DRAFT
FINAL REPORT TO THE TOWN OF LUNENBURG ON DIAGNOSTIC/FEASIBILITY STUDY OF LAKE SHIRLEY

LUNENBURG, MASSACHUSETTS
August, 1987

August 7, 1987

J-1917

Ms. Fran Vaughan
Office of Selectmen
Town Hall, 17 Main Street
P.O. Box 135
Lunenburg, MA 01462

Dear Ms. Vaughan:

Metcalf & Eddy is pleased to submit the draft Final Report on the Diagnostic/Feasibility Study of Lake Shirley, Lunenburg, Massachusetts. The report contains an environmental description of the lake and its watershed, an analysis of the data collected during the diagnostic survey and recommendations for improving conditions in the lake.

We look forward to receiving your comments on the report as well as those of the MDWPC. We are available to meet with the Advisory Committee as well as the Lake Shirley Improvement Corporation regarding the details of the report. Considering the upcoming October 1 deadline for applications for Phase II funding and the requirement that the application be submitted with a Final Report, please provide us with your comments in time for the town to meet this deadline.

If you have any questions regarding the report, please don't hesitate to contact us.

Very truly yours,

D. R. Bingham

David R. Bingham
Project Manager

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EXECUTIVE SUMMARY

This Diagnostic/Feasibility Study for Lake Shirley in Lunenburg was conducted by Metcalf & Eddy, Inc. for the Town of Lunenburg. Funding for the study was provided by the Town, the Lake Shirley Improvement Corporation, and by the Commonwealth of Massachusetts under the Chapter 628 Clean Lakes Program. The purpose of the study was to assemble limological, chemical, physical and biological data related to the lake and its watershed; determine the trophic state of the lake; and develop a cost-effective and publicly and environmentally acceptable restoration program.

In a one-year diagnostic study, data were collected on in-lake and tributary water quality, stormwater, aquatic macrophytes, sediments, septic tank leachate and groundwater. Water quality data were used to quantify sources of plant nutrients such as nitrogen and phosphorus. The diagnostic study focused on phosphorus inputs because over-enrichment of the lake with phosphorus can cause proliferation of aquatic macrophytes and algae and degraded water quality. The main sources of nutrients included natural tributaries, stormwater runoff, septic leachate and groundwater; however, nutrient loading was not severe and the lake is currently in a mesotrophic state. Despite moderate nutrient loading, the principal problem in the lake is the extensive aquatic macrophyte community of water milfoil (Myriophyllum) and fanwort (Cabomba) which covers a large

percentage of the lake bottom and diminishes the recreational value of the lake. Much of the lake is shallow and gradually sloped, and the lake's clear water allows sunlight to penetrate and promote plant growth.

Following the identification of the problems in the lake through data collection and public participation, and the establishment of objectives for the restoration program, potentially feasible restoration alternatives were assembled and evaluated. Evaluation criteria included technical effectiveness, public acceptability, environmental acceptability and cost. In order to achieve the main objective of eliminating macrophytes to improve recreation, the macrophyte control techniques of harvesting and water level drawdown were evaluated in detail. Due to economic and logistical constraints associated with harvesting, drawdown was chosen as the principal component of the final recommended restoration plan for Lake Shirley. Due to the drawdown capacity of the existing outlet, favorable lake bathymetry and sensitivity of the invading macrophyte species, it is anticipated that drawdown will provide an effective and inexpensive means of weed control. In the event that the drawdown program is not as effective as anticipated, a contingency plan of harvesting has been outlined. Although nutrients are not a severe problem with the lake, a variety of phosphorus education measures were evaluated.

Watershed management involving public education to reduce phosphorus loading from fertilizers and septic tanks has been included in the final recommended plan.

The cost of the recommended restoration plan including environmental permits, ~~public education~~ and a monitoring program is estimated at $125,000. The duration of the project including monitoring following a phased drawdown program is approximately five years. The most promising funding source for the Phase II program is the Commonwealth of Massachusetts, Chapter 628 Clean Lakes Program. This ten year program which began in 1981 has provided funding for diagnostic/feasibility studies across the state and many are advancing to Phase II.

CHAPTER 1

INTRODUCTION

In accordance with the State of Massachusetts Clean Lakes Program, this report contains the findings of a Phase 1 Diagnostic/Feasibility study for the restoration of Lake Shirley in Lunenburg, Massachusetts.

Chapter 628 Lakes Program

The Chapter 628 Massachusetts Clean Lakes and Great Ponds Program provides funds for the restoration, preservation and maintenance of the publicly owned lakes and ponds of the Commonwealth for public recreation and enjoyment. The program focuses primarily on cultural eutrophication. The primary cause of culturally accelerated eutrophication is the uncontrolled addition of nutrients to lakes and ponds which stimulates primary productivity by algae and/or macrophytes. Excessive growth of algae and macrophytes may impair recreation and wildlife.

A Chapter 628 restoration program is carried out in two phases. Phase I includes a diagnostic survey to gather information and data to identify existing or potential sources of pollution and to determine the limnological, morphological and other pertinent characteristics of the lake and its watershed. Diagnostic survey data are then analyzed to define methods for controlling causes of eutrophication in a Phase I feasibility study. The most cost-effective procedure to improve or preserve the quality of the pond is determined and a technical plan for implementing the restoration plan is developed. Phase II is the detailed design and implementation of the recommended restoration plan. This report contains a Phase I Diagnostic/Feasibility study of Lake Shirley.

Lake Shirley Description and Problems

Lake Shirley is located on the border of the towns of Lunenburg and Shirley as shown in Figure 1-1. The Lake Shirley watershed covers 14.3 square miles including parts of the towns of Lunenburg, Shirley, Leominster, and Lancaster and is composed of generally hilly terrain with interspersed wetlands, streams and upstream ponds and lakes. Although most of the watershed is forest, there are a variety of land uses including single family residences, commercial properties, gravel pits, landfills, junkyards and recreation areas. Lake Whalom, Massapoag Pond and several other small ponds drain into Lake Shirley. Flows to the lake occur largely from four main tributaries, three of which enter the northern basin including Easter Brook and Catacoonamug Brook. Several other tributaries and intermittent streams enter the lake, draining the extensive forested wetlands in the area. The outlet from the lake is the continuation of Catacoonamug Brook, a tributary of the Nashua River. The lake has an area of 354 acres with two major basins separated by two narrow channels at the center. The north and south basins have maximum depths of 11 and 38 feet, respectively.

The current major use of the lake is water-based recreation and aesthetics. Swimming, boating and fishing are allowed; however, these activities have become more difficult due to the

SOURCE: USGS TOPOGRAPHIC MAP
SHIRLEY, MASS., 1979

FIGURE 1-1. LAKE SHIRLEY PROJECT AREA

excessive growth of the aquatic macrophytes *Cabomba* and *Myriophyllum*. The lake is a popular fishing area with several recreational species including perch, pickerel and bass. There are also several boat docking facilities and numerous individually-owned docks.

The Massachusetts Division of Water Pollution Control conducted a water quality and biology survey of Lake Shirley in June 1977. The macrophyte population was characterized as very dense and several measured nutrient concentrations were elevated. This dense plant growth and degraded water quality is evidence that the lake is presently in an advanced trophic state. If steps are not taken to reverse this condition, it is expected that the macrophyte problem will persist and that water quality conditions in the pond will continue to degrade.

In summary, concern over the existing and future quality of the lake centers on several factors, including the following:

- Macrophyte growth reduces the aesthetic and recreational quality of the lake.
- Elevated nutrient concentrations may contribute to eutrophic conditions in the lake and generally degraded quality of the water.
- Pollutant influx from tributaries, groundwater, and sediments may have a detrimental effect on the lake water quality.
- Pollutants from several possible sources including septic systems, landfills, junkyards, underground storage tanks and salt storage facilities may be entering the lake.

These problems have generated an intense public concern and desire to improve conditions at Lake Shirley. In response to those concerns, the Town of Lunenburg successfully applied for Chapter 628 funds to conduct a Diagnostic/Feasibility study under the Clean Lakes Program.

Eutrophication

Eutrophication is a process whereby a body of water becomes enriched or over-fed with plant nutrients such as nitrogen and phosphorus, resulting in proliferation of nuisance aquatic macrophytes and algae. Eutrophication is a natural process which occurs gradually in all lakes; however, the process may be greatly accelerated by nutrient input from the routine activities of man when such nutrient sources as wastewater, fertilizer, decaying vegetation and others are carried to the lake by stormwater runoff, tributaries and groundwater.

Aquatic plants or macrophytes generally thrive in shallow parts of a lake where temperatures are warm and light is plentiful. Excessive phytoplankton growth stimulated by excess nutrients causes undesirable turbidity, thus decreasing the clarity of the water body. At the end of the growing season, dead plant material settles to the lake bottom. Decomposition of this material exerts a demand on the dissolved oxygen in the water, thereby reducing oxygen levels and discouraging fish life and occasionally causing odor problems. Further plant growth is encouraged since decaying plant material provides more nutrients to the lake sediments and the water column. Lake Shirley presently exhibits signs of eutrophication, and if remedial action is not taken, it is expected that this condition will advance.

Report Organization

The Lake Shirley Diagnostic/Feasibility Study report is organized according to major tasks conducted. These are briefly described as follows:

Environmental Description (Chapter 2) - This includes a discussion of the lake and its drainage area including morphometric features, area history, land uses, recreational uses, geology, wetlands, hydrogeology, historical water quality and biological data and other pertinent information. Chapter 2 also includes descriptions of potential sources of surface and groundwater contamination.

Diagnostic Data Collection and Analysis (Chapter 3) - A description and analysis of a full year of limnological data is presented, as well as stormwater and sediment data and the results of a septic leachate survey and inventory of on-site wastewater disposal practices within 1000 feet of the lake.

Assessment of Existing Conditions (Chapter 4) - Hydrologic and nutrient budgets are calculated to account for contributions and losses of flow and nutrients to and from the lake. Information from these budgets is used to assess existing conditions in the lake and to help define the lake's trophic (biological) state. These calculations are useful in identifying problem sources at the lake and in formulating and evaluating potential restoration alternatives.

Restoration Alternatives (Chapter 5) - Objectives for the study based on diagnostic survey data and public input are established and restoration alternatives which achieve the objectives are identified and evaluated. The restoration alternatives considered for Lake Shirley included macrophyte control techniques to control nuisance aquatic growth for immediate recreational benefits and measures to reduce phosphorus loading over the long-term. The product of this evaluation combines the most technically feasible, publicly and environmentally acceptable and cost-effective alternatives to form the recommended restoration plan.

Recommended Restoration Plan (Chapter 6) - The recommended plan is developed in detail. The technical components of the plan are integrated and their implementation is described. The anticipated effectiveness of the plan is described as are the environmental impacts, costs, and available funding. For the recommended plan, a budget, work schedule and other information have been prepared so that the restoration project can be advanced into Phase II implementation.

Appendices - Appendix A contains all raw data and plots of water quality data collected during the diagnostic survey. Appendix B contains the septic leachate survey report prepared by KV Associates. Appendix C presents the questionnaire which was distributed for the inventory of on-site wastewater disposal practices and Appendix D contains the public participation program documentation.

CHAPTER 2

ENVIRONMENTAL DESCRIPTION

An environmental description of Lake Shirley and its drainage area has been prepared as part of the diagnostic study. This description is based upon both historical and contemporary data and includes:

- Lake morphometry
- Watershed history and description
- Recreational use and public access
- Historical chemical data
- Historical biological data
- Potential contamination sources

This environmental description serves as an information source for evaluation of existing conditions and projection of future conditions.

Morphometric Description

Lake Shirley has an area of 354 acres with a convoluted shape extending approximately 1.3 miles along a north-south axis. The lake has no centralized deep basin but is composed of two large distinct basins which converge in a central but shallow area enclosed by several peninsulas. The lake is generally shallow with an average depth of 7.2 feet, compared to a maximum depth of 38.1 feet. The lake's maximum length is 7,780 feet and its maximum width is 4,340 feet. The northern basin is the largest and has an area of 173 acres, a volume of 1,170 acre-feet and a maximum depth of eleven feet. The southeast basin has an area of 85 acres and a volume of 782 acre-feet and includes the deepest part of the lake (38.1 feet) and the outlet dam. The remaining lake area which is composed of coves in the central area of the lake includes 95.5 acres of surface area and 605 acre-feet of volume.

Although the present study is the first major water quality study of Lake Shirley, some data are available from past studies. Morphometric data were collected by the Massachusetts DEQE, Division of Water Pollution Control during a baseline survey of Lake Shirley in 1977. This survey revealed the morphometric data in Table 2-1. To verify and update this previous morphometric information, a bathymetric survey of Lake Shirley was conducted by Metcalf & Eddy during August 1986. A total of 122 depth measurements were obtained along 32 transects. Transects were located from shoreline stations and distances across each transect were measured with a tag line. The results of the bathymetric survey are presented in Figure 2-1.

Watershed History and Description

Worcester County, in which most of the watershed of Lake Shirley lies, was established in 1731. The first settlements began in the mid 1600's with small farms and towns on the uplands. About 80 percent of the land in the county was burned and cleared for farming of crops, hay or pasture by the mid 1800's. The principal agricultural crop of the area is apples

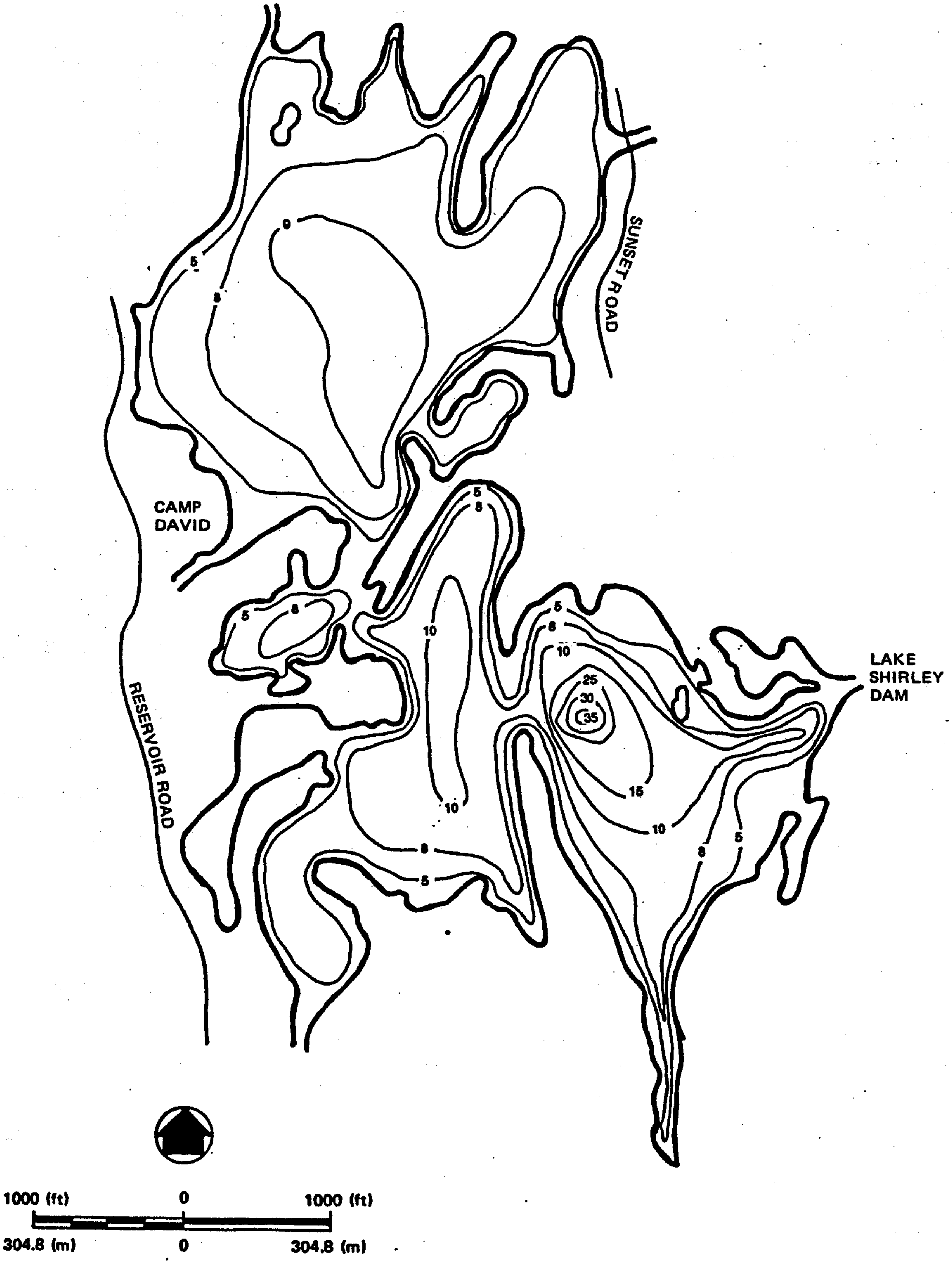


FIGURE 2-1. BATHYMETRIC MAP OF LAKE SHIRLEY

TABLE 2-1. LAKE SHIRLEY MORPHOMETRIC DATA

	MDWPC, 1977	Metcalf & Eddy, 1986
Maximum Length (ft)	7,800	7,780
Maximum Effective Length (ft)	4,450	4,450
Maximum Width (ft)	4,550	4,340
Maximum Effective Width (ft)	2,950	2,950
Mean Width (ft)	1,999	2,370
Maximum Depth (ft)	32	38.1
Average Depth (ft)	5.6	7.2
Area (acres)	358	354
Volume (acre-feet)	1,998	2,560
Shoreline Length (miles)	9.84	10.06
Development of Shoreline	3.71	3.82
Development of Volume	0.5	0.57
Mean to Maximum Depth Ratio	0.18	0.19
Drainage Area (sq. miles)	22.45	14.3

and this area leads the northeast in apple production. The Nashoba apple belt was established during the Civil War period and as railroads were constructed. The towns of Lancaster and Leominster are within this apple belt. In the early 1800's, manufacturing industries utilized the abundant streams in the area as sources of power. By 1965, the major industrial products of the area were nonelectrical machinery, fabricated metals, textile mill products, primary metals, rubber, leather and furniture (SCS, 1985).

Prior to the mid-19th century, the waterbody which is now Lake Shirley was a small pond of 10 to 20 acres fed by Catacoonamug Brook and other streams. During the development of the town of Shirley as an industrial area, Catacoonamug Brook was dammed just above its junction with the Nashua River in order to provide hydroelectric power for the Phoenix Mill in Shirley which was constructed during 1849 to 1850. The impoundment created most of the 354 acre Shirley Reservoir (now called Lake Shirley), most of which previously existed as a rocky grassy meadow in what is now the northern basin of the lake. During the 1880s, the Phoenix Mill and the dam were acquired by the Samson Cordage Company (Massachusetts Historical Commission, 1980).

General Description and Topography. The Lake Shirley watershed covers a total area of 14.3 square miles (9154 acres, 3,706 hectares) ranging in elevation from 297 feet to 670 feet above mean sea level. The watershed, which is located primarily in the town of Lunenburg is composed of varied topography including streams, upstream ponds, secondary roadways, wetlands, and several hills rising several hundred feet above the surface elevation of Lake Shirley including Flat Hill, Clarks Hill, Turkey Hill and Jocelyn Hill. Perhaps the most striking feature of the watershed is the expanses of wetland associated with the numerous streams and ponds located throughout the area. Approximately 1150 acres (13 percent) of the watershed is composed of various wetland habitats including forested and scrub-shrub wetlands. These wetlands are described in a subsequent section of this chapter. Much of the remainder of the watershed is forested with interspersed residential and commercial property.

Delineation of Drainage Areas. The watershed and sub-drainage basins of Lake Shirley were delineated as part of the diagnostic survey and are presented in Figure 2-2 and Table 2-2. The size of each area was determined from USGS maps

FIGURE 2-2. LAKE SHIRLEY WATERSHED AND SUBDRAINAGE AREAS

TABLE 2-2. SUB-DRAINAGE BASINS IN LAKE SHIRLEY WATERSHED

Drainage Sub-Basin	Description	Area (acres)
A	Easter Brook	1,943
B	Catacoonamug Brook	5,949
C	Forested area	170
D	Sunset Road culvert	196
E	Keating area	392
F	Overland runoff areas	504
TOTAL		9,154

and drainage area maps prepared by the DEQE Division of Water Supply using a Calcomp 9000 digitizer, which provides adequate detail for water quality assessments. The watershed was divided into six main sub-drainage areas which enter the lake through several brooks including Easter Brook and Catacoonamug Brook and smaller intermittent and unnamed streams. The largest sub-watershed basins in the watershed are areas A and B. Each sub-drainage area is described below:

- Area A, which is drained by Easter Brook and its tributaries, covers 3.04 square miles (1,943 acres) and is composed of part of the Keating site, wetlands, forest, sand pits and several residential areas.

- Area B is a 9.30 square mile area (5,949 acre) drained by Catacoonamug Brook and its tributaries. This area extends from the northwest corner of the lake to the Massachusetts Avenue (Route 2A), Lunenburg area and west to Route 13 in Whalom. Area B includes numerous main roads, upstream ponds including Massapoag Pond and Lake Whalom, wetlands and residential areas.

- Area C (170 acres) is composed of wetlands, forest and parts of Burrage Road and Flat Hill Road and drains to the lake through a culvert under Flat Hill Road.

- Area D (196 acres) is composed primarily of wetlands and forest and drains to the lake through a culvert under Sunset Road.

- Area E (392 acres) includes most of the Keating site, several small ponds and forested areas.
- All remaining areas drain to the lake by overland runoff and have been grouped as area F (504 acres).

Land Use. The Lake Shirley watershed contains residential areas, commercial areas such as the Keating site, recreational land, wetlands, woodlands and agricultural land. A breakdown of present land use within the watershed is presented in Table 2-3. This estimate of land use was made following review of land use and vegetative cover mapping prepared by MacConnell (1975). These maps were prepared in order to classify agricultural, forest and wetlands; mining and waste disposal areas, as well as urban land and outdoor recreation sites. Knowledge of land use throughout the Lake Shirley area will be used in the calculation of hydrologic and nutrient budgets for Lake Shirley (Chapter 4). Stormwater runoff and tributary sampling was conducted to establish additional data on the characteristics of this inflow (Chapter 3).

Geology and Soils. The watershed area is believed to have been subjected to the four major continental glaciers known to have occurred in North America. The most recent of these, the Wisconsin glacier, formed rounded, long, narrow hills, known as drumlins (such as Flat Hill and Turkey Hill in Lunenburg) consisting of firm material. As this glacier retreated, it dumped along its receding face a heterogeneous material called glacial till which constitutes the major land surface in the area. The meltwater from this receding glacier picked up some of

TABLE 2-3. LAND USE CLASSIFICATION IN LAKE SHIRLEY WATERSHED (PERCENT OF SUB-WATERSHED)

assification	A Easter Brook	B Catacoonamug Brook	C Flat Hill Rd. Culvert	D Sunset Rd. Culvert	E Keating Area	F Overland Runoff Areas	Total Watershed
ngle family ellings	5	8	5	-	-	15	7
developed odland	64	78	75	90	30	70	73
creational	1	1	-	-	-	5	1
mmerical	5	3	-	-	60	-	6
tlands	20	10	20	10	10	10	12
riculture	5	-	-	-	-	-	1

this glacial till, sorted it according to particle size, and redeposited it downstream from the glacier. This material is called glacial outwash. It contains layers of different thicknesses which often have contrasting particle sizes, ranging usually from sand to cobblestones. Where this redeposition covers a broad area, it is called an outwash plain. The region surrounding the Nashoba River Valley is an example of an outwash plain.

The surficial geology of the Lake Shirley watershed has been well documented (Soil Conservation Service, 1985). The two most common soil types in the watershed are Paxton and Quonset with Quonset predominant along the shoreline of the lake. The permeability of Quonset soil is rapid or moderately rapid in the subsoil and very rapid in the substratum. The water capacity is very low and the soil is excessively drained. Reaction is very strongly acid or strongly acid in the surface layer and subsoil and ranges from strongly acid to slightly acid in the substratum. This soil is a poor filter for septic tank absorption fields, and seepage of the effluent through the substratum may result in groundwater contamination (SCS, 1985). Much of the watershed is composed of Paxton soil which is typically found on drumlins or drumlin-like areas. The permeability of Paxton soil is moderate in the subsoil and slow or very slow in the substratum. The water capacity is high and the soil is well drained. Figure 2-3 shows the configuration of soil types within the Lake Shirley watershed and Table 2-4 lists the detailed soil types shown on Figure 2-3.

FIGURE 2-3. SURFICIAL GEOLOGY IN THE LAKE SHIRLEY WATERSHED (SCS, 1985)

TABLE 2-4. SOIL TYPES IN LAKE SHIRLEY WATERSHED

Map Designation	Soil Type
ChC, ChD	Chatfield-Hollis-rock outcrop complex
De	Deerfield sandy loam
Fm	Freetown muck
HgA, HgB	Hinckley sandy loam
PaB, PaC, PaD	Paxton fine sandy loam
PbB, PbC, PbD	Paxton fine sandy loam, very stony
PcE	Paxton fine sandy loam, extremely stony
Pg	Pits, gravel
QnA, QnB, QnC, QnD	Quonset loamy sand
Ra	Raynham silt loam
RdA, RdB	Ridgebury fine sandy loam
RsB	Ridgebury fine sandy loam, extremely stony
Sw	Swansea muck
Sc	Scarboro mucky fine sandy loam
Ud	Odorthents, smoothed
Wa	Walpole fine sandy loam
Wg	Whitman loam
Wh	Whitman loam, extremely stony
WnA, WnB, WnD	Windsor loamy fine sand
WrA, WrC	Woodbridge fine sandy loam
WsB, WsC	Woodbridge fine sandy loam, very stony
WtB	Woodbridge fine sandy loam, extremely stony

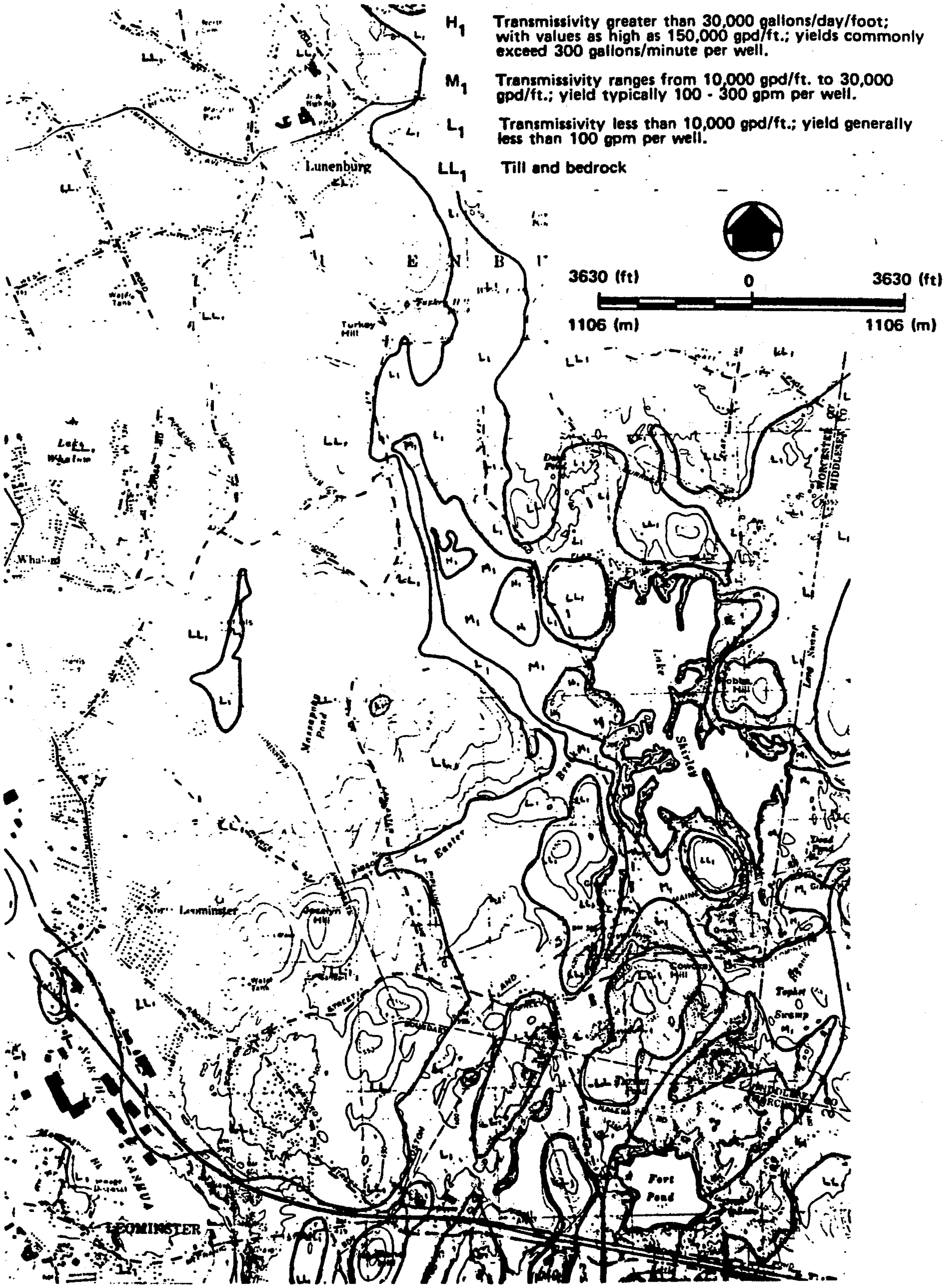
<u>Hydrogeology</u>. The types of sediments left covering the land by the retreating glacier vary in hydrogeologic characteristics. A parameter commonly used to describe the relationship of soil and water is transmissivity or the soil's ability to transmit water. Drumlins or moraines, which are composed of glacial till, have a large concentration of clay and silts which make these areas low in transmissivity and thus unsuitable for groundwater transmission. In contrast, eskers, kettlehole terraces and outwash plains have rounded sand and gravel deposits in which finer sediments may have been washed away giving a higher transmissivity. Glacial lakes may have delta deposits surrounded or covered by lacustrine clays. It is within these water bourne sediments that most of the high yield, public groundwater supplies have been located (D.L. Maher Co., 1985).

