Final Report
Diagnostic/Feasibility Study
Stockbridge Bowl
Stockbridge, Massachusetts

Project No.: E-701-88

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Prepared for the Town of Stockbridge, Massachusetts and the Massachusetts Division of Water Pollution Control.

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PROJECT SUMMARY

Stockbridge Bowl and its watershed were investigated during 1988 and early 1989 by Lycott Environmental Research. Stockbridge Bowl is a medium-sized, moderately deep lake in Stockbridge, Massachusetts. The Massachusetts Department of Environmental Quality Engineering, in cooperation with the Town of Stockbridge, funded this study through the Massachusetts Clean Lakes Program. The study consisted of a Diagnostic Phase -- a detailed assessment of the physical, chemical, and biological aspects of the lake and its watershed -- and a Feasibility Phase in which methods of rehabilitation and remediation were evaluated and selected for implementation.

The results of the Diagnostic Phase indicate that Stockbridge Bowl suffers from excessive macrophyte growth and hypolimnetic oxygen depletion. The latter restricts the cold-water fisheries and promotes release of phosphorus from the sediments. Anoxic sediments constitute the major source of phosphorus to Stockbridge Bowl.

To manage macrophytes in the near shore area, Lycott recommends that winter water-level drawdown of six feet be instituted. The outlet channel must be modified to permit a drawdown of this magnitude. Harvesting should be continued but intensified to control macrophytes in depths greater than the drawdown depth.

Lycott also recommends that a hypolimnetic aeration device be installed to prevent hypolimnetic oxygen depletion. This should enhance the cold-water fishery at Stockbridge Bowl and greatly reduce internal loading of phosphorus from anoxic sediments.

Table of Contents

Page

PROJECT SUMMARY

DIAGNOSTIC STUDY

Table of Contents cont'd.

Page

Table of Contents cont'd.

FEASIBILITY STUDY

Table of Contents cont'd.

BIBLIOGRAPHY

GLOSSARY OF TERMS

LIST OF TABLES

LIST OF TABLES cont'd.

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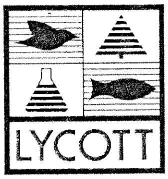
PROJECT SUMMARY



DIAGNOSTIC STUDY

SITE HISTORY

Historical Uses and Public Access

The following description of historical uses of Stockbridge Bowl is taken from an unpublished manuscript of an article by Henry Williams, Jr., of the Norman Rockwell Museum in Stockbridge, Massachusetts.

Located in north central Stockbridge, Stockbridge Bowl is a "great pond" with an area of 366 acres. It is the fifth largest lake in Berkshire County -- approximately one and a half miles long, a mile wide with a maximum depth of forty-eight feet and average depth of twenty-two feet.

In early days, it was called "Great Water". Its Indian name, **Mahkeenac**, meaning "abode of the Mohigans", displeased author Catherine Sedgwick of Stockbridge, because it would not fit easily into poetry. Early in the nineteenth century, she suggested the name "Stockbridge Bowl", and this is what it is most commonly called today.

At an altitude of 925 feet above sea level, it is bounded on the west by Lenox Mountain (also referred to as Stockbridge Mountain on older maps), on the north by Bald Head, and on the east by Rattlesnake Mountain. The boundary and topography of the watershed are shown in Figure 2, located in Appendix A. Rattlesnake is one of very few single mountain elevations in New England. In earlier times, it was cultivated to the summit. Five principal tributaries flow into Stockbridge Bowl as well as numerous springs which also feed it (see Watershed Sub-Basin Map, Figure 2).

Nathaniel Hawthorne lived in a small, red cottage at the north end of the lake in the mid-1850's. He and his children frequently visited a nearby glen full of brush, vines, rocks, and a stream. He called the glen "Tanglewood" and the stream "Shadowbrook".

The outlet runs south two miles to the first dam, named Newton Dam. It was built in the early 1800's and was placed to insure a steady flow of water to the Curtisville Mills below. One of these mills was renowned for producing the first wood pulp for paper-making in the United States in 1866. The mill was built by Albrech Pagenstrech and used grinder stones imported from Germany.

The outlet stream, called Larrywaug Brook, joins the Housatonic River about four miles to the south in the Glendale section of town.

Recreational development of the lake was slow in the early years with agriculture and grazing flourishing along the shore. Except for the Shadowbrook Boathouse (1895), Mahkeenac Boating Club (1890), the Treadway Cottage (1917), and a few other smaller waterfront cottages, the shore was pretty much open.

In the 1930's, this began to change. Claude A. Parker purchased 200 acres at the south end of the lake from the Parsons family of Lenox and began developing roads and a water system. Today, more than 115 cottages (many of them winterized) make up the Beachwood development. Other large areas are the Mahkeenac Shores, Mahkeenac Terrace, Mahkeenac Heights as well as additional developments on the western shore.

The revised Vaughn Gray (1985) map of Stockbridge Bowl (Figure 4) shows 408 cottages and houses in its watershed. In total, the property owners within the Stockbridge Bowl watershed represent about 27% of the Town's tax base. With private development on the shores of the Bowl, access to the lake was reduced, causing the county commissioners to require a public right-of-way. In 1959, a boat landing of 4.83 acres on the west shore off Route 183 (with a value then of $17,500) was acquired from the Stokes family. The 157 feet of frontage has provided adequate access to the Bowl. The Town Beach, for residents of Stockbridge, is located off Mahkeenac Road adjacent to Beachwood.

In October of 1946, the Stockbridge Bowl Association (SBA) was voted into existence at a meeting in the Brook Farm living room of the Rt. Rev. Arson Phelps Stokes. He championed its formation "To protect the natural beauty of the Stockbridge Bowl and its watershed, the health and well-being of its residents, the interests of the public at large, and to set standards that may aid the general cause of conservation." After the Association was officially incorporated in 1948, one of its first acts of carrying out its purpose was to purchase the 3-acre island at the south end of Stockbridge Bowl from the Laurel Lake Association for $1,400.

An additional 70 acres "to be left in its natural state" and to be called Bullard Park, came to the SBA by the will of Mary Robbins Reynolds Bullard, wife of Dr. William Norton Bullard in 1960. The land, with 1,200 feet of shore frontage, lies off Hawthorne Street on the northern shore between land owned by the Boston Symphony Orchestra and Camp Mah-kee-nac.

Gould Meadows, formerly the Higginson property, is one of the last pastoral landscapes in the area with a spectacular view of the Bowl. Located at the Northwest end of the Lake, it was offered to the Town of Stockbridge for $250,000 in 1980 after years of encouragement by the conservation-minded citizens to protect open lands.

The public access to Stockbridge Bowl has been extensively discussed in the application of the Town of Stockbridge for the Diagnostic/Feasibility Study funding. Four large, contiguous parcels of undeveloped land comprise the entire north end of the lake, approximately 4,000 feet of the shoreline. These include the Kripalu Center, Gould Meadows, Tanglewood, and Bullard Memorial Park which are described below together with other areas of public access.

1. **Gould Meadows** - This area includes a parking lot, trail system, and beach. It is open to the general public and is used extensively for passive recreation, swimming, hiking, and cross-country skiing.

2. **Stockbridge Boat Ramp** - This area is a concrete surfaced boat ramp and is open to the general public. It is on the northwestern shore of the lake off of State Route 183.

3. **The Cove** - This area is open to the public and is generally used for passive recreation. There is also an undeveloped beach and a parking area. The site is used for swimming, picnicking, and walking.

4. **Causeway at Lily Brook Inlet** - This undeveloped public access on the east side of the lake is extensively used for shoreline fishing and to a lesser extent, for swimming. There is a pull-off area for parking on both sides of the road.

5. **Bullard Memorial Park** - This 45-acre parcel of wooded hiking terrain is open to the general public for swimming, hiking, and cross-country skiing.

6. **The Island** - This undeveloped 3.13 acre island at the southern end of the lake is used extensively by the general public for swimming and passive recreation, including picnicking, hiking, and cross-country skiing.

7. **Stockbridge Town Beach** - This 2.7 acre developed beach with parking lot, bath houses, picnic tables, and trash collection is open for swimming to Stockbridge residents, renters, and guests.

8. **Quasi-Public Beaches** - The Tanglewood Beach is used for swimming by Tanglewood's summer residents and their guests. The Kripalu Center, an institution for yoga and holistic health, maintains a beach for its residents and guests.

Recreational Use

Stockbridge Bowl is heavily used for recreational purposes during all four seasons. The Bowl supports an abundant warm-water fishery and is stocked in the spring with trout. The boat ramp receives heavy boating usage including motor boats, sailboats, canoes, row boats, and wind surfers. Sailing regattas occur during the summer. Likewise, water skiing is a popular summer activity. The Great Josh Billings Run Aground Triathalon has included a five mile canoe race on Stockbridge Bowl for the past ten years.

Stockbridge Bowl has been enjoyed by swimmers, boaters, and fishermen for more than 100 years.

REVIEW OF REPORTS

An extensive data base exits on Stockbridge Bowl. Lycott reviewed the following information to determine the long-term status of Stockbridge Bowl.

- Chapter 628 Applications, Town of Stockbridge, September 29, 1986.
- Stockbridge Bowl Map - Its Residences and Sewered Areas, Residences were revised in 1985 and Sewered Areas were revised in 1987.
- Mass DEQE Division of Water Pollution Control, Massachusetts Lake Classification Program, January 1984, excerpts.
- Mass DEQE Division of Water Pollution Control, Six Ponds Dioxin Survey, June 1984.
- Mass DEQE Division of Water Pollution Control, Massachusetts Lake Classification Program, January, 1982, excerpts.
- Berkshire Enviro-Labs, Inc., Stockbridge Bowl Water Quality and General Aquatic Macrophyte Maps, 1980 and 1981.
- Berkshire Enviro-Labs, Inc., Stockbridge Bowl Eutrophication and Aquatic Vegetation Control Program, Final Application, October, 1980.
- Berkshire County Regional Planning Commission, Water Quality Plan for the Upper Housatonic River, Final Plan/Environmental Impact Statement, September 1978, excerpts.

- Mass DEQE Division of Water Pollution Control, 1976 Baseline Water Quality Studies of Selected Lakes and Ponds, Housatonic River Basin, December 1976, excerpts.
- Mass DEQE Division of Water Pollution Control, Berkshire County 208 Program Inlet Survey Data, May 1976.
- Mass DEQE Division of Water Pollution Control, 1974 Baseline Water Quality Studies of Selected Lakes and Ponds, Housatonic River Basin, September 1975, excerpts.
- S. Ludlam, K. Hutchinson and G. Henderson, The Limnology of Stockbridge Bowl, Stockbridge, Massachusetts, 1974.
- Curran Associates, Inc., Wastewater Collection and Disposal at Stockbridge Bowl, Stockbridge, Massachusetts, 1974.
- J. McCann and L. Daly, An Inventory of the Ponds, Lakes, and Reservoirs of Massachusetts, Berkshire and Franklin Counties, February, 1972, excerpts.
- Additional data from the Massachusetts Division of Fisheries and Wildlife.

According to data found in the reports above, much effort and expense has been expended to solve the lake's problems, including sewering of the Beachwood area at the south of the lake, restrictive zoning of the shoreline, and almost $300,000 spent on lake management and study.

Water quality problems afflicting Stockbridge Bowl over the years include the following:

- very dense macrophyte growth in essentially the entire littoral zone,
- depletion of hypolimnetic oxygen during the summer and winter, and
- slimy reddish brown deposits associated with blooms of *Oscillatoria rubescens*.

Stockbridge Bowl is alternately described as eutrophic (Ludlam et al. 1974) or mesotrophic (DEQE 1984). However, the latter seems an optimistic assessment. Phosphorus data provided by Berkshire Enviro-Labs (BEL) for the lake in 1980 and 1981 suggests that the lake is almost hypereutrophic (see Table 1 below). Total phosphorus concentrations from the deep-hole surface ranged from 0.11 mg/l on February, 1981 to 0.00 mg/l on August, 1980. Overall, the data provided by BEL averaged 0.05 mg/l over seven dates in 1980 and 1981. Using the classification scheme below, these data would classify the lake as hypereutrophic.

TABLE 1

TROPHIC STATE CLASSIFICATION SCHEME
(adapted from Reckhow et al., 1980)

Phosphorus Concentration (mg/liter)	Trophic State	Lake Use
<0.010	Oligotrophic	Suitable for water-based recreation and propagation of cold water fisheries such as trout. Very high clarity and aesthetically pleasing.
0.010 - 0.020	Mesotrophic	Suitable for water-based recreation but often not for cold water fisheries. Clarity less than oligotrophic lake.
0.020 - 0.050	Eutrophic	Reduction in aesthetic properties diminishes enjoyment for body contact recreation. Generally very productive for warm water fisheries.
> 0.050	Hyper-eutrophic	A typical "old-aged" lake in advanced succession. Some fisheries, but high levels of sedimentation and algae or macrophyte growth may be diminishing open water surface area.

Further discussion of previous reports can be found in sections where this data is relevant.

WATERSHED AND SUB-BASINS

Watershed Description

The Stockbridge Bowl watershed lies within the Housatonic River Basin of western Massachusetts. From Stockbridge Bowl, water drains into the outlet stream known as Larrywaug Brook, which in turn travels south into the Housatonic River.

The Stockbridge Bowl watershed is depicted in Figure 2, and represents portions of the U.S. Geological Survey (USGS) topographic maps of the Stockbridge and Pittsfield West quadrangles. It is predominantly located in the Town of Stockbridge, but also extends into the Towns of Richmond, Lenox, and Lee. According to Lycott's planimetric calculations, the watershed encompasses approximately 7,336 acres, or 11.46 square miles. Of this area, the lake occupies approximately 385 acres, which represents 5% of the total watershed.

Topography within the watershed varies dramatically. To the west and north, the outer portion of the watershed follows the steeply sloped West Stockbridge and Lenox Mountains, which peak at elevations of about 1,600 - 1,800 feet. Rattlesnake Hill, a north-south trending feature to the southeast of Stockbridge Bowl, is also very steeply sloped up to its high point of 1,556 feet. Water from this hill flows westward into the lake and eastward into a large wetland, which eventually drains into the lake via Lily Brook. More moderately sloping land (8 - 15%) borders all sides of Stockbridge Bowl except the southeast, and predominates in the eastern and northeastern sections of the watershed. The lake itself, according to USGS topography, is at an elevation of about 925 feet, placing it about 900 feet lower than the highest point in the watershed (Stockbridge Mtn., 1,828 feet).

Stockbridge Bowl receives surface-water runoff from five major tributaries, numbered 1 through 5 in Figure 10. (A sixth and much smaller tributary was also noted along the eastern margin of the lake.) As described below, these tributaries were used, along with other topographic and drainage characteristics, to delineate sub-basins for the lake's watershed.

Sub-Basins

The Stockbridge Bowl watershed was divided into eight drainage sub-basins (Figure 2). Six of these contain a tributary to the lake, and the other two (sub-basins #4 and #5) do not. Each sub-basin is discussed in detail below.

#1 - Sub-basin #1 encompasses the surface area drained by Lily Brook. This area is very large (approximately 4,029 acres), and covers the eastern half of the watershed. Within sub-basin #1, two further divisions have been made: sub-basin #1A represents the area that drains from the north into Lily Pond, and sub-basin #1B represents the area that drains from the south into Lily Brook. Both #1A and #1B contain large expanses of wetlands.

#2 - Sub-basin #2 consists of the northwestern flank of Rattlesnake Hill, which makes up the southeastern margin of the lake. Although a small tributary occurs within this sub-basin (designated sampling locality #8 on Figure 10), drainage from most of the sub-basin occurs by overland sheet flow or subsurface flow. In addition, water flows into the lake through several storm drains (see Figure 14) originating in the Mahkeenac Road area.

#3 - Land draining into the southern margin of the lake has been designated sub-basin #3. Within this sub-basin, area #3B is drained by tributary #5 (Duck Pond Brook), whereas area #3A is drained by overland sheet flow and subsurface flow.

#4 - This sub-basin along the southern margin of the watershed is distinguished from sub-basin #3 in that it drains from the east into the outflow channel, rather than into the lake proper.

#5 - Sub-basin #5 also drains into the outflow channel, but from the western side.

#6 - Sub-basin #6 consists of land abutting the lake on the west. Sub-basin #6B is drained by tributary #1 (Mahican Brook), and the remainder (sub-basin #6A) by subsurface flow and overland sheet flow.

#7 - The second largest sub-basin within the watershed, sub-basin #7 consists entirely of land drained by tributary #2 (Shadow Brook). The steep eastern flanks of West Stockbridge and Lenox Mountains are the predominant feature within this sub-basin.

#8 - Lastly, land immediately to the north of Stockbridge Bowl has been designated sub-basin #8 and divided into two portions. Sub-basin #8A represents the area drained by tributary #3, whereas sub-basin #8B drains by subsurface flow and overland sheet flow directly into the lake.

The sizes of the sub-basins, together with the corresponding tributary numbers, are summarized in Table 2.

TABLE 2

DRAINAGE SUB-BASINS

Sub-basin #	Tributary #	Sub-basin Size (acres)
1A	4	2311
1B	4	1718
2	8	143
3A		36
3B	5	200
4		354
5		100
6A		100
6B	1	157
7	2	1255
8A	3	350
8B		227

LAND USE

Land use in the Stockbridge Bowl watershed is summarized in Tables 3 and 4 and illustrated in Figure 3. Figure 3 has been modified from previous information in Lycott's quarterly reports to reflect more recent information obtained from the Town of Stockbridge.

Types of land uses can be grouped into the following categories, listed in order of total acreage in the watershed (greatest to least): woodland, residential land, open land, agricultural land, wetlands, and open water. In this largely undeveloped watershed, woodland comprises a vast majority of the acreage (64.4%). Residential lands (totaling about 15.5%) occur largely around the perimeter of the lake (especially sub-basins #2, #3, #4, #5 and #8) and in the northeastern section of the watershed (sub-basin #1A). Near the lake, these areas range in density from very light to light, with isolated pockets of medium-density residential land. In sub-basin #1A, more densely settled residential areas and small areas of urban land occur where the watershed encompasses a portion of the Town of Lenox.

TABLE 3

LAND USE IN THE STOCKBRIDGE BOWL WATERSHED

Land Use	Total Acreage	% of Watershed*
Woodland	4477	64.4
Residential	1080	15.5
Open Land	778	11.2
Agricultural	350	5.0
Wetlands**	246	3.9

* Exclusive of Stockbridge Bowl lake.
** Including Lily Pond (open water).

TABLE 4

PERCENT LAND USE BY SUB-BASIN

	Sub-Basin (Percent)											
Land Use	1A	1B	2	3A	3B	4	5	6A	6B	7	8A	8B
Woodland	57	73	42	17	73	80	18	63	40	85	46	34
Residential	25	2	58	83	25	10	44	2	8	3	12	34
Open land	9	4			2	10	38	35	48	8	36	32
Agricultural	4	12							4	4	5	
Wetlands	5*	9									1	

High P levels in trib

* Including Lily Pond

GEOLOGICAL DESCRIPTION OF DRAINAGE BASIN

In order to understand hydrologic processes which are important to Stockbridge Bowl, the geological setting must be identified and described. Information relative to both bedrock geology and surficial geology is presented below.

Bedrock

Bedrock units underlying the Stockbridge Bowl watershed consist of the Wallomsac, Stockbridge, and Dalton Formations, according to the Bedrock Geologic Map of the Stockbridge Quadrangle by N.M. Ratcliffe (USGS, 1974). All but the Dalton Formation contain carbonate rocks, which may be more permeable to groundwater flow relative to other types of bedrock due to dissolution processes. Details of the Ratcliffe map are reproduced in Figure 5.

The upper and middle Ordivician Wallomsac Formation consists of two members: a biotite-rich quartzose schist and a calcitic schistose marble. Those members of the Stockbridge Formation (lower Ordivician to lower Cambrian) contained in the watershed include: a coarsely crystalline calcite marble, calcitic quartzite and quartzose calcite marble, calcitic dolostone or dolomitic marble, and an impure micaceous quartzose dolostone. The lower Cambrian and Precambrian Dalton Formation, which is limited to the Rattlesnake Hill area, consists of a biotite-muscovite feldspathic meta-quartzite and a quartz schist.

Geologic structures within the watershed include folds and thrust faults. Thrust faults can be important because they have the ability to contain and transmit water. Since one of the thrust faults extends underneath Stockbridge Bowl, the lake could be receiving significant quantities of water due to seepage from bedrock.

Surficial Geology

Several different types of surficial deposits are present within the watershed, including till, swamps, and stratified drift. The surficial geology, as mapped by G.W. Holmes (USGS Open Files #732, #733 and #763), is reproduced in Figure 6.

Glacially-derived till, which covers the majority of the watershed, varies from thick (ten's of feet) to thin and even absent in places. The till consists of poorly transmissive unsorted clay, silt, sand, gravel, and boulders deposited directly on top of the bedrock surface. Areas of the watershed containing swamp sediments consist of decomposed to undecomposed organic matter, with some peat, silt, and sand. The stratified-drift deposits, which are limited to small areas near the marsh in sub-basin #1A, consist of ice-contact glacio-fluvial deposits of sand and gravel with small amounts of silt.

SOILS

Soil types are a major factor influencing the relative quantities of overland runoff and groundwater input to lakes. Soils of hydrologic group A or B are conducive to infiltration of rainfall into the subsurface whereas soils of hydrologic groups C or D result in high rates of overland runoff. In addition, soil permeability plays a major role in determining the suitability of a site for subsurface disposal of wastewater.

Soil types in the Stockbridge Bowl watershed have been identified using maps prepared by the U.S. Soil Conservation Service (see Figure 7). Key soil characteristics are summarized in the key to Figure 7. Table 5 describes the limitations of each soil type with respect to septic-system absorption fields.

TABLE 5

SOIL LIMITATIONS FOR SEPTIC TANK ABSORPTION FIELDS

Soil Type	Degree and Kind of Limitations for Septic Tank Absorption Fields
Amenia	Severe: Wetness, percs slowly
Copake	Severe: Poor filter
Farmington	Severe: Depth to rock
Hero	Severe: Wetness, poor filter
Hoosic	Severe: Poor filter
Limerick	Severe: Flooding, wetness
Lyman	Severe: Depth to rock
Peru	Severe: Wetness, percs slowly
Pittsfield	Slight to severe, depending on slope
Saco	Severe: Flooding, wetness
Tunbridge	Severe: Depth to rock
Winooski	Severe: Flooding, wetness

The soils found in the Stockbridge Bowl watershed are predominantly deep, moderately well drained loams formed from glacial till. Along the highest topographic features (West Stockbridge/Lenox Mountains and Rattlesnake Hill), soils belong to the Tunbridge-Lyman-Peru association and may predominantly be categorized in hydrologic group C. The majority of the remainder of the watershed has soils of the Amenia-Pittsfield-Farmington association, which are divided into two groupings according to slope: "C/D" for the steeper slopes and "A/B" where slopes are less steep. (Note: Capital letters are used by the Soil Conservation Service in two different ways -- as indicators of slope and as indicators of hydrologic group.) Much of the soil in the Amenia-Pittsfield-Farmington association is less conducive to runoff than the Tunbridge-Lyman-Peru association and may be classified in hydrologic group B.

HYDROGEOLOGY AND GROUNDWATER MONITORING

The surficial blanket of till that covers most of the Stockbridge Bowl watershed acts as a groundwater aquifer contributing water to the lake. However, till has relatively low permeability, and groundwater flow into and through the till can be expected to be relatively slow. Furthermore, bedrock occurs at shallow depths, limiting the saturated thickness of overlying till and the volume of groundwater moving through the till. The bedrock can be expected to act more or less as an impermeable boundary, although the predominance in this watershed of carbonate bedrock (which can become more permeable through dissolution processes) may mean there is more seepage into or out of the bedrock than would be expected for non-carbonate bedrock.

Since the surficial groundwater system is shallow, extending only to bedrock, flow directions are inferred to be controlled by local topography (i.e., a groundwater divide is assumed to be roughly coincident with the surface-water divide). Thus, incident precipitation that falls within the watershed and infiltrates to the water table will move downslope through the till, discharging either into a tributary to Stockbridge Bowl or directly into the lake itself.

In order to learn more about the hydrogeology and water quality of the Stockbridge Bowl watershed, available information on soils and geology was supplemented by data gained from drilling and installation of four monitoring wells. Prior to installation of the wells, a letter was submitted to Dr. Bob Haynes of the Massachusetts Division of Water Pollution Control requesting review of the proposed locations. All locations were approved, and the four wells were installed on June 22 and 23, 1988, by Soil Exploration Corporation of Leominster, Massachusetts, with all procedures closely supervised by Lycott personnel. Boring logs for these wells, included in Appendix B of this report, provide specific information on local surficial geology. In addition, the wells were used for collection of water-level data and water-quality samples throughout the study year.

Well Installation Procedures

All groundwater monitoring wells were installed in borings drilled by hollow-stem augers. Five-to fifteen-foot lengths of 1-1/2-inch or 2-inch diameter PVC screen were placed in boreholes at appropriate depths (as determined in the field), and each well was completed with riser pipe to the surface. Boreholes were backfilled with silica sand to at least 1 foot above the screened interval, and a 1-foot thick bentonite seal was placed above the silica sand to prevent vertical migration of water along the borehole. The remainder of the borehole was backfilled with materials brought to the surface during the drilling process. Finally, protective casing was cemented in place over each well and set flush with the ground surface in some locations and raised above the ground in others.

As described below, bi-level wells were installed at three of the four selected localities. Installation procedures for the bi-level wells were similar to those used in single-level well construction with one exception. Following emplacement of the screen, riser pipe, silica sand, and a bentonite seal for the deepest well, a second PVC screen and riser pipe were installed in the same borehole above the bentonite seal. The remainder of the borehole was then backfilled with silica sand to one foot above the second screened interval, and a second bentonite seal was placed above the silica sand. Material excavated during drilling was again used to finish the backfilling of the borehole.

The actual depth of each well was determined at the time of drilling because appropriate depth depends upon several factors that must be determined in the field. Factors that were taken into account in the determination of well depth included groundwater level, nature of the materials encountered during the drilling process, and information that would be gained by the installation of a deeper well. Split-spoon samples of surficial material encountered during the drilling process were collected at 5-foot or 10-foot intervals depending upon the homogeneity of the deposits and the expected depths for well placement.

Selection of Monitoring Well Sites

Locations of the monitoring wells are described below and depicted in Figure 8.

MW-1 - The location for well MW-1 is near the town boat ramp in the northwestern end of the lake. This location was chosen to assess water quality at an end of the lake which is relatively undeveloped. In addition, the well was constructed as a bi-level well (designated MW-1S for the shallower well and MW-1D for the deeper), and used to measure the vertical groundwater flow gradient in the vicinity of the thrust fault in the underlying carbonate bedrock (see Figure 5). A significant vertical gradient, either upward or downward, would suggest leakage to or from the bedrock.

Both MW-1S and MW-1D were installed into a boring which encountered a 3-foot-thick brown/tan topsoil followed by 4.5 feet of moderately well sorted fine-to-medium sand. From a depth of 7.5 feet to 16.0 feet, where the boring was terminated, a compact, poorly-sorted blue-gray till was encountered. Monitoring well MW-1D was set at this depth, and was constructed using five feet of screen and 11 feet of riser pipe. Well MW-1S was set at a depth of eight feet and screened to the surface. A protective casing was installed above the land surface to facilitate location of the well for sampling.

MW-2 - Well MW-2 was installed near the town beach in an effort to obtain information on groundwater flow from Rattlesnake Mountain and the Mahkeenac Heights residential development. Again, a bi-level construction was used in order to measure the vertical flow gradient. Boring at this locality encountered an 18-inch thickness of brown/black topsoil and root matter. The remaining 22.5 feet of the boring was drilled through a dense, poorly-sorted light-brown till. Monitoring well MW-2D, set at 24.0 feet, was constructed of a 10-foot section of screen and 14 feet of riser. Well MW-2S was set at five feet and screened to the surface.

MW-3 - Well MW-3 was installed in the Beachwood residential section on property owned by Edward Darrin. Until recently, there were a high number of on-site sewage disposal systems in this area. Sediments encountered during drilling were three feet of dark-brown, dense sand with organic matter, underlain by 17.5 feet of thick, compact till that changed in color from tan/brown to blue/gray as the depth increased. A deep well (MW-3D) was set at a depth of 20.5 feet, using 15 feet of screen, and a shallow well (MW-3S) at fivefeet with screening to the surface.

MW-4 - Well MW-4 was placed just south of the causeway where Lily Brook enters the lake. Within this boring, fill material composed of silt, sand, and gravel was encountered to a depth of two feet. Below two feet and to a depth of 15 feet was a layer of medium-dense, poorly sorted fine sand with some silt and gravel. This material likely represents recent (non-glacial) fluvial deposits. A very compact, bouldery till was encountered in the remaining 10.5 feet to a total depth of 25.5 feet. A single-level well was installed in the borehole using ten feet of screen. A steel casing equipped with a locking cap was installed at the land surface to prohibit vandalism and facilitate sampling procedures.

Data concerning the physical characteristics of the monitoring wells and surficial geology are summarized in Table 6. On August 19, 1988, elevations of all wells were surveyed relative to the lake level, which was measured relative to a fixed line marked on a boulder at the shoreline near the town boat ramp.

Results of Water-Level Measurements

Table 7 lists the water-table depths measured in each monitoring well during 1988-89.

TABLE 6

MONITORING WELL INFORMATION

Well#	Elevation of Well Above Lake (ft)*	Depth of Well (ft)	Permeability gal/(day-ft^2)	Avg. Depth to Bedrock
1S	+ 13.83	8	125	> 16
1D	+ 13.83	16	80	> 16
2S	+ 21.67	5	100	> 24
2D	+ 21.67	24	70	> 24
3S	+ 5.88	5	90	> 20
3D	+ 5.89	20	65	> 20
4	+ 6.31	25	85	> 25

* Note: Well elevations were measured from the top of the well casing (not necessarily the same as the ground surface). a similar pattern of short-term fluctuations, which appeared to be responsive to large rain events during the weeks preceding the date of measurement. Differences between the lowest and highest water levels recorded were almost three feet at locality MW-1 and about two feet at all other wells.

Vertical gradients at localities MW-1 and MW-2 were strongly upward. Both are situated near thrust faults (see Figure 5), and the upward gradients could indicate leakage from the carbonate bedrock into the till. At locality MW-3, no vertical gradient was measured except in January and May, 1989, when the gradient was downward. As expected, water levels in all wells were always higher than the lake level, indicating groundwater flow from the wells toward the lake.

TABLE 7

WELL-WATER DEPTHS, STOCKBRIDGE BOWL*
(July 1988 - May 1989)

WELL	7/11	8/19	10/6	10/24	11/25	12/22	1/5	5/30
1S	8.54	8.87	8.96	9.21	6.46	8.34	8.29	6.33
1D	7.38	7.71	7.75	8.08	5.34	7.13	6.96	5.17
2S	5.50	5.79	5.42	5.21	5.30	5.08	5.42	5.42
2D	5.08	5.37	5.25	4.58	3.42	3.34	**	3.21
3S	3.17	3.46	3.46	1.96	1.13	1.30	2.04	1.50
3D	3.17	3.46	3.46	1.96	1.13	1.30	2.67	1.79
4	3.96	4.21	4.25	3.21	2.25	3.54	2.38	2.38

* All measurements in feet below the top of the casing.
** Frozen over - could not measure.

HYDROLOGIC BUDGET

An annual hydrologic budget for Stockbridge Bowl must take into account all of the significant inputs to the lake and all of the significant losses. Assuming that the volume of the lake stays approximately the same, the inputs should balance the outputs.

For Stockbridge Bowl, there are four significant inputs: tributary flow, precipitation on the lake surface, direct subsurface flow, and storm runoff. Each of these is discussed in more detail below under "Methodology". Some flow into the lake also occurs through stormdrains in sub-basin #2; however, this volume is low relative to the watershed as a whole and can be neglected. Another input to the watershed is from homes which draw water from bedrock wells (commonly called "artesian" wells) and discharge water to on-site septic systems. Since the watershed is largely undeveloped and since many homes are on sewer systems, this factor has also been neglected.

The most significant losses are evaporation from the lake surface and flow through the outlet structure. Given the topography and surficial geology of the outlet area, little or no subsurface seepage out of the watershed should be occurring.

Thus, the equation describing the hydrologic budget is:

$$TR + GR + SR + P(1) = OU + E(1)$$

where TR represents tributary flow, GR represents direct subsurface inflow (groundwater and interflow), SR represents storm flow, P(1) represents precipitation on the lake, OU represents flow from the outlet, and E(1) represents evaporation from the lake surface.

Methodology

The major components of the water-budget equation are discussed below, together with the methodology used for volume calculations. Necessarily, these procedures have a significant potential for error due to limitations inherent in mathematical modeling and due to a lack of detailed, day-to-day data for the Stockbridge Bowl watershed. However, the results provide an approximate picture of the lake's water sources and water losses and a framework for interpretation of the field data collected for this study.

Storm Flow - Storm flow may be defined simply as that portion of runoff that reaches a stream shortly after a storm event, causing the volume of stream flow to rise above its "base flow" level. Predominantly, storm flow reaches the stream via small rivulets and/or thin, even layers of surface flow ("overland sheet flow"). To estimate storm flow, Lycott used a method developed by T.R. Schueler for the Washington Metropolitan Water Resources Planning Board (1987). This method treats the percent of impervious surface in a watershed as a predictor of the "runoff coefficient" Rv (fraction of rainfall converted to storm flow), based on the results of many studies throughout the United States. In the case of the Stockbridge Bowl watershed, Lycott estimated imperviousness (I) at 4%, yielding an Rv of 0.09 [where $Rv = 0.05 + 0.009(I)$]. Total storm flow was then calculated as

$$P * Pj * Rv * A$$

where P represents annual rainfall depth, Pj is a correction factor for storms that produce no runoff (set at 0.9), Rv is the runoff coefficient, and A is the area of the watershed.

Tributary and Subsurface Flow - Not all the incident precipitation that remains after storm flow has been subtracted will be available to travel through the subsurface and discharge into tributaries or directly into the lake. A large portion is lost from the land surface via "evapotranspiration" (evaporation of water from soil and plant surfaces and transpiration of water by living plants).

Lycott's procedure for calculating evapotranspiration and water available for runoff used a method developed by C.W. Thornthwaite and J.R. Mather (Publications in Climatology, 1957). This method takes into account the climatic regime of the area, as well as the nature of the predominant soils and vegetative cover, in order to calculate both potential and actual evapotranspiration. Once actual loss due to evapotranspiration is known, the volume of water available for runoff to the lake can be calculated by multiplying the area of land in the watershed times the depth of "available precipitation" (incident precipitation minus storm-flow runoff minus evapotranspiration).

Finally, this total for available water can be divided into "tributary flow" versus "direct subsurface flow". Each of Stockbridge Bowl's five major tributaries drains a discrete land area defined by the local topography, and receives its base flow entirely from the subsurface. Thus, water available for tributary runoff can be calculated by estimating the total land area drained by the five tributaries and multiplying that area times depth of available precipitation (determined by the Thornthwaite and Mather method described above).

Direct subsurface flow, on the other hand, represents runoff from land outside of the tributary drainage areas; thus, it can be estimated by subtracting total tributary runoff from the calculated total for non-storm runoff from all land in the watershed. The phrase "direct subsurface flow", as used by Lycott, includes both groundwater flowing within the surficial sediments and what is commonly termed "interflow", referring to lateral subsurface flow along relatively impermeable soil horizons above the water table.

Lake-Surface Precipitation and Evaporation - An important input to the lake is precipitation falling directly on the lake's surface. Total for the year was obtained by multiplying the annual depth of precipitation times the surface area of the lake. Adding this figure to the calculated volumes for tributary flow, storm flow, and direct subsurface flow yields the total volume of inputs to the lake from all sources (the left-hand side of the budget equation).

Prior to calculation of the lake's flushing rate, this total must be reduced by the volume of water evaporated off of the lake surface. The remainder represents total water actually supplied to the lake in the study year. To estimate total evaporation from the lake, Lycott used the relationship: evaporation = 0.7 x pan evaporation (Sharp and Sawden, 1984).

Surface-Water Outflow - Assuming the lake had approximately the same volume at the end of the study year as at the beginning, total water supplied to the lake should approximately equal total outflow for the year, that is:

$$TR + GR + SR + P(l) - E(l) = OU.$$

Lycott calculated total outflow by inserting values into the left-hand side of this equation, and then compared the result to measured surface outflow for the study year.

Long-Term Budget Versus Current-Year Budget

The hydrologic budget for Stockbridge Bowl was calculated using both long-term (average) data and data obtained during the current year of study (March, 1988 through February, 1989). The latter was used to produce a nutrient budget based on the results of Lycott's groundwater and surface-water analyses. The long-term budget, on the other hand, illustrates differences in "average" conditions as compared to the hydrologic regime for the current year.

Calculation of the long-term budget is important for several reasons. First, the effects of nutrient loadings depend in the long run on the average rate of water supply; the lower the average flushing rate (the rate at which the volume of water in the lake is replaced by new water), the lower the levels of nutrient loading that can be tolerated without promoting nuisance growths of plants and algae. Second, the long-term water budget will be important in assessing treatment options; the feasibility of options based on the current year might be assessed differently if long-term information were considered.

To calculate both the long-term and current-year hydrologic budgets, data on precipitation and temperature must be obtained from the closest NOAA weather stations having topographic and climatological characteristics similar to the study area. For the long-term budget, the weather stations must also have a long enough period of record to provide data in terms of departure from average (calculated by NOAA for the years 1951 through 1980).

In the case of Stockbridge Bowl, the nearest station with long-term data and a relatively high elevation is in Norfolk, Connecticut. In addition, long-term precipitation data for the Western Massachusetts Division was averaged with the Norfolk data, since Norfolk has an unusually high rate of rainfall. For the study year, data was used from three stations in Massachusetts located to the north and south of Stockbridge Bowl: Great Barrington, Lanesboro, and West Otis. All temperature and precipitation data are listed in Appendix C.

Results

The results obtained using the methodology outlined above are summarized in Tables 8 and 9. In addition, more detailed information concerning climatological data, storm flow calculations, and Thornthwaite and Mather calculations are provided in Appendix C. The following observations may be made on the basis of the hydrologic data and calculations:

1) Precipitation for the study year was 19% lower than during an average year, totaling 39.98 inches as compared to the average value of 49.51 inches. (Note, however, that the average value was obtained using data from the Norfolk, Connecticut weather station, which may receive more rainfall than Stockbridge. A more conservative estimate of average annual rainfall would be about 46 inches.) Rainfall was particularly low during the months of June 1988, December 1988, and January 1989. Higher than average rainfall occurred in July and November. Temperatures were significantly higher than average in the months of May, July, and August in 1988 and in January of 1989.

2) Of the precipitation that fell on land within the watershed (after storm flow was subtracted), 62% was lost to evapotranspiration during the study year as compared to 50% in an average year. This change contributed to the decline in total water supplied to the lake from 20,552,800 m^3 in an average year to 13,416,300 m^3 in the study year.

3) During the study year, total water supplied to the lake was divided as follows among the four principal sources: 58% tributary flow, 8% precipitation on the lake (less evaporation), 15% direct subsurface flow, and 19% storm flow. The percentages for an average year were: 63% tributary flow, 6% precipitation on the lake, 16% direct subsurface flow, and 15% storm flow.

measured

Comparison to Field Measurements

Tributary and outlet flow measurements taken during Lycott's study can be used to estimate total annual flows. However, flow volumes derived in this manner should be viewed as crude approximations only, since they are based on few measurements and since daily flows can vary significantly.

TABLE 8

ANNUAL WATER BUDGET (MARCH 1988 - FEBRUARY 1989)

SF -	Water from storm runoff:	2,531,800 m^3	✓
TR -	Water from tributary flow:	7,890,200 m^3	✓
GR -	Water from direct subsurface flow:	1,972,500 m^3	
P(l) -	Water from precipitation on lake:	1,581,800 m^3	
E(l) -	Evaporation from lake surface:	- 560,000 m^3	
	TOTAL SUPPLIED TO THE LAKE:	**13,416,300 m^3**	

Budget Equation:

$$SF + TR + GR + P(l) - E(l) = OU = 13,416,300\ m^3$$

Estimate of annual outflow based on field measurements: 15,665,000 m^3

TABLE 9

ANNUAL WATER BUDGET (Long-Term) Avg.

SF -	Water from storm runoff:	3,094,400 m^3	✓
TR -	Water from tributary flow:	12,921,600 m^3	✓
GR(i) -	Water from direct subsurface flow:	3,230,400 m^3	
P(l) -	Water from precipitation on lake:	1,959,800 m^3	
E(l) -	Evaporation from lake surface:	- 653,400 m^3	
	TOTAL SUPPLIED TO THE LAKE:	**20,552,800 m^3**	

Budget Equation:

$$SF + TR + GR + P(l) - E(l) = OU = 20,552,800\ m^3$$

Flow values for the five tributaries, if taken to be representative of the month in which they were measured, yield a value of 3,544,000 m^3 for total tributary input to the lake during the study year. This value is considerably lower than the calculated value of 7,890,200 m^3. The large discrepancy appears to arise primarily out of difficulties in obtaining flow measurements from tributary #4 (Lily Brook), which froze over during the winter months but likely had continual flow underneath the ice. As shown in Table 10, the values for tributaries #3 and #5 were also not close; however, discrepancies in these cases were probably due, at least in part, to uncertainties in delineating the areas drained by the tributaries. For the two remaining tributaries, the measured and calculated flows were very close.

Flow values for the outlet produce an estimate of 15,665,000 m^3 for total outflow during the study year. This figure compares extremely well to the calculated total of 13,416,300 m^3. It is possible that the somewhat higher field value reflects input of water to the watershed from the carbonate bedrock.

TABLE 10

COMPARISON OF MEASURED AND CALCULATED TRIBUTARY FLOWS MARCH 1988 - FEBRUARY 1989

Tributary #	Annual Flow: Measured	Annual Flow: Calculated	
1	152,700	157,800	
2	1,569,300	1,657,000	✓ Shadowbrk
3	152,200	473,400	
4	1,772,700	5,365,300	✓ Lily Pond
5	23,000	236,700	

Note: All flow volumes are in m^3.

MORPHOMETRIC DATA

Bathymetry

Bathymetric data was compiled from existing maps and reports and verified by Lycott with sonar measurement in the field.

TABLE 11

STOCKBRIDGE BOWL MORPHOMETRIC DATA

Maximum Length	2,057 m	(6,750 ft)
Maximum Width	1,134 m	(3,720 ft)
Maximum Depth	14.6 m	(48 ft)
Mean Depth	6.8 m	(22.4 ft)
Area	155 ha	(382 acres)
Shoreline (main basin)	5,372 m	(18,100 feet)
Shoreline Development Index	1.27	
Watershed Area (excluding lake)	25.5 km^2	(6,313 acres)

Many calculations (e.g., calculation of hypolimnetic volume) depend upon the volume of water or area of sediment below a certain depth. The following lists the volumes of strata between two meter intervals.

Depth Interval	(10^6 m^3)	(10^6 ft^3)
0 - 2 m	2.66	93.9
2 - 4 m	2.27	80.2
4 - 6 m	1.96	69.2
6 - 8 m	1.66	58.6
8 - 10 m	1.19	42.0
10 - 12 m	0.62	21.9
12 - 14 m	0.22	7.8
14 - 15 m	0.01	0.4
Total Volume	**10.59**	**374**

The surface area of a depth stratum also figures in the calculation of limnological parameters. For example, to estimate the Areal Hypolimnetic Oxygen Deficit (which is explained in detail in the Limnology section), the surface area of the hypolimnion must be estimated. The area of sediments under a certain depth, which is necessary to estimate the release of nutrients from sediments, can also be approximated by the surface area at that depth. That is, the area of sediments under 6 meters is approximately the area of the lake that is at least 6 meters deep.

Depth (m)	Area in m^2 below given depth *
0	1,450,000
2	1,213,000
4	1,053,000
6	909,000
8	750,000
9	595,000 **
10	440,000
11	313,000 **
12	186,000
13	108,000 **
14	31,000

* excluding outlet channel
** interpolated

Calculation of Flushing Rate and Residence Time

The long-term (average) flushing rate of the lake is calculated as the following ratio:

$$\frac{\text{total water supplied to the lake per year}}{\text{volume of the lake}}$$

The numerator of this ratio is also the same as the total outflow per year, assuming that the lake does not undergo a net loss or gain of volume. Flushing rate may be thought of as the rate at which the total volume of the lake is replaced by new water.

The total volume of Stockbridge Bowl, as calculated above, is 10,590,000 m^3. According to the hydrological budget, an average of 20,552,800 m^3 leaves the lake during an average year. Thus, the average flushing rate is:

20,552,800/10,590,000 = 1.94 lake volumes per year

This corresponds to a mean residence time of 0.52 years (6.2 months), where the residence time is calculated as the inverse of the flushing rate.

Because of the drought during 1988 and 1989, the flushing rate during the study period was only:

13,416,300/10,590,000 = 1.27 volumes per year.

LIMNOLOGY

Water Quality Parameters

For all limnological data, raw data can be found in Appendix E and average values are found in Table 12. Sampling stations are depicted in Figure 10.

Temperature and Stratification

Temperature gradients are set up in lakes as upper layers of water are warmed by radiant energy from the sun and thermal energy from the air. Because the density of water decreases as water temperature rises above 4°C, colder waters near the bottom tend to remain below the warmer water near the surface, setting up a temperature-density gradient called stratification. (Swimmers should recognize this phenomenon. Deeper waters tend to be much cooler than those near the surface.) Stratification usually begins in early spring, intensifies in summer, and breaks down in the fall as sunlight wanes and air temperatures fall.

Wind tends to counteract the formation of stable temperature gradients by mixing and stirring the water column. However, if the wind is too weak or the density gradient too strong or too deep, wind-mixing will be unable to stir the entire water column. (The resistance of the water column to mixing is discussed more fully in the next section on Relative Thermal Resistance.) In this case, long-term stratification can occur, dividing the lake into a warm, upper layer -- the epilimnion -- and a cold, bottom layer -- the hypolimnion. The zone of transition between the two strata is called the thermocline. Lakes that remain stratified for periods longer than several months are said to undergo stable stratification.

Because more energy (i.e., higher winds) is required to stir deeper columns of water, stratification tends to be more long-lived in deeper lakes compared to stratification in shallow lakes. Deep temperate lakes generally stratify from spring to fall and mix completely during early spring and late fall when winds are strong and thermal-density gradients are weak. Shallow lakes and ponds, on the other hand, tend to mix more or less completely throughout the summer. They may become stratified for short periods, especially during warm, calm days, but this stratification soon breaks down as the epilimnion cools and/or the wind rises. (While definitions vary from region to region, the propensity to stratify stably determines whether a body of water is called a lake or a pond. Bodies of water that undergo stable stratification are called lakes; those that do not stratify for long periods are called ponds.)

A es f nolc Dat

		STATIONS									
Parameter	unit of measure	1	2 overland flow	3	4 City bvlc	5	6	8	7S	7B	TH
Fecal Coliform*	(NO/100ml)	1.6	1.7	2.3	3.0	1.6	1.3	1.0	1.2	--	--
Fecal Streptococcus*	(NO/100ml)	11.9	9.1	9.3	18.6	11.8	36.9	40.0	3.5	--	--
Secci Disk*	(m)	--	--	--	--	--	--	--	2.4	--	--
Chlorophyll a	(mg/l)	--	--	--	--	--	--	--	7.8	--	--
Total Phophorus	(mg/l)	0.005	0.039	0.223	0.023	0.005	0.036	0.125	0.038	0.183	0.102
Nitrate Nitrogen	(mg/l)	0.46	0.17	1.49	0.17	0.21	0.13	0.10	0.17	0.17	0.29
Ammonia Nitrogen	(mg/l)	0.045	0.019	0.037	0.047	0.032	0.029	0.023	0.040	0.987	0.114
TKN	(mg/l)	0.25	0.17	0.21	0.43	0.27	0.26	0.15	0.34	1.39	0.28
pH	(SU)	7.5	7.3	7.3	7.3	7.3	7.6	7.0	7.7	7.1	--
Alkalinity	(mg/l)	202	110	199	136	198	119	43	120	134	117
Chloride	(mg/l)	43	47	40	18	32	22	14	18	19	17
Conductance	(hmos)	438	231	447	262	436	275	123	245	264	213
Total Susp. Solids	(mg/l)	38.1	44	11.5	6.9	13.4	5.4	20.5	5.0	16.0	9.0
Turbidity	(NTU)	3.6	3.4	3.9	3.6	5.4	4.1	3.3	4.0	6.0	5.0
Flow**	(cfs)	--	--	.041	.082	.029	.125	.076	.039	.746	--

* - These averages are geometric means.
** - time-weighted average

Key:

Station	Name	Station	Name
1	Mahican Brook	6	Outlet
2	Shadow Brook	8	Inlet Above Bean Hill
3	Inlet North of Kripalu Beach	7S	Deep Hole Surface
4	Lily Brook Inlet	7B	Deep Hole Bottom
5	Duck Pond Brook	TH	Thermocline

LYCOTT

Stratification is important because physical and biological processes behave quite differently in warm, sunlit epilimnia compared to these processes in cold, dark bottom waters. Consequently, the water column, which starts out essentially homogeneous from spring mixing, soon becomes divided into two strata with very different water chemistry and biology. For example, while the epilimnion is usually nearly saturated with oxygen, dissolved oxygen tends to become depleted in bottom waters. If the hypolimnion becomes completely anoxic, game-fish that require cold water (e.g., trout and salmon) may be unable to survive in the lake. In addition, nutrient dynamics in anoxic waters differ from those in oxygenated waters; oxygen-depletion promotes the release of phosphorus from the sediments, which may exacerbate eutrophication and impede efforts to redress excessive nutrient loadings.

Stockbridge Bowl behaves as a classic dimictic lake, having during spring and fall when the whole lake mixes. Stratification occur during summer and winter. Temperature stratification developed at Stockbridge Bowl between April 21 and May 17, 1988 as evidenced by the 11 degree Celsius drop between surface and bottom waters which was measured on May 17. Readings of temperatures at one meter intervals from the surface to the bottom of the in-lake station are given in Appendix D. Thermal stratification continued throughout the summer and disappeared during fall turnover, which occurred between October 7 and October 24. On October 24, 1988 there was a lack of an appreciable thermal gradient. Stratification later reformed under the ice.

Relative Thermal Resistance

Relative thermal resistance (RTR) is a measure of the stability of the water column or its resistance to vertical mixing. It is defined below:

$$\text{RTR} = \frac{(\text{density of top}) - (\text{density of bottom})}{(\text{density at } 5^{\circ}) - (\text{density at } 4^{\circ})}$$

where density of the top refers to density of water at the top of the water stratum, and density of the bottom refers to the density of the water at the bottom of the water stratum. RTR values were calculated for one meter intervals for Stockbridge Bowl and can be found in Appendix D.

Relative thermal resistance values greater than 35 generally indicate the presence of a metalimnion (the change in water temperature greater than 1°C per meter depth), which usually precludes mixing through that stratum. During summer stratification, the metalimnion typically divides the warm, oxygenated epilimnion from the cooler, anoxic hypolimnion.

Stockbridge Bowl often had multiple RTR peaks (Appendix D, and Figures 11A, 11B, and 11C), and the metalimnion tends to descend in the water column over the summer. The hypolimnetic depths figured from the RTR values (Appendix D) correspond to dissolved oxygen values found in Appendix D for late summer months.

The presence of secondary or multiple RTR peaks indicate metalimnia formed during early stratification. These conditions may exist when intense heating alternates with periods of extensive mixing. The mixing of the epilimnion can cease during a calm, hot period, during which the waters at the surface can absorb tremendous amounts of heat (e.g., August 15). Very light breezes may produce a second metalimnion.

Another cause of multiple RTR peaks is that the primary metalimnion is set up early in the heating season when lake waters are void of large numbers of phytoplankton. The secondary metalimnion is established later in the summer, when dense phytoplankton reduce the transmission of light to deeper depths in the lake. The stability of secondary metalimnia are not as great as the deeper, primary metalimnion.

Dissolved Oxygen

Oxygen concentrations in lakes are affected primarily by the physical processes of dissolution from the atmosphere (called reaeration) and by the biological processes of photosynthesis and respiration. During daylight hours, oxygen is produced by plants and phytoplankton in the euphotic zone, the upper strata in which light is adequate for photosynthesis. (The depth of the euphotic zone can be approximated by multiplying secchi disk depth by 3.) Since surface waters can also become oxygenated by contact with the air, upper strata generally contain high amounts of dissolved oxygen. Bacteria consume oxygen in the process of decaying dead algae and aquatic plants, etc. This process generally predominates over photosynthesis in the bottom water and sediments of deep lakes. The development of thermal stratification plays a key role in controlling the distribution of oxygen with depth. In shallow lakes without stable stratification, mixing continuously brings bottom waters to the surface where the oxygen is replenished through reaeration and photosynthesis. In deep lakes that undergo stable stratification, however, bottom waters without access to atmospheric or photosynthetic oxygen to meet the needs of biological respiration can become depleted of oxygen.

A lack of sufficient dissolved oxygen in bottom water decreases the available habitat for trout species, which require temperatures cooler than 70 degrees Fahrenheit (21 degrees Celsius) and also require at least five parts per million dissolved oxygen (Stroud, 1955). Due to its algal productivity, Stockbridge Bowl develops low oxygen conditions in the hypolimnion (cold bottom water) during the course of the summer thermal stratification.

Results for dissolved oxygen concentration and percentage of saturation with the atmosphere at the ambient temperature are given in Appendix D. The bottom water of Stockbridge Bowl during the period of stratification (May 17 to October 7, 1988) was extremely low in dissolved oxygen. Dissolved oxygen averaged 1.0 mg per liter (n = 9) with a standard deviation of 1.6 mg/liter. If not for the anomalously high reading of 5.2 mg/liter taken on June 28, the average would have been below 0.5 mg/liter.

The lack of dissolved oxygen in the bottom water of Stockbridge Bowl during stratification promotes recycling of phosphorus from the sediments to the water column. Low oxygen in bottom waters also favors bacteria which produce hydrogen sulfide. Malodorous hydrogen sulfide was readily and unpleasantly noted when bottom water samples were brought to the surface. Dissolved oxygen was generally highest in thermocline samples, presumably due to the metalimnetic layer of high photosynthetic activity. In Ludlum (1974), it was noted that there were high counts of the blue-green algae <u>Oscillatoria</u> <u>rubescens</u> located near the Stockbridge Bowl thermocline.

<u>Hypolimnetic Relative Aerial Oxygen Deficits</u>

This method is used to estimate the metabolism of the entire lake community by computing the rate at which oxygen is consumed in the hypolimnion. The method assumes that the oxidation of organic matter in the hypolimnion depends on the production of organic matter in the overlying epilimnion. It also assumes that all organic matter sinking into the hypolimnion is oxidized each year and that there is no residue carried over from one year to the next.

Using Lycott's sampling data suggests a less severe AHOD. From the sampling on 4/21/88 to the sampling on 5/17/88, oxygen concentrations decreased from a uniform level of 11.2 mg/l to an average of about 4.5 mg/l for water below 8 meters. From the Morphometric Data section, the corresponding volume of water depleted of oxygen is about 2,200,000 cubic meters or $2.2 * 10^9$ liters, so the amount of oxygen lost is given by:

$$(11.2 - 4.5 \text{ mg/l}) * 2.2 * 10^9 \text{ l} = 14,740 \text{ kg of } O_2$$

This gives a daily depletion rate of 566.9 kg/day.

For the period from 5/17/88 to 6/28/88, oxygen concentrations below 12 meters decreased from a mean of 4.35 mg/l to zero. Thus, the depletion rate over this period was:

$$(4.35 - 0 \text{ mg/l}) * 2.2 * 10^9 \text{ l} = 9{,}570 \text{ kg of } O_2,$$

which yields a daily depletion rate of about 227.9 kg of oxygen per day over the 42 day period.

The rate of oxygen depletion expressed on an areal basis is simply the total amount of oxygen lost over the depletion period divided by the area of sediment surface in contact with the water parcel subject to the oxygen depletion. Thus, for the period from 4/21 to 5/17, this rate is given by:

$$566.9 \text{ kg } O_2 / 186{,}000 \text{ m}^2 = 0.00304 \text{ kg/m}^2\text{/d}$$

or 0.304 $\text{mg/cm}^2\text{/d}$. For the period from 5/17 to 6/28, the AHOD equaled:

$$227.9 \text{ kg } O_2 / 186{,}000 \text{ m}^2 = 0.123 \text{ mg/cm}^2\text{/d}.$$

Thus, the estimated AHOD for 1988 ranged from 0.123 to 0.304 $\text{mg/cm}^2\text{/d}$. By comparison, Hutchinson has indicated that an oxygen depletion rate greater than 0.033 $\text{mg/cm}^{-2} \text{ day}^{-1}$ indicates a eutrophic condition. Thus, the AHOD suggests that Stockbridge Bowl is a very eutrophic lake.

Bacteria

Data indicates no significant bacterial contamination. The Massachusetts Division of Water Pollution Control standard for allowable fecal coliform bacteria in swimming waters is 200 organisms per 100 milliliters of water. This standard was never exceeded in the lake itself and was exceeded only once in one of the tributaries. The highest bacterial counts (266 fecal coliforms per 100 ml) were observed July 5 at the inlet north of the Kripalu Beach (station 3).

The ratio of fecal coliform to fecal streptococcus bacteria can be used as an indicator of the source of the contamination. Ratios of fecal coliform to fecal streptococci greater than 4:1 are indicative of a human source whereas ratios less than 0.7 to 1 are indicative of a livestock or non-human source. The ratio for the July 5 measurement at Station 3 was 5.32, indicating a human-waste related source. This reading was unexpected and anomalous; thus, it did not warrant further investigation. In any case, it would not be considered evidence of gross sewage contamination.

The in-lake samples are extremely clean from a bacterial standard. Fecal coliform bacteria were never detected at more than 10 organisms per 100 ml at this station.

Chlorophyll a

As the primary pigment of plants, the concentration of Chlorophyll a (Chl a) is a good indicator of algal biomass. Since excessive algal growth causes many of the negative impacts of eutrophication, Chl a values are often used as an index of eutrophication. Values for Stockbridge Bowl are moderate, averaging 7.8 mg/m^3 for the sampling period. These values are well below the hypereutrophic boundary of 25 mg/m^3 (Henderson-Sellers and Markland 1987).

