/l in 1979. During rehabilitation activities suspended solids ranged from 1 to 26 mg/l with mean concentrations ranging from 8.1 to 9.3 mg/l.

After rehabilitation activities ceased, mean suspended solids ranged from 4.9 to 6.9 mg/l, and the observed values ranged from less than 1 to 20 mg/l. Generally, suspended solids tended to be slightly higher in 1981 and 1982 during rehabilitation than before or after (Figures 25 and 26).

Before this project started, mean suspended solid concentrations ranged from 24 to 70 mg/l at sites SY01 and SY02 with observed values ranging from 21 to 550 mg/l. The sites upstream, SY03 and SY04, had mean concentrations ranging from 9.4 to 10.8 mg/l with observed values from <1.0 to 37 mg/l. These upstream sites were not impacted by human activity to the same degree as those sites closer to the lake. The outlet site, prior to construction had a mean concentration of 5.8 mg/L with values ranging from less than 1.0 to 22 mg/l.

During and after rehabilitation, mean concentrations at sites SY01 and SY02 ranged from 13 to 242 mg/l and the 242 mg/l mean occurred in 1983 when rehabilitation activities were apparently completed. A high value of 635 mg/l suspended solids was observed in 1983 but no explanation about this can be given. As in 1979, less suspended solids were observed upstream (mean concentrations of 5.8 mg/l and 4.2 mg/l). It is assumed that

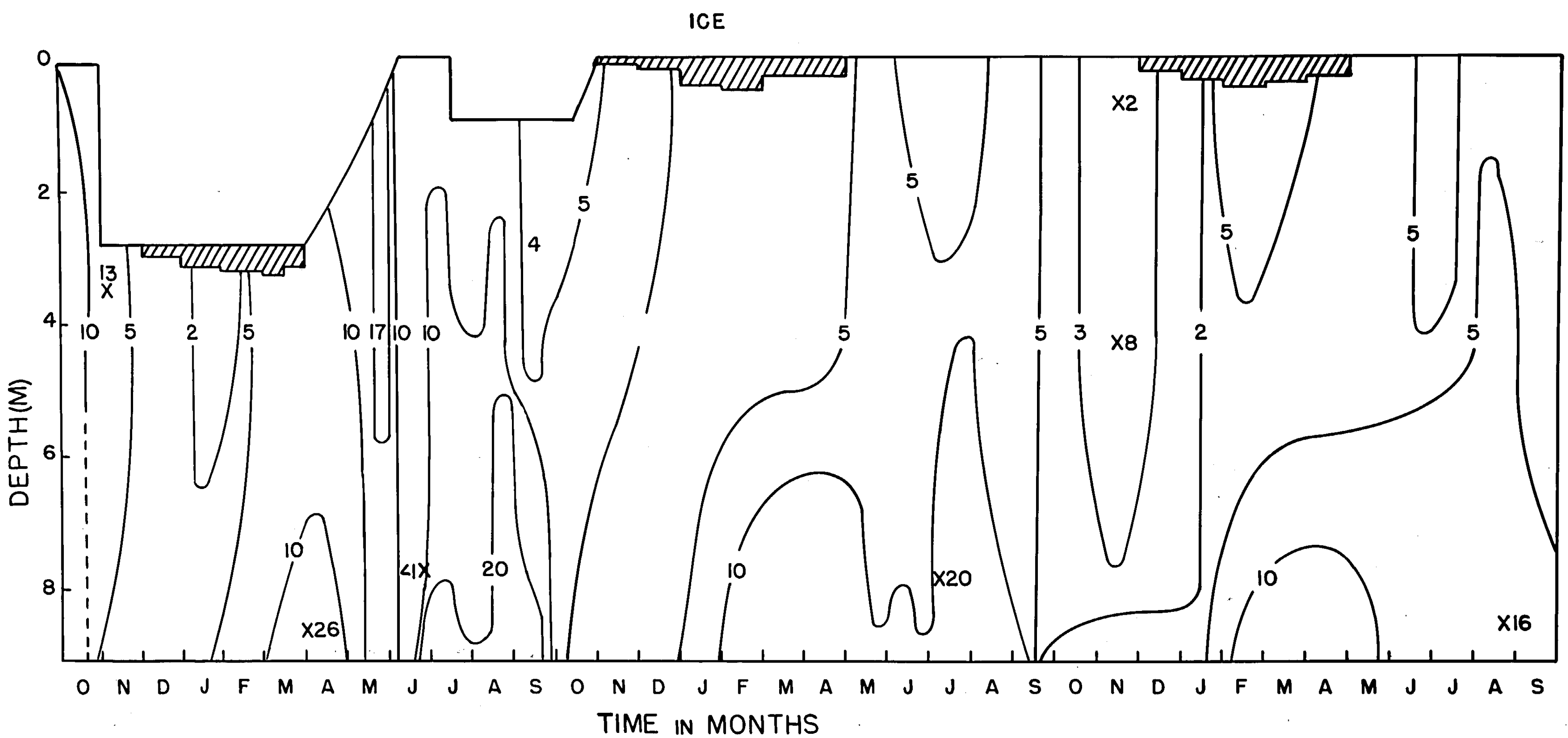


FIGURE 25. DEPTH-TIME DISTRIBUTION OF ISOPLETHS OF SUSPENDED SOLIDS (MG/L) AT SITE SY10 IN SYLVAN LAKE, 1981, 1982, 1983 AND 1984.

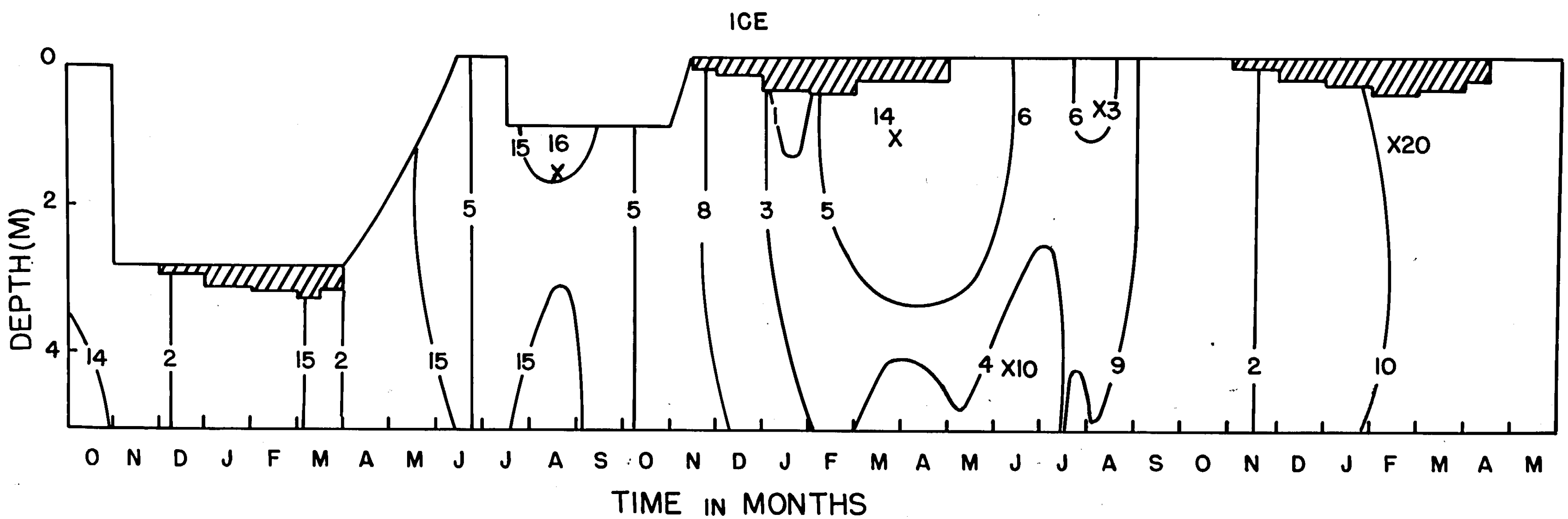


FIGURE 26. DEPTH-TIME DISTRIBUTION OF ISOPLETHS OF SUSPENDED SOLIDS(MG/L) AT SITE SYII IN SYLVAN LAKE 1981, 1982, 1983 AND 1984.

human activities are responsible for the high mean concentration observed close to the lake.

The outlet site, SY09, was determined to have suspended solid concentrations about the same as in 1979. Mean concentrations of 8.5 mg/l and 4.5 mg/l were calculated for 1983 and 1984 respectively.

TOTAL DISSOLVED SOLIDS

The total dissolved solids concentrations observed in the surface waters of Sylvan Lake between May and September 1979, 1982, 1983 and 1984 were statistically compared to determine if they increased over the projects life. No significant differences were detected.

During the course of the project and the year after the project was completed, total dissolved solids in the lake ranged from 3 to 120 mg/l with mean concentrations ranging from 51 to 62 mg/l. In the tributaries, the mean concentrations ranged from 41 to 79 mg/l in 1979 and from 44 to 79 mg/l during and after the project. There were no apparent differences in total dissolved solids before and after the project. Outlet sites had annual mean concentrations ranging from 37.5 to 63 mg/l and the test readings ranged from 23 to 81 mg/l.

AMMONIA

The ammonia as nitrogen data are plotted in Figures 27 and 28. It was expected that the removal of sediments in Sylvan Lake would uncover partially decomposed material that had been lost to the deeper sediments and that watershed construction activities would increase allochthonous inputs to the lake during runoff events, resulting in increases in organic matter available for decomposition. Statistical analyses supported this expectation as ammonia concentrations were greater during the project than before or after ($P<.05$).

However, further analyses using the data from surface waters at the deep site (SY10) showed that ammonia concentrations in 1984 were significantly greater ($P<.05$) than in 1979. (Note: Samples were not collected for the shallow site in 1984). The mean for 1984 was not significantly different from the means calculated in 1982 or 1983. In Figure 27, an ammonia concentration of .105 mg/l occurred between two "less than .03 mg/l" isopleths. The reason for this increase is unknown.

The deep site, SY10, accumulated ammonia under ice cover in the winter and in the summer during stratification. The same trend, to a lesser extent, was noted in the shallow site. This is not an uncommon occurrence in lakes where appreciable amounts of organic matter reach the sediments. When the hypolimnion becomes anoxic, ammonia accumulates because bacterial nitrification

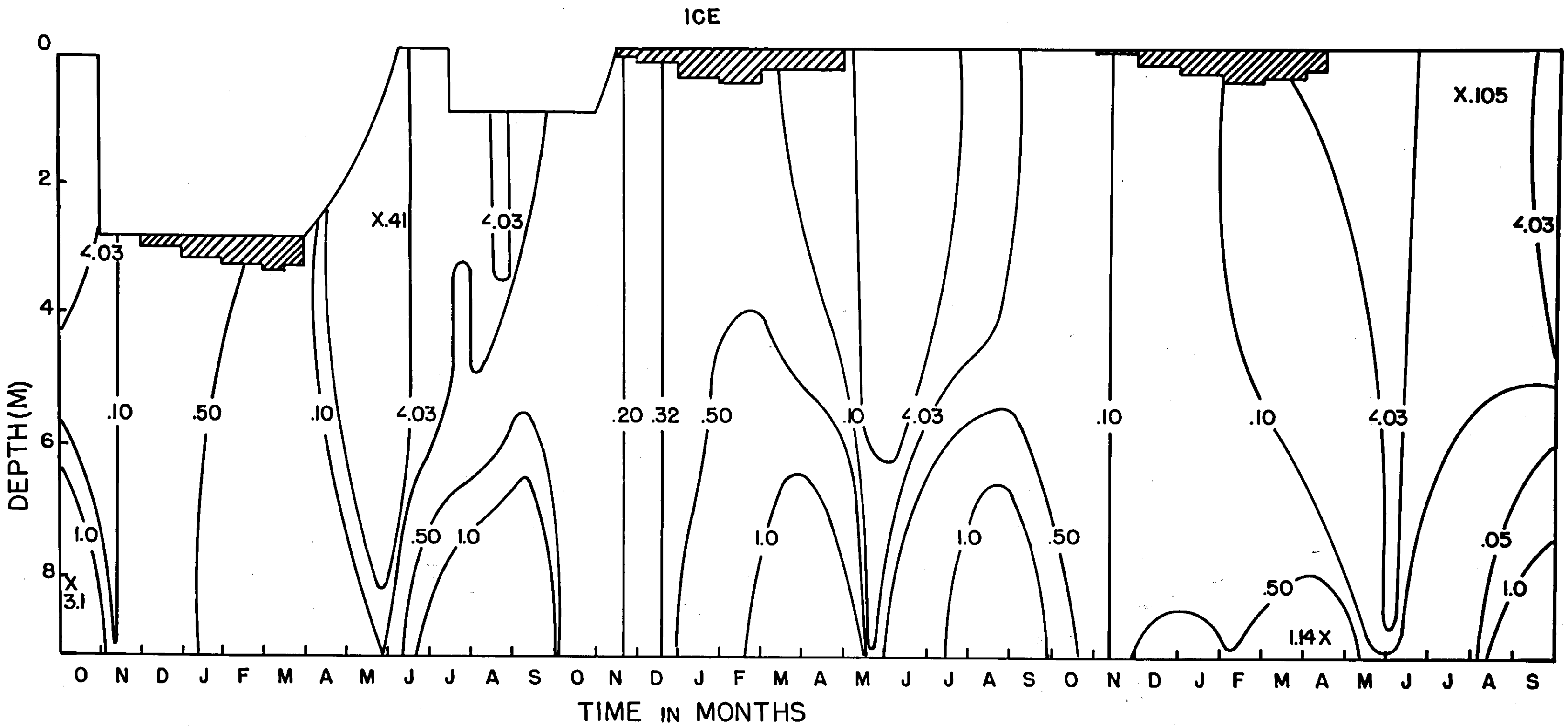


FIGURE 27. DEPTH-TIME DISTRIBUTION OF ISOPLETHS OF AMMONIA AS NITROGEN(MG/L) AT SITE SY10 IN SYLVAN LAKE, 1981, 1982, 1983 AND 1984.