The water supplies and groundwater resources of the Lake Shirley area were investigated by the USGS, Massachusetts DEQE and the Lunenburg Water District. These resources have been mapped in several documents including the Massachusetts DEQE Division of Water Supply's Water Supply Protection Atlas (1982). There is a series of groundwater wells in the Catacoonamug brook wetland area east of Lancaster Avenue. These wells are located in an area of high yield with transmissivity exceeding 30,000 gallons/day/foot with values as high as 150,000 gpd/ft. Well yields in such areas commonly exceed 300 gallons per minute per well. Areas of high, medium and low well yield throughout the entire watershed of Lake Shirley are delineated in the Water Supply Protection Atlas. The configuration of well yield areas throughout the watershed is outlined in Figure 2-4.

Lake Sediments. When glacial meltwater reaches a glacial lake, it drops its silt and clay particles. These materials combined with layers of decaying vegetation are glaciolacustrine deposits, or lakebed sediments. Metcalf & Eddy conducted a survey of Lake Shirley in August, 1986 to determine the depth of lake sediment deposits (Figure 2-5). Sediment depth data were collected by driving a metal probe to refusal at the same stations used for the bathymetric survey. Data collected were used to identify areas of sediment accumulation, calculate the volume of existing soft sediments and evaluate the feasibility of sediment removal as a lake restoration technique.

Sediment depths in Lake Shirley range from zero to 11 feet with depths of 2 to 3 feet over most of the lake. Sediments are 11 feet thick in the deepest basin of the lake which historically existed as a small pond before the present waterbody was created by impoundment. Data collected during the survey indicate that the total volume of soft sediment in the lake is 1,560,000 cubic yards with 334,000 cubic yards of that sediment located in the major lake basin.

Wetlands. Wetlands within the Lake Shirley watershed were described and mapped by the U.S. Fish and Wildlife Service under the National Wetlands Inventory. Wetlands are classified by a hierarchical system which is structured around a combination of



SOURCE: DEQE, 1982

FIGURE 2-4. GROUNDWATER AVAILABILITY IN THE LAKE SHIRLEY WATERSHED

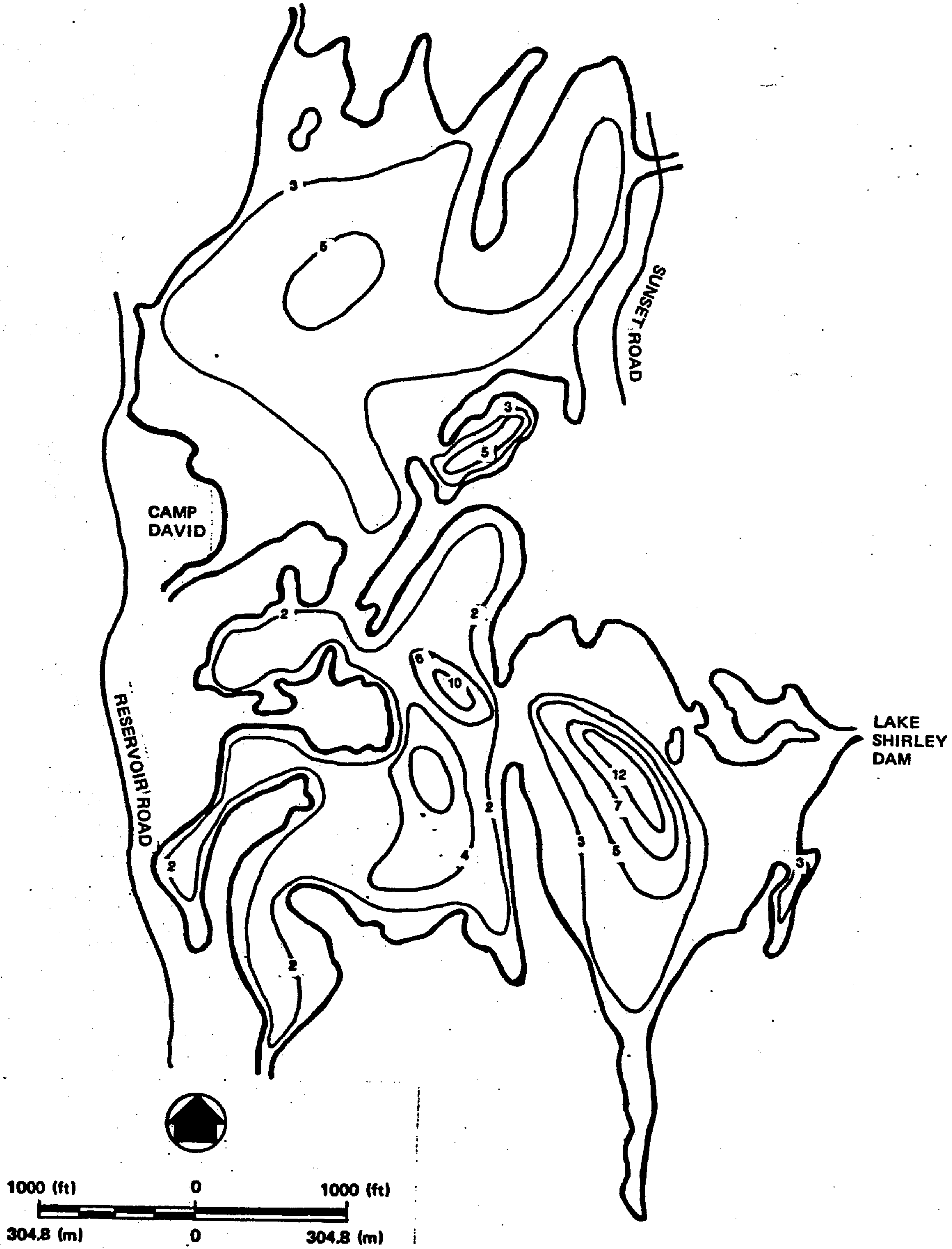


FIGURE 2-5. SEDIMENT DEPTH CONTOURS IN LAKE SHIRLEY

FIGURE 2-6. WETLANDS IN THE LAKE SHIRLEY WATERSHED

ecological, biological, hydrological and substrate characteristics. Riverine (rivers and streams), lacustrine (lake) and palustrine (swamp, bog and marsh) wetlands (Cowardin, 1979) are found in the Lake Shirley region. The wetlands found in the Lake Shirley watershed are shown in Figure 2-6.

Recreational Use and Public Access

With increasing population throughout the region and nearby industrial areas, Lake Shirley has been a valuable recreational area for Lunenburg, Shirley, and neighboring towns. However, the quality of recreation in the lake has been diminished by the growth of aquatic macrophytes. Activities at the lake include fishing, swimming, boating, and water-skiing. Anglers fish for bass, pickerel and perch from the shoreline and small boats. Several private areas provide beach facilities including Camp David, Shady Point Beach and Shirley Beach. Numerous private docks shelter recreational craft and private and public boat launching areas are available. Public access to Lake Shirley is provided along a stretch of land off Reservoir Road in an area known as Stump Cove.

Historical Chemical Data

Water quality data collected at Lake Shirley in previous surveys are summarized in this section. Historical data facilitate analysis of trends in water quality. An unidentified September 25, 1912 report entitled "Survey of Inland Waters" from

Division of Fisheries and Wildlife files provided water quality data. The survey found brown water with a visibility of 6 feet and provided a temperature profile with a surface temperature of 64° F and 49° F at a depth of about 35 feet. On July 28, 1951 the Massachusetts Division of Fisheries and Game conducted a biological and chemical survey of Lake Shirley. A water quality profile of temperature and dissolved oxygen (DO) taken to a depth of 40 feet indicated a temperature of 80° F at the surface and 48° F at the bottom with a thermocline at a depth of 12 feet. DO levels below the thermocline quickly fell to below 1 mg/l and were zero mg/l between 25 and 40 feet. Values of pH ranged from 7.2 at the surface to 6.0 at the bottom. The transparency of the water was 8 feet. Twenty-four years later on July 31, 1975 a profile of temperature and dissolved oxygen to a depth of 30 feet was recorded in an unidentified report. Temperatures on this date ranged from 82° F at the surface to 46° F at the bottom with a thermocline depth of about 12 feet. Dissolved oxygen was depressed to 1.0 mg/l at 30 feet. Transparency was measured at 8.5 feet.

Lake chemistry data collected in 1977 at Lake Shirley by the MDWPC are presented in Table 2-5 and Figure 2-7. Table 2-5 includes suspended and dissolved solids, nutrients, metals and bacteria data collected on June 21, 1977. In eutrophication studies, the chemicals of primary interest are species of nitrogen and phosphorus because in elevated concentrations, these plant nutrients can cause excessive macrophyte and algae

TABLE 2-5. LAKE SHIRLEY WATER QUALITY DATA (mg/l) June 21, 1977

STATION		L6		L7	L1	L2	L0	L3	L4	L5
	5'	20'	30'	5'	INLET	INLET	INLET	INLET	INLET	INLET
PARAMETER										
ph (Standard Units)	6.9	6.5	6.1	6.8	7.1	7.1	6	6	6	6
Total Alkalinity	16	15	13	15	49	24	7	19	5	16
Total Hardness	26	26	26	26	83	41	17	28	16	26
Suspended Solids	3.0	6.0	3.5	3.0	1.5	0.5	0.0	0.5	4.5	0.5
Total Solids	100	80	108	96	180	154	84	92	64	92
Specific Conductivity (micromhos/cm)	130.0	120	130	130	220	190	100	130	64	120
Total Kjeldahl-Nitrogen	0.60	0.35	0.92	0.82	0.70	0.82	0.55	0.75	0.50	0.62
Ammonia-Nitrogen	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrite-Nitrogen	0.001	0.002	0.017	0.003	0.005	0.007	0.003	0.003	0.024	0.003
Nitrate-Nitrogen	0.0	0.1	0.3	0.1	0.0	0.1	0.0	0.1	0.3	0.1
Orthophosphate	0.01	0.01	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02
Total Phosphorus	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.04	0.02	0.02
Silica	0.4	6.0	5.6	4.9	6.9	7.8	9.2	2.5	7.0	4.3
Chlorides	22	22	21	24	15	42	24	23	17	21
Total Iron	0.10	0.20	1.2	0.15	0.30	0.45	0.15	0.25	0.45	0.10
Total Manganese	0.03	0.12	0.59	0.02	0.31	0.01	0.02	0.04	0.07	0.09
Color (color units)	25	30	50	50	35	90	150	60	60	15
Total Coliform Bacteria/100 ml	50	--	--	10	380	300	300	40	300	70
Fecal Coliform Bacteria/100 ml	<5	--	--	5	5	30	40	20	<5	20

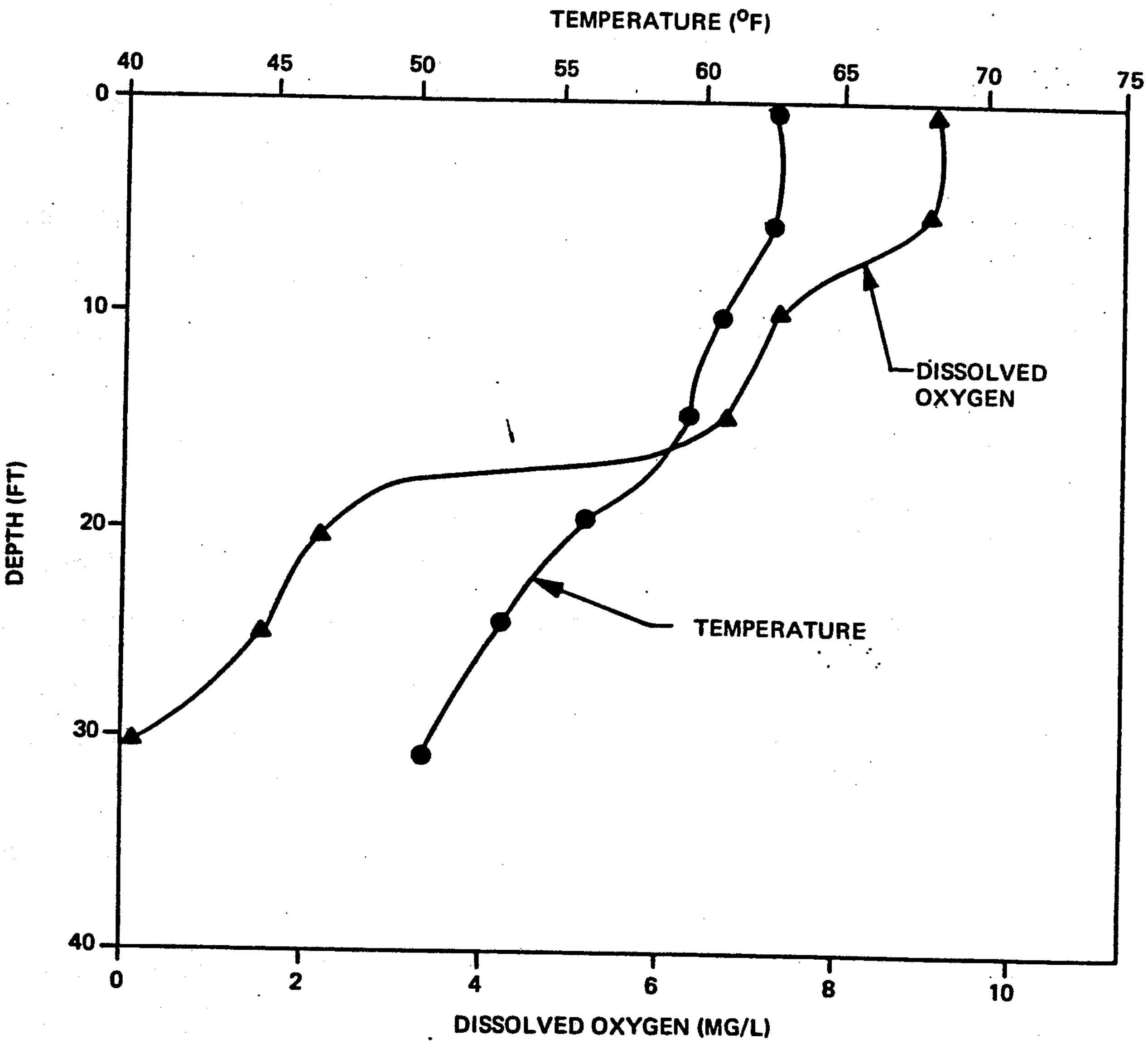


FIGURE 2-7. LAKE SHIRLEY TEMPERATURE AND DISSOLVED OXYGEN PROFILES JUNE 21, 1977 (DWPC, 1977)

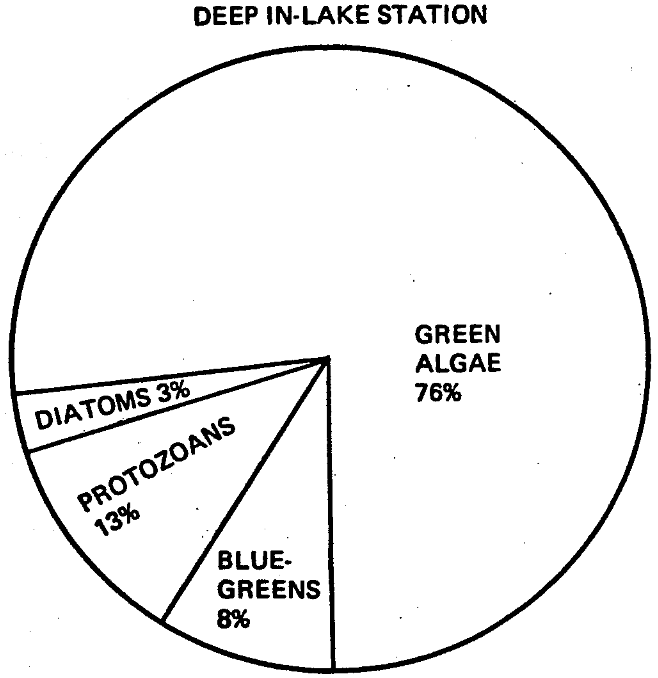
growth. At total phosphorus and total nitrogen concentrations greater than approximately 0.03 and 0.5 mg/l, respectively, it is often considered that eutrophic conditions exist (Wetzel, 1975). MDWPC data show that Wetzel's nitrogen criterion was exceeded in Lake Shirley during the 1977 survey and total phosphorus data were below the phosphorus criterion. Depressed phosphorus concentrations during the MDWPC survey could be due to plant uptake by the large populations of aquatic macrophytes and algae in the lake.

The temperature and dissolved oxygen profiles measured during the 1977 survey are shown in Figure 2-7. These temperature data reveal the development of density stratification during warm periods. Past dissolved oxygen data reveal that some very low concentrations occur in the hypolimnion or the lower depths of the lake during summer stratification. Data collected on June 21, 1977 show low dissolved oxygen just above the sediment at the deep basin at a depth of 30 feet. This condition can contribute to elevated water column nutrient concentrations. Although an increase in phosphorus concentration was not observed at the lower lake depths, increases in ammonia and nitrate did occur. DO levels were near saturation at the surface. More extensive discussion of water quality conditions in the lake and their implications based on historical and recently collected water quality data is given in Chapter 3.

Historical Biological Data

Historical biological data related to phytoplankton and aquatic macrophytes in Lake Shirley were obtained from files maintained by the Massachusetts Division of Fisheries and Wildlife and the Division of Water Pollution Control. Phytoplankton data collected during the 1977 MDWPC survey indicated a total cell count of 1210 cells/ml for the deep in-lake station and 920 cells/ml for the north shallow basin. The phytoplankton population was composed mostly of green algae with diatoms, blue-greens and protozoans also present. These data are presented for both stations in Figure 2-8 as percent of the total population.

A qualitative description of aquatic macrophytes at Lake Shirley is provided in a Survey of Inland Waters from 1912. Observed species included pondweed, eel grass, bladderwort and other algae. Aquatic macrophyte populations were assessed during a biological survey of Lake Shirley conducted on July 14, 1951 by the Massachusetts Division of Fisheries and Game. Emergent vegetation was classified as scant with water-lily *(Nuphar)* 30 percent, spike-rush *(Eleocharis)* 60 percent and bur-reed *(Eleocharis)* 10 percent. Submerged macrophytes were common with fanwort *(Cabomba)* 85 percent, bladderwort *(Utricularia)* 10 percent and miscellaneous aquatics. In a letter from J. Woolner (1953) of the Central Wildlife District to Kennedy of the Bureau of Wildlife Research and Management, Woolner states that "the entire pond, with the exception of deep water, which is



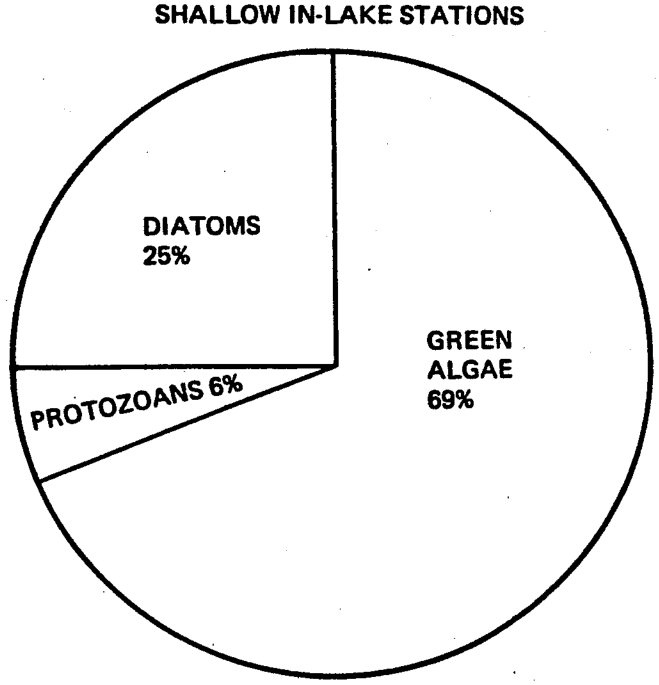


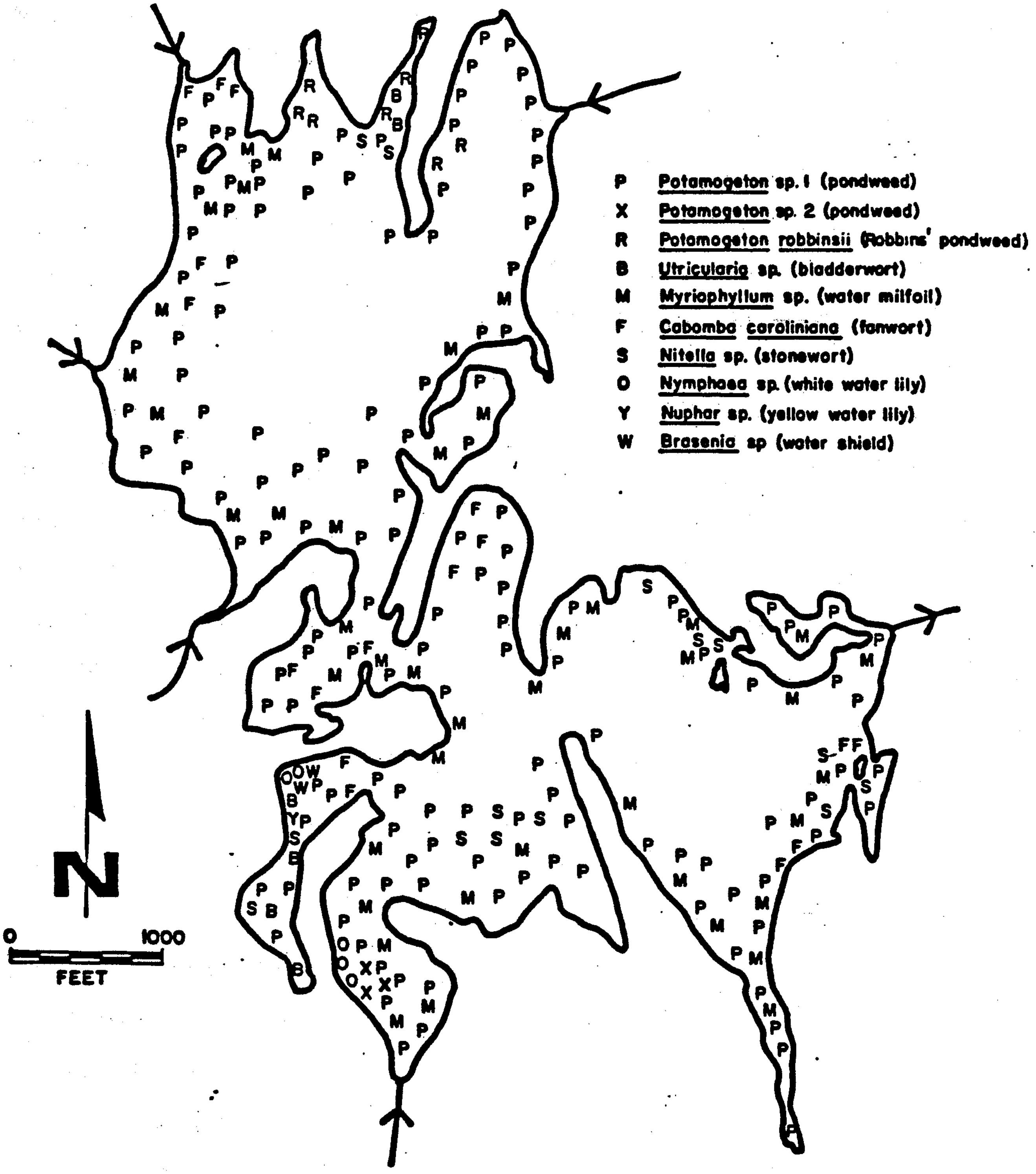
FIGURE 2-8. TAXONOMIC COMPOSITION OF PHYTOPLANKTON IN LAKE SHIRLEY ON JUNE 21, 1977 (MDWPC, 1977)

only a small part of the 381 acres, is choked with aquatic weed growth consisting mostly of *Cabomba caroliniana*."

It is interesting to note that water-milfoil *(Myriophyllum)* was not observed in any of the above accounts which date up to 1953. *Myriophyllum* was not documented until 1977 in an assessment of aquatic macrophyte populations conducted by the MDWPC suggesting that this species was inadvertently transplanted during the interim period. The MDWPC characterized the macrophytes as very dense with pondweed *(Potomogeton)* and water milfoil *(Myriophyllum)* as the dominant genera. A complete list of the aquatic macrophytes identified during the MDWPC survey and their approximate locations and densities is shown on Figure 2-9.

Representatives of the Massachusetts Division of Fisheries and Wildlife were contacted but no recent fisheries data were available. In response to an inquiry of whether the state would consider conducting a fish population survey, Cronin (1987) stated that due to past uncertainties over whether the lake was public or private, no work was planned for the lake in the near future.

Massachusetts Division of Fisheries and Wildlife files were reviewed for past information on fish populations and stocking history. Records showed that before 1952 nearly 821,000 fish were stocked officially in Lake Shirley as well as numerous other unofficial stockings. Species stocked in the past include rainbow trout, bluegills, horned pout, white perch, crappie, yellow perch and pickerel. Fish population surveys conducted by



Source: Reproduced from MDWPC, 1977

FIGURE 2-9. AQUATIC VEGETATION SURVEY OF LAKE SHIRLEY the Division of Fisheries and Wildlife and reports by local anglers indicated the presence of other species including largemouth bass, white suckers, banded sunfish, and pumpkinseed. The most recent stocking date found was 1952.

Division of Fisheries and Wildlife files contained some quantitative and qualitative analysis of the state of the fish population. Interagency letters, pages from unidentified reports and population surveys conducted by the Division indicated a concensus that much of the stocking of panfish such as bluegills, bullhead and white perch was ill-advised since these species go virtually unharvested by anglers. In addition, these species tend to lead to overcrowding. Several writers concluded that Lake Sirley was best suited to and should be managed for chain pickerel and that past "unofficial" stockings of largemouth bass were also ill-advised since these fish may compete with existing chain pickerel populations. In addition, largemouth bass are about three times as difficult to catch as chain pickerel. Peaslee (1944) stated that Lake Shirley was "one of the finest pickerel ponds in the area and is heavily fished throughout the season.

Potential Groundwater Contamination Sources

During the Lake Shirley diagnostic study, a number of potential sources of groundwater contamination were identified. Due to concerns over the impact of nutrient loading and toxic contamination from several potential groundwater pollution sources near Lake Shirley, Metcalf & Eddy conducted an inventory of these sources. These sources included landfills in Lancaster and Shirley; commercial and recreational facilities on the lake including Camp David, Shady Point and Lake Shirley Beach; junkyards; underground fuel tanks; a salt storage facility in Leominster; the Pioneer Drive industrial area; Penniman's septage disposal lagoons; the Keating Sand and Gravel site; a DEQE hazardous waste site and the Stillman and MacMillan farms. These sites are listed in Table 2-6 and their locations are shown on Figure 2-10. An analysis of the potential contribution of nutrients from these sites to the lake is presented in Chapter 4. Information on these sites was obtained from the DEQE Water Supply Protection Atlas, maps prepared by the Lunenburg Water District, site visits, and personal interviews.