Phosphorus

Phosphorus is an essential and often limiting plant nutrient. Increased supplies of phosphorus causes eutrophication and nuisance aquatic growths in freshwater bodies. According to EPA guidelines, phosphorus should not exceed 0.025 mg/l within a pond, lake, or reservoir. The level of phosphorus from the in-lake samples exceeds the limits set by the EPA, suggesting that phosphorus is a major source of nutrients for nuisance plant and algal growths (Table E-6, Appendix E). Because phosphorus is more soluble in water with reduced levels of dissolved oxygen, the correspondence of low dissolved oxygen values and high phosphorus values found at the bottom suggest that phosphorus is leaching out from the sediment.

The two "bursts" of phosphorus found on two sampling dates indicate various processes that release phosphorus to surface waters (Figure 12). A large increase on September 14, 1988 was probably due to thermocline erosion and the subsequent mixing of phosphorus-rich hypolimnetic waters with surface waters. The high levels on November 25, 1988 were probably due to the senescense of large amounts of aquatic macrophytes found in Stockbridge Bowl. The decomposition of plants releases phosphorus in large amounts to surface waters after the growing season.

The tributaries to Stockbridge Bowl had phosphorus values less than the values of the in-lake samples. Only Tributary #2 exceeded the EPA value set for running waters, (0.05 mg/l). This average value was affected by very high readings (0.137 and 0.146 mg/l) on two dates, November 25, 1988 and January 5, 1989. All other tributaries had values less than the EPA limit (see Table 12 and Appendix E).

Shadow BRK

Nitrogen

After phosphorus, nitrogen (N) is the most important nutrient essential for plant growth in aquatic systems. Three forms of nitrogen compounds were measured in Stockbridge Bowl: nitrate, ammonia, and Kjeldahl nitrogen.

Water from the deep-hole-surface generally had more nitrate and less ammonia than bottom waters.[2] This is a common phenomenon in lakes whose hypolimnia become oxygen deficient, since oxygen is required to transform ammonia to nitrate. Levels of nitrate from deep-hole surface waters ranged from undetectable (i.e., less than 0.10 mg/l) to 1.1 mg/l, with a mean concentration of 0.17 mg/l. Deep-hole-bottom samples averaged 0.17 mg/l, while the thermocline samples averaged 0.29 mg/l, almost double the deep-hole surface and bottom samples. Figure 13 represents total nitrogen over time for the deep-hole surface and bottom.

Tributaries averaged approximately 0.034 mg/l ammonia and 0.43 mg/l nitrate. However, as with other parameters, nitrogen values for the tributaries varied greatly from time to time and from site to site. Tributary #3 had the highest nitrate levels. Its average nitrate concentration, 1.49 mg/l, was more than three times the next highest mean concentration -- 0.46 mg/l from Tributary #1. Tributary #4 had the highest mean concentration of ammonia, 0.047 mg/l. Clearly, tributaries #3 and #4 represent a significant source of nitrogen to the lake.

Kripalu Beach

Lily Brk

Secchi Disc Transparency

Secchi disc is simple method to gauge water clarity. A black and white disc (the secchi disc) is lowered into the water until the disc disappears. The depth of disappearance is the secchi disc depth. Because one's ability to see through water depends upon ambient light, secchi disc measurements depend on weather conditions and time of day as well as on factors affecting water clarity: suspended solids, phytoplankton density, and concentration of some dissolved solids, especially dissolved organics.

Stockbridge Bowl is a fairly clear lake, with Secchi disk readings ranging from 1.5 to 4.0 meters with an average of 2.6 meters. Stockbridge Bowl visibility was always well

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[2] As with phosphorus concentrations, values less than detection were assumed to be equal to the detection limit when calculating a mean. For example, samples whose nitrate concentrations were below detection were set equal to 0.1 mg/l nitrate. Thus, the means reported for the nitrogen series are a maximum estimate of these concentrations.

above the 1.2 meter (four feet) standard set for bathing beaches by the Massachusetts Sanitary Code (310 CMR 17.00). The clarity of the water is one reason that nuisance aquatic weeds, especially milfoil are growing in water depths up to 20 to 25 feet of water.

pH and Alkalinity

The pH of a lake is a measure of the acidity of the water. A pH of 7.0 is neutral. Values below 7 denote acidic waters, and values above 7.0 denote basic waters. Massachusetts water quality standards for Class B waters, which are applicable to the Stockbridge Bowl Lake, specify that the pH should be in the range 6.5 to 8.0 pH units (Commonwealth of Massachusetts, 1984).

The in-lake surface values for pH in Stockbridge Bowl ranged from 7.0 to 9.2 pH units, averaging 8.2 for the deep-hole-surface while samples from the deep-hole-bottom averaged 7.5. (Note: all average pH values represent the negative log of the average of the hydrogen ion concentrations at each date.) These average values were within the class B standard for pH. The average pH for the outlet was 8.0 pH units.

The pH values for the tributaries were slightly lower than those for the lake itself, averaging 7.7 over all tributaries over all dates. There was little difference among tributaries: the highest average pH -- 7.9 -- was found in Tributary #1 (Mahican Brook) while the lowest -- 7.5 -- was found in Tributary #5, Duck Brook. Results for tributary sampling are given in Appendix E.

The pH and alkalinity of an aquatic system are closely related. The alkalinity measured in a pond represents the water body's buffering capacity or its acid neutralization capacity (ANC), which is measured in mg/l of $CaCO_3$. Low levels of alkalinity suggest either that a lake has undergone acidification and/or that it is prone to acidification. If a pond's alkalinity is less than 20 mg/l $CaCO_3$, it can be considered "sensitive" to acidic precipitation (Godfrey et al., 1985). Stockbridge Bowl's alkalinity averaged 157 mg/l of $CaCO_3$, suggesting that this lake is not sensitive to acidic precipitation.

Average alkalinity in tributaries and outlets ranged from 110 mg/liter for Tributary #2 to 205 mg/liter for Tributary #3. Thus, the tributaries are also well buffered against acid rain.

Chloride and Conductivity

The primary natural sources of chloride are from the weathering of soils and rocks and from wet and dry precipitation. The latter can be a particularly important source of chloride, especially in areas near the ocean. Anthropogenic sources of chloride are primarily roadway salts and waste-waters. Roadway salts and waste-waters compose the majority of chloride inputs to inland water bodies.

The mean value for the in-lake samples was 18 mg/l, which is above the average for unpolluted fresh waters, about 8.3 mg/l (Wetzel, 1975). The excess chloride is probably due to the minerology of the local bedrock because of the relatively great distance to any oceanic source of chloride.

Conductivity is the ability of a water sample to conduct electricity, and it measures the presence of ions in solution. Since chloride is often a predominant ion in surface waters, conductivity values for water samples will often show similar patterns to concentrations of chloride. The mean conductivity for Stockbridge Bowl in-lake samples was 240 micromhos, which is typical for "hard-water" lakes in limestone bedrock terrain. Average conductivity for the tributaries ranged from 231 micromhos for Tributary #2 to 447 micromhos for Tributary #3.

Suspended Solids

Suspended solids is a measurement of the amount of particulate matter that can be filtered out of the water. Suspended solids include living and non-living matter that may originate within the pond (autochthonous material) or outside the pond (allochthonous material). Autochthonous suspended solids are primarily phytoplankton or organic particles in some state of decay. Allochthonous particles may be a mixture of organic and non-organic particles that are washed or blown into the lake.

For a stream, suspended solids can be a good indicator of potential sedimentation. However, the motley nature of the particles that make up suspended solids decreases its information value for in-lake samples. If the suspended solids are primarily mineral solids washed into the watershed, high suspended solids could signify excessive erosion and a potential for filling of the lake basin. In contrast, if the suspended solids are primarily biodegradable organic materials produced within the lake itself, high suspended solids would not necessarily indicate either of the above conditions.

Suspended solids in Stockbridge Bowl averaged 10.0 mg/l in the in-lake samples: 5.0 mg/l in the deep-hole-surface, 16.0 mg/l in the deep-hole-bottom, and 9.0 mg/l in the thermocline.

Phytoplankton Taxa

Because individual phytoplankton cells from different taxa can differ in mass by several orders of magnitude, phytoplankton density (cells/ml) is a poor indicator of total algal biomass. Chlorophyll a offers a much better index of algal biomass. Both sets of data are presented in Appendix E.

However, phytoplankton species composition offers useful information concerning the ecology and nutrient status of a lake system. Stockbridge Bowl is dominated by Anabaena in the winter months and Cyclotella in the warmer summer months. Blooms of Oscillatoria rubescens have also been reported to occur in Stockbridge Bowl. According to Reynolds (1984), a phytoplankton composition similar to this is found in a mildly eutrophied, relatively large and deep basin. Hutchinson (1967) indicates that plankton dominated by Anabaena and Oscillatoria rubescens are typically found in the more productive lakes in temperate regions, where large phytoplankton blooms occasionally occur. Phytoplankton taxa information indicates that Stockbridge bowl is a mildy productive, eutrophic lake with occasional phytoplankton blooms.

Our in-lake sampling missed a large surface bloom of Oscillatoria rubescens that occured in the lake in November. During a visit in November, Lycott's field sampler noted a red patch along the shore that resembled red paint. This surface scum was brought back to Lycott for identification, and found to be a highly concentrated scum of O. rubescens. This species is capable of maintaining its buoyancy at the top of the hypolimnion or bottom of the thermocline, below the strata from which Lycott phytoplankton samples were taken. This species appears to be the source of the "reddish, brown slimy deposits" referred to in the RFP.

STORMWATER DRAIN MAPPING AND MAPPING

Lycott's engineer, Hamer Clarke, did a field investigation of storm drains at Stockbridge Bowl on May 27, 1988. Five drains were identified (Figure 14). All of these drain the storm water from the Mahkeenac Road area to the East of the Bowl.

Stormwater flows to Stockbridge Bowl were sampled at Station 2, draining Mahkeenac Road on July 19, 1988. Stormdrains #3 and #4 did not flow on this date. The water quality of this stormdrain was clearly poor, but the impact was negligible because the flow was so low -- only about 0.02 cfs. (see Table 13). Results for a flow-weighted sample indicated elevated levels of suspended solids (690 mg/liter), total phosphorus (0.53 mg/liter), and Nitrate-Nitrogen (1.6 mg/ liter). Fecal coliform (FC) counts (4100 organism per 100 ml) and fecal streptococci (FS) counts (112,000 cfu per 100 ml) were both elevated. The ratio FC/FS is an indication of the source of contamination; ratios less than 0.7 indicate a non-human source of bacteria (EPA, 1976). These samples indicate non-human source of bacteria. Heavy metals were generally low in this stormwater sample.

Inlet #4, Lily Brook, was also sampled on the same date. Of all the measured parameters, only total Kjeldahl nitrogen was higher than the usual range for this tributary.

Because of the extremely variable and intermittent nature of stormwater flows and concentrations of contaminants, a modelling procedure was adopted to estimate the impact of stormwater on Stockbridge Bowl. The proposed modelling procedure is the so-called "Simple Method" for estimating urban stormwater pollutant export. This method assumes that mean (flow-weighted) storm water concentrations for contaminants of interest can be estimated using the data set compiled by the National Urban Runoff Program (Schueler, 1987). The volume of runoff from an urbanized area which is the other determining parameter is calculating stormwater loadings, can be estimated on the basis of the area of the site and the percent of the area covered by impervious surfaces. These would include road surfaces, driveways, roofs, etc. This method is discussed more fully in the hydrological budget.

TABLE 13

STOCKBRIDGE BOWL STORM WATER

LYCOTT ENVIRONMENTAL RESEARCH

DATE	FLOW	FECAL COLIFORM (#/100ml)	FECAL STREP (#/100ml)	Cl (mg/l)	CONDUCT-ANCE (mhos)	SUSP'D SOLIDS (mg/l)	NITRATE (mg/l)	AMMONIA (mg/l)	TKN (mg/l)	TOTAL PHOS. (mg/l)	SOLUABLE PHOS (mg/l)	Cd (mg/l)	Cr (mg/l)	Cu (mg/l)	Fe (mg/l)	Pb (mg/l)	Zn (mg/l)	Mn (mg/l)
19-Jul-88		4100	112000	10	190	690	1.9	0.267	0.94	0.527	0.115	(0.01)	(0.01)	0.01	2.12	0.02	0.18	0.58

COMMENTS:
STORM DRAIN #2 COMPOSITE

VALUES APPEARING WITHIN PARANTHESES ARE THE DETECTION LIMITS, SIGNIFYING THAT THE LEVEL PRESENT IS BEL IE LI F DE ON.

WASTEWATER INVENTORY

Wastewater disposal practices for residences near the shoreline of Stockbridge Bowl have been inventoried by a combination of on-site visits by Lycott personnel and mailed-out questionnaire surveys. Water quality samples were also obtained from shore-line areas of the Bowl near ten residences spaced fairly evenly around the shoreline. These samples were obtained to check for any possible impact of leachate "plumes" on lake water. Of the 83 survey sheets completed, 15 were from the Beachwood area, which has been served by a conventional sanitary sewer collection system since 1984.

The period of occupancy ranged from three weeks per year to year-round with the most frequent period being 10 to 20 weeks per year. Average occupancy ranged from one to more than six with the most frequent response being two people. Roughly half of the homes now being occupied year-round were originally built for seasonal use. Homes typically have three bedrooms and one to two bathrooms. Commercial fertilizer is used by 19% of the shorefront residents. The most common class of a wastewater disposal system is a septic tank and leaching area, which is used by 68% of the respondents. Of the on-site disposal systems, 38% are over 20 years old and 68% have never been repaired or re-built. Distances of leach fields to the lakeshore varied between 30 and 2,000 feet; responses clustered in the range of 50 - 60 feet (20% of responses) and also in the neighborhood of 100 feet (20% of responses). Septic systems were generally between 10 and 50 feet above the lake level (80% of responses). Lack of any recurrent problems with the on-site wastewater system was noted by 93% of respondents.

Lycott also sampled the near-shore on October 7, 1988, to determine the impact of septic tanks on water quality (Figure 15). Results indicated no impact on in-lake levels of total phosphorus, ammonia, sodium, and total and fecal coliform and fecal streptococci (see Table 14). Near-shore sampling did indicate elevated levels of nitrate ranging from 1.2 to 4.5 mg/liter as nitrate. This indicates that soils near the lakeshore are removing phosphorus in septic leachate much more efficiently than nitrate.

STOCKBRIDGE BOWL, STOCKBRIDGE, MASSACHUSETTS. LEACHATE SAMPLING LYCOTT ENVIRONMENTAL RESEARCH

SAMPLE NO.	DATE	SAMPLE LOCATION	NITRATE (mg/l)	AMMONIA (mg/l)	SODIUM (mg/l)	TOTAL COLIFORM (#/100ml)	FECAL COLIFORM (#/100ml)	FECAL STREP (#/100ml)	TOTAL PHOSPHORUS (mg/l)
88007324	07-Oct-88	#11	1.2	0.038	6.98	10	(10)	(10)	(0.001)
88007323	07-Oct-88	#10	3.4	0.026	7.10	(10)	(10)	(10)	(0.001)
88007322	07-Oct-88	#9	4.4	0.022	7.02	(10)	(10)	70	(0.001)
88007321	07-Oct-88	#5	3.3	0.020	7.00	60	(10)	40	0.016
88007320	07-Oct-88	#4	2.4	0.043	6.84	(10)	(10)	(10)	(0.001)
88007319	07-Oct-88	#3	2.1	0.021	6.92	(10)	(10)	(10)	(0.001)
88007318	07-Oct-88	#2	4.5	0.015	7.10	10	20	(10)	(0.001)
88007317	07-Oct-88	#1	2.4	0.014	6.95	(10)	(10)	(10)	(0.001)

PAGE 1 VALUES APPEARING WITHIN PARANTHESES ARE THE DETECTION LIMITS.

LIMITING NUTRIENT ANALYSIS

According to what is called Liebig's "Law of the Minimum", the productivity of aquatic systems is controlled by the nutrient that is in lowest supply compared to the nutritional requirements of aquatic plants and algae. This nutrient, called the limiting nutrient, is the component that most constrains plant production and growth. In fact, the need for nutrients varies somewhat among different plant species; therefore, current theory suggests that several nutrients can be limiting at the same time, although for different species of aquatic plants. Nevertheless, in most freshwater lakes, a single nutrient constrains most plant growth. Most often, phosphorus limits plant growth in freshwater systems. In fewer cases, other nutrients, primarily nitrogen, may also limit plant growth.

Because the types of control measures and their ultimate success depend on the nutrient that must be managed (e.g., nitrogen is more difficult to control than phosphorus), lake management programs must first identify the limiting nutrient. Since either nitrogen or phosphorus limit production in almost all freshwater lakes, a simple and reliable method to determine the limiting nutrient is to compare the relative concentrations of these two nutrients (Sakamoto 1969 and Smith 1979). A ratio (by weight) of total nitrogen (TN) to total phosphorus (TP) exceeding 17 suggests that nitrogen occurs in excess as compared to the supply of phosphorus, which suggests that phosphorus limits plant growth in the lake. (The lower TN/TP limit for P-limitation varies from 20 in Smith (1979) to 13 according to the EPA. Lycott will use the mid-range value of 17 reported by Sakamoto.) Ratios of TN/TP between 10 and 17 imply that plant growth is limited by both nitrogen and phosphorus, while ratios less than 10 suggest that nitrogen is limiting.

TABLE 15

RATIOS OF N TO P AS INDICATORS OF NUTRIENT LIMITATION

N:P Ratio	Limiting Nutrient
Greater than 17	Phosphorus
10-17	Phosphorus and/or Nitrogen
Less than 10	Nitrogen

Because nitrogen and phosphorus compounds vary considerably throughout the year as nutrients are gained or lost to the system, the ratio of TN to TP will also vary considerably throughout the year. Most experts suggest, however, that this ratio should be calculated for data gathered during spring mixes or during summer stratification.

The N:P ratio at spring turnover provides information about the maximum availability of these nutrients in the lake basin and serves as a measure of the basin-wide limitation (Wetzel, 1975). On the other hand, summer values of TN/TP are important indicators of nutrient status, because nutrients are most likely to become limiting during the summer when growth and biological uptake is most rapid.

Values of the N/P ratio (by weight) for the in-lake samples are depicted in Figure 16. Since nutrient limitation occurs primarily in surface waters where light intensity is adequate for plant growth, the ratios of TN/TP for the surface are the most important indicators of nutrient limitation.

Data from the deep-hole-surface suggests that phytoplankton growth in Stockbridge Bowl is limited by phosphorus. During the summer stratification period (17 May through 24 October, 1988), TN to TP for the surface waters were greater than 17 on 9 of 12 occasions, and all but one of the rest were within the range (10 to 17) in which both nutrients limit algal growth. For the entire sampling period, data from 14 of 17 dates suggested that phosphorus was limiting in the water column. Thus, these data suggest that plant production in Stockbridge Bowl is limited by phosphorus.

This assessment conflicts with that of the Berkshire County Regional Planning Commission (BCRPC 1978), which concluded that nitrogen was limiting in Stockbridge Bowl. However, instead of using the more normal ratio of total nitrogen to total phosphorus, this report relied on a different measure, the ratio of available nitrogen (ammonia and nitrate) vs available phosphorus (ortho-phosphorus). Lycott was unable to find any other uses of this measure and no references were provided for this technique; therefore, its legitimacy could not be assessed.

It should be stressed that the discussion above pertains mostly to phytoplankton growth, because macrophytes may derive most of their nutrients from the nutrient rich sediments. Macrophyte growth may be controlled by other factors, especially light. Therefore, TN:TP ratios from the water column may have little or no relevance to the excessive macrophyte growth found at Stockbridge Bowl.

Trophic State of Stockbridge Bowl

The relationship between phosphorus concentration and trophic state/recreation potential was given in Table 1. When one considers data from all the bottom, top, and thermocline samples (Appendix E, Figure 12), it is apparent that Stockbridge Bowl can be classified as a very eutrophic lake according to total phosphorus levels.

ANNUAL PHOSPHORUS BUDGET

Since phosphorus (P) limits plant growth in the water column of Stockbridge Bowl, it would be useful to determine the major sources and sinks for P. A phosphorus budget for a lake measures the annual phosphorus inputs to and exports from the lake. Assessment of these inputs and exports determines the major sources of this limiting nutrient and permits estimation of the impact and efficacy of proposed management measures.

Phosphorus comes into a lake from precipitation, from lake sediments, and from the watershed in runoff, stormflows, and groundwater. The following section accounts for these sources and estimates the total phosphorus available to the lake from all sources.

Wet and Dry Precipitation

Phosphorus inputs due to wet and dry precipitation were estimated on the basis of a rainfall-phosphorus concentration of 0.006 mg phosphorus per liter, a value used for a study on East Lake Waushakum. The total volume of rain falling on the lake is usually about 2.1 billion liters, producing an estimate of 12.6 kg P per year falling in rain. However, this only includes the phosphorus falling in rain, and phosphorus is always raining down in dust and other forms of dry deposition. Uttormark et al. (1974) estimate that dry deposition totals about three times the total phosphorus in wet precipitation. Thus, the phosphorus delivered to the lake from wet and dry precipitation is about 50.4 kg per year.

Summer Internal Loading from Sediment Release

Because the hypolimnion of Stockbridge Bowl becomes anoxic during the summer (Appendix D), phosphorus release from the sediments may be a major source of phosphorus to the lake. Phosphorus release can be estimated in several ways. The following describes two alternative methods of estimation based upon our sampling data.

1. Estimate Based on Duration of Hypolimnetic Anoxia and Area of Anoxic Sediments

From Dissolved Oxygen profiles, the hypolimnion was anoxic below 9 meters between the sampling of 6/28/88 and 8/15/88 (estimated duration of 51 days). After this, anoxia persisted below 13 meters for another 44 days (from 8/23 to 10/6). From the section on Bathymetry, the areas of Stockbridge Bowl affected are:

Area below 9 meters: 595,000 square meters
Area below 13 meters: 108,000 square meters

Release rates of phosphorus from anoxic sediments ranges from 6 to 28 mg/m^2/day with a median value of 12 mg/m^2/day (Nurnberg, 1984). Using the median value, the phosphorus load for the 51 day period beginning 6/28 can be calculated by:

$$595{,}000 \text{ m}^2 * 0.000012 \text{ kg/m}^2\text{/day} * 51 \text{ days} = 364 \text{ kg P}$$

and the phosphorus load for the subsequent 44 day period ending 10/6/88 is given by:

$$108{,}000 \text{ m}^2 * 0.000012 \text{ kg/m}^2\text{/day} * 44 \text{ days} = 57 \text{ kg P}$$

The loading is additive; thus, the total internal loading is the sum of the two, or

$$364 \text{ kg} + 57 \text{ Kg} = 421 \text{ kg phosphorus}$$

from anoxic sediments over the summer of 1988.

2. Empirical determination of Phosphorus Release from Anoxic Sediments

This method uses observed changes in P concentrations to estimate the amount that was released from the sediments. The method assumes no diffusion to the epilimnion, no external sources of P, and no uptake by biota or sediments. Two stable periods come close to meeting these assumptions: from 6/28/88 to 8/15/88 and from 8/23/88 to 10/6/88.

For the first period, total P concentration increased at an average rate of 0.0058 mg/liter per day for volume-weighted concentrations below 9 meters. This was determined by regression, a statistical technique that fits a line to a series of points. The r^2 statistic was 0.8, which suggests that the fit to the line was quite good, implying that one can use the calculated release rate with some degree of reliability.

From the section on Bathymetry, the volume of water below the 9 meter depth contour is approximately 1.45 million cubic meters. Thus, the total released from the sediments can be estimated by multiplying the volume times the change in concentration in that volume or

$$1.45 \text{ X } 10^6 \text{ m}^3 * 0.0058 \text{ g/m}^3 * 51 \text{ days} = 428 \text{ kg phosphorus.}$$

For the thirty five days from 8/23 through 9/28, total P increased at an average rate of 0.0058 mg/liter per day for bottom water concentrations. In this case, however, the fit to the regression line was not very good (the r^2 values was only 0.12) implying that this value can be used with less confidence than the first rate.

Nevertheless, this is the best estimate of the release rate based on field data. As above, the total phosphorus released by the sediments can be estimated by multiplying the volume of water times the average change in P concentrations. The volume of water below the 13 meter depth contour is approximately 130,000 cubic meters. Thus, the total P released from the sediments during this second period can be calculated as

$$130{,}000\ m^3 * 0.00625\ g/m^3/day * 35\ days = 28\ kg\ phosphorus$$

The total rate of accumulation for the two stable periods is given by

$$427\ kg + 28\ kg = 455\ kg\ phosphorus$$

released during the summer of 1988.

3. Comparison of the Two Estimation Methods

Method 1 predicted a total P release of 421 kg while method 2 estimated a P release of 455 kg P. Thus, the methods agree fairly well, even though both are based on simplistic assumptions about a process which is, in reality, quite complicated.

Winter Internal Loading from Sediment Release

The bottom strata of Stockbridge Bowl also become depleted of oxygen during the winter, although winter depletion may not be as regular as summer depletion. For example, Lycott's first sample in March of 1988 showed no anoxic water in the lake, but our 1989 sampling and that of previous researchers has shown wintertime anoxia at the bottom. In 1989, depletion was seen below 11 meters on January 5 and below 13 meters on February 14. For the purposes of calculation, Lycott assumed that the average depth was that volume below 12 meters for three and a half months from January to ice-out in mid-April. According to the section on Bathymetry, the area of sediment below 12 meters is approximately 186,000 m^2.

Because the speed of chemical reactions depends on temperature, the rate of release from the sediments during the winter should be slower than the rate of release during the summer. Thus, to calculated the release of phosphorus from the sediments during winter, Lycott will use 0.006 $g/m^2/day$ as a release rate, a rate half of the median value observed by Nurnberg. Therefore, release of phosphorus from the sediments during winter of 1988-1989 was estimated by

$$186{,}000\ m^2 * 0.006\ g/m^2 * 105\ days = 117.2\ kg\ P$$

1. Long-Term Phosphorus Export Calculated from Land-Use Patterns

A water-phosphorus budget from the watershed may be obtained in two ways. The more involved method, described in detail by Cooke et al. (1986) and by Reckhow et al. (1980), involves extrapolations from actual measurements of all sources of water and phosphorus inputs and outputs over a year. This first method is more accurate for any one year, but may be unduly influenced by aberrant weather, as was observed in the summer of 1988. This method will be called the short-term phosphorus budget and will be discussed in the next section.

A second method, hereafter called a long-term or land-use phosphorus budget, is also discussed by Cooke et al. (1986) and by Reckhow et al. (1980). This method estimates total P loading from an area by multiplying that area by the appropriate export coefficients. Export coefficients are derived from measurement of rates of export from many watersheds having a particular land-use. Thus, the first step is to determine the areas of the various land-use categories in the watershed. The McConnell land-use map for the Stockbridge Quadrangle was updated by ground truth supplied by members of the Stockbridge Bowl Technical Advisory Committee and Lycott's field observations.

Because long-term method can be applied without any field sampling, its major strength lies in its simplicity and cost-effectiveness. However, because the method relies on data generated from other watersheds at other places, it may not apply to the particular watershed being studied. Thus, the land-use P budget should be used as a guide for what is average, not necessarily for what pertains to any particular lake or pond.

The dominant land use types in the Stockbridge Bowl water-shed are residential, forest, and open (meadow), with a small portion agricultural use. In calculating phosphorus loading from forest in the Stockbridge Bowl watershed, Lycott used a phosphorus export coefficient based on average estimates for this type of land: 0.20 kg P ha^{-1} yr^{-1}. By way of comparison, 25% out of 26 reported phosphorus export coefficients for forested lands fall below 0.098 kg P $yr^{-1}ha^{-1}$ and 75% of the reported export coefficients fall below 0.314 kg P $ha^{-1}yr^{-1}$ (Reckhow et al., 1980).

Since 1971, much of the agricultural land has become open pasture land and grassy fields. Thus, agricultural lands were grouped with open lands.

The phosphorus export coefficients describing residential land exhibit a high degree of variability depending upon the type of urban activity (i.e., low-density residential, heavy industrial, etc.) and the associated percentage of impervious surface area. The following factors affect the nutrient loading from residential areas:

1) presence and effectiveness of on-site septic systems;
2) housing density;
3) grass and vegetative cover;
4) fertilizer applications;
5) pet density and type (dogs, cats, etc.)

Grass and housing density affect the infiltration/runoff ratio; fertilizers, septic tanks, and pets are additional nutrient sources. Because the density of houses varies greatly within the watershed, Lycott subdivided the residential portion of the watershed into several different types of residential use (Table 16). This finer scale resolution should produce a greater degree of accuracy for the long-term phosphorus budget.

Septic System Phosphorus Sources

Septic tank effluents from near-shore dwellings can be major contributors to a lake's phosphorus loading. The amount of septic effluent phosphorus which enters the lake system depends upon factors such as lake shore lot sizes, soil retention coefficients, seasonal versus permanent residency, and use of appliances such as garbage disposals, dishwashers, and washing machines.

Septic system inputs will be estimated based upon literature values and the characteristics of the Stockbridge Bowl watershed. According to the EPA (1988), septic tanks and leach fields can, on average, be expected to adsorb about 80% of the phosphorus. According to recent maps, there are approximately 80 homes within 1,000 feet of the lake in the unsewered area northeast of Beachwood. On the other side of the lake, another 25 homes are within 1,000 feet. Homes south and to the west of Beachwood were ignored since their loading were assumed to flow into the outlet channel and out the outlet without having any real effect on the water quality of the main basin. Likewise, phosphorus from septic tanks more than 1,000 feet from the lake were considered to have minimal impact and were ignored.

According to our survey average residence time for the houses around the lake was 18.4 weeks and average number of persons per house was 2.8. This represents an average yearly population of about 110 people. Per capita production of phosphorus totals about 0.80 kg/yr (Vollenweider 1968). Hence, with 80% adsorption, septic fields should release about 0.16 kg of P per capita per year. If the estimated yearly population of Stockbridge Bowl is 110 persons, this produces an annual loading from septic tank effluents of about 17.6 kg of phosphorus per year.

TABLE 16

Calculation of Land-Use Nutrient Loading for Stockbridge Bowl

Category of Use	Area		P Export	P Loading	Reference
	(acres)	(ha)	kg/ha/yr	(kg/yr)	
Forested	4447.7	1801	0.20	363.9	Reckhow median for forest
Open*	1120.8	454	0.31	142.6	Reckhow 75% value for forest
Wetland	244.0	99	0.00	0.0	Cooke et al. 1984, p. 29
Residential Land					
Forested Res.	332.4	135	0.22	30.2	Controlling Urban Runoff, p 1.22
Medium Density Res.	11.2	5	0.65	3.0	Controlling Urban Runoff, p 1.22
Light Density Res.	265.2	107	0.34	36.2	Controlling Urban Runoff, p 1.22
Garden Apt./Hwy/Comme	66.0	27	1.30	34.8	Controlling Urban Runoff, p 1.22
Public land/estates	387.2	157	0.65	102.1	Controlling Urban Runoff, p 1.22
Recreat. Land	10.0	4	0.79	3.2	Reckhow 25% value for urban
Total loading from land-use				715.9	

Reckhow refers to Reckhow et al. 1980. Controlling Urban Runoff refers to METROCOG.

In contrast, BCRPC estimated that the total loading phosphorus loading in 1976 was 102 kg, and they predicted that total loading in the year 2000 would be 302 kg of phosphorus per year. Extrapolating between the two dates suggests that loading from 1989 should be about 200 kg/yr, over 10 times the value estimated above. In the interim, however, the Beachwood area was sewered, which effectively halved the number of households in the zone within 1000 ft of the lake. Lycott also ignored the houses on the outlet channel, which also reduced the estimate of loading.

These two factors would have cut the number of septic tanks by about 2/3. Reducing the BCRPC prediction by this factor yields a new estimate of 66.7 kg of phosphorus per year, which is now fairly close to Lycott's estimate of 17.6 kg. Given the magnitude of other sources, either value could be used without appreciably affecting the total phosphorus of the lake. Thus, Lycott will use the average of the two -- 42.2 kg per year -- as the estimated loading from septic tanks.

Long-Term Phosphorus Budget Summary

The table below gives a preliminary estimate of phosphorus loading to Stockbridge Bowl. Sources of phosphorus are summarized graphically in Figure 17.

TABLE 17

LONG-TERM PHOSPHORUS BUDGET SUMMARY

	Total Loading (kg/yr)	% of Total (percent)
Land-Use	715.9	52.5
Septic Tanks	42.2	3.1
Anoxic sediments		
summer release	438.0	32.1
winter release	117.2	8.6
Wet and Dry Precipitation	50.4	3.7
Total Loading	**1363.7**	**100.0**

According to the long-term budget, loading due to land-use accounts for the major source of phosphorus. Release from anoxic sediments accounts for about 41% of the total.

2. Short-Term Phosphorus Budget Calculated from Field Data

The second method to calculate the phosphorus budget relies on field data collected during the year of sampling.

Base-Flow Phosphorus Inputs

According to Lycott's hydrological budget, total water coming into Stockbridge Bowl was divided into portions coming from rain on the lake itself, from overland flow after storms (storm runoff), from tributaries during base flow, and from subsurface flow. The phosphorus inputs due to each input are discussed below.

Inputs from Tributary Base Flow

The normal tributary sampling data was assumed to be indicative of tributary base flow. Thus, phosphorus inputs were estimated by multiplying flow-weighted phosphorus data by the measured and predicted base-flow. As discussed in the section on the Hydrological Budget, field measurements of base flow were less than half of the predicted discharge. The major discrepancy came from Tributary 4 (Lily Brook), where the measured flow was less than a third of the amount predicted. Thus, the flow-weighted mean phosphorus concentrations were multiplied by the predicted flow as well as the flow measured by field sampling.

Both methods produce similar results. A total of about 105.0 to 160.6 kg/yr were estimated to have come down the tributaries during base flow in the period from March 1988 to February 1989. To be conservative, Lycott will use the larger number to estimate loading during the sampling period.

used larger no. to est. loading March 88 - Feb

TABLE 18

PHOSPHORUS LOADING FROM TRIBUTARY BASE FLOW

Sampling Station	[P] mg/l	Total Discharge Measured m^3/yr	Estimated m^3/yr	Total P Loading Measured kg/yr	Estimate kg/yr
#1	0.002	152,657	157,800	0.3	0.3
#2	0.051	1,569,306	1,657,000	79.8	84.5
#3	0.044	152,209	473,400	6.7	20.8
#4	0.010	1,772,675	5,365,300	18.1	53.6
#5	0.006	23,044	236,700	0.1	1.4
TOTAL				105.0	160.6

Shadow Brk

Lily

2 largest P inputs

Storm-Flow Phosphorus Inputs

Other than a single sampling, storm flows were not measured at Stockbridge Bowl. Instead, phosphorus inputs from storm flows were estimated from the Simple Method. According to the Simple Method, loading due to phosphorus is equal to:

$$L = [P * P_j * Rv/12] * C * A * 2.72$$

where L = the phosphorus loading in pounds;
P = the rainfall depth (in) over the time interval;
P_j = factor to corrects for storms with no runoff;
Rv = runoff coefficient, which expresses the fraction of rain that is converted into runoff;
C = is the flow-weighted concentration of the pollutant in urban runoff; and
A = the area of site in acres.

For the sampling period (March 1988 to February 1989), total rain (P) equaled 39.98 inches. As recommended by NURP, P_j was set equal to 0.9, Rv was assumed equal to 0.09, C was assumed to be equal to that of hardwood forest and set equal to 0.15 mg/l, and A was 6951 acres. This produced a total estimated loading of 343.6 kg (756 lbs) from storm flow during the study period.

storm flows 72 X normal flow [illegible]

Groundwater Phosphorus Inputs

According to Lycott's hydrological budget, almost 2 million cubic meters of water came into Stockbridge Bowl through direct groundwater. Groundwater phosphorus concentrations averaged 0.0052 mg/l (0.0052 g/m^3). Therefore, total phosphorus inputs from groundwater totaled only 10.46 kg of phosphorus during the study period.

Total Short-Term Phosphorus Budget

The short-term phosphorus budget estimated that almost 1120.1 kg of phosphorus were supplied to the lake during the sampling period. Almost exactly half came from came from internal loading from anoxic sediments.

TABLE 19

TOTAL SHORT-TERM PHOSPHORUS BUDGET

	P loading (kg)	% of total (percent)
Tributary Base Flow	160.4	14.3
Storm Flow	343.6	30.7
Groundwater	10.5	0.9
Anoxic sediments		
summer release	438.0	39.1
winter release	117.2	10.5
Wet and Dry Precipitation	50.4	4.5
TOTAL	**1120.1**	**100.0**

Comparison of Short-term and Long-term Budgets

The two methods produced very similar rates of total loading: 1120.1 kg/yr for the short-term budget vs. 1363 kg/yr for the long-term. Given the errors inherent in both methods, this similarity is reassuring. Furthermore, the loading calculated for the sampling period should be less than the long-term loading rate, because there was less runoff and less base-flow. Thus, the two methods agree quite well.

Neither method, however, agrees with the P loading projected by Berkshire County Regional Planning Commission which found a total loading from the watershed of 1415 kg in 1976, not including internal loading. Some of the difference between Lycott's estimates and the BCRPC estimate results from the sewering of Beachwood area and a decrease in agriculture since 1976. Most of the discrepancy, however, results from the different methods employed by Lycott vs. BCRPC. The close agreement between the two methods presented above suggests that Lycott's calculated loading rates are appropriate.

MODELING PHOSPHORUS CONCENTRATIONS

Because the concentration of phosphorus generally limits plant growth in aquatic systems, simple models have been developed to predict the concentration of phosphorus in the water column. The models have two major uses. First, they can be used to test the validity of data and assumptions. A large difference between an observed and predicted value would suggest either that the data put into the model or the observed in-lake concentrations were wrong, or that the lake was acting atypically. Secondly, the models can assess the potential success of a proposed management technique, because they can predict water quality under different rates of phosphorus loading. (The second property will be used later in the Feasibility section on Expected Effects of Remediation.)

The phosphorus models are based on regression equations of data from many lakes. Several slightly different models have been generated, since different authors used slightly different statistical techniques and/or data from different lakes and different times of the year. Generally, however, their predictions are quite similar.

Lycott used the Reckhow models (Reckhow et al. 1980.), because the Reckhow data base was used to construct the land-use P budget. In addition, Reckhow has a model for lakes like Stockbridge Bowl, whose hypolimnia become depleted of oxygen during the summer. (Other models by Vollenweider and Dillon and Kirchner 1975 are included in Table 20 for comparison). The Reckhow model predicts average surface water phosphorus over the "growing season", and assumes the following:

1. The lake behaves, on a long-term basis, as a completely mixed system. Stockbridge Bowl mixes completely during spring and fall, so this assumption is satisfied.

2. Lake volume remains constant. This is roughly true for Stockbridge Bowl.

3. The influx of phosphorus is constant, losses occur through deposition and outflow, and the net internal loss is proportional to phosphorus concentration in the lake. In truth, the influx of phosphorus to both Stockbridge Bowl is not constant, but primarily associated with the erratic phosphorus dynamics in the tributaries and storm drains.

4. For the anoxic model, that the hypolimnion becomes depleted of oxygen.

The anoxic Reckhow model is:

$$P = Lp / (0.17 * z + 1.13 * qs)$$

where P is the phosphorus concentration of surface water during the growing season; Lp is the phosphorus loading rate, in $kg/m^2/yr$, the total amount of phosphorus available to the lake from all sources divided by the surface area; z is the average depth, and q_s is the areal water load, which is the flushing rate times the mean depth.

From the Sections on Morphometry and the Hydrological Budget, the long-term flushing rate of Stockbridge Bowl is about 1.94 volumes per year, and the average depth is 6.8 meters. This produces an areal water load (q_s) equal to 13.19 m/yr.

From the long-term P budget, a loading rate of 808.5 kg/yr. (Because the phosphorus loading equals the total phosphorus coming into the lake, it excludes the amount from internal loading.) This equals an Lp of 0.52 $g/m^2/yr$. With this areal loading rate, the Reckhow model predicts an in-lake phosphorus concentration of 0.0325 mg/l. Using the short-term data (564.9 kg/yr of phosphorus and flushing rate of 1.24) produces a prediction of 0.0336 mg/l.

Field-sampling of the deep-hole surface during 1988 and early 1989 produced a time-weighted average concentration of 0.038 mg/l, which is very close to the concentration predicted by the Reckhow model. Thus, our 1988 field data for loading and in-lake phosphorus concentrations are internally consistent with respect to the phosphorus models.

Consideration of the other models for oxic lakes illustrates the impact of hypolimnetic oxygen depletion. If the hypolimnion of Stockbridge Bowl did not go anoxic during the summer and winter, the models predict that the lake would have an average phosphorus concentration of about 0.018 mg/l during the growing season. Thus, these models suggest that hypolimnetic oxygen depletion causes almost a doubling of average phosphorus concentrations in Stockbridge Bowl.

TABLE 20

MODELS TO PREDICT AVERAGE PHOSPHORUS CONCENTRATIONS AS A FUNCTION OF THE LOADING AND MORPHOMETRIC CALCULATIONS

P loading = 808 kg/yr, flushing = 1.94 /yr

AUTHOR	MODEL	PREDICTED P
	Anoxic hypolimnion	
Reckhow	$P = Lp / (0.17 * z + 1.13 * qs / z)$	0.0325
	Lakes with sufficient oxygen	
Reckhow	$P = Lp / (11.6 + 1.2 * qs)$	0.0190
Vollenweider	$P = Lp / (10 + qs)$	0.0225
Dillon-Kirchner	$P = Lp / (13.2 + qs)$	0.0198

P loading = 564.9 kg/yr, flushing = 1.24 /yr

AUTHOR	MODEL	PREDICTED P
	Anoxic hypolimnion	
Reckhow	$P = Lp / (0.17 * z + 1.13 * qs / z)$	0.0336
	Lakes with sufficient oxygen	
Reckhow	$P = Lp / (11.6 + 1.2 * qs)$	0.0167
Vollenweider	$P = Lp / (10 + qs)$	0.0196
Dillon-Kirchner	$P = Lp / (13.2 + qs)$	0.0167

Lp is the phosphorus loading rate, gram P per meter squared per year

z is the average depth, meters

qs is the areal water load, which is the mean depth times the flushing rate

INTERCONVERSION OF NITROGEN COMPOUNDS

Nitrogen gas (N_2) is the most common element of air, and natural waters are generally saturated with this gas (Birge and Juday 1911). Despite its wide and plentiful distribution in natural waters, however, nitrogen is the second most common limiting nutrient (after phosphorus) in freshwater aquatic systems because elemental nitrogen is unavailable to all but a few biological organisms.

Some organisms, known as nitrogen fixers, do convert nitrogen gas to biologically useful nitrogen in a process called nitrogen fixation (Figure 18). When phosphorus is particularly plentiful and nitrogen is limiting, some aquatic organisms, notably the blue-green algae and some aquatic bacteria, fix nitrogen and incorporate this fixed nitrogen into bacterial and algal biomass. When these organisms die or are consumed, their nitrogen becomes available to other consumers, usually in the form of ammonia (NH_3).

Nitrogen infrequently limits freshwater systems, however, so in-situ nitrogen fixing rarely constitutes a major source of nitrogen to lakes and ponds. Even in those lakes where nitrogen limitation occurs, in-situ nitrogen fixing rarely produces a significant proportion of the total nitrogen used by aquatic plants (Wetzel 1975). Most biologically-available nitrogen in lakes and ponds originates from nitrogen fixed by man or by bacteria in terrestrial ecosystems, especially bacteria associated with legumes like clover and alfalfa.

Ammonia (NH_3) is the primary breakdown product of organic nitrogen, generated by bacteria as they oxidize organic matter. Ammonia is also produced as an excretory product by animals, but this is usually much less significant than bacterial production. In the presence of oxygen, ammonia is converted first to nitrite (NO_2) and then to nitrate (NO_3) in a process known as nitrification. Therefore, the presence of high concentrations of ammonia denotes that the rate of decomposition exceeds the rate of nitrification, occurring as a result of an intense rate of decomposition and/or a reduced rate of nitrification due to low dissolved oxygen levels. Since organic decomposition produces ammonia and reduces dissolved oxygen levels, ammonia often accumulates in the hypolimnia of eutrophic lakes, especially when they become depleted of oxygen in the summer. In contrast, nitrate (NO_3) predominates in surface waters where oxygen is plentiful. Both nitrate and ammonia are readily available to plants, and these two species constitute the major source of nitrogen for plant growth. Even in cases where nitrogen fixing does occur, most of the nitrogen used for plant growth comes from that already fixed as ammonia and nitrate (Wetzel 1975).

With excess fixed-nitrogen and the absence of oxygen, which may occur in lake sediments, some bacteria break down nitrate to nitrogen gas, completing the cycle. This process is called denitrification. The nitrogen cycle, as described above, is influenced considerably by humans. Humans fix nitrogen gas artificially, producing ammonia and nitrate for use as fertilizer for crops and lawns. Nitrogen from septic tanks or sewage can be a major source of nitrogen to groundwater and then to lakes. Lastly, a major source of biologically available nitrogen is wet and dry precipitation of particulate nitrogen (Wetzel 1975). For example, acids of nitrogen (NO_x) are a major component of acid precipitation, and these nitrogen compounds fertilize waters as well as acidify them.

Precipitation of nitrogen may be the major source of biologically-available nitrogen in some aquatic systems (e.g., Chesapeake Bay). Large atmospheric contributions make controlling nitrogen availability very difficult. Due in part to the great amount of nitrogen literally falling from the air, it is generally not feasible to control eutrophication by controlling nitrogen (Wetzel 1975; EPA 1988). The mobility of nitrate and ammonia in groundwater also makes controlling nitrogen availability difficult. In contrast to phosphates which are tightly bound to soil particles, nitrate and ammonia move relatively freely through the soil in groundwater. Nitrogen from fertilizer and from naturally fertile soils moves readily from the watershed to the lake via groundwater or surface flow.

STATUS OF FISHERY RESOURCES

The Massachusetts Division of Fisheries and Wildlife (DFW) releases roughly 200 nine to twelve inch brown trout in Stockbridge Bowl each spring and fall. Not surprisingly, brown trout dominate the sport fishery. The lake is not heavily fished during the peak recreational season because of the heavy competing use of the lake by water skiers, sailboats, kayaks, and speed boats. Panfish, including yellow perch, blue gills, black crappie, pumpkin-seed and yellow bullheads are taken by shore anglers fishing from a causeway on the east shore. Ice fishing for chain pickerel and yellow perch is popular during the winter.

A complete fishery survey was carried out on Stockbridge Bowl by DFW personnel in 1978. Samples for determination of weights, lengths and growth rates were obtained by a combination of gill netting and electro-shocking. Species composition by weight and by number were determined as were growth rates for bluegill, yellow perch, chain pickerel, largemouth bass, rock bass, and pumpkinseed. Condition factors for these species were also determined. At that time, the dominant species by both number and weight was yellow perch with 65% by number and 41% by weight of the overall sample. Largemouth bass and chain pickerel were the major sport fish. Both species were present at 3.5% by number; largemouth bass made up 13.8% by weight and chain pickerel made up 10.1% by weight of the sample.

Stockbridge Bowl was re-sampled at the end of October 1988, by the DFW personnel using the same methods as 1978. Only the length-frequency tabulation is available at this time. Currently, yellow perch make up 17% by weight and 54% by number of the population. Largemouth bass make up only 2% by number and 0.1% by weight of the sample. Chain pickerel made up 7.8% by number and 23% by weight of the sample. Rainbow and brown trout were also a significant group in 1988, totalling 7.2% by number and 32.6% by weight of the sample. Detailed information on growth rates and condition factors will be available from the DFW within a few months and will be included in the Draft Final Report.

Lycott spoke with Mr. Joseph Bergin of DFW. He indicated that the major problem with the fishery was dissolved oxygen depletion in the hypolimnion during the summer. The month of August is usually the critical period for trout habitat degradation in the hypolimnion due to the oxygen depletion. According to Mr. Bergin, the "trout habitat layer" is defined as that water layer having temperatures less than 70 degrees Fahrenheit and 5 ppm or more dissolved oxygen. Trout are very susceptible to diseases when the layer drops to less than 25% of the total lake volume. The "trout habitat layer" in Stockbridge Bowl has declined over the past several decades. In 1947 this layer was 20% of the volume of the lake, whereas in 1974, it was only 8%.

Lycott's bi-weekly monitoring of temperature and dissolved oxygen values at 1 meter (roughly 3 feet) intervals at the deepest portion of the basin have yielded the following information on the available trout habitat in Stockbridge Bowl:

TABLE 21

STOCKBRIDGE BOWL TROUT WATER - 1988

Date	Depth Interval	% Volume
4/22	0 to 15 m	100.0
5/17	0 to 13 m	98.0
6/14	0 to 14 m	99.0
6/28	5 to 9 m	30.0
7/5	3.5 to 8.5 m	42.0
7/25	5 to 7.5 m	19.6
8/11	7 to 9.5 m	16.2

The trout volume was minimal on August 11, 1988 when only 16% of the lake was habitable by trout. The percentage of total volume useful as trout habitat during August is used as a criteria for the Massachusetts Division of Fisheries and Wildlife (MDFW) to classify the value of trout fisheries. According to Mr. Joseph Bergin of the MDFW, if the percentage of volume of trout water at Stockbridge Bowl could be significantly increased by hypolimnetic aeration, the value of the fishery for holdover trout and possible trophy size trout would be greatly increased.

The warm water recreational fishery in Stockbridge Bowl does not appear to have any notable problems. There were large chain pickerel and largemouth bass present. This is somewhat unusual for a lake that has extensive weed beds, such as is the case with Stockbridge Bowl. Mr. Bergin indicated that the MDFW would look favorably on a winter drawdown of 7 to 8 feet to control weed growth, if it were done properly.

TABLE 22

RECENT FISH STOCKING HISTORY 1986-1988

Year	Rainbow Trout		Brown Trout		
	>9 in.	>12 in.	6-9 in.	>9 in.	>12 in.
1986	1,250	2,700	1,850		5,800
1987	500	3,135		450	4,085
1988	2,750	1,600		150	4,500

MACROPHYTE COMPOSITION AND DISTRIBUTION

Macrophytes were surveyed from a boat using a grapple to sample deep water plants on July 30 and August 12, 1988, and on June 10, 1989. Results of Lycott's mapping are depicted in Figures 19, 20, and 21. Plant distributions were similar at both dates during 1988 except that Elodea was observed near the town boat ramp on the August 12. None was observed there on July 30. It is possible that this weed was brought in attached to a boat or trailer between the two surveys and rapidly established itself, although sparse populations of Elodea have been found in the lake since 1980.

Even in late summer, the entire near-shore zone out to a depth of roughly two feet had markedly reduced aquatic plant density (generally less than 25% coverage). This probably results from the two foot drawdown which has been in effect since 1981. However, the drawdown appears to be less successful near the Beachwood Area. According to Mr. Ed Darrin, a long-time resident of this area, the Beachwood area was formerly a swamp which was filled in the 1930's and 1940's by the developer, Mr. C.A. Parker, using spoils taken from dredging the outlet channel. The highly organic nature of these soils may be a factor in limiting the effectiveness of the drawdown in the Beachwood area. Drawdown, in general tends to decrease the organic content of surface sediments, but this effect may not yet be noticeable.

The major problem weed is milfoil, which infests roughly 140 - 180 acres from a depth of 2 - 3 feet out to a depth of 20 - 25 feet. Various *Potamogeton* species are growing at nuisance abundances in roughly 50 acres of the littoral zone.

The survey in 1989 revealed a similar picture. Milfoil was again the major problem species, growing in water up to about 20 feet deep and almost 500 feet from the shoreline in spots. Apparently due to the drawdown, weed were less dense in water less than about two feet deep. Milfoil was found predominantly in the band of water 5 to 20 feet deep in densities of 75 to 100% coverage. *Potamogeton* species and *Chara* dominated the shallower water. These plants grew densely but less densely than the milfoil -- usually attaining 50-75% cover.

The current macrophyte situation seems to resemble the situation in 1971. Ludlum et al. (1974) reported that "*Myriophyllum spicatum* was the dominant vascular plant. The thickest beds occurred in the depth range of 1 to 3.5 meters, although isolated plants occurred as deep as 5.5 meters. In depths less than 3.5 m, *Myriophyllum spicatum* extended to the surface by early summer."

However, surveys by DEQE during 1974 and 1976 suggested that plant densities decreased considerable during the mid-70's. In a June 1974 survey by DEQE, the major species was *Chara*, and major parts of the shoreline (the southeast and northwest edges) were relatively clear of macrophyte growth. In a July 1976 survey, DEQE reported that weeds now formed an almost continuous band around the edge of the lake. However, the weeds were not particularly dense and were dominated by *Chara*.

Weed surveys by Berkshire Enviro-Labs during 1980 and 1981 were similar to the current situation and that found in 1971. By 1980 and 1981, milfoil again became dominant in the lake and again occupied deeper water and wider distributions than other species. As noted above, milfoil continued to grow in excessive densities during Lycott's study, and residents on the lake often suggested that the "milfoil problem is getting worse every year."

The long-term data do not suggest a recent worsening of macrophyte growth due to a worsening of eutrophication of Stockbridge Bowl. If this explanation were true, the obvious solution to excessive macrophytes growth in Stockbridge Bowl would be methods that prevent and reverse eutrophication of the lake. However, the recent history of Stockbridge Bowl -- the sewering of the southern shore of the lake and reduction of farm land in the watershed -- suggests that nutrient inputs to the lake have waned rather than increased over the last two decades. In addition, the macrophyte species composition and distribution found in 1989 appears to be very similar to that found in 1971 by Ludlum et al. Thus, little evidence supports a hypothesis of that increasing plant growth in the 80's resulted from increasing nutrient availability. In fact, Ludlum et al. report that macrophytes grew abundantly in the 1940's.

Since organic herbicides were used routinely in the mid-70's but not in the 80's and late 60's when milfoil densities were problematic, the worsening of macrophyte growth could simply be due to a cessation of effective herbicide application. This explanation would suggest that further reductions in nutrients would have little impact on macrophyte growth in Stockbridge Bowl. Thus, methods for controlling macrophyte growth probably should not depend on techniques that reduce nutrient loading to the lake.

reducing nutrient inputs do little to control growth

Sediment Analysis

Bottom sediment at the deep hole of Stockbridge Bowl was sampled using a Ponar clamshell-type sampler on September 14, 1988. Sediments in the outlet channel were sampled on December 15, near the "old dam", which is also referred to as Deacon's Bridge. These results are not yet available. Results of the deep hole sediment analysis, together with "guideline" concentrations for unpolluted sediments (U.S. EPA, 1988), are given in the table on the following page.

TABLE 23

DEEP HOLE SEDIMENT SAMPLE

Parameter	Stockbridge Deep Hole Sediments	EPA Guidelines Non-Polluted Sediments	Dredge Criteria Cat. One	Sludge Criteria Type I
	mg/kg	mg/kg	mg/kg	
Percent Volatile Solids	21	--	--	--
Total Kjeldahl Nitrogen	3	--	--	--
Total Phosphorus	130	<420	--	--
Iron	45,400	<17,000	--	--
Manganese	600	<300	--	--
Arsenic	341	<3	<10	--
Chromium	8	<25	<100	<1000
Copper	260	<25	<200	<1000
Lead	147	--	<100	<300
Mercury	0.432	<1	<0.5	<10
Zinc	82	--	<200	<2500
Cadmium	2.0	<6	<5	≤ 2
Barium	173	<20	--	
Selenium	<1	--	--	
Silver	<1	--	--	

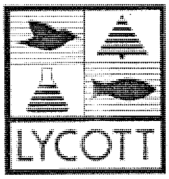
Of the results given above, three are particularly noteworthy. Arsenic was relatively high; phosphorus and nitrogen were relatively low.

The elevated concentration of arsenic is probably due to the use of a sodium arsenite herbicide from 1960 through 1969. During these years, a total of 206,000 gallons of sodium arsenite was used for weed control. Elevated levels of copper are presumably due to the applications of copper sulfate for algae/weed control. From 1966 to 1969, a total of 5,000 pounds of copper sulfate was applied to the lake.

The concentrations of Total Kjeldahl Nitrogen and Total Phosphorus are relatively low for a eutrophic water body. For a sediment which is 21% organic, the expected values of Total Phosphorus and Total Kjeldahl Nitrogen would be considerably higher. One possible explanation is very efficient recycling of sediment phosphorus and nitrogen under anaerobic conditions.

WETLAND EVALUATION

In conjunction with the feasibility evaluation of water-level drawdown, an evaluation of the bordering wetlands is required. This has been done previously by Robert Brown Associates in a 1974 report on the Inland Wetlands of the Housatonic River Basin in the Town of Stockbridge. Information on the wetlands near Stockbridge Bowl is presented on the Bordering Vegetated Wetland Map included in Appendix A.



FEASIBILITY STUDY

FEASIBILITY STUDY

Summary

The following is a short synopsis of the management program proposed by Lycott.

A. Construction activity to allow six feet of drawdown.

   1. A outlet pipe must be layed below the gas main to allow a total of six feet of drawdown.

   2. The outlet channel must be deepened to allow a six foot drawdown.

   3. The outlet of tributary #3 must be dammed to prevent impacts to the wetland immediately above.

B. Improvement of Harvesting Program

C. Implementation of Hypolimnetic Aeration.

D. Cost for implementation should total $469,547 for capital expenditures and construction with an annual operation and maintenence cost of $122,400.

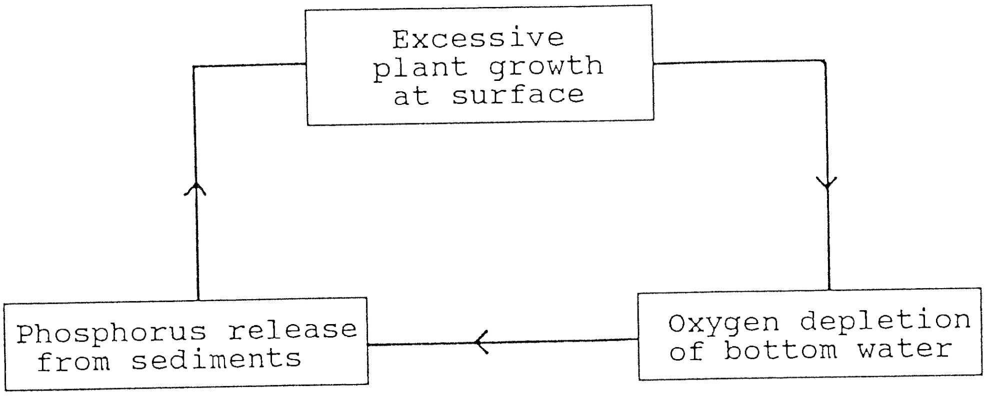
PRELIMINARY SCREENING OF ALTERNATIVES

Techniques available for lake and watershed management can be divided into those dealing with the causes of water quality problems and those attempting to alleviate the symptoms. Techniques dealing with the causes of eutrophication usually restrict inflow of nutrients by managing the watershed. Amelioration of symptoms usually include in-lake methods of controlling plant biomass (macrophytes and phytoplankton). These methods can be applied at different levels of intensity and in combination with other techniques; thus, there are many possible management approaches. Since each lake is a unique ecosystem, a restoration and management program must be tailored to the site-specific needs and characteristics of the lake or pond.