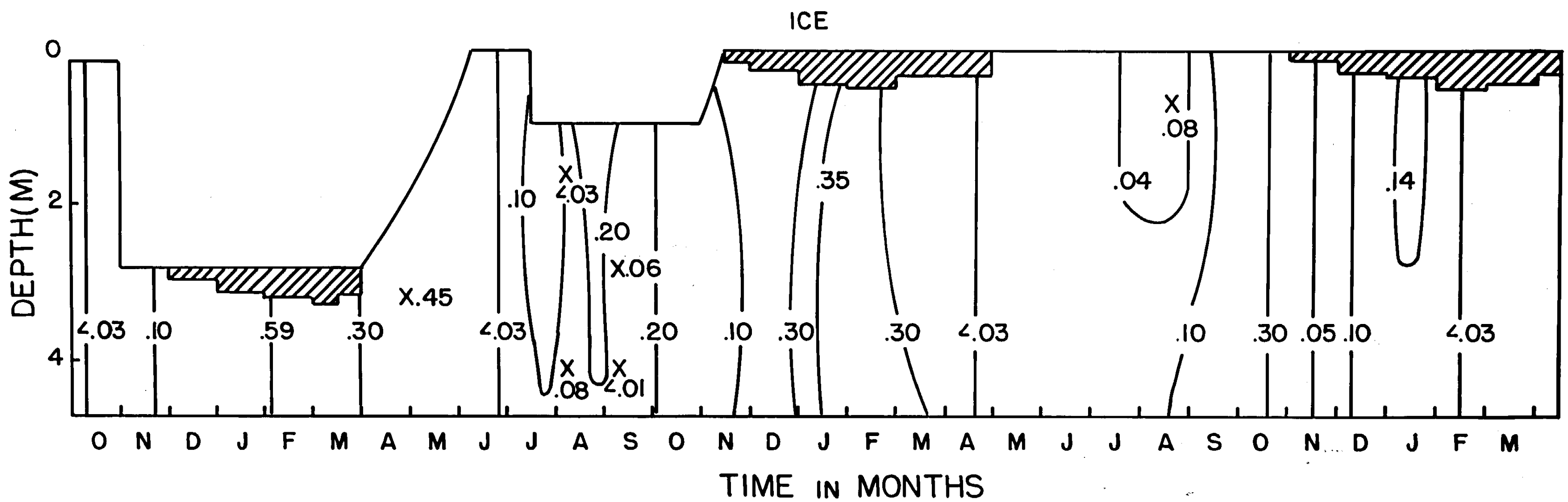


FIGURE 28. DEPTH-TIME DISTRIBUTION OF ISOPLETHS OF AMMONIA AS NITROGEN(MG/L) AT SITE SYII IN SYLVAN LAKE, 1981, 1982, 1983 AND 1984.

ceases and the absorptive capacity of the sediments is reduced (Wetzel, 1983).

In the tributaries ammonia ranged from .02 to .59 mg/l with the highest value observed in 1979 before rehabilitation. The values in the outlet ranged from .03 to .330 mg/l with the highest value occurring in 1979.

NITRATE

Figures 29 and 30 are time-depth isopleths of nitrate as nitrogen data. Statistical comparisons between means were conducted and no significant differences between years were determined even though the mean observed in 1982 was greater than the other calculated means. Although no significant differences were observed, it is of interest to compare the time-depth isopleths for nitrate, ammonia and dissolved oxygen at Site SY10. During the anoxic periods, ammonia levels increased and nitrate levels decreased supporting the concept that nitrification reactions could not be completed under anoxic conditions. These differences were not observed in the shallow site where dissolved oxygen values remained greater than 0.0 mg/l.

During the project sampling period, mean nitrate concentrations ranged from .100 mg/l to .157 mg/l and the observed values ranged from less than .10 to .630 mg/l. The highest values occurred during the rehabilitation phase. (Figures 29 and 30).

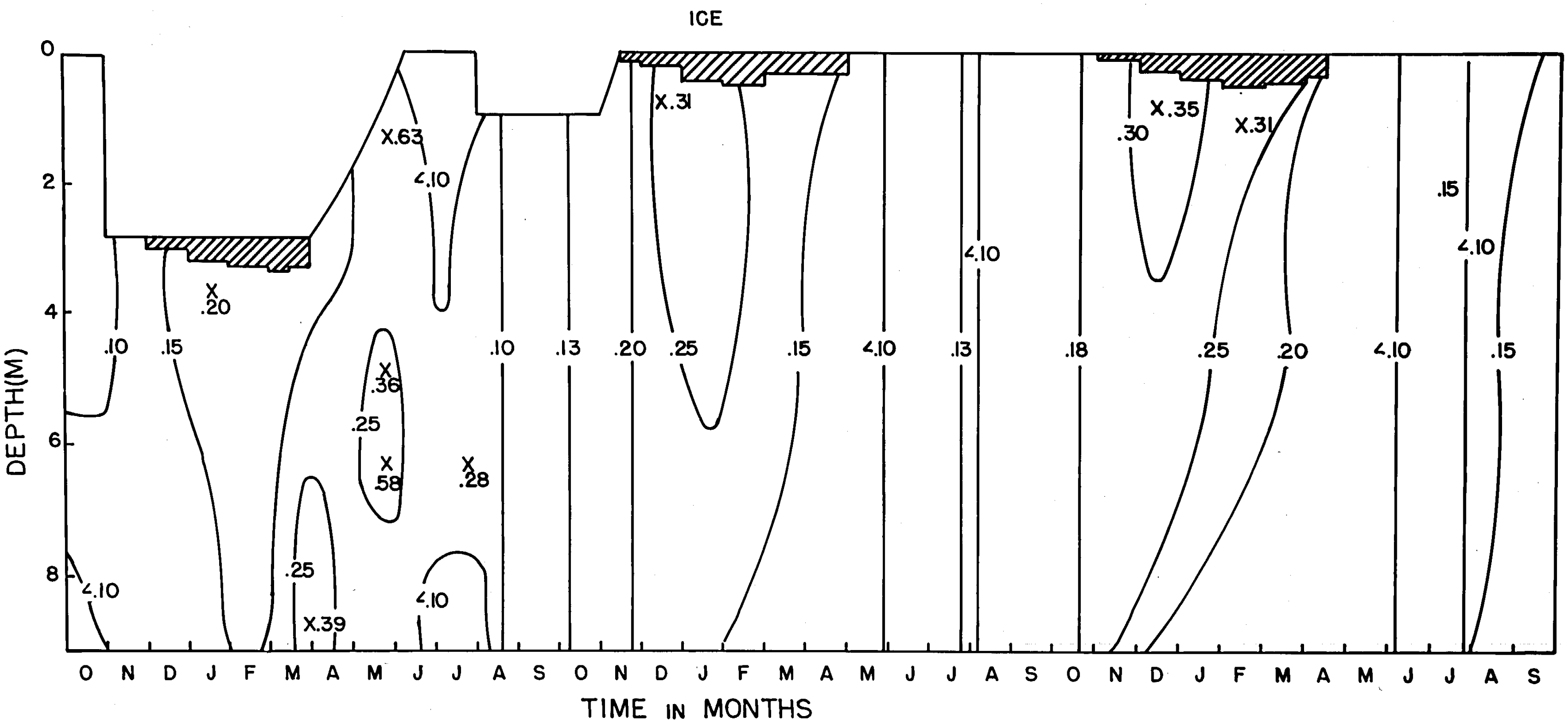


FIGURE 29. DEPTH-TIME DISTRIBUTION OF ISOPLETHS OF NITRATE AS NITROGEN(MG/L) AT SITE SY10 IN SYLVAN LAKE, 1981, 1982, 1983 AND 1984.

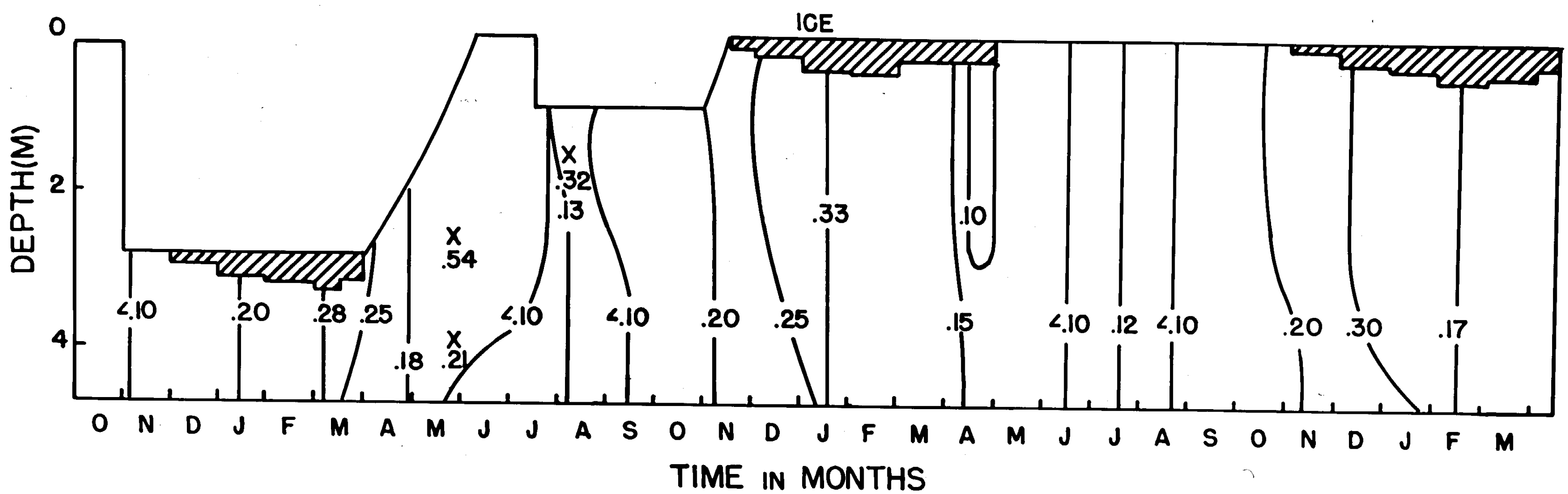


FIGURE 30. DEPTH-TIME DISTRIBUTION OF ISOPLETHS OF NITRATE AS NITROGEN (MG/L) AT SITE SY11 IN SYLVAN LAKE, 1981, 1982, 1983 AND 1984.

Nitrate concentrations in the tributaries ranged from less than .1 to .200 mg/l and in the outlet they ranged from less than .1 to .180 mg/l. In 1982, 1983, and 1984, nitrate concentrations ranged from less than .10 to .490 mg/l in the tributaries and from .100 to .680 mg/l in the outlet. Although there was an indication of increased nitrates in the inflowing and outflowing waters it is difficult to make statistical inferences because of the paucity of data and the lack of coordinated sampling efforts between similar seasons.

NITRITE

Mean nitrite concentrations in Sylvan Lake ranged from .01 to .015 mg/l and the observed values ranged from less than .01 to .085 mg/l. The majority of the observed values were less than .01 mg/l, the detection limits used during the project.

The majority of the values observed from the inflows and outflows were less than .01 mg/l. Mean concentrations ranged from less than .01 to .014 mg/l. Nitrites were apparently not impacted by this project.

ORGANIC AND INORGANIC NITROGEN

Figures 31 and 32 are depth-time isopleths of the organic nitrogen concentrations observed during and after the project.