TABLE 2-6. POTENTIAL GROUNDWATER CONTAMINATION SOURCES

Sub-drainage Area A

Sand Pits

DPW Salt Storage Facility

Lancaster Landfill

Pioneer Drive Industrial Park

Stillman Farm

MacMillan Farm

Camp David

Shady Point Beach

Glenny's Marina

Sub-drainage Area B

Penniman Septage Disposal Lagoons

Closed Hazardous Waste Site

Sand Pits

Arbor Street and Stone Fence Road Developments

Sub-drainage Area E

Keating Sand and Gravel

Sources in Several Subareas

Junkyards

Underground Fuel Tanks

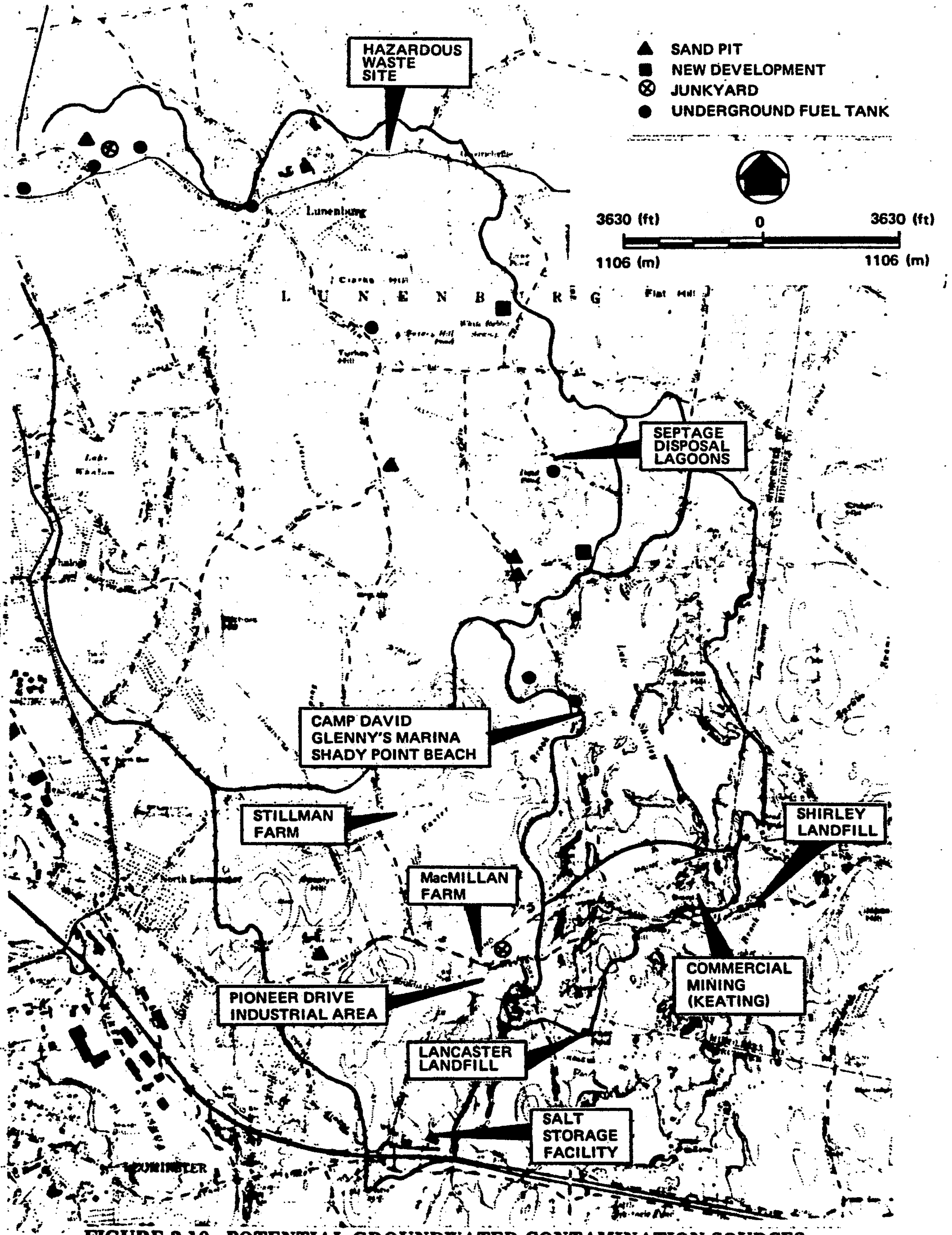


FIGURE 2-10. POTENTIAL GROUNDWATER CONTAMINATION SOURCES IN THE LAKE SHIRLEY WATERSHED

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CHAPTER 3

DIAGNOSTIC SURVEY

A Phase I diagnostic survey of Lake Shirley has been conducted to provide baseline information on the lake and to aid in the development and evaluation of methods for improving conditions in the lake. The diagnostic survey included collection of data on in-lake water quality, inlet and outlet flow and quality, stormwater runoff quantity and quality, lake bottom sediment quality, water and sediment depth measurements, a septic leachate survey, a wastewater disposal questionnaire, and a macrophyte survey. The data collection programs are described in this chapter, followed by a presentation and analysis of the data. Sampling techniques, sample preservation, and analytical methodology were conducted in accordance with Standard Methods and EPA Methods for Chemical Analysis of Water and Wastewater.

Description of Field Measurement Program

A one-year data collection program was conducted at Lake Shirley from March, 1986 to February 1987. A schedule of the surveys conducted is presented in Table 3-1. The locations of monitoring stations are shown in Figure 3-1. The various data collection efforts are described in detail in the following paragraphs.

In-Lake and Inlet/Outlet Data. Water quality data were collected at eight stations during the diagnostic survey. Stations L1 through L4 are the major inlets, station L5 is the outlet dam and stations L6 and L7 are located at the centers of

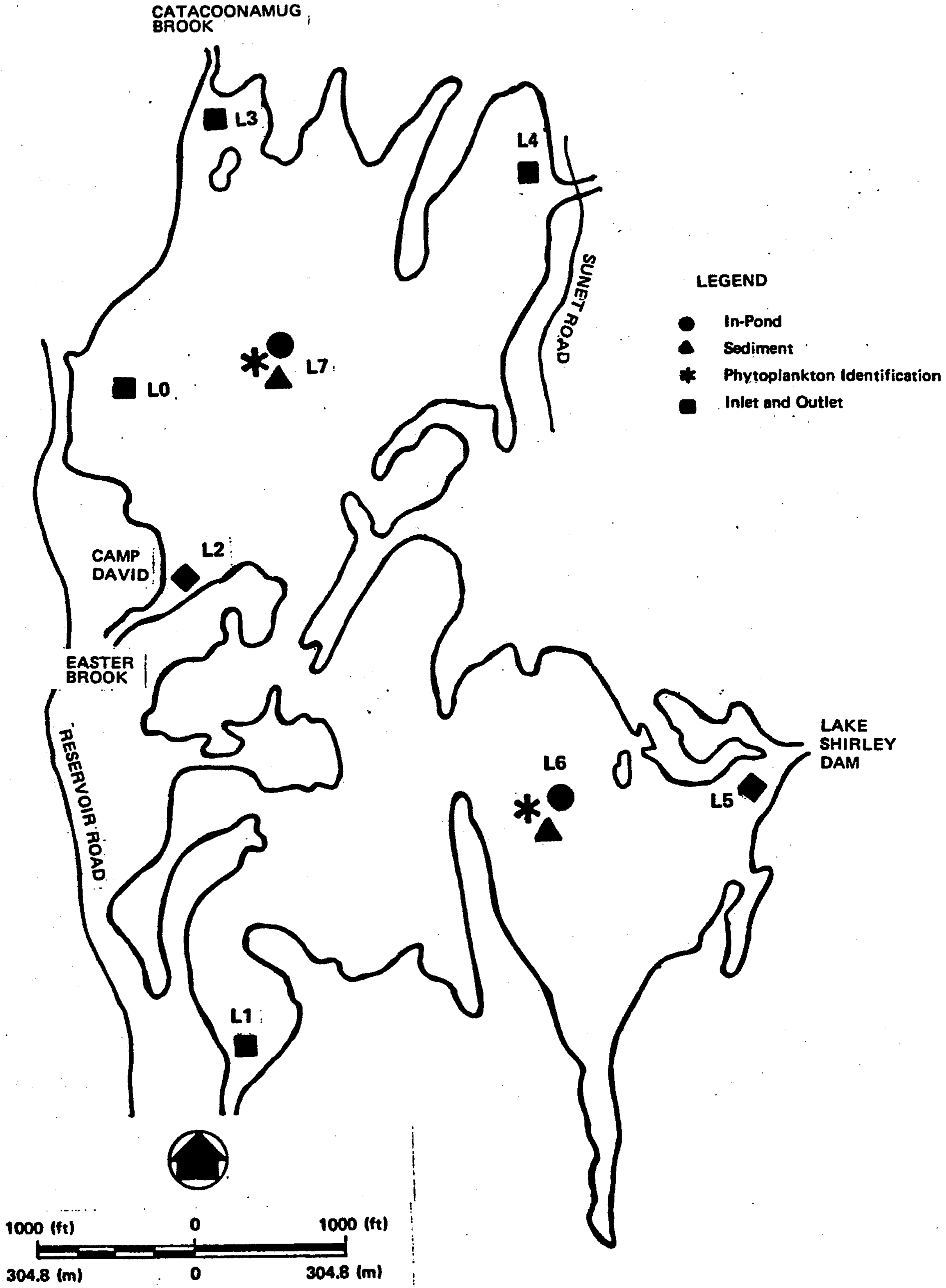


FIGURE 3-1. DIAGNOSTIC SURVEY SAMPLING STATIONS

TABLE 3-1. SCHEDULE OF SURVEYS CONDUCTED AT LAKE SHIRLEY

Survey Type	Date
In-lake water quality	March 11, 1986
In-lake water quality	March 26
In-lake water quality	April 10
Sediment quality	April 24
In-lake water quality	April 24
In-lake water quality	May 14
In-lake water quality	May 28,
In-lake water quality	June 10
In-lake water quality	June 24
In-lake water quality	July 8
In-lake water quality	July 22
Septic leachate survey	August 12, 13, 14
In-lake water quality	August 12
Macrophyte survey	August 13
Bathymetric survey	August 13
Macrophyte survey	August 21
Bathymetric survey	August 21
In-lake water quality	September 2
In-lake water quality	September 18
In-lake water quality	September 30
In-lake water quality	October 16
In-lake water quality	October 28
In-lake water quality	November 20
In-lake water quality	December 30
In-lake water quality	January 15, 1987
In-lake water quality	February 25
Stormwater sampling	March 1
Stormwater sampling	April 28

the two major lake basins. An additional inlet station, station LO, was added during the second half of the diagnostic survey. This station was initially thought to be an intermittent stream but was subsequently found to run on a constant basis. Data collection surveys were conducted bi-weekly during most of the survey period, and monthly during the winter months (November to February). Direct in-lake measurement of various water quality parameters was conducted using a HYDROLAB Surveyor II water quality instrument. In addition to these in-situ measurements, discrete samples were collected for laboratory analysis of chemical parameters. The parameters measured during these surveys are listed in Table 3-2.

At stations L6 and L7, data on the vertical variation of water quality were obtained. In situ measurements of temperature, dissolved oxygen, pH, and conductivity were taken at one-half meter depth intervals. Discrete samples were taken at 20 percent and 80 percent of the total depth. During periods of stratification, a discrete water sample was collected at the thermocline. Samples for coliform bacteria were collected near the water surface only. Chlorophyll-a and phytoplankton samples were depth-integrated over the depth of light penetration. For an indication of light penetration, a 20 cm diameter Secchi disk with alternating black and white quadrants was used to record the water transparency (the depth at which the disk is no longer visible). In addition to the water quality measurements, the flow rate at each inlet and the outlet was measured.

Stormwater Data. One source of nutrient and sediment loading to Lake Shirley is stormwater runoff which enters the lake through each inlet and several smaller storm drains from nearby areas. As part of the diagnostic study, two rainfall events were monitored to assess the impact of stormwater runoff entering the lake. Prior to submission of the Final Report, a third storm will be monitored.

TABLE 3-2. PARAMETERS MEASURED DURING WATER QUALITY SURVEYS

	Measurement Detection Limit
DIRECT IN-LAKE MEASUREMENTS	
Temperature	± 0.1 deg C
Dissolved Oxygen	0.1 mg/l
pH	0.1 unit
Conductivity	1 umho/cm
Secchi Disk Transparency	-
Inflow/Outflow	0.1 cfs
SAMPLES WITHDRAWN FOR LABORATORY ANALYSIS	
<u>Physical-Chemical Parameters</u>	
Suspended Solids	1.0 mg/l
Dissolved Solids	1.0 to 5.0 mg/l
Chlorides	0.5 mg/l
Alkalinity	0.1 mg/l
<u>Nutrients</u>	
Total Phosphorus	0.01 mg/l
Total Kjeldahl Nitrogen (TKN)	0.05 mg/l
Ammonia-Nitrogen	0.05 mg/l
Nitrate-Nitrogen	0.01 mg/l
<u>Biological Parameters</u>	
Phytoplankton	Genus level
Chlorophyll-*a*	0.1 mg/m^3
<u>Bacteria</u>	
Total Coliform	1 colony/100 ml
Fecal Coliform	1 colony/100 ml

Stormwater runoff surveys were conducted during March and April, 1987. During the first storm, a flow-composited sample was collected from each runoff station. During the second storm, based on the results of the first survey, three sites were chosen and sampled in detail according to established protocol which includes sampling at the first hydraulic flush and at specific time intervals thereafter for a minimum of two hours or one hour after peak flow. Flow measurements were obtained using a portable flow velocity meter. Total rainfall was measured on-site during each event. The parameters analyzed are listed in Table 3-3.

Sediment Data. Sediment samples were taken at in-lake Stations L6 and L7 (Figure 3-1) at Lake Shirley on April 24, 1986. Samples were taken with a hand-operated, stainless steel Ponar grab sampler, transferred to bottles and transported to the laboratory. Each sample was analyzed for the parameters listed in Table 3-4.

Macrophyte Survey. A macrophyte survey of the lake was performed on August 13 and August 21, 1986 to determine areal extent and to identify dominant genera of submerged, emergent and floating aquatic macrophytes. In order to characterize adjacent wetlands such as marshes, meadows, swamps and bogs, plants were also identified around the edges of the lake and in the nearby wetlands.

Septic Tank Leachate Survey. A septic leachate survey was performed by KV Associates, Inc. around the shoreline of Lake Shirley on August 12, 13 and 14, 1984, to locate any septic system leachate plumes or overflows entering the lake. This survey was conducted using an ENDECO Type 2100 "Septic Snooper", a KVA Model 12 "Peeper Beeper", and a KVA Groundwater Flow

TABLE 3-3. PARAMETERS MEASURED DURING STORMWATER RUNOFF SURVEYS

Parameter	Measurement Detection Limit
Suspended solids	1.0 mg/l
Dissolved solids	1.0 to 5.0 mg/l
Total Kjeldahl nitrogen	0.05 mg/l
Ammonia nitrogen	0.05 mg/l
Nitrate nitrogen	0.01 mg/l
Total phosphorus	0.01 mg/l
Chlorides	0.5 mg/l
Total and fecal coliform	1 colony/100 ml
Heavy metals (1)	
Chromium	0.05 mg/l
Manganese	0.01 mg/l
Iron	0.03 mg/l
Copper	0.02 mg/l
Zinc	0.01 mg/l
Cadmium	0.01 mg/l
Lead	0.05 mg/l
Discharge	0.01 cfs
Total rainfall	-

1. Flow weighted composite at each site.

TABLE 3-4. PARAMETERS FOR SEDIMENT ANALYSIS

Parameter	Minimum Detection Limit
Total phosphorus	0.5 mg/kg
Total nitrogen	5.0 mg/kg
Organic fraction	1 percent
Oil and grease	1.0 mg/kg
Heavy metals (1)	0.5 mg/kg

1. Chromium, manganese, iron, copper, zinc, cadmium and lead.

Meter. The Septic Snooper detects both fluorescence (organics) and conductivity. The instrument is calibrated with wastewater effluent. After calibration, the meter probe is submerged in the lake near the shoreline, and conductivity and fluorescence signals are generated. These signals are recorded on a stripchart recorder as the probe is moved along the shoreline. High signals of conductivity and fluorescence are indicative of a plume entering the lake through surface or groundwaters.

The Peeper Beeper is a fluorescence detector sensitive to the degradation products of human urine as well as the fluorescent characteristics found in commercial laundry detergents. The unit is calibrated with human urine. Whereas the Septic Snooper will detect influent bog plumes as well as septic plumes, the Peeper Beeper will not detect bog plumes. Thus, by using both of these instruments additional characterization of the influent plumes was possible. To verify plume locations and to allow estimation of influent contaminant loading from the plumes, discrete samples were collected at locations where plumes were detected and analyzed in the laboratory for nutrient concentrations.

Groundwater flow measurements were taken at eight shoreline locations around the lake. Both flow direction and rate were measured. These measurements were taken to determine the direction of groundwater flow along the shoreline. A detailed description of these surveys is presented in the lake hydrology section of this chapter and in Appendix B, Septic Leachate Survey Report.

<u>Inventory of Wastewater Practices</u>. An inventory of on-site wastewater disposal practices was conducted by distributing a questionnaire to each home within 300 meters (about 1000 feet) of the lake. Residents were asked to respond to questions

related to septic systems, distance from lakeshore, number of people per unit, number of days of use per year, age of the system, types of appliances used, and other data. The questionnaire was developed in consultation with the Lake Shirley Advisory Committee and the Division of Water Pollution Control and is shown in Appendix C. This inventory was used in conjunction with direct measurements taken during the septic leachate survey to estimate the loading from on-site wastewater systems to Lake Shirley.

The remainder of this chapter includes presentation and discussion of the data collected during the diagnostic survey of Lake Shirley. The following general categories are included:

- Lake Hydrology
- Lake Water Quality
- Water Quality of Incoming Sources
- Lake Biology

Lake Hydrology

This section examines data collected on the hydrology of Lake Shirley. The components of the hydrology of the lake include inflow and outflow, stormwater, precipitation, evaporation and groundwater.

Inflow/Outflow Data. Flow data collected at the lake inlets and outlet during each water quality survey and the average flow for each station are shown in Table 3-5. Flow was generally highest at Easter Brook (Station L2) and Catacoonamug Brook (Station L3) and varied at all stations depending on

TABLE 3-5. LAKE SHIRLEY TRIBUTARY AND OUTLET FLOW DATA (cfs)

	Station					
Date	L0	L1	L2	L3	L4	L5
3/11/86		0.15	1.75	10.4	0.2	1.2
3/26/86		0.2	12.5		1.7	20
4/10/86		0.18	4.0	12.8	0.9	15.1
4/24/86		1.0	4.5	3.8	0.9	3.4
5/14/86		0.03	2.7	3.2	0.31	7.0
5/28/86		0.05	3.1	5.2	0.72	8.4
6/10/86		0.8	2.4	12.2	0.9	14.7
6/24/86		0.1	2.6	12	0.61	50
7/8/86		0.1	2.2	7.2	0.1	21.6
7/22/86		0.8	6.0	6.4	0.4	13.2
8/12/86		0.58	0.72	11.44	0.23	8.32
9/2/86		0.19	1.92	2.12	0.3	8.97
9/18/86	0.11	0.08	0.68	3.2	0.1	4.8
9/30/86	0.11	0.07	1.7	2.4	1.0	6.4
10/16/86	0.06	0.05	1.5	2.0	0.06	72
10/28/86	0.07	0.1	3.2	12	2.7	15.6
11/20/86	0.04	0.04	5.4	7.2	0.22	4.8
12/30/86	0.16	0.24	10.6	30	1.2	48
1/15/87	0.24	0.4	3.6	15	0.5	36
2/25/87	0.24	2.5	5.0	6.0	0.25	15
Average	0.13	0.38	3.8	8.2	0.7	18.7

rainfall. The wide variations in outflow at Station L5 which is the continuation of Catacoonamug Brook were due to the operation of the outlet dam. The operation of the outlet dam and fluctuations in lake level are discussed in the following paragraphs.

The rate of outflow and the lake elevation are controlled with a spillway dam which has a current capacity of about 1,200 cubic feet per second and is equipped with an adjustable subaqueous outlet gate. The outlet structure is operated by a damkeeper appointed by the Lake Shirley Improvement Corporation. The goal of the outlet operation is to maintain the Lake Shirley surface at an elevation of approximately 1"-6" over the crest of the dam during the heavy recreational period (April to October) and approximately 3.0 feet below the crest of the dam during winter (October to March) to allow for flood control during winter and spring and a limited drawdown to control shoreline weeds. The most acceptable level of drawdown for Lake Shirley has been a subject of debate for many years and is subject to several regulations and required permits.

The present level of drawdown was established through consideration of a number of factors that are influenced by the lake elevation. Flood control and dam safety concerns are addressed by lowering the lake level during flood season and by opening the gate when rain is forecast. As the lake level rises significantly over the crest of the dam, as has occurred during past floods, numerous lakeshore residents experience basement flooding problems. On the other hand, when the lake elevation is lowered, some lakeshore residents experience reduced water supply from private wells. Environmental concerns related to lake level focus on potential impact on water supply, wetlands and aquatic life. Prior to 1977, drawdown practices at Lake Shirley involved an annual six-foot drawdown as permitted by the Lunenburg Conservation Commission. During this period, lake residents noticed that the macrophyte population was reduced and water clarity was improved. From 1977 to 1984, the drawdown was 3 feet below the spillway from October 15 to November 30 and 2 feet below the spillway from November 30 to March 15.

Drawdown procedures are controlled by the Wetlands Protection Act (General Laws, Chapter 131, Section 40) which protects wetlands, water supply and fisheries resources. The Lake Shirley Improvement Corporation applied for a variation under the Wetlands Protection Act in 1984, however it was determined that a Massachusetts Environmental Policy Act Environmental Impact Report would be required and the application was denied. Further, several residents expressed concern that a more extensive drawdown would threaten private water supplies. Thus the current DEQE order permits a drawdown of 2.5 feet below the spillway.

During May of 1987, the dam at Lake Shirley developed a serious leak resulting in an emergency drawdown of the lake supervised by the DEQE and the Department of Environmental Management (DEM). During the drawdown period which has extended from May to submission of this report, the lake has been drawn down below the cement portion of the dam or about 9-12 feet below the top of the spillway and many lakeshore residents have experienced water shortages or dry wells. Some residents are improving their wells in order to maintain water supply during the remainder of the drawdown. Preparations are currently being made to install a temporary dam until a permanent dam can be designed and constructed.

Stormwater Inflows. Surface water flow to the lake increases significantly during rainfall events. The purpose of the stormwater sampling program is to characterize the quality and quantity of stormwater inflow to the lake during wet weather periods. A total of six sub-basins were monitored during wet weather. Two of the initial six sub-basins were monitored in detail on one additional storm event. Data on a third storm will be presented in the Final Report. These data are used in Chapter 4 in the calculation of the hydrologic and nutrient budgets.

Precipitation and Evaporation. The total annual precipitation in the study area is about 44 inches, and is fairly evenly distributed throughout the year. The heaviest 1-day rainfall during the period of record was 4.43 inches at Fitchburg on September 12, 1954. Thunderstorms occur on about 21 days each year, and most occur in summer (SCS, 1985).

Evaporation measurements available from the weather station at Rochester, Massachusetts have been used to estimate evaporation. Evaporation loss for lakes in Massachusetts is estimated at 27 inches per year (Linsley et al., 1975).

Groundwater. The topography of the watershed indicates a general pattern of easterly groundwater flow toward the Nashua River. This was confirmed by groundwater flow measurements conducted during August. A map indicating measurement locations and groundwater flow vectors (magnitude and direction) is shown in Figure 3-2. The ratio of the lake drainage area to the surface area is 26:1. This ratio is relatively large and thus the contribution of surface water to the lake hydrologic budget is expected to be large in comparison with groundwater.

Lake Water Quality

Water quality data obtained during the diagnostic survey are presented in this section. A brief description of the significance of each parameter is provided, as well as specific interpretation of the data collected at Lake Shirley. According to the Massachusetts Water Quality Standards, Lake Shirley is a Class B water. Reference will be made to the State's Standards for those parameters for which water quality criteria have been established. A listing of all water quality measurements obtained during the diagnostic survey is presented in Appendix A.

Temperature and Dissolved Oxygen. Wide variations in water temperature occur in Lake Shirley over the course of the year due to variations in climatic conditions. Water temperature influences a variety of biological and water quality processes, as well as the dissolved oxygen concentration. Oxygen which has been absorbed into the water from the atmosphere is referred to

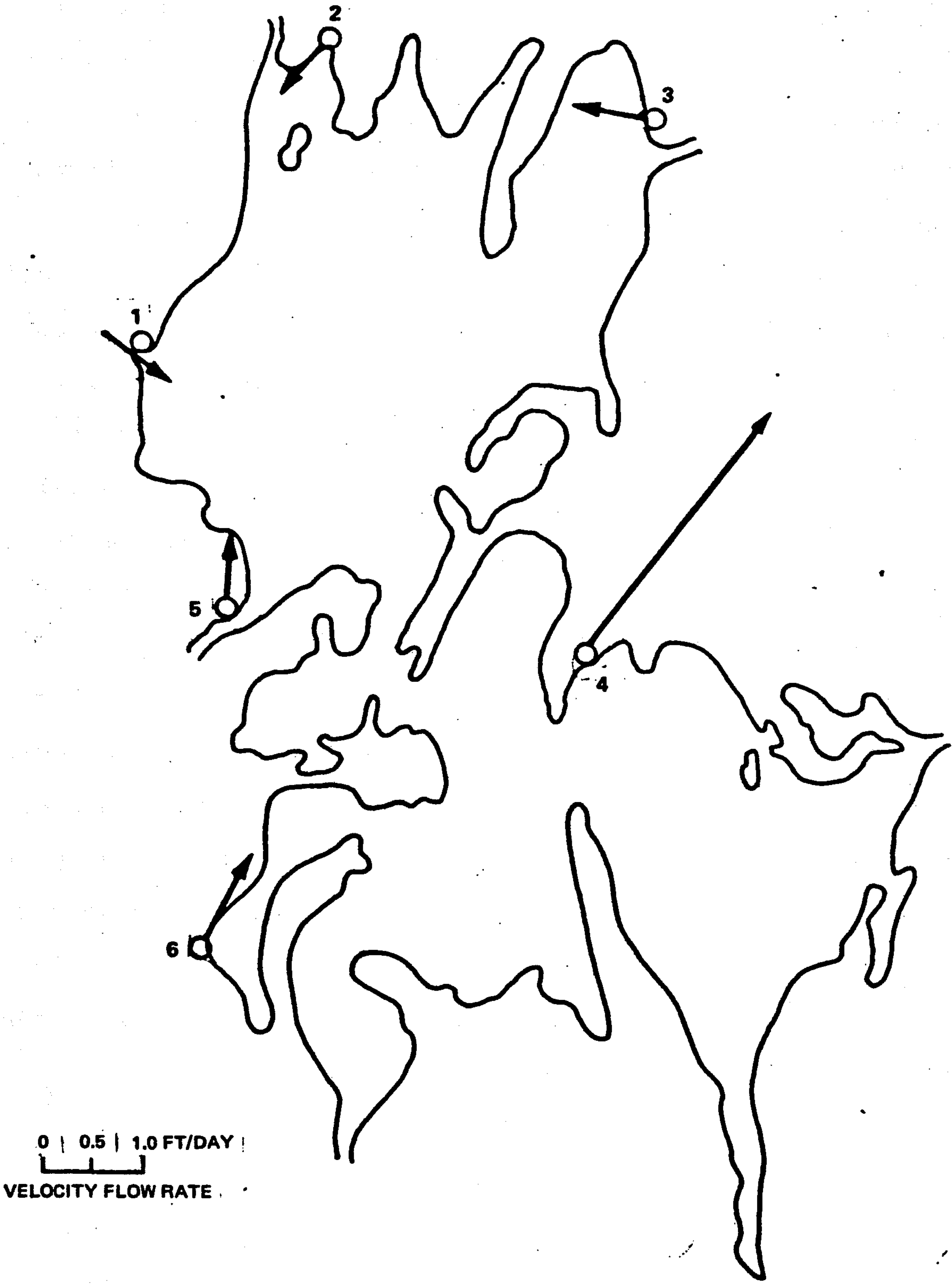


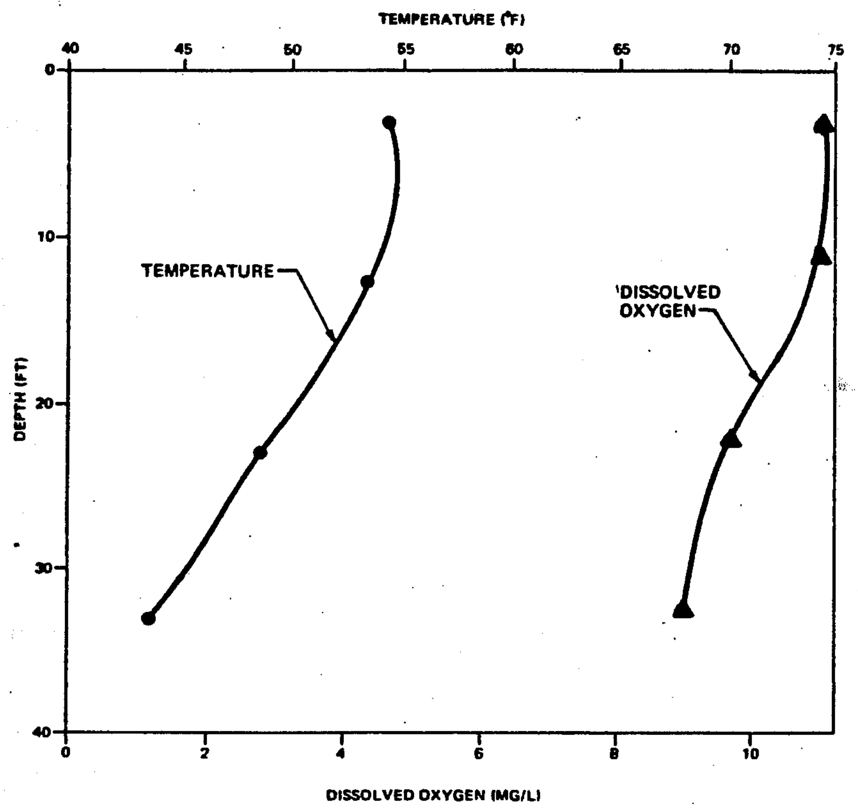
FIGURE 3-2. LAKE SHIRLEY GROUNDWATER VELOCITY AND DIRECTION

as dissolved oxygen. At colder temperatures, water has the capacity to retain higher dissolved oxygen (DO) concentrations. The maximum stable DO concentration that water will retain at a given temperature is defined as the saturated DO concentration. During the summer when the water temperature can reach 22°C (72°F), DO saturation values are approximately 8.5 mg/l. During winter periods when the water temperature may approach freezing, saturation values may be as high as 14 mg/l. Occasionally, supersaturated DO concentrations may occur. A possible precursor of supersaturated conditions is a severe algal bloom. Algal growth produces oxygen through photosynthesis and may cause supersaturated conditions near the surface. This phenomenon is reduced in winter due to depressed biological activity in cold temperatures.