According to Lycott's results, Stockbridge Bowl has two major problems: excessive macrophyte growth and hypolimnetic oxygen depletion. The latter causes three related water-quality problems: restriction of cold-water fisheries, high water-column phosphorus due to release from anoxic sediments, and presumably, the "slimy, reddish brown deposits" which are probably fall blooms of *Oscillitoria rubescens*. Thus, Lycott's major feasibility options will address methods to prevent oxygen depletion in the hypolimnion and to reduce macrophyte growth in the littoral zone. Available methods of oxygen enhancement and macrophyte control are discussed in the following sections.

Part 1 - Methods to Improve Dissolved Oxygen Levels and Redress Internal Loading.

There is a positive feedback loop between hypolimnetic oxygen depletion, internal nutrient loading, and excessive plant growth. More hypolimnetic oxygen depletion causes more phosphorus to be released which can spur more plant growth which produces more organic matter. The organic matter must be oxidized; hence, greater plant production increases the degree of oxygen depletion, which increases phosphorus release from the sediments, etc. Due to the interaction depicted below, methods that redress one of the links often have positive effects on the other problems. Thus, Lycott addressed the problems of oxygen depletion and internal loading in the same section.



Methods that attack the cycle by directly improving oxygen concentrations -- aeration, hypolimnetic withdrawal, and hypolimnetic aeration -- not surprisingly, tend to be successful at solving those problems associated with low oxygen (e.g., poor trout survival). However, they tend to be less successful at solving indirectly other links in the cycle (e.g., excessive phosphorus release and excessive plant growth). Similarly, methods that directly solve internal loading (dredging, alum application) are often less effective at improving oxygen depletion. Thus, the choice of a solution depends upon how the links in the cycle are weighted.

Internal loading is the primary source of phosphorus to Stockbridge Bowl. Normally, lake management attempts to control plant growth by restricting nutrient sources. Thus, in the usual case, priority would be give to those methods that reduce internal loading directly and, hence, function with a high degree of success with respect to internal loading (e.g., alum treatment, dredging, sediment oxidation).

However, the perceived and the actual water-quality problems at Stockbridge Bowl are not really direct results of high internal loading. The extensive macrophyte growth derives most of its nutrients from the sediments during the spring and early summer. However, internal loading primarily affects water column nutrients in the late summer and early fall. Hence, reducing internal loading would have little impact on macrophytes, because internal major water quality problem. Also, according to the Request for Proposals, the people of Stockbridge apparently consider trout survival and the health of the cold-water fishery appears to be more important problem than internal loading. For these reasons, Lycott's feasibility will emphasize methods that improve oxygen concentrations directly and reduce internal loading indirectly, rather than vice-versa.

- Spring plant growth from sed. nut.
Die-back,
x deep wa P
[illegible] release
summer
[illegible] algae

__Artificial Circulation (Aeration)__ - Artificial circulation prevents thermal stratification by forcing air into the hypolimnion. The rising air mixes the water column. Whole-lake circulation is identical to hypolimnetic aeration, except the latter retains thermal stratification. Aeration improves dissolved oxygen conditions near the bottom, which should increase the habitat area for fish and should decrease phosphorus loading from anoxic sediments. Circulation may control algal biomass in some situations, although it has been known to enhance algal growth in other situations.

Aeration will not be recommended for Stockbridge Bowl. Aeration has only mixed success with phytoplankton control, and would completely eliminate any trout habitat in the lake. The problem of hypolimnetic oxygen depletion and internal loading will be addressed by hypolimnetic aeration, which is cheaper and less disruptive than whole-lake circulation.

__Dredging - Sediment Removal__ - This procedure is among the most frequently recommended methods for removing internal nutrient sources and for improving very shallow lakes. It has a significant advantage over nutrient inactivation or oxygenation techniques in that the source of internal nutrient loading is removed rather than left in place. Since dredging removes nutrient-laden sediments, it also can reduce macrophyte density, whereas neither nutrient inactivation nor aeration have an effect on macrophyte growth (Mesner and Narf 1987). Since the sediments themselves represent a significant oxygen demand, removing the sediments could improve oxygen by decreasing TOD. The major disadvantages of dredging result from problems and costs associated with the disposal of dredge spoils.

Dredging will not be recommended to control internal loading in Stockbridge Bowl. Dredging would be prohibitively expensive. In addition, since most of the oxygen demand probably results from plant matter produced in the epilimnion, dredging the hypolimnion would probably produce only minor and/or short-term improvement of hypolimnetic oxygen concentrations.

__Hypolimnetic Withdrawal__ - Nutrient-rich, oxygen-poor hypolimnetic waters may be removed by siphon, pumping, or deep discharge at the dam. Water from the well-oxygenated upper strata replaces the withdrawn bottom water, thereby increasing oxygen concentrations in deep water. Maintaining minimal oxygen concentrations (> 2 mg/l) greatly reduces internal loading (Bernhardt 1975), and maintaining levels above 4 mg/l provides habitat for fish and other organisms. This method could be applied at Stockbridge Bowl and will be discussed in detail in the following section.

Hypolimnetic Aeration - Hypolimnetic aeration is a procedure to increase the dissolved oxygen concentration of the hypolimnion without de-stratifying the lake. This is usually accomplished with an air lift device which brings cold hypolimnetic water to the surface, where gases are exchanged, and then returns the water to the hypolimnion. This procedure can improve reservoir discharge quality, allow the re-establishment of a cold-water fishery, provide a daytime refuge for zooplankton, and eliminate problems with iron and manganese in potable water supplies.

This method could be applied to Stockbridge Bowl and will be discussed in detail below.

Phosphorus Inactivation - Release of phosphorus from the sediments can be controlled by adding aluminum salts to the hypolimnion. Phosphorus and other particulates bind tightly to aluminum hydroxide, forming an insoluble precipitate that falls to the bottom. The layer of alum floc forms a semi-impermeable barrier which prevents the release of phosphorus even after the onset of anoxia. An alum inactivant can also be added to incoming waters to neutralize the water before it can cause problems. Phosphorus inactivation is a powerful and effective technique when coupled with the diversion of nutrients or when internal loading is a major source of nutrients. By reducing the phosphorus available for phytoplankton and macrophyte growth, sediment inactivation could improve dissolved oxygen levels by decreasing the oxygen demand due to decomposing organic material. This method could be applied to Stockbridge Bowl, and will be addressed in greater detail below.

Sediment Oxidation - The large quantity of organic matter in the sediments of eutrophic lakes serves as a substrate for high levels of microbial respiration which can lead to oxygen depletion. Anoxia, in turn, promotes phosphorus release from the sediments, because phosphorus that is bound to oxidized forms of iron (Fe^{+++}) is released when the iron becomes reduced (Fe^{++}) in the absence of oxygen. Nitrate serves as an alternative (to Fe^{+++}) electron receptor and is reduced to nitrite and N_2; thus, the reduction of iron (III) is delayed and P is more tightly bound in nitrate-rich waters and sediments. This relationship has led lake managers to add nitrate to hypolimnetic waters to control sediment phosphorus release. This method has been successful in some cases, but the data on this technique is very limited.

Sediment oxidation will not be recommended for Stockbridge Bowl for the following reasons. Its affect on TOD would probably be minor. Treatment of other lakes resulted in only a 30% decrease in sediment oxygen demand (Cooke et al. 1986), and the oxygen demand of the overlying water was, presumably, unaffected. In addition, this is a relatively untested technique.

RECOMMENDED OPTION -- HYPOLIMNETIC AERATION

In-Depth Analysis: Hypolimnetic Withdrawal vs Hypolimnetic Aeration vs Sediment Sealing - Alum

Hypolimnetic withdrawal, hypolimnetic aeration, and alum treatments could provide methods for the remediation of Stockbridge Bowl. Each method is treated in detail in the following section.

1. Sediment Sealing - Alum Application

As noted above, alum application prevents release of phosphorus from sediments under both anoxic and oxygenated conditions. Alum application lowers pH, especially in lakes with low alkalinity (0 - 50 mg/l $CaCO_3$) or buffering capacity. When applying alum, care must be taken to keep the pH above 5, because aluminum becomes soluble at levels below 5. Soluble aluminum is problematic for two reasons: high levels of dissolved aluminum may harm fish and other aquatic organisms, and dissolved aluminum resists flocculation which precipitates phosphorus and forms the insoluble blanket. The high alkalinity values in Stockbridge Bowl (Appendix E) are substantial enough to keep dissolved aluminum levels to a minimum.

Calculations of dosage and costs for phosphorus inactivation were based on data for a sediment-sealing project on Lake Morey in Vermont carried out during the summer of 1986 (Vermont DWR, 1986). Stockbridge Bowl should receive a dose like that applied at Lake Morey -- 37 g Al per m^2 --which is in the middle of the range of rates (11 to 122 g Al per m_2) used in previous sediment-sealing projects. Since Stockbridge Bowl has about 750,000 m^2 of hypolimnetic sediment below 8 meters, this produces a total of 27,750 kg of aluminum.

A total of 197 gallons per acre x 382 acres totals 75,300 gallons of alum that would be required. Estimated cost for alum in 1988 dollars is $80,140. Labor for the project is estimated at 140 man-days at $135/hour. Total labor costs, including equipment costs, would total $151,200. Thus, the total estimated cost of the project would be $231,000.

Alum treatments are long-lived treatments. Depending upon lake depth and rate of sedimentation, alum treatments can control internal nutrient loading from 5 to 12 years (DNR 1989). Conditions at Stockbridge Bowl suggest that effectiveness would tend toward the high end, indicating that the lake would probably have to be treated every 8 to 12 years at an expense of approximately $230,000 per treatment. This equals a yearly cost of about $30,000.

It is not recommended that phosphorus inactivation be pursued at this time. Hypolimnetic withdrawal or hypolimnetic aeration can provide adequate control of phosphorus release from the sediments without introducing foreign substances to the environment. In addition, hypolimnetic withdrawal and hypolimnetic aeration would have positive effects on the cold water fishery by improving dissolved oxygen concentrations in the hypolimnion.

In contrast, alum treatment would produce, at best, a minor improvement of dissolved oxygen levels. Alum could have an indirect effect on the oxygen depletion of the hypolimnion by reducing the amount of organic matter fixed by plants. However, macrophytes produce most of the organic matter in Stockbridge Bowl, and their growth is not affected by alum treatments.

1. Hypolimnetic Withdrawal

Hypolimnetic withdrawal can have three different positive effects on a lake:

- Hypolimnetic withdrawal can improve dissolved oxygen levels in the hypolimnion by drawing off oxygen-poor water from the bottom. This water is replaced by more oxygenated water from the upper layers of the lake. Increasing dissolved oxygen levels of bottom water would improve the habitat for cold-water fish such as trout. Also, since sediments overlain by anoxic water tend to release phosphorus, increasing hypolimnetic oxygen levels could reduce the rate of phosphorus release from sediments.

- Hypolimnetic withdrawal can also reduce internal loading of phosphorus from bottom sediments by replacing nutrient-rich bottom water with comparatively nutrient-poor water from the surface. Deep water tends to have higher phosphorus concentrations compared to phosphorus values in the epilimnion. Since hypolimnetic phosphorus can diffuse, or in major mixing events be mixed into the epilimnion, decreasing the concentration of phosphorus in the hypolimnion should also reduce phosphorus in the epilimnion.

- Hypolimnetic withdrawal can bleed the sediments of phosphorus and improve the quality of the lake over the long-term. As noted above, sediments overlain by anoxic waters tend to release phosphorus. Thus, lakes with rich sediments and a tendency toward hypolimnetic oxygen depletion (as occurs with Stockbridge Bowl) may derive a substantial portion of their nutrients from their sediments -- a phenomenon termed internal loading. This internal loading can be a significant impediment to the control of eutrophication and, according to the phosphorus budget, accounts for about half of the total phosphorus available to the Stockbridge Bowl. If the amount of phosphorus flushed out of the sediments exceeds that being added over time, hypolimnetic withdrawal can eventually deplete the sediments of phosphorus, reducing the amount that is released to the lake.

Because all of the effects depend on replacing hypolimnetic water with water from the surface, withdrawal works best when there is a substantial flow out of the lake during the period of stratification. The lake's hypolimnion during 1988 was that volume below 8 m; hence, its volume was about 2,040,000 m^3. Outlet flow for April through October totaled 5,090,000 m^3, approximately 2.5 times the hypolimnetic volume.

Cooke et al. (1986) suggest that, generally, the hypolimnetic volume should be replaced "several fold per stratification period" with a minimum of once every two to three months. However, Nurnberg's (1987) review finds positive effects of withdrawal with much lower flushing rates. Since the success of hypolimnetic withdrawal (except for case #3) requires adequate hypolimnetic oxygen concentrations, Cooke et al. suggest that the sufficiency of flushing rate should be determined in relation to the rate of oxygen depletion observed at the site.

Two factors complicate assessment of a sufficient hypolimnetic flushing rate for Stockbridge Bowl:

> First, oxygen depletion rate would decline as the lake's productivity responded to hypolimnetic withdrawal. Less algal production should equal less TOD falling down into the hypolimnion. For this reason, the oxygen needed for replenishment calculated in the 1988 should overestimate that needed in subsequent years. The aberrantly hot weather in 1988 should also produce an abnormally high depletion rate, since oxygen consumption depends upon temperature.
>
> Second, the high clarity of Stockbridge Bowl suggests that much of the thermocline and the very top of the hypolimnion could be in the euphotic zone (roughly three times the Secchi disk depth). Thus, observed changes in oxygen concentration of the hypolimnion probably include some oxygen production by plants.

These factors should have antagonistic effects on calculation of the oxygen depletion rate and were assumed to cancel each other.

Lycott calculated the rate of depletion for an assumed hypolimnion below eight meters, which is close to the bottom of the euphotic zone and is very close to the top of the homogeneous bottom layer. For the purpose of calculation, oxygen concentration for a depth interval (e.g., 8 to 10 meters) was assumed to be the average of the oxygen concentration at the top and the bottom of that interval. Original oxygen data are taken from Appendix D. Depletion rates are calculated for each sampling interval between June 14 and July 24, and for the period as a whole.

TABLE 24

OXYGEN DEPLETION RATE - 1988

Date	Interval (meters)	Dissolved Oxygen	Volume (cu m)	Kg O_2
June 14, 1988	8-10	7.2 mg/l	1.19×10^6	8568
	10-12	6.9 mg/l	0.62×10^6	4247
	12-14	5.9 mg/l	0.22×10^6	1309
	14-15	5.0 mg/l	0.01×10^6	50
		Total O_2		14174 KG
June 28, 1988	8-10	7.4 mg/l	1.19×10^6	8782.2
	10-12	0.1 mg/l	0.62×10^6	31
	12-14	0.0 mg/l	0.22×10^6	0
	14-15	0.0 mg/l	0.01×10^6	0
		Total O_2		8813.2 KG
July 5, 1988	8-10	8.6 mg/l	1.19×10^6	10245
	10-12	0.2 mg/l	0.62×10^6	114.7
	12-14	0.1 mg/l	0.22×10^6	18.7
	14-15	0.1 mg/l	0.01×10^6	0.6
		Total O_2		10379 KG
July 25, 1988	8-10	2.1 mg/l	1.19×10^6	2409.75
	10-12	0.5 mg/l	0.62×10^6	297.6
	12-14	0.1 mg/l	0.22×10^6	23.1
	14-15	0.0 mg/l	0.01×10^6	0
		Total O_2		2730.5 KG

Interval	O_2 change per day (kg)	O_2 (kg/d)
June 14 - June 28 (14 days)	-5360.8	-382.91
June 28 - July 5 (7 days)	+1565.8	+223.69
July 5 - July 25 (20 days)	-7648.6	-382.43
OVERALL PERIOD:		
June 14 - July 25 (41 days)	-11443.6	-541.65

As shown above, the oxygen in the total oxygen in the hypolimnion actually increased during the period from June 28 to July 5. This was a period of extremely clear water, and the oxygen increase indicates intense photosynthetic oxygen production in the metalimnion and top of the hypolimnion. The two periods on either side of this interval represent better estimates of the rate of actual oxygen consumption. Thus, Lycott will assume that the rate of oxygen consumption is 382 kg/day.

To maintain adequate oxygen concentrations, the rate of oxygen replenishment should be at least twice the observed rate of oxygen depletion, because oxygen consumption increases as oxygen concentrations increase (Cooke et al. 1986; Kortman 1989). Hypolimnetic withdrawal also exports any oxygen contained in bottom water, adding to the amount that must be replaced. Hence, even though the observed rate of depletion is probably around 382 kg/day, the suggested necessary rate should be about 764 kg of O_2 per day.

TABLE 25

OXYGEN REPLENISHMENT WITH HYPOLIMNETIC WITHDRAWAL
1988 DATA

Date	Daily Discharge (cu meters)	O_2 added to hypo (kg/day)	% of required O2	
			382 kg/day	764 kg/day
March	36677	366.8	96.0%	48.0%
04/21/88	25429	254.3	66.6%	33.3%
05/26/88	84846	848.5	222.1%	111.1%
06/14/88	10367	103.7	27.1%	13.6%
07/05/88	14573	145.7	38.1%	19.1%
08/11/88	20221	202.2	52.9%	26.5%
10/24/88	37166	371.7	97.3%	48.6%
Mean for April to September	25906	259.1	67.8%	33.9%
Mean + 33%			90.2%	45.1%

The discharge from the outlet observed in 1988 could not keep up with the rate of oxygen consumption, much less supply twice that rate as suggested by Cooke et al. (1986). According to the hydrological budget, outflow and replenishment rates during a normal year should be about 33% higher than those observed in 1988. This additional flushing would also not be enough to compensate for observed depletion nor twice the rate of observed depletion. The difference between oxygen needs and oxygen replenishment would be especially bad during late summer months. Thus, hypolimnetic withdrawal would probably improve oxygen levels, but not enough to trout and other cold-water fish.

Hypolimnetic withdrawal can also export phosphorus that accumulates in bottom waters. The following table shows the predicted phosphorus export with hypolimnetic withdrawal vs. withdrawal from the epilimnion and withdrawal over the outlet as it is currently configured.

TABLE 26

ESTIMATED PHOSPHORUS EXPORT BY DEPTH OF OUTLET

Date 1988-1989	Outlet flow 1000 m^3/m	Measured Concentration of P 1988 mg/l	surface mg/l	bottom mg/l	Monthly Estimated Loss of P 1988 kg/m	surface kg/m	bottom kg/m
Mar-88	1118.6	0.009	0.017	0.002	10.1	19.0	2.2
Apr-88	775.6	0.023	0.036	0.068	17.8	27.9	52.7
May-88	2587.8	0.018	0.010	0.037	46.6	25.9	95.7
Jun-88	316.2	0.151	0.010	0.093	47.7	3.2	29.4
Jul-88	444.5	0.025	0.001	0.078	11.1	0.4	34.7
Aug-88	616.7	0.020	0.010	0.360	12.3	6.2	222.0
Sep-88	0.0	--	0.370	1.160	0.0	0.0	0.0
Oct-88	1133.6	0.001*	0.001	0.001	1.1	1.1	1.1
Nov-88	3378.3	0.163	0.120	0.082	550.7	405.4	277.0
Dec-88	1939.0	0.087	0.019	0.016	168.7	36.8	31.0
Jan-89	2461.0	0.001	0.001	0.001	2.5	2.5	2.5
Feb-89	894.2	0.001	0.001	0.001	0.9	0.9	0.9
Total	**15,665.5**				**869.5**	**529.3**	**749.2**

Note: 1988 - refers to values estimated coming out of current spillway during sampling period.

* Values less than detection were set equal to detection limit.

According to 1988 data, continually taking water from the bottom of the lake would have actually reduced the amount of phosphorus exported from the lake. In 1988, about 870 kg of phosphorus were estimated to leave the lake. If continual hypolimnetic withdrawal had been implemented, only 750 kg would have been flushed from the lake. This surprising result occurred, because very little water flowed out of the lake when hypolimnetic water had high phosphorus concentrations (i.e., August and September), and much water left the lake when the epilimnion and outlet had higher levels of phosphorus than the hypolimnion.

In practice, water could be withdrawn from the hypolimnion only during stratification. In late fall when the macrophytes are dying and releasing nutrients, the hypolimnetic withdrawal could be closed, and exiting water would come from the epilimnion and outlet channel as it does now. This schedule -- hypolimnetic withdrawal from May through October and epilimnetic withdrawal for the rest of the year -- would have exported a total of more than 1,160 kg of phosphorus during the sampling period. Thus, instituting hypolimnetic withdrawal could increase P export by almost 30% per year.

The export of P could be enhanced even more by coupling the drawdown with hypolimnetic withdrawal -- a process that could be termed hypolimnetic drawdown. If much of the phosphorus-rich water in the hypolimnion could be exported, a substantial amount of phosphorus could be exported during a very short time period. Thus, for example, the deep-hole bottom averaged about 0.5 mg/l P for the months of August and September. The hypolimnion below 12 meters had a volume of almost 221,000 m^3. Exporting this volume during drawdown would export an additional 1,105 kg of P in a very short time. Thus, a combination of hypolimnetic withdrawal and hypolimnetic drawdown could send as much as 2,200 kg of phosphorus per year out of the system. Since this exceeds the current inputs by almost a factor of 2, export of this amount of phosphorus would eventually bleed the system of phosphorus. Of course, the export of phosphorus from the lake would be reduced as the phosphorus in the system were exported downstream.

Due to the great distance between the outlet and the deep-hole, almost 1.5 miles (7,700 feet) of pipe would have to be laid to permit hypolimnetic withdrawal. Since the rate of outflow during the summer is, at best, barely sufficient to compensate for oxygen depletion, all outflow during the summer should be forced out of the hypolimnion. None should be "wasted" by allowing it to spill over the dam. Thus, the outlet pipe would need be fairly large to capture almost all of the short-term high outflow associated with summer storms.

Based on rough calculations, Lycott estimated that the pipe would have to at least 30 inches in diameter. PVC pipe of this diameter costs approximately $45 per foot, making a total cost for pipe of about $350,000. The dam would have to modified for withdrawal at an estimated construction cost of about $50,000. Construction costs, engineering design and oversight, and contingency would add another $200,000 of so, and another $50,000 would need to be budgeted if the pipe were buried instead of left open in the outlet channel. Burying might be necessary for aesthetic reasons and to protect the pipe from adverse weather. Hence, the total estimated cost for hypolimnetic withdrawal unit would be about $650,000. The hypolimnetic withdrawal would require little maintenance or repair, so this would essentially be a one-time cost. Assuming a 20-year capital recovery cost based on 8% interest, this equals a yearly cost of about $65,000.

3. Hypolimnetic Aeration

Hypolimnetic aeration oxygenates bottom waters without destroying thermal stratification of the water column. Hypolimnetic aeration can be used to redress internal nutrient loading, insufficient oxygen in hypolimnetic water, and improvement of water quality for domestic use. The first two are problems at Stockbridge Bowl. McQueen and Lean (1983) have given a general summary of the effects of hypolimnetic aeration on water chemistry:

"1) the thermocline remains intact and hypolimnetic temperatures are not appreciably increased;

2) hypolimnetic O_2 levels increase;

3) hypolimnetic PO_4 generally decreases;

4) hypolimnetic total phosphorus decreases;

5) NO_3 increases or remains unaltered;

6) ammonia increases or decreases;

7) total Fe and Mn decrease;

8) pH generally remains unaltered;

9) H_2S and CH_4 should decrease."

Potential biological effects, from McQueen and Lean (1983) are summarized below.

"1) chlorophyll levels are generally unaltered;

2) zooplankton populations usually exhibit little or no response although in one case abundance decreased by 45%;

3) benthic macro-invertebrates generally increase in terms of numbers, diversity and distribution;

4) cold water fish stocking programs are usually successful and endemic fish populations increase their depth distributions."

Costs of hypolimnetic aeration are dictated by the amount of compressed air needed and the cost of siting, housing, running, and maintaining the air compressor and aeration apparatus. According to Lycott's field data, the depletion rate at Stockbridge Bowl is about 382 kg/day for water below eight meters. Given a volume of $2.04 * 10^6$ m^3, our calculated depletion rate was about 0.187 mg/l/d. Lycott sent hypolimnetic oxygen data to Aqua Technique, Inc., and they calculated a depletion rate of 0.36 mg/l/d during early spring (see Appendix I). (Their higher estimate probably results from faster oxygen depletion in the presence of higher oxygen concentrations during early spring.)

Based on their calculated rate of oxygen depletion, Aqua Technique quoted a price of $104,700. According to Aqua Technique, the equipment has an expected lifetime of about ten years. Lycott estimates that housing the air compressor will be a one time cost of about $25,000, assuming that the compressor can be sited on public land (i.e., land costs are zero). Adding a 15% engineering contingency, the total is $149,155.

The operating cost for the unit would be about $50 per day. Assuming that the unit would need to be run for 180 days in the summer and 60 days in the winter, this produces an annual cost of $12,000 for electricity. Approximately $4,000 should be added for routine maintenance and inspection of the unit -- costs of materials and labor costs due to 18 biweekly visits per year at $200 per visit. The total operating expenses should total about $16,000 per year. Given expected reductions in plant growth due to aeration and increased harvesting, the need for winter aeration may be very short-lived. This would decrease operating costs by 25%.

Thus, the total yearly cost for hypolimnetic aeration ranges from $33,635 to $68,427 for a twenty year lifetime. This assumes a capital recovery factor of 6% and an operating and maintenance increase at 6% per year. Major expenditures for equipment renewal would be expected every 8 to 12 years and should be built into the budget process.

Summary: Hypolimnetic Withdrawal vs Hypolimnetic Aeration

As noted above, both hypolimnetic aeration and hypolimnetic withdrawal can be expected to improve dissolved oxygen concentrations at the bottom. This, in turn, should reduce hypolimnetic phosphorus, iron, and manganese levels. In terms of improving trout habitat, hypolimnetic aeration would be the better technique. An appropriately sized aerator could oxygenate the entire hypolimnion, and, barring malfunction of the aerator, would successfully aerate the hypolimnion no matter what the weather. In contrast, the success of hypolimnetic withdrawal in any one year would depend heavily on the timing and quantity of rainfall. Hypolimnetic aeration would also be able to meet oxygen depletion needs should the rate of oxygen depletion increase due to increased development in the area. In this case, the capacity of aeration could be increased by simply increasing the size of the compressor.

Both techniques would also reduce phosphorus in the hypolimnion, but withdrawal probably works better in this respect. Hypolimnetic withdrawal almost always improves epilimnetic phosphorus levels (Nurnberg 1987), whereas aeration has a mixed record with respect to phosphorus control in the epilimnion (Cooke et al. 1986). However, phosphorus concentrations in the epilimnetic water column are probably not a major problem at Stockbridge Bowl, since the major nuisance plants derive most of their nutrients from sources other than epilimnetic water column. The macrophytes probably derive most of their nutrients from the sediments, and Oscillitoria rubescens derives its nutrients from the hypolimnetic or metalimnetic water column.

In terms of price, hypolimnetic withdrawal costs about twice what aeration costs, and would require major financing in times of severe budget constraints. Hypolimnetic withdrawal would, however, constitute a long-term solution that would function far into the future no matter what, whereas aeration would require mobilizing political and financial support every decade or so. A withdrawal device also would not pose hazards to boating and wouldn't require any land to house the aeration device. However, withdrawal could cause aesthetic impacts if the bottom waters contain substantial amounts of hydrogen sulfide and ammonia. Export of high phosphorus levels to the outlet also might violate discharge levels and impact downstream water quality.

Either technique would be applicable to Stockbridge. Based largely on the cost differential and the increased benefits of aeration, Lycott recommends that hypolimnetic aeration be implemented at Stockbridge Bowl. Aeration would have a more dependable and extensive impact on the trout fishery, should have as great an impact on Oscillitoria rubescens blooms, and should reduce any turbidity due to Mn and Fe. If epilimnetic phosphorus levels do not respond adequately to aeration, an alum treatment could be added to seal the sediments and provide greater control of epilimnetic oxygen.

Part 2 - Methods to Control or Remove Plant Biomass

Because rooted macrophytes can derive nutrients from the nutrient-rich sediments, methods that control nutrients in the water column may have little effect on weed growth. The following sections list the methods of macrophyte control that were considered for application in Stockbridge Bowl. Several largely experimental techniques (diver-operated dredging, rototilling, shallow-water cultivation, and hydraulic washing) were immediately eliminated from consideration because of their largely untested nature.

Lycott considered several in-lake management techniques to control macrophyte growth:

- benthic barriers
- biological control
- dredging
- herbicidal treatment
- hydroraking
- lake-level manipulation (drawdown)
- mechanical harvesting

The following section lists those options that were considered with an explanation for their selection or rejection.

Benthic Barriers - A variety of opaque materials have been extensively tested for localized control of aquatic vegetation, by application to shallow lake shorelines. Porous materials with negative buoyancy have proven most effective, and common burlap is the least expensive (Armour et al., 1979). Bottom barriers are expensive and require maintenance. For this reason, they were not recommended for use in Stockbridge Bowl.

Biological Controls - Encouraging survival of phytophagious insects and fish and manipulating food webs to enhance grazing on algae are among the newest lake improvement techniques. With the exception of some successes with plant eating insects in the South, biological control of algae or macrophytes has not worked well (see Smith 1988 and Cooke et al. 1986). Introduction of grass carp into Massachusetts is currently illegal, and the fish have proven difficult to manage. They tend to produce little effect or too much effect, completely eliminating macrophytes from a lake. Other techniques for biological control are experimental or largely ineffective. For these reasons, biological control will not be considered to control macrophytes or phytoplankton in Stockbridge Bowl.

Dredging - Dredging can manage macrophyte biomass by removing the nutrient-laden sediments in which the plant grow and by deepening the pond so that the bottom becomes too dark to allow macrophyte growth. In the short-term, dredging removes plant rhizomes and storage organs, preventing re-growth of perennial plants the next spring. Future growth must come from re-invasion by new plants.

There are two types of dredging or sediment removal techniques. Dry dredging occurs after water has been drained from the pond/lake, allowing the sediments to dry out. Then the dried sediments are removed with heavy equipment. Because the level of Stockbridge Bowl cannot be easily manipulated, dry dredging is not feasible there. The second method, wet dredging, involves the removal of sediments with either a drag line (bucket) or with a piece of heavy equipment such as a Mud Cat (hydraulic dredge). This method of sediment removal is accomplished without altering the water level in the pond/lake.

Since Stockbridge Bowl cannot be drained, it would have to be wet-dredged. Wet dredging costs between $7 and $20 per cubic yard. Assuming, for illustration, that the sediment depth averages one yard, dredging would cost from $40,000 to $100,000 per acre.

In addition to cost, dredging has some other salient disadvantages. Dredging may cloud the water with sediments, producing a temporarily turbid lake that can discourage swimming and fish growth. It also disrupts reproduction of aquatic fauna that rely on bottom nests. The use of the pond/lake for human activities is precluded during dredging. Disposal of the dredged spoils is costly and may pose environmental impacts. Dredging does not always solve aquatic weed and algae growth problems. Weeds sometimes regrow within a short time.

Dredging will not be proposed to manage macrophytes in Stockbridge Bowl for the following reasons. Deepening will have only a moderate impact on macrophyte growth because the lake is so clear. In addition, dredging is also very expensive and, over the short-term, ecologically disruptive.

Harvesting - Specially designed machinery has been developed by various manufacturers (including Lycott) to cut, capture, and remove aquatic plants from ponds/lakes. Harvesting functions like a lawn mower, clipping and removing the top portion of the plants, usually a maximum of six feet. Since the lower portion of the plant remains, plants regrow after cutting. In some lakes, weeds must be harvested several times per year. Costs of weed harvesting range from $350 and $1,000 per acre. Harvesting is currently practiced at Stockbridge Bowl, and will be given detailed consideration in the next section.

Herbicidal Control - Herbicides are an inexpensive and effective method to manage macrophyte biomass. When applied correctly, currently registered herbicides pose little if any health risk to man or the environment. Herbicide application is also not restricted by water depth or physical obstructions. Herbicides exert control before the weeds reach nuisance densities, and the experienced applicator can often manage macrophytes with some degree of selectivity, preferentially eliminating certain species without disturbing more-preferred macrophytes. Cost depend on the species to be managed and local conditions, but usually ranges from $500 to $800 per acre. Herbicides have been used successfully in Stockbridge Bowl in the past and will be considered in detail in the section below.

Hydroraking - The major mechanical macrophyte control method used to clear shoreline areas is called hydro-raking. The hydro-rake is essentially a floating, paddle-wheel propelled back-hoe with a wide, stiff, rake attached to the end of the hydraulically-powered mechanical arm. This arm is operated with a diesel engine and hydraulic system. The sediment of the plant bed is scoured with the rake, and the uprooted plants, rhizomes, and attached sediments are put on a barge for later disposal. Cost ranges from $1,500 to $2,500 per acre. Hydroraking could be used to control macrophyte at Stockbridge Bowl, and will be considered in detail below.

Lake-Level Drawdown - This management technique serves several purposes in lakes and impoundments. Drawdown is used primarily to control macrophyte densities. Exposing rooted plants to freezing or hot conditions effectively controls many species of macrophytes, does not affect others, and stimulates a third group of species (Cooke et al. 1986). In addition, drawdown can be combined with other management methods. During drawdown, near-shore sediments can be removed, dock and break-walls can be repaired, benthic screens can be put in place, and the fisheries can be managed. In addition, appropriately times drawdown can export significant amounts of phosphorus from the system. Drawdown will be recommended to control the macrophytes in the nearshore area of Stockbridge Bowl and will be discussed in detail below.

RECOMMENDED ALTERNATIVES

DRAWDOWN FOR CONTROL OF NEARSHORE MACROPHYTES

Drawdown of water level is a well-established management technique for lakes and ponds. Drawdown will be recommended for Stockbridge Bowl, because it has a reasonable one-time cost and can control macrophytes for long periods without further expenditure.

In Stockbridge Bowl, drawdown has managed macrophytes in the drawdown areas. Lycott's proposed remediation will increase the drawdown depth and extend control to the littoral zone less than 6 feet in depth. Drawdown retards macrophyte growth by destroying their seeds and storage structures through exposure, drying/freezing conditions, and by altering their substrate by de-watering, freeze-thaw cycles, and consolidation and oxidation of sediments.

While water can be drawn down at any time, winter drawdown has many advantages. Recreational impacts of drawdown are less during the winter. Although freezing alone does not usually kill rhizomes and roots, drawdown functions best when the exposed sediment freezes completely. Freeze-thaw cycles disrupt the sediments, destroying root tissue. In addition, water is generally most available to a watershed during spring, so the lake can refill most quickly and reliably after winter drawdown. (Drawdown, therefore, also increases the lakes potential for flood control.) In addition, rapid refilling severely disrupts the sediments, especially when they are frozen, because the frozen hydrosoil often floats to the top. Since it is dark colored, this material rapidly heats up and drops back to the bottom. During Lycott's 19 years of lake management, we have found that the disruption of the root habitat significantly improves macrophyte control compared to that achieved with less rapid refilling.

Water level drawdown can also be used to manage fish populations. As fish are concentrated in the deeper waters, small "pan" fish are less able to avoid predation by large game fish and overall effect can be to remove a portion of the less desirable "pan fish" and to increase growth rates of predatory fish prized by anglers. Based on their study of three Louisiana lakes, Lantz _et al_. (1964) found that over-winter drawdown resulted in less turbid water, better spawning and survival of sunfishes, and increased growth rate and survival of the bass population.

The effectiveness of over-winter drawdown depends largely on the susceptibility of the nuisance species to drawdown control. Drawdown is effective in controlling milfoil, which is the major nuisance plant at Stockbridge (Cooke et al. 1986). The <u>Potamogeton</u> species found in the lake may also be controlled by drawdown.

Potential disadvantages of drawdown include stimulation of algal blooms, oxygen depletion, user dissatisfaction during drawdown, failure to refill after drawdown, invasion of undesirable plant species, and lowering of water levels in nearby wells (Nichols, 1975; Cooke, 1980). If level adjustment reduces the growth of shoreline vegetation, a greater percentage of the nutrients in the water column will be available to support phytoplankton growth, and algal blooms could result. However, it should be noted the macrophyte control may substantially reduce internal cycling of nutrients and release of organic matter (e.g., Carpenter, 1983), thereby helping to reduce algal growth. None of the potential problems are likely to be severe in Stockbridge Bowl.

Other than the costs associated with laying an outlet pipe below the gas line and dredging out the outlet, drawdown has no cost other than the time associated with opening and closing the valve.

Lycott recommends that drawdown be started around the beginning of September. Starting the drawdown at this date allows aquatic organisms to migrate to the adjusted water level. Depending on the weather conditions during drawdown, the water level should be drawn down six feet by the end of September or early October. The lake should begin to refill during late December -early January, when the frozen bottom will rise to the surface, further disrupting the aquatic plant life on the bottom.

Feasibility of Drawdown at Stockbridge Bowl.

Two major issues must be addressed to determine the feasibility of drawdown. First, can the water level be drawn down enough? Second, can the water level be raised back up? Stockbridge Bowl presents problems with respect to both criteria.

Currently, the outlet channel will not allow drawdown of more than several feet without construction of a siphon over or pipe system under the Tenneco gas line. A drawdown by-pass must be constructed along the easterly shore of the outlet channel. This by-pass is proposed to be layed under the Tennessee Gas main and under the sewer line.

Drawdown of more than the existing two feet will also require deepening of the outlet channel at the site of the old dam. We foresee the use of conventional earth excavating equipment during drawdown and after emplacement of coffer dams and pumping out contained water. Excavation would have to be carried out over a distance of roughly 400 feet immediately upstream of the old dam.

The existing slide gate also needs repair. Concrete in the dam in the vicinity of the slide gate will need minor repairs. A new trash rack with a sloping cleanable face will need to be constructed upstream of the slide gate. A considerable number of trees need to be removed from the dike. Portions of the dike banking which are undercut due to erosion need protection with a layer of trap rock.

In order to determine the feasibility of lake drawdown as a treatment option, Lycott has calculated both the volume of water that would be lost from the lake during a 6-foot drawdown and the volume of water available for refilling. The latter was derived from average (long-term) precipitation values for the months of January, February, and March. These months were used because drawdown would be accomplished in the late fall, and because normal lake-levels should ideally be re-established by the spring. During winter months, loss of precipitation to evapotranspiration would be very small; thus, nearly all precipitation would be available to replenish the lake.

If Stockbridge Bowl were drawn down six feet, the volume of water needed to refill it would be approximately 2,851,300 m^3. During an average winter, the Stockbridge area would receive a total of 11.34 inches of precipitation, based on NOAA records for the Western Massachusetts Division and for Norfolk, Connecticut (averaged). Thus, 8,609,700 m^3 of water would be available to replenish the lake, given that the total watershed area is about 7336 acres in size (including the lake itself).

During a drought year, the available water would be reduced substantially. Lycott's calculations for a drought year assume a 50% reduction in available water, resulting in a decrease in total available water to about 4,304,900 m^3. Even in this case, available water would be well above the 2,851,300 m^3 needed to refill the lake. This result indicates that refilling of the lake can be accomplished during the 3-month winter period, even under conditions of substantial water depletion.

RECOMMENDED OPTION

HARVESTING TO CONTROL DEEP-WATER MACROPHYTES

In-Depth Evaluation: Herbicides vs. Hydroraking vs. Harvesting

Drawdown is recommended to control macrophytes in the near-shore area up to six feet. For deeper water in which macrophyte growth becomes excessive, three choices are appropriate -- herbicides, hydroraking, and harvesting. The following section addresses the pros, cons, effectiveness, and cost of the three alternative measures.

1. Harvesting

A. Advantages and Disadvantages of Herbicides

Aquatic plant harvesting has a number of advantages over other control technologies, including:

- Mechanical harvesting is not inhibited, as herbicidal control may be, by local regulations, adverse public opinion, or requirements to ban use of the water for 10-14 days after treatment.
- Harvesting is fully controlled by the machine operator, and the size of treatment areas may be determined and limited readily.
- The main nuisance is removed immediately without addition of potentially deleterious substances, and the nutrients incorporated in this biomass are removed.
- Harvesting removes biomass that otherwise will release nutrients at senescence and will contribute to an oxygen depletion that will stimulate further nutrient release form reduced sediments.
- Harvesting prior to herbicide treatments may facilitate dispersal of the formulation to the target vegetation and enhance overall effectiveness by increasing the susceptibility of the plants to herbicides.
- Multiple use of the water body may continue with minor interference during harvesting.
- Harvesting activities pose little hazard to non-target organisms other than those inadvertently removed with the cut vegetation.

- Harvested vegetation may be a beneficial product, sought after by farmers and gardeners.

Disadvantages of aquatic plant harvesting include:

- Cut vegetation must be collected and removed from the water; these steps may be energy-or labor-intensive and relatively costly.
- Effective harvesting in temperate waters is seasonal.
- Harvesting is reactive, i.e., it works best after growth has peaked and plants are at nuisance heights and densities.
- Only relatively small areas can be treated by individual machine units during the harvesting season, when nuisance conditions may require simultaneous treatments over large areas in a short time period.
- In locations where a short operating season prevails, a high capital outlay is needed for the required machine capacity, which is used only for brief time periods.
- Harvesting may encourage vegetative fragmentation of target and non-target plants and may encourage more rapid growth or shifts in species composition by encouragement of opportunistic species.
- Harvesters may inadvertently kill large numbers of small fish.
- Operating depths are usually limited if cutting units incorporate collection and storage functions.
- Favorable weather is essential to safe and effective operations.
- Harvesting operations must rely, at the present, on mechanical systems that usually involve high capital cost, are technically specialized, and could break down or require extensive maintenance.
- Harvesting operations are limited by access to the site, by confined spaces that limit movement, by obstacles such as docks and breakwater, and by physical factors such as submerged rocks, deadheads, and other bottom irregularities.
- Because of slowness, harvesting operations may create public dissatisfaction and disputes over which treatment areas have priority.

- Harvested vegetation may become a waste material that must be disposed of, adding costs.

B. Costs of Harvesting

Costs for harvesting will be estimated for the case of contractual harvesting of Stockbridge Bowl. According to Cooke et al. (1986), costs for harvesting range from $60 to $600 per acre. Lycott will use the median value of $350.

According to the Town of Stockbridge records and others involved in the project, about 150 acres of Stockbridge Bowl are harvested during the season. This equates to $52,500. However, Lycott recommends the harvesting of these 150 acres twice per season, for a total of 300 acres harvested per year. This would cost $105,000.

For comparison, Lycott will compare the contractual value obtained above to the harvesting of Stockbridge Bowl by the town owned and operated harvester. Annual harvester operation costs have been obtained from two sources: 1.) Town of Stockbridge records on the operation of the harvester at Stockbridge Bowl and 2.) Berkshire Enviro-Labs' records of the harvesting program on Lake Buel in Monterey during 1987. These costs for Stockbridge Bowl Harvesting are presented below:

Salaries -	Operator $8/hr. x 40 hr./wk. x 15 wk.	= $ 4,800
	Truck Driver 2 hrs/day x 90 days	= 3,600
	Mechanic $20/hr. x 80 hrs.	= 1,600
	Moving 32 man hours	= 380
Repairs -	Parts	= $ 2,500
	Fuel	= $ 450
	Oil/Hydraulic Fluid	= $ 450
	TOTAL	$13,780

Harvester Purchase Cost (1983)	$43,800
Shore Conveyor Purchase Cost (1985)	$11,000

Note: Marine insurance was carried on the harvester for an annual premium of $1,500 through 1987, when it was discontinued after the harvester capsized in September, 1987. Also, the labor costs do not include any overload factor for benefits, administration, etc.

Harvesting costs for the harvesting operation on Lake Buel (240 acres) are presented below.

Insurance	$ 3,049.00
Harvester prep. labor	1,688.00
Pre-season repair	1,000.00
Program Manager	1,555.51
General O&M during season:	
Labor	$11,328.00
Parts, fuel, oil, etc.	1,557.14
Major repairs	770.58
Welding	627.00
End of season prep.:	
For storage	$ 1,488.00
Storage & Tarps	900.00
Total 1987 season	$23,963.23

From an analysis of the two sets of costs, certain conclusions can be drawn: the higher costs for the Lake Buel harvesting are partly due to a larger harvested area, more thorough cost accounting system, and partly to higher overhead costs for contractor operation of the harvester. The possibility exists that needed maintenance is being deferred or was not being properly accounted for on the Stockbridge harvester.

For the years 1984 - 1986, when the harvester was in operation for the entire 15-week season, the O & M costs, as reported in the Clean Lakes Program application form, averaged $21,066/year, not including depreciation.

A full cost accounting for harvesting should include depreciation since a harvester has a useful life of only 5 - 10 years depending upon the level of maintenance. Assuming a 5 year life-span, depreciation on the Stockbridge harvester and conveyor would be $11,000 per year since the purchase cost was $55,000.

Lycott's minimum estimate for harvesting costs at Stockbridge Bowl by the town would be the O & M estimates provided by the town officials plus depreciation for a total of $24,780. This should be considered a lower limit because it may not include optimal maintenance, and no costs are included for overall management of the harvesting program or insurance. With respect to the experience at Lake Buel, insurance and management should add another $4500, bringing the yearly cost to $29,280 per year.

Assuming that the entire area of the lake between a depth of 5 feet and 25 feet is harvested once during the season, this would represent an area of about 150 acres, with the cost per acre equal to $195. However, Lycott recommends that the lake be harvested twice per season, for a total of 300 acres per year. In order for the town owned machine to achieve this acreage in one season, approximately 5 acres would have to be harvested per day (Assuming the harvester is operated 5 days per week, four weeks per month for three months). According to Cooke et al. (1986), average harvesting rates range from 1-2 acres per day. Therefore, it is unlikely that the town operated harvester would be able to achieve the level of harvesting recommended by Lycott.

2. Herbicides

A. Advantages and Disadvantages of Herbicides

With respect to Stockbridge Bowl, the major advantages and disadvantages of herbicides follow:

Benefits

- Used properly, herbicides will not adversely affect fisheries or other aquatic fauna.
- In certain cases, specific plant species can be managed while not affecting other more desirable aquatic plants.
- The technique is somewhat spatially specific. With proper application of some herbicides, only target areas will be affected.
- Some herbicides kill both above ground and below ground portions of the plant. Thus, this method can be a medium-term solution (i.e., several years per application.)
- In most instances, application causes minimal disruption of recreational activities in the pond/lake.
- There is no disruption or detrimental effects to the reproductive activities of aquatic fauna.
- The technique is proactive. One can apply the herbicides before the plants grow to nuisance heights and/or densities.
- The application and effect of herbicides are fairly quick. Residents need not tolerate long periods between effective management.

- By properly treating the pond/lake's aquatic plants, the natural reproduction of those plants is precluded.

Detriments

- Caution must be used by the applicator. These compounds in high concentrations can be toxic to the user and other living organisms.

- There may be some restrictions to the pond/lake's water usage for a short period of time. Herbicide application can also produce problems, because of the threat of contamination of drinking wells.

- Herbicide application may secondarily cause fish kills, because decay of dense weeds may deplete dissolved oxygen. This does not, however, normally occur in larger ponds/lakes in the Northeastern U.S., and the chances of fish kills due to oxygen depletion can be further minimized by proper herbicide application.

- Some herbicides leave residues that remain in the ecosystem for many years, although most currently registered herbicides break down relatively quickly.

- Many people fear the use of chemicals and would feel uncomfortable with their use.

B. Costs of Herbicide Treatment

Lycott estimated the cost of three type of herbicide treatment in Stockbridge Bowl. SONAR (fluridone) is a relatively new herbicide discovered and developed by Elanco Products Company. Numerous cooperators from various federal and state agencies as well as Elanco biologists have participated in the testing of fluridone under an experimental use permit from 1981 to 1985. In March 1986, SONAR received full registration from the EPA.

Since then, aquatic plants in numerous ponds, lakes, and reservoirs throughout the United States have been treated with fluridone. Aquatic plant managers have found that it works well on selected plants, notably hydrilla and Eurasian watermilfoil, when treatment areas are a minimum of 10 acres in size. Acceptable plant control has often been maintained over a larger area than that treated, often 3 to 4 times as much. This, along with the longevity of control, tends to put fluridone in a competitive cost position with other aquatic herbicides that are effective on hydrilla and milfoil.

Of the aquatic weeds identified in the Stockbridge Bowl, SONAR is effective in controlling the following:

Yellow water-lily	(Nuphar spp.)
White water-lily	(Nymphaea spp.)
Pondweed	(Potamogeton spp.)
Watermilfoil	(Myriophyllum spp.)
Common Elodea	(Elodea Canadensis)

The weeds Najas and Chara, which are low growing and generally not nuisance species, are not susceptible to the effects of SONAR and would probably become more dominant after SONAR treatment.

It is important to maintain the maximum concentration of SONAR in contact with the weeds as long as possible. Rapid water movement or any condition which results in rapid dilution of SONAR-treated water will reduce its effectiveness. SONAR is best applied after spring runoff and prior to weed growth or when weeds begin actively growing.

Only state-licensed supervisory personnel should be involved in conducting any herbicide treatments, and it is strictly illegal for anyone to introduce chemicals into the waters of Massachusetts without being licensed and without acquiring a permit from the Commonwealth.

SONAR, has been thoroughly tested and has a minimal effect on the aquatic environment. Tests have been conducted to assess the product's safety for use by humans, for wildlife exposure, and for side effects on environmental quality. The test results indicate a very low order of toxicity to mammalian species following acute, sub-chronic or chronic exposure. In addition, large repeated doses of SONAR did not result in the development of tumors, impairment of reproduction, or abnormal effects on the development of offspring.

SONAR has been tested in acute and chronic laboratory studies in birds, fish, and invertebrates. In laboratory tests, the 96-hour LC 50 (lethal concentration) for fish such as trout, blue gills, catfish, and minnows, ranges from 4.2 to 22 ppm. This is approximately 42-220 times the concentration at the recommended dosage rate. Some invertebrates are more sensitive than fish. The 48 hour LC 50 values for Daphnia and midge larvae are 4.4 and 1.3 ppm, respectively. By comparison, the SONAR concentration, after uniform distribution at the recommended dosage rate, is roughly 0.08 ppm. Chronic studies were also conducted with amphipods, Daphnia and midges. A concentration of 0.6 ppm had no effect on the growth or survival of amphipods or on the emergence of adult midge. Reproduction of Daphnia, was not affected by a concentration of 0.2 ppm.

In studies with mallards and quail, maximum concentrations of 5,000 ppm in the diet of young birds of both species caused no mortality.

Herbicide Treatment Costs

1) SONAR
   Basis of costs:
   250 acre treatment area (to compensate for dilution)
   3 quarts per surface area
   $440./quart
Total Cost $330,000 + $20,000 applicator fee = $350,000

SONAR destroys the entire plant including the rhizomes and reproductive structures. Thus, treatment of macrophytes, especially perennial species like milfoil, can last moderately long. If the entire lake is treated, control of milfoil can be even longer. Assuming a treatment every 5 years, produces a yearly cost of about $70,000 per year for Sonar.

2) Combination of 2,4-D (for milfoil) and Aquathol K for (potamogeton spp.)
   Basis of costs
   140 acres x 200/acre for 2,4-D = $28,000,
   50 acres x 500/acre for Aquathol K = $25,000

Of these costs roughly $37,000 represents the costs of the chemicals and $16,000 represents the fee for the professional applicator. Because of the carry over effect from one year to the next, it is anticipated that the maximum cost for re-treatment in succeeding years would be roughly $26,500 and a more likely cost for re-treatment in succeeding years would be about $14,000. Thus, over 20 years costs would range up to maximum of $556,500, but would more likely be nearer $319,000. Annual costs would probably total about $16,000 per year.

3) Diquat (effective on both milfoil and potamogeton spp.)

   Basis of costs:
   140 acres x $214/acre = $30,000

Because of the carry over effect from one year to the next, it is anticipated that the maximum cost for re-treatment with Diquat in succeeding years would be roughly $15,000. Thus over 20 years likely costs would be $315,000, and expected yearly costs would average $15,750. Diquat require restricting water uses for 14 days and would probably be politically unfeasible at Stockbridge Bowl.

3. Hydroraking

A. Advantages and Disadvantages of Hydroraking

Benefits

- Removal of plants from lakes and ponds.
- Export from the lake of nutrients and BOD associated with dead plant material.
- Removal of some root systems and some sediment.
- The method is spatially specific. Only those areas hydroraked are significantly disturbed. Beneficial plants and/or beneficial densities of plants can be maintained by well-planned hydroraking.
- Hydroraking is proactive. It can be implemented successful before the plants reach nuisance densities or heights.
- Reduced macrophyte cover can reduce sediment accretion rates.

Detriments

- Can kill fish and other aquatic fauna entraped in the uprooted weeds.
- Fragments aquatic plants which may re-vegetate other areas of the pond/lake.
- Reduces reproduction of aquatic fauna dependent on weed beds and sediment.
- Disturbance and suspension of sediments which may significantly increase turbidity and nutrient levels.
- By removing the upper layer of the sediment, a lower layer of sediment may be exposed which can provide higher concentrations of nutrients for plant and algae growth.
- Aquatic plant raking cannot be done around rocks, boulders, stumps, docks, or moorings.
- Problems associated with disposal of the harvested weeds.

B. Costs of Hydroraking

Hydroraking can be expensive, running from $1000 to $2000 per acre. Thus, hydroraking the entire littoral zone from 5 to 25 feet deep, an area of about 150 acres, could cost as much as several hundred thousand dollars. In addition, the hydroraked material would need to be disposed of properly, Using a moderate density of 0.2 kg/m^2 (dry weight) for submerged aquatic weeds such as Milfoil (Cooke et al. 1986), the total mass of weeds to be removed would about 109,000 kg or more than 100 metric tons (dry weight). This total should be doubled to account for attached hydrosoil and incomplete dewatering, making a total of 200 metric tons that would require disposal. Unless residents were willing to use the material as compost, the trucking charge and tipping fee would be cost an extra $20,000 to $30,000.

Thus, hydroraking the entire littoral zone greater than 5 feet would cost anywhere from $150,000 to $300,000 per hydroraking. Because hydroraking removes roots and rhizomes, however, control can be moderately long-lived, especially with annuals like Milfoil. However, hydroraking activities in Berkshire County have not provided control of milfoil for more than one season. Thus, Lycott assumes that the raking would be required every year, and the yearly cost would be $150,000 to $300,000 per year. Costs could be cut considerably if the city were to buy its own hydrorake and transport the weeds with city trucks.

Summary: Harvesting vs. Herbicides vs. Hydroraking

Each of these techniques has been tried by the residents of Stockbridge Bowl and each has been found wanting for one reason or another. From 1960 through 1977 various herbicides, including 2,4-D, Sodium arsenite, copper sulfate, Silvex (Kuron), Aquathol K, Hydrothol-47, Aquazine and Cutrine G were used to treat nuisance macrophytes and algae in Stockbridge Bowl. (As noted in the section on macrophytes, the organic herbicides used in the mid-70's were apparently very effective.) From 1979 through the present, Stockbridge Bowl has been hydro-raked 3 years (1980-1982) and harvested the remainder of those years. Since 1983 harvesting has been performed by the Town of Stockbridge itself with its own harvester.

Herbicide treatments with Diquat or Aquathol K and 2,4-D are clearly cheaper than the alternatives. Both treatments cost approximately 20% of the cost of harvesting, and they both provide a more effective control of weeds that does harvesting. However, Diquat application requires a 14 day waiting period after use, which would be politically unpalatable as well as having significant cost. Application of 2,4-D effectively controls milfoil, but this herbicide has recently been embroiled in controversy concerning its potential carcinogenic properties. Furthermore, 2,4-D should not be applied to drinking water supplies. Since Stockbridge Bowl has been used in the past as a emergency water supply by the Town of Lenox, applying 2,4-D to Stockbridge Bowl would be difficult (and, therefore, costly) from a regulatory standpoint. Sonar had minimal toxicity and few use restrictions, but costs almost twice as much as harvesting.

Hydroraking costs from 1.4 to 3 times the cost of harvesting, but it provides better control of weeds than harvesting and can provide more nutrient export than harvesting. However, Stockbridge already has a harvester, so continuing to harvesting will cost the town only maintenance costs, which makes the margin between the two techniques even larger. Thus, primarily on the basis of cost, Lycott recommends that harvesting be continued on Stockbridge Bowl. However, we propose the following modification to the current program.

Proposed modifications to the Harvesting Program

Based on our evaluation of the harvesting program at Stockbridge Bowl, Lycott recommends the following changes to the harvesting operation. Justifications for the recommendations follows.

A.) Harvesting should be accomplished by a contractor that can achieve 300+ acres in a three month harvesting season. The estimated cost for this is $105,000.

B.) If harvesting is to be accomplished by the town, the following changes should be made to the program:

Done

1) Expand the harvesting season and expand the goal of harvesting to include nutrient removal as well as nuisance plant removal. Scheduling of harvesting priority should consider the potential for nutrient removal as well as other considerations. Records should be kept detailing areas harvested and weights of plants removed.

2) Designate a project manager to manage the program or consider hiring a part-time professional manager to oversee the entire harvesting operation.

3) Train a second operator for the harvester.

4) Buy insurance for the harvester

The first recommendation aims to achieve an intense harvesting operation (removal of aquatic weeds on a fairly regular basis, which could reduce nutrient levels within the pond).

If the town were to conduct the harvesting program, the next three recommendations aim to greatly increase the nutrient removal associated with macrophyte harvesting. Very intensive macrophyte harvesting can help balance out nutrient loading, and in some cases, may actually reverse eutrophication (Welch 1979). (The latter could only be a very long term goal -- 20 to 100 years --because sediments in shallow water of Stockbridge Bowl are apparently very rich in phosphorus, as evidenced by the samples taken at the outlet channel.)

An average harvesting operation in the northern U.S. removes 0.675 g of phosphorus per m^2 harvested (Cooke et al. 1986). Harvesting the littoral zone from 5 to 25 feet (about 137 acres or 550,000 m^2) should remove about 371 kg of phosphorus per year. This would be expected with a <u>moderately</u> intensive harvesting program. According to the literature (Burton et al. 1979), a more intensive harvesting effort could export about twice this amount.