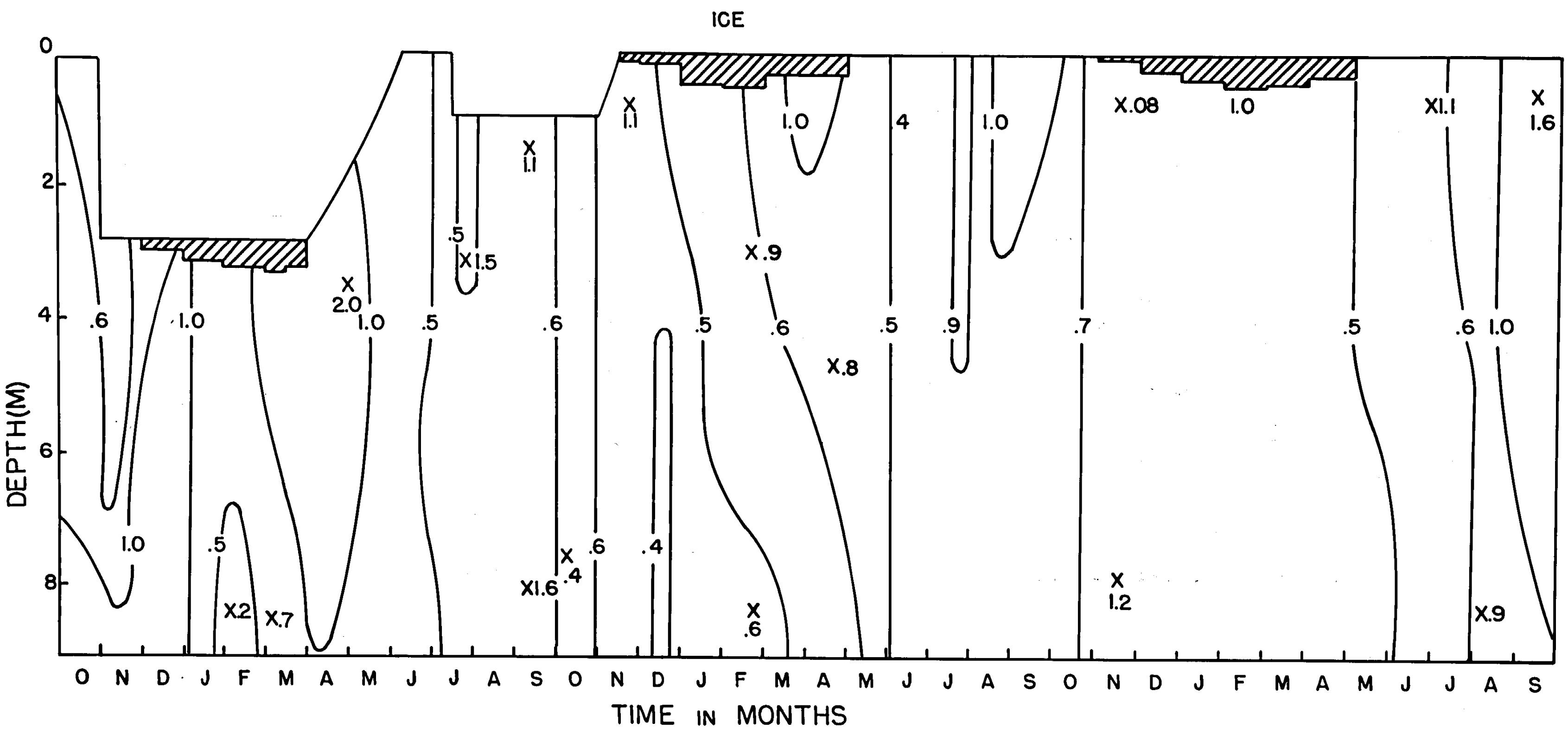


FIGURE 31. DEPTH-TIME DISTRIBUTION OF ISOPLETHS OF ORGANIC NITROGEN(MG/L) AT SITE SYIO IN SYLVAN LAKE, 1981, 1982, 1983 AND 1984.

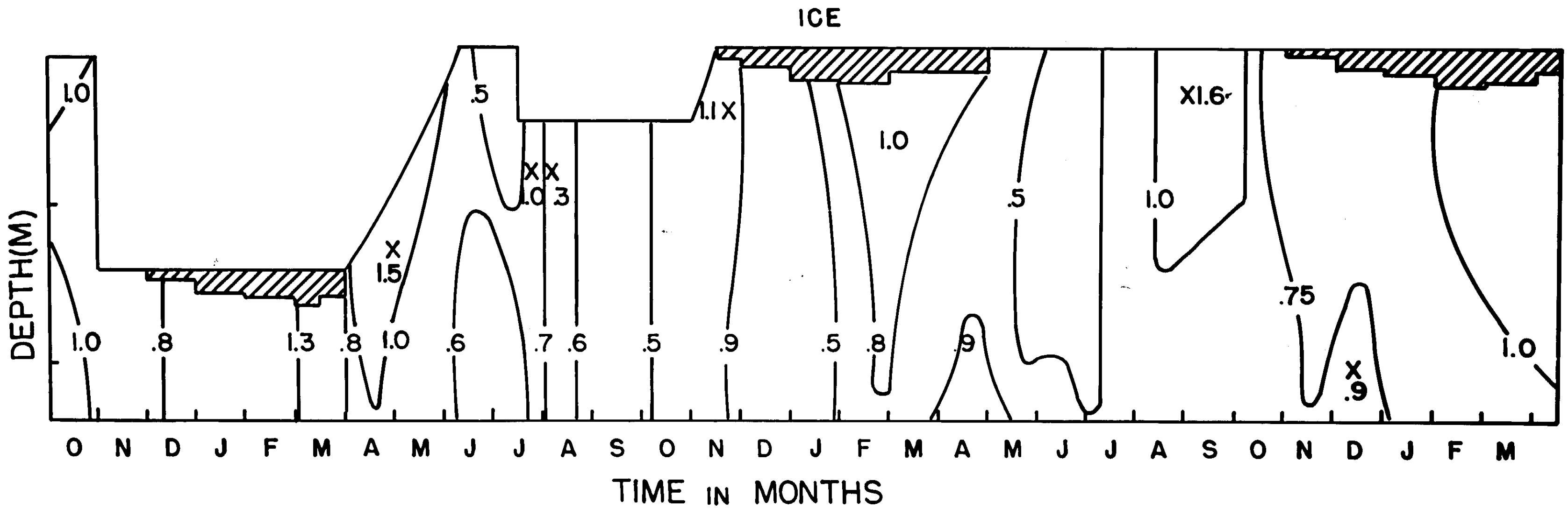


FIGURE 32. DEPTH-TIME DISTRIBUTION OF ISOPLETHS OF ORGANIC NITROGEN (MG/L) AT SITE SYII IN SYLVAN LAKE, 1981, 1982, 1983 AND 1984.

Test statistics did not reveal significant differences between years.

Means and standard deviations were calculated for both organic and inorganic nitrogen to assess the trophic status of the lake (Table 7). Only the means and standard deviations for 1982 and 1983 represent annual values. The surface water samples collected in 1979 for inorganic nitrogen indicate ultra-oligotrophic conditions while those collected in 1981 through 1984 indicated oligo-mesotrophic conditions (see Wetzel, 1983; Table 12-4). Mean organic nitrogen concentrations in 1979 indicated a trophic status of meso-eutrophic and the mean concentrations in 1981 through 1984 indicated eutrophic conditions.

MINOR CONSTITUENTS

A number of water quality parameters were monitored at sites SY10 and SY11 on November 11 and December 7, 1981 throughout the water column when the lake was being drawn down. It is assumed that these parameters reflect lake conditions and not impacts associated with the project.

Hardness

The mean concentration of hardness was 32.5 mg $CaCO_3$/l and observed values ranged from 32 to 34 mg $CaCO_3$/l.

TABLE 7. MEAN INORGANIC AND ORGANIC NITROGEN CONCENTRATIONS OBSERVED IN SYLVAN LAKE, 1979, 1981, 1982, 1983 AND 1984

A. Mean Inorganic Nitrogen Concentrations (mg/L)

	1979	1981	1982	1983	1984
# of observations	18	16	111	98	39
Mean	.077	.233	.436	.370	.350
Standard Deviation	.0195	.2969	.3691	.3957	.3447

B. Mean Organic Nitrogen Concentrations (mg/L)

	1979	1981	1982	1983	1984
# of observations	18	16	111	97	39
Mean	.60	.896	.725	.719	.731
Standard Deviation	.2700	.2616	.3035	.2995	.3375

Calcium

The calcium concentrations ranged from 9.0 to 10 mg/l and the mean concentration was 9.55 mg/l. Based on those data Sylvan Lake would be considered to be borderline calcium deficient (Wetzel, 1983).

Magnesium

The concentration of magnesium ranged from 1.8 to 2.0 mg/l with a mean concentration of 1.9 mg/l.

Sodium

The mean sodium concentration was 3.4 mg/l and ranged from 3.0 to 4.0 mg/l. Wetzel (1983) reported that that a threshold level of 4 mg/l of sodium is needed for near optimal growth of several blue-green algae species.

Potassium

Potassium concentrations ranged from .80 to 2 mg/l. The mean concentration was 1.4 mg/l.

Chloride

The mean concentration of chloride was 3.25 mg/l and ranged from 3.0 to 4.0 mg/l. In natural fresh waters, Wetzel (1983) reported the average concentration to be 8.3 mg/l.

Sulfate

The mean sulfate concentration was 4.4 mg/l and ranged from 3.0 to 7.0 mg/l on the two sampling dates. Wetzel (1983) reports the usual range is from 5 to 30 mg/l with an average of 11 mg/l in natural lakes.

Manganese

The average concentration of manganese was about .035 mg/l based on a world average distribution and ranges from .010 to .850 mg/l (Wetzel, 1983). In Sylvan Lake, the average concentration was .546 mg/l and ranged from .16 to .66 mg/l.

Iron

In typical neutral alkaline lakes total iron ranges from .050 to .200 mg/l (Wetzel, 1983). The mean concentration in Sylvan Lake was .973 mg/l and the range was .65 to 1.3 mg/l.

SECCHI DISC

Figures 33 and 34 illustrate the Secchi disc depths observed in Sylvan Lake. Between November and December, 1981 the mean Secchi disc transparency was 1.2 m and the range was 1.1 to 1.4 m. The annual mean Secchi disc transparency values for the two lake sites in 1982 and 1983 ranged from .8 to 1.4 m and the observed values ranged from .3 to 2.1 m. In 1984 the mean values ranged from 1.3 to 1.5 m and the observed values ranged from 0.4 to 2.1 m.

TROPHIC STATE INDICES

Trophic State Indices (TSI's) were calculated for surface water total phosphorus concentrations, chlorophyll a concentrations and Secchi disc measurements (Carlson, 1977). Table 8 summarizes the calculations. Only the means reported for 1982 and 1983 represent annual values. The 1979 values were based on data collected between May and September, the 1981 values on data collected between October and December, and the 1984 values on data collected between January and September. Besides calculating means and standard deviations, 95% confidence intervals were calculated to see if significant differences occurred between the different parameters and between years for each parameter.