The vertical variation of temperature in the water column is important for a number of reasons. Temperature is related to water density, with 4 degrees Centigrade (39°F) being the point of maximum density. As water temperatures increase above 4°C, density decreases. During the summer months, solar radiation raises the temperature of the surface waters more readily than deeper waters, and thus a layer of warmer, less dense water may sometimes overlay the colder, denser water. Mixing between the upper and lower layers of the lake is limited due to density differences. This effect is referred to as stratification. During periods of stratification it is possible to develop very low dissolved oxygen concentrations in the bottom waters due to demand by microbes in the sediments and lack of oxygen influx from the surface waters. DO concentrations may be influenced by the decomposition of summer algae, macrophytes and leaves which have fallen into the lake. In Lake Shirley, stratification develops for extended periods of time in the deepest areas of the lake; however, due to wind mixing and the shallow depth of the northern basin, stratification does not occur in this area.

The State water quality standard for dissolved oxygen is 5.0 mg/l minimum. It is common to find DO concentrations below this standard near the bottom of stratified lakes with a reasonable amount of biological productivity. Extended periods of low dissolved oxygen are undesirable for several reasons. Reasonable DO concentrations must be maintained in order to support biological communities. Fish, as well as other aquatic organisms, require oxygen, and several game species are more sensitive to depressed DO than non-game species. Extended periods of depressed DO will reduce biological populations to those few that can withstand such conditions. Severely depressed DO may encourage the growth of anaerobic bacteria which produce obnoxious gases and offensive odors. Also, when the DO concentration approaches zero at the sediment/water interface, it is possible for nutrients to be released from the sediments into the water column, thus further stimulating plant growth.

Figure 3-3 shows the temperature and dissolved oxygen profiles measured at Station L6, the deepest in-lake station in Lake Shirley, on April 24, and July 8, 1986. During the April



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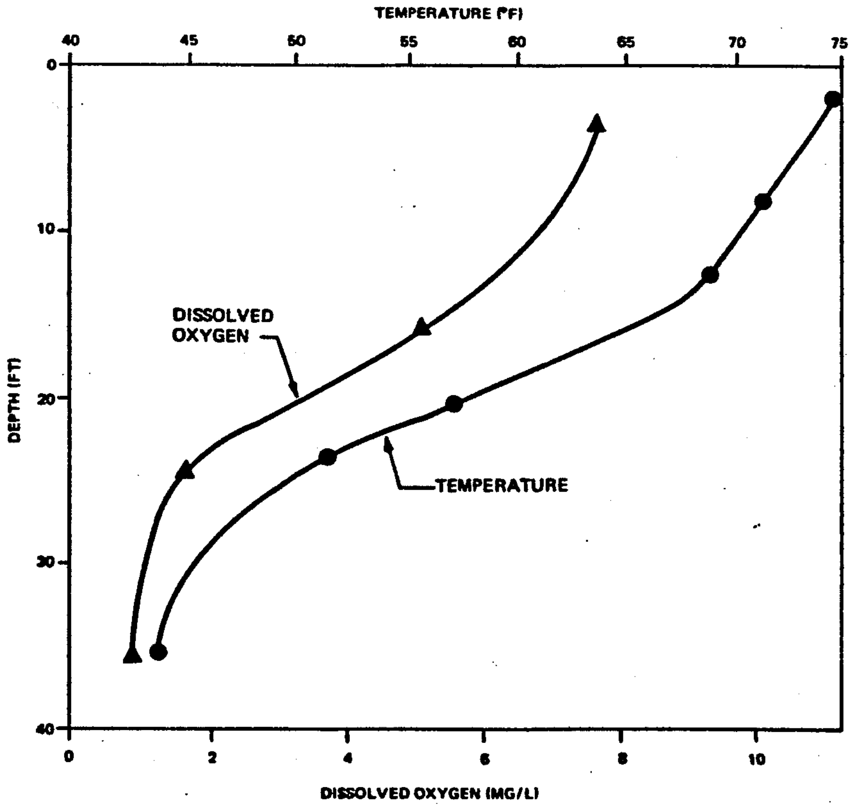

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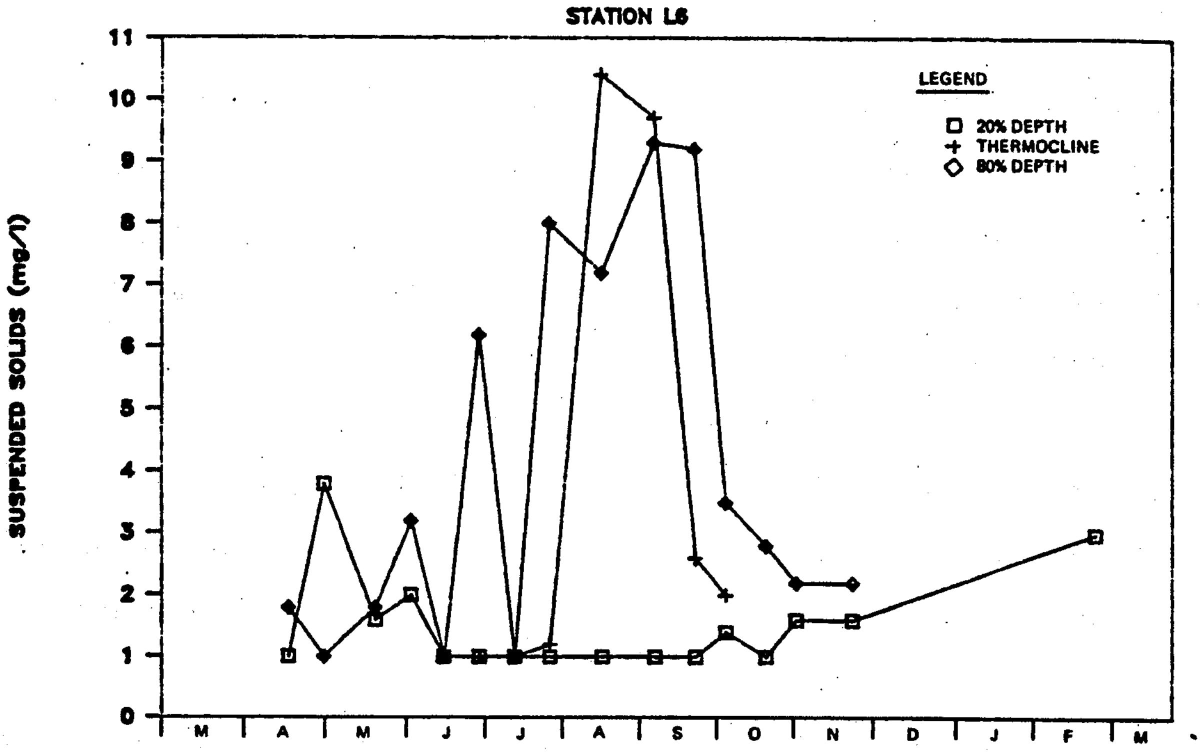
FIGURE 3-3. LAKE SHIRLEY TEMPERATURE AND DISSOLVED OXYGEN PROFILES AT STATION L6 survey, the temperature and DO profiles were fairly uniform. Water temperatures were still fairly low and slight vertical variation was caused by surface warming. DO concentrations ranged from 9 to 11 mg/l or about 90 percent of saturation for the concurrent temperatures. On July 8, stratification was present and this condition continued and intensified until the end of October. In the hypolimnion during stratification, DO concentrations approached zero as compared to saturation values of approximately 10 to 12 mg/l for the associated water temperatures.

As previously described, stratification causes chemically reducing conditions in the hypolimnion (deepest depths) which can cause the release of phosphorus from the sediments to the water column. The development of this condition in Lake Shirley may be due, in part, to the decomposition of the dense macrophyte population. However, deep water in Lake Shirley is limited to a small area and the release of phosphorus from this area during stratification is negligible as presented in Chapter 4. Most of the areal extent of Lake Shirley is less than ten feet deep and stratification does not occur. Data collected at Station L7 are representative of average conditions throughout the lake and were generally consistent with surface readings at Station L6. Dissolved oxygen concentrations in Lake Shirley were safe for aquatic life, with the exception of hypolimnetic conditions during warm weather. However, these depressed DO conditions involved only a small volume of the lake and no impact on fisheries is expected.

Suspended Solids and Secchi Depth. Suspended solids consist of particles which remain in suspension in the water column and do not settle to the bottom. High concentrations of suspended solids may inhibit aquatic macrophyte growth and fish species that cannot tolerate turbid conditions. Suspended solids can contribute to the brown or green color of water. Suspended solids measured during the diagnostic survey at the deep in-lake station (Station L6) and the shallow in-lake station (Station L7) are shown in Figure 3-4. Suspended solids concentrations in the lake during the diagnostic survey varied from <1 to 10.4 mg/l. There was an increase in suspended solids at Station L6 below the thermocline which may have been related to the stratified condition of the lake. There is no established water quality standard for suspended solids applicable to Lake Shirley, and these elevated readings represent a considerable increase from background concentrations; however, these conditions affected only a small portion of the lake and no adverse impacts on the lake are expected.

Secchi depth readings provide a relative indication of water clarity. These readings can vary from near zero in extremely turbid water to several hundred feet in deep oligotrophic lakes and tropical oceans. Secchi depth measurements in Lake Shirley usually ranged from 9 to 14 feet at Station L6 and from 7 to 10 feet at Station L7 and showed no obvious seasonal pattern. These readings indicate that the clarity of the lake water is very good which probably contributes to the excessive macrophyte growth in the lake.



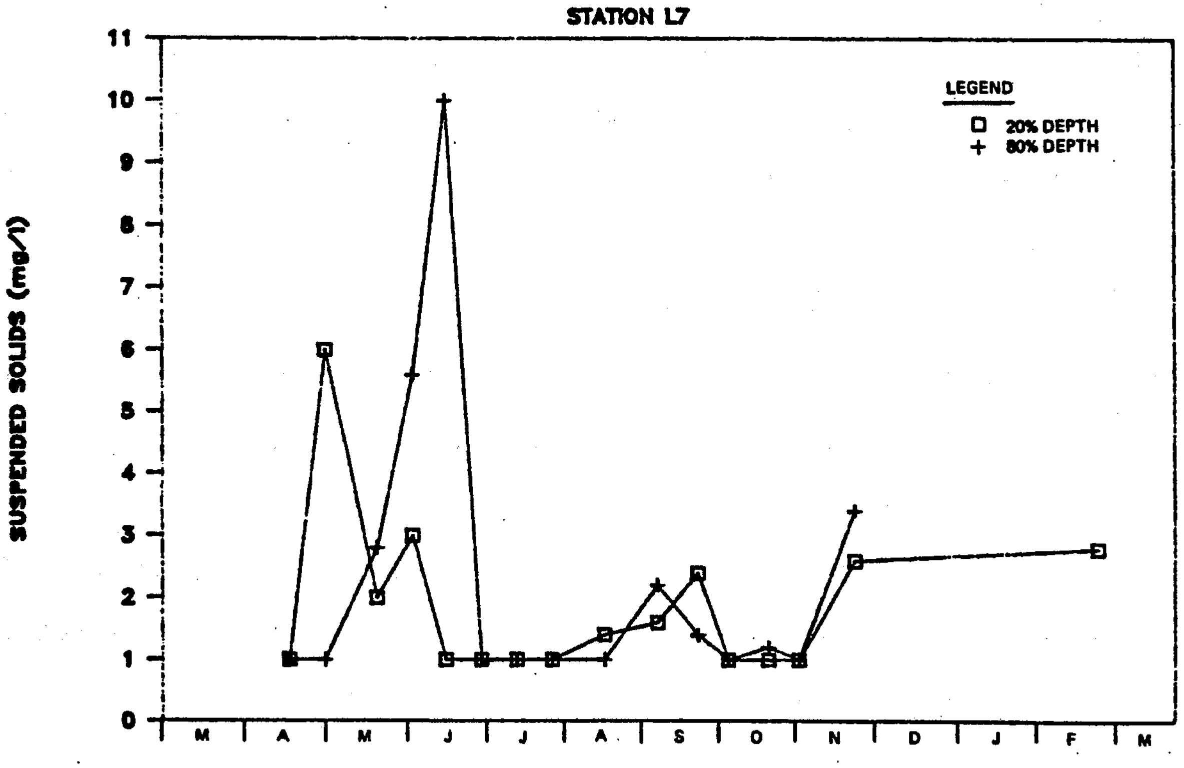


FIGURE 3-4. TOTAL SUSPENDED SOLIDS CONCENTRATIONS AT LAKE SHIRLEY STATION L6 (TOP) AND STATION L7 (BOTTOM)

Nutrients. A variety of elements are required to stimulate plant growth in a water body. Most commonly, the elements which govern plant growth are the nutrients nitrogen and phosphorus. Total phosphorus, nitrate-nitrogen (NO_3-N), ammonia nitrogen (NH_3-N), and total Kjeldahl nitrogen (TKN) were monitored during each in-lake water quality survey. These nutrients are present in commercial fertilizers, animal manure, soap, septic tank leachate and are typically very concentrated in stormwater. A water body can develop increased phytoplankton and macrophyte growth as the result of an increased supply of nutrients.

Although nitrogen is required in much greater quantities for plant growth, it is most commonly phosphorus that is the limiting nutrient in lake systems. The concentration of nitrogen in most natural waters exceeds that of phosphorus by at least an order of magnitude. As a general guideline, it is assumed that phosphorus limits primary productivity when the ratio of nitrogen to phosphorus is greater than 15:1 (Tsia, 1979). Based on nutrient data collected during the diagnostic survey, nitrogen to phosphorus ratios indicate that phosphorus is the limiting nutrient in Lake Shirley.

Total phosphorus concentrations measured at Station L6 and L7 are shown in Figure 3-5. At total phosphorus concentrations greater than 0.03 mg/l, a lake may show symptoms of eutrophication (Wetzel, 1975), such as excessive macrophyte and algae growth. Although this number varies for every lake based

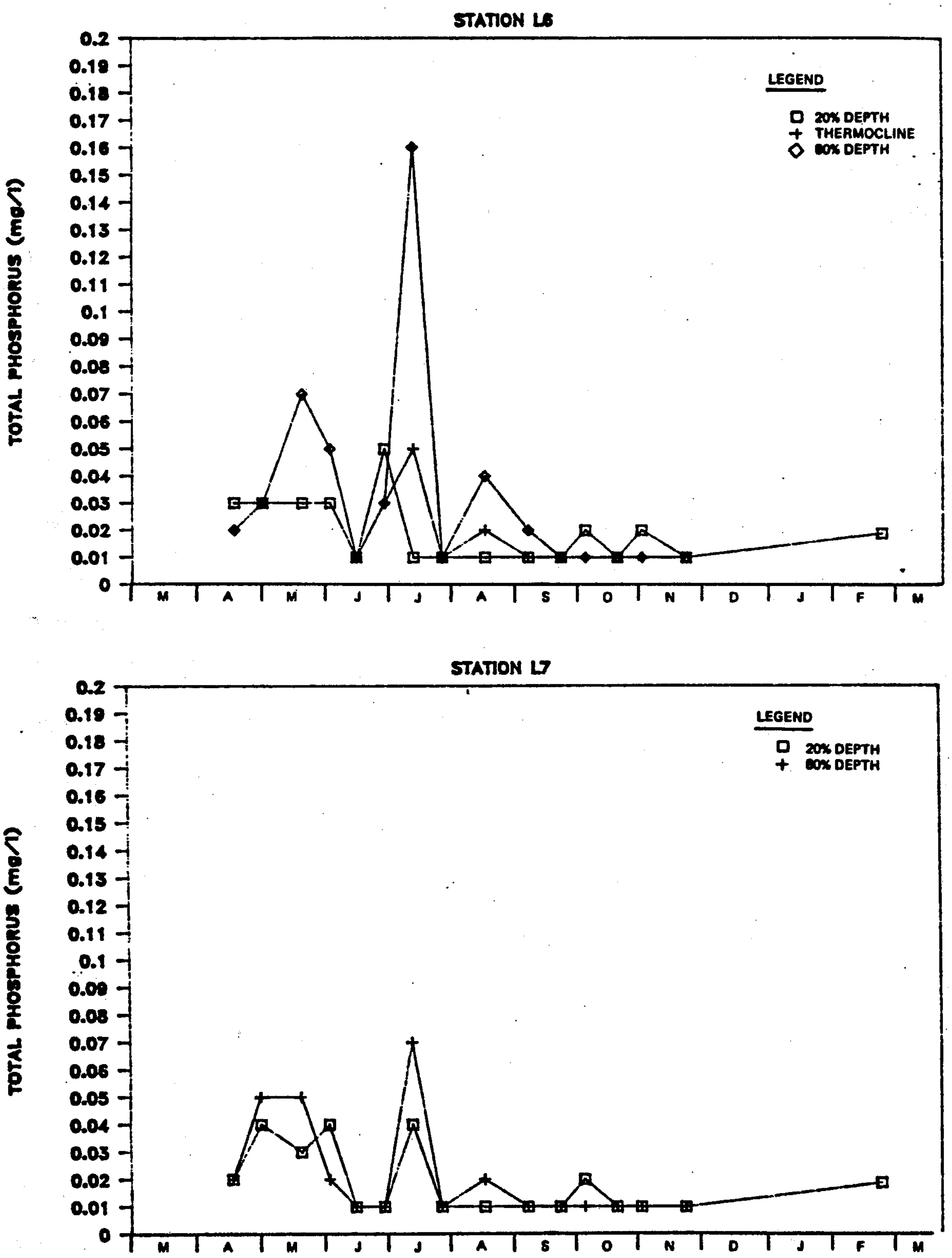


FIGURE 3-5. TOTAL PHOSPHORUS CONCENTRATIONS AT LAKE SHIRLEY STATION L6 (TOP) AND STATION L7 (BOTTOM)

on several factors including lake flushing rate, phosphorus loading, and type of algae, it is useful as a general guideline. As shown in Figure 3-5, Wetzel's phosphorus criterion was exceeded several times during the spring and early summer but remained below the criterion during the second half of the diagnostic study. The peak concentration of 0.16 mg/l at the 80 percent depth at Station L6 near the sediment/water interface and other elevated readings in July, August and September may indicate release of phosphorus to the water column during stratification; however, as discussed earlier, this release is not significant as it is limited to a very small area. The generally low concentrations throughout most of the lake during the summer months may have resulted from plant uptake.

Ammonia and nitrate can also contribute to excessive macrophyte and algae growth. Elevated ammonia concentrations may be caused by sewage inputs, fertilizers and decaying organic matter. Ammonia concentrations in the lake ranged from <0.1 to 1.26 mg/l as presented in Figure 3-6. The elevated ammonia concentrations measured during the winter months may have been related to winter decay of the macrophyte population and reduced algal and macrophyte uptake during periods of depressed biological activity.

Nitrate occurs in natural waters from precipitation and decaying organic matter; however, major sources include sewage, industrial wastes, fertilizers and decaying vegetation. In-lake nitrate measurements obtained during the survey period ranged

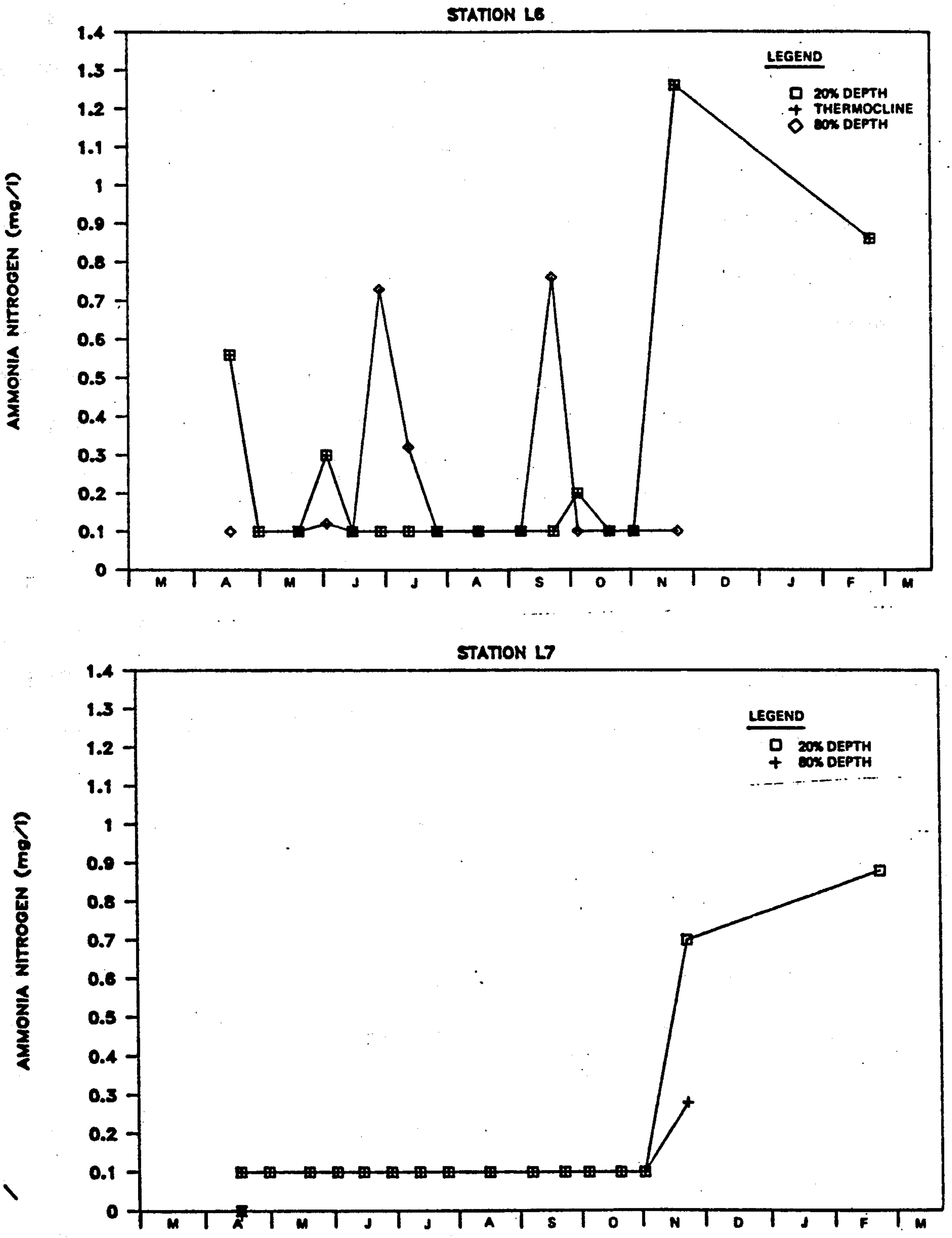


FIGURE 3-6. AMMONIA NITROGEN CONCENTRATIONS
AT LAKE SHIRLEY STATION L6 (TOP) AND STATION L7 (BOTTOM)

from <0.1 to 0.76 mg/l (Figure 3-7). As with ammonia, elevated winter nitrate concentrations may have resulted from macrophyte decay and reduced plant assimilation during winter.

Total Kjeldahl nitrogen represents the total of organic and ammonia nitrogen. The protein molecules in plant material, phytoplankton and bacteria contain organic nitrogen. TKN concentrations over the diagnostic survey period are shown in Figure 3-8 and ranged from <0.1 to 1.77 mg/l. TKN measurements correlate well with ammonia concentrations but were slightly higher, accounting for the nitrogen bound in plant material and bacteria as lipids, amino acids and other organic compounds.

Wetzel (1975) cites total nitrogen concentrations significantly greater than 0.5 mg/l as being sufficient to cause eutrophic conditions. The combined (ammonia) nitrate and organic nitrogen concentrations measured in Lake Shirley are usually less than 0.5 mg/l. Total nitrogen concentrations in Lake Shirley usually exceeded total phosphorus concentrations by a ratio of 15:1 indicating that phosphorus would likely become limiting before nitrogen.

<u>Alkalinity and pH</u>. The alkalinity of a water body gives an indication of its buffering capacity or ability to withstand changes in pH. The alkalinity of a lake is controlled to a large degree by the characteristics of its watershed. In Massachusetts, carbonate-rich watersheds (i.e. limestone regions) tend to have higher alkalinities, whereas lakes in the Cape Cod and other

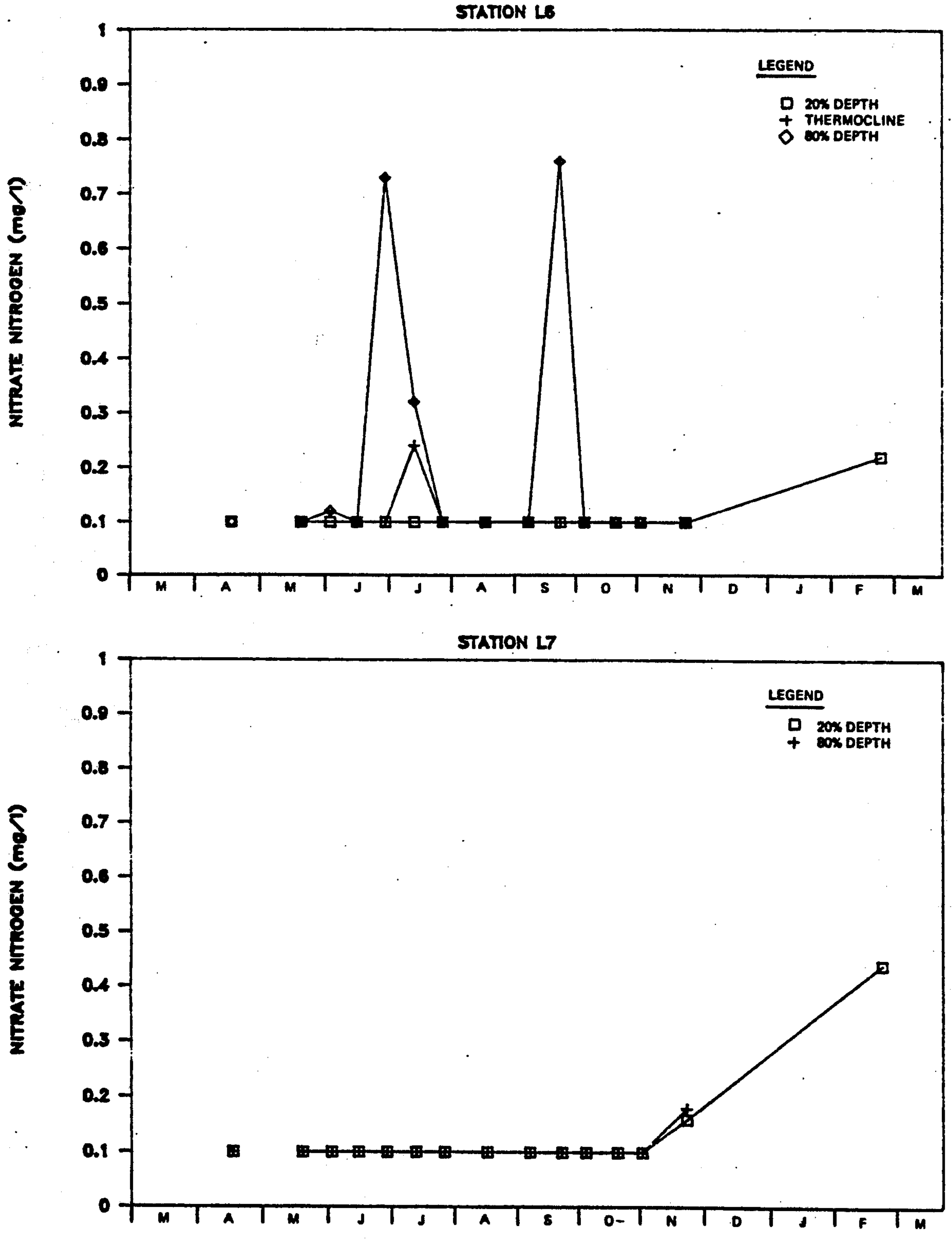


FIGURE 3-7. NITRATE NITROGEN CONCENTRATIONS AT LAKE SHIRLEY STATION L6 (TOP) AND L7 (BOTTOM)

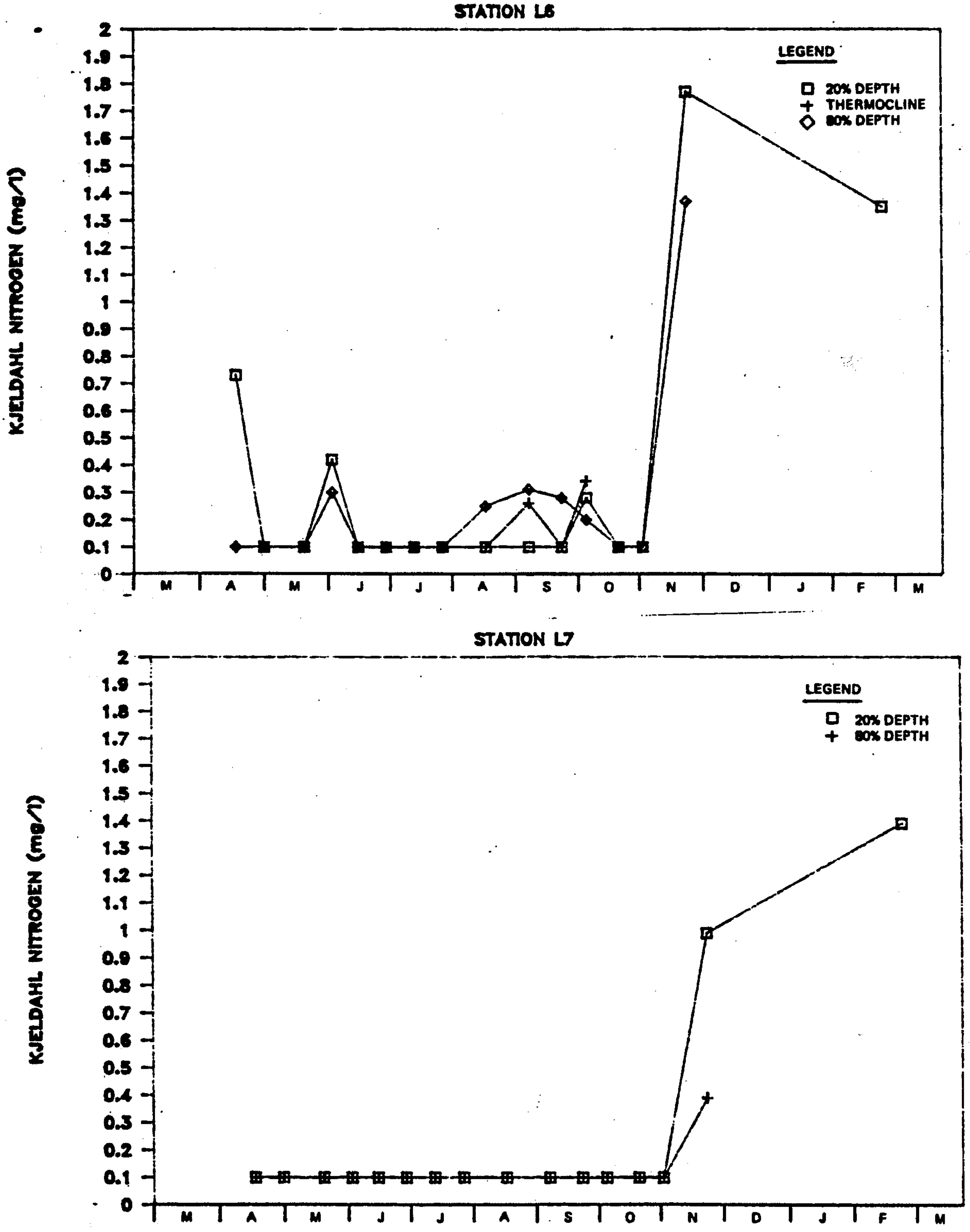


FIGURE 3-8. TOTAL KJELDAHL NITROGEN CONCENTRATIONS AT LAKE SHIRLEY STATION L6 (TOP) AND L7 (BOTTOM)

regions tend to have lower alkalinities. The alkalinity measurements obtained at the in-lake stations are shown in Figure 3-9. Measurements at the in-lake station have ranged from 12 mg/l to 38 mg/l as $CaCO_3$. As a general guideline, an adequately buffered lake has an alkalinity of 20 mg/l as $CaCO_3$ or more. There is also a Massachusetts guideline which indicates that 10 mg/l is adequate. As shown in Figure 3-9, the alkalinity in Lake Shirley is sometimes less than 20 mg/l, but always above 10 indicating adequate buffering capacity.