By comparison, septic tanks in the area above Beachwood may introduce about 20 kg/yr of phosphorus to the Bowl. Sewering this area would cost around 1 million dollars, including costs to individual residents. The same net effect on the phosphorus budget could be attained by harvesting an extra 30,000 m^2, about 7.5 acres. Harvesting at Stockbridge now costs about $255 per acre, so an annual outlay of less than $2000 for extra harvesting could produce the same effect on nutrients as $1 million spent on sewering. Furthermore, harvesting removes the weeds; sewering would have no impact on weed growth for many, many years.

Thus, increasing the efficiency and scope of the harvesting seems a cost effective manner to redress both the symptoms (excessive macrophyte growth) and the ultimate cause (too much phosphorus) of eutrophication in Stockbridge Bowl. As noted above, however, depleting the nearshore sediments of phosphorus, even with a very intensive harvesting program, would be a very long-term project. So intensive harvesting should practically be viewed as an cost-effective method of nutrient control rather than a method of nutrient reduction.

To increase the intensity of harvesting, Lycott recommends that a program manager be hired. Currently, the Stockbridge Bowl harvesting program has no designated program manager, which may be responsible for some of the public complaints of the program. Now, the choice of which areas to harvest seems to be made by the operator, with no overall plan or schedule for harvesting priority areas more frequently. Better records concerning harvesting areas and volumes need to be kept.

In addition, an additional summer employee should be hired. The reliance of the Town of Stockbridge on a single trained individual to carry out the harvesting operations for the entire season would seem to be inadvisable since it could lead to significant lapses of harvesting due to operator illness, etc. An additional operator could also work on week-ends, if the need arose.

DONE

Since the capsizing of the harvester in September 1987, some guidelines should be established for maximum safe operating winds and maximum safe loading of the harvester. Another capsizing of the harvester could result in a injury or death and major financial loss to the town since the harvesting is presently uninsured against this sort of loss. Lycott recommends that insurance be bought before harvesting continues.

WATERSHED MANAGEMENT

With respect to watershed management, two points should be stressed at the outset. First, the primary water quality problems at Stockbridge Bowl -- excessive macrophyte growth and excessive internal loading -- result from internal sources of phosphorus. Consequently, more emphasis should be placed on in-lake management than on watershed management. Second, many of the options for watershed management are either already implemented or not relevant, leaving little opportunity for further watershed management.

Table 27 presents options for watershed management. Sewering, zoning, and maintenance of septic systems are already in place in the watershed. Lycott recommends that the latter two continue to be emphasized in the future. Further sewering does not appear warranted. More intensive harvesting is far cheaper method to control nutrients. If further sewering is pursued, the area on the east side of the lake should receive priority since areas contiguous to the outlet channel probably have minimal impact on water quality in the main basin of the lake. The rest of the shoreline is too sparsely populated to make sewering cost-effective.

There is only very limited agriculture in the watershed of Stockbridge Bowl, so best management practices (BMP) would have minor impact. However, BMP's should continue to be emphasized especially in the area above Tributary 2, as long as agriculture is continued. Some educational effort should be undertaken by the Stockbridge Bowl Association to encourage residents with septic tanks to forgo garbage disposals, phosphate detergents, and lawn fertilization. Sources of phosphorus from these practices can be reduced with little cost.

TABLE 27

Lake Restoration and Management Options

Technique	Descriptive Notes
Watershed Level: Physical Approaches Applied to the Drainage Area of a Water Body	
1. Zoning/Land Use Planning	Management of land to minimize deleterious impacts on water
2. Stormwater/Wastewater Diversion	Routing of pollutant flows away from a target water body
3. Detention Basin Use and Maintenance	Lengthening of time of travel for pollutant flows and facilitation of natural purification processes
4. Construction of Sanitary Sewers	Community level collection and treatment of wastewater to remove pollutants
5. Maintenance and Upgrade of On-Site Disposal Systems	Proper operation of localized systems and maximal treatment of wastewater to remove pollutants
6. Agricultural Best Management Practices	Application of techniques in forestry, animal, and crop science intended to minimize impacts
7. Bank and Slope Stabilization	Erosion control to reduce inputs of sediment and related substances
8. Increased Street Sweeping	Frequent removal of potential runoff pollutants from roads
Behavioral Modifications: Actions by Individuals	
a. Use of Non-Phosphate Detergents	Elimination of a major wastewater phosphorus source
b. Eliminate Garbage Grinders	Reduce load to treatment system
c. Minimize Lawn Fertilization	Reduce potential for nutrient loading to a water body
d. Restrict Motorboat Activity	Reduce wave action, vertical mixing, and sediment re-suspension
e. Eliminate Illegal Dumping	Reduce organic pollution, sediment loads and potentially toxic inputs to a water body.

Done

ENGINEERING RECOMMENDATIONS

Outlet Control Structure - The existing outlet control structure for Stockbridge Bowl consists of a timber type rising stem slide gate draining to a 5 1/2' diameter steel outlet pipe. Both the slide gate and the trash rack are in need of replacement.

Lycott has proposed that the slide gate and trash rack be replaced during the normal summer construction season by the construction of a temporary coffer dam across the outlet channel leading to the slide gate. The construction of the coffer dam will permit dewatering of the outlet channel and subsequently allow the contractor to work in dry conditions.

Once the coffer dam is in place, the timber slide gate and trash rack can be removed. The concrete framework around the slide gate will be cleaned and modified to accept a new cast in place concrete structure. The new structure will include the framework for a 6' x 6' square cast iron slide gate, and an adequate trash rack to protect the slide gate. The top elevation of the trash rack will be set at the same elevation as the existing spillway. If the trash rack becomes completely plugged with debris, water will be discharged over the existing spillway without danger of overtopping the outlet control structure.

② Diversion

Drawdown Diversion Pipe - The presence of gas transmission mains has long been a source of difficulty in drawing down the level of Stockbridge Bowl. The problem has further been compounded by the installation of a gravity sewer main, crossing the channel at approximately the same location and elevation as the gas mains. Rather than attempting to reconstruct the gas mains and converting the sewer main into an inverted siphon, which has been estimated to cost one million dollars, it is proposed that a diversion pipe be constructed under the mains at a slightly different location. This location, approximately 100 feet away from the diversion channel takes advantage of the fact that the gas mains tend to follow the contour of the ground. As such, the mains are located well above the drawdown elevation of the Stockbridge Bowl at the proposed diversion pipe location (see Engineering drawings #1 and 2).

The location of the diversion pipe north of the existing channel will allow construction to proceed without interference to the outlet channel. It is recommended, but not essential, that the construction proceed during a normal drawdown phase of the lake. This will reduce the cost of coffer damming necessary to protect this outlet control structure.

The diversion pipe will be constructed of reinforced concrete pipe, and installed with a modest slope. This will insure that sedimentation will not occur within the pipe during the drawdown process. Any sedimentation which may take place will occur in the pool downstream of the diversion pipe outlet.

Old Dam Removal - The stone remains of the old dam still hinders the drawdown of the lake. It is proposed that the remains of the old dam, particularly its foundation, be removed utilizing conventional construction equipment. The rock approaches to the old dam from the west side appear adequate to handle typical construction equipment. The existing trees and brush located on this approach can be removed, allowing access for an excavator and trucks.

DONE

Since excavation will remove only the boulders which had formed the old dam and its base, it is not recommended that sediment control measures be taken during this process. The short time frame required to remove these boulders, coupled with the normally significant flow of water through the channel, does not warrant the expense associated with diversion, or bypass pumping needed to adequately contain the minor sediments to be stirred up by this process.

Construction of a Drawdown Channel - Lycott does not recommend dredging the drawdown channel until the diversion pipe and removal of the old dam have been completed for a period of approximately two years. This will give the existing channel located upstream of the old dam adequate time to deepen itself through the natural process of sediment compaction, and scour. If natural action does not produce sufficient depth for the desired drawdown of Stockbridge Bowl, then construction of a drawdown channel should proceed at that time.

④ Dredge channel to divert pipe if drawdown not work

It is proposed that the drawdown channel be constructed along the easterly portion of the existing drawdown channel from the site of the old dam approximately 2000' upstream toward the island. This channel should be constructed along the easterly and southerly side of the existing channel area. The construction must take place during the normal drawdown of Stockbridge Bowl.

The excavation would be proceeded by the construction of an access road on the surface of the existing old dam from the west and the installation of two 42" diameter reinforced concrete culverts at the site of the old dam. Next, a temporary coffer dam consisting of jersey barriers overlain by heavy plastic and sand bagged in place should be installed along the easterly side of the existing low level channel. This will allow water to be diverted through the existing channel during the construction of the drawdown channel.

As the coffer dam is being placed, a temporary road, consisting of gravel overlaying a geotextile fabric placed on the existing sediment, will run from the 42" culverts to the entrance of the drawdown channel. The excavation and hauling equipment will travel on this road as the channel is excavated. The excavation of the channel should proceed from the upstream end towards the downstream end. This will contain all sediment which will occur as a part of the excavation process within the coffer dam area. Once the channel has been excavated to the vicinity of the old dam, the coffer dam can be removed during a period of low flow utilizing the gravel road. After removing the coffer dam, the 42" diameter culverts will be removed and the gravel road abandoned.

The sediments of the outlet channel were samples through the ice on February 14, 1989. Two samples were analyzed, a sample from immediately above the dam and a composite sample of a mixture of three samples taken along the length of the channel. Both sediment samples were determined to be a type I sludge in accordance with section 32.12(a), 310 CMR. Results are presented in Table 28 below.

It is proposed that the site immediately downstream of the old dam and on the westerly side of the outlet channel be selected as the dewatering and disposal area for the excavated sediment. Once stabilized, spread, and seeded, no further monitoring of these sediments is required.

TABLE 28

Sediment Quality from Outlet Channel

Parameter	Dam Site Sediments mg/kg	Outlet Channel Sediments mg/kg	Dredge Criteria Cat. One mg/kg	Sludge Criteria Type I mg/kg
Percent Volatile Solids	5	3	--	--
Total Kjeldahl Nitrogen	500	380	--	--
Total Phosphorus	1270	1100	--	--
Iron	15400	14900	--	--
Manganese	320	490	--	--

Arsenic	18.1	7.1	<10	--
Chromium	5	5	<100	<1000
Copper	14	15	<200	<1000
Lead	23	7	<100	<300
Mercury	0.058	0.064	<0.5	<10
Zinc	420	650	<200	<2500
Cadmium	>0.5	>0.5	<5	<2

Wetland Protection - The wetland area located in the vicinity of Tributary #3 can be protected by the installation of a sand bag barrier located along the lake's edge (Engineering Drawing #3). The sand bags should be constructed of a biodegradable material, such as burlap, and filled with an organically rich clay based soil. The installation of the sand bag barrier should be left in place after the completion of drawdown and allowed to decompose. The presence of the organics within the soil will promote vegetative growth during the ensuing season. During a period of approximately two to three years, it should no longer be necessary to install a barrier since the previous years installation will have built a natural barrier, providing permanent protection to the wetland area.

COST ANALYSIS

A detailed breakdown of costs can be found in Appendix L. Total cost for implementing drawdown is a one-time cost of about $300,000. The cost estimate for dredging the outlet channel also represents a worst-case. Lycott recommends that natural processes be allowed to minimize the sediment in the channel before dredging. Once the pipe is laid under the gas line and the old dam is removed, the lake should be drawn down as much as possible for two years. The combination of aeration, compaction, and scouring should significantly reduce the amount of material that must be removed and, thus, the cost of removing it. Since dredging the outlet channel immediately could cost about $410,000, significant reductions in material dredged would produce significant reductions in the cost of dredging.

Lycott also recommends that the current harvesting program be performed on a contractual basis. Harvesting should be seen as a cost-effective form of nutrient management as well as short-term elimination of nuisance weed-growth. To implement this recommendation, the total cost would be $105,000.

To redress hypolimnetic oxygen depletion, Lycott recommends that hypolimnetic aeration be implemented. The cost for aeration device will total about $150,000 with an expected lifetime of about 10 years. Yearly operating and maintenance costs should be around $16,000.

IMPLEMENTATION OF ENGINEERING RECOMMENDATIONS

A timetable for implementation is presented in Table 29. The town of Stockbridge must implement all capital construction programs which have been recommended as a part of this study and which are planned to be funded by any governmental grant program. The authority for this action requires an approval vote by the Town meeting which then delegates administrative authority to the Board of Selectmen.

It is recommended that the Town proceed with the design for the repairs to the drawdown structure, drawdown diversion pipe, removal of the old dam, and installation of the Hypolimnetic Aeration system and its attendant compressor building.

The major projects listed above will be initiated by the selection of a consultant by the Board of selectmen after authorization and funding by the annual Town Meeting. It will be the responsibility of the consultant to develop the plans and specifications necessary to the development of the construction bidding process.

The Lake Association should establish a fund-raising mechanism to provide funding for the expanded weed harvesting program and for the operation and maintenance of the aeration system. Additionally, the Association can install the wetland protection barriers for the Tributary 3 area by manually constructing the system with volunteer labor.

TABLE 29

CAPITAL CONSTRUCTION PROGRAM ITEM	ESTIMATED TOTAL [illegible] YEAR QUARTER	[illegible]
[illegible] GATE		[illegible]
[illegible] DIVERSION PIPE		[illegible]
[illegible] DAM		[illegible]
EXCAVATE CHANNEL		[illegible]
[illegible] WETLANDS DAM		[illegible]
WETLANDS PROTECTION BARRIER		[illegible]
[illegible]		[illegible]
CAPITAL NON CONSTRUCTION PROGRAMS		
HYPOLIMNETIC AERATION		[illegible]
HIGH SPEED HARVESTING BARGE		[illegible]
PHASE II MONITORING PROGRAM		[illegible]

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SOURCES OF FUNDING

Funding for the implementation of the recommendations put forth in this section of the report can be pursued through the following agencies:

- Clean Lakes Program
- D.E.Q.E., Division of Water Pollution Control in Westborough. Phase II Funding
- Massachusetts Department of Environmental Management Rivers and Harbor Division
- Massachusetts Department of Environmental Management Heritage Park Restoration Program

Unfortunately, at this time there is a crisis regarding State and local government projects. Prospects for state funding through the Phase II Clean Lakes Program are pessimistic. At this date, the Clean Lake Program has received no funding for more projects for fiscal year 1991.

PREDICTED EFFECTS OF REMEDIATION

As noted in the section on phosphorus modeling, models can predict water-quality improvements expected to result from remediation. This section will try to predict the impacts of the proposed remediation on water quality of Stockbridge Bowl.

Lycott's recommendations focus on in-lake remediation, primarily hypolimnetic aeration. If the hypolimnion is continually aerated, the phosphorus models for oxic lakes become applicable to Stockbridge Bowl. Thus, phosphorus modeling suggests that aeration should cut the average phosphorus in Stockbridge Bowl by almost half. This would change Stockbridge Bowl from a moderately eutrophic lake to a mesotrophic one. Since the effects of internal loading are most apparent in late summer/early fall and early spring after ice-out, the phytoplankton blooms during these periods should be noticeable reduced.

If implemented, Lycott's recommendations should also substantially increase the phosphorus export from the lake. Currently, total outputs probably balance out inputs: long-term inputs total 818.5 in a normal year and flow out of the lake took an estimated 869.5 kg during the sampling period. Correctly timing drawdown could export an extra 320 kg of phosphorus from the lake, and a more intensive harvesting program should be able to export at least another 370 kg of phosphorus per year. Thus, implementation of Lycott's suggestions should increase total phosphorus export from the lake to about 180% of the total external loading, exporting a net 750 kg of phosphorus per year from the lake.

This enhanced export should not be seen as a method of lake rehabilitation. Given the large stores of phosphorus in the sediments of the littoral zone, it would take many decades before excess export had any noticeable effect on water quality or macrophyte growth. However, excess export can be seen as cost-effective form of nutrient control that can prevent in-lake nutrient concentrations from increasing.

Lycott's other recommendations concern control of macrophyte biomass. The predicted results of these recommendations need no elaboration.

IMPACTS ON FISH AND WILDLIFE

No adverse effects are likely to occur to fish or wildlife due to Lycott' recommendations. Drawdown should increase the habitat diversity and increase the shallow spawning habitat. Increased harvesting will also increase the small fish that caught in the weeds and removed. However, small fish have a very low survival rate anyway, so additional mortality is unlikely to have any noticeable impact on fish stocks. Furthermore, no matter how intensive the harvesting, some weed beds will still remain to provide shelter for small fish and other prey organisms.

Aeration should have direct benefits on the fish, especially the trout and other cold-water species. Aeration should substantially increase the carrying capacity and summer survival of trout in the Bowl. No other fish or wildlife are likely to be significantly impacted by any of Lycott's suggestions.

The lake now provides good habitat for warm-water fish. Drawing the lake down 6 feet should have a positive or negligible effect on fish growth. Drawdown should add to the diversity of the near shore habitat in terms of macrophyte species and macrophyte density. Fish production peaks at moderate macrophyte densities (Cooper and Crowder 1982), and drawdown should moderate densities of macrophytes at Stockbridge Bowl. In addition, relatively bare areas in the near shore areas are used by some fish for spawning. Drawdown should increase this nesting area for these species of fish. According to our conversations with Mass. Department of Fish and Wildlife, they would support a drawdown of Stockbridge Bowl.

IMPACTS OF DRAWDOWN

Because wetlands at the mouth of Lily Brook and at the mouth of Tributary #3 (the inlet north of Kripalu Beach) are contiguous to the lake, drawdown could possibly affect these wetlands. However, Lycott's recommendations will prevent impacts to these wetlands.

The causeway located at the mouth of Lily Brook currently limits dewatering of the Lily Brook wetland to 36". However, the presence of sediment in the causeway further limits the impact to approximately 24". Furthermore, drawdown will occur in mid-winter when wetland plants are dormant, so any small changes in water level would have no impact.

A semipermanent dam should be constructed at the mouth of tributary #3. During drawdown, this dam will maintain water levels in the wetland at the current winter water level, so no appreciable alteration in water levels will occur during drawdown. Thus, no impacts to this wetland are anticipated. Furthermore, as mentioned above, drawdown will occur in mid-winter when wetland plants are dormant, so any small changes in water level would have no impact.

PHASE II MONITORING PROGRAM

Lycott's major remedial program involve hypolimnetic aeration, drawdown, and a more intensive harvesting program. Monitoring the success of these ventures is straightforward. Macrophyte densities should be mapped twice per year for the year preceding drawdown, and for three years after drawdown has been started. Both densities (% cover) and species composition should be mapped during June and August of each year. The goal of the macrophyte survey would be to assess the effectiveness of drawdown, so special effort should be geared to measuring the impact in the area immediately inside and outside the drawdown area. Each survey should cost about $700 -- including field time, data interpretation, and data reporting. The three surveys should total about $2100.

With respect to harvesting, effectiveness should be monitored in terms of user-satisfaction and total tonnage and total phosphorus exported from the lake. Total tonnage and phosphorus export may vary somewhat from year to year depending on the growth of the weeds. User satisfaction could be measured with an informal survey conducted by the Stockbridge Bowl Association. The total weight of weeds harvested should be maintained as public information by the harvesting program.

Monitoring the success of hypolimnetic aeration can be performed with monthly samples of the water column at the top and bottom of the deep-hole during the entire year. Oxygen and temperature reading should be taken at each meter interval and water samples from the top and bottom of the deep hole should be sampled for the nitrogen series (ammonia, nitrate, and total Kjeldahl Nitrogen) and phosphorus. Chlorophyll and phytoplankton should be depth integrated samples taken from the epilimnion and taken from the metalimnion. (If the metalimnion is 2 to 3 meters wide, the metalimnetic sample should also be depth integrated.)

These samples should be taken for each of three years after implementation. Total costs for each sample should be about $650 including sampling, analysis, interpretation and reporting. Samples would be taken once per month during June, July, August, and September and once each during February and March. Samples would for three years after implementation for a total of 18 samples. Thus, the total sampling budget should be about $11,700.

Total costs of Phase II sampling are $13,800 (11,700 + $2100).

PUBLIC PARTICIPATION

A public informational meeting was held on June 4, 1988, at the Stockbridge Town Hall. The meeting was organized by members the Clean Lakes Committee, R.J. McDonald and Henry Williams; Lycott's President, Lee Lyman; the Project Manager, Dr. Alex Duran; and the Project Engineer, Hamer Clarke, P.E. A total of 16 members of the Stockbridge Bowl Association attended the meeting. Lycott personnel presented the scope of work and reviewed preliminary options available for lake restoration including: drawdown, hypolimnetic withdrawal, hypolimnetic aeration, sewer extension, and short-term mechanical/chemical weed control. Two individuals, Mr. Don Deno and Mr. Robert Oppenheim, volunteered to assist Lycott with the collection of storm samples. Mr. Ed Darrin volunteered to collect weekly secchi disk readings at the deep hole and near Lily Brook.

Periodically throughout the contract period, Lycott personnel also met with the technical advisory committee to discuss the status of the project.

NECESSARY PERMITS AND LICENSES

The remediation plan proposed above has many elements; therefore, many state and local agencies will have to be notified or asked for review and approval of the proposed remediation. The following are the agencies that must be contacted:

TABLE 30

REQUIRED PERMITS AND APPROVALS

Requirements	Agency/Contact
Approval needed from: Mass. Commission Against Discrimination	Donald Ng Commission Against Discrimination 1 Ashburton Place Boston, MA 02108 (617) 727-7309
Approval needed from: Executive Order 215 Fair Housing Order)	Executive Office of Communities & Development 100 Cambridge Street, Rm 1404 Boston, MA 02202 (617) 727-7130
Approval needed from: Historical Commission	Historical Commission 294 Washington Street Boston, MA 02108 (617) 727-8470
Certification of Title to Project Site	DEQE, DWPC Westview Building Lyman School Grounds Westborough, MA 01581 (617) 366-9181
Notification of: Division of Fisheries and Wildlife	Field Headquarters Westborough, MA 01581 (508) 366-4470
Notice of Intent	Stockbridge Conservation Commission Town Hall, West Main Street Stockbridge, MA 01262
Review by: Natural Heritage Program	Natural Heritage Program 100 Cambridge Street Boston, MA 02202 (617) 727-9194
Review by: Mass. Environmental Policy Act	Executive Office of Environmental Affairs MEPA Unit 100 Cambridge Street, 20th Floor (617) 727-5830
License needed from: Chapter 91 Waterways License	Division of Waterways/Wetlands DEQE 1 Winter Street Boston, MA 02108 (617) 292-5517

Water Quality Certificate	Permits Section DWPC 1 Winter Street Boston, MA 02108 (617) 292-5673
Permit to dispose of dredge spoils on land needed from DEQE	DEQE 5 Commonwealth Avenue Woburn, MA 01801 (617) 935-2160
Permit to Apply Chemicals needed from DWPC	Gary Gonyea Mass Division of Water Pollution Control Lakes Section Lyman School, Westview Building Westborough, MA 01581 (617) 366-9181

HISTORICAL COMMISSIONS

The draft final report was sent to local and state Historical Commissions. Comments received by Lycott are presented in Appendix M.

APPENDIX A

LYCOTT

Final Report
Diagnostic/Feasibility Study
Stockbridge Bowl
Stockbridge, Massachusetts

LYCOTT ENVIRONMENTAL RESEARCH, INC.

600 CHARLTON STREET • SOUTHBRIDGE • MASSACHUSETTS 01550

LIST OF APPENDICES

APPENDIX A

List of Figures

APPENDIX A cont'd.

List of Figures

APPENDIX B

Boring Logs

APPENDIX C

Hydrologic Budget Calculations

APPENDIX D

Temperature, Dissolved Oxygen, and Relative Thermal Resistance (RTR)

APPENDIX E

Water Quality Data: Tributaries and In-lake Sampling

APPENDIX F

Water Quality Data: Groundwater Sampling

LIST OF APPENDICES cont'd.

LIST OF DRAWINGS

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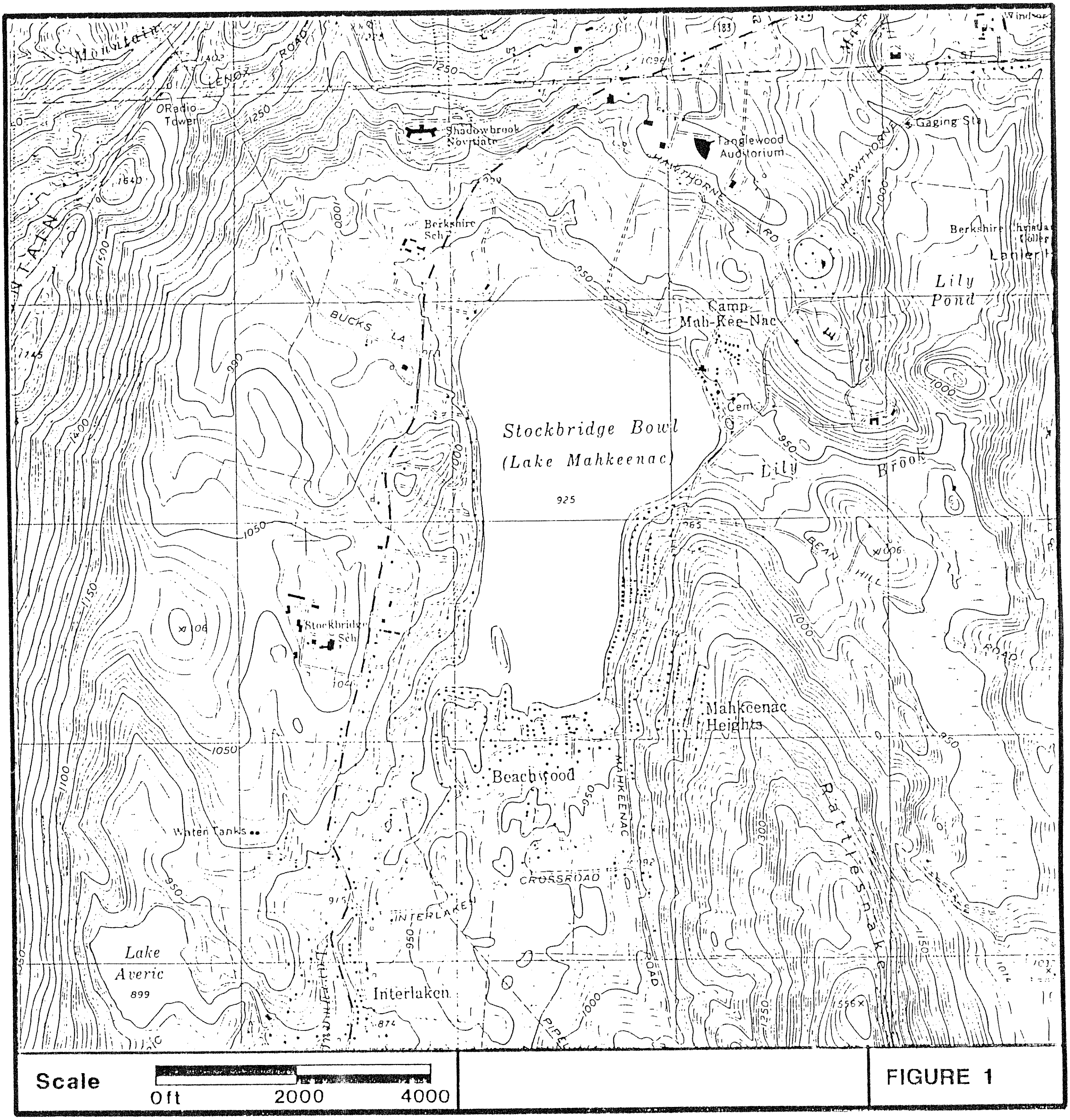

FIGURE 1

SITE LOCATION MAP

Stockbridge Bowl
Stockbridge, Massachusetts

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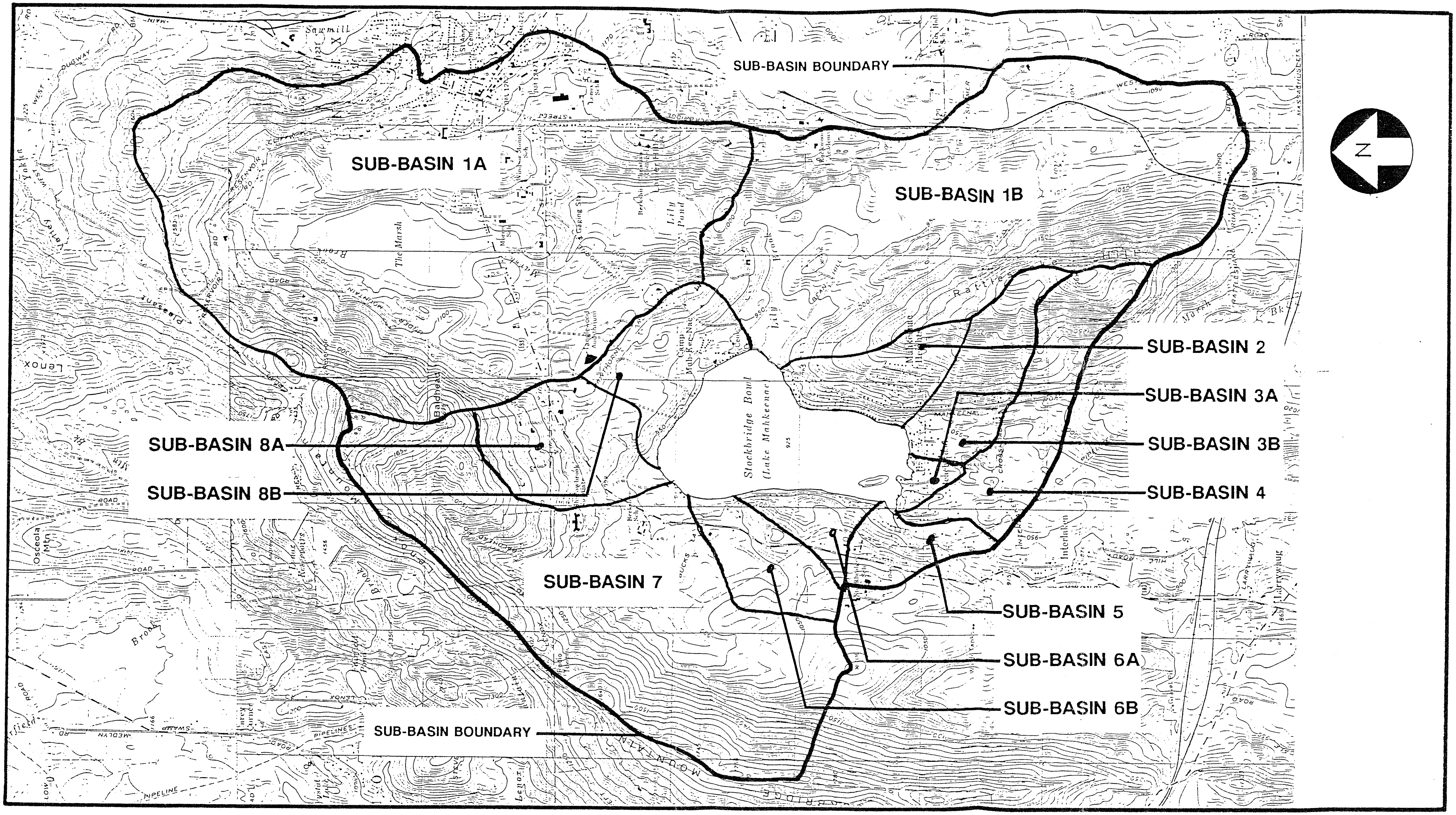

WATERSHED SUB-BASINS

Stockbridge Bowl
Stockbridge, Massachusetts

Scale
0ft. 1800 3600

FIGURE 2

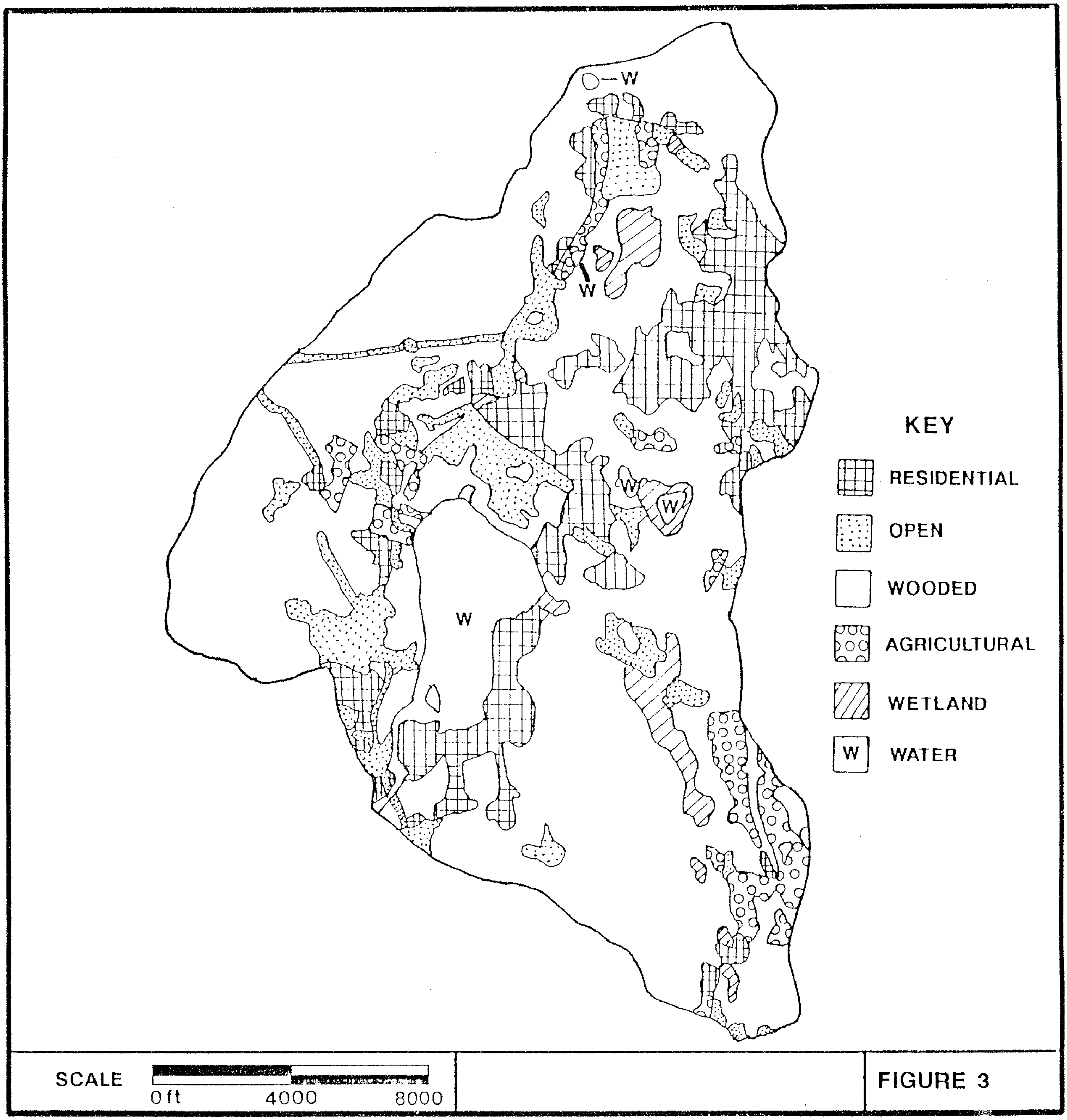

FIGURE 3

LAND USE MAP

Stockbridge Bowl
Stockbridge, Massachusetts

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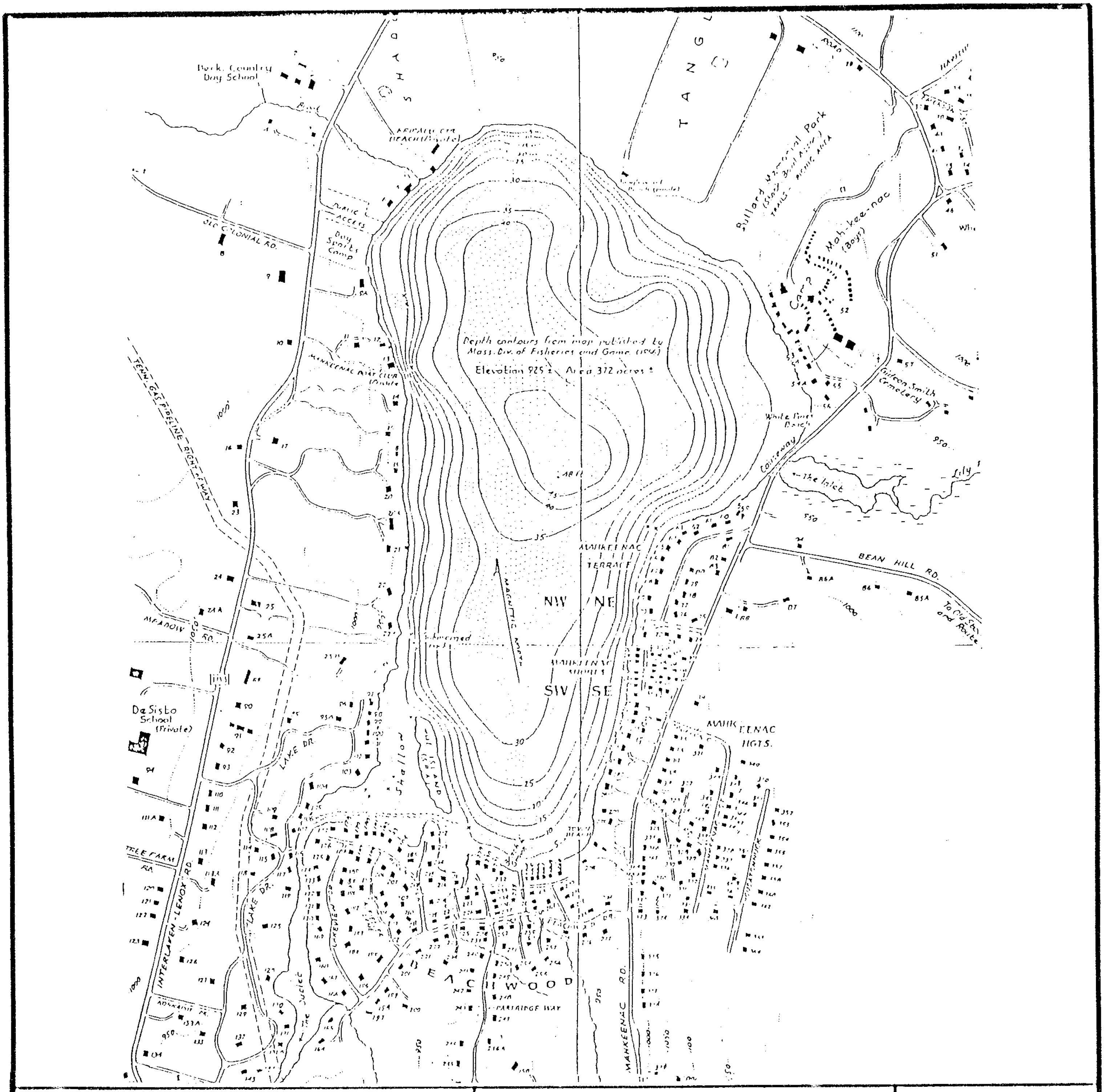

Scale 0 ft. 900 1800

FIGURE 4

DETAIL OF SHORELINE DEVELOPMENT

Stockbridge Bowl

Stockbridge, Massachusetts

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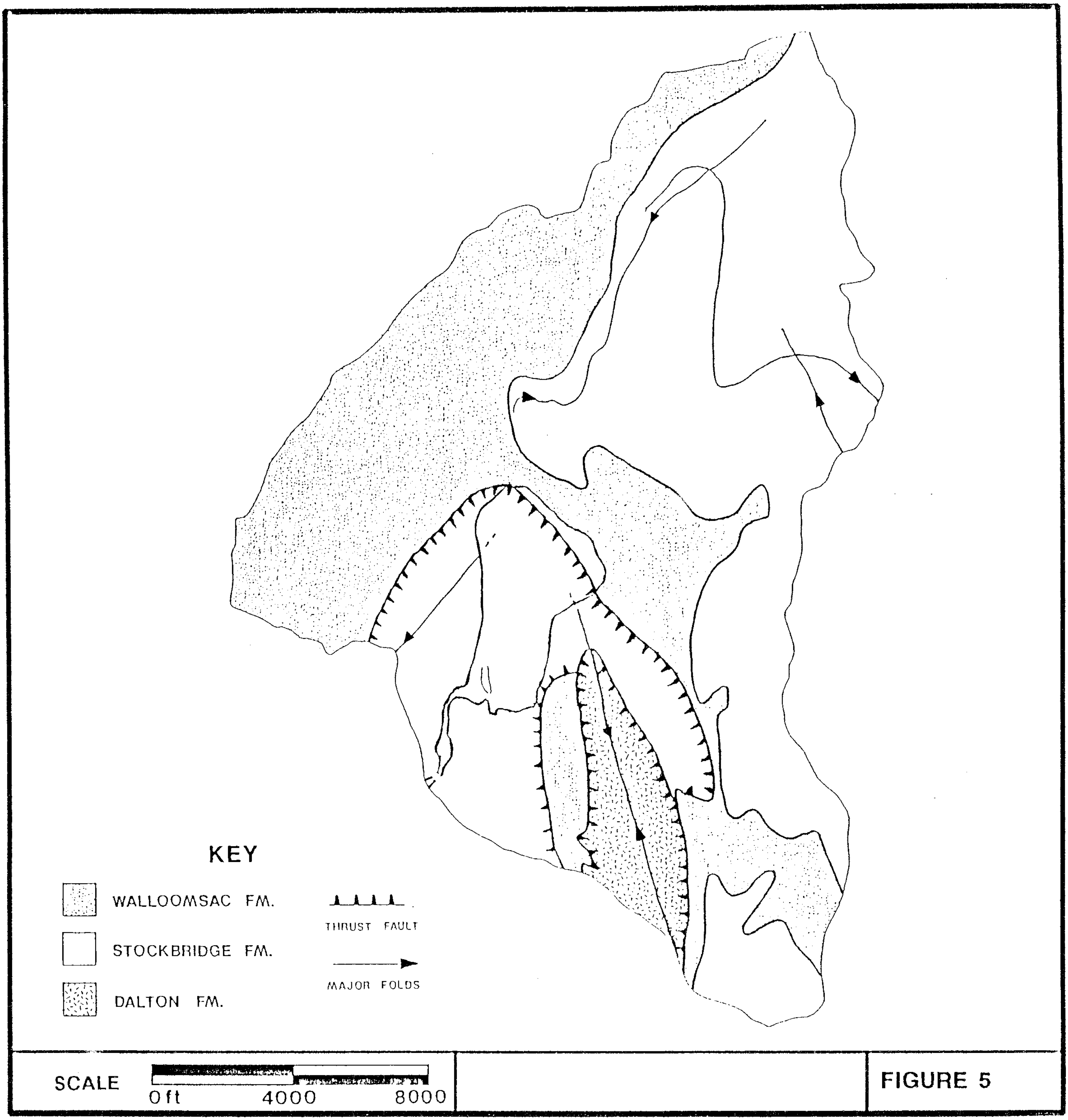

FIGURE 5

BEDROCK GEOLOGY

Stockbridge Bowl
Stockbridge, Massachusetts

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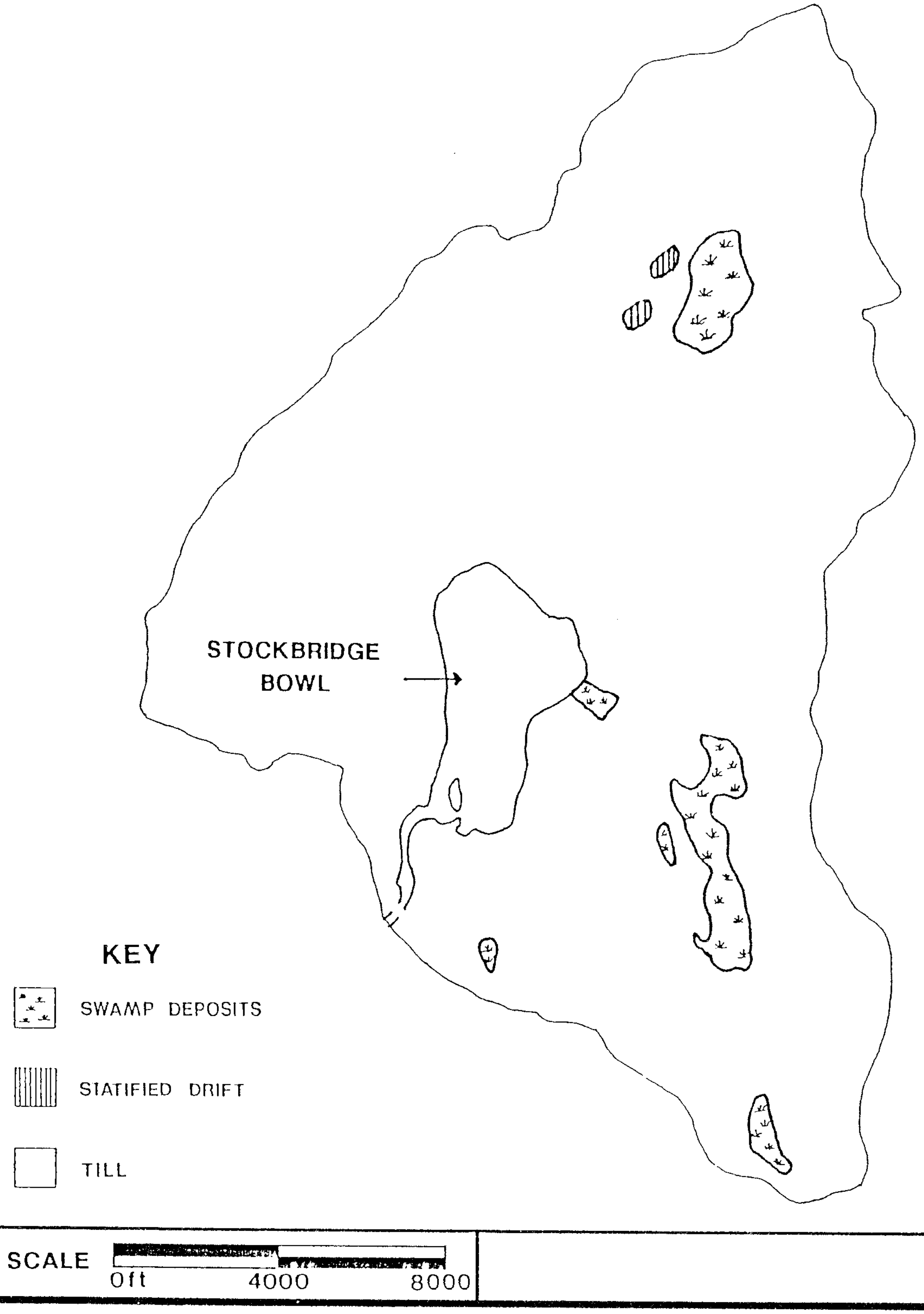

FIGURE 6

SURFICIAL GEOLOGY

Stockbridge Bowl
Stockbridge, Massachusetts

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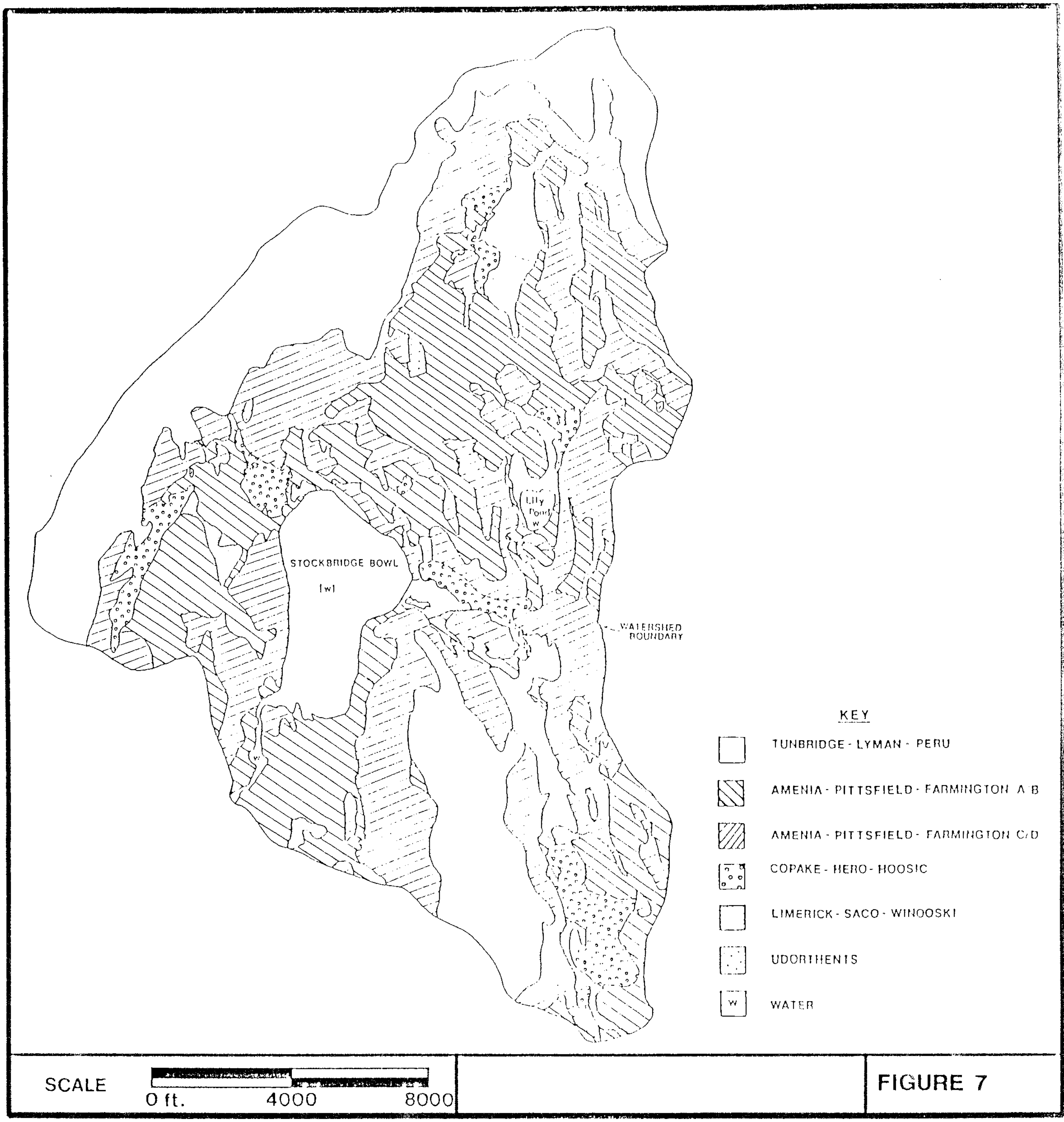

FIGURE 7

WATERSHED SOILS MAP

Stockbridge Bowl

Stockbridge, Massachusetts

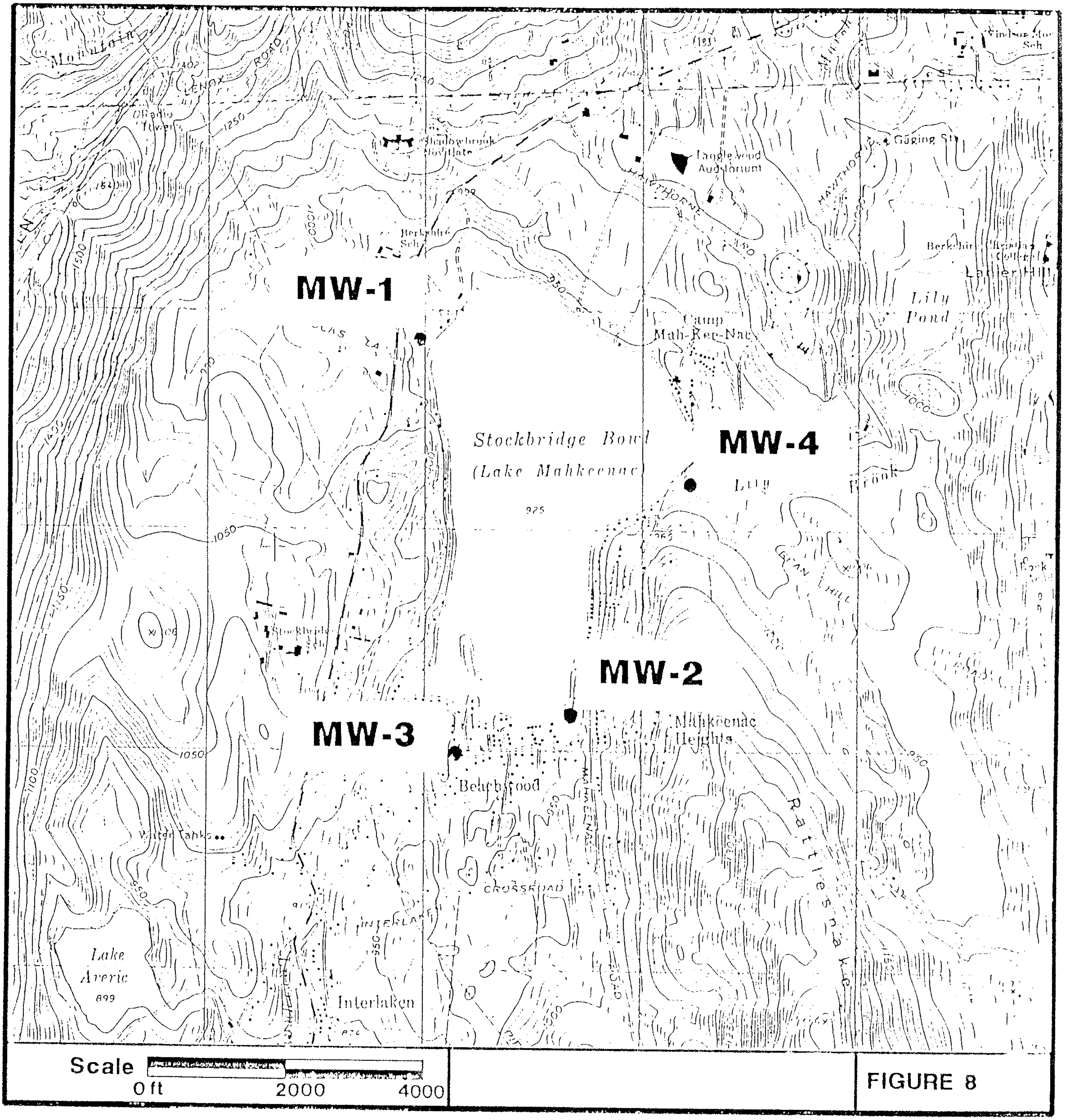

FIGURE 8

MONITORING WELL LOCATION

Stockbridge Bowl
Stockbridge, Massachusetts

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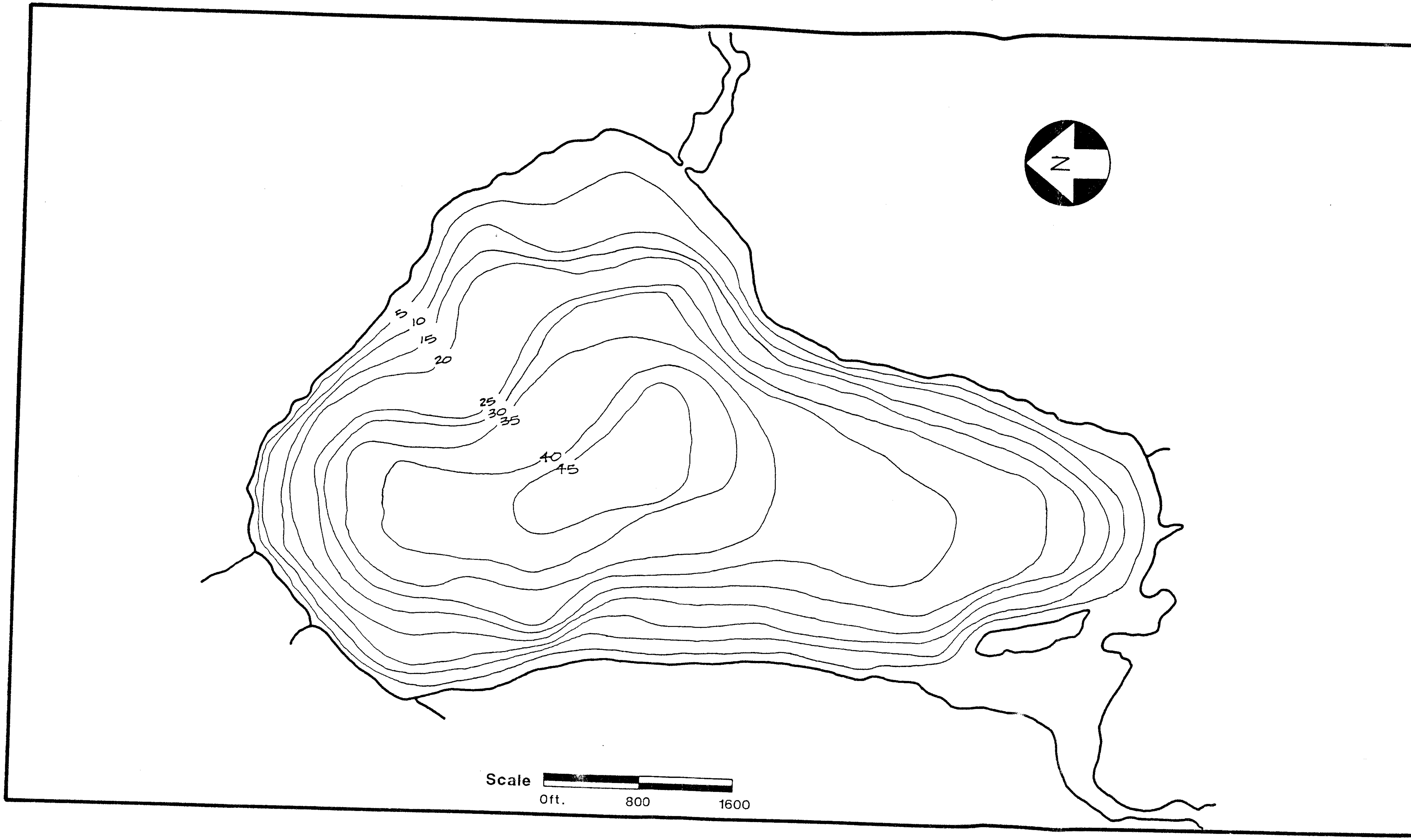