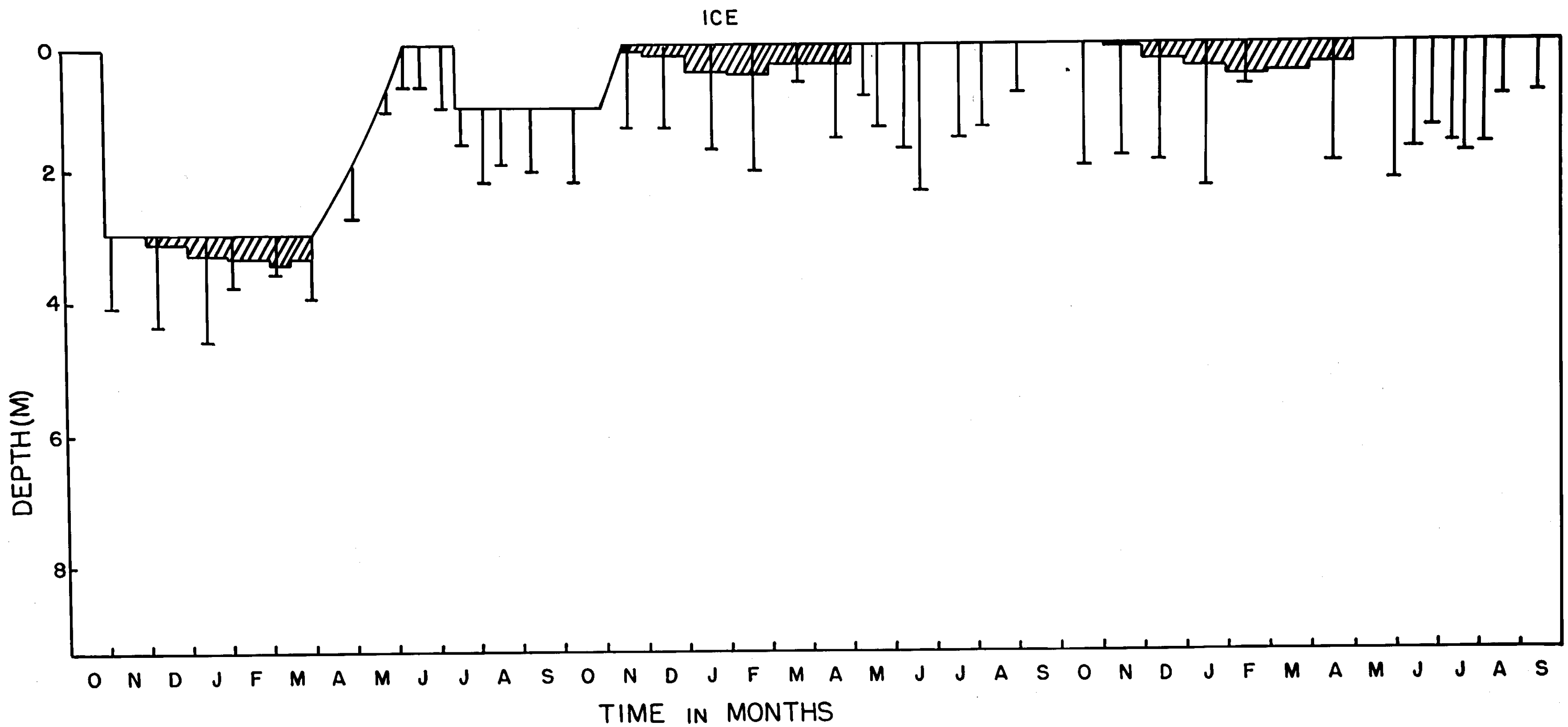


FIGURE 33. SECCHI DISC TRANSPARENCY MEASUREMENTS(M) OBSERVED AT SITE SY10 IN SYLVAN LAKE, 1981, 1982, 1983 AND 1984.

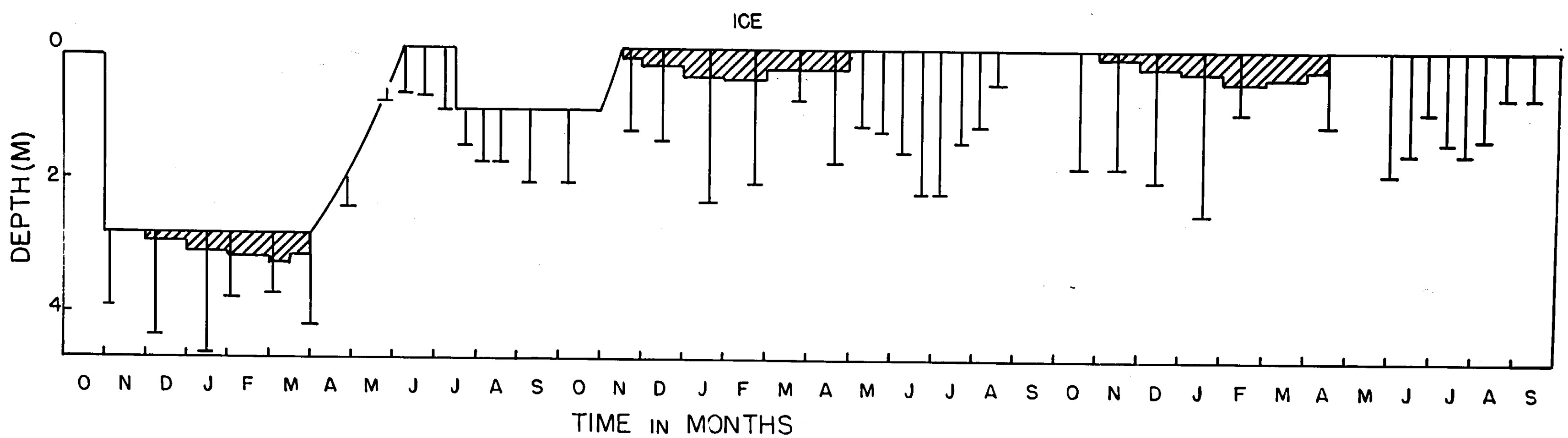


FIGURE 34. SECCHI DISC TRANSPARENCY MEASUREMENTS (M) OBSERVED AT SITE SYII IN SYLVAN LAKE, 1981, 1982, 1983 AND 1984.

TABLE 8. SUMMARY STATISTICS FOR TROPHIC STATE INDICES CALCULATED FOR TOTAL PHOSPHORUS, CONCENTRATIONS, CHLOROPHYLL a CONCENTRATIONS AND SECCHI DISC MEASUREMENTS*

	Total Phosphorus	Secchi disc	Chlorophyll a
1979			
x	59.8	---	---
s.d.	3.3475	---	---
n	18	---	---
R	55-68	---	---
1981			
x	63.2	57.3	---
s.d.	4.9565	2.0616	---
n	6	4	---
R	56-68	55-59	---
1982			
x	69.2	63.3	58.3
s.d.	5.7536	5.8729	9.4327
n	32	32	30
R	61-90	53-77	41-72
1983			
x	64.2	55.9	49.9
s.d.	10.3252	5.8793	11.7686
n	32	29	32
R	46-81	49-71	25-71
1984			
x	63.8	57.5	36.8
s.d.	7.4067	7.8168	14.3000
n	13	13	14
R	51-74	49-73	22-59

(*x=mean, s.d.=standard deviation, n=number of observations, r=range)

The TSI's for chlorophyll a were significantly lower (P<.05) than the TSI's for phosphorus in all years. This trend was also true for Secchi disc TSI's in 1982 and 1983. There were no significant differences between chlorophyll a TSI's and Secchi disc TSI's. These results suggest that the phosphorus was not being completely used by the phytoplankton.

CHLOROPHYLL a

Table 9 summarizes statistics calculated for chlorophyll a concentrations observed in the lake. Based on the mean annual chlorophyll a concentrations for 1982 and 1983, Sylvan Lake would be classified as eutrophic. (Wetzel, 1983). However, the mean concentration of chlorophyll a samples collected between January and September 1984 at site SY10 suggest mesotrophic conditions.

Another method was used to look at the chlorophyll a concentrations since the above statistics assume normal distributions. Median concentrations and box plots (Figure 35) were used as a method to see if significant differences occurred between years. The use of the median is considered to be a more robust statistic with water quality data (Reckhow and Chapra, 1983). The median chlorophyll a values observed in 1983 and 1984 were significantly less than that observed in 1982 (Figure 35). This observation was not true when mean values were used. Only the 1984 mean was significantly less (P<.05) than the 1982 mean.

TABLE 9. MEAN CHLOROPHYLL a CONCENTRATIONS (mg/m3) IN SYLVAN LAKE, 1982, 1983 AND 1984

	SY10 (2 feet)	SY10 (8 feet)	SY11 (2 feet)	SY11 (4 feet)
1982				
x	20.93	19.10	26.94	23.69
s.d.	13.51	18.33	15.57	22.67
n	15	15	15	15
R	1.42-45.98	0-68.65	1.23-68.74	1.32-89.45
1983				
x	13.65		14.75	
s.d.	17.16		19.37	
n	16		16	
R	1.24-64.60		4.13-60.68	
1984				
x	5.29		.85	
s.d.	6.1230		.4066	
n	12		2	
R	<0.80-17.41		1.13-1.14	

*x=mean, s.d.=Standard Deviation, N=Number of observations, R=Range.

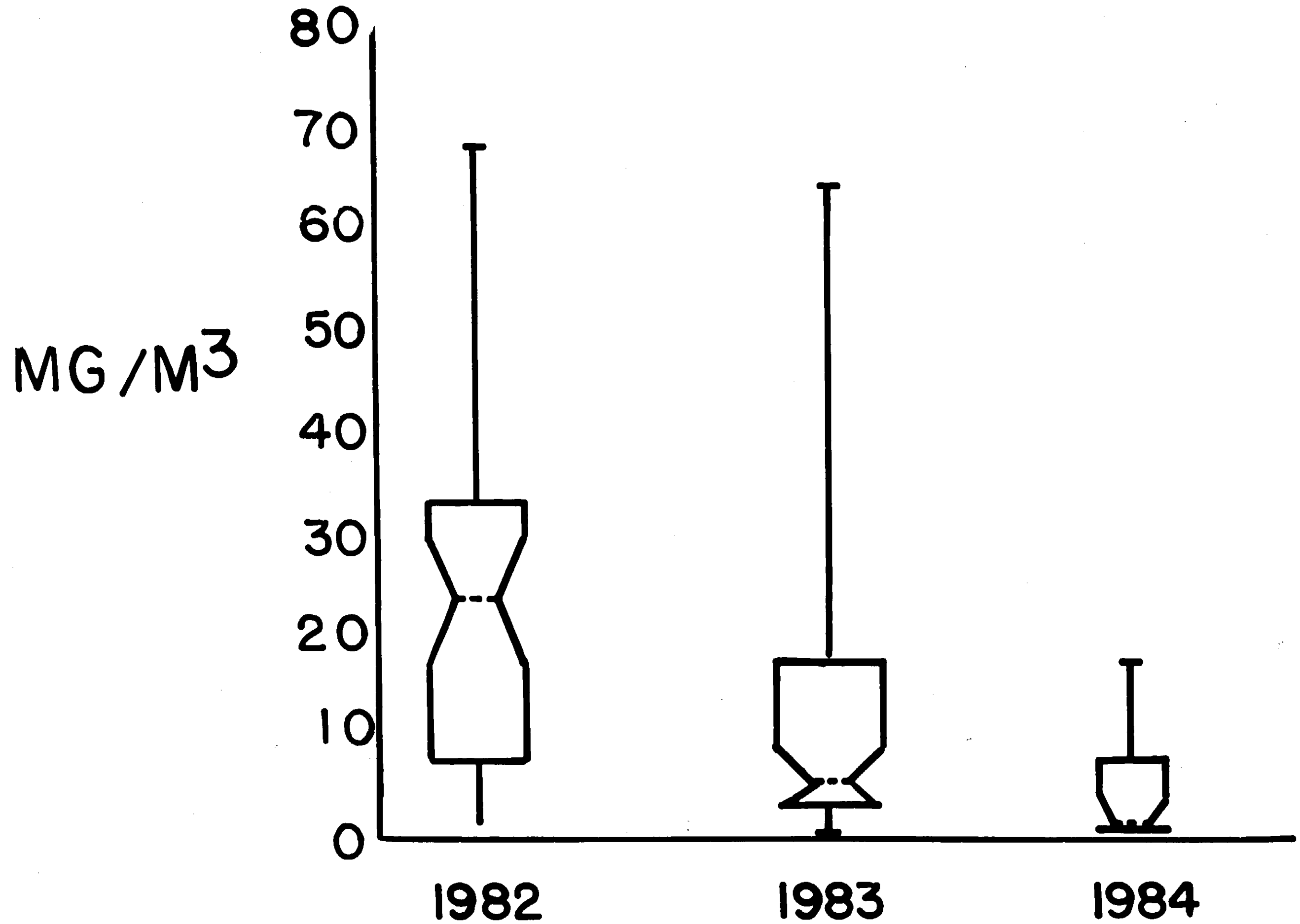


FIGURE 35. BOX PLOTS OF CHLOROPHYLL A CONCENTRATIONS (MG/M^3) OBSERVED IN SYLVAN LAKE, 1982, 1983 AND 1984.

The median values suggest that phytoplankton production was decreasing after rehabilitation activities ceased.

Figure 36 (average surface water chlorophyll a values observed at sites SY10 and SY11) supports the change in chlorophyll a values based upon the medians. Generally, chlorophyll a values were relatively high throughout 1982 compared with 1983 and 1984 values.

LIMITING NUTRIENT

Two methodologies were used to determine whether phosphorus or nitrogen was the limiting nutrient in Sylvan Lake. The first method was to calculate the inorganic nitrogen to dissolved orthophosphate ratio and to use a ratio of 7:1 as the division line between nitrogen limitation and phosphorus limitation. A ratio less than 7:1 indicates nitrogen limitation and a ratio greater than 7:1 indicates phosphorus limitation (Rast and Lee, 1978). The second method used the ratio of total nitrogen to total phosphorus and the division between phosphorus or nitrogen limitation was the ratio 15:1 (EPA, 1980). A value less than 15:1 indicates nitrogen limitation and a value greater than 15:1 indicates phosphorus limitation.