The principal reason for monitoring a lake's alkalinity is because of its effect on pH. The pH is a measure of a water's acidity. Depletion of alkalinity may result in reduced pH values, or increased acidity. The pH of water that is neutral is 7, and pH below 7 indicates acidic water. The normal pH range of ponds and lakes is from 6 to 8. Measurements of pH have fluctuated within the expected natural range, thus indicating that acidification of Lake Shirley is not a problem.

Chlorides, Dissolved Solids and Conductivity. Chlorides are dissolved in small amounts from sedimentary rocks and soils; however, much larger amounts are present in animal wastes, sewage, road salts and deicing agents and industrial wastes. While background concentrations are normal, elevated chlorides from sources such as street runoff may be harmful to aquatic fish and plant life. Although no state standard for surface water has been established for chlorides, federal drinking water standards provide a limitation of 250 mg/l of chloride for potable water

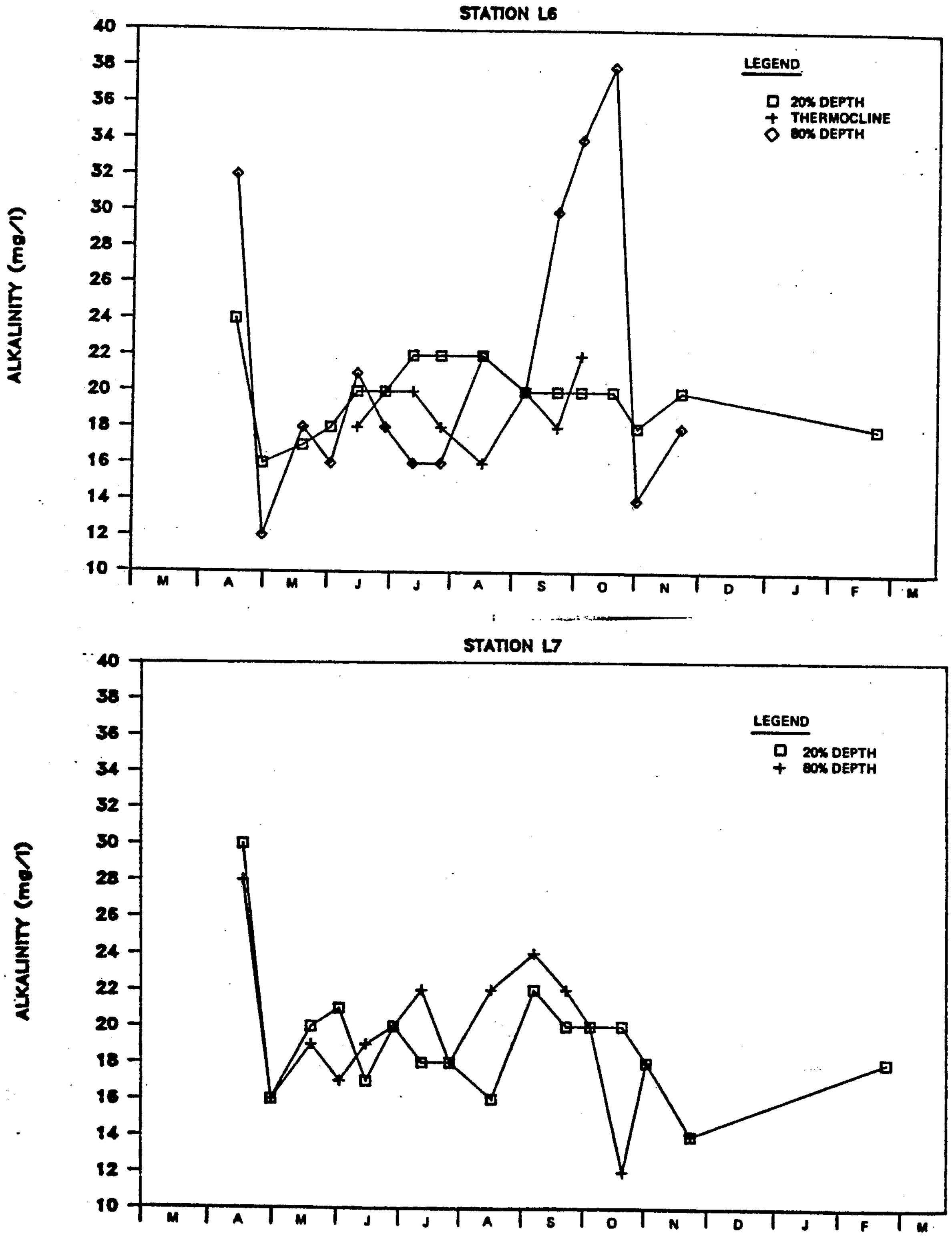


FIGURE 3-9. ALKALINITY CONCENTRATIONS AT LAKE SHIRLEY
STATION L6 (TOP) AND L7 (BOTTOM)

supplies. Concentrations at the in-lake stations have ranged from 21 to 37 mg/l as shown in Figure 3-10. Hanes (1970) reports that 95 percent of the waters supporting a good mixed fish fauna have less than 170 mg/l chloride. Since observed concentrations are well below drinking water standards, no adverse impacts are expected. Total dissolved solids, which is a measure of dissolved mineral constituents such as chloride ions ranged from 66 to 181 mg/l as shown in Figure 3-11. As with chlorides, no surface water quality standard exists for total dissolved solids, however, a limit of 500 parts per million is recommended for drinking water. All measurements at Lake Shirley were well below this limit. Conductivity, which is an electrical measurement of the concentration of dissolved ions in water, such as chlorides, ranged from 135 to 275 μmhos/cm. These chloride, dissolved solids and conductivity data all indicate normal, safe levels.

Coliform Bacteria. Total coliform and fecal coliform bacteria have been measured in Lake Shirley throughout the diagnostic survey. Total coliforms are widespread in the environment and are fairly innocuous, whereas elevated fecal coliform counts are often an indicator of sewage pollution. In evaluating fecal coliform data, however, it is difficult to discern between human sewage pollution and that which may be caused by animal droppings. Fecal coliforms are present in the intestines of all warm-blooded animals. The State water quality standard for bacteria for Class B waters is in terms of fecal

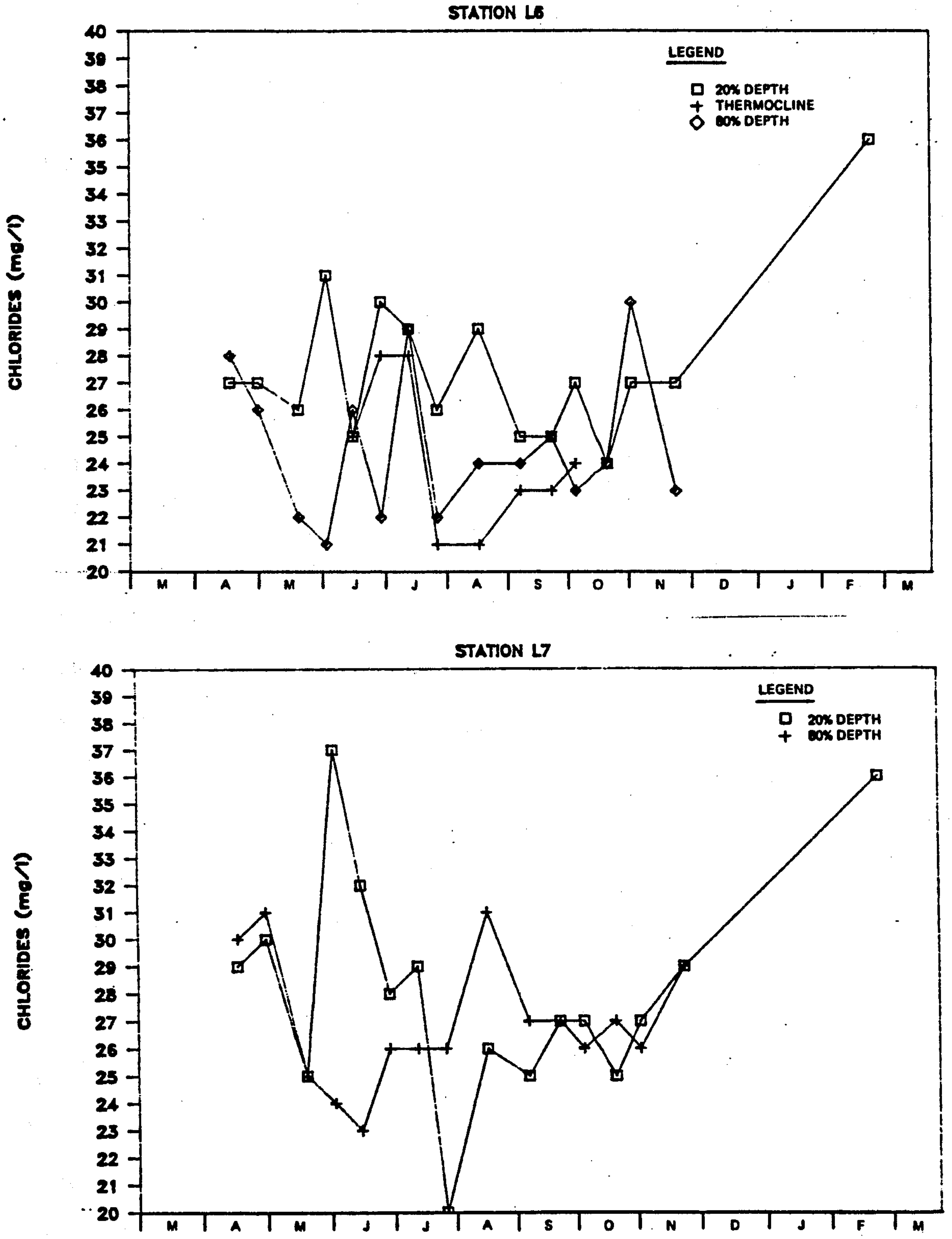


FIGURE 3-10. CHLORIDE CONCENTRATIONS AT LAKE SHIRLEY STATION L6 (TOP) AND L7 (BOTTOM)

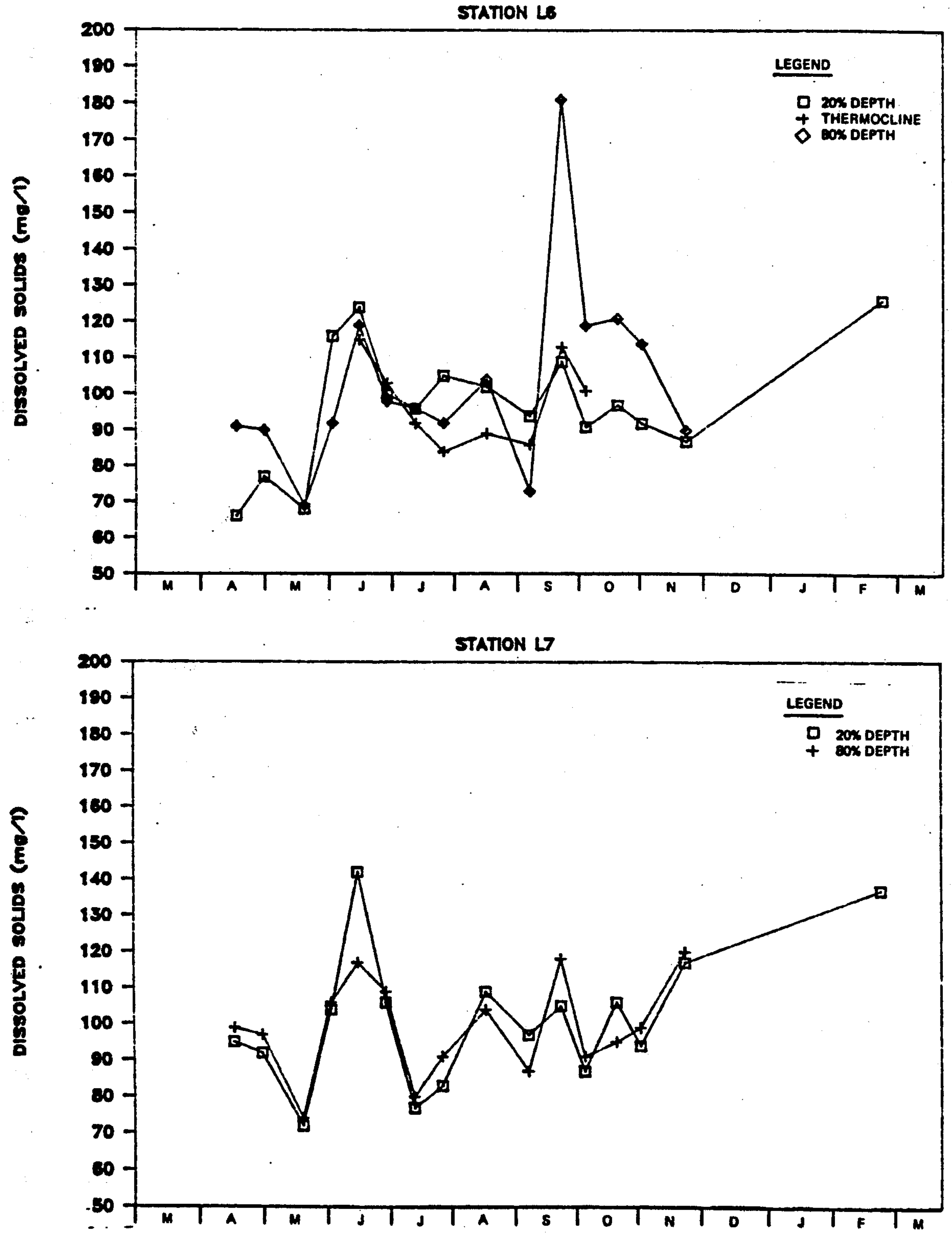


FIGURE 3-11. TOTAL DISSOLVED SOLIDS CONCENTRATIONS AT LAKE SHIRLEY STATION L6 (TOP) AND L7 (BOTTOM)

coliform bacteria and the log mean for a set of samples shall not exceed 200 per 100 ml. This standard is for primary contact recreation (i.e. swimming). Since sets of samples were not collected at Lake Shirley, this standard cannot be applied directly to measured values. The fecal coliform measurements obtained at Lake Shirley ranged from <2 to 36 colonies per 100 ml at Station L6 and from <2 to 40 colonies per 100 ml at Station L7. These bacteria counts represent no threat to aquatic life or recreation.

Total coliform counts at Lake Shirley, Station L6, ranged from 10 to 3900 per 100 ml and from 6 to 920 cells per 100 ml at Station L7. There is no total coliform bacteria water quality standard for Class B water. Total coliforms are not indicative of sewage pollution and often exceed fecal coliform counts, thus this range of concentrations is considered normal and not harmful.

Water Quality of Incoming Sources

In order to characterize the quality of water entering Lake Shirley, water quality measurements have been obtained at the lake inlets (Stations L0 - L4), from storm drains (Stations LS1 to LS6) and from groundwater and surface water in areas of suspected subsurface wastewater or groundwater plumes. Diagnostic study data related to incoming sources are described in the following paragraphs.

Inlet Measurements. Water quality measurements taken at the five inlets are summarized in Table 3-6. Nutrient

TABLE 3-6. AVERAGE AND RANGE OF INLET WATER QUALITY MEASUREMENTS FOR LAKE SHIRLEY (mg/l)

Parameter	Station L0	Station L1	Station L2 Easter Brook	Station L3 Catacoonamug Brook	Station L4
Total Suspended Solids	3.6 (<1.0-8.8)	14.5 (2.4-3.5)	3.6 (<1.0-17.7)	2.2 (<1.0-6.4)	4.1 (<1.0-14.5)
Total Dissolved Solids	109 (79-168)	253 (110-714)	126 (98-173)	114 (92-132)	94 (63-185)
Ammonia-N	0.43 (<0.10-1.4)	0.45 (<0.10-1.4)	0.29 (<0.10-0.84)	0.24 (<0.10-0.98)	0.21 (<0.10-0.85)
Nitrate-N	0.21 (<0.10-0.42)	0.13 (<0.10-0.32)	0.24 (<0.10-0.65)	0.16 (<0.10-0.43)	0.19 (<0.10-0.32)
TKN	0.61 (<0.10-2.06)	0.61 (<0.10-1.96)	0.42 (<0.10-1.18)	0.35 (<0.10-1.37)	0.27 (<0.10-1.1)
Total Phosphorus	0.021 (<0.01-0.07)	0.029 (<0.01-0.11)	0.03 (<0.01-0.08)	0.03 (<0.01-0.14)	0.024 (<0.01-0.07)
Total Alkalinity	10.5 (6-14)	67 (24-90)	22 (14-42)	18 (10-24)	10 (6-22)
Chlorides	34.3 (25-56)	35 (9-340)	33 (22-55)	34 (22-52)	25 (17-36)
Total Coliform (colonies/100 ml)	77 (10-400)	870 (<5-10,000)	276 (8-1900)	1104 (20-15,000)	335 (<5-400)
Fecal Coliform (colonies/100 ml)	8 (<5-30)	30 (<5-275)	36 (<2-310)	35 (<2-160)	15 (<2-180)

concentrations at lake inlets will be combined with inlet flows to calculate annual loadings. A general discussion of each parameter is presented below and raw data summary tables are presented in Appendix A.

Inlet concentrations of total phosphorus, ammonia, TKN and nitrate were higher than corresponding in-lake concentrations, indicating that these nutrients are utilized by photosynthetic activity, undergo chemical transformations, are diluted or settle to the bottom sediments.

Suspended solids concentrations were generally low in the inlets, although slightly elevated as compared to in-lake levels. Suspended solids are influenced by dust and eroded earth which is scoured from the drainage basin and stream bottoms. Suspended solids concentrations at Stations L1 (Keating area) and L2 (Easter Brook) which have head waters near a local gravel pit operation both showed slightly elevated suspended solids concentrations. Similarly, dissolved solids were low at the inlets and consistent with in-lake levels with the exception of Stations L1 and L2 which consistently showed elevated levels. Alkalinity measurements, like dissolved solids, were consistent with in-lake concentrations. Chlorides, which are a constituent of road deicing agents, were highest at Stations L2 (Easter Brook) and L3 (Catacoonamug Brook) which have the largest drainage areas and the most streets.

Total and fecal coliform levels were very low at the inlets. Readings over background levels were probably associated with periods of high runoff during spring. As in the evaluation of in-lake bacteria data, fecal coliform levels did not reach levels which would threaten recreation. Total coliform levels infrequently reached several thousand colonies per 100 ml.

Stormwater Data. Stormwater-caused water pollution can be a problem of major importance near sensitive lakes with increasing development. Stormwater from urbanized areas and streets typically contains high concentrations of nitrogen, phosphorus and solids. Much of the nutrient content is associated with particulate matter such as dust and sand, organic matter from animal droppings, grass clippings, fertilizers and soaps. Solids include sand from winter road maintenance, dust, and eroded dirt. During winter, road salts, deicing agents, sand and associated chemicals are spread on streets and sidewalks in order to keep them safe for travel. Automobile crankcase oil, emissions exhaust and other sources of air pollution eventually settle on surfaces washed by stormwater which reaches the lake. Nutrient concentrations in stormwater runoff generally exceed receiving water concentrations, thereby increasing receiving water concentrations.

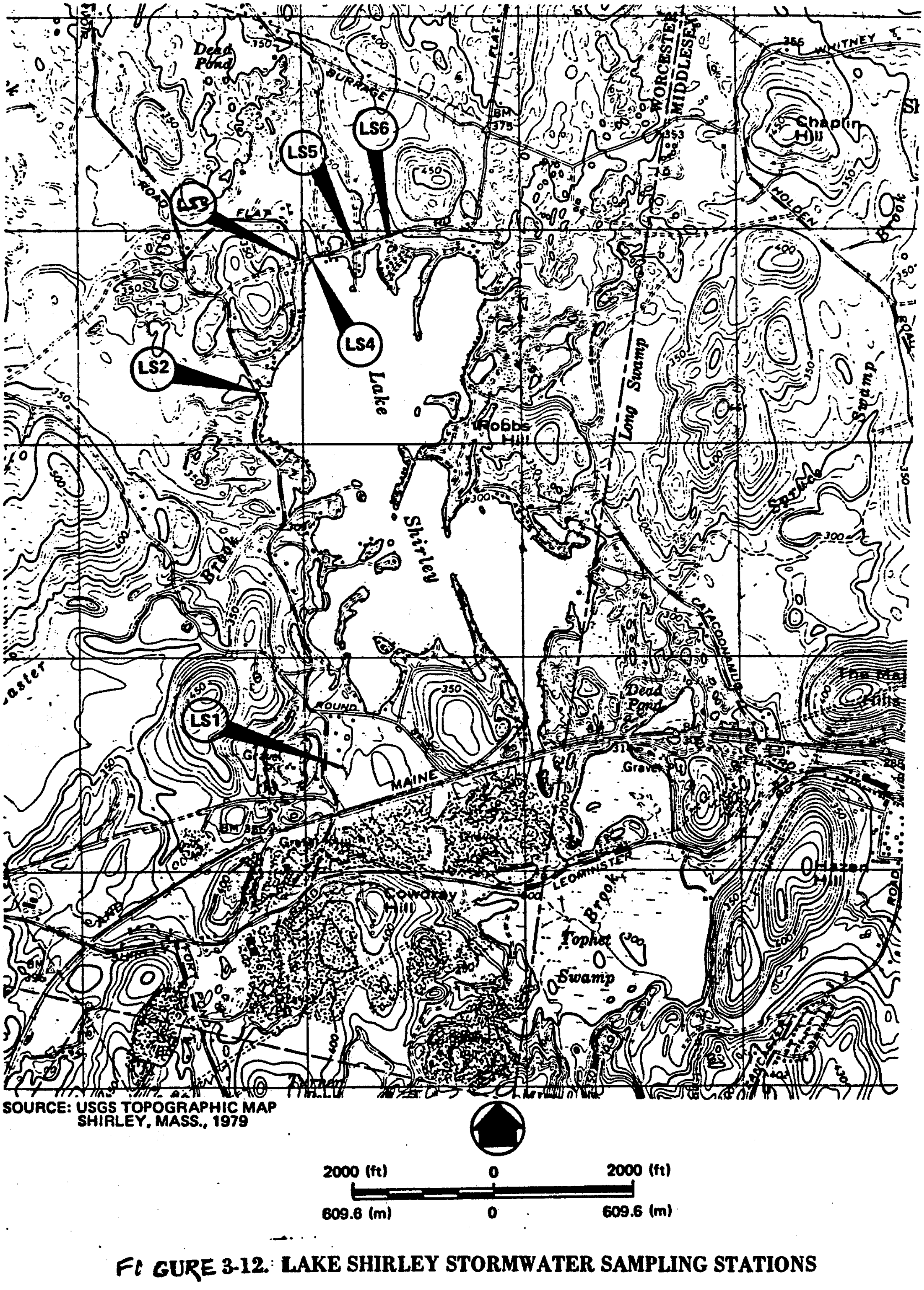
Two rainfall events were monitored at Lake Shirley during the diagnostic survey. During each event, the "first flush" or initial runoff was sampled since this portion of the flow is typically higher in nutrients and solids. In subsequent flow, reduced nutrients and solids are expected since area streets are washed by the stormwater.

The stormwater sampling approach during the first storm event was to monitor storm runoff from different land use types around the lake. These land use types included a commercial (mining) area, a wetland/street area, a residential area, a large inlet stream (Catacoonamug Brook), a new housing development and a forested area. Three of the stormwater monitoring stations were regular water quality monitoring stations (stations L1, L0 and L4), enabling comparison of wet weather data with baseline data. Figure 3-12 shows the location of each sampling station. A description of each selected station and the rationale for each selection is provided below:

Station LS1. Commercial Mining Area (Keating Site) - The Keating site is a large local sand and gravel mining operation covering several hundred acres south of the lake. It was anticipated that storm runoff from the Keating site would contribute sediment and nutrient loading to the lake. Preliminary site observations during wet weather and site topography showed that storm runoff from the Keating site flows to a variety of areas around the site including wooded areas, streams and small ponds. A wet weather flow-composited sample was collected from an unnamed small stream which runs east along the north side of the railroad tracks adjacent to the site. This station was also sampled on a regular basis as Station L1 during the diagnostic survey.

Station LS2. Shoreline Wetland/Street Area - A significant portion of the Lake Shirley watershed is composed of scrub-shrub and forested wetlands. In order to characterize wet weather runoff from these areas, a flow-composited sample was collected from a metal corrugated culvert under Reservoir Road which drains a wetland and small pond. This area also includes runoff from part of Reservoir Road. A stormwater catch basin and pipe drain into this wetland adjacent to the corrugated metal culvert which drains the wetland to Lake Shirley. This station was also sampled on a regular basis as Station L0 during the diagnostic survey.

Station LS3. Shoreline Residential Area - Although most roads around the lake have no storm sewers and drain via overland runoff to the lake, several areas have had street drainage systems installed. One such area is located on Flat



SOURCE: USGS TOPOGRAPHIC MAP
SHIRLEY, MASS., 1979

FIGURE 3-12. LAKE SHIRLEY STORMWATER SAMPLING STATIONS

Hill Road near the Catacoonamug Brook bridge. Street drainage is typically high in solids, nutrients and metals and may cause localized water quality and weed growth problems. A composite sample was collected from a metal culvert which drains to the lake.