BATHYMETRIC PROFILE

Stockbridge Bowl
Stockbridge, Massachusetts

FIGURE 9

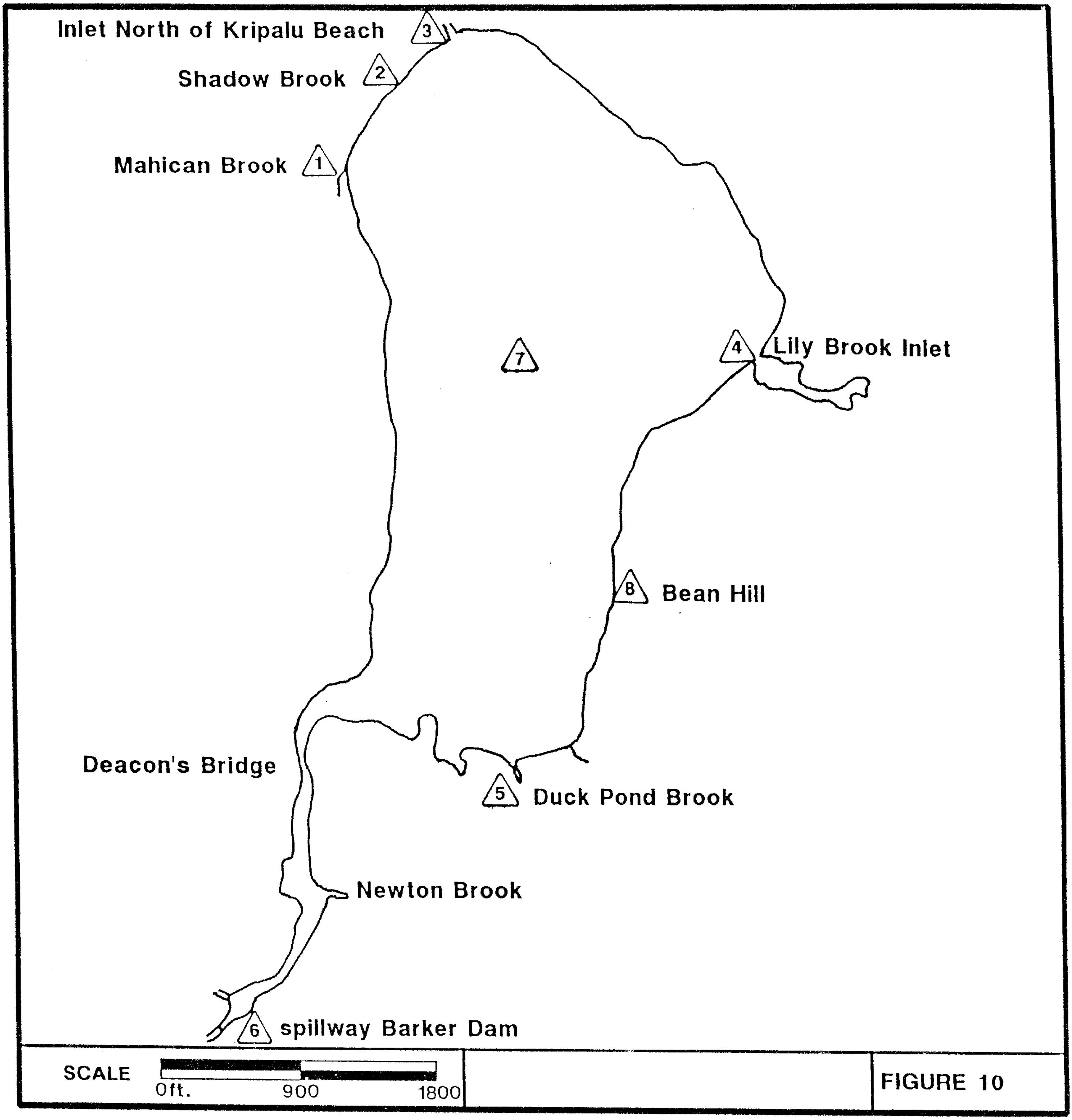

FIGURE 10

SAMPLING STATION LOCATIONS

Stockbridge Bowl
Stockbridge, Massachusetts

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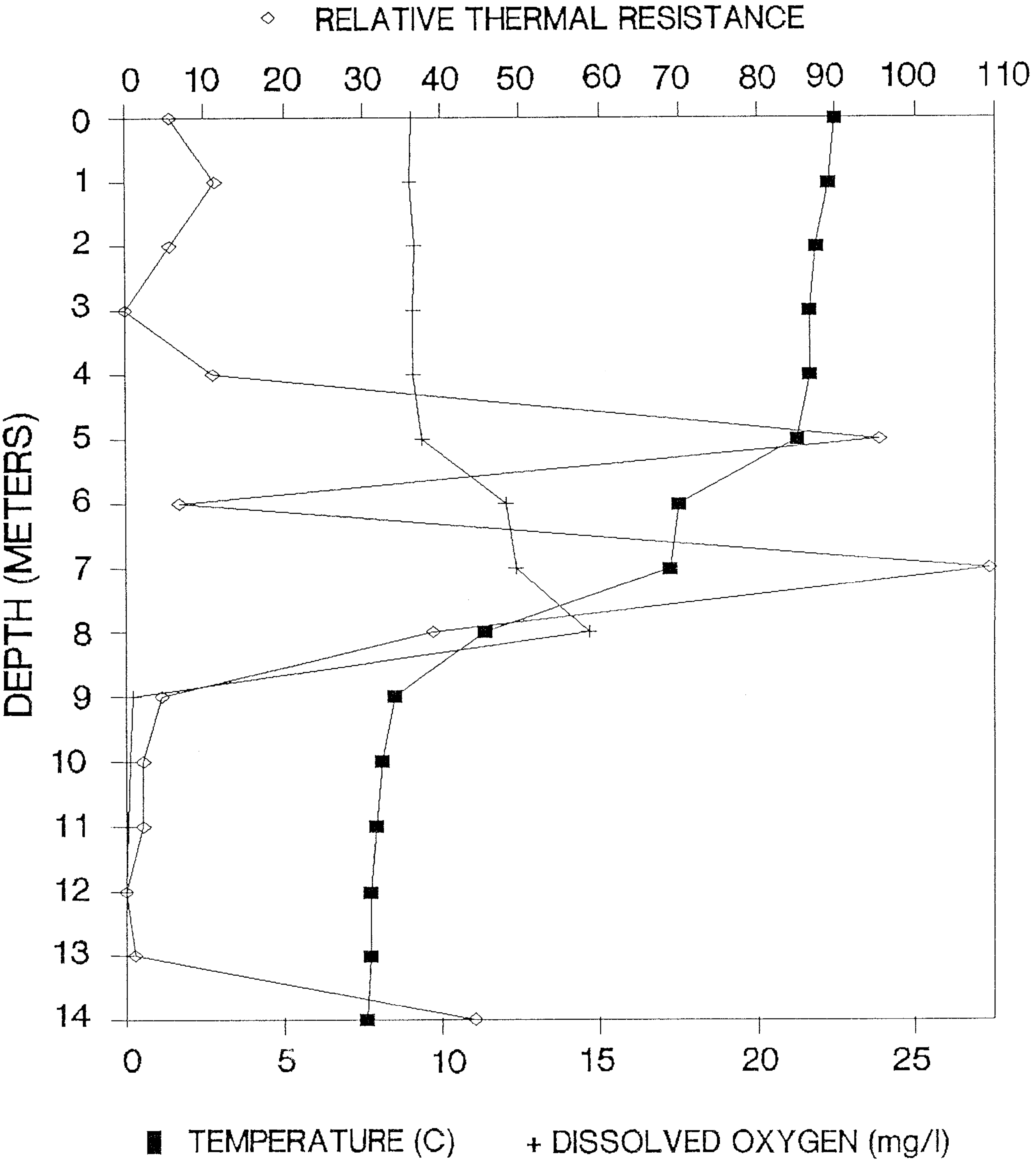
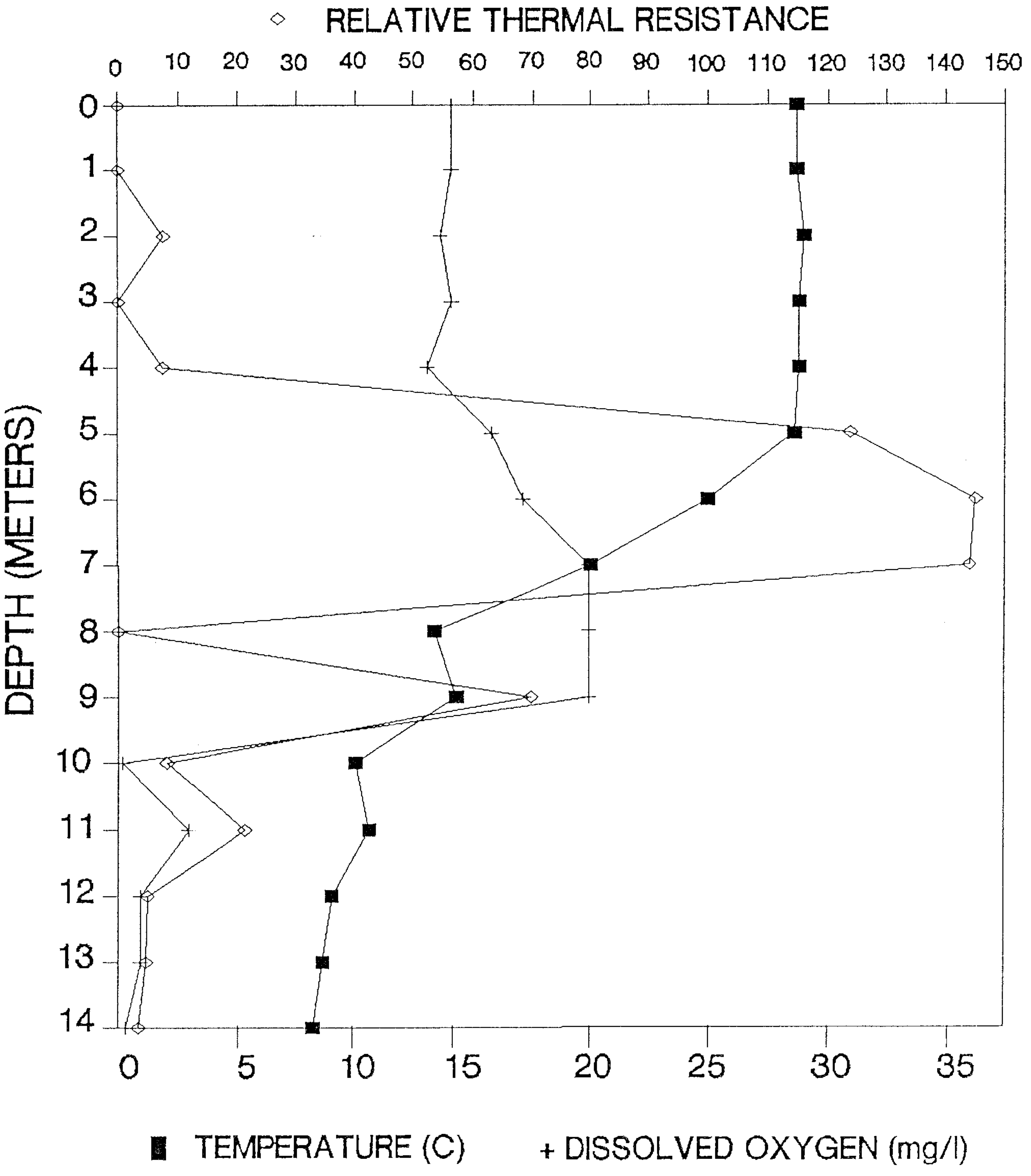
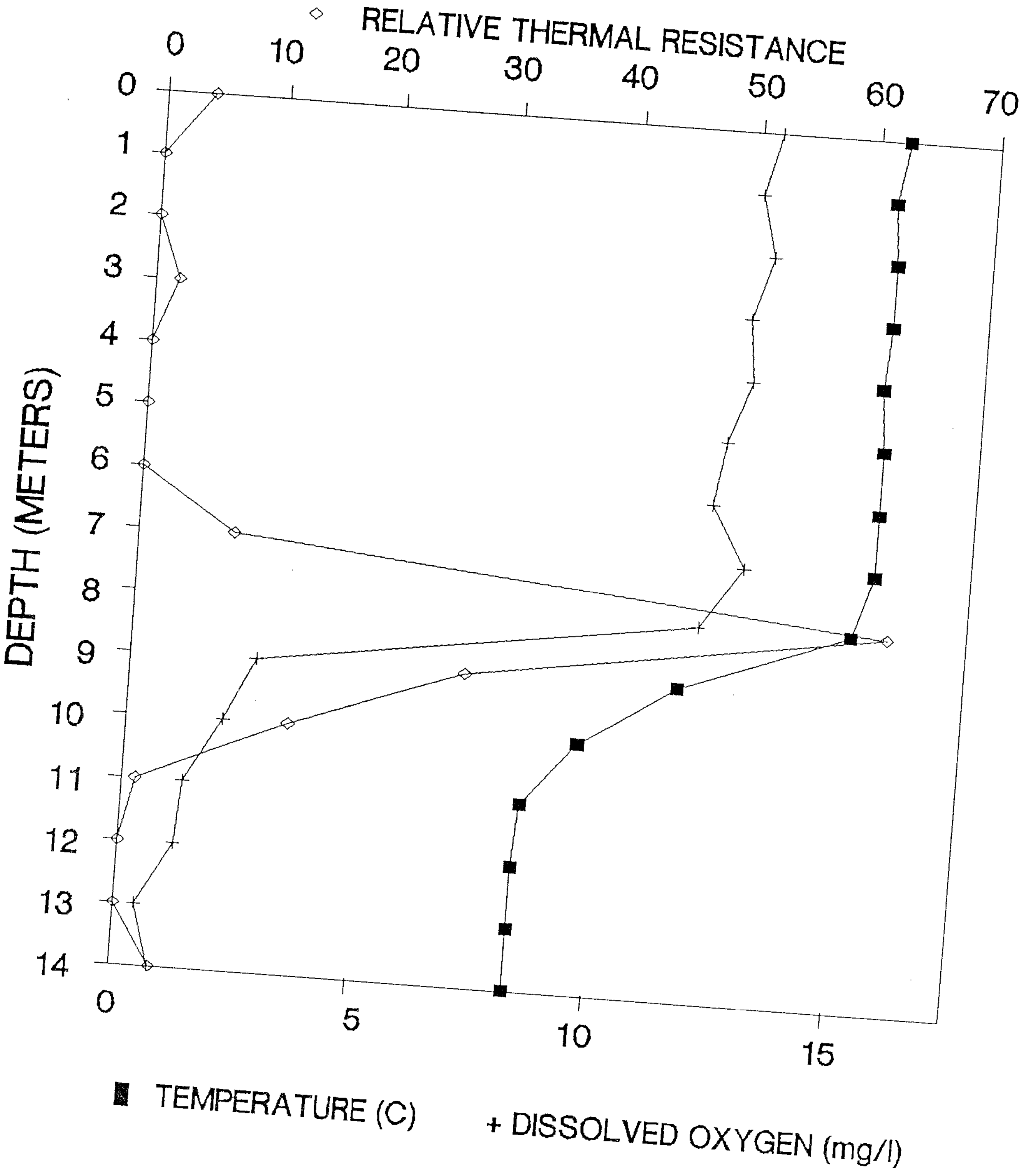
TEMPERATURE, DISSOLVED OXYGEN, AND RTR VS . DEPTH
STOCKBRIDGE BOWL
STOCKBRIDGE, MASSACHUSETTS
JUNE 28, 1988



TEMPERATURE, DISSOLVED OXYGEN, AND RTR VS. DEPTH
STOCKBRIDGE BOWL
STOCKBRIDGE, MASSACHUSETTS
AUGUST 15, 1988

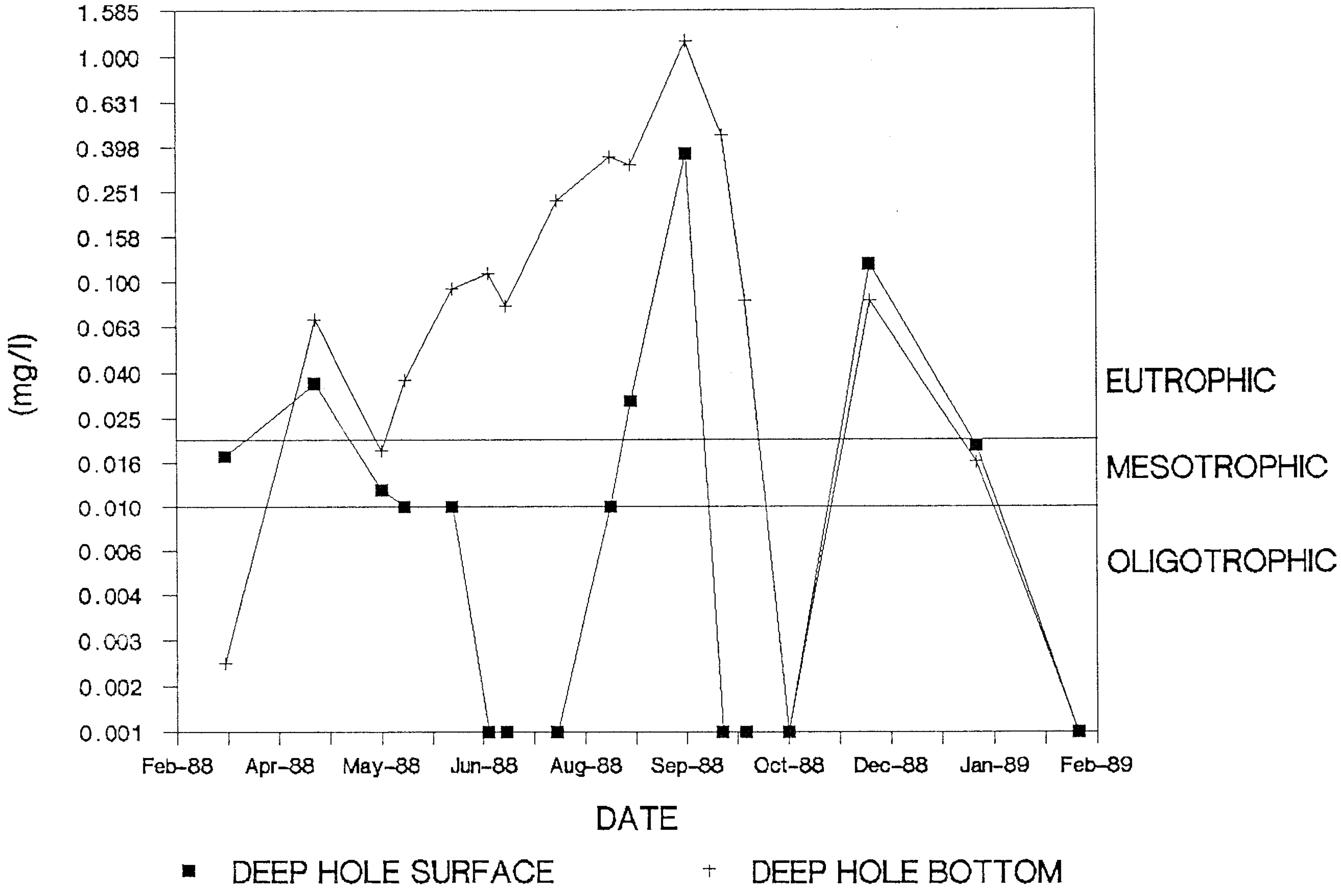


TEMPERATURE, DISSOLVED OXYGEN, AND RTR VS . DEPTH
STOCKBRIDGE BOWL
STOCKBRIDGE, MASSACHUSETTS
OCTOBER 8, 1988



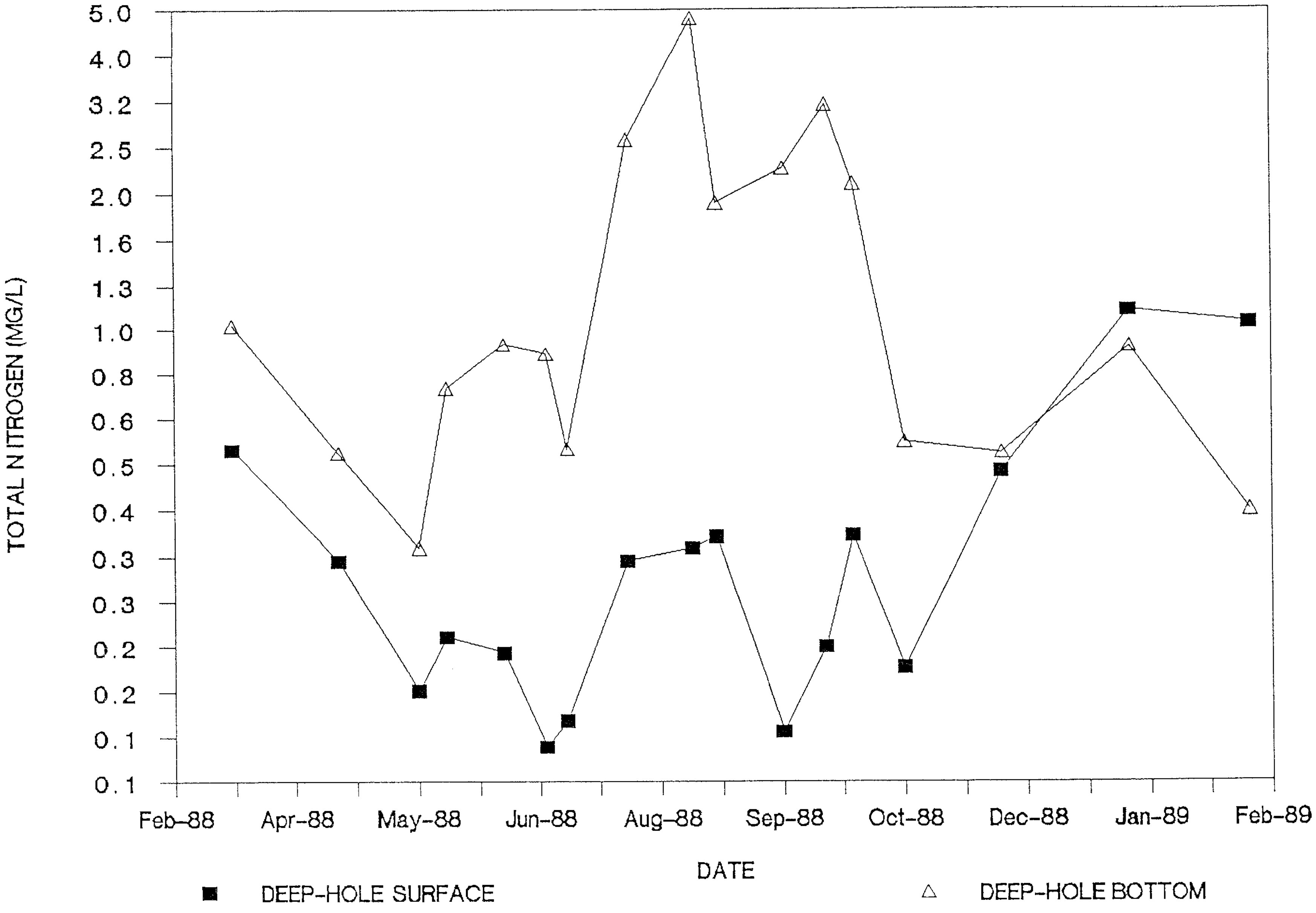
TOTAL PHOSPHORUS VS. TIME

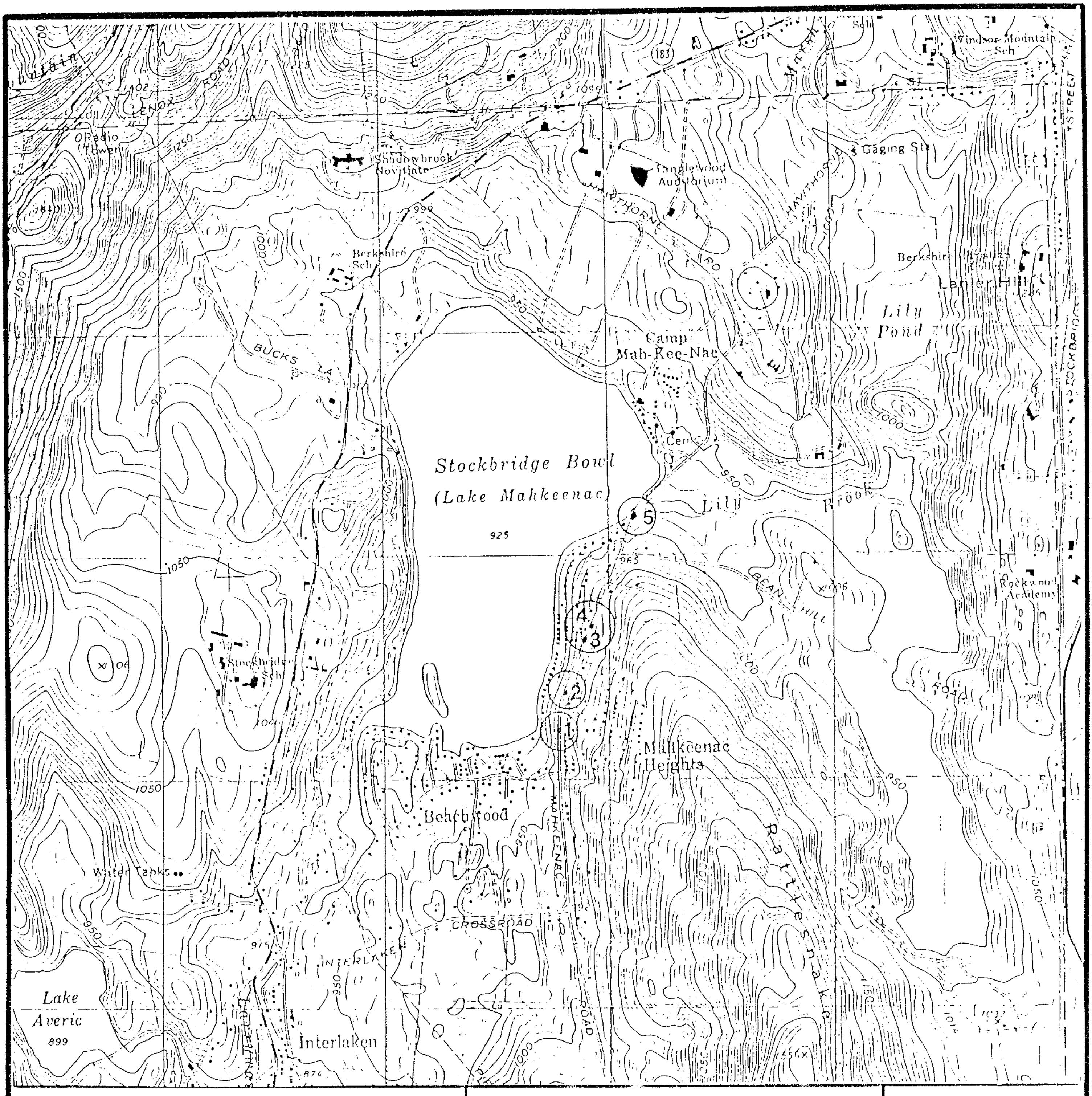
STOCKBRIDGE BOWL



TOTAL NITROGEN VS. TIME

STOCKBRIDGE BOWL





SCALE 0ft 2000 4000

FIGURE 14

STORM DRAIN LOCATIONS

Stockbridge Bowl
Stockbridge, Massachusetts

LYCOTT

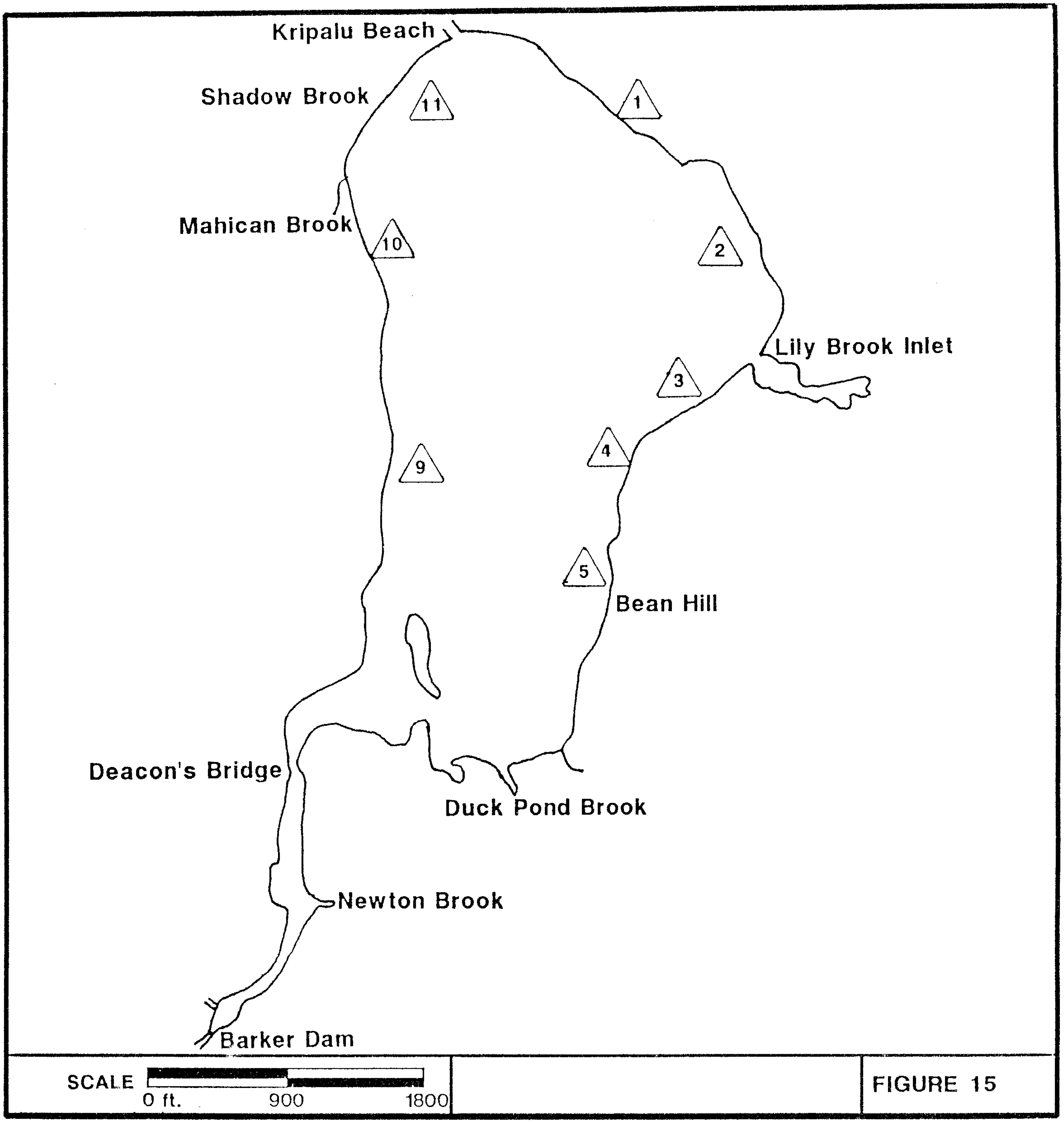
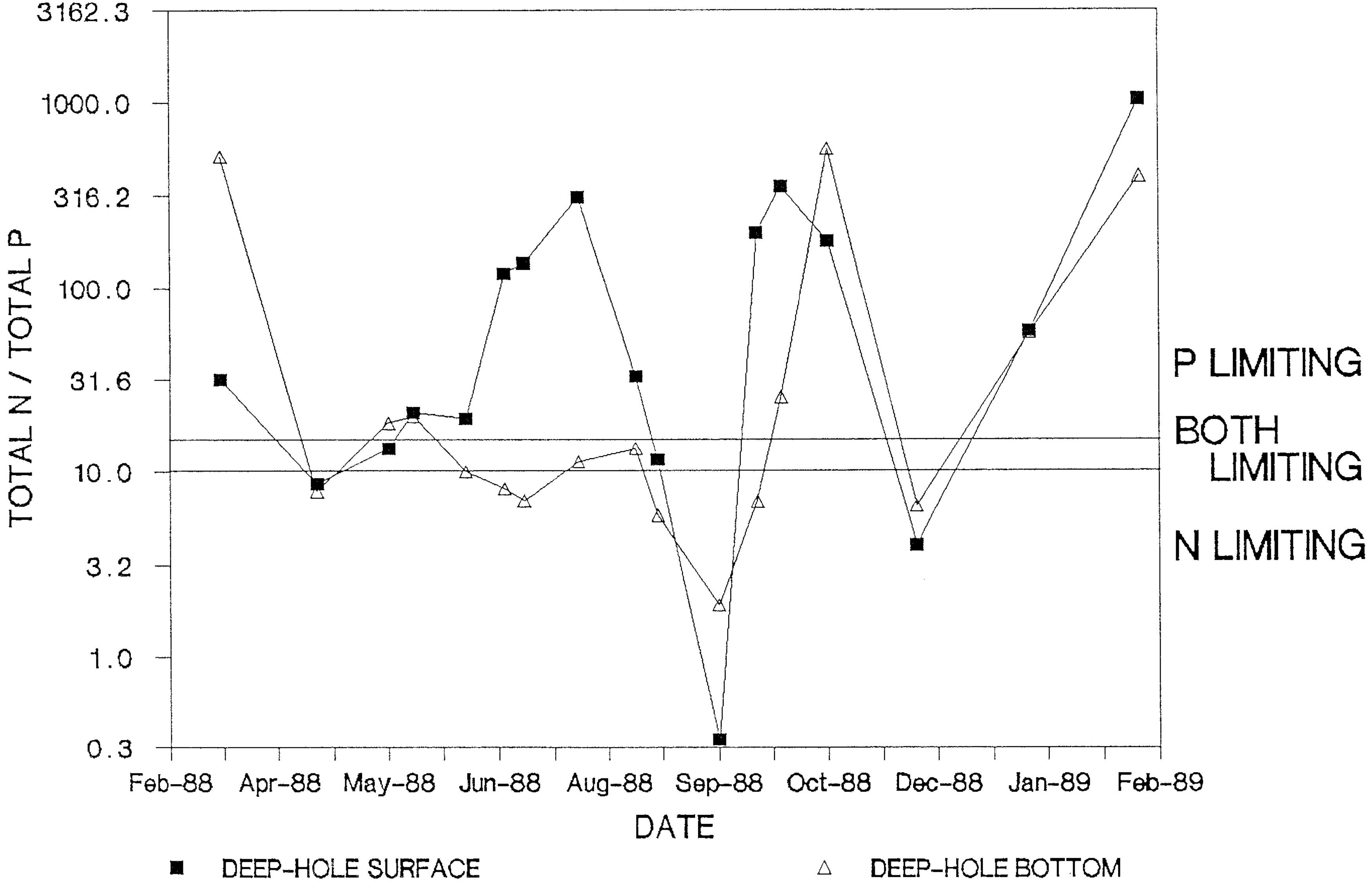


FIGURE 15

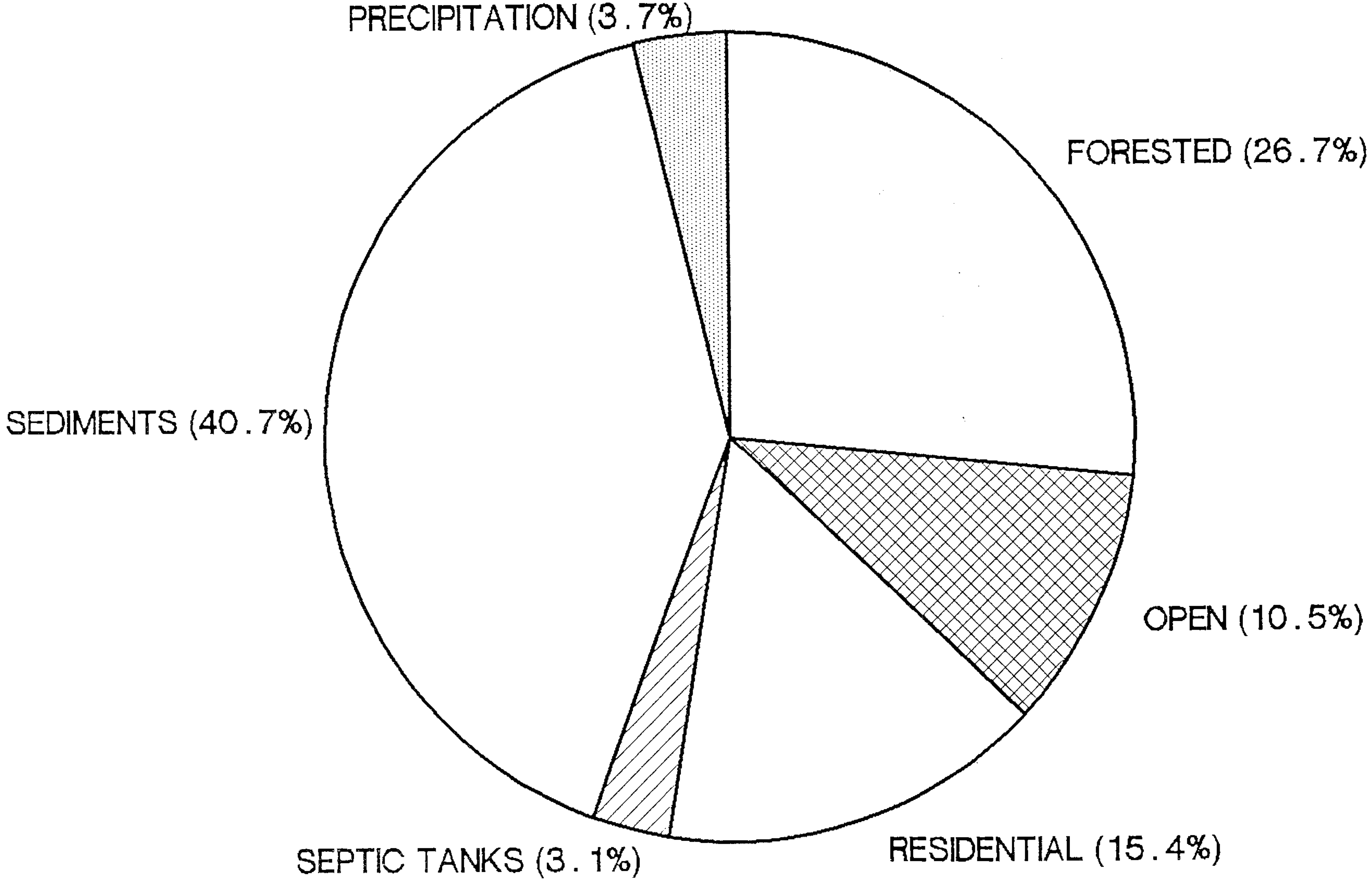
LEACHATE SAMPLING LOCATIONS

Stockbridge Bowl
Stockbridge, Massachusetts

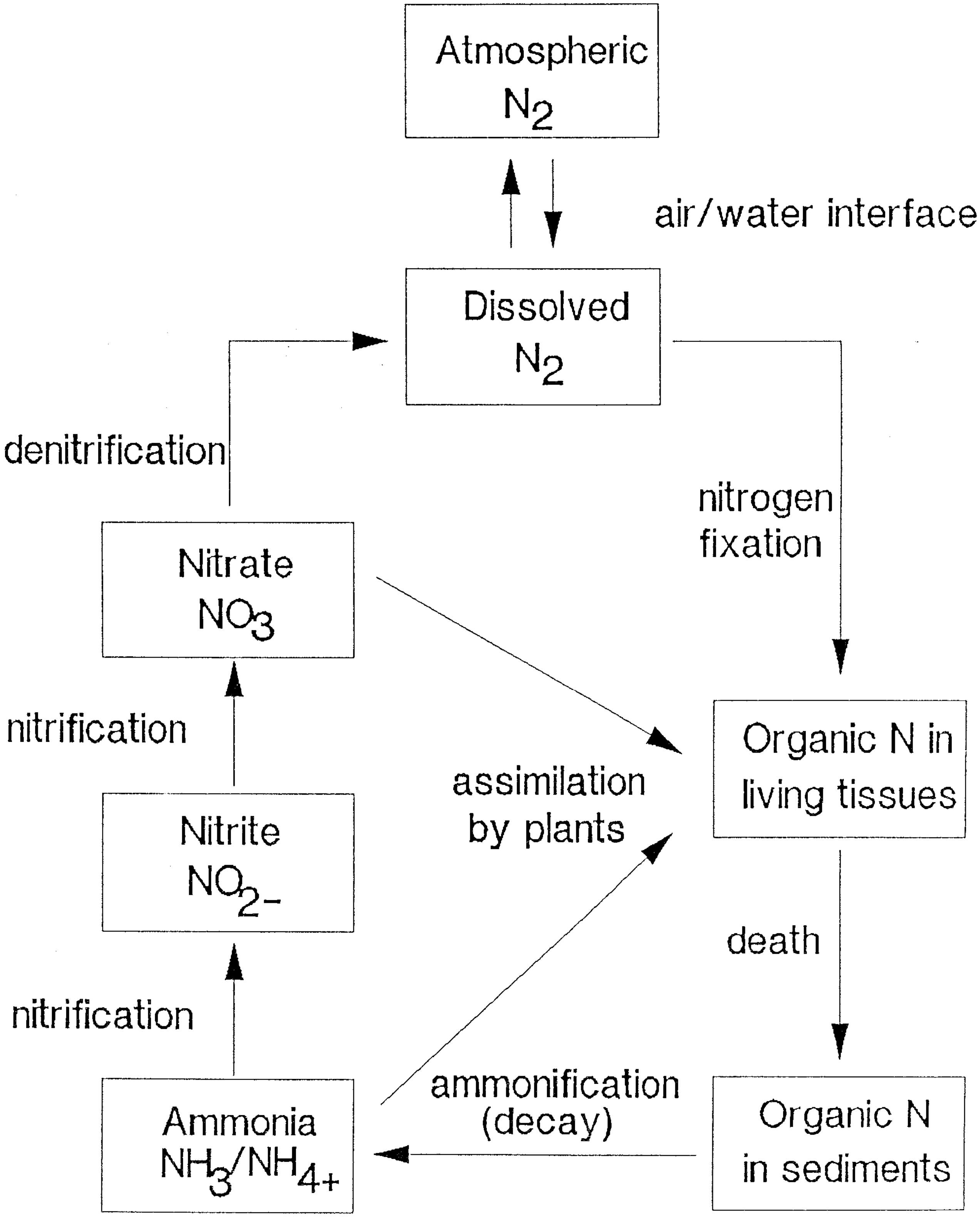
TOTAL NITROGEN / TOTAL PHOSPHORUS
STOCKBRIDGE BOWL

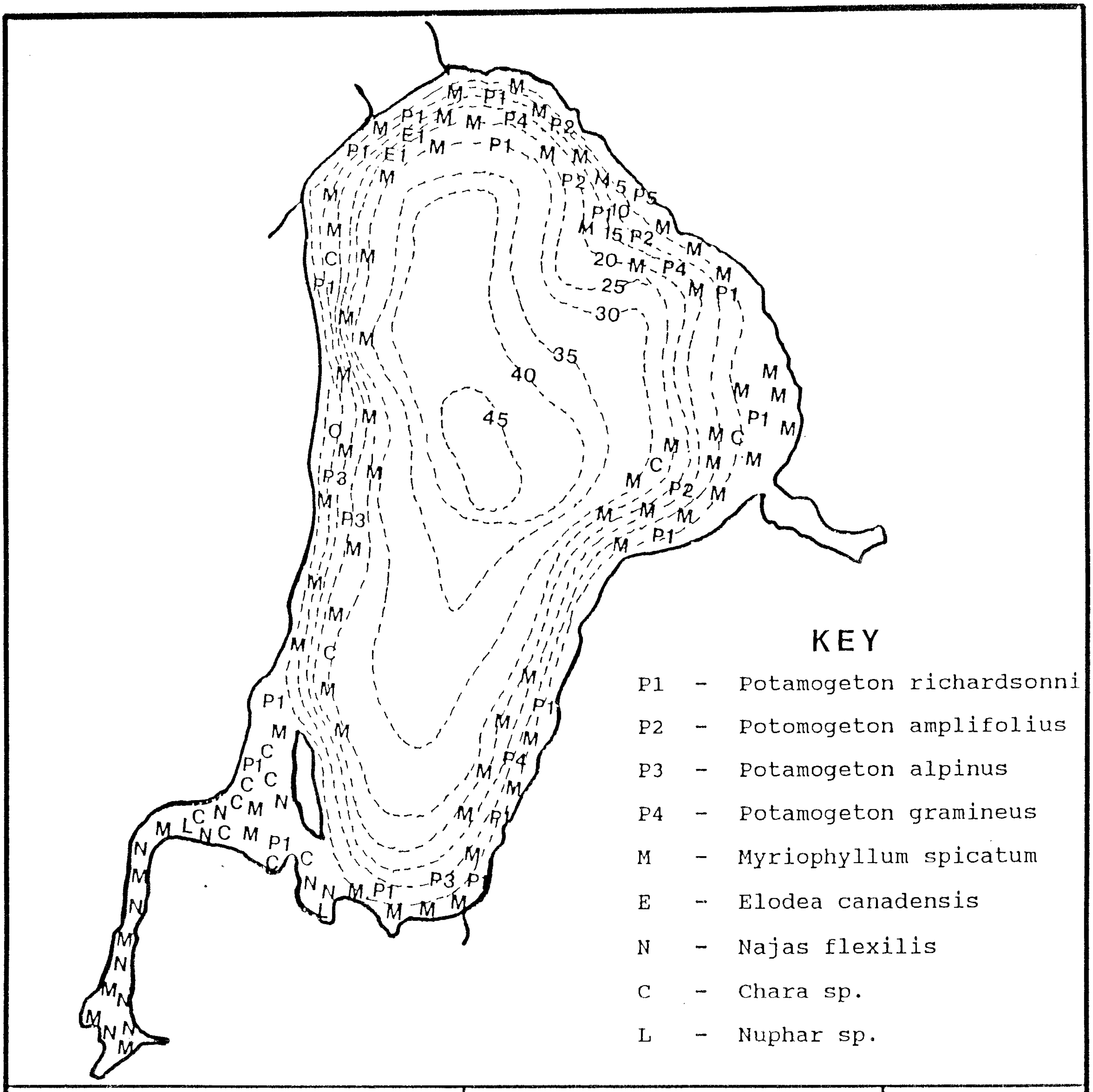


SOURCES OF PHOSPHORUS
STOCKBRIDGE BOWL



The Aquatic Nitrogen Cycle





KEY

P1	-	Potamogeton richardsonni
P2	-	Potomogeton amplifolius
P3	-	Potamogeton alpinus
P4	-	Potamogeton gramineus
M	-	Myriophyllum spicatum
E	-	Elodea canadensis
N	-	Najas flexilis
C	-	Chara sp.
L	-	Nuphar sp.

Scale 0ft 1100 2200

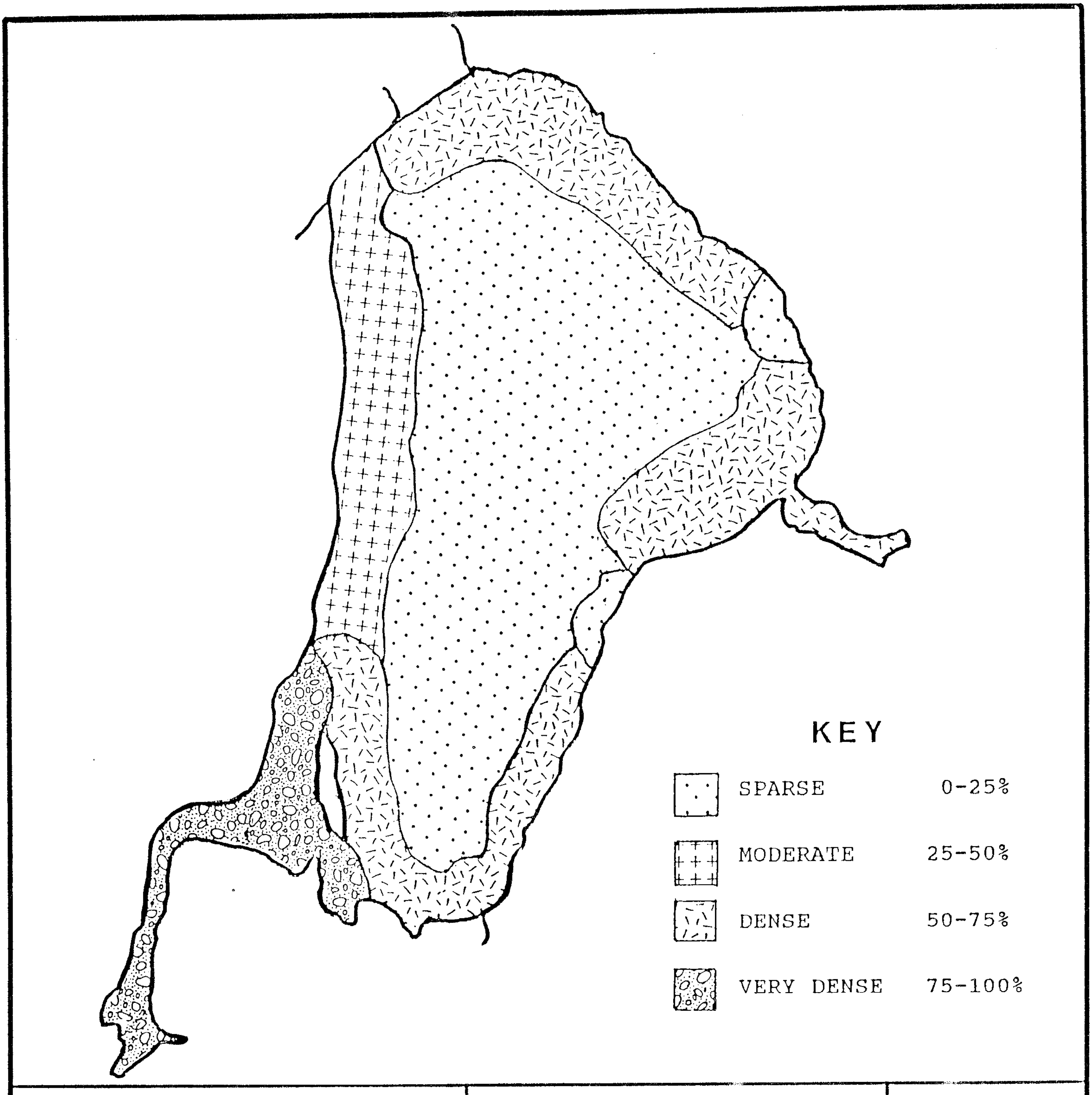
AUGUST 12, 1988

FIGURE 19

N

AQUATIC MACROPHYTE SURVEY

Stockbridge Bowl
Stockbridge, Massachusetts



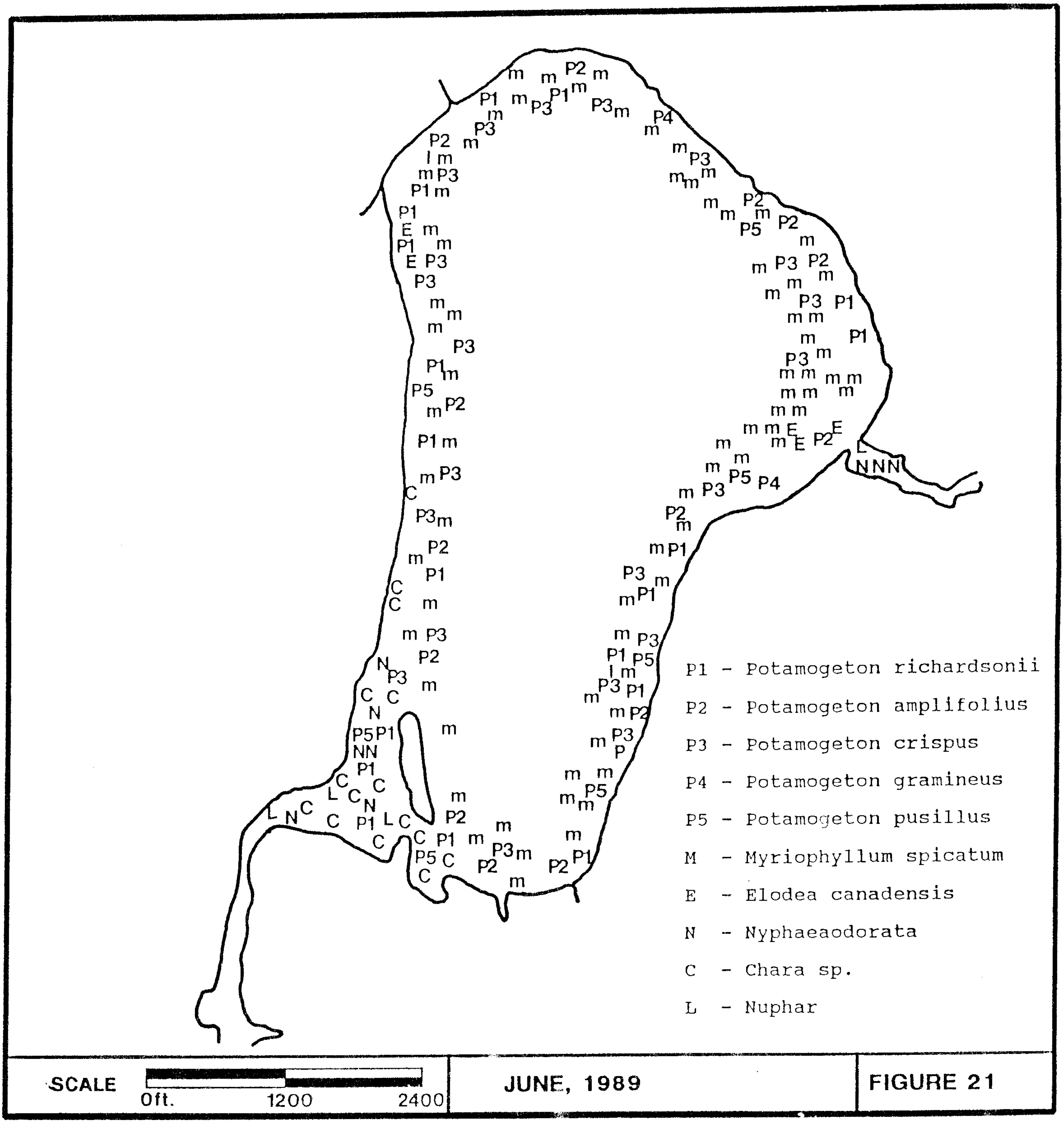
Scale 0 ft 1100 2200

AUGUST 12, 1988

FIGURE 20

Aquatic Macrophyte Densities

Stockbridge Bowl
Stockbridge, Massachusetts



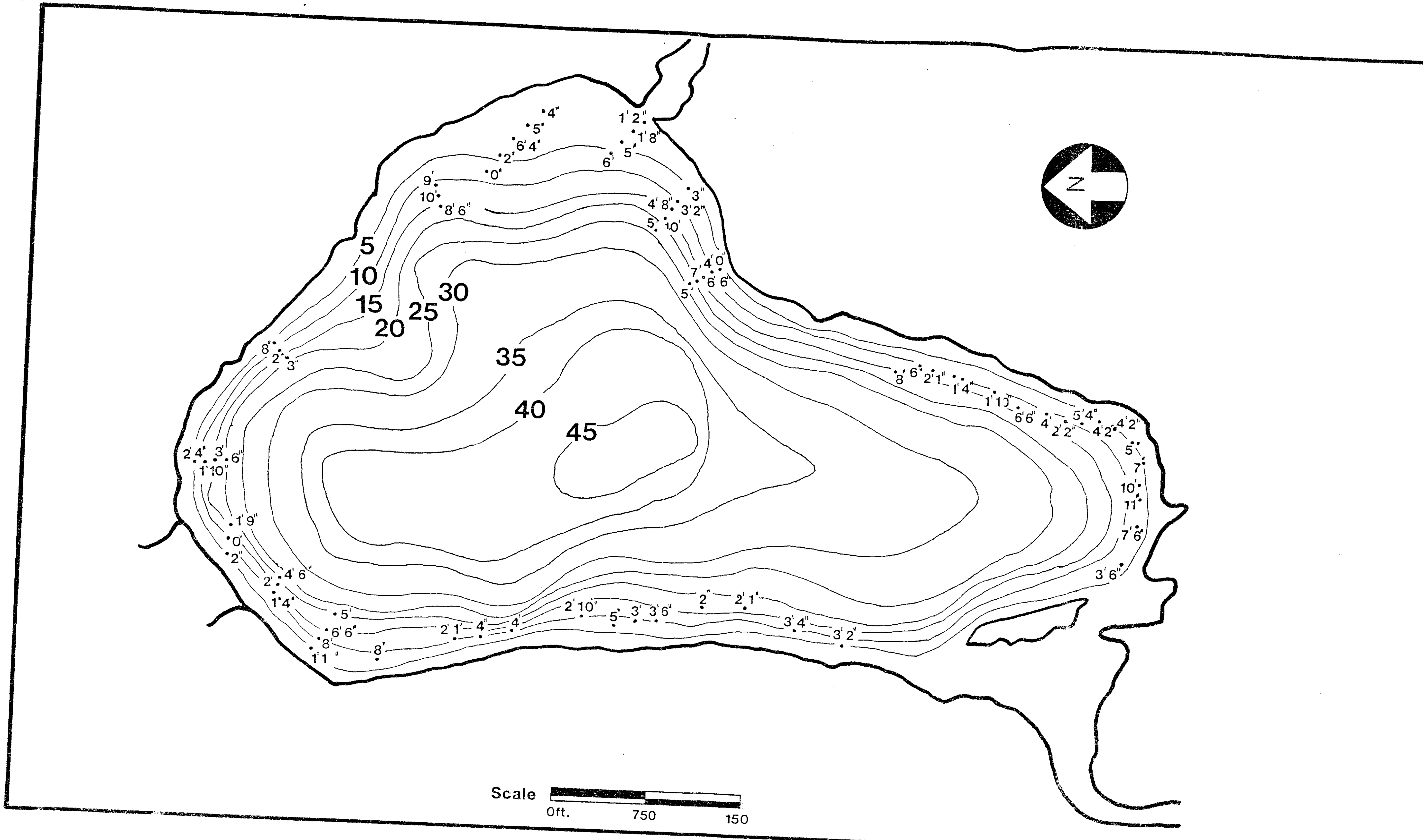
JUNE, 1989

FIGURE 21

AQUATIC MACROPHYTE SURVEY

Stockbridge Bowl

Stockbridge, Massachusetts



SEDIMENT DEPTHS

Stockbridge Bowl
Stockbridge, Massachusetts

FIGURE 22

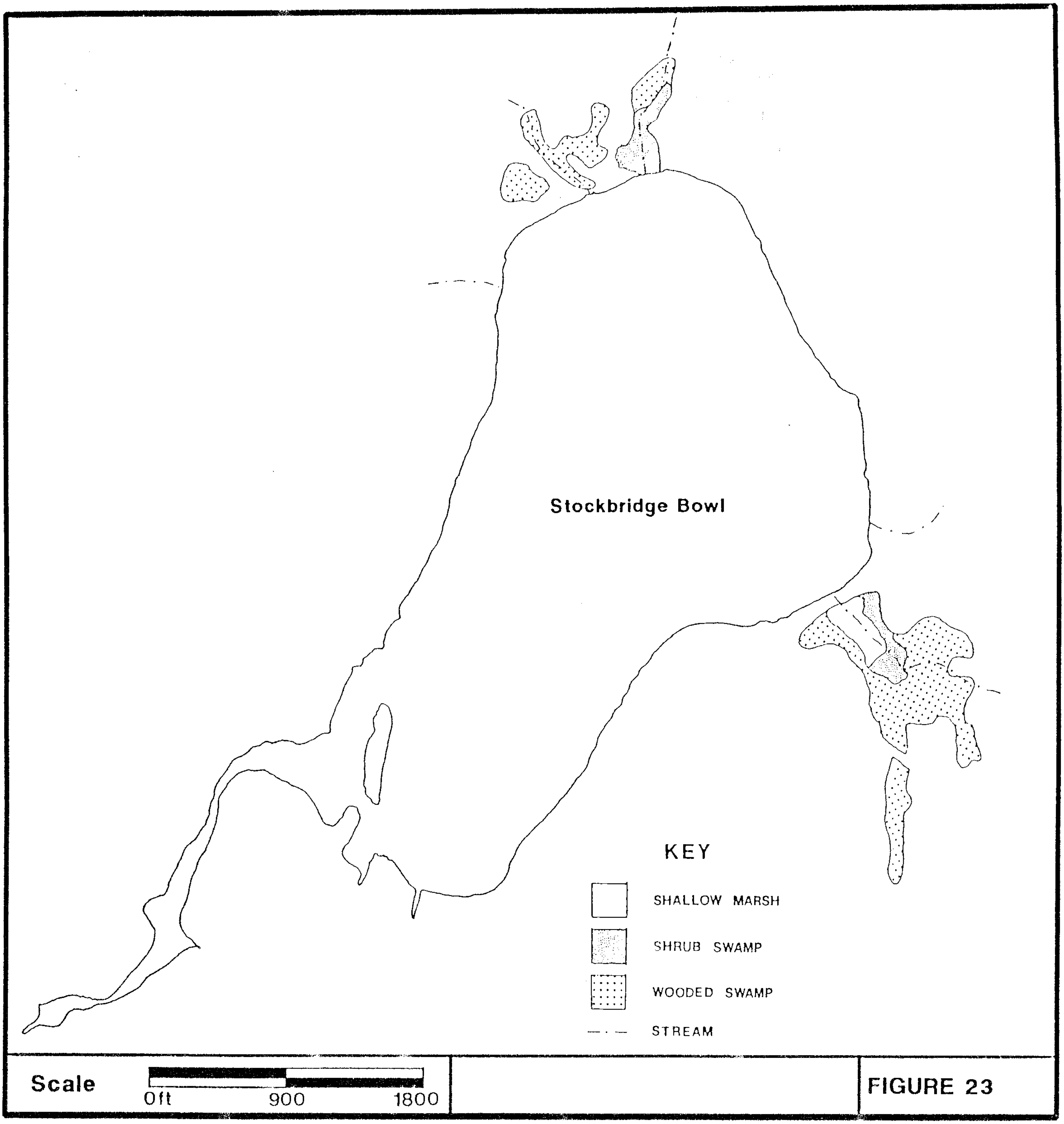


FIGURE 23

BORDERING WETLANDS

Stockbridge Bowl
Stockbridge, Massachusetts

LYCOTT

APPENDIX B

Sheet # ____ of ____

148 Pioneer Dr.
Leominster, MA 01453
(617) 840-0391

SOIL EXPLORATION CORPORATION
Geotechnical Drilling and Groundwater Monitor Wells

23 Ingalls St.
Nashua, NH 03060
(603) 882-3601

Client LYCOTT ENVIRONMENTAL RESEARCH Date 06/28/88 Job No. 88-405

Location STOCKBRIDGE BOWL, OFF ROUTE 183, WEST STOCKBRIDGE, MASSACHUSETTS

BORING NO. MW-2D & MW-2S Ground Elev. Date Start 06/23/88 Date Complete 06/23/88 Drilling Foreman J.C. Eng./Hydrol. Geologist R.T.