Figure 37 illustrates the results of calculating the inorganic nitrogen to dissolved orthophosphate ratio. Figure 38 shows the results of the total nitrogen to total phosphorus ratio

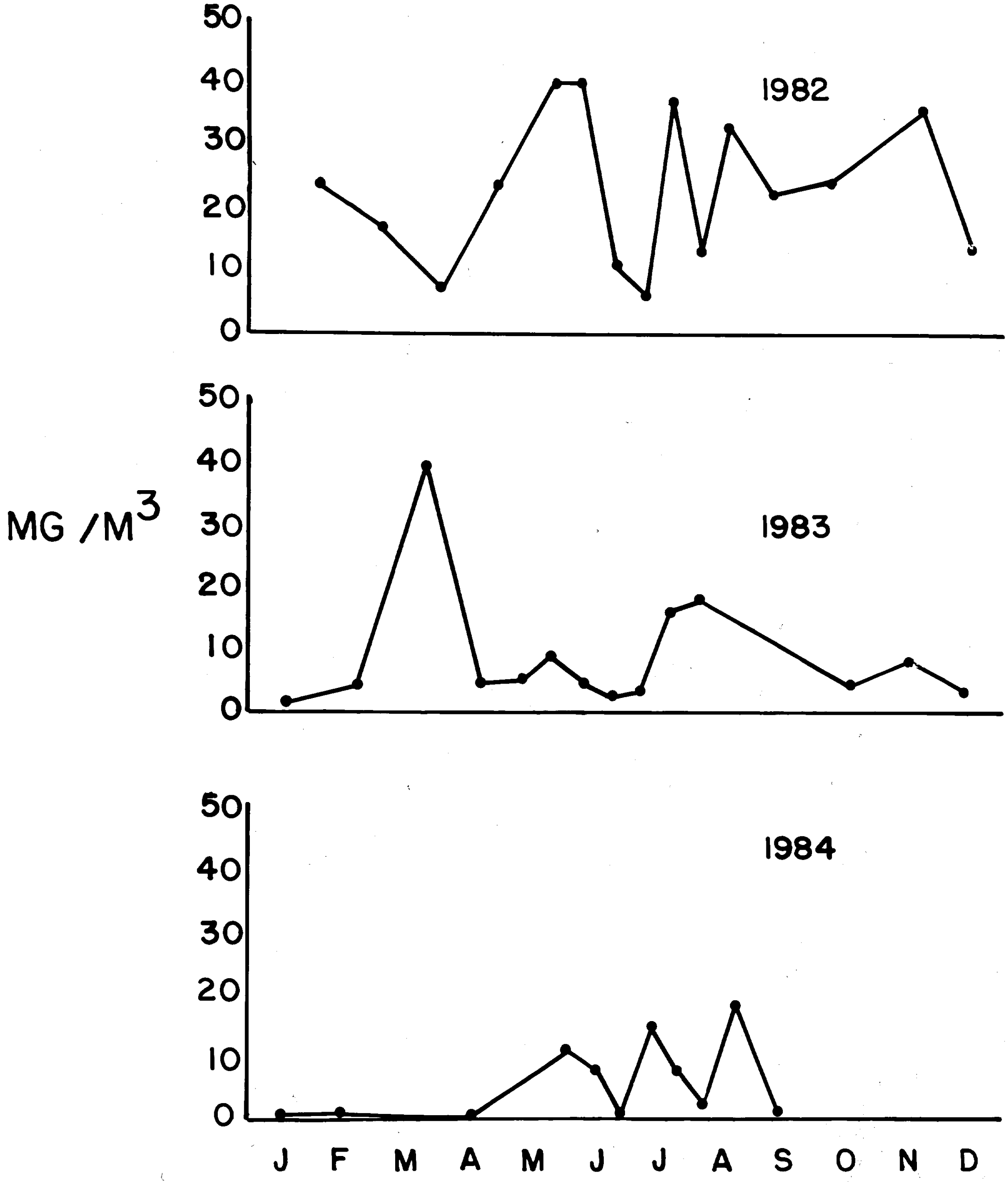


FIGURE 36. CHLOROPHYLL A VALUES (MG/M^3) OBSERVED IN SYLVAN LAKE, 1982, 1983 AND 1984.

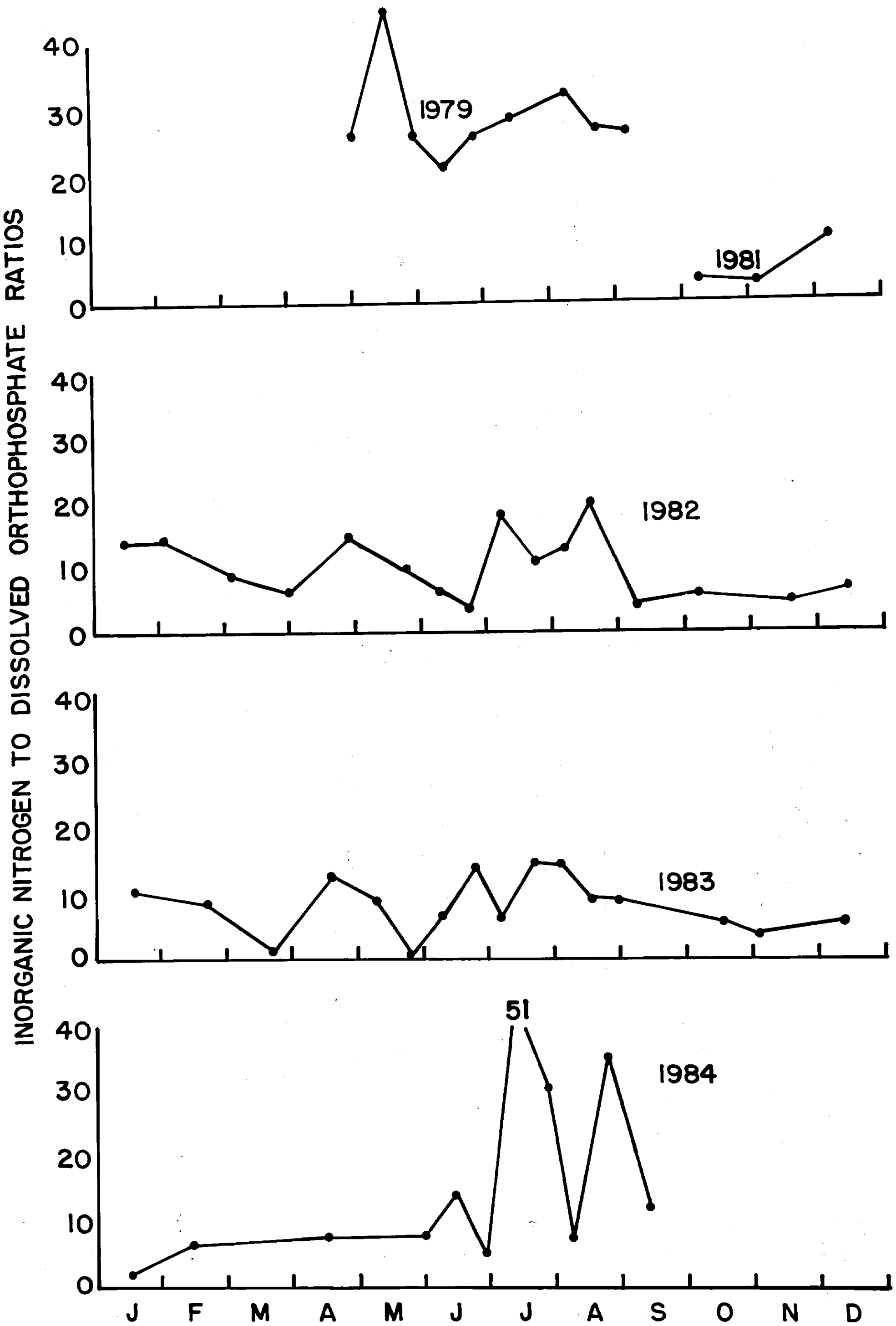


FIGURE 37. INORGANIC NITROGEN TO DISSOLVED ORTHOPHOSPHATE RATIOS OBSERVED IN THE SURFACE WATERS OF SYLVAN LAKE, 1979, 1981, 1982, 1983 AND 1984.

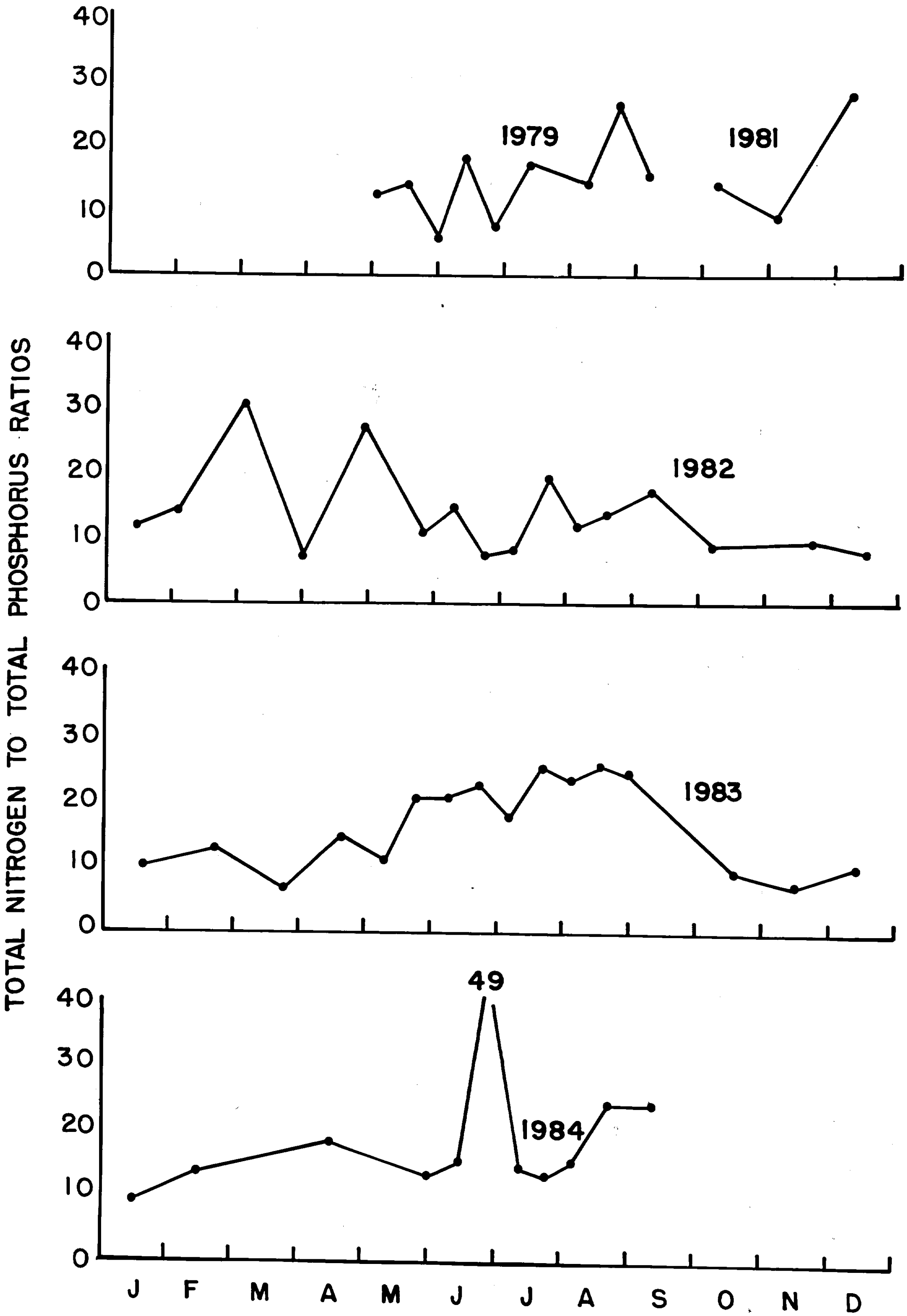


FIGURE 38. TOTAL NITROGEN TO TOTAL PHOSPHORUS RATIOS OBSERVED IN THE SURFACE WATERS OF SYLVAN LAKE, 1979, 1981, 1982, 1983 AND 1984.

calculations. The values in the figures were based on summing the two lake site observations on a given date and dividing by two. It was felt that a combination of the two lake sites would better reflect the overall lake condition. Also, for any value reported as less than some detection limit, the midpoint between the given number and zero was used to calculate the ratios.