Station LS4. Catacoonamug Brook - In order to compare wet-weather conditions with baseline water quality, Catacoonamug Brook, which drains the largest subdrainage area (B, 5949 acres) was included as a stormwater sampling station.

Station LS5. New Development - The drainage patterns of several housing developments around Lake Shirley including Autumn Road and Stone Fence Road were surveyed in order to locate an accessible storm drain which carries storm runoff to the lake. The drain at the Stone Fence Road development was determined to be the most suitable for wet weather sampling. In order to evaluate the quality of storm runoff from new development near the lake, Metcalf & Eddy sampled storm runoff from this development. Storm flow from this area runs south through a storm sewer system and into a depression north of Flat Hill Road. The samples were collected from the cement culvert which drains the stormwater from Stone Fence Road into this depression and Lake Shirley.

Station LS6. Shoreline Forested Area - Direct over-land runoff from shoreline areas around the lake is principally from forested areas. In order to characterize the quality of this runoff, samples were taken in a forested area at the north end of the lake. Storm runoff from a 170 acre shoreline forested area which passes through a corrugated metal culvert under Flat Hill Road and into Lake Shirley was sampled.

The stormwater sampling plan for Lake Shirley was initiated on March 1, 1987. During this storm, a flow-composited sample was collected from the six stations described in the stormwater sampling plan described above. Sampling was conducted for approximately four hours during heavy rain. Approximately 0.35 inches of rain fell during the monitored period. The storm was preceded by a long dry period during which pollutants from various sources could accumulate. The results of the analysis of flow-composited stormwater samples from March 1, 1987 are shown in Table 3-7. Concentrations of solids, nutrients and heavy metals were generally higher at Stations LS1, LS2, LS3 and LS6 which contained mainly street runoff. Suspended and dissolved solids concentrations were lowest at Stations LS4 (Catacoonamug Brook) and LS5 (Forested area). The total phosphorus concentration of <0.015 mg/l for Catacoonamug Brook is consistent with baseline data for that station. This indicates that phosphorus loading from this tributary is not significantly affected over the short-term by storm runoff. Several copper and lead concentrations exceeded recommended exposure limits for aquatic life; however, these readings were taken at the point of discharge and it is expected that these concentrations would be diluted to safe levels after mixing with lake water in the area of the discharge.

In order to complete the stormwater sampling task, two of the original six stations were chosen for detailed sampling. Since most of the watershed is composed of forested and residential areas, preference was given to storm drains which serve these types of areas. Based on review of data from the first storm, drainage area size and representative land use, Station LS3 (Flat Hill Road storm drain), and Station LS6 (forested area) were selected for detailed sampling (see Figure 3-12).

The second phase of stormwater sampling was conducted on April 28, 1987. Stations LS3, LS6 and an additional station

TABLE 3-7. FLOW-COMPOSITED STORMWATER SAMPLING RESULTS FROM LAKE SHIRLEY

Sampling Date 3/1/87

Parameter	LS1 Stream near Keating	LS2 Wetland and Reservoir Rd Runoff	LS3 Flat Hill Rd Storm Drain	LS4 Catacoonamug Brook	LS5 Forested Area	LS6 Stone Fence Rd Storm Drain
Total Suspended Solids (mg/l)	218	381	356	2.6	16	145
Total Dissolved Solids (mg/l)	751	1,040	4,870	114	367	4,630
Chlorides (mg/l)	360	650	3,050	39	230	3,200
Total Kjeldahl Nitrogen (mg/l)	1.02	0.98	1.56	1.8	1.32	1.61
Ammonia-N (mg/l)	0.76	0.65	0.96	0.78	0.82	0.98
Nitrate-N (mg/l)	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Total Phosphorus (mg/l)	0.113	0.204	0.110	<0.015	0.291	0.343
Conductivity ()mhos/cm)	1,125	1,525	6,250	163	588	7,000
pH (std. units)	7.27	6.29	6.04	6.97	6.65	6.67
Heavy Metals (mg/l)						
Cadmium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium	0.02	0.02	0.05	<0.01	<0.01	0.03
Copper	0.02	0.03	0.03	<0.01	<0.01	0.02
Iron	3.35	3.96	4.89	0.17	0.43	3.60
Lead	0.07	0.08	0.10	0.03	0.03	0.07
Manganese	1.53	0.19	0.30	0.04	0.05	0.18
Zinc	0.11	0.14	0.23	<0.01	0.02	0.06
Coliform Bacteria (colonies/100 ml)						
Total coliforms--						
Start of rainfall	140	20	100	1,260	160	60
Mid-storm	180	120	200	660	260	100
End of sampling	140	60	380	680	240	60
Fecal coliforms--						
Start of rainfall	10	<10	<10	270	40	<10
Mid-storm	20	40	15	120	60	15
End of sampling	20	<10	60	140	30	<10

(Station LS5) were sampled over a 1.5 hour period during light rain at approximately 0.5 hour intervals. The decision to sample three stations was made in the field when it was discovered that Station LS6 was carrying baseflow and data collected from that station may not be representative of the desired land use quality. The storm produced 0.11 inches of rainfall during the monitored period. The analyses of discrete samples from Stations LS3, LS6 and LS5 are listed in Appendix A.

The April 28 storm produced very light runoff, making flow velocity measurements difficult. At the beginning of the storm, neither catch basin produced flow and samples were collected from runoff flowing into the basin. As the storm progressed, the ground became saturated and measureable runoff was produced.

Runoff from Stations LS3 and LS5 produced runoff which was high in solids and nutrients with concentrations diminishing with time after the "first flush" effect. Figures 3-13 and 3-14 show storm hydrographs and the concentrations of total phosphorus and suspended solids in runoff at Station LS3, the Flat Hill Road storm drain and at Station LS5, Stone Fence Road. Pollutants are high in the initial runoff as the streets are washed by the stormwater. In subsequent flow, total phosphorus and suspended solids concentrations were decreased substantially. In contrast, the forested area north of the lake (Station LS6) produced a relatively clean runoff in terms of nutrients and solids with no

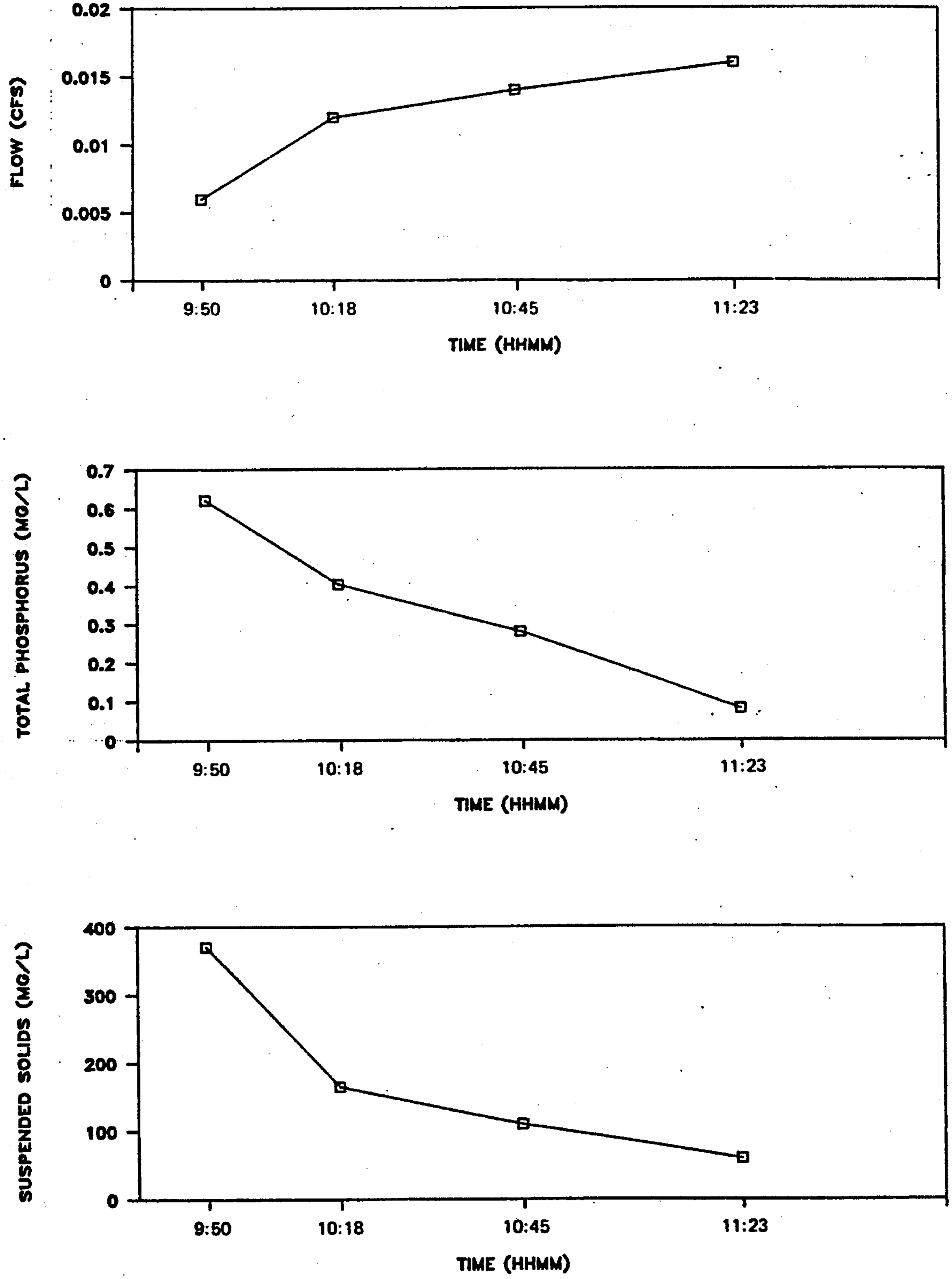


FIGURE 3-13. INFLOW, TOTAL PHOSPHORUS AND SUSPENDED SOLIDS DATA AT FLAT HILL ROAD STORM DRAIN (STATION LS3) FROM APRIL 28, 1987 RAIN EVENT

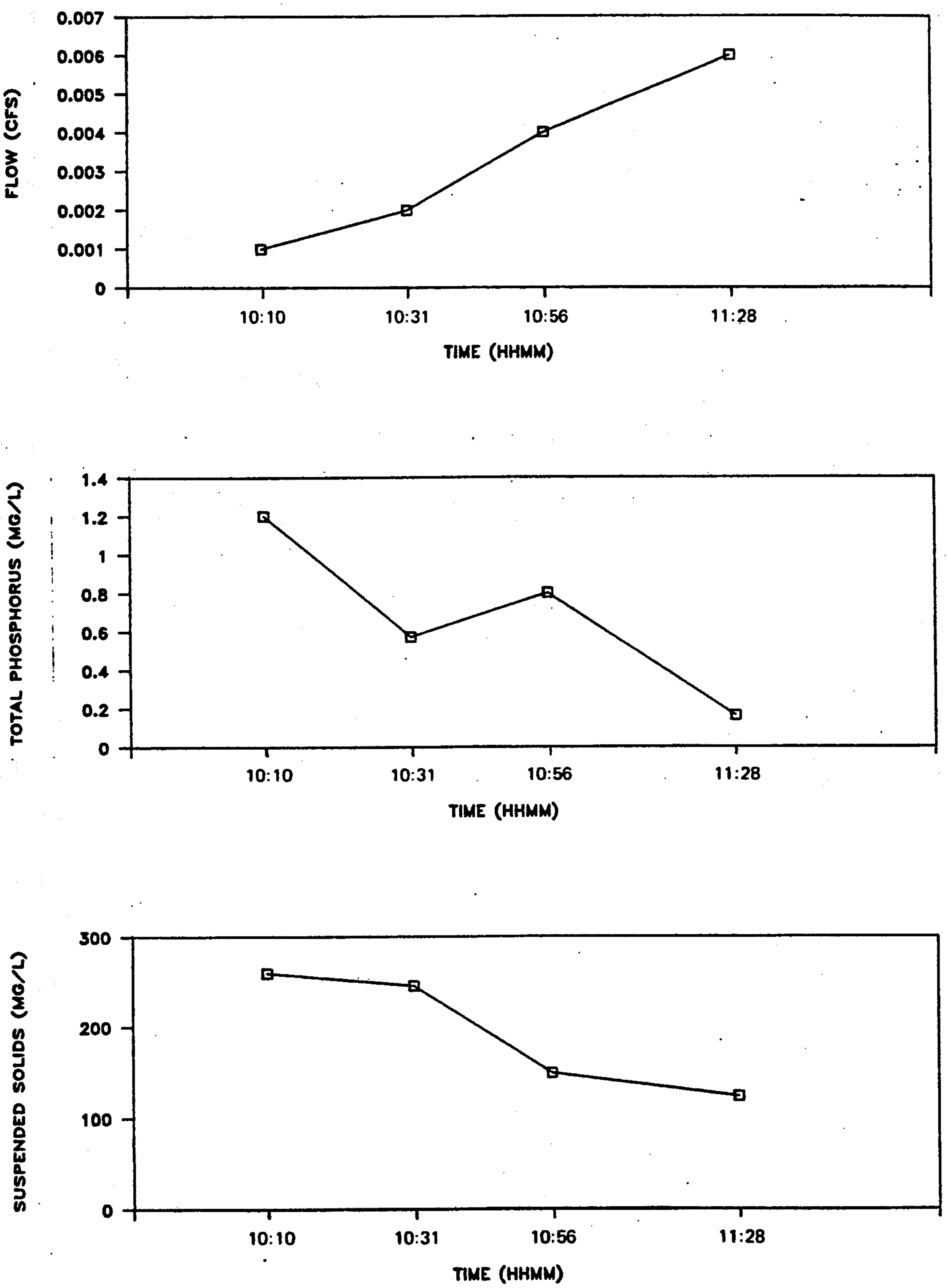


FIGURE 3-14. INFLOW, TOTAL PHOSPHORUS AND SUSPENDED SOLIDS DATA AT STONE FENCE ROAD STORM DRAIN (STATION LS5) FROM APRIL 28, 1987 RAIN EVENT

discernable first flush effect; however, this station was carrying baseflow prior to the rainfall. Table 3-8 presents heavy metals concentrations from the April 28 storm. Concentrations were markedly lower than those measured during the first storm and did not produce levels threatening to aquatic life.

TABLE 3-8. FLOW-COMPOSITED STORMWATER HEAVY METALS DATA (APRIL 28, 1987)

Parameter	Flat Hill Road Station LS3	Stone Fence Road Station LS5	Forested Area Station LS6
Cadmium (mg/l)	<0.01	<0.01	<0.01
Chromium (mg/l)	<0.01	<0.01	<0.01
Copper (mg/l)	0.03	0.01	<0.01
Iron (mg/l)	3.20	2.31	0.05
Lead (mg/l)	0.03	<0.01	<0.01
Manganese (mg/l)	0.29	0.14	<0.01
Zinc (mg/l)	0.53	0.04	<0.01

Although many of the pollutant concentrations measured in the stormwater are high, the pollutant loads entering the lake and associated water quality impacts are dependent on the total runoff volume. This is taken into consideration when calculating the lake's nutrient budget, as presented in Chapter 4.

Septic Tank Leachate Survey. KV Associates, Inc., a subcontractor to M&E, conducted a survey of Lake Shirley to locate and evaluate pollutant plumes entering Lake Shirley from

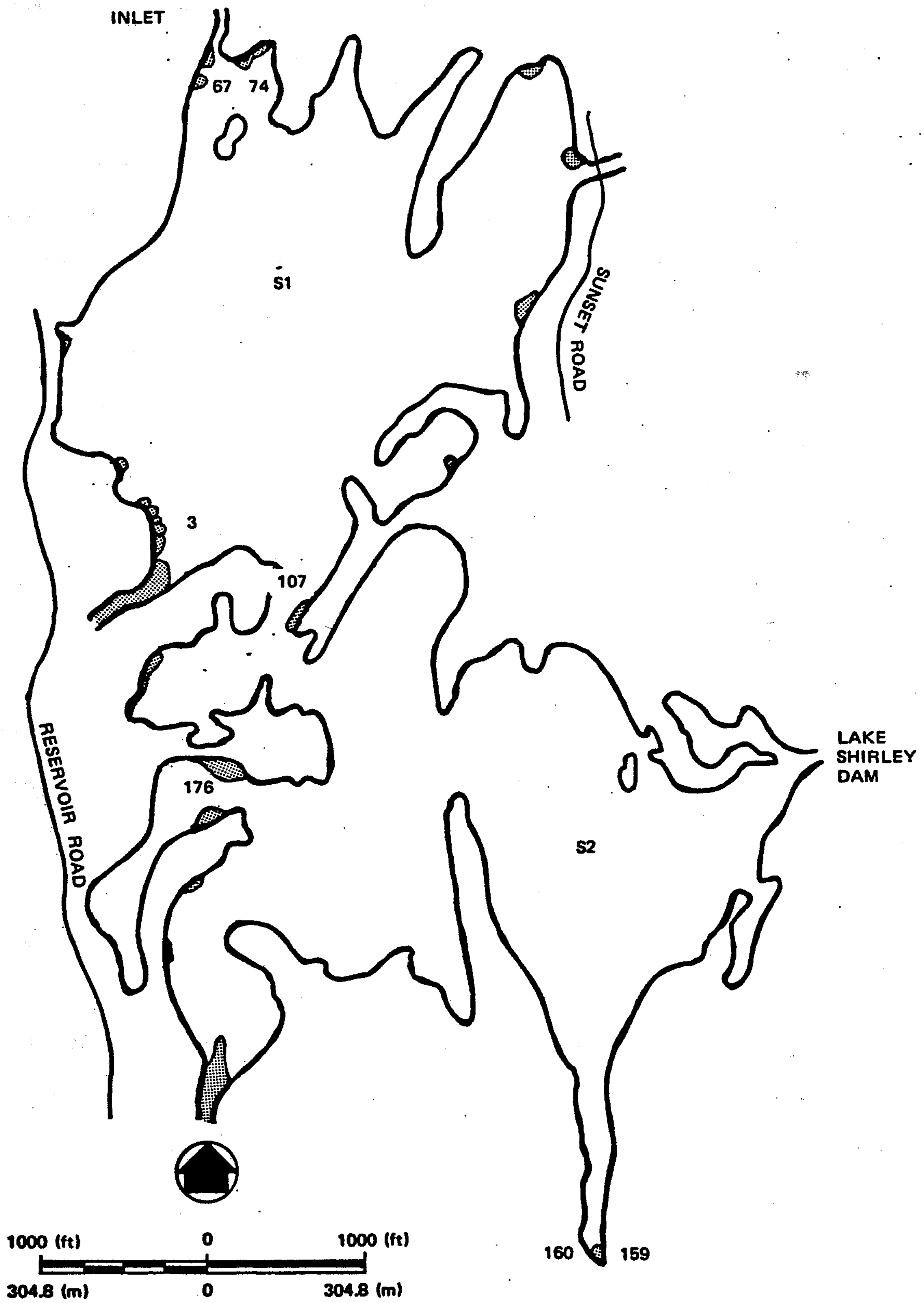


FIGURE 3-15. SEPTIC LEACHATE AND GROUNDWATER PLUME LOCATIONS DETECTED AROUND LAKE SHIRLEY DURING SEPTIC LEACHATE SURVEY

septic systems and groundwater. The entire shoreline of Lake Shirley was surveyed. The report is presented in Appendix B, and specific findings of the survey are summarized below.

Although no surface water plumes indicative of overflowing septic systems were found, there were numerous subsurface plumes characteristic of septic tank leachate. In addition, other plumes were identified which are thought to be caused by nutrient enriched groundwater flow from bog regions which have been flooded and now exist as lake bottom. Figure 3-15 shows the locations of the influent plumes detected. The graphical representation of the plumes reflects their approximate strength as related to the magnitude of concentrations. In some cases the nutrient concentrations in the plume region are significantly higher than the background lake water concentrations. Plumes were detected primarily along the north, west and south shores which is consistent with the inward groundwater flow in these regions. Groundwater well point sampling from lots showing the existence of plumes often revealed minor septic discharges with pronounced peaty bog contents. As mentioned above, in many locations, the bottom consists of inundated bogs or marshes which have created anoxic conditions favorable to septic leachate breakthrough. The macrophyte growth on these organic deposits was more noticeable than sandy areas as these regions serve as nutrient sources.

Samples were collected for nutrient analysis at five locations where leachate plumes were detected, at the two in-lake stations (L6 and L7), at the lake outlet and at the Catacoonamug Brook inlet. At the leachate plumes at lots 67, 160, 176 and 74, nutrient samples were collected from the water near the shoreline and from a hand-driven well point on shore. The results of these analyses are given in Table 3-9.

Several of the larger plume areas are located at lots 74 and 176 on the west shore. The nature of these plumes as determined from the leachate monitoring instruments indicates that they are not due to septic leachate, but rather from the influence of bogs which were submerged when the lake was originally filled. The plumes are high in organic content, but low in urine degradation products.

The remaining plumes entering the pond are attributed to leachate from septic systems located near the shoreline. Localized increased plant growth was observed in the vicinity of these plumes. This increase in algae and macrophyte growth is attributed to elevated phosphorus concentrations in the emerging plumes, also causing elevated nutrient concentrations in the sediments in these areas. Despite the higher background phosphorus concentrations within these plumes, none were sufficiently high to be indicative of failed septic systems.

In summary, the septic leachate survey determined the following:

- There were no high-bacteria surface malfunctions or breakouts of lakeshore septic systems.

TABLE 3-9. SEPTIC LEACHATE SURVEY SAMPLING RESULTS

Station	Conductivity (umhos)	Coliforms (#/100 ml)		Total Phosphorus (mg/l)	Nitrate Nitrogen (mg/l)	Ammonia Nitrogen (mg/l)	Total Kjeldahl Nitrogen (mg/l)
		TC	FC				
Outflow	170	40	4	0.019	BDL(1)	0.27	0.94
S1	169	<20	4	0.034	BDL	0.15	1.22
S2	170	<20	11	0.031	BDL	0.18	1.10
67S	170	<20	6	0.026	BDL	0.02	1.06
67G	154	--	--	0.016	1.17	0.34	1.90
Inlet	169	<20	10	0.021	BDL	0.06	0.72
107	174	--	20	--	--	--	--
Coves 159-160S	170	<100	22	0.016	--	--	--
159-160G	166	--	--	0.073	--	--	--
3S	171	--	--	0.066	--	--	--
176S	186	th	32	0.113	--	--	--
176G	320	--	--	0.087	--	--	--
74S	171	*	44	0.027	BDL	0.12	1.36
74G	510	--	--	0.054	BDL	1.36	1.42

1. BDL = Below Detection Limit.

- Numerous septic tank leachate plumes emerge from the lake shoreline, particularly in regions of shallow depths to groundwater.
- Thick aquatic macrophyte growth was often associated with plume areas.
- The heaviest vegetation was associated with areas which were once bogs and now exist as lake bottom.

Inventory of Wastewater Practices. An inventory of on-site wastewater disposal practices was conducted by distributing a questionnaire by mail to each home within 300 meters (about 1000 feet) of the lake. The questionnaire included questions related to septic systems, distance from lakeshore, number of people per unit, number of days of use per year, age of the system and types of applicances used. The inventory will be used in conjunction with direct measurements taken during the septic leachate survey to estimate nutrient loading from on-site wastewater systems to Lake Shirley and to evaluate methods of reducing nutrient loading from individual households.

The questionnaire elicited an approximate 50 percent response which was considered excellent given the nature of the information sought. Of the total of 75 responses, 68 were single family homes and 65 had septic tanks. The most significant water quality related findings of the survey were that many homes that had previously been seasonal cottages never had their septic systems expanded, and that some homes had never had their septic tanks pumped. These factors often lead to overloaded and inefficient systems. A summary of the results of the survey is presented in Table 3-10 and a detailed table of questionnaire results is presented as part of Appendix A.

TABLE 3-10. SUMMARY OF RESULTS OF ON-SITE WASTEWATER DISPOSAL SURVEY

Residences	
Single family homes (SF) =	68
Apartments (AP) =	1
Two family homes (TF) =	2
Other land uses (OT) =	4
Total Responses =	75
Total Population	
Total residents (Num Pers) =	186
Residences with sump pumps =	5
Lot Sizes	
Average lot size (sq. ft.) =	40,651
Average lot size (acres) =	0.93
Water Supply	
Number of private wells (PW) =	73
Source is community well (CW) =	0
Residences on town water (TW) =	0
Other sources of water supply =	3
Waste Disposal - Year Installed	
System installed before 1950 =	13
System installed in 1950's =	10
System installed in 1960's =	17
System installed in 1970's =	13
System installed in 1980's =	0
Installation date not known =	22
Year of Construction	
Homes built before 1950 =	24
Homes built in the 1950's =	18
Homes built in the 1960's =	11
Homes built in the 1970's =	6
Homes built in the 1980's =	4
Date of construction not known =	12

Previous Cottages	
Number of previous cottages =	54
Prev. cottage - system unexpanded =	8
Waste Disposal Methods	
Number of septic tanks =	65
Number of holding tanks =	3
Leachate galleries =	1
Number of dry wells =	3
Method unknown =	2
Frequency of System Pumping	
Systems pumped every 1 yr. =	13
Systems pumped every 2 yrs. =	12
Systems pumped every 3 yrs. =	11
Systems pumped every 4 yrs. =	1
Systems pumped every 5 yrs. =	5
Systems pumped every 6 yrs. =	2
Systems never pumped =	22
Frequency unknown =	9
Proximity to Lake	
Within 50 feet of shore =	10
Within 100 feet of shore =	41
Within 150 feet of shore =	57
Within 200 feet of shore =	63
Within 250 fee of shore =	68
Over 250 feet from shore =	3
Distance not known =	4
Connections to System	
Clothes washers connected =	36
Garbage disposals connected =	10
Sump pumps connected =	0
Dishwashers connected =	22
Other connections =	0

As described later in this report, the potential for phosphorus loading increases with proximity of the septic tank to the lake. Systems within 100 feet of the lake have the highest potential to load untreated wastewater through the groundwater. Figure 3-16 shows the distribution of septic systems over distance from the lake, revealing that over 60 percent of the septic systems are within 100 feet of the lake shore. This indicates that proper care of these systems could result in reduced phosphorus loading. Over 50 percent of those responding to the questionnaire lived in converted summer cottages that had not had their systems expanded. Further, as represented in Figure 3-17, over 30 percent of the homes had never had their systems pumped. Alternatives for reducing phosphorus loading from septic systems are evaluated in Chapter 5.