DEPTH	Sample Data					Soil and/or bedrock strata descriptions	
	Sample		Blows 6" Penetration	Rec. Inches	Casing Blows Per ft.	Strata Change Depth	Visual Identification of Soil and/or Rock Strata
	No.	Depth (ft.)					
	1	0'0"- 1'6"	3-3-3				Loose, moist, fine to coarse SAND, trace of organic and inorganic silt, trace root matter.
						3'0"	Medium dense, wet, fine SAND, inorganic silt, some fine to coarse gravel, trace cobbles, and clay.
5	2	4'0"- 5'6"	13-15-13				
10							
15	3	14'0"- 15'6"	10-21-9				
20							
						24'0"	End of boring at 24'0" Set well point for MW-2D at 24'0" Water level at 4'0" upon completion Set well point for MW-2S at 5'0" Water level at 4'0" upon completion Well Materials for MW-2D; 1 - 1½" PVC end plug 1 - 10' x 1½" PVC screen 1 - 10' x 1½" PVC riser 1 - 5' x 1½" PVC riser 1 - protective locking casing 1 bag - sakrete sand 5 bags - silica sand 1 pail - bentonite pellets Well Materials for MW-2S 1 - 1½" PVC end plug 1 - 5' x 1½" PVC screen
25							
30							
35							
40							

Type of Boring Casing Size: Hollow Stem Auger Size: 4¼

Proportion Percentages
Trace 0 to 10%
Some 10 to 40%
And 40 to 50%

Granular Soils (blows per ft.)		Cohesive Soils (blows per ft.)	
0 to 4 Very Loose	30 to 50 Dense	0 to 2 Very Soft	8 to 15 Stiff
4 to 10 Loose	Over 50 Very Dense	2 to 4 Soft	15 to 30 Very Stiff
10 to 30 Medium Dense		4 to 8 Medium Stiff	Over 30 Hard

Standard penetration test (SPT) = 140# hammer falling 30"
Blows are per 6" taken with an 18" long x 2" O.D. x 1 3/8" I.D. split spoon sampler unless otherwise noted.

The terms and percentages used to describe soil and or rock are based on visual identification of the retrieved samples. ■ Moisture content indicated may be affected by time of year and water added during the drilling process. ■ Water levels indicated may vary with seasonal fluctuation and the

Sheet # ____ of ____

148 Pioneer Dr.
Leominster, MA 01453
(617) 840-0391

SOIL EXPLORATION CORPORATION

Geotechnical Drilling and Groundwater Monitor Wells

23 Ingalls St.
Nashua, NH 03060
(603) 882-3601

Client	LYCOTT ENVIRONMENTAL RESEARCH			Date	06/28/88	Job No.	88-405
Location	STOCKBRIDGE BOWL, OFF ROUTE 183, WEST STOCKBRIDGE, MASSACHUSETTS						
BORING NO.	MW-1D & MW-1S	Ground Elev.		Date Start	06/22/88	Date Complete	06/22/88
Drilling Foreman	J.C.	Eng./Hydrol. Geologist	R.T.				

DEPTH	Sample Data No.	Sample Depth (ft.)	Blows 6" Penetration	Rec. Inches	Casing Blows Per ft.	Soil and/or bedrock strata descriptions Strata Change Depth	Visual Identification of Soil and/or Rock Strata
	1	0'0"- 1'6"	6-8-8				Medium dense, dry, fine SAND, trace of inorganic silt, and organic silt, trace of root matter.
5	2	4'0"- 5'6"	4-3-1			3'0"	Loose, moist, fine to medium SAND, trace of inorganic silt.
10	3	9'0"- 10'6"	12-17-15			7'6"	Dense, wet, fine SAND, inorganic silt, some fine to medium gravel, trace clay, and cobbles.
15							
						16'0"	Refusal at 16'0" with hollow stem auger
20							Set well point for MW-1D at 16'0" Water level at 7'0" upon completion Set well point for MW-1S at 8'0" Water level at 7'0" upon completion
25							Well Materails for MW-1D; 1 - 1½" PVC end plug 1 - 5' x 1½" PVC screen 1 - 10' x 1½" PVC riser 1 - 5' x 1½" PVC riser 1 - protective locking casing
30							1 bag - sakrete sand 5 bags - silica sand 1 pail - bentonite pellets
35							Well Materials for MW-1S; 1 - 1½" PVC end plug 1 - 10' x 1½" PVC screen
40							

Type of Boring Casing Size: Hollow Stem Auger Size: 4¼

Proportion Percentages	Granular Soils (blows per ft.)		Cohesive Soils (blows per ft.)	
Trace 0 to 10%	0 to 4 Very Loose	30 to 50 Dense	0 to 2 Very Soft	8 to 15 Stiff
Some 10 to 40%	4 to 10 Loose	Over 50 Very Dense	2 to 4 Soft	15 to 30 Very Stiff
And 40 to 50%	10 to 30 Medium Dense		4 to 8 Medium Stiff	Over 30 Hard

Standard penetration test (SPT) = 140# hammer falling 30"
Blows are per 6" taken with an 18" long x 2" O.D. x 1 3/8" I.D. split spoon sampler unless otherwise noted.

The terms and percentages used to describe soil and or rock are based on visual identification of the retrieved samples. ■ Moisture content indicated may be affected by time of year and water added during the drilling process. ■ Water levels indicated may vary with seasonal fluctuation and the degree of soil saturation when the

Sheet # ____ of ____

148 Pioneer Dr.
Leominster, MA 01453
(617) 840-0391

SOIL EXPLORATION CORPORATION
Geotechnical Drilling and Groundwater Monitor Wells

23 Ingalls St.
Nashua, NH 03060
(603) 882-3601

Client LYCOTT ENVIRONMENTAL RESEARCH Date 06/28/88 Job No. 88-405

Location STOCKBRIDGE BOWL, OFF ROUTE 183, WEST STOCKBRIDGE, MASSACHUSETTS

BORING NO. MW-3D & MW-3S Ground Elev. Date Start 06/23/88 Date Complete 06/23/88 Drilling Foreman J.C. Eng./Hydrol. Geologist R.T.

DEPTH	Sample Data					Soil and/or bedrock strata descriptions	
	Sample No.	Sample Depth (ft.)	Blows 6" Penetration	Rec. Inches	Casing Blows Per ft.	Strata Change Depth	Visual Identification of Soil and/or Rock Strata
	1	0'0"- 1'6"	3-5-2				Loose, moist, fine SAND, some organic and inorganic silt.
						3'0"	Very dense to dense, moist, fine SAND, some inorganic silt, and fine to medium gravel, trace cobbles, and clay.
5	2	4'0"- 5'6"	6-8-12				
10	3	9'0"- 10'6"	27-41-73				
15	4	14'0"- 15'6"	20-27-33				
20	5	19'0"- 20'6"	13-16-19				
						20'6"	End of boring at 20'6" Set well point for MW-3D at 20'0" No water encountered upon completion Set well point for MW-3S at 5'0" No water encountered upon completion Well Materails for MW-3D; 1 - 2" PVC end plug 1 - 10' x 2" PVC screen 1 - 5' x 2" PVC screen 1 - 5' x 2" PVC riser 1 - buffalo box 1 bag - sakrete sand 6 bags - silica sand 1 pail - bentonite pellets Well Materials for MW-3S; 1 - 2" PVC end plug 1 - 5' x 2" PVC screen 1 - buffalo box 2 bags - silica sand
25							
30							
35							
40							

Type of Boring Casing Size: Hollow Stem Auger Size: 4¼

Proportion Percentages	Granular Soils (blows per ft.)		Cohesive Soils (blows per ft.)	
Trace 0 to 10%	0 to 4 Very Loose	30 to 50 Dense	0 to 2 Very Soft	8 to 15 Stiff
Some 10 to 40%	4 to 10 Loose	Over 50 Very Dense	2 to 4 Soft	15 to 30 Very Stiff
And 40 to 50%	10 to 30 Medium Dense		4 to 8 Medium Stiff	Over 30 Hard

Standard penetration test (SPT) = 140# hammer falling 30"
Blows are per 6" taken with an 18" long x 2" O.D. x 1 3/8" I.D. split spoon sampler unless otherwise noted.

The terms and percentages used to describe soil and or rock are based on visual identification of the retrieved samples. ■ Moisture content indicated may be affected

Sheet # ____ of ____

148 Pioneer Dr.
Leominster, MA 01453
(617) 840-0391

SOIL EXPLORATION CORPORATION

Geotechnical Drilling and Groundwater Monitor Wells

23 Ingalls St.
Nashua, NH 03060
(603) 882-3601

Client	LYCOTT ENVIRONMENTAL RESEARCH			Date	06/28/88	Job No.	88-405
Location	STOCKBRIDGE BOWL, OFF ROUTE 183, WEST STOCKBRIDGE, MASSACHUSETTS						
BORING NO.	MW-4D	Ground Elev.		Date Start	06/23/88	Date Complete	06/23/88
Drilling Foreman	J.C.	Eng./Hydrol. Geologist	R.T.				

DEPTH	Sample Data					Soil and/or bedrock strata descriptions	
	Sample No.	Sample Depth (ft.)	Blows 6" Penetration	Rec. Inches	Casing Blows Per ft.	Strata Change Depth	Visual Identification of Soil and/or Rock Strata
	1	0'0"- 1'6"	12-5-7				Medium dense, moist, fine SAND, some organic silt.
						2'0"	Medium dense, wet, fine SAND, some medium to coarse sand, and inorganic silt.
5							
10	2	9'0"- 10'6"	12-16-17				
15						15'0"	Very dense, dry, fine SAND, silt, some medium to coarse sand, and fine to medium gravel, trace cobbles, and clay.
20	3	19'0"- 19'6"	120/6"				
25	4	24'0"- 25'6"	30-49-51				
						25'6"	End of boring at 25'6" Set well point at 25'0" Water level at 8'0" upon completion Well Materials for MW-4D; 1 - 2" PVC end plug 1 - 10' x 2" PVC screen 1 - 10' x 2" PVC riser 1 - 5' x 2" PVC riser 1 - buffalo box 5 bags - silica sand
30							
35							
40							

Type of Boring Casing Size: Hollow Stem Auger Size: 4¼

Proportion Percentages	Granular Soils (blows per ft.)		Cohesive Soils (blows per ft.)	
Trace 0 to 10%	0 to 4 Very Loose	30 to 50 Dense	0 to 2 Very Soft	8 to 15 Stiff
Some 10 to 40%	4 to 10 Loose	Over 50 Very Dense	2 to 4 Soft	15 to 30 Very Stiff
And 40 to 50%	10 to 30 Medium Dense		4 to 8 Medium Stiff	Over 30 Hard

Standard penetration test (SPT) = 140# hammer falling 30"
Blows are per 6" taken with an 18" long x 2" O.D. x 1 3/8" I.D. split spoon sampler unless otherwise noted.

The terms and percentages used to describe soil and or rock are based on visual identification of the retrieved samples. ■ Moisture content indicated may be affected by time of year and water added during the drilling process. ■ Water levels indicated

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APPENDIX C

TABLE 1

PRECIPITATION DATA, LONG-TERM

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
NORFOLK, CT	4.16	3.68	4.83	4.54	3.95	4.24	4.08	4.98	4.81	4.26	4.71	4.84
WESTERN MA	3.36	2.85	3.79	3.96	4.03	3.84	3.99	4.26	4.09	3.65	4.17	3.94
Average for the sites, in inches	3.76	3.27	4.31	4.25	3.99	4.04	4.35	4.62	4.45	3.96	4.44	4.39
Converted to mm	95.50	82.93	109.47	107.95	101.35	102.62	102.49	117.35	113.03	100.46	112.78	111.51

TOTAL FOR YEAR: 49.51 inches (1,257.43 mm)

TEMPERATURE DATA, LONG-TERM

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
NORFOLK, CT	19.8	20.8	29.9	42.5	53.9	62.7	67.4	65.6	58.1	47.1	36.8	24.5

PRECIPITATION DATA, MARCH, 1988 - FEBRUARY, 1989

	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB
GR BARRINGTON, MA	2.22	2.30	3.63	1.22	9.74	4.21	1.68	2.33	7.75	1.28	1.28	2.11
LANESBORO, MA	3.12	2.91			7.46	3.80	2.40	2.63	5.75	1.42	1.31	1.57
W. OTIS, MA	3.03	2.85	3.77	0.58	8.36	5.88		3.03	8.55	1.48	1.26	2.38
Average for the sites, in inches	2.79	2.69	3.70	0.90	8.52	4.63	2.04	2.66	7.35	1.39	1.28	2.02
Converted to mm	77.60	87.12	50.55	76.45	102.11	34.67	142.62	97.66	53.47	77.47	165.74	30.61

TOTAL FOR MARCH, 1988 - FEBRUARY, 1989: 39.98 INCHES (1,015.41 mm)

TEMPERATURE DATA, MARCH, 1988 - FEBRUARY, 1989:

	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB
GR BARRINGTON, MA	32.95	44.00	56.80	63.10	71.90	70.80	57.70	44.30	39.40	25.30	26.10	23.60
LANESBORO, MA	29.60	41.50			69.40	68.30	55.40	43.00	38.00	22.90	22.90	21.20
Average for the three sites (C)	31.25	42.75	56.80	63.10	70.65	69.55	56.55	43.65	38.70	24.10	24.50	22.40

TABLE 2

1988 LONG-TERM STORM RUNOFF - STOCKBRIDGE BOWL

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Amount Runoff (9% P)	0.34	0.29	0.39	0.38	0.36	0.36	0.36	0.42	0.40	0.36	0.40	0.40
Net P	3.42	2.97	3.92	3.87	3.63	3.68	3.67	4.20	4.05	3.60	4.04	3.99
Total P	3.76	3.27	4.31	4.25	3.99	4.04	4.04	0.42	4.45	3.96	4.44	4.39

TOTALS FOR YEAR:

Amount Runoff - 4.46 inches

Net P - 45.05 inches

Total P - 49.51 inches

MARCH, 1988 - FEBRUARY, 1989 STORM RUNOFF - STOCKBRIDGE BOWL

	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB
Amount Runoff (9% P)	0.25	0.24	0.33	0.08	0.77	0.42	0.18	0.24	0.66	0.13	0.12	0.18
Net P	2.54	2.44	3.37	0.82	7.75	4.21	1.86	2.42	6.69	1.27	1.17	1.84
Total P	2.79	2.69	3.70	0.90	8.52	4.63	2.04	2.66	7.35	1.39	1.28	2.02

TOTALS FOR MARCH, 1988 - FEBRUARY, 1989:

Amount Runoff - 3.60 inches

Net P - 36.38 inches

Total P - 39.98 inches

NOTE: Storm runoff was calculated by the Simple Method (Schueler, 1987) and assumed that 4% of the watershed (excluding the lake) is impervious.

TABLE 3

LONG-TERM WATER BUDGET

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
Temperature (C)	-6.78	-6.22	-1.17	5.83	12.17	17.06	19.67	18.67	14.50	8.39	2.67	-4.17	
Heat Index (i)	0.00	0.00	0.00	1.25	3.86	6.44	7.97	7.37	5.01	2.19	0.39	0.00	34.48
Unadjusted PE (mm)*	0.00	0.00	0.00	0.90	2.00	2.80	3.30	3.10	2.40	1.40	0.40	0.00	
Correction Factor	24.60	24.60	30.90	33.60	37.80	38.10	38.40	35.70	31.20	28.50	24.60	23.70	
Adjusted PE	0.00	0.00	0.00	30.24	75.60	106.68	126.72	110.67	74.88	39.95	9.84	0.00	574.53
Precipitation (mm)	86.87	75.44	99.57	98.30	92.20	93.47	93.22	106.68	102.87	91.44	102.62	101.35	
Precipitation - PE (mm)	86.87	75.44	99.57	68.06	16.60	-13.21	-33.50	- 3.99	27.99	51.54	92.78	101.35	
Soil Storage (up to 200 mm)	200.00	200.00	200.00	200.00	200.00	187.00	158.00	154.00	182.00	200.00	200.00	200.00	
AE (mm)*	0.00	0.00	0.00	30.24	75.60	106.47	122.22	110.68	74.88	39.90	9.84	0.00	569.83

* PE = potential evapotranspiration
AE = actual evapotranspiration

Calculations follow the method developed by Thornethwaite and Mather (1957).

Temperature and precipitation data are for the Norfolk, Connecticut weather station and Western Massachusetts division; see Table 1 of this appendix.

TABLE 4

MARCH, 1988 - FEBRUARY, 1989 WATER BUDGET - STOCKBRIDGE BOWL

	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	TOTALS
Temperature ('C)	-0.42	5.97	13.78	17.28	21.47	20.86	13.64	6.47	3.72	-4.39	-4.17	-5.33	
Heat Index (i)	0.00	1.32	4.65	6.55	9.16	8.72	4.55	1.49	0.63	0.00	0.00	0.00	37.01
Unadjusted PE (mm)*	0.00	0.90	2.20	2.90	3.60	3.50	2.20	1.00	0.50	0.00	0.00	0.00	
Correction Factor	30.90	33.60	37.80	38.10	38.40	35.70	31.20	28.50	24.60	23.70	24.60	24.60	
Adjusted PE	0.00	30.24	83.16	110.49	138.24	124.95	68.64	28.50	12.30	0.00	0.00	0.00	596.52
Precipitation (mm)**	64.52	61.98	85.60	20.83	196.85	106.93	47.24	61.47	169.92	32.26	29.72	46.74	
Precipitation - PE (mm)	64.52	31.74	2.44	-89.66	58.61	-18.02	-21.40	32.97	157.62	32.26	29.72	46.74	
Soil Storage (up to 200 mm)	200.00	200.00	200.00	127.00	186.00	170.00	153.00	186.00	200.00	200.00	200.00	200.00	
AE (mm)*	0.00	30.24	83.16	93.83	138.24	122.93	64.24	28.50	12.30	0.00	0.00	0.00	573.45

* PE = potential evapotranspiration
AE = actual evapotranspiration

** Overland runoff has been subtracted from these values; see Table 2 of this Appendix.

Calculations follow the method developed by Thornethwaite and Mather (1957).

Temperature and precipitation data are for the Great Barrington, Lanesboro, and West Otis, Massachusetts weather stations; see Table 1 of this appendix.

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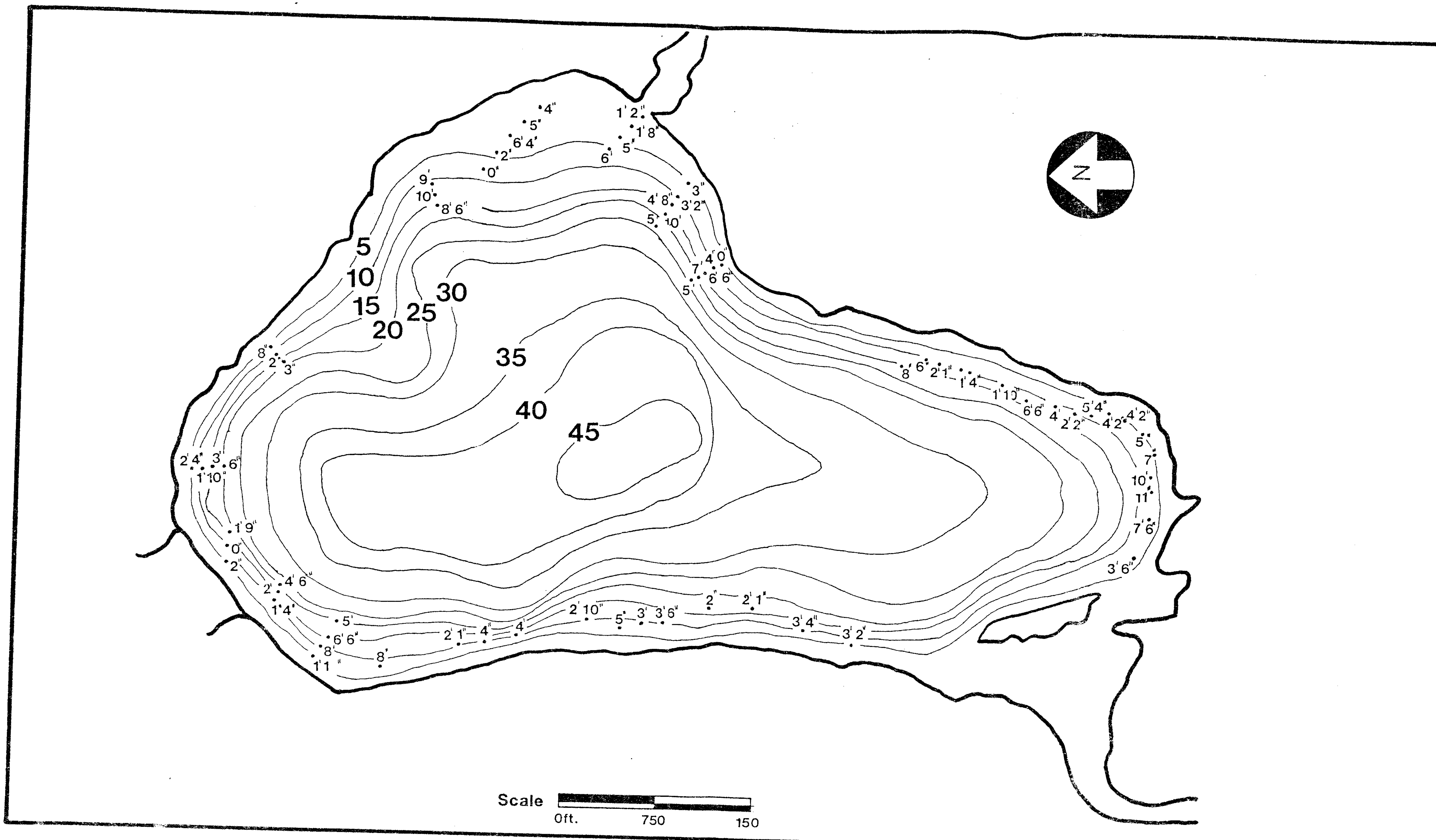
APPENDIX D



SEDIMENT DEPTHS

Stockbridge Bowl
Stockbridge,Massachusetts

FIGURE 22

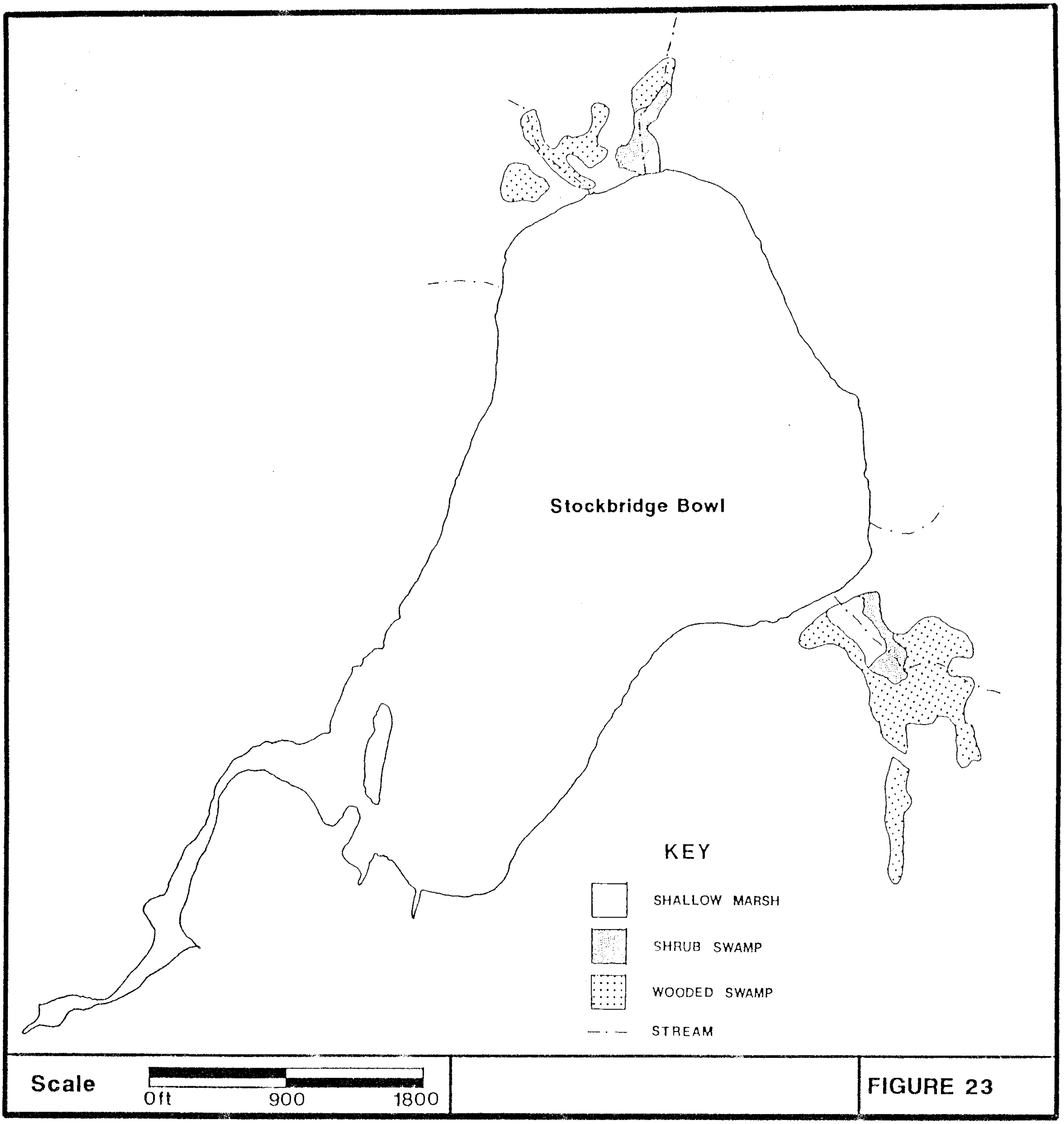


FIGURE 23

BORDERING WETLANDS

Stockbridge Bowl
Stockbridge, Massachusetts

LYCOTT

APPENDIX B

Sheet # ____ of ____

148 Pioneer Dr.
Leominster, MA 01453
(617) 840-0391

SOIL EXPLORATION CORPORATION
Geotechnical Drilling and Groundwater Monitor Wells

23 Ingalls St.
Nashua, NH 03060
(603) 882-3601

Client LYCOTT ENVIRONMENTAL RESEARCH Date 06/28/88 Job No. 88-405

Location STOCKBRIDGE BOWL, OFF ROUTE 183, WEST STOCKBRIDGE, MASSACHUSETTS

BORING NO. MW-2D & MW-2S Ground Elev. Date Start 06/23/88 Date Complete 06/23/88 Drilling Foreman J.C. Eng./Hydrol. Geologist R.T.

DEPTH	Sample Data					Soil and/or bedrock strata descriptions	
	Sample		Blows 6" Penetration	Rec. Inches	Casing Blows Per ft.	Strata Change Depth	Visual Identification of Soil and/or Rock Strata
	No.	Depth (ft.)					
	1	0'0"- 1'6"	3-3-3				Loose, moist, fine to coarse SAND, trace of organic and inorganic silt, trace root matter.
						3'0"	Medium dense, wet, fine SAND, inorganic silt, some fine to coarse gravel, trace cobbles, and clay.
5	2	4'0"- 5'6"	13-15-13				
10							
15	3	14'0"- 15'6"	10-21-9				
20							
						24'0"	End of boring at 24'0" Set well point for MW-2D at 24'0" Water level at 4'0" upon completion Set well point for MW-2S at 5'0" Water level at 4'0" upon completion Well Materials for MW-2D; 1 - 1½" PVC end plug 1 - 10' x 1½" PVC screen 1 - 10' x 1½" PVC riser 1 - 5' x 1½" PVC riser 1 - protective locking casing 1 bag - sakrete sand 5 bags - silica sand 1 pail - bentonite pellets Well Materials for MW-2S 1 - 1½" PVC end plug 1 - 5' x 1½" PVC screen
25							
30							
35							
40							

Type of Boring Casing Size: Hollow Stem Auger Size: 4¼

Proportion Percentages	Granular Soils (blows per ft.)		Cohesive Soils (blows per ft.)	
Trace 0 to 10%	0 to 4 Very Loose	30 to 50 Dense	0 to 2 Very Soft	8 to 15 Stiff
Some 10 to 40%	4 to 10 Loose	Over 50 Very Dense	2 to 4 Soft	15 to 30 Very Stiff
And 40 to 50%	10 to 30 Medium Dense		4 to 8 Medium Stiff	Over 30 Hard

Standard penetration test (SPT) = 140# hammer falling 30"
Blows are per 6" taken with an 18" long x 2" O.D. x 1 3/8" I.D. split spoon sampler unless otherwise noted.

The terms and percentages used to describe soil and or rock are based on visual identification of the retrieved samples. ■ Moisture content indicated may be affected by time of year and water added during the drilling process. ■ Water levels indicated may vary with seasonal fluctuation and the

Sheet # ____ of ____

148 Pioneer Dr.
Leominster, MA 01453
(617) 840-0391

SOIL EXPLORATION CORPORATION
Geotechnical Drilling and Groundwater Monitor Wells

23 Ingalls St.
Nashua, NH 03060
(603) 882-3601

Client LYCOTT ENVIRONMENTAL RESEARCH Date 06/28/88 Job No. 88-405

Location STOCKBRIDGE BOWL, OFF ROUTE 183, WEST STOCKBRIDGE, MASSACHUSETTS

BORING NO. MW-1D & MW-1S Ground Elev. Date Start 06/22/88 Date Complete 06/22/88 Drilling Foreman J.C. Eng./Hydrol. Geologist R.T.

DEPTH	Sample Data: Sample No.	Sample Depth (ft.)	Blows 6" Penetration	Rec. Inches	Casing Blows Per ft.	Soil and/or bedrock strata descriptions: Strata Change Depth	Visual Identification of Soil and/or Rock Strata
	1	0'0"- 1'6"	6-8-8				Medium dense, dry, fine SAND, trace of inorganic silt, and organic silt, trace of root matter.
5	2	4'0"- 5'6"	4-3-1			3'0"	Loose, moist, fine to medium SAND, trace of inorganic silt.
10	3	9'0"- 10'6"	12-17-15			7'6"	Dense, wet, fine SAND, inorganic silt, some fine to medium gravel, trace clay, and cobbles.
15							
						16'0"	Refusal at 16'0" with hollow stem auger
20							Set well point for MW-1D at 16'0" Water level at 7'0" upon completion Set well point for MW-1S at 8'0" Water level at 7'0" upon completion
25							Well Materails for MW-1D; 1 - 1½" PVC end plug 1 - 5' x 1½" PVC screen 1 - 10' x 1½" PVC riser 1 - 5' x 1½" PVC riser 1 - protective locking casing
30							1 bag - sakrete sand 5 bags - silica sand 1 pail - bentonite pellets
35							Well Materials for MW-1S; 1 - 1½" PVC end plug 1 - 10' x 1½" PVC screen
40							

Type of Boring Casing Size: Hollow Stem Auger Size: 4¼

Proportion Percentages	Granular Soils (blows per ft.)		Cohesive Soils (blows per ft.)	
Trace 0 to 10%	0 to 4 Very Loose	30 to 50 Dense	0 to 2 Very Soft	8 to 15 Stiff
Some 10 to 40%	4 to 10 Loose	Over 50 Very Dense	2 to 4 Soft	15 to 30 Very Stiff
And 40 to 50%	10 to 30 Medium Dense		4 to 8 Medium Stiff	Over 30 Hard

Standard penetration test (SPT) = 140# hammer falling 30"
Blows are per 6" taken with an 18" long x 2" O.D. x 1 3/8" I.D. split spoon sampler unless otherwise noted.

The terms and percentages used to describe soil and or rock are based on visual identification of the retrieved samples. ■ Moisture content indicated may be affected by time of year and water added during the drilling process. ■ Water levels indicated may vary with seasonal fluctuation and the degree of soil saturation when the

Sheet # ____ of ____

148 Pioneer Dr.
Leominster, MA 01453
(617) 840-0391

SOIL EXPLORATION CORPORATION

Geotechnical Drilling and Groundwater Monitor Wells

23 Ingalls St.
Nashua, NH 03060
(603) 882-3601

Client	LYCOTT ENVIRONMENTAL RESEARCH	Date	06/28/88	Job No.	88-405
Location	STOCKBRIDGE BOWL, OFF ROUTE 183, WEST STOCKBRIDGE, MASSACHUSETTS				

BORING NO.	MW-3D & MW-3S	Ground Elev.		Date Start	06/23/88	Date Complete	06/23/88	Drilling Foreman	J.C.	Eng./Hydrol. Geologist	R.T.

DEPTH	Sample Data					Soil and/or bedrock strata descriptions	
	Sample No.	Sample Depth (ft.)	Blows 6" Penetration	Rec. Inches	Casing Blows Per ft.	Strata Change Depth	Visual Identification of Soil and/or Rock Strata
	1	0'0"- 1'6"	3-5-2				Loose, moist, fine SAND, some organic and inorganic silt.
5	2	4'0"- 5'6"	6-8-12			3'0"	Very dense to dense, moist, fine SAND, some inorganic silt, and fine to medium gravel, trace cobbles, and clay.
10	3	9'0"- 10'6"	27-41-73				
15	4	14'0"- 15'6"	20-27-33				
20	5	19'0"- 20'6"	13-16-19				
						20'6"	End of boring at 20'6" Set well point for MW-3D at 20'0" No water encountered upon completion Set well point for MW-3S at 5'0" No water encountered upon completion Well Materails for MW-3D; 1 - 2" PVC end plug 1 - 10' x 2" PVC screen 1 - 5' x 2" PVC screen 1 - 5' x 2" PVC riser 1 - buffalo box 1 bag - sakrete sand 6 bags - silica sand 1 pail - bentonite pellets Well Materials for MW-3S; 1 - 2" PVC end plug 1 - 5' x 2" PVC screen 1 - buffalo box 2 bags - silica sand
25							
30							
35							
40							

Type of Boring Casing Size: Hollow Stem Auger Size: 4¼

Proportion Percentages	Granular Soils (blows per ft.)		Cohesive Soils (blows per ft.)	
Trace 0 to 10%	0 to 4 Very Loose	30 to 50 Dense	0 to 2 Very Soft	8 to 15 Stiff
Some 10 to 40%	4 to 10 Loose	Over 50 Very Dense	2 to 4 Soft	15 to 30 Very Stiff
And 40 to 50%	10 to 30 Medium Dense		4 to 8 Medium Stiff	Over 30 Hard

Standard penetration test (SPT) = 140# hammer falling 30"
Blows are per 6" taken with an 18" long x 2" O.D. x 1 3/8" I.D. split spoon sampler unless otherwise noted.

The terms and percentages used to describe soil and or rock are based on visual identification of the retrieved samples. ■ Moisture content indicated may be affected

Sheet # ____ of ____

148 Pioneer Dr.
Leominster, MA 01453
(617) 840-0391

SOIL EXPLORATION CORPORATION
Geotechnical Drilling and Groundwater Monitor Wells

23 Ingalls St.
Nashua, NH 03060
(603) 882-3601

Client LYCOTT ENVIRONMENTAL RESEARCH Date 06/28/88 Job No. 88-405

Location STOCKBRIDGE BOWL, OFF ROUTE 183, WEST STOCKBRIDGE, MASSACHUSETTS

BORING NO. MW-4D Ground Elev. Date Start 06/23/88 Date Complete 06/23/88 Drilling Foreman J.C. Eng./Hydrol. Geologist R.T.

DEPTH	Sample Data					Soil and/or bedrock strata descriptions	
	Sample		Blows 6" Penetration	Rec. Inches	Casing Blows Per ft.	Strata Change Depth	Visual Identification of Soil and/or Rock Strata
	No.	Depth (ft.)					
	1	0'0"- 1'6"	12-5-7				Medium dense, moist, fine SAND, some organic silt.
						2'0"	Medium dense, wet, fine SAND, some medium to coarse sand, and inorganic silt.
5							
10	2	9'0"- 10'6"	12-16-17				
15							
						15'0"	Very dense, dry, fine SAND, silt, some medium to coarse sand, and fine to medium gravel, trace cobbles, and clay.
20	3	19'0"- 19'6"	120/6"				
25	4	24'0"- 25'6"	30-49-51				
						25'6"	End of boring at 25'6" Set well point at 25'0" Water level at 8'0" upon completion Well Materials for MW-4D; 1 - 2" PVC end plug 1 - 10' x 2" PVC screen 1 - 10' x 2" PVC riser 1 - 5' x 2" PVC riser 1 - buffalo box 5 bags - silica sand
30							
35							
40							

Type of Boring Casing Size: Hollow Stem Auger Size: 4¼

Proportion Percentages
Trace 0 to 10%
Some 10 to 40%
And 40 to 50%

Granular Soils (blows per ft.)

0 to 4 Very Loose	30 to 50 Dense
4 to 10 Loose	Over 50 Very Dense
10 to 30 Medium Dense	

Cohesive Soils (blows per ft.)

0 to 2 Very Soft	8 to 15 Stiff
2 to 4 Soft	15 to 30 Very Stiff
4 to 8 Medium Stiff	Over 30 Hard

Standard penetration test (SPT) = 140# hammer falling 30"
Blows are per 6" taken with an 18" long x 2" O.D. x 1 3/8" I.D. split spoon sampler unless otherwise noted.

The terms and percentages used to describe soil and or rock are based on visual identification of the retrieved samples. ■ Moisture content indicated may be affected by time of year and water added during the drilling process. ■ Water levels indicated may vary with

APPENDIX C

TABLE 1

PRECIPITATION DATA, LONG-TERM

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
NORFOLK, CT	4.16	3.68	4.83	4.54	3.95	4.24	4.08	4.98	4.81	4.26	4.71	4.84
WESTERN MA	3.36	2.85	3.79	3.96	4.03	3.84	3.99	4.26	4.09	3.65	4.17	3.94
Average for the sites, in inches	3.76	3.27	4.31	4.25	3.99	4.04	4.35	4.62	4.45	3.96	4.44	4.39
Converted to mm	95.50	82.93	109.47	107.95	101.35	102.62	102.49	117.35	113.03	100.46	112.78	111.51

TOTAL FOR YEAR: 49.51 inches (1,257.43 mm)

TEMPERATURE DATA, LONG-TERM

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
NORFOLK, CT	19.8	20.8	29.9	42.5	53.9	62.7	67.4	65.6	58.1	47.1	36.8	24.5

PRECIPITATION DATA, MARCH, 1988 - FEBRUARY, 1989

	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB
GR BARRINGTON, MA	2.22	2.30	3.63	1.22	9.74	4.21	1.68	2.33	7.75	1.28	1.28	2.11
LANESBORO, MA	3.12	2.91			7.46	3.80	2.40	2.63	5.75	1.42	1.31	1.57
W. OTIS, MA	3.03	2.85	3.77	0.58	8.36	5.88		3.03	8.55	1.48	1.26	2.38
Average for the sites, in inches	2.79	2.69	3.70	0.90	8.52	4.63	2.04	2.66	7.35	1.39	1.28	2.02
Converted to mm	77.60	87.12	50.55	76.45	102.11	34.67	142.62	97.66	53.47	77.47	165.74	30.61

TOTAL FOR MARCH, 1988 - FEBRUARY, 1989: 39.98 INCHES (1,015.41 mm)

TEMPERATURE DATA, MARCH, 1988 - FEBRUARY, 1989:

	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB
GR BARRINGTON, MA	32.95	44.00	56.80	63.10	71.90	70.80	57.70	44.30	39.40	25.30	26.10	23.60
LANESBORO, MA	29.60	41.50			69.40	68.30	55.40	43.00	38.00	22.90	22.90	21.20
Average for the three sites (C)	31.25	42.75	56.80	63.10	70.65	69.55	56.55	43.65	38.70	24.10	24.50	22.40

SBTAB1

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TABLE 2

1988 LONG-TERM STORM RUNOFF - STOCKBRIDGE BOWL

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Amount Runoff (9% P)	0.34	0.29	0.39	0.38	0.36	0.36	0.36	0.42	0.40	0.36	0.40	0.40
Net P	3.42	2.97	3.92	3.87	3.63	3.68	3.67	4.20	4.05	3.60	4.04	3.99
Total P	3.76	3.27	4.31	4.25	3.99	4.04	4.04	0.42	4.45	3.96	4.44	4.39

TOTALS FOR YEAR:

Amount Runoff - 4.46 inches

Net P - 45.05 inches

Total P - 49.51 inches

MARCH, 1988 - FEBRUARY, 1989 STORM RUNOFF - STOCKBRIDGE BOWL

	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB
Amount Runoff (9% P)	0.25	0.24	0.33	0.08	0.77	0.42	0.18	0.24	0.66	0.13	0.12	0.18
Net P	2.54	2.44	3.37	0.82	7.75	4.21	1.86	2.42	6.69	1.27	1.17	1.84
Total P	2.79	2.69	3.70	0.90	8.52	4.63	2.04	2.66	7.35	1.39	1.28	2.02

TOTALS FOR MARCH, 1988 - FEBRUARY, 1989:

Amount Runoff - 3.60 inches

Net P - 36.38 inches

Total P - 39.98 inches

NOTE: Storm runoff was calculated by the Simple Method (Schueler, 1987) and assumed that 4% of the watershed (excluding the lake) is impervious.

SBTAB2

TABLE 3

LONG-TERM WATER BUDGET

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
Temperature (C)	-6.78	-6.22	-1.17	5.83	12.17	17.06	19.67	18.67	14.50	8.39	2.67	-4.17	
Heat Index (i)	0.00	0.00	0.00	1.25	3.86	6.44	7.97	7.37	5.01	2.19	0.39	0.00	34.48
Unadjusted PE (mm)*	0.00	0.00	0.00	0.90	2.00	2.80	3.30	3.10	2.40	1.40	0.40	0.00	
Correction Factor	24.60	24.60	30.90	33.60	37.80	38.10	38.40	35.70	31.20	28.50	24.60	23.70	
Adjusted PE	0.00	0.00	0.00	30.24	75.60	106.68	126.72	110.67	74.88	39.95	9.84	0.00	574.53
Precipitation (mm)	86.87	75.44	99.57	98.30	92.20	93.47	93.22	106.68	102.87	91.44	102.62	101.35	
Precipitation - PE (mm)	86.87	75.44	99.57	68.06	16.60	-13.21	-33.50	- 3.99	27.99	51.54	92.78	101.35	
Soil Storage (up to 200 mm)	200.00	200.00	200.00	200.00	200.00	187.00	158.00	154.00	182.00	200.00	200.00	200.00	
AE (mm)*	0.00	0.00	0.00	30.24	75.60	106.47	122.22	110.68	74.88	39.90	9.84	0.00	569.83

* PE = potential evapotranspiration
AE = actual evapotranspiration

Calculations follow the method developed by Thornethwaite and Mather (1957).

Temperature and precipitation data are for the Norfolk, Connecticut weather station and Western Massachusetts division; see Table 1 of this appendix.

TABLE 4

MARCH, 1988 - FEBRUARY, 1989 WATER BUDGET - STOCKBRIDGE BOWL

	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	TOTALS
Temperature ('C)	-0.42	5.97	13.78	17.28	21.47	20.86	13.64	6.47	3.72	-4.39	-4.17	-5.33	
Heat Index (i)	0.00	1.32	4.65	6.55	9.16	8.72	4.55	1.49	0.63	0.00	0.00	0.00	37.01
Unadjusted PE (mm)*	0.00	0.90	2.20	2.90	3.60	3.50	2.20	1.00	0.50	0.00	0.00	0.00	
Correction Factor	30.90	33.60	37.80	38.10	38.40	35.70	31.20	28.50	24.60	23.70	24.60	24.60	
Adjusted PE	0.00	30.24	83.16	110.49	138.24	124.95	68.64	28.50	12.30	0.00	0.00	0.00	596.52
Precipitation (mm)**	64.52	61.98	85.60	20.83	196.85	106.93	47.24	61.47	169.92	32.26	29.72	46.74	
Precipitation - PE (mm)	64.52	31.74	2.44	-89.66	58.61	-18.02	-21.40	32.97	157.62	32.26	29.72	46.74	
Soil Storage (up to 200 mm)	200.00	200.00	200.00	127.00	186.00	170.00	153.00	186.00	200.00	200.00	200.00	200.00	
AE (mm)*	0.00	30.24	83.16	93.83	138.24	122.93	64.24	28.50	12.30	0.00	0.00	0.00	573.45

* PE = potential evapotranspiration
AE = actual evapotranspiration

** Overland runoff has been subtracted from these values; see Table 2 of this Appendix.

Calculations follow the method developed by Thornethwaite and Mather (1957).

Temperature and precipitation data are for the Great Barrington, Lanesboro, and West Otis, Massachusetts weather stations; see Table 1 of this appendix.

APPENDIX D

STOCKBRIDGE BOWL TEMPERATURE, DISSOLVED OXYGEN, AND RTR VS. DEPTH

DATE	03/17/88	04/21/88	05/17/88	05/26/88	06/14/88	06/28/88	07/05/88	07/25/88	08/15/88	08/23/88	09/12/88	09/28/88	10/06/88	10/24/88	11/25/88	12/22/88	01/05/89	02/13/89
AIR TEMPERATURE (deg f)			60	58	90	76	84	91	85	85	75	63	52	54	52	38	16	28
WEATHER	SUNNY, 20 MPH WIND		OVERCAST	OVERCAST	CLEAR	P/CLOUDY	HAZY BREEZY	HAZY HUMID	CLOUDY	CLEAR	PTLY CLOUDY CALM	PTLY CLOUDY CALM	CLOUDY CALM	RAIN V. WINDY	CLEAR LT. BREEZE	CLOUDY WINDY	-15 DEG. WIND-CHILL FACTOR	PTLY CLOUDY WINDY
SECCHI DEPTH (meters)	ICE	2	2	1.5	3	3	3.3	3	4	3	3	3	2.5	1.7	1.1 (MURKY)	NOT READ	6" ICE COVER	NOT READ
TEMPERATURE (degrees centigrade)																		
DEPTH (meters)																		
0	0.2	6	16.8	16.1	21.2	22.5	23.7	25	28.7	28.5	19.6	18.1	15.6	10.4	5.2	ICE COVER	0.9	0.8
1	1.8	6	16.6	15.5	21.1	22.3	23.7	25	28.7	28.5	19.6	17.7	15.4	10.4	5.4	UNSAFE FOR	1.5	4.1
2	2	6	15.8	15.5	20.1	21.9	23.2	24.8	29	28.5	19.5	17.6	15.5	10.4	5.3	ACCESS	2.4	4
3	2	6	14.8	14.3	19.5	21.7	22.9	24.1	28.8	28.3	19.5	17.6	15.5	10.3	5.3		3.2	4.1
4	2	6	13.8	13.9	18.8	21.7	20.4	23.2	28.8	28	19.5	17.4	15.4	10.3	5.3		3	4
5	2	6	13	13.1	17.5	21.3	20.2	20.7	28.6	28	19.5	17.3	15.5	10.3	5.3		2.9	3.8
6	2	6	12.2	10.1	16.3	17.5	17.6	15.3	25	27.8	19.5	16.8	15.5	10.4	5.3		2.4	3.7
7	2	6	10.6	8.2	11.5	17.2	14.3	10.9	20	25.5	17.3	14.7	15.5	10.3	5.2		2.5	3.8
8	2	6	9.1	8	9.1	11.4	11.8	8.5	13.4	20.1	15	11.3	15.1	10.3	5.2		2.5	3.8
9	1.9	6	8	7.9	7.9	8.5	8.8	8.3	14.3	16.8	12.7	10	11.5	10.3	5.2		2.4	3.7
10	1.9	6	7.5	7.6	7.5	8.1	8.6	8.2	10	16.7	12.4	9.4	9.5	10.3	5.2		2.2	3.7
11	2	6	7.2	7.6	7.2	7.9	8.5	7.7	10.6	15	11.3	8.4	8.4	10.3	5.2		2.2	3.7
12	2	6	6.9	7.5	7.1	7.7	8.4	7.4	9	14.7	10.9	8.4	8.3	10.3	5.2			3.8
13	2.5	6	6.8	6.7	6.7	7.7	8.1	7.2	8.6	14	9.4	8.1	8.3	10.3	5.2			3.8
14	2.5	6	6.8	6.2	6.5	7.6	8	7.2	8.2	10.2	8.9	7.9	8.3	10	5.2			4
DISSOLVED OXYGEN (milligrams per liter)																		
DEPTH (meters)																		
0	11	11.6	10.9	D.O.	9	9.1	9.28	7.8	14.1	15.1	14.2	9.72	12.92	10.91	12.42	ICE COVER	13.68	16.85
1	11	11.4	11.4	PROBE	8.9	9.01	9.28	7.8	14.1	15.1	15.38	9.43	12.6	10.3	12.37	UNSAFE FOR	13.17	17.1
2	11.2	11.4	11.7	FAILURE	8.9	9.17	9.16	6.4	13.65	15.03	15.2	11.24	12.93	9.97	12.81	ACCESS	12.29	16.84
3	11.3	11.4	11.5		8.7	9.13	9.17	6.23	14.1	14.81	15.5	10.5	12.53	9.65	12.66		8.71	16.16
4	11.5	11.4	11.6		8.4	9.13	9.6	5.22	13.1	14.23	15.3	9.3	12.65	9.78	12.47		7.65	16.04
5	11.5	11.4	11.2		8.6	9.4	9.03	6.6	15.75	15.3	15.6	7.96	12.2	9.18	12.33		8.03	16.22
6	11.5	11.4	10.9		8.3	12.06	11.94	9.36	17.05	15.41	15.88	7.8	12	9.97	12.97		6.21	13.87
7	11.6	11.4	9.9		7.7	12.37	14.7	9.35	19.9	19.9	19.9	6.25	12.74	9.6	12.86		4.14	13.36
8	11.6	11.4	8.8		7.4	14.65	16.91	3.3	19.9	19.9	19.9	0.68	11.85	9.15	11.01		4.36	12.23
9	11.6	11.4	8.3		7.5	0.24	0.14	2.8	19.9	19.9	10.4	0.74	2.63	9.09	11.24		3.79	8.81
10	7.64	11.4	7.2		7	0.11	0.32	0.75	0.18	7.08	8.45	1.49	2.04	8.81	11.9		1.12	8.17
11	6.83	11.4	6.5		6.8	0.07	1	0.28	2.9	2.88	2.41	0.54	1.29	9.12	11.81		0	6.43
12	6.42	11.4	6.1		6.7	0	0.05	0.21	0.93	0.26	1.09	0.38	1.18	8.43	11.07			6.02
13	2.4	11.4	5.2		6	0	0	0.2	0.9	0	8.6	0.59	0.44	8.21	11.36			0.74
14	2	11.4	2.3		5.2	0	0.12	0	0.29	0	0	0.78	0.8	8.05	11.2			0
15	2	11.2				0	0	0	0.06									
RELATIVE THERMAL RESISTANCE																		
DEPTH (meters)																		
0-1	0	0	4	12	3	6	0	0	0	0	0	9	4	0	0	ICE COVER	0	0
1-2	0	0	17	0	27	11	15	6	0	0	3	2	0	0	1	UNSAFE FOR	3	0
2-3	0	0	20	24	15	6	9	22	7	7	0	0	0	1	0	ACCESS	4	0
3-4	0	0	19	7	17	0	70	27	0	11	0	5	2	0	0		1	0
4-5	0	0	14	14	31	11	5	71	7	0	0	2	0	0	0		0	0
5-6	0	0	13	46	26	96	64	127	124	7	0	11	0	0	0		2	0
6-7	0	0	24	24	88	7	69	76	145	79	53	43	0	1	1		0	0
7-8	0	0	20	2	33	109	43	32	144	159	49	59	8	0	0		0	0
8-9	0	0	13	1	14	39	42	2	0	79	42	19	63	0	0		0	0
9-10	0	0	5	3	4	5	2	1	70	2	5	8	28	0	0		1	0
10-11	0	0	3	0	3	2	1	5	8	35	17	12	13	0	0		0	0
11-12	0	0	3	1	1	2	1	3	21	6	6	0	1	0	0		5	0
12-13	0	0	1	8	4	0	3	2	5	13	21	3	0	0	0		0	0
13-14	0	0	0	5	2	1	1	0	5	61	6	2	0	4	0		0	0
14-15	0	0	36	31	33	44	1	2	3	76	4	48	3	22	23		0	0

APPENDIX E

STOCKBRIDGE BOWL, STOCKBRIDGE, MASSACHUSETTS TEMPERATURE (^{O}C) TABLE

	STATION									
DATE	1	2	3	4	5	6	8	7S	7B	TH
03/17/88	5.5	4.0	3.0	2.5	2.0	2.0		0.2	2.5	
04/21/88	7.6	7.0	8.0	8.2	8.0	7.5		6.0	6.0	
05/17/88	----	----	----	----	----	----		16.8	6.7	
05/26/88	12.2	12.0	14.4	17.7	11.8	14.9		16.1	6.2	
06/14/88	23.0	16.2	22.7	23.0	DRY	21.7		21.2	6.5	
06/28/88	----	----	----	----	----	----		22.3	7.6	
07/05/88	DRY	15.4	23.7	24.1	DRY	22.1		23.7	7.9	17.6
07/25/88	----	----	----	----	----	----	DRY	25.0	7.0	15.3
08/15/88	DRY	17.9	DRY	28.1	DRY	27.8	DRY	28.5	10.2	20.1
09/14/88	DRY	DRY	DRY	DRY	DRY	DRY	DRY	19.6	8.6	17.3
09/28/88	----	----	----	----	----	----	DRY	18.1	7.9	14.7
10/07/88	----	----	----	----	----	----	DRY	12.3	0.8	
10/24/88	DRY	7.6	DRY	7.4	DRY	7.4	DRY	10.9	1.1	
11/25/88	1.7	2.1	8.1	DRY	3.7	3.0	2.6	5.2	5.2	
12/27/88	0.3	1.8	7.1	FROZEN	1.8	0.9	1.0	UNSAFE	ACCESS	
01/05/89	FROZEN	0.2	5.9	FROZEN	2.0	0.0	FROZEN	0.9	2.2	
02/14/89	0.9	0.6	4.5	FROZEN	FROZEN	0.6	FROZEN	0.8	4.0	
AVERAGES	7.31	7.71	10.8	15.6	4.88	9.81	1.80	14.2	5.7	17.0

STATION 1 - MAHICAN BROOK
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4 - LILY BROOK INLET
5 - DUCK POND BROOK
6 - OUTLET
8 - INLET ABOVE BEAN HILL
7S - DEEP HOLE SURFACE
7B - DEEP HOLE BOTTOM
TH - THERMOCLINE

TRIBUTARIES WERE SAMPLED ON A MONTHLY BASIS.