Table 10 summarizes the statistics calculated from the ratios. In general, inorganic nitrogen to dissolved orthophosphate ratios indicated phosphorus limitation. However, Figure 37 shows that phosphorus limitation occurred in the summer and winter and nitrogen limitation in the fall. Nitrogen limitation probably occurs during turnover when phosphorus from the anoxic lower depth is circulated throughout the water column.

The total nitrogen to total phosphorus ratios in Table 10 did not reflect the trend noted using inorganic nitrogen to dissolved orthophosphate ratios. The mean ratios suggest neither nutrient was limiting (i.e. the means were right around the 15:1 ratio). However, Figure 38 suggests that nitrogen limitation occurs in the winter and co-limitation or phosphorus limitation occurs the rest of the year.

PHYTOPLANKTON

Table 11 shows the phytoplankton observed on two sampling dates in 1979. Based upon cell counts, chlorophytes or green algae

TABLE 10. LIMITING NUTRIENT DETERMINATION BASED ON 7:1 RATIO AND 15:1 RATIO*

		Inorganic Nitrogen: Dissolved Orthophosphate	Total Nitrogen: Total Phosphorus
1979			
	x	28.6	14.6
	s.d.	7.1884	6.1082
	n	18	18
1981			
	x	5.7	17.2
	s.d.	3.7771	9.1960
	n	6	6
1982			
	x	10.3	14.3
	s.d.	7.1075	7.9167
	n	32	32
1983			
	x	8.7	16.5
	s.d.	4.4825	7.43
	n	32	32
1984			
	x	15.0	17.7
	s.d.	14.7139	10.4832
	n	13	13

*x=mean, s.d.=Standard Deviation, N=Number of observations, R=Range.

TABLE 11. PYHTOPLANKTON SPECIES AND NUMBER PER MILLILITER OBSERVED IN SYLVAN LAKE ON JUNE 21, 1979 AND AUGUST 7, 1979

Sampling			
Algal Units per ml 6/21/79		Algal Units per ml 8/7/79	
Crucigenia rectangulars	3,216	Anabaena flos-aquae	5,106
Oocystic sp.	1,398	Cosmarium sp.	916
Anabaena circinalis	699	Anabaena circinalis	858
Anabaena flos-aquae	680	Unidentified Desmid	308
Scenedesmus sp.	419	Scenedesmus sp.	264
Cosmarium sp.	214	Crucigenia rectangularis	141
Tetraedron minimum	163	Crytomonas erosa	31
Cryptomonas ovata	124	Staurtastrum sp.	26
Staurastrum sp.	101	Schroederia sp.	22
Chroococcus limnetieus	93	Cryptomonas ovata	22
Fragilaria crotonerisis	93	Oocystis sp.	18
Asterionella formosa	89	Closterium sp.	13
Dinobryon sertularia	54	Tetraedron minimum	9
Closterium sp.	54	Trachelomonas sp.	9
Pediastrum sp.	54	Cocconeis placentula	4
Unidentified Desmid	35	Lagerheima subsalsa	4
Schroederia sp.	19	Navicula sp.	4
Trachelomonas sp.	16	Ceratium hirundirella	*
Navicula sp.	4	Pediastrum sp.	*
Gomphonema sp.	*	Selenastrum sp.	*
Lagerheima subsalsa	*	Synedra acus	*
Synedra acus	*		

* = less than 4 units per ml.

were the most abundant on June 21, 1979, constituting 76% of the total phytoplankton community. Cyanophytes (blue green algae) were the second most abundant and made up to 20% of the community. Chrysophytes only comprised 3% of the community. By August 7, 1979, the pattern reversed with cyanophytes being more prevalent (77%) than chlorphytes (22%). Based on Table 15-2 in Wetzel (1983) and the limited 1979 algal data, Sylvan Lake would be considered eutrophic based.

Figures 39 and 40 summarizes the phytoplankton data collected during the life of the project. Figure 39 is based upon cell counts and Figure 40 is based upon biomass as a measure of cell volume. Original data can be obtained from SDDWNR.

During the project, chrysophytes, based on counts, were the most abundant between January and March 1982, June and July 1982, and between October and December 1983. Dinobryon was the most abundant chrysophyte in the the winter of 1982 but was replaced on March 7 and July 23, 1982 by Asterionella. In October and November 1983, Fragilaria was the most abundant diatom. It is of interest to note the abundance of Dinobryon, a phytoplankton indicative of nutrient poor lakes (oligotrophic) or productive lakes during periods of nutrient reduction (Hutchinson, 1967; Wetzel, 1983).

The blue-green Anacystis was the most abundant genus of the phytoplankton community in May and June 1982. This was interrupted by the Asterionella pulse mentioned above. By July,

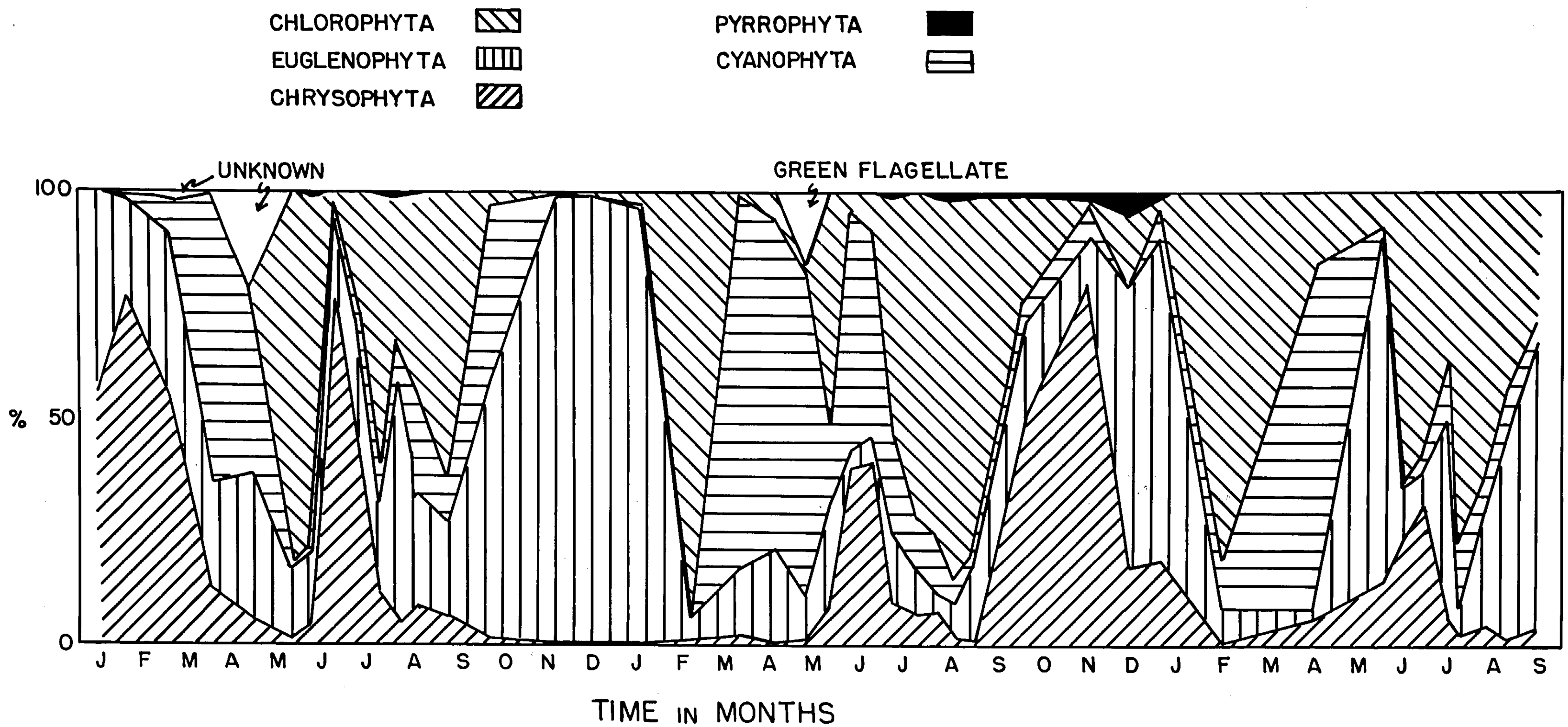


FIGURE 39. PERCENT COMPOSITION BY DIVISIONS OF THE PHYTOPLANKTON BASED ON COUNTS/M^3 IN SYLVAN LAKE, 1982, 1983 AND 1984.

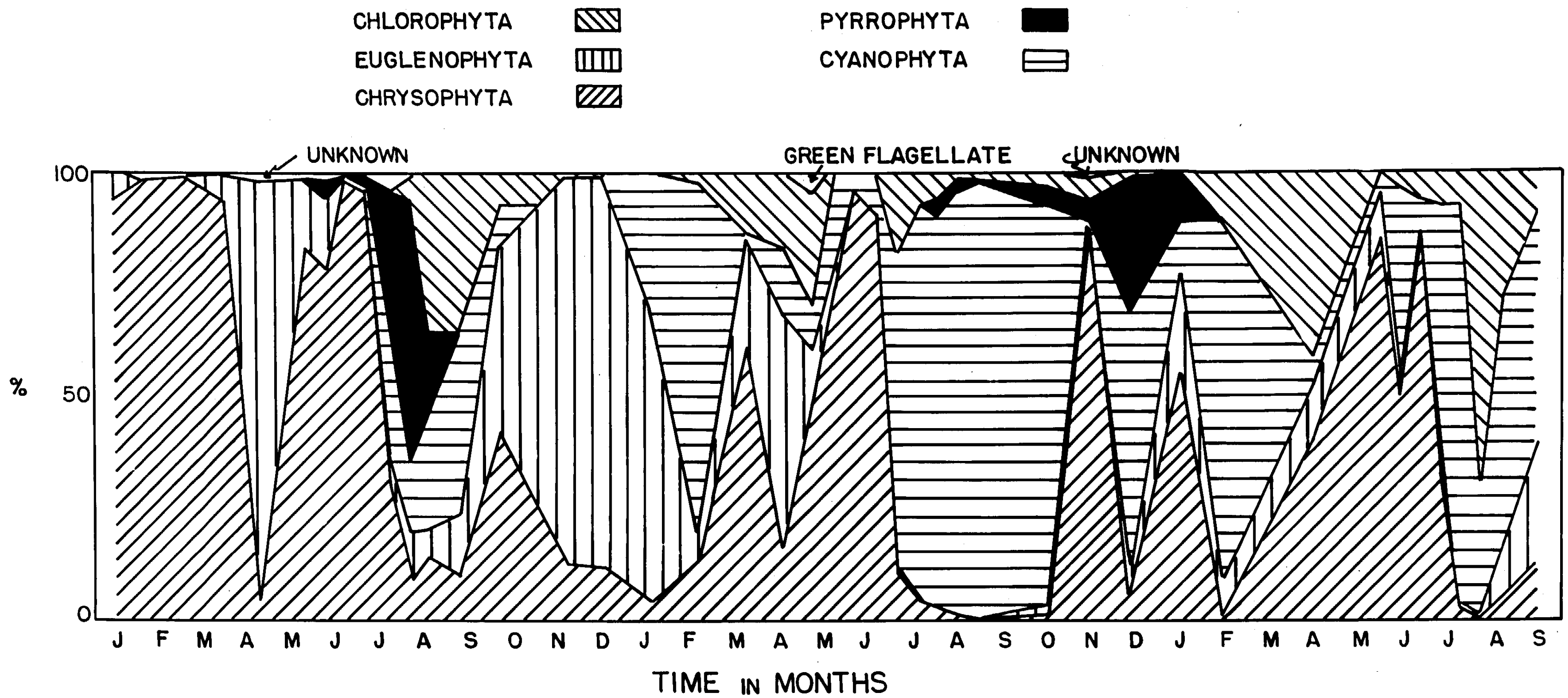


FIGURE 40. PERCENT COMPOSITION BY DIVISIONS OF THE PHYTOPLANKTON BASED ON BIOMASS(MG/L) IN SYLVAN LAKE, 1982, 1983 AND 1984.

Anabaena became the most abundant blue-green and remained so until the latter part of September. On August 5, 1982, Euglena became the second most common species. From October to January Euglenophytes were the most abundant Division with Euglena peaking in October and November and Trachelomonas peaking in December and January. According to Hutchinson (1967), the euglenophytes are often abundant in small pools rich in organic matter and are unimportant in lakes. However, in Sylvan Lake the euglenophytes, based on cell counts, were important and the inference is drawn that the lake was organically enriched.