Lake Sediments. Sediment chemistry analyses were conducted in order to estimate the effect of sediments on the trophic state of the lake, as well as to identify potential toxicity, suitability for dredging, and marketability. Sediment samples were collected at the in-lake stations (Figure 3-1) and a listing of sediment analysis results is presented in Table 3-11. The organic and nutrient content of the sediments was fairly high, indicating the existence of organic materials such as decayed aquatic plants and algae. These characteristics increase the marketability of the sediments for use in landscaping and agriculture. High nutrient content in the sediments may contribute to eutrophication of the lake; however,

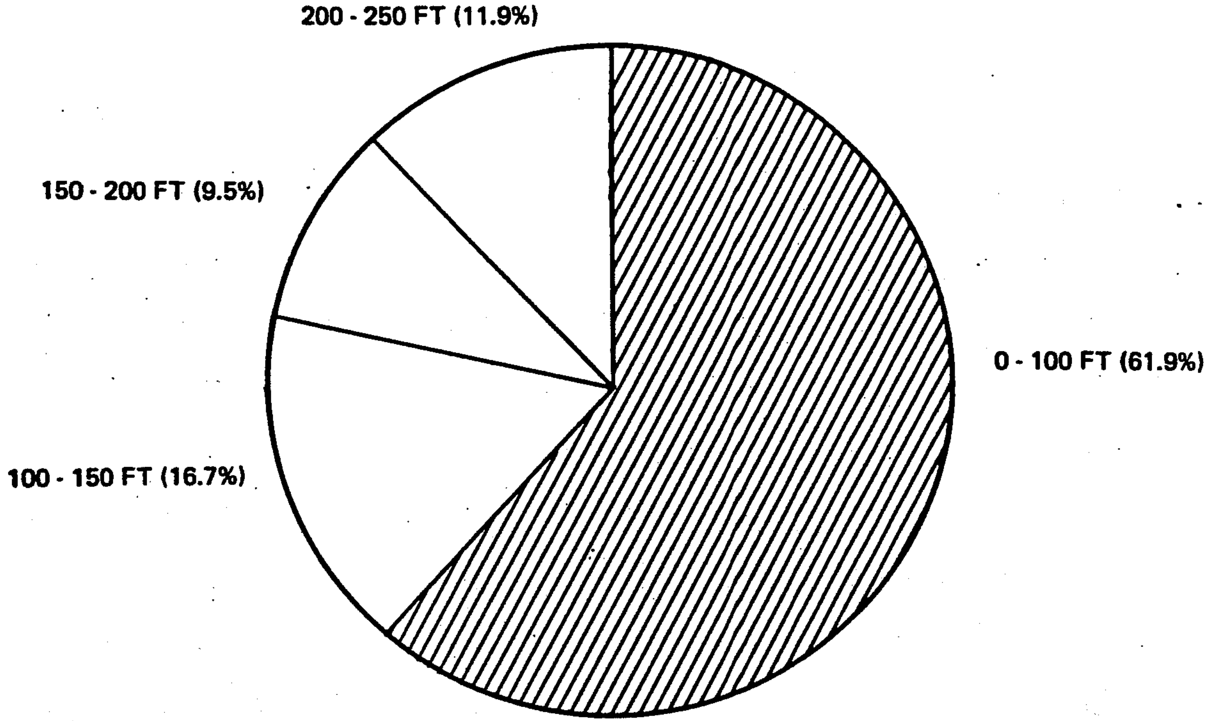


FIGURE 3-16. DISTANCE OF SEPTIC SYSTEMS FROM SHORELINE OF LAKE SHIRLEY

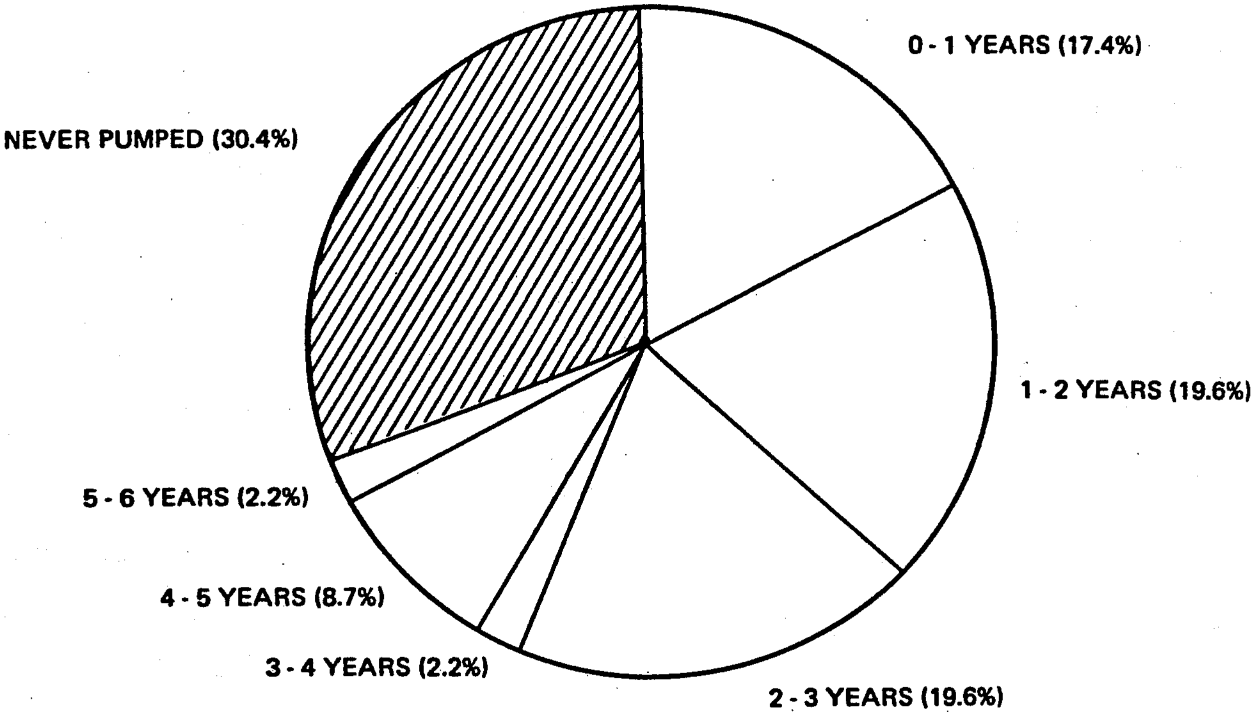


FIGURE 3-17. FREQUENCY OF MAINTENANCE OF SEPTIC SYSTEMS

TABLE 3-11. LAKE SHIRLEY SEDIMENT SAMPLING RESULTS

Parameter	L6	L7
Organic/Inorganic Fraction	0.25	0.42
Total Nitrogen (mg/kg)	1,678	1,810
Total Phosphorus (mg/kg)	759	139
Chromium (mg/kg)	79	117
Manganese (mg/kg)	224	705
Iron (mg/kg)	19,182	20,793
Copper (mg/kg)	49	65
Zinc (mg/kg)	190	378
Cadmium (mg/kg)	3.5	9
Lead (mg/kg)	124	283

as discussed earlier in this chapter, sediment release of nutrients occurs only during anoxic conditions and this is not a problem in Lake Shirley. Heavy metals concentrations in the lake sediments were consistently higher in the northern basin at Station L7. This basin receives the discharge from four major inlets and several storm drains which drain most of the watershed to the lake. Settling of sediments and associated metals would therefore be greater in this basin; however, concentrations toxic to aquatic life were not found. A discussion of the classification of the Lake Shirley sediments in terms of suitability for dredging is presented in Chapter 5.

Lake Biology

Freshwater lakes or lentic ecosystems, are characterized by standing water habitats and associated communities of living organisms. Lentic ecosystems can be subdivided into vertical and horizontal strata based on photosynthetic activity. The littoral or shallow water zone is the near shore zone in which light penetrates to the bottom. This area is occupied by rooted aquatic plants such as waterlilies, rushes and sedges. Beyond this is the limnetic or open water zone, which extends to the depth of effective light penetration. It is inhabited by plant and animal plankton and the nekton or free swimming organisms such as fish which are capable of moving about voluntarily. Beyond the depth of effective light penetration is the profundal zone, which depends on organic material settling from the limnetic zone as an energy source. Common to both the profundal zone and the littoral zone is the benthic zone, or bottom region, which is the zone of decomposition of settled organic material. The following discussion focuses on the biological life in Lake Shirley, including phytoplankton (floating, microscopic algae) which inhabit the littoral and limnetic zones, aquatic macrophytes (rooted, aquatic plants) which inhabit the littoral zone and the fishes or nekton which inhabit all zones of lentic environments.

Phytoplankton. The most fundamental level of the food web of Lake Shirley is occupied by phytoplankton which incorporate sunlight and nutrients to form plant matter. They are photosynthetic, non-vascular, free-floating, plants that exist as single cells, colonies, or filaments. A number of factors affect their distribution and abundance including concentrations of nutrients (nitrogen and phosphorus), penetration and intensity of light, various physical and chemical interactions and season.

Phytoplankton biomass and its composition in general, as well as species in particular, are good indicators of water quality and trophic condition of a lake (Vollenweider, 1974). This is because certain species are better adapted to compete under increased nutrient conditions, resulting in changes in community composition. Thus, specific algal associations may be indicative of trophic state and may provide evidence of eutrophic conditions. Phytoplankton counts also provide an indication of trophic state. Algal blooms are commonly caused by elevated nutrient concentrations. Excessive phytoplankton concentrations can cause adverse DO impacts such as (a) wide diurnal variation in surface DO due to daytime photosynthetic oxygen production and nighttime oxygen depletion by respiration and (b) depletion of bottom DO through the decomposition of dead algae and other organic matter. Excessive algal growth may also result in shading which reduces light penetration in the water.

Concentrations of chlorophyll-a, the principal photosynthetic pigment in algae and vascular plants, can provide an indication of phytoplankton biomass. Chlorophyll-a is a good indicator of algal concentrations and of nutrient over-enrichment. Chlorophyll-a samples were collected at Stations L6 and L7 during each water quality sampling. Chlorophyll-a concentrations at Lake Shirley during the diagnostic study ranged from 1.9 to 9.5 μg/l with most values ranging from 2 to 4 μg/l. Readings above 10 μg/l are considered indicative of eutrophic conditions, and concentrations in Lake Shirley did not exceed this level.

A phytoplankton sample was collected during each in-lake water quality survey and algae were enumerated and identified to the genus level. A list of all genera of phytoplankton species identified in Lake Shirley is presented in Table 3-12. Organisms grouped as "unidentified" could not be identified to genus because of complications arising from their classification, preservation, size or lack of internal cell structure.

Seasonal variations of phytoplankton populations can be quantified by cell density per unit volume and by changes in taxonomic composition by percent of phyla of phytoplankton. The most obvious feature of the seasonal population cycle at Lake Shirley is the increase in cells per milliliter during the summer months as presented in Figure 3-18. Cell counts at Lake Shirley have ranged from 111 to over 13,000 cells per milliliter with peaks occurring during the summer months. Peaks or blooms typically occur when temperatures are favorable and when nutrient loads from sources such as stormwater or sediments enter the lake. Although phytoplankton cell counts often exceeded the recommended level of 1,500 cells per milliliter, no noticeable massive blooms occurred during the diagnostic survey. Changes in

TABLE 3-12. PHYTOPLANKTON TAXA OF LAKE SHIRLEY FROM APRIL, 1986 TO FEBRUARY 1987

- Cryptophyceae
  - *Cryptophytes*
  - Unid. cryptophytes

- Chrysophyceae
  - *Dinobryan* sp.
  - *Chrysococcus* sp.
  - *Calycomonas* sp.
  - *Ochromonas* sp.
  - *Pseudopedinella* sp.
  - Chrysophyte statospores
  - *Synura* sp.
  - Unidentified Chrysophytes
  - *Mallomonas* sp.

- Bacillariophyceae - diatoms
  - Centric diatoms
    - *<10 µm centric diatoms*
    - *Rhizosolenia sp.*
    - *Asterionella sp.*
  - Pennate Diatoms
    - *Fragilaria sp.*
    - *Tabellaria sp.*
    - *Navicula sp.*
    - *Eunotia sp.*
    - *Cocconeis sp.*
    - *10 - 30 µm pennate*
    - *Nitzchia sp.*
    - *Meridion sp.*

- Euglenophyceae
  - *Phacus sp.*
  - *Euglena sp.*

- Dinophyceae
  - *Gymnodinium sp.*
  - *Peridinium sp.*

- Cyanophyceae
  - *Anabaena* filament
  - *Anacystis* colony
  - *Oscillatoria* filament
  - Unidentified cyanophyte colony
  - *Gomphosphaeria* colony
  - *Coccochloris* sp colony
  - *Spirulina* (fillament)
  - *Chroococcus* sp.
  - Unid blue-green filament
  - Unid blue-green trichome
  - *Oscillatoria* trichome
  - *Gloeocystis*
  - *Sphaerocystis*

- Chlorophyceae
  - *Ankistrodesmus* sp.
  - *Tabellaria* sp.
  - *Asterionella* sp.
  - Scenedesmus sp.
  - *Unidentified chlorophyte*
  - *Peridinium* sp.
  - *Schroederia* sp.
  - *Pediastrum* sp.
  - *Kirschneriella* sp.
  - *Gloeocystis* sp.
  - *Sphaerocystis* sp.
  - *Tetradesmus* sp.
  - *Closteriopsis* sp
  - *Tetraedron* sp
  - *Coccomonas* sp.
  - *Coelastrum* sp.
  - *Staurastrum* sp.
  - *Pedinopera* sp.
  - *Nephrocytium* sp.
  - *Selenastrum* sp.
  - *Crucigenia* sp.
  - *Tetradesmus* sp.
  - *Gonium* colony
  - *Oocystis* sp.
  - *Chlamydomonas* sp.
  - *Tetraselmis* sp.
  - *Geminella* sp.
  - *Arthrodesmus* sp.
  - *Elakatothrix* sp.
  - *Gomphosphaeria* sp.
  - *Tetrastrum* sp.

- Miscellaneous
  - Monads
  - Unidentified flagellates

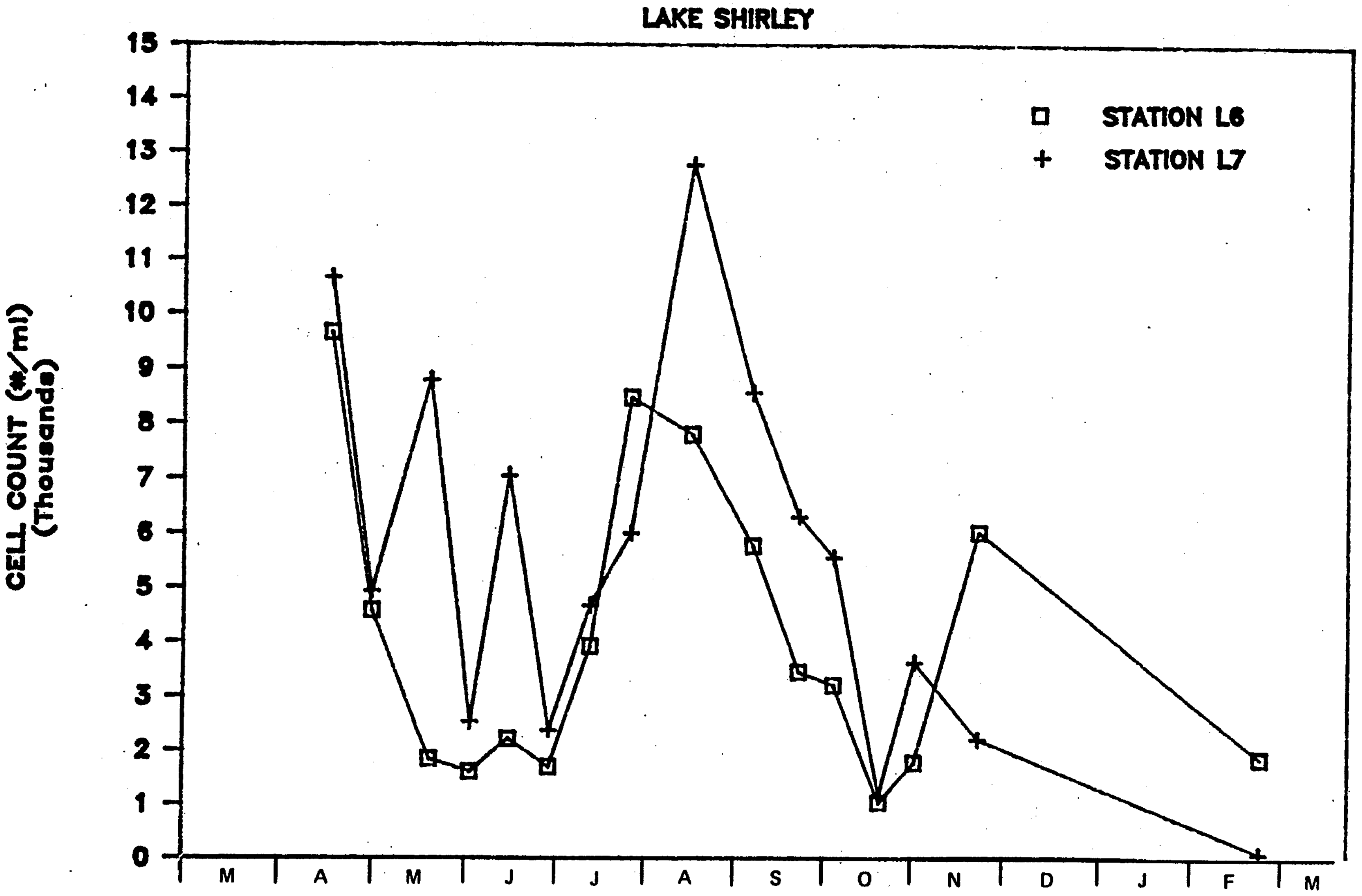


FIGURE 3-18. PHYTOPLANKTON CELL COUNTS AT LAKE SHIRLEY STATION L6 AND L7

taxonomic composition during the study period at in-lake stations L6 and L7 are shown in Figure 3-19. Green algae were dominant through the study period but not in bloom proportions. Moderate cell counts and a taxonomically diverse population indicate a fairly healthy population and no evidence of severe eutrophication.

Aquatic Macrophytes. Historical descriptions of the aquatic macrophyte population of Lake Shirley which date from 1912 to 1977, as described in Chapter 2, indicate a steadily increasing population. A moderate population of aquatic macrophytes can provide the benefits of oxygen production through photosynthesis, shading of sediments and food and habitat for microbes, insects and fish. However, overgrowth by macrophytes, as has occurred at Lake Shirley, may be detrimental to recreation and the environmental health of the waterbody.

In order to assess the current aquatic macrophyte population of Lake Shirley, Metcalf & Eddy conducted a macrophyte survey of Lake Shirley during August of 1986. In addition to submerged macrophytes which cause the most nuisance to boating and swimming, emergent and marshland macrophytes in wetland areas adjacent to the lake were identified.

The conduct of this survey confirmed that much of the areal extent of Lake Shirley is infested with nuisance aquatic macrophytes. The growth of water milfoil (*Myriophyllum*), water celery (*Vallisineria*) and fanwort (*Cabomba*) is extremely dense in the northern basin of the lake and approaches 100 percent in many

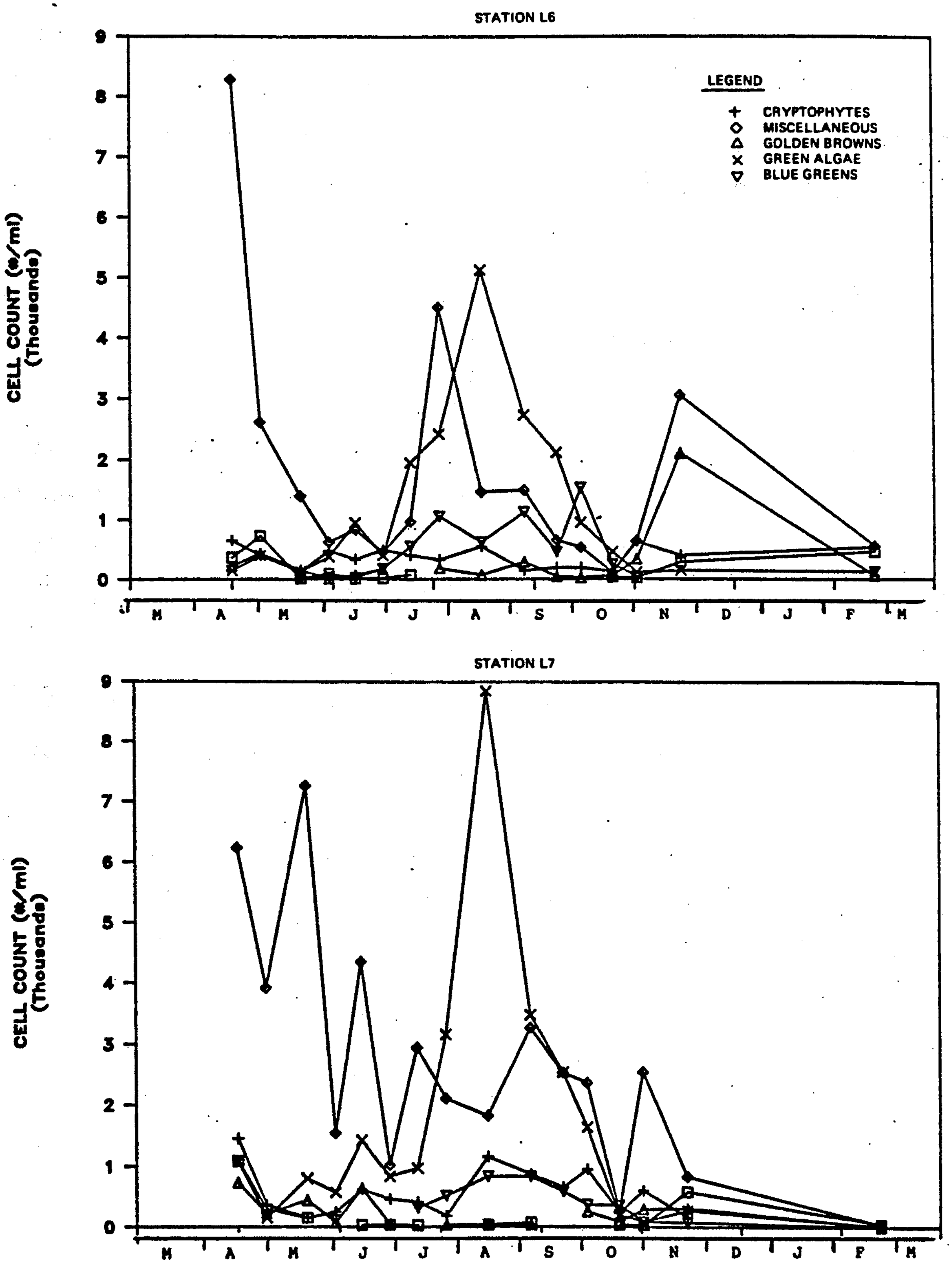


FIGURE 3-19. SEASONAL PHYTOPLANKTON TAXONOMIC COMPOSITION AT LAKE SHIRLEY STATION L6 (TOP) AND STATION L7 (BOTTOM)

areas as depicted in Figure 3-20. The deepest section of the lake was not populated due to lack of light penetration. Pondweed (*Potamogeton*) was common in several shoreline areas and especially at Stump Cove on the west side of the lake near Reservoir Road.

Due to the density of forested areas, residences, swimming beaches and stone walls along the periphery of the lake, palustrine or marsh wetlands were scarce. Several wetland areas were found near the Lake Shirley dam which were dominated by cattails (*Typha*), goldenrod (*Solidago*), jewelweed (*Impatiens*), buttonbush (*Cephalanthus*), and loosestrife (*Lythrum*). A list of all aquatic and wetland macrophyte species identified is presented in Table 3-13.

Fisheries. Although no fisheries data were collected during the diagnostic survey through field surveys, discussions with local anglers and field observations indicate that existing fish populations are consistent with data presented in Chapter 2. The lake is currently overpopulated with panfish such as bluegills and pumpkinseed; however, the lake is also maintaining adequate populations of bass and pickerel.

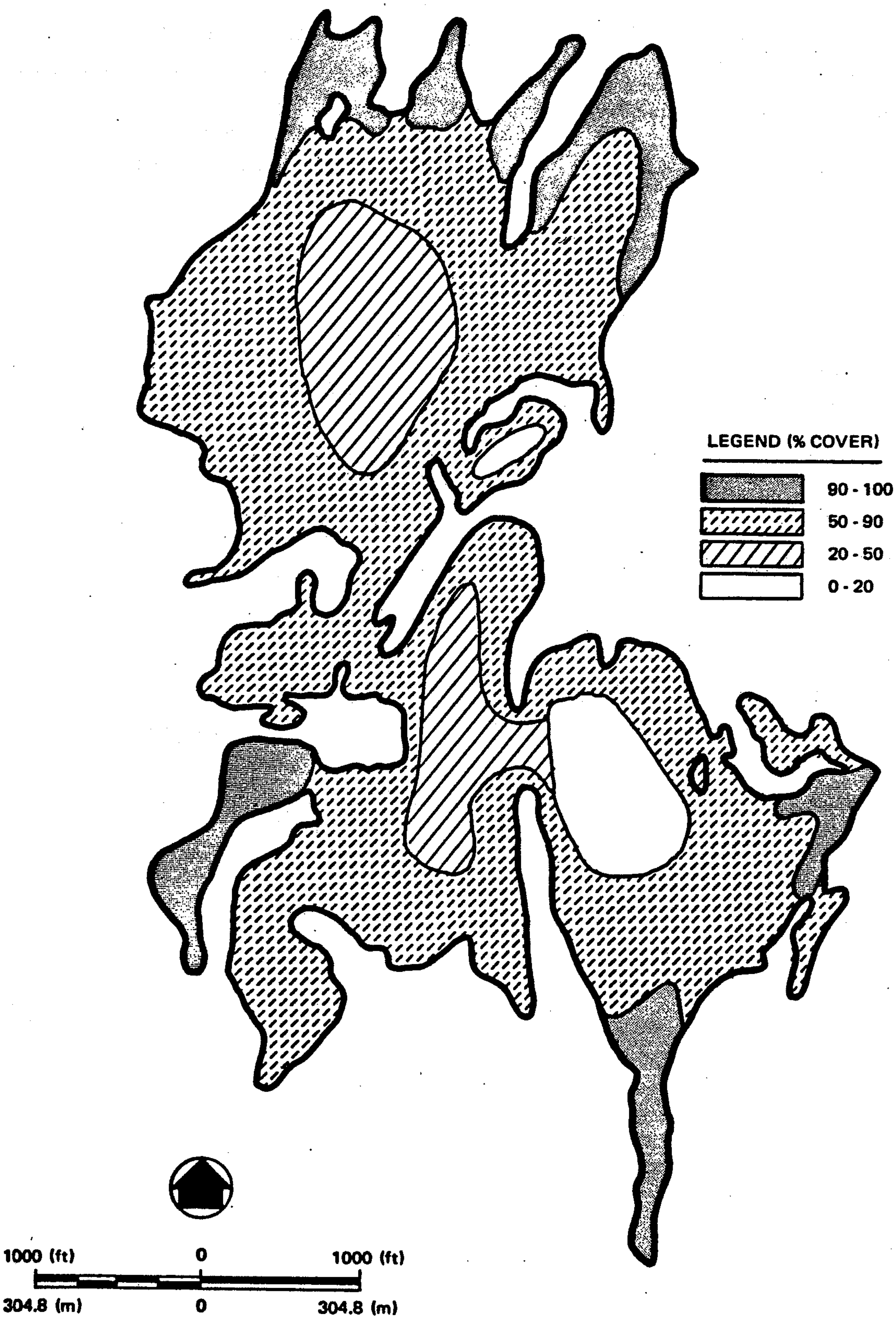


FIGURE 3-20. MACROPHYTE SURVEY OF LAKE SHIRLEY, AUGUST 13 AND 21, 1986

TABLE 3-13. MACROPHYTES OF LAKE SHIRLEY

Myriophyllum sp. 1	Water-milfoil 1
Myriophyllum sp. 2	Water-milfoil 2
Vallisineria corkscrewi	Corkscrew Water-celery
Cabomba carolineana	Fanwort
Potamogeton amplifolius	Pondweed
Potamogeton robbinsii	Pondweed
Utricularia	Bladderwort
Nuphar	Spatterdock
Lythrum	Loosestrife
Thalictrum	Meadow-rue
Najas flexis	Bushy Pondweed
Brasenia schreber	Water-shield
Nymphaea	Pond lily
Gratiola aurea	Golden-pert
Eriocaulon	Pipewort
Hypericum	St. John's-wort
Chelone	Turtlehead
Cyperus	Sedge
Lycopus	Water Horehound
Sambucus	Elder
Iris	Iris
Impatiens capensis	Jewelweed
Cephalanthus occidentialis	Buttonbush
Juncus	Rush
Typha latifolia	Broad-leafed cattail
Solidago	Bog goldenrod

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CHAPTER 4

ASSESSMENT OF EXISTING CONDITIONS

In this chapter, the data collected during the diagnostic survey are utilized to assess existing conditions in the lake. The hydrologic, nutrient and sediment inflows and outflows are summarized in the form of budgets, or mass balance calculations. From these budgets, the relative magnitude of each flow and pollutant load to the lake can be evaluated. This information along with the in-lake measurements has been used to define the overall status, or trophic state, of the lake. In addition, the hydrologic and nutrient budgets developed herein are used in formulating and evaluating alternatives for improving conditions in the lake (Chapter 5).

The diagnostic survey data have indicated that nutrient concentrations in the lake are stable, with generally little variation between sampling dates and no distinct seasonal variation. Based on this information, a dynamic model accounting for inflow and outflow from the lake on a daily basis will not be required to assess conditions at the lake. Rather, an annual budget of the hydrologic and nutrient loads to the lake has been used to define existing conditions and establish the lake's trophic state.

Hydrologic Budget

The sources of inflow to Lake Shirley are inlet stream flow, storm drain runoff, direct overland runoff, direct precipitation, groundwater, and septic inflow. Outflow from the lake occurs at the lake outlet, as evaporation from the lake water surface and as groundwater outflow. A hydrologic budget was formulated for Lake Shirley based on direct measurements of flow at inlet monitoring stations, groundwater stations and storm runoff sampling stations. For drainage basin areas not directly monitored, runoff coefficients were extrapolated to the remainder of the drainage basin for similar areas. The hydrologic budget based on estimated average annual flows is summarized in Table 4-1.

Average annual flows at the four inlet stations and at the outlet are based on an average of the measurements obtained at these locations during the diagnostic survey period. The drainage areas of these four inlets encompasses over 90 percent of the entire drainage basin. The remaining areas for which no direct measurements were collected include area F. Average annual flow from area F is based on the average annual precipitation and a runoff coefficient of 0.22. This coefficient is based literature values for forested and residential areas. Annual flows from storm drains are based on annual precipitation and literature runoff coefficients. The average annual precipitation of 44 inches is based on rainfall data recorded by the National Weather Service. Groundwater inflow is based on approximate estimates of flow velocity and contributing areas. Septic inflow is based on a count of the number of houses in the immediate lake area, assuming 2.5 persons/home and an estimated water use of 65 gallons per person/day. Evaporation loss is

TABLE 4-1. SUMMARY OF ANNUAL HYDROLOGIC BUDGET FOR LAKE SHIRLEY

Source	Quantity	Equivalent Annual Average Flow (cfs)
Inflow		
Inlet (Station L0)	0.13	0.13
Inlet (Station L1)	0.38	0.38
Inlet (Station L2)	3.81	3.81
Inlet (Station L3)	8.23	8.23
Inlet (Station L4)	0.66	0.66
Flat Hill Road Drain (Station LS3)	10 acres	0.018
Stone Fence Road Drain (Station LS5)	9 acres	0.013
Forested area (Station LS6)	171 acres	0.13
Direct Runoff (Area F)	504 acres	0.56
Direct Precipitation	44 in/yr	1.79
Groundwater		1.22
Septic Inflow	65 gal/capita/day	0.07
TOTAL		17.01
Outflow		
Outlet (Station L5)	14.41 cfs	14.41
Groundwater		1.50
Evaporation	27 in/yr	1.10
TOTAL		17.01

Flushing rate = 4.07 times per year
Residence time = 0.245 years = 89 days

based on the average annual evaporation from lakes in Massachusetts (Linsley et al., 1975).