STOCKBRIDGE BOWL, STOCKBRIDGE, MASSACHUSETTS

DISSOLVED OXYGEN (mg/l) TABLE

	STATION									
DATE	1	2	3	4	5	6	8	7S	7B	TH
03/17/88	18.8	18.2	18.0	15.0	13.8	17.4		19.0	3.5	
04/21/88	11.1	11.4	11.2	11.2	10.1	11.8		11.6	11.2	
05/17/88	----	----	----	----	----	----		10.9	2.3	
05/26/88		D.O.	PROBE	FAILURE						
06/14/88	9.1	9.6	8.6	8.6	DRY	8.3		9.0	5.2	7.7
06/28/88	----	----	----	----	----	----		9.1	0.0	13.4
07/05/88	DRY	9.6	8.7	9.5	DRY	8.4		9.3	0.0	8.9
07/25/88	----	----	----	----	----	----	DRY	7.8	0.0	
08/15/88	DRY	9.6	DRY	9.0	DRY	DRY	DRY	14.1	0.1	1.0
09/14/88	DRY	DRY	DRY	DRY	DRY	DRY	DRY	14.5	0.0	19.9
09/28/88	----	----	----	----	----	----	DRY	9.7	0.8	0.7
10/07/88	----	----	----	----	----	----	DRY	12.3	0.8	2.6
10/24/88	DRY	12.1	DRY	12.3	DRY	12.9	DRY	10.9	1.1	
11/25/88	11.8	12.9	11.1	DRY	12.5	12.1	12.6	12.4	11.2	
12/27/88	13.7	12.3	10.4	FROZEN	12.2	13.1	13.5	UNSAFE	ACCESS	
01/05/89	FROZEN	15.3	11.3	FROZEN	10.8	14.1	FROZEN	13.7	0.0	
02/14/89	11.7	17.5	12.6	FROZEN	FROZEN	17.3	FROZEN	16.9	0.0	
AVERAGES	12.7	12.8	11.4	10.9	11.9	12.3	13.1	7.7	7.1	9.3

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7B - DEEP HOLE BOTTOM
TH - THERMOCLINE

TRIBUTARIES WERE SAMPLED
ON A MONTHLY BASIS.

TRIBUTARIES WERE SAMPLED
ON A MONTHLY BASIS.

STOCKBRIDGE BOWL, STOCKBRIDGE, MASSACHUSETTS   FECAL COLIFORM BACTERIA (#/100ml) TABLE

	STATION							
DATE	1	2	3	4	5	6	8	7S
03/17/88	(10)	(10)	(10)	(10)	(10)	(10)		(10)
04/21/88	(10)	(10)	(10)	(10)	(10)	(10)		(10)
05/17/88	--	--	--	--	--	--		(10)
05/26/88	24	26	DRY	41	14	22		(10)
06/14/88	(10)	(10)	(10)	15	DRY	(10)		(10)
06/28/88	--	--	--	--	--	--		(10)
07/05/88	DRY	(10)	266	(10)	DRY	(10)		(10)
07/25/88	--	--	--	--	--	--	DRY	10
08/15/88	DRY	10	DRY	(10)	DRY	DRY	DRY	(10)
09/14/88	DRY	DRY	DRY	DRY	DRY	DRY	DRY	(10)
09/28/88	---	---	---	---	---	---	DRY	(10)
10/07/88	---	---	---	---	---	---	DRY	(10)
10/24/88	DRY	(10)	DRY	(10)	DRY	(10)	DRY	(10)
11/25/88	(10)	(10)	(10)	DRY	(10)	(10)	DRY	UNSAFE
12/27/88	(10)	(10)	(10)	FROZEN	(10)	(10)	(10)	(10)
01/05/89	FROZEN	(10)	(10)	FROZEN	(10)	(10)	FROZEN	(10)
02/14/89	(10)	(10)	(10)	FROZEN	FROZEN	(10)	FROZEN	(10)
AVERAGES	1.6	1.7	2.3	3.0	1.6	1.3	1.0	1.2

STATION 1 - MAHICAN BROOK
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6 - OUTLET
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7S - DEEP HOLE SURFACE
7B - DEEP HOLE BOTTOM
TH - THERMOCLINE

TRIBUTARIES WERE SAMPLED ON A MONTHLY BASIS.

STOCKBRIDGE BOWL, STOCKBRIDGE, MASSACHUSETTS   FECAL STREPTOCOCCUS BACTERIA (#/100ml)

	STATION							
DATE	1	2	3	4	5	6	8	7S
03/17/88	(10)	(10)	(10)	10	(10)	20		10
04/21/88	(10)	10	230	(10)	28	128		96
05/17/88	--	--	---	--	--	---		(10)
05/26/88	50	20	DRY	110	120	40		(10)
06/14/88	190	60	50	30	DRY	220		(10)
06/28/88	---	--	--	--	---	---		(10)
07/05/88	DRY	50	50	20	DRY	50		(10)
07/25/88	---	--	--	--	---	---	DRY	(10)
08/15/88	DRY	60	DRY	20	DRY	DRY	DRY	(10)
09/14/88	DRY	DRY	DRY	DRY	DRY	DRY	DRY	(10)
09/28/88	---	---	---	---	---	---	DRY	(10)
10/07/88	---	---	---	---	---	---	DRY	(10)
10/24/88	DRY	100	DRY	10	DRY	100	DRY	20
11/25/88	(10)	(10)	(10)	DRY	20	10	DRY	(10)
12/27/88	30	(10)	100	FROZEN	40	10	40	UNSAFE
01/05/89	FROZEN	10	(10)	FROZEN	(10)	20	FROZEN	60
02/14/89	120	(10)	(10)	FROZEN	FROZEN	(10)	FROZEN	150
AVERAGES	11.9	9.1	9.3	18.6	11.8	36.9	40.0	3.5

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TRIBUTARIES WERE SAMPLED ON A MONTHLY BASIS.

STOCKBRIDGE BOWL, STOCKBRIDGE, MASSACHUSETTS

DEEP HOLE SURFACE
CHLOROPHYLL-a (mg/m3) AND SECCHI DISK DEPTHS (m)

DATE	CHLOROPHYLL	SECCHI DEPTH
03/17/88	5.4	*
04/21/88	2.8	1.7
05/17/88	9.1	1.8
05/26/88	3.5	1.5
06/14/88	2.4	3.0
06/28/88	10.0	2.9
07/05/88	0.4	2.9
07/25/88	8.0	3.0
08/15/88	4.0	4.0
08/23/88	2.0	3.0
09/14/88	7.0	3.0
09/28/88	19.0	3.0
10/07/88	8.0	2.5
10/24/88	24.0	2.0
11/25/88	16.0	1.1
12/27/88	UNSAFE	ACCESS
01/05/89	3.5	*
02/14/89	3.5	*
AVERAGES	7.8	2.4

* - MEASUREMENT NOT RECORDED

STOCKBRIDGE BOWL, STOCKBRIDGE, MASSACHUSETTS TOTAL PHOSPHORUS (mg/l) TABLE

	STATION									
DATE	1	2	3	4	5	6	8	7S	7B	TH
03/17/88	(0.001)	0.004	0.046	0.016	0.007	0.009		0.017	0.002	
04/21/88	0.002	0.069	0.036	0.039	0.016	0.023		0.036	0.068	
05/17/88	-----	-----	-----	-----	-----	-----		0.012	0.018	
05/26/88	0.003	0.016	DRY	0.017	0.004	0.018		0.010	0.037	
06/14/88	0.027	0.016	0.088	0.052	DRY	0.151		0.010	0.093	0.192
06/28/88	-----	-----	-----	-----	-----	-----		(0.001)	0.109	0.045
07/05/88	DRY	0.029	0.036	0.015	DRY	0.025		(0.001)	0.078	0.056
07/25/88	-----	-----	-----	-----	-----	-----	DRY	(0.001)	0.230	
08/15/88	DRY	0.010	DRY	0.040	DRY	DRY	DRY	0.010	0.360	0.020
09/14/88	DRY	DRY	DRY	DRY	DRY	DRY	DRY	0.370	1.160	0.310
09/28/88	-----	-----	-----	-----	-----	-----	DRY	(0.001)	0.449	0.059
10/07/88	-----	-----	-----	-----	-----	-----	DRY	(0.001)	0.082	0.083
10/24/88	DRY	(0.001)	DRY	(0.001)	DRY	(0.001)	DRY	(0.001)	(0.001)	
11/25/88	(0.001)	0.146	0.002	DRY	(0.001)	0.146	0.163	0.120	0.082	
12/27/88	(0.001)	(0.001)	(0.001)	FROZEN	(0.001)	(0.001)	0.087	UNSAFE	ACCESS	
01/05/89	FROZEN	0.137	(0.001)	FROZEN	(0.001)	(0.001)	FROZEN	0.019	0.016	
02/14/89	(0.001)	(0.001)	(0.001)	FROZEN	FROZEN	(0.001)	FROZEN	(0.001)	(0.001)	
AVERAGES	0.005	0.039	0.023	0.023	0.005	0.036	0.125	0.038	0.183	0.102

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TH - THERMOCLINE

TRIBUTARIES WERE SAMPLED ON A MONTHLY BASIS.

LYCOTT

STOCKBRIDGE BOWL, STOCKBRIDGE, MASSACHUSETTS NITRATE NITROGEN (mg/l) TABLE

	STATION									
DATE	1	2	3	4	5	6	8	7S	7B	TH
03/17/88	0.40	0.20	1.80	0.40	0.30	0.20		(0.10)	0.10	
04/21/88	0.50	0.30	1.50	0.20	0.20	(0.10)		(0.10)	(0.10)	
05/17/88	----	----	----	----	----	----		(0.10)	(0.10)	
05/26/88	(0.10)	(0.10)	DRY	(0.10)	(0.10)	(0.10)		(0.10)	(0.10)	
06/14/88	0.16	0.29	2.00	0.11	DRY	0.12		0.11	0.11	0.11
06/28/88	----	----	----	----	----	----		(0.10)	(0.10)	(0.10)
07/05/88	DRY	0.42	1.90	0.25	DRY	0.17		0.17	0.14	0.12
07/25/88	----	----	----	----	----	----	DRY	(0.10)	(0.10)	
08/15/88	DRY	(0.10)	DRY	(0.10)	DRY	DRY	DRY	(0.10)	(0.10)	(0.10)
09/14/88	DRY	DRY	DRY	DRY	DRY	DRY	DRY	(0.10)	(0.10)	(0.10)
09/28/88	----	----	----	----	----	----	DRY	(0.10)	(0.10)	(0.10)
10/07/88	----	----	----	----	----	----	DRY	1.10	1.30	1.60
10/24/88	DRY	(0.10)	DRY	(0.10)	DRY	(0.10)	DRY	(0.10)	(0.10)	
11/25/88	0.42	0.24	1.90	DRY	0.44	(0.10)	(0.10)	0.15	(0.10)	
12/27/88	0.26	(0.10)	0.84	FROZEN	0.10	(0.10)	(0.10)	UNSAFE	ACCESS	
01/05/89	FROZEN	(0.10)	0.74	FROZEN	0.12	(0.10)	FROZEN	(0.10)	(0.10)	
02/14/89	1.40	0.41	1.20	FROZEN	FROZEN	0.22	FROZEN	0.14	0.21	
AVERAGES	0.46	0.17	1.49	0.17	0.21	0.13	0.10	0.17	0.17	0.29

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TH - THERMOCLINE

TRIBUTARIES WERE SAMPLED ON A MONTHLY BASIS.

STOCKBRIDGE BOWL, STOCKBRIDGE, MASSACHUSETTS AMMONIA NITROGEN (mg/l) TABLE

	STATION									
DATE	1	2	3	4	5	6	8	7S	7B	TH
03/17/88	0.018	0.010	0.023	0.103	0.054	0.024		0.126	0.587	
04/21/88	0.012	0.011	0.010	0.033	0.035	0.037		0.075	0.085	
05/17/88	-----	-----	-----	-----	-----	-----		0.026	0.223	
05/26/88	0.105	0.024	DRY	0.029	0.040	0.075		0.014	0.443	
06/14/88	0.056	0.028	0.127	0.044	DRY	0.051		0.027	0.762	0.032
06/28/88	-----	-----	-----	-----	-----	-----		0.008	0.643	0.006
07/05/88	DRY	0.031	0.073	0.043	DRY	0.033		0.026	0.483	0.022
07/25/88	-----	-----	-----	-----	-----	-----	DRY	0.052	2.130	
08/15/88	DRY	0.019	DRY	0.071	DRY	DRY	DRY	0.019	2.600	
09/14/88	DRY	DRY	DRY	DRY	DRY	DRY	DRY	0.016	2.250	0.014
09/28/88	-----	-----	-----	-----	-----	-----	DRY	0.022	3.030	0.126
10/07/88	-----	-----	-----	-----	-----	-----	DRY	0.115	1.730	0.584
10/24/88	DRY	0.007	DRY	0.012	DRY	0.007	DRY	0.090	0.006	
11/25/88	0.063	0.024	0.017	DRY	0.022	0.016	0.011	0.013	0.012	
12/27/88	0.016	0.018	0.022	FROZEN	0.032	0.023	0.035	UNSAFE	ACCESS	
01/05/89	FROZEN	0.022	0.016	FROZEN	0.007	0.011	FROZEN	0.015	0.013	
02/14/89	0.048	0.015	0.010	FROZEN	FROZEN	0.022	FROZEN	0.011	0.083	
AVERAGES	0.045	0.019	0.037	0.047	0.032	0.029	0.023	0.040	0.987	0.114

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TH - THERMOCLINE

TRIBUTARIES WERE SAMPLED ON A MONTHLY BASIS.

STOCKBRIDGE BOWL, STOCKBRIDGE, MASSACHUSETTS TOTAL KJELDAHL NITROGEN (mg/l) TABLE

	STATION									
DATE	1	2	3	4	5	6	8	7S	7B	TH
03/17/88	(0.10)	0.17	(0.10)	0.21	(0.10)	0.28		0.54	1.00	
04/21/88	(0.10)	(0.10)	(0.10)	0.24	(0.10)	0.18		0.31	0.53	
05/17/88	----	----	----	----	----	----		0.16	0.33	
05/26/88	0.25	0.26	DRY	0.29	0.22	0.29		0.21	0.74	
06/14/88	0.19	(0.10)	0.36	0.38	DRY	0.29		0.17	0.90	0.25
06/28/88	----	----	----	----	----	----		0.12	0.88	0.19
07/05/88	DRY	(0.10)	0.41	0.23	DRY	0.25		0.10	0.51	0.11
07/25/88	----	----	----	----	----	----	DRY	0.31	2.60	
08/15/88	DRY	0.31	DRY	0.40	DRY	DRY	DRY	0.33	4.80	
09/14/88	DRY	DRY	DRY	DRY	DRY	DRY	DRY	0.13	2.25	0.11
09/28/88	----	----	----	----	----	----	DRY	0.20	3.10	0.34
10/07/88	----	----	----	----	----	----	DRY	0.11	1.80	0.66
10/24/88	DRY	(0.10)	DRY	0.12	DRY	0.22	DRY	0.18	0.56	
11/25/88	0.38	0.30	0.22	DRY	0.29	0.36	0.20	0.45	0.53	
12/27/88	0.14	(0.10)	(0.10)	FROZEN	(0.10)	0.17	0.10	UNSAFE	ACCESS	
01/05/89	FROZEN	(0.10)	0.15	FROZEN	0.79	0.14	FROZEN	1.10	0.91	
02/14/89	0.62	0.27	0.25	FROZEN	FROZEN	0.26	FROZEN	1.00	0.35	
AVERAGES	0.25	0.17	0.21	0.43	0.27	0.26	0.15	0.34	1.39	0.28

STATION 1 - MAHICAN BROOK
2 - SHADOW BROOK
3 - INLET NORTH OF KRIPALU BEACH
4 - LILY BROOK INLET
5 - DUCK POND BROOK
6 - OUTLET
8 - INLET ABOVE BEAN HILL
7S - DEEP HOLE SURFACE
7B - DEEP HOLE BOTTOM
TH - THERMOCLINE

TRIBUTARIES WERE SAMPLED ON A MONTHLY BASIS.

STOCKBRIDGE BOWL, STOCKBRIDGE, MASSACHUSETTS pH (NTU) TABLE

	STATION								
DATE	1	2	3	4	5	6	8	7S	7B
03/17/88	8.1	7.8	8.0	7.9	7.7	8.1		8.0	7.5
04/21/88	7.3	7.1	7.2	7.1	7.1	7.5		7.3	7.3
05/17/88	---	---	---	---	---	---		8.4	7.8
05/26/88	8.1	7.9	DRY	8.0	7.8	8.3		8.7	7.5
06/14/88	8.4	7.1	7.3	7.0	DRY	7.8		7.9	6.8
06/28/88	---	---	---	---	---	---		9.2	7.9
07/05/88	DRY	8.3	9.0	7.7	DRY	9.3		9.1	9.2
07/25/88	---	---	---	---	---	---		8.4	7.6
08/15/88	DRY	8.2	DRY	8.2	DRY	DRY	DRY	8.2	7.2
09/14/88	DRY	DRY	DRY	DRY	DRY	DRY	DRY	8.2	7.5
09/28/88	---	---	---	---	---	---	DRY	7.0	6.1
10/07/88	---	---	---	---	---	---	DRY	8.5	7.6
10/24/88	DRY	7.1	DRY	7.0	DRY	7.4	DRY	7.7	7.3
11/25/88	7.4	7.0	7.2	DRY	7.4	7.4	7.0	7.2	7.0
12/27/88	7.1	7.1	7.0	FROZEN	7.2	7.3	7.0	UNSAFE	ACCESS
01/05/89	FROZEN	7.1	6.9	FROZEN	7.0	7.3	FROZEN	7.5	7.6
02/14/89	7.6	7.8	7.9	FROZEN	FROZEN	8.1	FROZEN	8.4	7.5
AVERAGES	7.5	7.3	7.3	7.3	7.3	7.6	7.0	7.7	7.1

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TH - THERMOCLINE

TRIBUTARIES WERE SAMPLED ON A MONTHLY BASIS.

STOCKBRIDGE BOWL, STOCKBRIDGE, MASSACHUSETTS ALKALINITY (mg/l) TABLE

	STATION									
DATE	1	2	3	4	5	6	8	7S	7B	TH
03/17/88	177	81	187	139	178	134		96	180	
04/21/88	199	99	191	148	188	139		132	128	
05/17/88	---	- -	---	---	---	---		125	130	
05/26/88	194	106	DRY	141	200	130		143	141	
06/14/88	255	123	226	141	DRY	119		97	13	154
06/28/88	---	---	---	---	---	---		134	143	26
07/05/88	DRY	140	210	130	DRY	100		120	140	110
07/25/88	---	---	---	---	---	---	DRY	140	180	
08/15/88	DRY	130	DRY	100	DRY	DRY	DRY	112	150	112
09/14/88	DRY	DRY	DRY	DRY	DRY	DRY	DRY	104	146	120
09/28/88	---	---	---	---	---	---	DRY	126	156	153
10/07/88	---	---	---	---	---	---	DRY	116	145	143
10/24/88	DRY	120	DRY	150	DRY	130	DRY	120	130	
11/25/88	180	86	210	DRY	190	120	27	120	130	
12/27/88	180	110	200	FROZEN	200	140	58	UNSAFE	ACCESS	
01/05/89	FROZEN	100	190	FROZEN	230	130	FROZEN	130	120	
02/14/89	230	120	180	FROZEN	FROZEN	130	FROZEN	120	120	
AVERAGES	202	110	199	136	198	119	43	120	134	117

STATION 1 - MAHICAN BROOK
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7S - DEEP HOLE SURFACE
7B - DEEP HOLE BOTTOM
TH - THERMOCLINE

TRIBUTARIES WERE SAMPLED ON A MONTHLY BASIS.

STOCKBRIDGE BOWL, STOCKBRIDGE, MASSACHUSETTS CHLORIDE (mg/l) TABLE

DATE	STATION 1	2	3	4	5	6	8	7S	7B	TH
03/17/88	25	11	33	21	26	16		13	25	
04/21/88	35	13	35	20	28	18		15	23	
05/17/88	--	--	--	--	--	--		16	16	
05/26/88	21	9	DRY	17	22	18		17	16	
06/14/88	105	20	36	21	DRY	20		27	23	20
06/28/88	---	--	--	--	---	--		16	16	16
07/05/88	DRY	22	47	20	DRY	15		25	17	17
07/25/88	---	--	--	--	---	--	DRY	20	18	
08/15/88	DRY	17	DRY	15	DRY	DRY	DRY	22	12	
09/14/88	DRY	DRY	DRY	DRY	DRY	DRY	DRY	16	16	18
09/28/88	---	---	---	---	---	---	DRY	20	20	20
10/07/88	---	---	---	---	---	---	DRY	19	16	16
10/24/88	DRY	7	DRY	15	DRY	16	DRY	8	25	
11/25/88	30	10	25	DRY	20	18	11	18	18	
12/27/88	28	16	57	FROZEN	75	52	16	UNSAFE	ACCESS	
01/05/89	FROZEN	21	36	FROZEN	23	28	FROZEN	26	27	
02/14/89	55	12	47	FROZEN	FROZEN	20	FROZEN	16	18	
AVERAGES	43	47	40	18	32	22	14	18	19	17

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TRIBUTARIES WERE SAMPLED ON A MONTHLY BASIS.

LYCOTT

STOCKBRIDGE BOWL, STOCKBRIDGE, MASSACHUSETTS CONDUCTANCE (NTU) TABLE

	STATION									
DATE	1	2	3	4	5	6	8	7S	7B	TH
03/17/88	366	189	439	322	416	302		207	340	
04/21/88	367	312	405	282	354	272		253	260	
05/17/88	---	---	---	---	---	---		310	339	
05/26/88	416	237	DRY	326	467	333		303	323	
06/14/88	485	162	321	183	DRY	180		192	193	170
06/28/88	---	---	---	---	---	---		220	220	190
07/05/88	DRY	220	470	230	DRY	200		280	160	220
07/25/88	---	---	---	---	---	---	DRY	290	340	
08/15/88	DRY	210	DRY	220	DRY	DRY	DRY	150	190	
09/14/88	DRY	DRY	DRY	DRY	DRY	DRY	DRY	190	230	200
09/28/88	---	---	---	---	---	---	DRY	210	270	250
10/07/88	---	---	---	---	---	---	DRY	210	250	250
10/24/88	DRY	240	DRY	330	DRY	300	DRY	280	300	
11/25/88	380	190	460	DRY	400	270	96	270	260	
12/27/88	430	240	480	FROZEN	490	330	150	UNSAFE	ACCESS	
01/05/89	FROZEN	250	460	FROZEN	490	310	FROZEN	300	260	
02/14/89	620	290	540	FROZEN	FROZEN	330	FROZEN	300	340	
AVERAGES	438	231	447	262	436	275	123	245	264	213

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TRIBUTARIES WERE SAMPLED
ON A MONTHLY BASIS.

LYCOTT

STOCKBRIDGE BOWL, STOCKBRIDGE, MASSACHUSETTS TOTAL SUSPENDED SOLIDS (mg/l) TABLE

	STATION									
DATE	1	2	3	4	5	6	8	7S	7B	TH
03/17/88	1.5	4.0	3.0	4.0	13.3	3.5		4.0	23.0	
04/21/88	0.5	2.0	1.0	8.0	22.0	3.5		4.0	17.0	
05/17/88	---	---	---	---	----	---		4.3	5.0	
05/26/88	2.5	4.0	DRY	5.3	15.0	4.6		3.0	6.4	
06/14/88	3.0	2.0	10.0	5.3	DRY	3.3		2.5	10.0	3.0
06/28/88	---	---	---	---	---	---		2.5	8.0	9.0
07/05/88	DRY	4.5	5.0	5.3	DRY	3.5		3.0	28.0	7.0
07/25/88	---	---	---	---	---	---	DRY	6.7	14.0	
08/15/88	DRY	1.0	DRY	3.0	DRY	DRY	DRY	6.0	4.0	
09/14/88	DRY	DRY	DRY	DRY	DRY	DRY	DRY	8.0	52.0	24.0
09/28/88	---	---	---	---	---	---	DRY	6.0	30.0	12.0
10/07/88	---	---	---	---	---	---	DRY	2.0	8.0	4.0
10/24/88	DRY	1.5	DRY	2.0	DRY	1.5	DRY	1.0	2.0	
11/25/88	6.0	6.5	5.5	DRY	4.5	8.5	20.0	6.5	8.5	
12/27/88	3.5	2.5	40.0	FROZEN	22.0	5.5	21.0	UNSAFE	ACCESS	
01/05/89	FROZEN	16.0	7.5	FROZEN	3.5	18.0	FROZEN	7.5	6.5	
02/14/89	250	4.0	20.0	FROZEN	FROZEN	7.0	FROZEN	4.5	34.0	
AVERAGES	38.1	4.4	11.5	6.9	13.4	5.4	20.5	5.0	16.0	9.0

STATION 1 - MAHICAN BROOK
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TRIBUTARIES WERE SAMPLED ON A MONTHLY BASIS.

STOCKBRIDGE BOWL, STOCKBRIDGE, MASSACHUSETTS TURBIDITY (NTU) TABLE

	STATION									
DATE	1	2	3	4	5	6	8	7S	7B	TH
03/17/88	1.2	1.7	1.2	2.2	6.0	2.8		1.6	7.0	
04/21/88	3.4	3.3	3.5	4.4	5.0	4.1		4.2	6.5	
05/17/88	---	---	---	---	---	---		2.1	2.4	
05/26/88	2.1	2.8	DRY	3.1	3.9	3.4		2.9	4.1	
06/14/88	3.5	3.5	6.4	4.8	DRY	3.4		2.9	4.1	3.0
06/28/88	---	---	---	---	---	---		3.1	7.0	10.0
07/05/88	DRY	2.7	3.4	4.5	DRY	2.8		2.7	7.4	3.0
07/25/88	---	---	---	---	---	---	DRY	3.0	8.3	
08/15/88	DRY	2.4	DRY	3.1	DRY	DRY	DRY	2.8	6.9	
09/14/88	DRY	DRY	DRY	DRY	DRY	DRY	DRY	3.7	5.5	3.0
09/28/88	---	---	---	---	---	---	DRY	5.2	8.9	9.0
10/07/88	---	---	---	---	---	---	DRY	3.6	4.5	3.0
10/24/88	DRY	2.6	DRY	2.8	DRY	3.8	DRY	4.2	3.9	
11/25/88	3.9	3.7	3.4	DRY	3.7	6.6	3.6	5.5	5.8	
12/27/88	2.4	2.6	4.3	FROZEN	6.2	5.8	2.9	UNSAFE	ACCESS	
01/05/89	FROZEN	8.3	3.3	FROZEN	7.4	6.1	FROZEN	5.4	3.1	
02/14/89	8.9	3.9	5.9	FROZEN	FROZEN	4.1	FROZEN	3.9	8.8	
AVERAGES	3.6	3.4	3.9	3.6	5.4	4.1	3.3	4.0	6.0	5.0

STATION 1 - MAHICAN BROOK
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TRIBUTARIES WERE SAMPLED
ON A MONTHLY BASIS.

APPENDIX F

STOCKBRIDGE BOWL, MONITORING WELLS

LYCOTT ENVIRONMENTAL RESEARCH

WELL NO.	DATE	SAMPLE NUMBER	CONDUCT-ANCE (mhos)	TKN (mg/l)	AMMONIA NITROGEN (mg/l)	DO (mg/l)	SOLUABLE PHOS. (mg/l)	TEMP (C)	NITRATE (mg/l)	Cl (mg/l)	FECAL COLIFORM (#/100ml)	FECAL STREP (#/100ml)
1D	12-Aug-88	88005814	480	0.84	0.007		0.020		(0.01)	145	(10)	5,200
1D	24-Oct-88	88007699	680	(0.10)	0.010	6.08	0.016	11.9	(0.10)			
1D	05-Jan-89	89000105	600	1.20	0.045	6.75	0.064	6.8	(0.10)	65	40	40
1D	31-May-89	89003542	550	0.50	0.060		(0.001)	12.3	(0.10)	45	(10)	40
1S	12-Aug-88	88005815	500	0.80	0.010		0.009		0.10	50	(10)	(10)
1S	05-Jan-89	89000106	920	(0.10)	0.030	8.95	0.030	5.1	0.39	140	40	40
1S	31-May-89	89003543	990	1.60	0.068		(0.001)	12.3	(0.10)	190	(10)	(10)
2D	12-Aug-88	88005816	380	0.11	0.012		0.004		0.33	52	10	400
2D	24-Oct-88	88007700	500	(0.10)	0.006	8.83	(0.001)	11.6	0.52			
2D	23-Dec-88	88009374	480	(0.10)	0.042	9.71	(0.001)	4.5	(0.10)			
2D	31-May-89	89003539	610	0.42	0.047		(0.001)	12.0	0.11	48	(10)	(10)
2S	12-Aug-88	88005817	510	0.48	0.032		(0.001)		0.35	92	240	200
2S	23-Dec-88	88009375	260	0.25	0.040	11.05	(0.001)	3.2	(0.10)			
2S	05-Jan-89	89000108	990	0.45	0.030	10.79	0.002	2.0	0.26	93	10	(10)
2S	31-May-89	89003540	1200	1.00	0.235		(0.001)	12.0	0.11	120	(10)	(10)
3D	12-Aug-88	88005819	220	0.52	0.069	8.65	0.030	2.6	0.90	7	(10)	10
3D	26-Oct-88	88007759	700	0.18	0.012	9	(0.001)	11.2	(0.10)			
3D	05-Jan-89	89000110	310	0.35	0.016	8.65	(0.001)	2.6	(0.10)	36	(10)	40
3D	31-May-89	89003538	360	2.20	0.753		(0.001)	14.2	0.12	21	(10)	(10)
3S	12-Aug-88	88005820	280	0.70	0.110		(0.001)		2.20	22	120	1,400
3S	26-Oct-88	88007760	1,000	0.21	0.004	8.06	(0.001)	11.2	(0.10)			
3S	05-Jan-89	89000109	410	0.62	0.009	7.13	(0.001)	1.5	(0.10)	71	(10)	50
3S	31-May-89	89003544	320	2.50	0.920		(0.001)	14.2	0.22	10	(10)	50
4	12-Aug-88	88005818	190	2.30	1.200		(0.001)		(0.10)	12	(10)	(10)
4	24-Oct-88	88007701	330	(0.10)	0.012	9.53	0.016	12.1	(0.10)			
4	05-Jan-89	89000107	350	0.69	0.022	7.07	0.002	6.3	0.60	16	(10)	(10)
4	31-May-89	89003541	350	(0.10)	0.022		(0.001)	12.0	0.15	13	(10)	(10)

VALUES APPEARING WITHIN PARANTHESES ARE THE DETECTION LIMITS, SIGNIFYING THAT THE LEVEL PRESENT IS BELOW THE LIMIT OF DETECTION.

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APPENDIX G

Calculation of Averages - For the purposes of data analysis, Lycott calculated several different types of averages, also called means. For the most part, reported averages were simply the sum of all observations divided by the number of observations. This result was termed the "simple average." However, for means that were used to estimate total flows or nutrient loading over the year, means were "flow-weighted" and/or "time-weighted" to remove the bias of irregular sampling or irregular flows.

The rationale for this is the following. Because samples were taken once each month from October to March, and twice each month from April to September, calculating a simple average would bias the average toward conditions found from April to September. This could underestimate the yearly flow, because the summer and fall tend to have much lower flow than the winter.

Time-weighting consisted of taking an average flow for each month, and then taking an average for the two samples for bimonthly sampling periods, and using this average monthly flow to calculate a yearly average

Time-weighted mean = (Jan. flow + Feb. flow + Average March flow + Average April flow + ... + Dec. flow) / 12

Flow-weighted averages were calculated such that sample concentrations were weighted by the amount of water associated with that concentration.

Flow-weighted average = [concentration of sample 1 * sample 1 flow + concentration of sample 2 * sample 2 flow + ...] / total flow of all samples

A special mean, the geometric mean, was calculated for the Secchi disc and bacterial numbers. This mean is the product of all observations taken to the nth root, where n is the number of observations. The formula is below.

$$\text{Geometric} = [\text{Sample}_1 * \text{Sample}_2 * \ldots * \text{Sample}_n]^{\wedge(1/n)}$$

When calculating any mean, samples whose concentrations were below the level of detection were set equal to the limit of detection. For example, samples whose phosphorus concentrations were less than the detection limit 0.005 mg/l were set equal to 0.005 mg/l. However, for calculation of geometric means, samples whose values were less than the limit of detection were set equal to 1.

APPENDIX H

ANALYTICAL METHODS

Analytical methods used are found in either 40 CFR 136 Oct. 1984, for organic priority pollutants (600 series), the EPA 500 series, SW-846 3rd ed. (8000 series), or EPA Methods for Chemical analysis of Water and Wastes, March 1983. Sample preservation techniques in each manual are followed.

ACCURACY AND PRECISION

Lycott follows the philosophy and procedures in the EPA manual "Handbook for Analytical Quality Control in Water and Wastewater Laboratories" EPA 600 / 4-79-019. For those analyses performed under 40 CFR 136 i.e. organic priority pollutants, the Quality Control procedures in paragraph 8 for each method are employed. For those analyses in SW-846 3rd ed., the procedures under each method's Quality Control section are followed.

For those analyses from "Standard Methods" and "Methods for Chemical Analysis of Water and Wastes", March 1983, 10% of all samples are repeated, and 10% are spiked and re-analyzed. All accuracy and precision data are kept in laboratory notebooks. These data are then plotted on quality control charts with each successive analysis being compared with the existing upper and lower control limits.

Lycott also analyzes blind samples from a commercial supplier, and samples from EPA in addition to the EPA external Quality Assurance Program. The commercial QC samples are analyzed monthly, and the EPA QC samples are analyzed quarterly. Each analyst is provided monthly with a performance assessment on these samples.

LABORATORY INSTRUMENTATION

GAS CHROMATOGRAPH/MASS SPECTROMETER - Hewlett Packard 5995C Valveless. Packed or Capillary operation. Accuracy: +/-0.1 amu Detection Limit: microgram range to picogram range.

GAS CHROMATOGRAPH - Tracor 560
Equipped with Hall 700A Electolytic Conductivity Detector and Tracor Flame Ionization Detector.
Sensitivity: 5 x 10 - 13 Cl/sec (Hall)
4 x 10 - 11 amps (FID)

GAS CHROMATOGRAPH - Tracor 550
Equipped with dual Nickel - 63 electron capture detectors
Detection Limit: picogram range

SAMPLE CONCENTRATORS - (2) Tekmar LSC - 2
For purging volatile organics onto gas chromatographs

AUTOMATED SAMPLE PURGER - Tekmar ALS

AUTOMIC ABSORPTION SPECTROPHOTOMETER - Perkin-Elmer 1100B
Single beam instrument with air/acetylene and nitrous oxide/acetylene capability. Also equipped for cold vapor mercury determinations.

FURNACE - Perkin-Elmer HGA 700 / AS 70 Autosampler
Graphite furnace for picogram level determinations. Also equipped with As and Se electodeless discharge lamps.

SPECTROPHOTOMETER - Bausch & lomb Spectronic 88
Single beam instrument. Accuracy: <1.0 nm
Sensitivity: 0.002 abs Detection limit: microgram range.

PH/ION METERS - Fisher models 825MP and 915MP
Microprocessed units with digital readouts. Equipped with Nitrate sensing electrode. Orion model 9307 ammonia sensing electrode. Orion model 9512, and Fisher AccuHast electrode.
Accuracy: +/- 0.2 mV Sensitivity: 0.1 mV

ANALYTICAL BALANCE - Mettler H31AR
Range: 0.160 g
Accuracy: 0.1 mg
Sensitivity: 0.05 mg
Detection Limit: 0.1 mg

CONDUCTANCE METER - Yellow Springs Instruments Co. Model 35
All glass probe. Digital readout.
Accuracy: 0.05 umho
Sensitivity: 0.01 umho

LYCOTT

FLASH POINT TESTER - Boekel Model 152800
Closed cup with two speed stirrer.
Accuracy: +/- 1F
Sensitivity: +/- 0.5F

LABORATORY OVEN - Precision Scientific Model 18
Accuracy: +/- 2C
Sensitivity: +/- 0.5C

AUTOCLAVE - Pelton and Crane Model OCR
Steam or dry sterilization

INCUBATOR - Precision Scientific Model 2
Sensitivity: 0.1C

INCUBATOR BATH - Precision Scientific Model 66850
Accuracy: +/- 0.2C

TURBIDITY METER - HF Instruments Model DRT 15
Accuracy: +/- 1%
Sensitivity: 0.02 NTU

DISSOLVED OXYGEN METER - Yellow Springs Instruments Model 57
Accuracy: +/- 0.05 mg/l
Sensitivity: 0.03 mg/l

FURNACE - Thermolyne Model 1500
Range: 100-1200 C

INSTRUMENT CALIBRATION PROCEDURES

GAS CHROMATOGRAPH/MASS SPECTROMETER -

All runs made with internal standards for calibration. Instrument tuned to DRTPP daily. Benzidine and Pentachlorophenol tailing factors checked daily. Response factors updated regularly. All calculations performed by data system. Standards are from high purity (>95%) neat compounds, volatiles replaced monthly, semi-volatiles replaced every six months.

GAS CHROMATOGRAPHS -

All standard solutions are from high purity (>95%) neat compounds. Volatiles replaced monthly, and semi-volatiles replaced every six months. Instruments calibrated with standard solutions every eight hours. External standard calibration method used.

ATOMIC ABSORPTION SPECTROPHOTOMETER -

All standard solutions are from certified concentrates and checked against EPA Quality Control samples. Instrument calibration performed prior to every element determination. Recalibration is every fifteen minutes for each element. Five point calibration curves used.

SPECTROPHOTOMETER -
All standard solutions made from ACS reagent grade or better. All analyses immediately preceded by standard curve determination. Five point calibration is updated every four hours.

pH MEASUREMENTS -
Two point calibration on pH 4 and pH 10 certified buffers. Calibration updated every two hours.

SPECIFIC IONS WITH METERS -
Multipoint calibration with standard solutions made from ACS reagent grade or better. Calibration updated every two hours.

SPECIFIC CONDUCTANCE -
Electronics factory calibrated. Probe constant calculated with EPA Quality Control Solutions. Calibration checked with EPA Quality Control Solutions regularly.

FLASH POINT -
NBS traceable thermometers used. Xylene standard solution used for quality control.

ANALYTICAL BALANCE -
Calibrated by Mettler annually. Calibration checked with NBS every six months.

LABORATORY OVEN AND INCUBATORS -
Temperature recorded daily. Thermometers checked against NBS every six months.

AUTOCLAVE -
Temperature recorded from each usage.

TURBIDITY METER -
Calibrated in EPA certified solutions every two hours.

CALCULATION PROCEDURES

GAS CHROMATOGRAPH/MASS SPECTROMETER -

All calculations are performed by the data system based on input information. Data are retained on disc file.

GAS CHROMATOGRAPHS -

All calculations are performed by a Hewlett-Packard reporting integrator based on input information. Chromatograms are retained in laboratory notebooks.

ATOMIC ABSORPTION SPECTROPHOTOMETER -

All calculations are performed from a linear calibration curve using linear regression analysis internal in the instrument. All data are retained in laboratory notebooks.

SPECTROPHOTOMETER -

Same as the Atomic Absorption above except that the regression is done on a calculator.

ION SELECTIVE ELECTRODE -

Readings are taken directly by the instrument which also performs the necessary calculations.

LYCOTT

APPENDIX I

October 24, 1988

Dr. Alex Duran
Lycott Environmental Research, Inc.
600 Charlton Street
South Bridge, MA 01550

Re: Stockbridge Bowl Lake

Dear Dr. Duran:

Thank you for your letter of October 11, 1988 and the information related to Stockbridge Bowl Lake.

The data indicates a relatively high oxygen depletion rate of around .36 mg/l/day during the critical spring period. Based on our sizing approach, we would propose a LIMNO system supplying 1090 kg/day.

We are pleased to enclose the following for your consideration:

1. LIMNO Project Proposal
2. LIMNO Performance/Cost Estimates
3. Map of Proposed LIMNO/Compressor Sites
4. LIMNO Leaflet
5. Atlas Copco GA 30-37 Compressor Leaflet
6. Aqua Technique Conditions of Sale

In that there is consideration of a trout fishery in the lake, we would call your attention to a very successful LIMNO project done this past spring in California. At the time of the start-up on April 8, 1988, oxygen levels at the bottom had dropped to 1.8 mg/l. From April 12, and throughout the summer oxygen levels at the bottom remained over 6.0 mg/l.

At Notch Reservoir, a water supply reservoir in North Adams, MA, a LIMNO unit was installed on July 27, 1988 when the oxygen level at the bottom was 2.0 mg/l. By mid-August, the oxygen level was at 5.5 mg/l compared to near zero a year earlier.

We would welcome the opportunity to discuss this proposal in more detail and to provide any assistance in presenting the LIMNO system to your client.

Sincerely,

R. S. Genley
Sales Manager

RSG:blr
cc: J. Natalino

LIMNO - Project Proposal

Customer: (Town of Stockbridge) Date: 10/24/88
Lycott Environmental Research Inc.
600 Charlton Street
Southbridge, MA 01550

Contact: Dr. Alex Duran
Tel No.: 508-765-0101

Project: Stockbridge Bowl Lake Hypolimnetic Aeration

*Oxygen to be Supplied 1090 kg/day

Aqua Technique Supplied LIMNO System Includes:

Project Engineering

(1) LIMNO Unit Model 30 52 100
33 Ft. High 17 Ft. O.D.

(1) Air Cooled, Base Mounted, Oil-Flooded, Rotary Screw Air Compressor w/Aftercooler and Separator, Model GA 30-100

200 CFM at 60 psig 40 HP Motor

Accessory Items - Air Supply Lines, Anchors, Regulating System, Oil Separator Filter, Air Receiver

Installation Supervision for LIMNO Unit and Expenses

Price: $ 94,220.00

Customer (Contractor) Supplied Items and Services:

Installation Labor and Supervision
Diver Team
Boats
Crane
Plumbing and Electrical Services and Materials
Freight

Estimated Price: $ 10,500.00

Total Estimated Price: $ 104,720.00
(Not Including State or Local Taxes Where Applicable)

NOTE: This price does not include an enclosure for the compressor, bringing electrical power to the site, trenching of air lines or other items not specifically stated.

Price Valid Until: 4/30/89

Terms: 20% with order; 70% on shipment of materials, Net 30 days
Balance on project completion, Net 30 days.

Material: F.O.B. Factory (Estimated Cost included in Proposal)

Delivery: 8-10 weeks

*The oxygen supplied includes that which may be consumed internally in the unit by the chemical oxygen demand (C.O.D.). The system size is conditional on the validity of the data and no claims are made on the response of the lake/reservoir to the system's operation.

R. S. Geney
Sales Manager

STOCKBRIDGE BOWL LAKE

LIMNO Performance/Cost Estimates

kg of O_2 per day	Power (kW) Consumption	kg O_2/ kW hr.	Oper. Cost/ kg O_2/Day (.07/kW hr.)	Oper. Cost/ Day (.07/kW hr.)	Total Project Cost	Installed Cost kg O_2/Day
1090	25.5	1.78	$ .04	$ 42.85	$104,720	$ 96

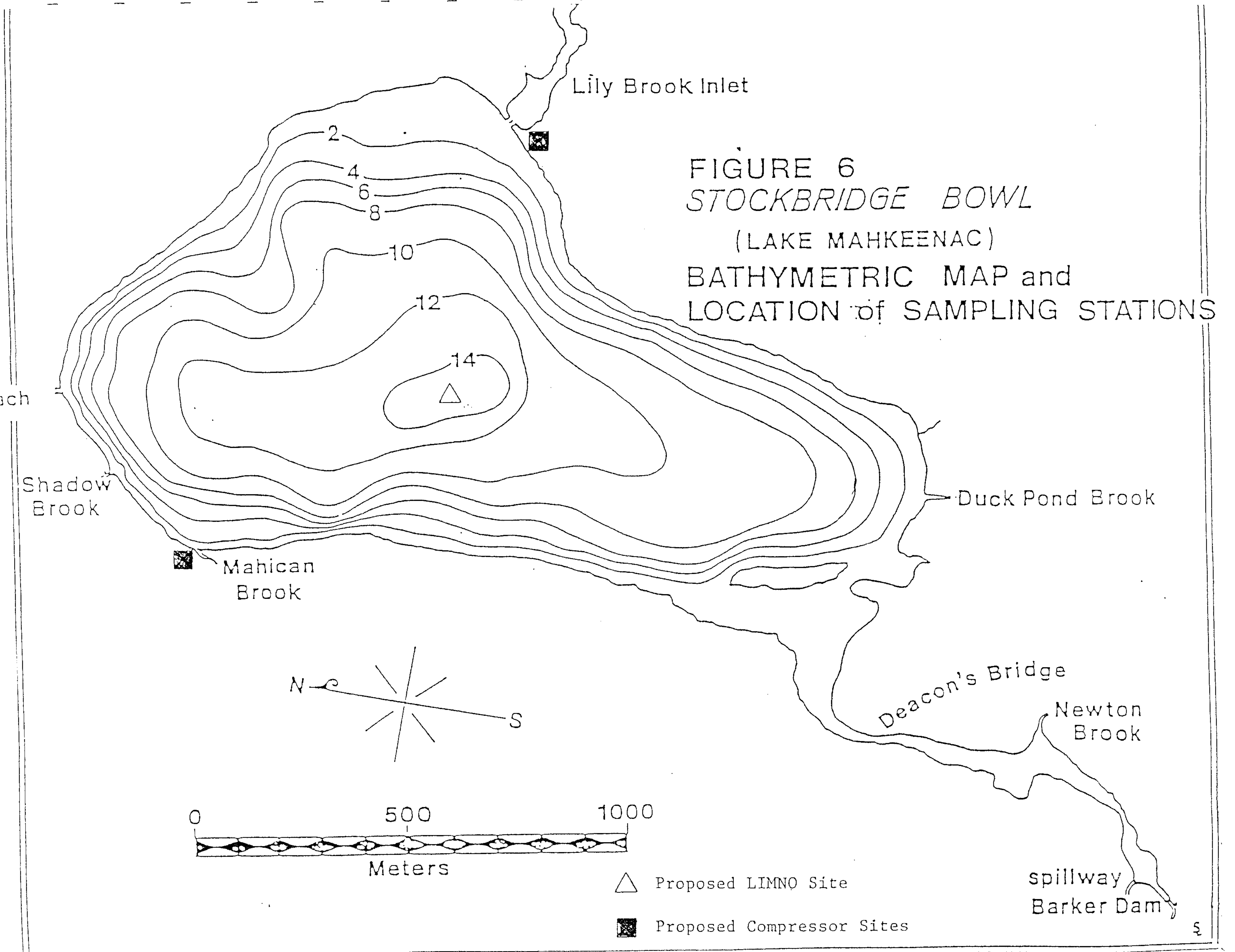
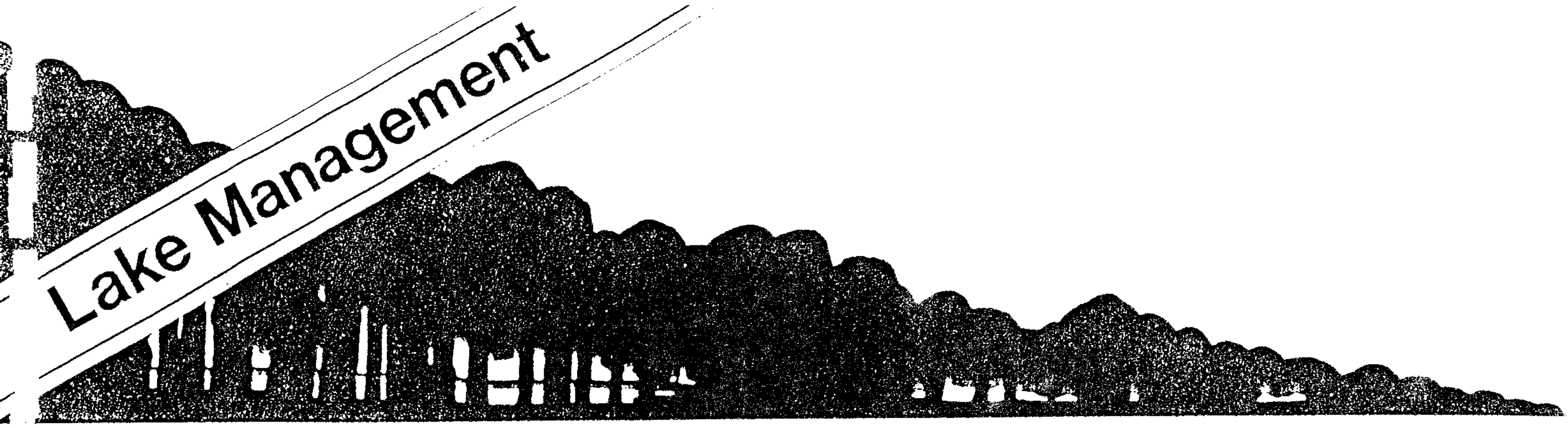


FIGURE 6
STOCKBRIDGE BOWL
(LAKE MAHKEENAC)
BATHYMETRIC MAP and
LOCATION of SAMPLING STATIONS



Cure for degraded waters

Our lakes and watercourses have long been victims of pollution.
Even freshwater basins and reservoirs can be polluted through inflow water containing phosphorus and nitrogen. In addition, airborne contaminations can contribute. All these types of water may need help to recover.
The problem is often oxygen shortage. If nothing is done, the lake's condition frequently becomes worse with little or no oxygen in the bottom strata, which puts all its biological life at stake.
The hypolimnion aerator LIMNO offers an effective treatment for deep lakes which have become oxygen deficient.

LIMNO

Aqua Technique

Oxygen – basic element of life

Oxygen is the most important single element involved in the total dynamic balance of the ecosystem. Without oxygen, no lake can survive.

In a healthy lake or reservoir, there is a balance between the oxygen supply – from the atmosphere and by photosynthesis – and the oxygen consumed in the process of decomposition and mineralisation of organic matter.

In a temperate climate, and especially in stratified lakes and reservoirs, the distribution of oxygen is highly dependent on the characteristics of the lake such as the relation between the volume of the warmer, upper layer (the epilimnion) and the cooler bottom water body (the hypolimnion).

By studying the concentration and distribution of dissolved oxygen in a lake, you get a good picture of its general health status.

The amount of oxygen consumed in the hypolimnion during a stagnation period – the oxygen deficit – provides an indirect estimate of the productivity of the lake.

A polluted lake produces an excess of organic matter due to a too rich nutrient supply. The decomposition of this matter requires more oxygen than the ecosystem may be able to provide.

If the oxygen in the hypolimnion is completely consumed, the condition becomes critical:

Fermentation processes transform both organic and inorganic matter. Methane and hydrogen sulphide are produced and inorganic nutrients such as phosphorus and nitrogen, are relased and dissolved in the water and then distributed during the lake's periods of circulation. This increases the nutrient concentrations and the productivity escalates even more.

The Atlas Copco LIMNO aerator has been developed to supply oxygen to the hypolimnion without disturbing the thermal stratification. In this way a high oxygen concentration is maintained throughout the stagnation periods and the release of nutrients from the sediment is minimized.

The LIMNO aeration system

The LIMNO system is especially designed for oxygenation of stratified lakes and reservoirs.
It is very important to make a careful limnological investigation and state a definite diagnosis of the lake's condition before any LIMNO installation can be made. Only then can the adequate number, size and location of the aerators be determined.

How does it work?

The LIMNO aerator consists of two concentric tubes, covered by a dome, and interconnected by radial walls.

The outer tube has a number of outlets close to the lower end. From the dome a venting pipe connects the unit with the atmosphere.

The unit is permanently anchored to the bottom by means of concrete weights and nylon bands attached to the outer tube and the lower ring frame.

During operation and standstill the unit is held upright by the air cushion trapped in the dome top.
A compressor on the shore supplies the aerator with compressed air via a hose placed on the lake bottom.

Through the primary diffusor, placed under the intake cone, the airflow is disintegrated into fine air bubbles.

As the bubbles rise through the inner tube, an upward water flow is generated – the airlift pump principle.

During the intense contact between the air bubbles and the water, oxygen is transferred to the water.

When the water spreads over the rim of the inner tube, the flow velocity is reduced. The air then separates from the water and leaves the aerator via the venting pipe.

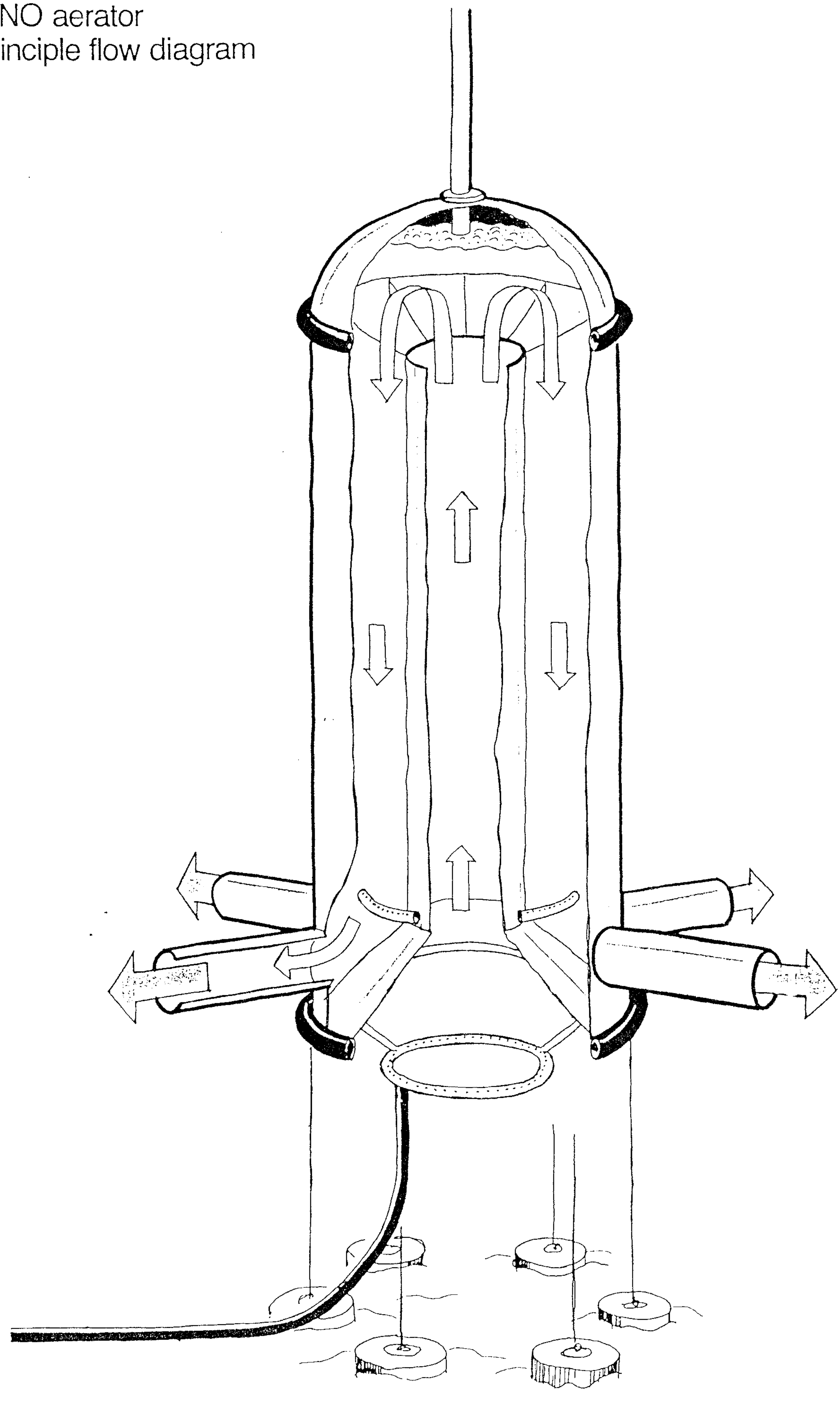
The water flow then turns downward through the space between the tubes and leaves the unit as a number of horizontal jets through the outlets and spreads in the hypolimnion.

Compressed air is also supplied to a secondary, ring-shaped air diffusor placed between the tube walls in the lower part of the unit. The air bubbles from this diffusor meet the downward water flow and in this way optimizes the aerator's oxygen transfer.

The airflow from the secondary diffusor is collected at the top of the unit and released to the atmosphere through the venting pipe, which is provided with a buoy close to the surface.

The oxygen-poor water just above the sediment is drawn towards and through the aerator becoming oxygenated and then spread horizontally through the hypolimnion. In this way, the oxygen is supplied for the required normal decomposition and mineralisation of organic sediment.

LIMNO aerator
– principle flow diagram



Design features

The new LIMNO aerator is made of flexible material which greatly facilitates transport and installation.

All components of a LIMNO unit are of non-corrosive material, mainly plastic. The tubes, walls and top dome as well as the inlet cone and outlet arms are of PVC-coated polyester fabric.

This material meets the following standards: BS No. 3424, DIN No. 53352 and 53354, Fed-Std-5041 and 5100.

All joints are made by automatic, high-frequency welding. Reinforcement strips prevent tearing damages.

The upper and lower support ring frames are made of polyethylene and so are the venting pipe and the diffusors.

The air supply hose is of polyethylene. Depending on the diameter required it is anchored to the bottom of the lake either by a lead wire, wound around it (small diameters), or by concrete blocks secured by nylon bands.