After rehabilitation activities ceased, euglenophytes were not as common in the phytoplankton community as in 1982 (Figure 39). They were abundant in December 1983, and January, May, August and September, 1984. In February of 1983, Anacystis was the most abundant whereas Dinobryon was prevalent the year before. Another change observed in 1983 from 1982 was the magnitude of abundance of green algae from March to May Chlorococcum succeeded by Chlorella). This pulse was followed by a brief pulse of the blue-green Chroococcus and then another pulse of chlorophytes represented by Carteria and Chlorococcum. Chroococcus again peaked in July and was rapidly succeeded by Anabaena which was common from July 21st to August 31st. By October blue-greens constituted only a minor portion of the phytoplankton. Through November the diatom (Chrysophyta) Fragilaria was the most abundant alga.

In February 1984, *Chroococcus* was the most abundant algae followed in March by the chrysophyte *Ankistrodesmus* which was followed in turn by the euglenophyte, *Euglena*.

Generally, the phytoplankton was dominated numerically by the blue-greens in the summer and in February, except in 1982. Chrysophytes were most abundant in the fall except in 1983. Euglenophytes were nearly always present, especially in the fall and winter of 1983 and fall of 1984. Based upon these results Sylvan Lake is a eutrophic lake and there is an inference of organic enrichment.

In addition to looking at which group and genera of algae was most prevalent based on counts, biomass was also used. Although Figure 40 illustrates abundance of phytoplankton based upon biomass, Figures 41, 42 and 43 illustrate which genera were most prevalent and when. The use of biomass represents a different viewpoint of which genera dominated the phytoplankton community.

In 1982, *Dinobryon* was the major the alga between January and March as it did in the discussion of cell counts (Figure 41). *Euglena* and *Trachelomonas* peaked in May and in November and December. *Anabaena* was observed to have two minor peaks, one in July and one in September. Of interest is the presence of the pyrrophyte *Ceratium* in August. *Ceratium* is characteristic of mesotrophic and eutrophic lakes which are neutral to slightly alkaline; characteristics exhibited by Sylvan Lake.

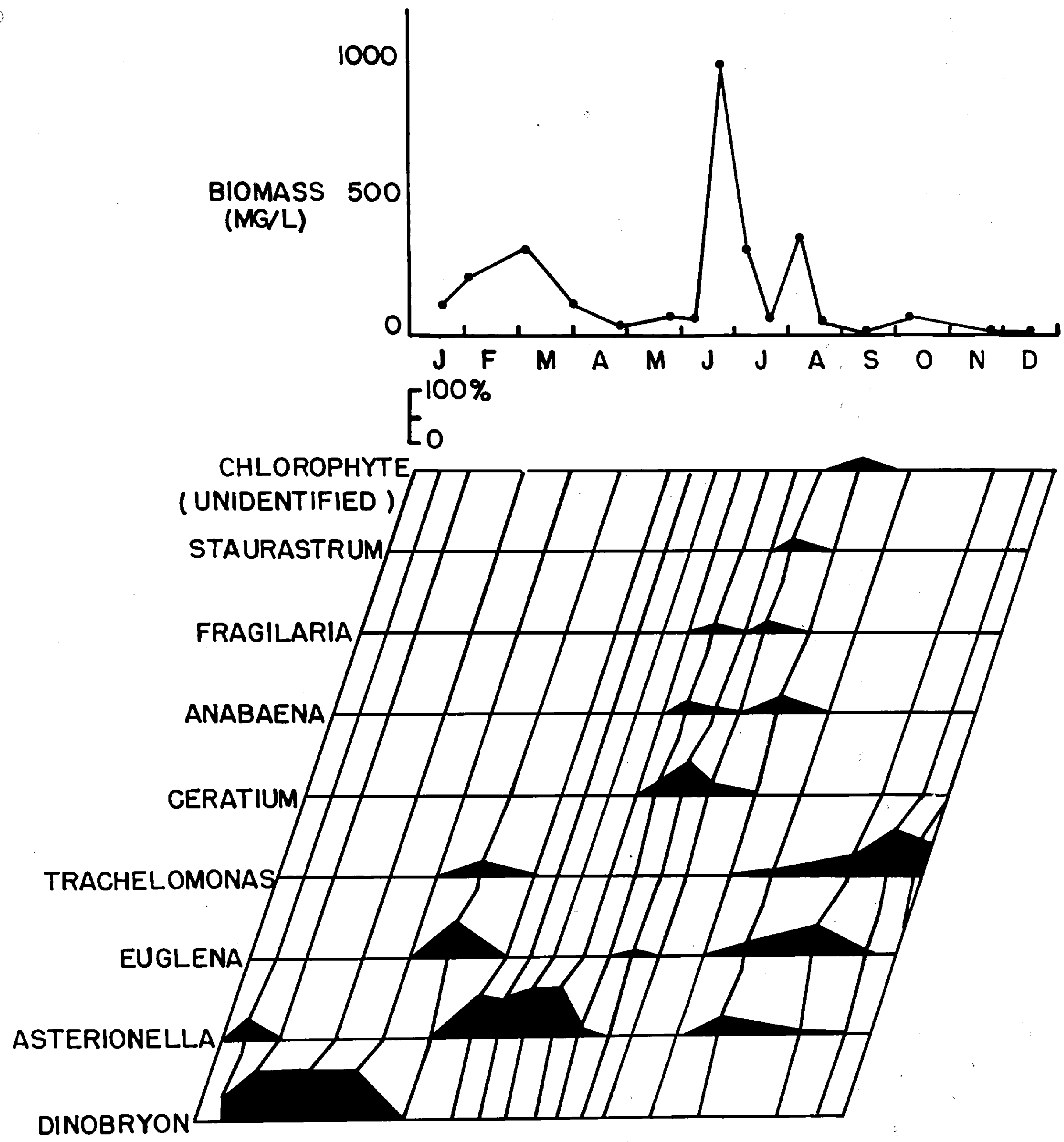


FIGURE 41. GENERA THAT DOMINATED THE BIOMASS OF PHYTOPLANKTON AND THEIR PERCENT CONTRIBUTION IN SYLVAN LAKE IN 1982.

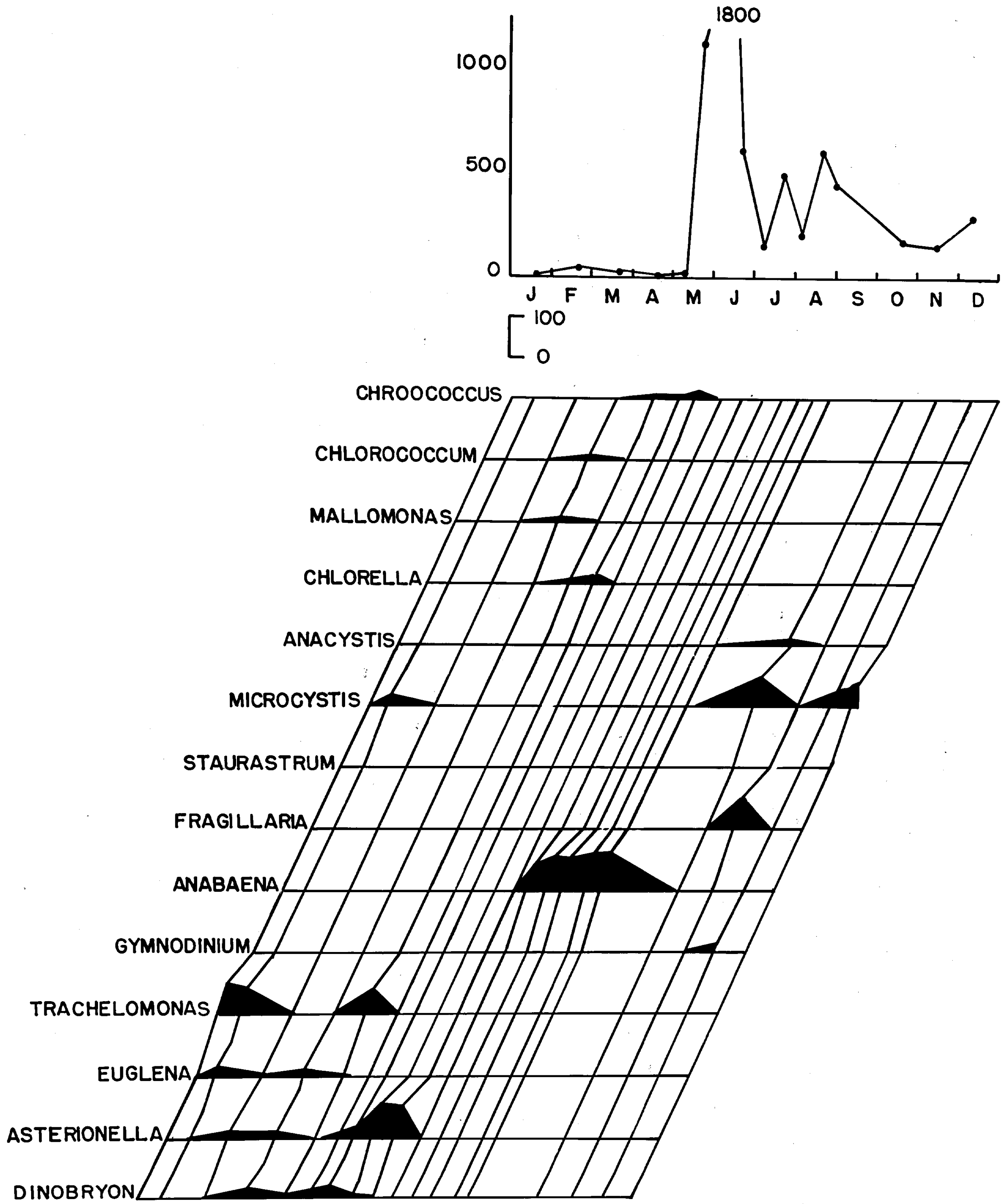


FIGURE 42. GENERA THAT DOMINATED THE BIOMASS OF PHYTOPLANKTON AND THEIR PERCENT CONTRIBUTION IN SYLVAN LAKE IN 1983.

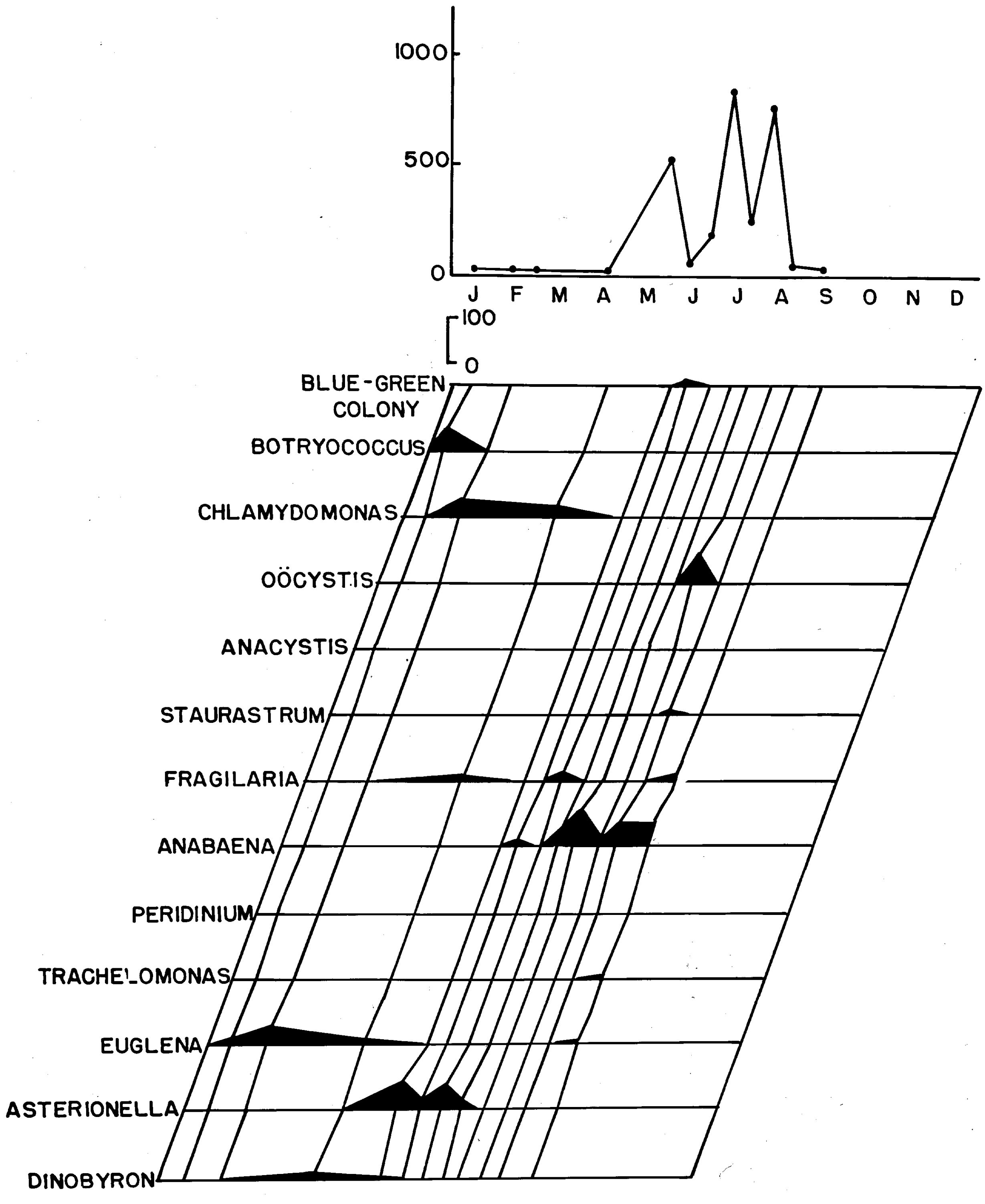


FIGURE 43. GENERA THAT DOMINATED THE BIOMASS OF PHYTOPLANKTON AND THEIR PERCENT CONTRIBUTION IN SYLVAN LAKE IN 1984.