The average measured outflow at Station L5 of 18.7 cfs was not used for the hydrologic budget. Operation of the outlet gate produced a number of high values which profoundly influenced the average value. The median value of approximately 14 cfs was adjusted by about three percent in order to balance the hydrologic budget. Based on the adjusted outflow of 14.41 cfs and an average lake volume of 2,561 acre-ft., the flushing rate of the pond is approximately 4 times per year. The hydrologic budget developed here will be used in the development of the nutrient budget for the lake.

Nutrient Budgets

Each of the flows in the hydrologic budget carries a nutrient load. Measurements obtained during the Diagnostic Survey and from the literature have been used to quantify these loads. Nutrient budgets are developed for both total phosphorus and nitrogen.

Phosphorus Budget. The annual average phosphorus loads to and from the lake are summarized in Table 4-2. The phosphorus concentrations at the inlet stations and the outlet are based on averages of the measurements from the diagnostic survey. Phosphorus loading from direct runoff from shoreline areas (Area F) is based on measured values from areas of similar land use. The phosphorus load to the lake from direct precipitation is based on values reported in the literature (Brezonick, 1972).

TABLE 4-2. SUMMARY OF ANNUAL AVERAGE PHOSPHORUS BUDGET FOR LAKE SHIRLEY

Source	Flow (cfs)	Concentration (mg/l)	Load (kg/yr)
Inflow			
Inlet (Station L0)	0.13	0.021	2
Inlet (Station L1)	0.38	0.029	10
Inlet (Station L2)	3.81	0.025	86
Inlet (Station L3)	8.23	0.030	219
Inlet (Station L4)	0.66	0.024	14
Flat Hill Road Drain (Station LS3)	0.018	0.2	5
Stone Fence Road Drain (Station LS5)	0.013	0.35	4
Forested Area (Station LS6)	0.13	0.1	20
Direct Runoff (Area F)	0.56	0.06	53
Direct Precipitation	1.79	0.025	40
Groundwater	1.22	0.025	27
Septic Inflow	0.07	1.1	40
Sediments			7
Non-Point Sources			40
TOTAL			567
Outflows			
Outlet (Station 5)	14.41	0.019	314
Groundwater	1.50	0.025	37
TOTAL			351

Net Gain: 216

Percent Retained: 38

The phosphorus load from septic tanks is based on the septic leachate survey and questionnaire results described in detail in Chapter 3 as well as literature values. During the septic leachate survey, influent plumes were located and sampled for phosphorus concentrations within the plume area. The value obtained from calculations based on these data was compared with literature values. Phosphorus load from septic systems is based on a total of approximately 165 homes within 100 feet of the lakeshore with an average of 2.5-persons per home. An average phosphorus loading rate of 0.1 kg/cap/year as estimated by the USEPA National Eutrophication Survey has been used. For systems located several hundred feet from shore, at least a 90 percent phosphorus removal could be expected (U.S. EPA, 1977) and these homes were not included.

The phosphorus budget summarized in Table 4-2 shows that the main external loads to the lake are contributed by runoff from large, developed watershed areas. In addition to the external phosphorus load, there is an internal load from the lake bottom sediments. The phosphorus leaving the lake is about 62 percent of the influent load. The remaining influent phosphorus is retained in the lake. Retention of phosphorus in the lake is expected since removal of phosphorus occurs by plant uptake and settling of solids and their associated phosphorus.

In some situations phosphorus from the bottom sediments may be released back into the water column. Phosphorus loading from anoxic sediments was calculated by comparing the average mass of phosphorus in the hypolimnion during stratification compared with epilimnion values. This method indicates a small annual phosphorus load of 7 kg/yr which has been included in the phosphorus budget.

Another potential source of nutrient loading to Lake Shirley is from groundwater pollution from specific sites within the watershed. In response to the concerns raised by the Town and at public meetings about specific activities within the watershed which may cause groundwater pollution, the potential contribution of nutrients from these sites was estimated. Potential groundwater contamination sources were identified in Chapter 2. In the following paragraphs, these sites are described and evaluated with respect to their potential for causing groundwater pollution. Following this screening process, nutrient loading from selected sites is calculated.

Sub-drainage Area A

Sand Pits - Several small sand pits are located near the headwaters of small tributaries to Easter Brook. Uncontrolled runoff from these sites may contribute to stream sedimentation and nutrient inputs including phosphorus and silicates; however, the potential for groundwater contamination from these sites is low.

DPW Salt Storage Facility - The DPW maintains a salt storage facility on Route 2 near Harvard Street and Mechanic Street in Leominster. Improper management practices at salt storage areas can result in groundwater contamination by constituents of road deicing agents. Improper handling and storage of fuels may lead to hydrocarbon pollution. Surface and groundwater contamination from these sites can be minimized by proper storage, proper truck washing, spill prevention and drainage improvements. There was no indication of problem levels of chlorides in the lake or tributaries.

Lancaster Landfill - This landfill is located near Lunenburg Road and Kaleva Road Lancaster and is used for all types of household waste. One half of its approximate 5 acre capacity is currently being used. Although this landfill is small and has not been used for industrial waste disposal, subsurface leachate from the site may be high in phosphorus content. An estimate of groundwater phosphorus loading from this site has been included in the nutrient budget.

Pioneer Drive Industrial Park - The industries on Pioneer Drive include Ecological Fibers, Inc., Monson Chemicals, Inc., Gary Chemicals, S.A.Y. Industries and Star Container. The volume of potential spills from these industries would be small. These may cause a local groundwater impact but would not significantly effect Lake Shirley.

Stillman and MacMillan Farms - The use of fertilizers, pesticides and storage or disposal of livestock or fowl wastes on land can contribute to groundwater pollution. Although farms within the watershed are used primarily for pasture and groundwater impacts are not expected to be severe, these sites have been included in the nutrient budget.

Camp David and Shady Point Beach - These private recreational facilities located at the mouth of Easter Brook feature swimming beaches, picnic benches, cooking grills, a boat launch facility and public rest rooms. Potential contamination from these sites includes grill washoff and septic leachate. Nutrient contribution from septic leachate was quantified separately.

Glenny's Marina - This private recreational facility near the confluence of Easter Brook provided boat docking and refueling services but is currently not operating.

Sub-drainage Area B

Penniman Septage Disposal Lagoons - Portajohns and septage pumping trucks are stored at this area on Burrage Road. Septage dumping at this site was stopped in a recent (1986) action by the DEQE. There is a large fuel tank at this site and several drums were observed. Due to the steep topography of the site, its proximity to the lake and the potential for subsurface leaching of domestic wastewater, an estimate of phosphorus loading from this site is included in the nutrient budget.

Closed Hazardous Waste Site - The DEQE (1984) Water Supply Protection Atlas shows a remediated hazardous waste site near Route 2A in the northern part of the watershed. Based on 1979 data, this site contained 2,000 drums of waste resins and organics, such as toluene, dumped between 1972 and 1975. According to Keith (1986), the drums have been removed, the site has been excavated, private wells have shown no evidence of contamination, and the site is considered secure.

Sand Pits - USGS topographic mapping shows two small sand pits in this area, both located near Catacoonamug Brook. In addition, during field reconnaissance, several sand pits were discovered on Reservoir Road at the junction of Catacoonamug Brook. Uncontrolled runoff from these sites may contribute to stream sedimentation and nutrient inputs including phosphorus and silicates; however, the potential for groundwater contamination from these sites is low.

New Developments - There are several new developments in this area including one year old developments off Arbor Street and Stone Fence Road. Surface and groundwater pollution from these areas have been quantified in tributary and stormwater nutrient load estimates.

Sub-drainage Area E

Keating Sand and Gravel - The Keating Sand and Gravel mining area occupies a large area directly south of the lake. In addition to increased surface runoff of solids and nutrients, this operation may increase subsurface loading of dissolved phosphorus and silicates, both vital plant nutrients. Thus, an estimate of phosphorus loading from this site is included in the nutrient budget.

Sources in Several Subareas

Shirley Municipal Landfill - This landfill is used for municipal, industrial, agricultural and solid waste but is located just outside the watershed of Lake Shirley. Based on the types of wastes present, there is potential for groundwater contamination; however, the pathway of groundwater flow from the site is uncertain and is likely not to reach the lake.

Junkyards - There are several automobile junkyards and repair shops located throughout the watershed. None are located immediately adjacent to the lake; however, several are located near major tributaries including Easter Brook and Catacoonamug Brook. These businesses typically use moderate amounts of oil, grease, degreasing agents and other hydrocarbons. As a general practice, all cars should be free of liquids prior to junking. Assuming reasonable housekeeping and the absence of any major chemical spills, these sites are not expected to have a significant affect on the lake and have not been included in the nutrient budget.

Underground Fuel Tanks - There are a number of underground fuel tanks of over 1,000 gallon size within the watershed at filling stations and commercial areas. Due to recent concerns over fuel tank leakage and groundwater pollution and new regulations in Massachusetts, many tank owners are being required to implement leak detection programs or even replace existing tanks. In a recently proposed action by EPA, underground storage tanks would have to be protected against corrosion and equipped with leak detection devices. Improvements in tank design and leak detection technology may reduce future concerns of pollution from underground fuel tanks. Should a leak occur, contamination of subsurface drinking water supplies may result. Despite this, little contamination of Lake Shirley itself would occur due to its large dilution and flushing rate, and nutrient contributions would not be expected.

The estimation of groundwater loading from potential sources is based on the size of the area and the estimated nutrient loading from literature values of pollutant concentrations, and estimates of the amount of subsurface leachate from each site. In order to provide a worst case analysis, conservative estimates of the site area, nutrient loading and leachate production have been used. Table 4-3 lists the sites evaluated, their location, environmental pathway to Lake Shirley, area, estimated leachate concentration, reference, estimated loading, percent of total phosphorus in the tributary which drains the site and percent of the overall phosphorus budget of the lake. As shown in Table 4-3, groundwater phosphorus contamination from sources of concern accounts for a maximum of 7.4 percent of the total P budget and a maximum of 7.6 percent of the phosphorus loading in any tributary.

The phosphorus budget indicates that 216 kilograms of phosphorus are retained in the lake per year, or about 38 percent of the phosphorus loading to the lake. This portion of the

TABLE 4-3. ESTIMATED PHOSPHORUS LOADING FROM POTENTIAL GROUNDWATER CONTAMINATION SOURCES

Contamination Source	Location in Relation to Lake	Environmental Pathway to Lake Shirley	Site Area	Total Phosphorus Concentration	Reference	Estimated P Loading (Kg/yr)	Percent Phosphorus Load of Tributary (%)	Percent of Overall Phosphorus Budget of Lake (%)
Lancaster Landfill	10,000 feet southwest	Groundwater discharge to wetland and tributary of Easter Brook	3 acres	3 mg/l	Freeze and Cherry, 1979	8.1	7.6	1.5
Penniman Septage Disposal Lagoons	4,000 feet north	Groundwater discharge to Dead Pond to groundwater to Catacoonamug Brook	3 acres	15 mg/l	Metcalf & Eddy, 1979	10.5	4.8	1.9
Keating Sand and Gravel Co.	300 to 5,000 feet south	Groundwater discharge to Lake Shirley and to unnamed tributary south of lake	100 acres	0.11 mg/l	Metcalf & Eddy, 1987	9.9	—	1.8
Stillman Farm	5,000 feet west	Groundwater discharge to Wetland and Easter Brook	100 acres	0.067 mg/l	Allen and Kramer, 1972	6.0	5.6	1.1
MacMillan Farm	2,500 feet southwest	Groundwater discharge to Easter Brook	100 acres	0.067 mg/l	Allen and Kramer, 1972	6.0	5.6	1.1

phosphorus budget is retained by sedimentation of particulate phosphorus, chemical precipitation to the sediments or by biological uptake by aquatic macrophytes and algae and subsequent deposition to the sediments during winter.

Nitrogen Budget. The annual average nitrogen loads to and from the lake are summarized in Table 4-4. The nitrogen concentrations at the inlets and the outlet are based on averages of the measurements form the diagnostic survey. Nitrogen loading from direct runoff from shoreline areas (Area F) is based on measured values from areas of similar land use. The nitrogen load to the lake from direct precipitation is based on values reported in the literature (Brezonick, 1972). Unlike the phosphorus budget, little nitrogen is retained in the lake. Phosphorus tends to precipitate more readily, whereas nitrogen, if not assimilated by aquatic vegetation, will pass through the lake system. A comparison of the annual nitrogen and phosphorus loads shows that nitrogen is very abundant in Lake Shirley and that phosphorus is the limiting nutrient.

Sediment Budget

Each of the flows to the lake also carries a sediment load. A sediment budget for Lake Shirley is presented in Table 4-5. Sediment loading from tributaries may contribute to cloudy water and the deposition of sediments in quiescent areas of the lake. As with the phosphorus and nitrogen budgets, the flow and suspended solids concentrations from the inlet stations from the diagnostic survey have been used to estimate sediment

TABLE 4-4. SUMMARY OF ANNUAL AVERAGE NITROGEN BUDGET FOR LAKE SHIRLEY

Source	Flow (cfs)	Concentration (mg/l)	Load (kg/yr)
Inflow			
Inlet (Station L0)	0.13	0.81	95
Inlet (Station L1)	0.38	0.74	254
Inlet (Station L2)	3.81	0.66	2260
Inlet (Station L3)	8.23	0.51	3736
Inlet (Station L4)	0.66	0.39	233
Flat Hill Road Drain (Station LS3)	0.018	1.83	29
Stone Fence Road Drain (Station LS5)	0.013	1.96	23
Forested Area (Station LS6)	0.13	1.26	146
Direct Runoff (Area F)	0.56	0.68	523
Direct Precipitation	1.79	0.54	864
Groundwater	1.22		556
Septic Inflow	0.07	20	718
Sediments			17
Non-Point Sources			662
TOTAL			10,116
Outflows			
Outlet (Station L5)	14.41	0.466	7800
Groundwater	1.50		705
TOTAL			8505

Net Gain: 1611

Percent Retained: 16

TABLE 4-5. SUMMARY OF ANNUAL AVERAGE SEDIMENT BUDGET FOR LAKE SHIRLEY

Source	Flow (cfs)	Concentration (mg/l)	Load (kg/yr)
Inflow			
Inlet (Station L0)	0.13	3.6	416
Inlet (Station L1)	0.38	14.7	5,040
Inlet (Station L2)	3.81	3.6	12,177
Inlet (Station L3)	8.23	2.2	16,312
Inlet (Station L4)	0.66	4.3	2,535
Flat Hill Road Drain (Station LS3)	0.018	160.0	4,035
Stone Fence Road Drain (Station LS5)	0.013	173.0	1,844
Forested Area (Station LS6)	0.13	12.0	1,540
Direct Runoff (Area F)	0.56	11.0	5,401
TOTAL			49,300
Outflows			
Outlet (Station 5)	14.41	1.6	26,712
Net Gain: 22,588			
Percent retained: 46			

loads and losses from the lake. In general, the tributaries were low in solids concentrations, with the exception of Station L1 near the Keating site and several storm drains; however, these sources accounted for only a small portion of the hydrologic budget and thus a small portion of the sediment budget.

Based on the net sediment loading rate of 22,588 kg/yr and assuming a specific weight of 38 lbs/cu.ft. (ASCE, 1977) that is typical of fine clay material, the average sediment accumulation is approximately 0.0018 inches per year. The value used for specific weight is highly conservative since much of the incoming sediment load is expected to be sand and silt. The estimate is also conservative since it has been assumed that deposition occurs only in the northern basin of the lake which is affected by inlets and storm drains and in other shoreline areas affected by overland runoff for a total of about 200 acres. The deposition of the aquatic macrophyte population and phytoplankton is also expected to contribute to sediment accumulation in the lake; however, given the depth of the lake and the extremely low rate of estimated deposition, sediment accumulation in the lake is not expected to be a problem.

Assessment of Trophic State

Trophic state assessments relate physical features of lakes, such as depth and flushing rate, with nutrient input to the lake using empirical correlations. By comparing characteristics of large numbers of lakes and developing correlations, a projection is made of the conditions in other lakes.

Trophic state assessments began with Vollenweider (1968) and have been improved by many others (for example Dillon (1974) and Kirchner and Dillon (1975)) to account for additional factors which affect the eutrophication of lakes. Trophic state assessments are useful as a rough estimate and are widely used.

The trophic state of Lake Shirley is shown in Figure 4-1. According to this calculation, which is based on the method of Vollenweider (1975), Lake Shirley is in a mesotrophic state. This is approximately in agreement with the in-pond quality data discussed in Chapter 3. In general, load estimates are conservative to provide a worst-case analysis. There is sufficient phosphorus and nitrogen in the lake to support growth of algae and aquatic weeds, which is verified by the nutrient and algae data and macrophyte mapping. However, the external loads are not sufficient to cause serious problems.

Summary

The calculations presented in this chapter provide the basis for the identification and development of restoration alternatives and the final recommended plan. The phosphorus budget, of primary concern since phosphorus is the limiting nutrient, indicates moderate phosphorus loading rates and mesotrophic conditions in the lake. The phosphorus budget indicates that 38 percent of the phosphorus input to the lake is retained, probably due to sedimentation, chemical precipitation and biological uptake by aquatic macrophytes and algae and subsequent deposition. The nitrogen budget indicates that unlike phosphorus, little nitrogen is retained in the lake. Similarly, sediment accumulation in the lake is not a problem.

Given the moderate nutrient loading rates, and low epilimnetic nutrient concentrations and good clarity, it is felt that nutrient inputs are not the major cause of the excessive

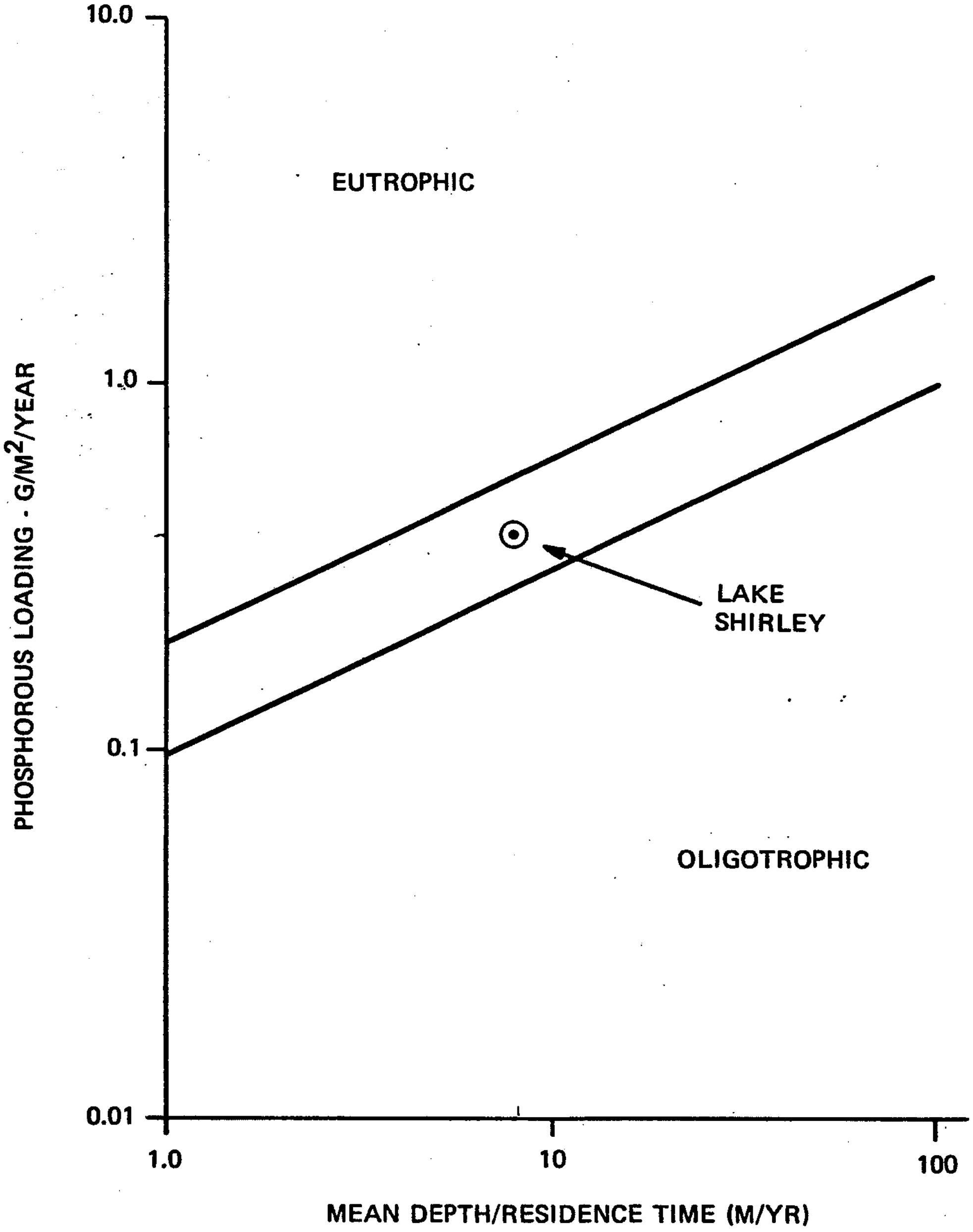

FIG. 4-1. TROPHIC STATE OF LAKE SHIRLEY, LUNENBURG

macrophyte growth in the lake. The gentle slopes, abundant sunlight, and nutrient rich sediments flooded during creation of the lake are highly favorable to macrophyte growth. Therefore, in the development of the restoration plan, macrophyte control alternatives are given major emphasis, and nutrient control alternatives are aimed at phosphorus inputs which cause localized problems near the lake shoreline, such as septic tanks.

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CHAPTER 5

ASSESSMENT OF ALTERNATIVES

This chapter presents an array of possible restoration alternatives that address the problems identified in the lake. The alternatives presented focus on aquatic macrophyte population reduction and nutrient control. The description of the alternatives is followed by an evaluation of their expected effectiveness, economic feasibility and environmental and public acceptability. Based on this analysis, appropriate alternatives to correct problems in the lake are selected as part of the recommended restoration plan described in Chapter 6.

Lake Shirley Problems and Objectives

The first step in the alternatives assessment process was to define the problems in the lake and to develop a set of objectives which, when achieved, would alleviate these problems and allow the desired uses. In order to provide input to the problem assessment and alternative development processes, public input was sought at a public meeting held on May 29, 1986 and several subsequent meetings with the Lake Shirley Advisory Committee and the Lake Shirley Improvement Corporation. During these meetings, desired uses of the lake, as well as complaints and problems which currently inhibit those uses were identified. The desired uses of Lake Shirley include continued swimming, boating and fishing. These uses must be preserved for public benefit and the economic value of the lake. Concern over potentially harmful activities within the watershed which may affect surface and groundwater was also evident.

The problems which currently inhibit desired uses and pose a threat to the future value of the lake include:

- Aquatic macrophyte growth reduces the aesthetic and recreational quality of the lake.
- Nutrient influx from tributaries, septic tanks and submerged bogs contributes to localized dense aquatic macrophyte growth and deteriorated water quality.

The principal problem identified in Lake Shirley is dense aquatic macrophyte growth. In addition, although nutrient loading is not a serious problem as discussed in Chapter 4, localized overfeeding of the lake with plant nutrients results in deteriorated water quality and proliferation of localized nuisance aquatic macrophytes in shoreline areas.

Aquatic plants are a natural and vital component of a healthy and diverse aquatic ecosystem. However, when there are large shallow areas with gentle slopes, plentiful sunlight, sufficient nutrients and suitable soil conditions in an aquatic system, aquatic plants may overpopulate to the extent that they interfere with recreational activities. In order to maintain conditions suitable for recreation, their removal may be required. Complete removal of native aquatic plants is normally not prudent. Some species present at Lake Shirley, such as cattails (*Typha latifolia*), jewelweed (*Impatiens capensis*) and pondweed (*Potamogeton* spp.) provide useful habitat for aquatic life and terrestrial animals. On the other hand, nuisance species or overgrowth by one or relatively few species interferes with the aesthetic value and recreational use of the lake. Nuisance aquatic macrophytes such as water milfoil (*Myriophyllum*), fanwort (*Cabomba*), and eel grass (*Vallisineria*) have populated most of the areal extent of Lake Shirley making boating and swimming difficult in many areas. A principal objective of the restoration plan for Lake Shirley will be to control nuisance aquatic vegetation and restore recreational benefits. Numerous macrophyte control techniques are evaluated for use at Lake Shirley in the following section. In addition, although nutrient loading is not a significant problem with the lake, a variety of phosphorus reduction measures have been evaluated. Reduction of phosphorus in the lake may curtail localized macrophyte growth, contribute to an overall improvement in water quality, and reduce algae populations.

Description of Alternatives

A comprehensive list of restoration alternatives has been compiled and evaluated in order to meet the restoration objectives for Lake Shirley. Some alternatives may result in several improvements which are consistent with lake restoration objectives. For example, dredging of in-lake sediments may reduce the internal phosphorus loading as well as remove nuisance aquatic macrophytes. Since inputs of phosphorus to Lake Shirley are both point (tributaries and storm drains) and non-point (overland runoff and groundwater), a variety of phosphorus reduction measures which address these sources have been evaluated. In the case of Lake Shirley which is a valuable recreational area, it will be particularly important to develop a comprehensive lake restoration plan which will provide long-term correction of this use impairment. The alternatives evaluated are listed in Table 5-1 and are described in the following sections.

Macrophyte Control Alternatives

This section presents a variety of in-lake measures to control macrophyte growth.

Harvesting. Harvesting removes plants from the lake with specialized barges equipped with cutting blades. The harvesting operation is conducted by maneuvering the harvester through the infested area. Harvested weeds are then transferred to shore for disposal. This macrophyte removal technique removes weeds to a depth of 5-7 feet and is particularly effective for plants that grow in tall stalks such as water milfoil (*Myriophyllum*) and fanwort (*Cabomba*), the principal nuisance species present at Lake Shirley.

Sediment Agitation. Several relatively new weed control techniques have been developed which involve agitating the bottom sediments, thereby disturbing or removing plant roots. One sediment agitation method is called rotavating. A rotavator is essentially a floating barge that drags a rototiller behind it

TABLE 5-1. RESTORATION ALTERNATIVES FOR LAKE SHIRLEY

- Macrophyte Control -
  - Harvesting
  - Sediment Agitation
  - Herbicides
  - Dyes
  - Fall/Winter Drawdown
  - Dredging
  - Biological Control
  - Lake Liner

- Phosphorus Reduction
  - Sediment P Reduction
    - Sediment Removal
    - Aeration
  - Inlet P Reduction
    - Sand/Alum Barriers
    - Wetland Enhancement
  - In-lake P Reduction/Inactivation
  - Watershed Management Plan
    - Watershed and Aquifer Protection
    - Septic System Management Plan
    - Public Education Program

along the lake bottom. The upper 2"-4" inches of lake bottom are tilled, chopping the roots of the plants into pieces. The pieces are either buried or float to the surface of the water. Since floating fragments could grow new plants, the operation should be conducted in late fall so the fragments would not have time to establish roots and grow before ice forms on the lake. The success of rotavating depends on the extent to which the roots are broken up and die.

Herbicides. Aquatic weeds can be controlled by the periodic application of one or several of a variety of chemical herbicides. The aquatic herbicide most commonly chosen to control milfoil is 2,4-Dichlorophenoxyacetic acid, better known as 2,4-D. This chemical has a high specificity for milfoil, thus pondweeds and other desirable plants would survive the dosage of 2,4-D required to kill milfoil. Herbicides are most effective in water with low turbidity when temperatures are from 15° to 18°C. It is most practical to apply chemicals before the plants develop seeds.

<u>Dyes</u>. Macrophytes and phytoplankton require sunlight for photosynthesis in order to survive. Non-toxic, vegetable based dye is available for use in lakes and ponds as a means of reducing light penetration and thereby reducing plant growth. The dye would give the lake water a blueish tint. Dyes of this nature are most commonly used in small ponds such as golf course ponds.

<u>Drawdown</u>. Drawdown involves lowering the water level to expose the plants to dessication (drying) and heat or freezing. The success of this measure depends on the macrophyte species present, shape of the lake bottom, sediment characteristics, and the severity of the weather during the drawdown period, thus the necessary duration of the drawdown may vary. Sufficient freezing will kill vegetative reproduction structures and inactivate seeds that would grow in the pond during the following season, inhibiting growth for one or more years. In addition, exposed sediments may consolidate, making them less favorable for the growth of certain nuisance aquatic plants.