Figure 42 shows the 1983 data and they exhibit few of the characteristics noted in 1982, the rehabilitation year. Trachelomonas and to a lesser extend Euglena were the major phytoplankton in January. In February, Asterionella, a diatom, had the greatest biomass as opposed to Anacystis in the count discussion. Asterionella again peaked in June and was followed by Anabaena from July to September. This Asterionella/Anabaena trend was also observed in 1984 (Figure 43). Asterionella peaked in late May and in June with a brief decline in early June probably due to competition with Anabaena. As Anabaena declined in 1983, Microcystis increased with peaks in October and December. Fragilaria peaked in November between the Microcystis peaks.

In 1984 Chlamydomonus and Euglena were the major algae from February into May with Fragilaria making an appearance in May. Again, Anabaena was the major algae of the summer phytoplankton community except for a brief pulse of Oocystis in August.

Generally the chyrsophytes were the most abundant in the winter months, except in 1984, and in the early summer. Typically these periods of abundance were followed by cyanophytes although euglenophytes interrupted the pattern between October and January in 1982. There were differences in successional patterns depending upon whether counts or biomass were used. However, either method suggested a eutrophic lake with organic enrichment.

In attempting to interpret the impacts of this project on the phytoplankton, another method of data presentation was employed. Figure 44, illustrates a side by side comparisons of the percentage contribution of the Divisions observed in Sylvan Lake based on counts and biomass. Using this method, the percentages based upon counts show that chlorophytes and euglenophytes demonstrated no consistent trend, whereas the chryosphytes consistently decreased and the cyanophytes consistently increased. On the other hand, biomass percentages demonstrated a consistent decrease in chrysophytes and pyrrophytes. Chlorophytes consistently increased and cyanophytes and euglenophytes were inconsistent. Generally, it appears that the chrysophytes were decreasing and being supplanted by the cyanophytes, which are not a particularly preferred food item for zooplankton.

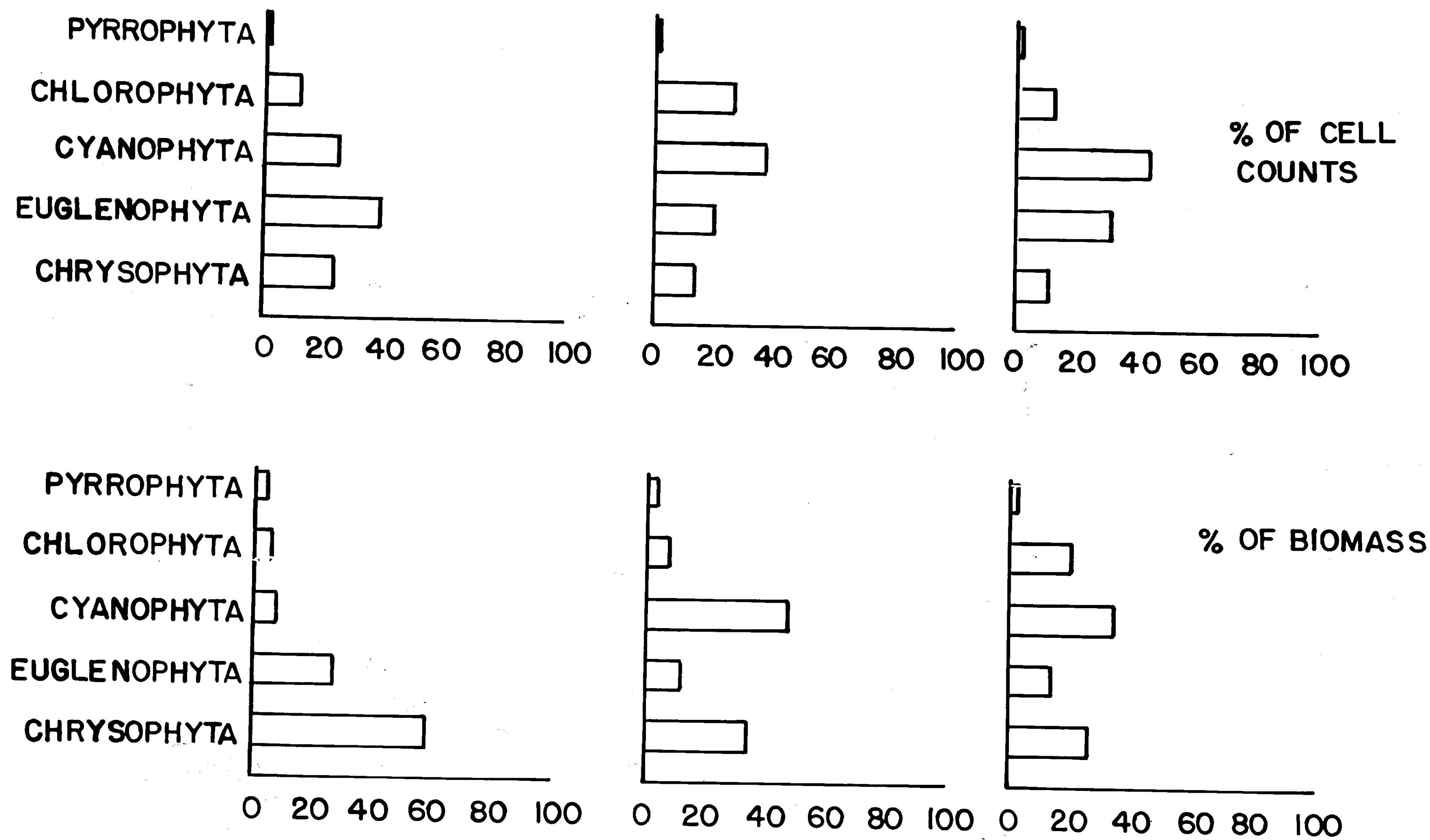


FIGURE 44. ANNUAL PERCENT COMPOSITION OF DIVISIONS OF PHYTOPLANKTON BASED UPON CELL COUNTS AND BIOMASS IN SYLVAN LAKE.

SECTION 6

SUMMARY AND CONCLUSIONS

Sylvan Lake is a small man-made lake (7.5 hectares) located in Custer State Park, South Dakota; one of the most scenic areas in the Black Hills. A focal point of intense recreational activity, the lake had experienced severe aesthetic and water quality problems. Shoreline and watershed areas were denuded of vegetation and active erosion of the unprotected soils resulted in accelerated sedimentation to the lake. The reduction in depth of the lake from sedimentation and nutrient loadings associated with the sedimented particles had resulted in undesirable aesthetics (algal blooms), limited access, and reduced fish habitat.

The Sylvan Lake Restoration Project was initiated by the South Dakota Department of Game, Fish and Parks in 1979 with the general objectives of correcting watershed and in-lake problems, and controlling activities detrimental to the recreational experience provided by the lake and its surroundings. Application was made and a grant awarded to the South Dakota Department of Water and Natural Resources by the United States Environmental Protection Agency under Public Law 92-500, Section 314. Matching funds were provided by the South Dakota Department of Water and Natural Resources' Lake Protection and Rehabilitation Program and the South Dakota Department Game, Fish and Parks operational budget. Supplemental funding was provided by the National Park Service through the Land and Water Conservation Fund, the South Dakota Department of Transportation, and the South Dakota Game, Fish and Parks operational budget.

Construction activities included: 1)partial removal of lake sediment deposits; 2)paving existing gravel surface access roads and parking areas; 3)construction of new hard surface access roads and parking areas; 4)surface restoration and revegetation; and 5)construction of sediment control structures. In addition to the construction activities, the project included changes in management practices and land uses by Custer State Park to enhance and accommodate restoration activities.

In the lake, approximately 18,580 m^3 (24,300 c.y.) of sediment were removed using conventional construction equipment. In the watershed numerous activities occurred. Access road and parking improvements included: 1) reconstruction of the west side parking area and paving the access road to the east parking area (former campground); 2) construction of new paved parking facilities for the new east side day use area; and 3) construction of new paved parking facilities 1.6 km (one mile) south of the lake at the Cathederal Spires Trailhead. Previously these areas had been denuded and contributed to the lake's sedimentation problems. Other construction activities included: 1) topsoiling and seeding (or sodding) approximately 12.4 Ha (5 ac.) of denuded or disturbed surfaces; 2) minor grading and evacuation to correct steep eroding slopes unsuitable for revegation work and to stabilize eroding shoreline areas; 3) construction of a gravel surfaced lake shore hiking trail system; 4) construction of eight sediment control structures or devices in the watershed; 5) finish grading and seeding of sediment disposal areas; and 6) construction of a small swimming beach. Changes in land management and land use practices included: 1) eliminating lakeshore camping; 2) designating lakeshore facilities for day use only; 3) eliminating horeseback riding in the watershed; 4) instituting an extensive timber thinning and management program to remove excessive under story material and enhance light penetration for the development of ground cover; 5) eliminating gasoline sales operations in the main parking area; and 6) instituting a tree and shrub planting program to aid soil stabilization, provide natural foot traffic controls in high use areas, improve aesthetics and increase privacy for lake users.

The impacts of this project on Sylvan Lake are difficult to ascertain. During actual construction activities, the lake was observed to have increased total phosphorus, dissolved orthophosphate, suspended solids and ammonia as nitrogen concentrations. With the exception of dissolved orthophosphate, all concentrations were about the same level before the project began and after construction activities ceased. The problem in determining changes in water quality is due to differences in sampling procedures before, during and after the project and changes in sampling sites. Before the project, samples were collected just offshore and only from the surface waters between May and September. During and after construction samples were collected at two new sites in the lake and throughout the water column. Samples were collected between October and December in 1981, over the year in 1982 and 1983, and between January and September in 1984 at the deep site and between January and March in 1984 at the shallow site. Statistical comparison before, during and after the project were conducted using only surface water data and only data collected between May and September. As mentioned above, there were significant ($P<.05$) increases in some nutrient concentrations during the construction activities, but they tended to decrease to levels that were similar to pre-restoration levels.

In general, the water chemistry parameters were not greatly impacted by the project. The lake was still eutrophic after project completion.

An observation based upon the water quality data collected throughout the water column at the deep site may explain the lack of changes in water quality due to restoration activities. Sediments were only removed from the shallow areas and not from the deep areas. These deep waters go anoxic in the summer and winter when the lake stratifies, resulting in the release of phosphorus from the sediments into the water column and the accumulation of ammonia. With turnover these nutrients are available throughout the water column.

Although water chemistries did not change, the biological data do indicate a change in water quality. In 1984, the chlorophyll a levels suggest mesotrophic conditions, a lesser degree of eutrophy than observed in 1982 and 1983. This decline in eutrophy is based upon data collected only between January and September at the deep site and does not incorporate the shallow sites. Therefore, the decline must be viewed with this qualifier in mind. Using counts per cubic meter and biomass in milligrams per liter data, there is an indication that the phytoplankton is shifting with an overall decline in chrysophytes and an increase in cyanophytes. Therefore, although eutrophy may have declined, the algae may have shifted to cyanophytes or blue-greens which are generally not a desired food for zooplankton.

Because of manpower and budgetary constraints, very limited data were collected in the tributaries upstream and downstream from the sediment control structures. Some of the data were collected as construction activities were on-going which masked any real effectiveness the structures may have had.

If this project were continued or a similar project started, the following recommendations are made based on the experiences with this project.

1) Sample the lake throughout the water column prior to restoration activities, for at least one year.

2) Specifically define the objectives of the sampling program and develop an adequate budget to cover sample analyses.

3) Develop a sound statistical program before the first sample is collected.

4) Use only dedicated personnel. One individual should be assigned to a project of this magnitude full-time so that all sampling requirements are fulfilled (e.g. storm events) and data can be processed as they are available.

5) Ensure that data are available to construct nutrient, hydrologic, and sediment budgets before, during and after the project.

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