LIMNO FABRIC DATA	Outer tube	Inner tube and radial walls
Overall weight	1 000 g/m²	670 g/m²
Warp tensile	4 400 N/50 mm	3 000 N/50 mm

Capacity range and dimensions

All LIMNO units are designed and manufactured to the customer's specifications to fit a particular project. The table gives a general idea of the capacity range within which LIMNO aerators work and their possible dimensions. Bigger units are designed on request.

		Range	Examples				
Oxygenation	kg/day	100–1600	100	200	400	800	1600
capacity	lb/day	220–3500	220	440	880	1760	3500
Air consumption	l/s	7–112	7	14	28	56	112
(free air)	cfm	15–240	15	30	60	120	240
Diameter	m	2–8.8	2.0	2.9	4.3	5.8	8.8
	ft	6.6–29	6.6	9.5	14	19	29
Height	m	5–20	15	15	15	15	15
	ft	16–66	66	66	66	66	66
Weight	kg	250–1300	250	350	600	900	1300
(excl. anchor)	lb	550–2860	550	770	1320	1980	2860
Anchoring weight	kg	350–4500	350	500	1000	2000	4500
(submerged)	lb	770–9900	770	1100	2200	4400	9900

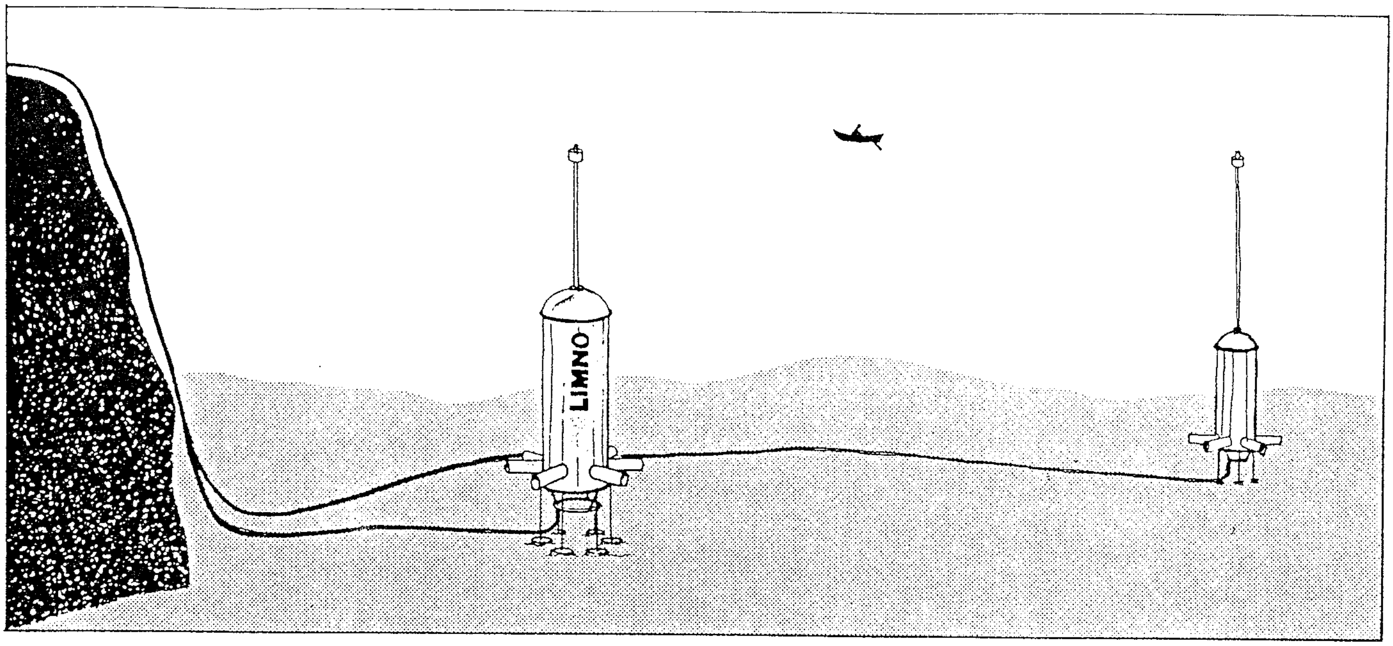
Installation

Atlas Copco offers to supervise the installation of LIMNO plants – either carried out by our own people or the customer's personnel.

The equipment is delivered to the lake shore. Of course, the LIMNO unit comes folded, packed in a box. A fork lift, or the like, is used for the unloading and for launching the bucket-shaped, concrete anchor weights into the water at a depth of about one meter, where they stay afloat. From here they can be tugged to their determined location, filled with water and sunk to the bottom.

On a suitable free space on the shore the LIMNO unit is unfolded and completed by mounting the accessories to the body. Then it is launched, tugged into position, attached to the anchors and pulled down and secured by a diving team.

The air supply line comes in a roll, either pre-loaded with lead wire, wound around it, or successively provided with concrete anchor weights as it is laid out from a raft. After connection and control, the installation is ready for immediate operation.



LIMNO gives optimum oxygen transfer efficiency

A high oxygen transfer efficiency of an aerator unit is possible to obtain by having long contact times between air and water resulting in low flow velocities. However, for low flow velocities, the oxygenation capacity, e.g. ton/day, decreases. For a given capacity demanded, the number or the size of units installed then has to be increased. Thus the investment cost increases.

So, although a high transfer efficiency results in a low running cost, it is of course the total cost that is important.

Main factors contributing to oxygenation efficiency:

1 According to Henry's law, the solubility of a gas in a liquid increases with the pressure. Thus, the deeper the LIMNO installation, the higher the hydrostatic pressure and the more oxygen can be dissolved (per unit of liquid volume). In most aeration projects LIMNO is installed just above the bottom taking maximum advantage of this law.

2 Solubility of oxygen in water is affected by the temperature and increases considerably in cold water. The LIMNO aerator runs in the cold hypolimnion and benefits from its low temperature.

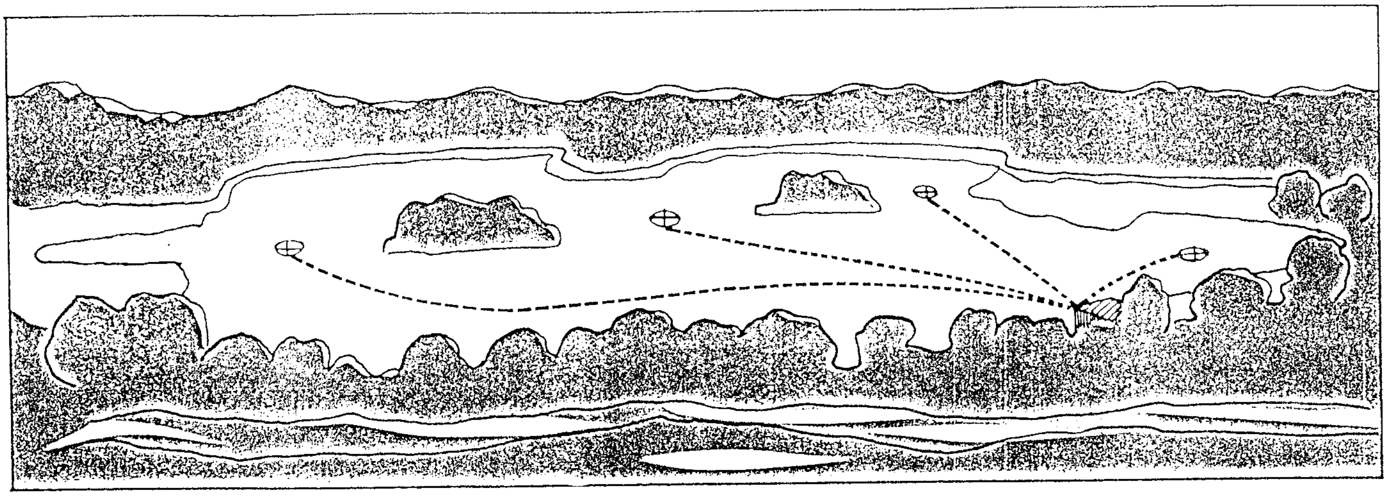
3 The oxygen transfer efficiency depends on the oxygen concentration of the intake water. The more the intake water is depleted of oxygen, the better the transfer efficiency.

4 Likewise, the lower oxygen concentration required of the aerated water, the higher the efficiency.

5 The secondary air diffusor not only gives a favourable oxygen transfer due to the counterflow principle, but also makes it possible to dissolve the maximum amount of oxygen according to Henry's law.

6 Some fractions, representing the BOD and the COD portions, may be instantaneously oxidised already in the aerator unit. This fact must be included when calculating the efficiency.

7 The transfer efficiency also depends on the specific compressor efficiency. This in turn depends on the air-pressure needed and the compressor design.



Operation

The LIMNO plant is normally started after the spring circulation period to counterbalance the increasing oxygen demand in the hypolimnion.

The LIMNO units are commonly run throughout the summer stagnation period with only a short stop around the autumn circulation, whereafter they are restarted for the winter if required. The design of the system makes it possible to run during the winter without disturbing the ice cover.

The oxygenation capacity of the LIMNO units can be matched against the varying oxygen consumption to maintain a specific oxygen concentration by reducing the airflow to the units or running a reduced number of units.

Compressed air supply and control

Compressor

The airflow to the LIMNO units is supplied by a compressor installed on land close to the shore.

The air-pressure required is the total sum of the hydrostatic pressure at the LIMNO diffusors and the pressure drops over the air supply lines.

The compressed air must be oil-free, which is why non-lubricated compressors are recommended.

For polyethylene air supply lines, a compressed air aftercooler might be required.

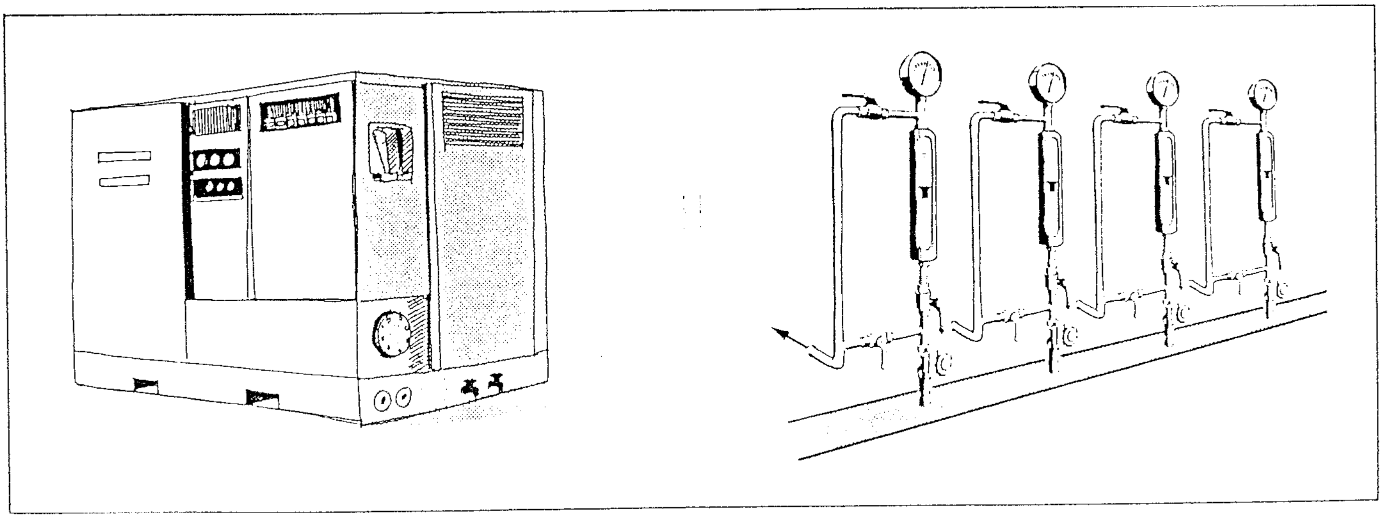
Although compressors today normally are silenced, packaged units, special considerations may have to be taken in view of the sensitive lake environment. No house is required for modern package-type compressors, but normally at least a shed is erected.

Modern screw type compressors are used for larger systems and require a minimum of service. Service contracts for the compressor installation are frequently applied.

Control

From the compressor unit, the airflow is led to a manifold to which the air supply line for each LIMNO unit is connected. There is a control system comprising an airflow meter with a precision pressure gauge, a regulating valve and a by-pass circuit for each unit.

The control system offers easy checking of the proper functioning of the LIMNO units installed out in the lake.



Results

For each lake management project, the results of hypolimnetic aeration vary with the characteristics of the ecosystem – the eutrophicated lake or the iron-manganese rich drinking-water reservoir. However, some common typical results from LIMNO projects have been summarised in the principle diagram below.

OXYGEN

When the LIMNO plant is started in a completely oxygen depleted hypolimnion, the full installed air capacity is supplied to all the LIMNO units. A rapid increase in the oxygen concentration is achieved.

When the desired oxygen concentration is reached through aeration during the stagnation period, the system can be adjusted to run with reduced capacity – just enough to maintain this concentration.

PHOSPHORUS

With the increased oxygen concentration, there is normally an immediate and steep drop in the phosphate concentration from say 0.8 to 0.05 mg/l, and at the same time the concentration of iron is rapidly reduced. This initial reduction is supposed to be caused through precipitation of ferric iron hydroxide with adsorbed phosphate. A slower decrease in the phosphate concentration, following the first rapid one, is normally depending on adsorption to the successfully oxidised sediment surface.

NITROGEN

The aeration also causes a drop in the inorganic nitrogen concentration. Typical values are from more than 2 to less than 0.3 mg/l. E.g. if the nitrogen mainly occurs as ammonium in the hypolimnion before aeration, the aeration typically brings about a rapid reduction in the concentration of ammonium and a synchronous increase in nitrate.

IRON and MANGANESE

The drop in the iron concentration has already been mentioned in connection with the phosphate reduction. The concentration of ionic iron is exceedingly low in aerated waters, most iron occurs as ferric hydroxide in particulate form.

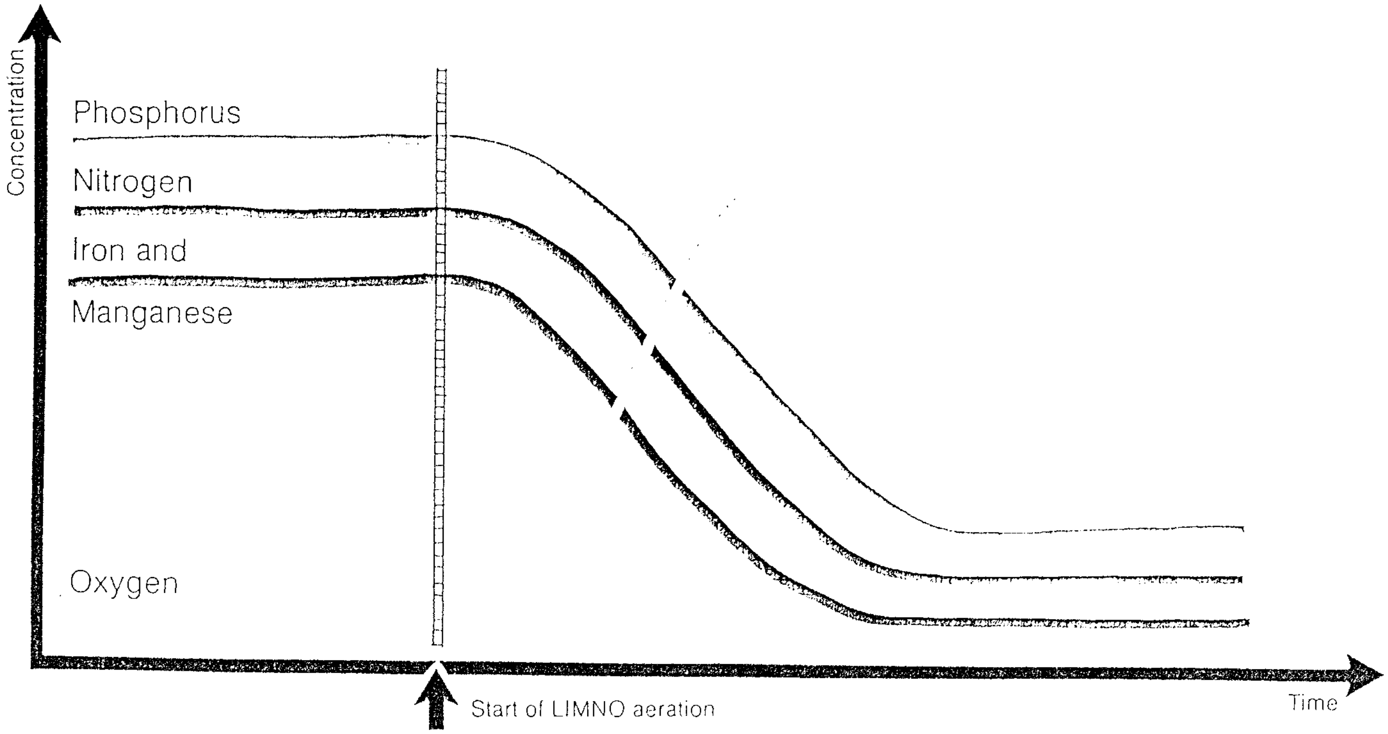
The solubility of manganese is considerably higher than that of iron, but it reacts in an analogous manner. These similarities in chemical reactivity between iron and manganese, although clear differences exist between the two metals, make them behave in a similar fashion in freshwaters. In drinking-water reservoirs where LIMNO aeration has been applied, the concentration of both metals have been almost completely suppressed improving the drinking-water quality and reducing the preparation cost.

TRANSPARENCY and CHLOROPHYLL

The normal variation of these parameters are big due to e.g. difference in meteorological and hydrological factors and irregular diffuse leakage of nutrients into the upper water layer – the epilimnion.

The effect of aeration on transparency and chlorophyll consequently has to be studied over a longer time period as it is not as immediate as on the elements above.

However, a steady reduction of chlorophyll has been recorded at many LIMNO aeration projects, and for the new installations the tendencies are positive.



Our line of business:
Water care

We specialize in environmental programs for water management. We have the know-how and the resources to investigate and diagnose polluted lakes, watercourses, ponds and reservoirs and to design and carry out successful restoration projects.

For more than a decade now, Atlas Copco has been involved in pioneering work within the field. During this time, we have been cooperating closely with limnological experts at several universities. Today, this collaboration has become permanently established which enables us to offer our customers solutions and services that are second to none.

The Atlas Copco Group has sales companies in 46 countries and representatives in another 120.

Our program of products and processes can be divided into two main categories – restoration of polluted lakes and preventive measurements against pollution.

Lake Management

LIMNO

The LIMNO system is especially designed for oxygenation of stratified lakes and reservoirs i.e. to supply oxygen to the hypolimnion without disturbing the natural stratification.

In lakes LIMNO decreases the internal phosphorus concentration and thereby reduces the production of algae, making the lake an aesthetic and recreational asset.

In reservoirs LIMNO suppresses the release of phosphorus, iron and manganese. Thereby the drinking water quality improves, the preparation cost is lowered and the chlorination demand reduced.

Diffuse aeration/destratification

Aeration of shallow waters, e.g. waterways and canals, by releasing an airflow from submerged, perforated hoses to increase the oxygen concentration throughout the water column.

RIPLOX

Biochemical oxidation of lake sediment with nitrate. A more economic alternative than dredging that drastically reduces the oxygen demand of the sediment, thereby minimising the internal release and loading of phosphorus.

CONTRACID

Buffer injection of sodium carbonate into the sediment of acidified lakes for long-term neutralisation of acid rain and acid flow from tributaries. An attractive alternative to liming in lakes with high humus content and short retention time.

Oil Spill Control Systems

Barrier

Pneumatic barriers for oil spill containment for permanent installations at oil loading/unloading jetties and docks to prevent spreading of oil spills. No deployment work, no maintenance, always ready to work.

Skimmer

Oil spill recovery unit based on the airlift principle, designed to handle a huge flow of oil-water mixture, recovering just the oil.

Ice Prevention

Ice prevention systems for ferry routes, hydroelectric power dams, marinas and the like to facilitate operations or protect existing structures.

Mixing

Different applications of the airbubble technique for mixing of density stratified flows, such as prevention of salt water intrusion into harbours, locks and estuaries, and homogenization of solids in a liquid.

Silting Prevention

Silting prevention comprises a MUD-TRAP and an airlift pump installation in harbours and locks where conventional dredging is difficult.

Ialis Offset 1986.

Aqua Technique Inc.

447 Route 10, Suite 14, Randolph, New Jersey 07869
Telephone (201) 361-1116 Telefax (201) 361-3233

1900 Lake Park Drive, Suite 345, Smyrna, Georgia 30080
Telephone (404) 436-9362 Telefax (404) 435-9064

LYCOTT

APPENDIX J

ENVIRONMENTAL NOTIFICATION FORM

I. SUMMARY

A. Project Identification

1. Project Name Stockbridge Bowl
   Address/Location Stockbridge, MA
   City/Town Stockbridge, MA
2. Project Proponent Town of Stockbridge
   Address
3. Est. Commencement ? . Est. Completion ? .
   Approx. Cost $ 850,000 . Status of Project Design - % Complete.
4. Amount (if any) of bordering vegetated wetlands, salt marsh, or tidelands to be dredged, filled, removed, or altered (other than by receipt of runoff) as a result of the project.
   0 acres square feet.
5. This project is categorically included and therefore requires preparation of an EIR.
   Yes No X ?

B. Narrative Project Description
Describe project and site.

In 1989, Lycott Environmental Research, Inc. completed a Diagnostic/ Feasibility Study for the restoration and management of Stockbridge Bowl in Stockbridge, MA. The major recommendations of the report were:

A. Constuction activity to allow six feet of drawdown.
   1. An outlet pipe must be layed below the gas main to allow a total of 6 feet of drawdown.
   2. The outlet channel must be deepened to allow a six foot drawdown.
   3. The outlet of Lily Brook must be dammed to prevent impacts to this wetland during drawdown.
   4. The outlet of tributary #3 must be dammed to prevent impacts to the wetland immediately above.

B. Drawdown should occur during periods of high nutrient concentrations in early winter/late fall resulting from macrophyte senescence and decomposition.

C. Improvement of Harvesting Program

D. Implementation of Hypolimnetic Aeration

Copies of the complete ENF may be obtained from (proponent or agent):
Name: Daniel W. Smith Firm/Agency: Lycott Environmental Research,In
Address: 600 Charlton Street Phone No. 508-765-0101
Southbridge, MA 01550

1987 THIS IS AN IMPORTANT NOTICE. COMMENT PERIOD IS LIMITED.
For Information, call (617) 727-5830

C. List the State or Federal agencies from which permits or other actions have been/will be sought:

Agency Name	Permit	Date filed; file no.

See Feasibility Section

D. List any government agencies or programs from which the proponent will seek financial assistance for this project:

Agency Name	Funding Amount

See Feasibility Section

E. Areas of potential impact (complete Sections II and III first, before completing this section).

1. Check all areas in which, in the proponent's judgment, an impact of this project may occur. Positive impacts, as well as adverse impacts, may be indicated.

	Construction Impacts	Long Term Impacts
Inland Wetlands	X	
Coastal Wetlands/Beaches		
Tidelands		
Traffic		
Open Space/Recreation	X	X
Historical/Archaeological		
Fisheries/Wildlife	X	X
Vegetation/Trees		
Agricultural Lands		
Water Pollution	X	
Water Supply/Use	X	X
Solid Waste	X	
Hazardous Materials	X	
Air Pollution	X	
Noise	X	
Wind/Shadow	NO	
Aesthetics	X	X
Growth Impacts	X	
Community/Housing and the Built Environment		

Other (Specify)____________________

2. List the alternatives which have been considered.

See Feasibilty Section

F. Has this project been filed with EOEA before? No X Yes ______ EOEA No. ______

G. WETLANDS AND WATERWAYS

1. Will an Order of Conditions under the Wetlands Protection Act (c.131s.40) or a License under the Waterways Act (c.91) be required?
   Yes X No ______
2. Has a local Order of Conditions been: NO
   a. issued? Date of issuance ______ ; DEQE File No. ______ .
   b. appealed? Yes ______ ; No ______ .
3. Will a variance from the Wetlands or Waterways Regulations be required? Yes ______ ; No NO .

II. PROJECT DESCRIPTION

A. Map; site plan. Include an original 8½ x 11 inch or larger section of the most recent U.S.G.S. 7.5 minute series scale topographic map with the project area location and boundaries clearly shown. If available, attach a site plan of the proposed project.

B. State total area of project: 382 acres.
Estimate the number of acres (to the nearest 1/10 acre) directly affected that are currently:

1. Developed .... ______ acres
2. Open Space/ Woodlands/Recreation ______ acres
3. Wetlands .... 392 acres mostly land under water.
4. Floodplain .... ______ acres
5. Coastal Area .... ______ acres
6. Tidelands .... ______ acres
7. Productive Resources
   Agriculture .... ______ acres
   Forestry .... ______ acres
   Other .... ______ acres

C. Provide the following dimensions, if applicable:

	Existing	Increase	Total
Length in miles			
Number of Housing Units			
Number of Stories			
Gross Floor Area in square feet			
Number of parking spaces			
Total of Daily vehicle trips to and from site (Total Trip Ends)			
Estimated Average Daily Traffic on road(s) serving site			
1.			
2.			
3.			

D. TRAFFIC PLAN. If the proposed project will require any permit for access to local roads or state highways, attach a sketch showing the location and layout of the proposed driveway(s).

III. ASSESSMENT OF POTENTIAL ADVERSE ENVIRONMENTAL IMPACTS

Instructions: Explain direct and indirect adverse impacts, including those arising from general construction and operations. For every answer explain why significant adverse impact is considered likely or unlikely to result. Positive impact may also be listed and explained.

Also, state the source of information or other basis for the answers supplied. Such environmental information should be acquired at least in part by field inspection.

A. Open Space and Recreation

1. Might the project affect the condition, use, or access to any open space and/or recreation area? Yes

   Explanation and Source: If harvesting is accomplished, aquatic vegetation will be stockpiled on public lands around the lake.

2. Is the project site within 500 feet of any public open space, recreation, or conservation land?

   Explanation and Source: Yes

   Parcels of public lands are located along the shore of Stockbridge Bowl

B. Historic and Archaeological Resources

1. Might any site or structure of historic significance be affected by the project? (Prior consultation with Massachusetts Historical Commission is advised.)

   Explanation and Source:

   NO

2. Might any archaeological site be affected by the project? (Prior consultation with Massachusetts Historical Commission is advised.)

   Explanation and Source:

   NO

C. Ecological Effects

1. Might the project significantly affect fisheries or wildlife, especially any rare or endangered species? (Prior consultation with the Massachusetts Natural Heritage Program is advised).

   Explanation and Source: YES

   The project shold improve fisheries, rare or endangered species will not be affected.

2. Might the project significantly affect vegetation, especially any rare or endangered species of plant? (Prior consultation with the Massachusetts Natural Heritage Program is advised.)

   (Estimate approximate number of mature trees to be removed: 0)

   Explanation and Source: YES. Reduction of macrophytes in the lake. No rare or endangered species will be affected.

3. Agricultural Land. Has any portion of the site been in agricultural use within the last 15 years? If yes, specify use and acreage.

   Explanation and Source:

   NO

D. Water Quality and Quantity

1. Might the project result in significant changes in drainage patterns?

   Explanation and Source: NO. Outlet will only be deepened.

2. Might the project result in the introduction of any pollutants, including sediments, into marine waters, surface fresh waters or ground water?

   Explanation and Source: Yes. Harvesting activities could result in the spilling of fluids (hydraulic oils & diesel fuels) into surface waters. Harvesting activities may result in the re-suspension of pollutants found in the sediments.

3. Does the project involve any dredging? No ______ Yes X Volume 4,500 cu.yd. . If 10,000 cy or more, attach completed Standard Application Form for Water Quality Certification, Part I (314 CMR 9.02(3), 9.90, DEQE Division of Water Pollution Control).

4. Will any part of the project be located in flowed or filled tidelands, Great Ponds, or other waterways? (Prior consultation with the DEQE and CZM is advised.)

   Explanation and Source:

   NO

5. Will the project generate or convey sanitary sewage? No __X__ Yes ____

   If Yes, Quantity: ________ gallons per day

   Disposal by: (a) Onsite septic systems .... Yes ____ No ____

   (b) Public sewerage systems (location; average and peak daily flows to treatment works) .... Yes ____ No ____

   Explanation and Source:

6. Might the project result in an increase in paved or impervious surface over a sole source aquifer or an aquifer recognized as an important present or future source of water supply?

   Explanation and Source:

   NO

7. Is the project in the watershed of any surface water body used as a drinking water supply?

   Explanation and Source: YES. In 1980, the town of Lenox Massachusetts used the stockbridge Bowl as an emergency water supply.

8. Are there any public or private drinking water wells within a 1/2-mile radius of the proposed project?

   Explanation and Source:

   YES

9. Does the operation of the project result in any increased consumption of water?

Approximate consumption __________ gallons per day. Likely water source(s) __________

Explanation and Source:

NO

E. Solid Waste and Hazardous Materials

1. Estimate types and approximate amounts of waste materials generated, e.g., industrial, domestic, hospital, sewage sludge, construction debris from demolished structures. How/where will such waste be disposed of?

Explanation and Source:

Harvesting ans construction activities could result in the release of fluids(hydraulic or diesel). Harvested materials will be used as compost or transported to a local landfill. Dredged materials (4,500 cu. yd.) will be placed adjacent to stream channel.

2. Might the project involve the generation, use, transportation, storage, release, or disposal of potentially hazardous materials?

Explanation and Source: **YES. Dredged materials will be generated from the deepening of the outlet structure.**

3. Has the site previously been used for the use, generation, transportation, storage, release, or disposal of potentially hazardous materials?

Explanation and Source:

NO

F. Energy Use and Air Quality

1. Will space heating be provided for the project? If so, describe the type, energy source, and approximate energy consumption.

Explanation and Source:

NO

2. Will the project require process heat or steam? If so, describe the proposed system, the fuel type, and approximate fuel usage.

   Explanation and Source:

   NO

3. Does the project include industrial processes that will release air contaminants to the atmosphere? If so, describe the process (type, material released, and quantity released).

   Explanation and Source: YES. Harvesting and constructing activities could release exhaust into the atmosphere.

4. Are there any other sources of air contamination associated with the project (e.g. automobile traffic, aircraft traffic, volatile organic compound storage, construction dust)?

   Explanation and Source:

   NO

5. Are there any sensitive receptors (e.g. hospitals, schools, residential areas) which would be affected by air contamination caused by the project?

   Explanation and Source:

   NO

G. Noise

1. Might the project result in the generation of noise?

   (Include any source of noise during construction or operation, e.g., engine exhaust, pile driving, traffic.)

   Explanation and Source: YES. Noise may originate from heavy construction equipment used to relocate an outlet pipe.

2. Are there any sensitive receptors (e.g., hospitals, schools, residential areas) which would be affected by any noise caused by the project?

   Explanation and Source:

NO

3. Is the project a sensitive receptor, sited in an area of significant ambient noise?

   Explanation and Source:

NO

H. Wind and Shadow

1. Might the project cause wind and shadow impacts on adjacent properties?

   Explanation and Source:

NO

I. Aesthetics

1. Are there any proposed structures which might be considered incompatible with existing adjacent structures in the vicinity in terms of size, physical proportion and scale, or significant differences in land use?

   Explanation and Source:

NO

2. Might the project impair visual access to waterfront or other scenic areas?

   Explanation and Source:

NO

IV. CONSISTENCY WITH PRESENT PLANNING

Discuss consistency with current federal, state and local land use, transportation, open space, recreation and environmental plans and policies. Consult with local or regional planning authorities where appropriate.

V. FINDINGS AND CERTIFICATION

A. The public notice of environmental review has been/will be published in the following newspaper(s):

(NAME) ______________________ (Date) ______________________

______________________ ______________________

______________________ ______________________

B. This form has been circulated to all agencies and persons as required by 301 CMR 11.24.

Date	Signature of Responsible Officer or Project Proponent	Date	Signature of person preparing ENF (if different from above)
	Name (print or type)		Name (print or type)
	Address ______________		Address ______________
	Telephone Number ______________		Telephone Number ______________

FORMS OF NOTICE

(1) PUBLIC NOTICE OF ENVIRONMENTAL REVIEW

PROJECT: STOCKBRIDGE BOWL PHASE I
(Brief description of project)

LOCATION: STOCKBRIDGE, MASSACHUSETTS

PROPONENT: TOWN OF STOCKBRIDGE

The undersigned is submitting an Environmental Notification Form ("ENF") to the Secretary of Environmental Affairs on or before ______________________ .
(Date)

This will initiate review of the above project pursuant to the Massachusetts Environmental Policy Act ("MEPA", G.L. c. 30, secs. 61, 62-62H). Copies of the ENF may be obtained from:

______________________ .
(Name, address, phone number of proponent or proponent's agent)

Copies of the ENF are also being sent to the Conservation Commission and Planning Board of ______________ ,
(Municipality)

where they may be inspected.

The Secretary of Environmental Affairs will publish notice of the ENF in the Environmental Monitor, will receive public comments on the project for twenty days, and will then decide, within ten days, if an Environmental Impact Report is needed. A site visit and consultation session on the project may also be scheduled. All persons wishing to comment on the project, or to be notified of a site visit or consultation session, should write to the Secretary of Environmental Affairs, 100 Cambridge Street, Boston, Massachusetts 02202, Attention: MEPA Unit, referencing the above project.

By ______________________
(proponent)

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APPENDIX K

```
                    TR-55 CURVE NUMBER COMPUTATION                  VERSION 1.

Project : STOCKBRIDGE BOWL                          User: HDC        Date: 07-17-
County  : BERKSHIRE              State: MA        Checked: ____      Date: ______
Subtitle: 100 YEAR STORM EVENT
Subarea : 1A
--------------------------------------------------------------------------------
                                                       Hydrologic Soil Group
       COVER DESCRIPTION                            A         B         C        D
                                                           Acres (CN)
--------------------------------------------------------------------------------

FULLY DEVELOPED URBAN AREAS (Veg Estab.)
Residential districts     Avg % imperv
  (by average lot size)
    2 acre                    12                    -     444(65)       -        -


OTHER AGRICULTURAL LANDS
Woods - grass combination        poor               -        -          -    374(86

Woods                            good               -     537(55)   924(70)      -


Total Area (by Hydrologic Soil Group)                       981       924      374
                                                           ====      ====     ====

--------------------------------------------------------------------------------
SUBAREA: 1A     TOTAL DRAINAGE AREA: 2279 Acres      WEIGHTED CURVE NUMBER:6
--------------------------------------------------------------------------------
```

```
                 TR-55 CURVE NUMBER COMPUTATION                  VERSION 1.

Project : STOCKBRIDGE BOWL                       User: HDC        Date: 07-17-8
County  : BERKSHIRE            State: MA      Checked: _____      Date: ________
Subtitle: 100 YEAR STORM EVENT
Subarea : 1B
-------------------------------------------------------------------------------
                                                     Hydrologic Soil Group
        COVER DESCRIPTION                           A        B        C        D
                                                        Acres (CN)
-------------------------------------------------------------------------------

FULLY DEVELOPED URBAN AREAS (Veg Estab.)
Residential districts     Avg % imperv
  (by average lot size)
    1 acre                      20                  -        -     15(79)      -


OTHER AGRICULTURAL LANDS
Pasture, grassland or range       fair              -    221(69)     -         -

Woods - grass combination         poor              -        -       -     193(86)

Woods                             fair              -    514(60)  669(73)      -



Total Area (by Hydrologic Soil Group)                    735      684      193
                                                        ====     ====     ====


-------------------------------------------------------------------------------
SUBAREA: 1B     TOTAL DRAINAGE AREA: 1612 Acres      WEIGHTED CURVE NUMBER:7
-------------------------------------------------------------------------------
```

```
                    TR-55 CURVE NUMBER COMPUTATION                   VERSION

Project : STOCKBRIDGE BOWL                          User: HDC           Date: 07-17-
County  : BERKSHIRE               State: MA      Checked: ____          Date: ______
Subtitle: 100 YEAR STORM EVENT
Subarea : 2
---------------------------------------------------------------------------------------
                                                       Hydrologic Soil Group
       COVER DESCRIPTION                           A        B        C        D
                                                          Acres (CN)
---------------------------------------------------------------------------------------

FULLY DEVELOPED URBAN AREAS (Veg Estab.)
Residential districts     Avg % imperv
  (by average lot size)
    2 acre                    12                   -     82(65)      -        -


OTHER AGRICULTURAL LANDS
Woods - grass combination        fair              -     55(65)   12(76)      -


Total Area (by Hydrologic Soil Group)                  137        12
                                                       ====      ====

---------------------------------------------------------------------------------------
SUBAREA: 2      TOTAL DRAINAGE AREA: 149 Acres      WEIGHTED CURVE NUMBER:6
---------------------------------------------------------------------------------------
```

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```
                                                              User: HDC       Date: 07-17-8
Project : STOCKBRIDGE BOWL                                 Checked: _____     Date: ________
County  : BERKSHIRE                  State: MA
Subtitle: 100 YEAR STORM EVENT
Subarea : 3
------------------------------------------------------------------------------------------
                                                          Hydrologic Soil Group
        COVER DESCRIPTION                              A        B        C        D
                                                              Acres (CN)
------------------------------------------------------------------------------------------
FULLY DEVELOPED URBAN AREAS (Veg Estab.)
Residential districts     Avg % imperv
  (by average lot size)
    1 acre                     20                      -      38(68)     -        -


OTHER AGRICULTURAL LANDS
Woods                              fair                -     148(60)   61(73)     -


Total Area (by Hydrologic Soil Group)                         186       61
                                                             ====      ====

------------------------------------------------------------------------------------------
SUBAREA: 3      TOTAL DRAINAGE AREA: 247 Acres          WEIGHTED CURVE NUMBER:6
------------------------------------------------------------------------------------------
```

```
                TR-55 CURVE NUMBER COMPUTATION                       VERSION 1.

Project : STOCKBRIDGE BOWL                          User: HDC        Date: 07-17-8
County  : BERKSHIRE              State: MA       Checked: ____       Date: _______
Subtitle: 100 YEAR STORM EVENT
Subarea : 4
---------------------------------------------------------------------------------
                                                      Hydrologic Soil Group
        COVER DESCRIPTION                          A        B        C        D
                                                         Acres (CN)
---------------------------------------------------------------------------------
FULLY DEVELOPED URBAN AREAS (Veg Estab.)
Residential districts     Avg % imperv
  (by average lot size)
    1 acre                      20                 -     74(68)      -        -


OTHER AGRICULTURAL LANDS
Woods - grass combination          poor            -       -         -     17(86)

Woods                              fair            -     75(60)  204(73)      -



Total Area (by Hydrologic Soil Group)                    149      204      17
                                                         ====     ====     ====


---------------------------------------------------------------------------------
SUBAREA: 4      TOTAL DRAINAGE AREA: 370 Acres        WEIGHTED CURVE NUMBER:7
---------------------------------------------------------------------------------
```

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```
                    TR-55 CURVE NUMBER COMPUTATION                  VERSION 1.1

Project : STOCKBRIDGE BOWL                         User: HDC       Date: 07-17-8
County  : BERKSHIRE            State: MA        Checked: ____      Date: _____
Subtitle: 100 YEAR STORM EVENT
Subarea : 5
------------------------------------------------------------------------------
                                                  Hydrologic Soil Group
        COVER DESCRIPTION                     A         B         C         D
                                                        Acres (CN)
------------------------------------------------------------------------------
FULLY DEVELOPED URBAN AREAS (Veg Estab.)
Urban Districts            Avg % imperv
  Industrial                  72              -         -       23(91)      -

Residential districts      Avg % imperv
  (by average lot size)
    1 acre                    20              -       13(68)    69(79)      -


Total Area (by Hydrologic Soil Group)                  13        92
                                                      ====      ====

------------------------------------------------------------------------------
SUBAREA: 5      TOTAL DRAINAGE AREA: 105 Acres       WEIGHTED CURVE NUMBER:80
------------------------------------------------------------------------------
```

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                        TR-55 CURVE NUMBER COMPUTATION                      VERSION 1.1

Project : STOCKBRIDGE BOWL                              User: HDC        Date: 07-17-8
County  : BERKSHIRE              State: MA           Checked: _____      Date: ________
Subtitle: 100 YEAR STORM EVENT
Subarea : 6
-------------------------------------------------------------------------------------
                                                           Hydrologic Soil Group
         COVER DESCRIPTION                              A        B         C         D
                                                                 Acres (CN)
-------------------------------------------------------------------------------------
FULLY DEVELOPED URBAN AREAS (Veg Estab.)
Residential districts     Avg % imperv
  (by average lot size)
    1 acre                    20                        -     56(68)    63(79)      -


OTHER AGRICULTURAL LANDS
Pasture, grassland or range     fair                    -        -      66(79)      -

Brush - brush, weed, grass mix  poor                    -        -         -     15(83)

Woods - grass combination       good                    -     15(58)       -        -

Woods                           fair                    -        -      55(73)      -


Total Area (by Hydrologic Soil Group)                         71       184       15
                                                            ====      ====      ====

-------------------------------------------------------------------------------------
SUBAREA: 6      TOTAL DRAINAGE AREA: 270 Acres      WEIGHTED CURVE NUMBER:75
-------------------------------------------------------------------------------------
```

```
              TR-55 CURVE NUMBER COMPUTATION                    VERSION 1.1

                                                   User: HDC        Date: 07-17-89
Project : STOCKBRIDGE BOWL
County  : BERKSHIRE               State: MA      Checked: ____      Date: ________
Subtitle: 100 YEAR STORM EVENT
Subarea : 7
--------------------------------------------------------------------------------
                                                      Hydrologic Soil Group
         COVER DESCRIPTION                         A         B         C        D
                                                              Acres (CN)
--------------------------------------------------------------------------------

OTHER AGRICULTURAL LANDS
Pasture, grassland or range           fair         -      57(69)       -        -

Woods - grass combination             poor         -         -         -     77(86)

Woods                                 fair      14(36)   227(60)   939(73)      -


Total Area (by Hydrologic Soil Group)             14       284       939       77
                                                ====      ====      ====     ====

--------------------------------------------------------------------------------
SUBAREA: 7      TOTAL DRAINAGE AREA: 1314 Acres      WEIGHTED CURVE NUMBER:71
--------------------------------------------------------------------------------
```

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```
Project : STOCKBRIDGE BOWL                          User: HDC        Date: 07-17-89
County  : BERKSHIRE             State: MA        Checked: ____       Date: _________
Subtitle: 100 YEAR STORM EVENT
Subarea : 8
--------------------------------------------------------------------------------
                                                      Hydrologic Soil Group
         COVER DESCRIPTION                          A         B         C         D
                                                              Acres (CN)
--------------------------------------------------------------------------------

FULLY DEVELOPED URBAN AREAS (Veg Estab.)
Urban Districts             Avg % imperv
  Commercial & business        85                   -      30(92)    83(94)      -

Residential districts       Avg % imperv
  (by average lot size)
    1 acre                     20                   -      64(68)      -         -


OTHER AGRICULTURAL LANDS
Pasture, grassland or range       fair              -      70(69)    23(79)      -

Woods - grass combination         poor              -        -         -       2(86)

Woods                             fair              -     254(60)    79(73)      -



Total Area (by Hydrologic Soil Group)                     418        185        2
                                                         ====       ====       ====


--------------------------------------------------------------------------------
SUBAREA: 8      TOTAL DRAINAGE AREA: 605 Acres       WEIGHTED CURVE NUMBER:71
--------------------------------------------------------------------------------
```

```
                    TR-55 CURVE NUMBER COMPUTATION                 VERSION 1.11

Project : STOCKBRIDGE BOWL                         User: HDC       Date: 07-17-89
County  : BERKSHIRE             State: MA       Checked: ____      Date: ________
Subtitle: 100 YEAR STORM EVENT
Subarea : LAKE
-------------------------------------------------------------------------------
                                                     Hydrologic Soil Group
         COVER DESCRIPTION                       A        B        C        D
                                                        Acres (CN)
-------------------------------------------------------------------------------
FULLY DEVELOPED URBAN AREAS (Veg Estab.)
User defined urban (F9 to define)                -        -    385(98)      -
             % impervious                                         100%
             % unconnected impervious                              0%
             pervious curve number                                 98



Total Area (by Hydrologic Soil Group)                          385
                                                               ====

-------------------------------------------------------------------------------
SUBAREA: LAKE   TOTAL DRAINAGE AREA: 385 Acres     WEIGHTED CURVE NUMBER:98
-------------------------------------------------------------------------------
```

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```
            TR-55 Tc and Tt THRU SUBAREA COMPUTATION          VERSION 1.11


Project : STOCKBRIDGE BOWL                        User: HDC       Date: 07-17-89
County  : BERKSHIRE             State: MA      Checked: _____     Date: _________
Subtitle: 100 YEAR STORM EVENT

------------------------------ Subarea #1 - 1A -------------------------------
Flow Type     2 year   Length   Slope  Surface  n   Area     Wp  Velocity  Time
               rain     (ft)   (ft/ft)  code       (sq/ft)  (ft) (ft/sec)  (hr)
-------------------------------------------------------------------------------
Sheet          2.9      300      .09      I                                0.864
Shallow Concent'd       1000     .09      U                                0.057
Shallow Concent'd       2147     .09      U                                0.123
Open Channel            7328                                        .7     2.908
Open Channel            6012                                        1.7    0.982
                                                Time of Concentration = 4.93*
                                                                        =====

Open Channel            5910                                        1.3    1.263
                                                          Travel Time = 1.26*
                                                                        =====


------------------------------ Subarea #2 - 1B -------------------------------
Flow Type     2 year   Length   Slope  Surface  n   Area     Wp  Velocity  Time
               rain     (ft)   (ft/ft)  code       (sq/ft)  (ft) (ft/sec)  (hr)
-------------------------------------------------------------------------------
Sheet          2.9      300      .11      I                                0.797
Shallow Concent'd       1000     .11      U                                0.052
Shallow Concent'd       2564     .11      U                                0.133
Open Channel            6889                                        2.1    0.911
Open Channel            9819                                        .61    4.471
                                                Time of Concentration = 6.36*
                                                                        =====

Open Channel            8694                                        4      0.604
                                                          Travel Time = 0.60*
                                                                        =====


------------------------------ Subarea #3 - 2 --------------------------------
Flow Type     2 year   Length   Slope  Surface  n   Area     Wp  Velocity  Time
               rain     (ft)   (ft/ft)  code       (sq/ft)  (ft) (ft/sec)  (hr)
-------------------------------------------------------------------------------
Sheet          2.9      300      .11      I                                0.797
Shallow Concent'd       1000     .11      U                                0.052
Open Channel            2964                                        5.3    0.155
                                                Time of Concentration = 1.00*
                                                                        =====

Open Channel            6367                                        4      0.442
                                                          Travel Time = 0.44*
                                                                        =====


* - Generated for use by TABULAR method
```

```
Project : STOCKBRIDGE BOWL                          User: HDC        Date: 07-17-89
County  : BERKSHIRE              State: MA      Checked: ____        Date: _________
Subtitle: 100 YEAR STORM EVENT

-------------------------------- Subarea #4 - 3 --------------------------------
Flow Type      2 year   Length   Slope   Surface   n    Area    Wp   Velocity   Time
                rain     (ft)   (ft/ft)   code        (sq/ft)  (ft)  (ft/sec)   (hr)
---------------------------------------------------------------------------------
Sheet           2.9      300      .13       I                                  0.746
Shallow Concent'd        1000     .13       U                                  0.048
Open Channel             2620                                         5.1      0.143
Open Channel             2592                                         2.8      0.257
                                                    Time of Concentration =  1.19*
                                                                             =====

Open Channel             5759                                          4       0.400
                                                              Travel Time =  0.40*
                                                                             =====


-------------------------------- Subarea #5 - 4 --------------------------------
Flow Type      2 year   Length   Slope   Surface   n    Area    Wp   Velocity   Time
                rain     (ft)   (ft/ft)   code        (sq/ft)  (ft)  (ft/sec)   (hr)
---------------------------------------------------------------------------------
Sheet           2.9      300      .10       I                                  0.828
Shallow Concent'd        1000     .10       U                                  0.054
Open Channel             5599                                         5.1      0.305
Open Channel             3442                                         1.4      0.683
                                                    Time of Concentration =  1.87*
                                                                             =====

Open Channel             1377                                          4       0.096
                                                              Travel Time =  0.10*
                                                                             =====


-------------------------------- Subarea #6 - 5 --------------------------------
Flow Type      2 year   Length   Slope   Surface   n    Area    Wp   Velocity   Time
                rain     (ft)   (ft/ft)   code        (sq/ft)  (ft)  (ft/sec)   (hr)
---------------------------------------------------------------------------------
Sheet           2.9      300     .043       E                                  0.288
Shallow Concent'd        1000    .043       U                                  0.083
Open Channel             1242                                         3.3      0.105
                                                    Time of Concentration =  0.48*
                                                                             =====

Open Channel             1932                                          4       0.134
                                                              Travel Time =  0.13*
                                                                             =====


-------------------------------- Subarea #7 - 6 --------------------------------
Flow Type      2 year   Length   Slope   Surface   n    Area    Wp   Velocity   Time
                rain     (ft)   (ft/ft)   code        (sq/ft)  (ft)  (ft/sec)   (hr)
---------------------------------------------------------------------------------
Sheet           2.9      300     .025       E                                  0.358
Shallow Concent'd        1000    .025       U                                  0.109
Open Channel             3429                                         2.6      0.366
                                                    Time of Concentration =  0.83*

Open Channel             8280                                          4
```

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- Generated for use by TABULAR method
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                TR-55 Tc and Tt THRU SUBAREA COMPUTATION          VERSION 1.11

 oject  : STOCKBRIDGE BOWL                      User: HDC        Date: 07-17-89
 unty   : BERKSHIRE              State: MA    Checked: ____      Date: ________
 btitle: 100 YEAR STORM EVENT

--------------------------------- Subarea #8 - 7 -------------------------------
 ow Type     2 year    Length   Slope  Surface   n    Area     Wp   Velocity  Time
               rain     (ft)   (ft/ft)   code        (sq/ft)  (ft)  (ft/sec)  (hr)
---------------------------------------------------------------------------------
 eet          2.9      300      .08      I                                   0.905
 allow Concent'd       1000     .08      U                                   0.061
 en Channel            8247                                          4.8     0.477
Open Channel           3138                                          2.8     0.311
                                                Time of Concentration =  1.75*
                                                                         =====

 en Channel            6814                                          4       0.473
                                                          Travel Time =  0.47*
                                                                         =====


--------------------------------- Subarea #9 - 8 -------------------------------
Flow Type     2 year    Length   Slope  Surface   n    Area     Wp   Velocity  Time
               rain     (ft)   (ft/ft)   code        (sq/ft)  (ft)  (ft/sec)  (hr)
---------------------------------------------------------------------------------
Sheet         2.9      300      .17      I                                   0.670
 allow Concent'd       1000     .17      U                                   0.042
 en Channel            1648                                          6.6     0.069
 en Channel            3157                                          3.9     0.225
                                                Time of Concentration =  1.01*
                                                                         =====

Open Channel           7548                                          4       0.524
                                                          Travel Time =  0.52*
                                                                         =====


------------------------------- Subarea #10 - LAKE -----------------------------
 ow Type               Length   Slope  Surface   n    Area     Wp   Velocity  Time
                        (ft)   (ft/ft)   code        (sq/ft)  (ft)  (ft/sec)  (hr)
---------------------------------------------------------------------------------
 en Channel            7254                                          4       0.504
                                                Time of Concentration =  0.50*
                                                                         =====

        --- Sheet Flow Surface Codes ---
    A Smooth Surface           F Grass, Dense      --- Shallow Concentrated ---
    B Fallow (No Res.)         G Grass, Burmuda    ---    Surface Codes     ---
    C Cultivated < 20 % Res.   H Woods, Light             P Paved
    D Cultivated > 20 % Res.   I Woods, Dense             U Unpaved
    E Grass-Range, Short

 - Generated for use by TABULAR method
```

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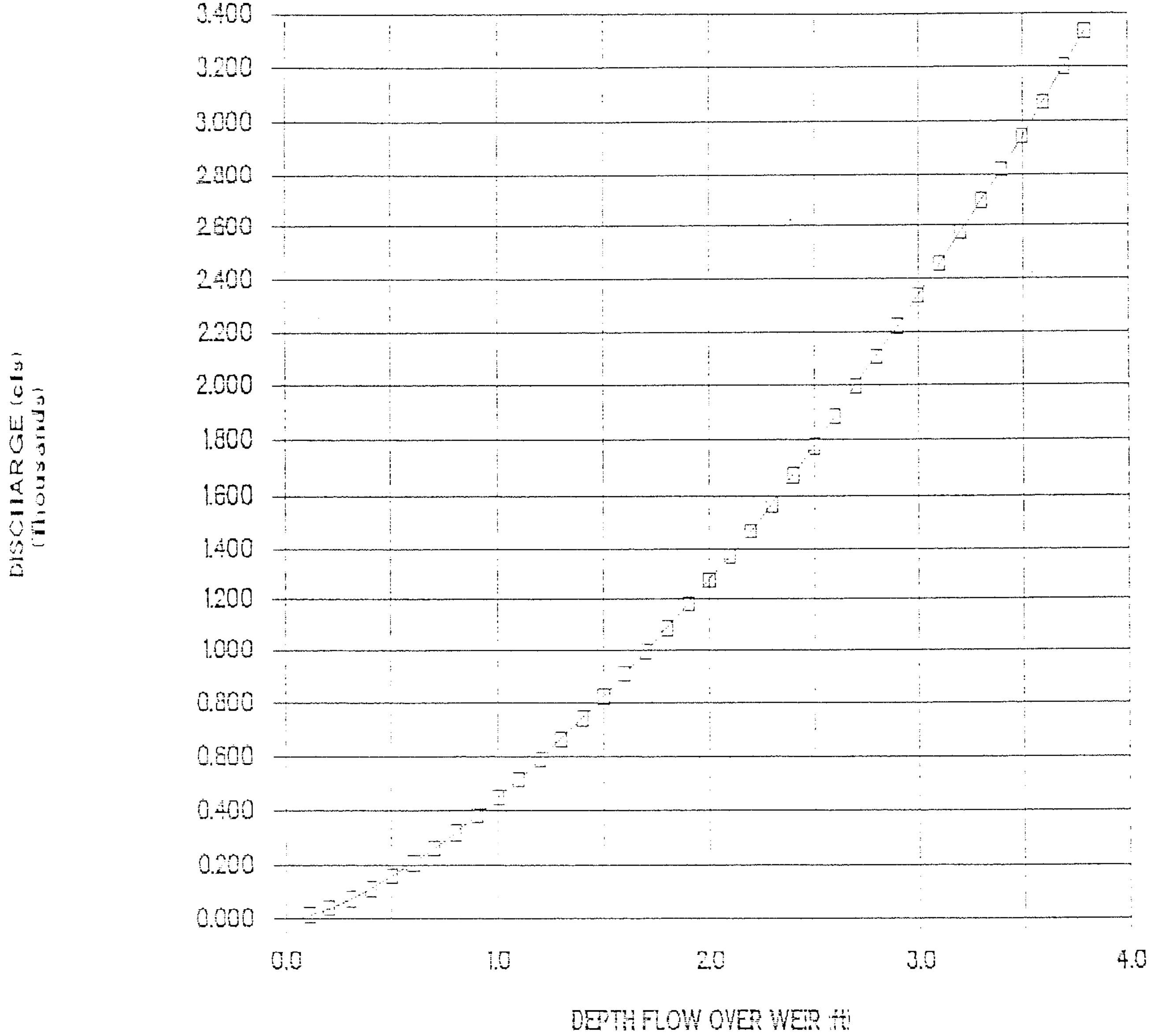
```
Project : STOCKBRIDGE BOWL                        User: HDC        Date: 07-17-
County  : BERKSHIRE           State: MA       Checked: _____      Date: _______
Subtitle: LILY BROOK OVERVIEW

  Data: Drainage Area          :   2279 * Acres
        Runoff Curve Number    :   68 *
        Time of Concentration:     4.93 * Hours
        Rainfall Type          :   III
        Pond and Swamp Area    :
=============================================================================
| Storm Number            |   1   |   2   |   3   |   4   |   5   |   6   |   7   |
|-------------------------|-------|-------|-------|-------|-------|-------|-------|
| Frequency  (yrs)        |   1   |   2   |   5   |  10   |  25   |  50   |  100  |
|                         |       |       |       |       |       |       |       |
| 24-Hr Rainfall (in)     |  2.5  |  2.9  |  3.8  |  4.4  |  5.1  |  5.9  |  6.4  |
|                         |       |       |       |       |       |       |       |
| Ia/P Ratio              | 0.38  | 0.32  | 0.25  | 0.21  | 0.18  | 0.16  | 0.15  |
|                         |       |       |       |       |       |       |       |
| Runoff  (in)            | 0.39  | 0.58  | 1.08  | 1.47  | 1.95  | 2.54  | 2.93  |
|                         |       |       |       |       |       |       |       |
| Unit Peak Discharge     |0.137  |0.144  |0.154  |0.157  |0.160  |0.162  |0.164  |
|    (cfs/acre/in)        |       |       |       |       |       |       |       |
|                         |       |       |       |       |       |       |       |
| Pond and Swamp Factor   | 0.72  | 0.72  | 0.72  | 0.72  | 0.72  | 0.72  | 0.72  |
|    5.0% Ponds Used      |       |       |       |       |       |       |       |
|-------------------------|-------|-------|-------|-------|-------|-------|-------|
| Peak Discharge (cfs)    |   87  |  136  |  272  |  377  |  512  |  678  |  787  |
=============================================================================

* - Value(s) provided from TR-55 system routines
```



RECTANGULAR WEIR DISCHARGE

150 FOOT WEIR LENGTH

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STAGE DISCHARGE
Lilly Brook
Stockbridge, MA

REGULATING WIER

	Q=CLH^(3/2)	
FLOW (cfs)	Q	
RECTANGULAR WIER	C	3
LENGTH (ft)	L	150
HEAD (ft)	H	
ELEVATION		620.8

	REGULATING WIER		STORM FLOWS BASED ON TR-55 GRAPHICAL SOLUTION			
ELEVATION (ft)	HEAD (ft)	FLOW (cfs)	RETURN PERIOD (years)	FLOW (cfs)	DEPTH ABOVE LILLY BROOK DAM (ft)	WATER SURFACE ELEVATION (ft)
620.80	0.00					
620.90	0.10	14				
621.00	0.20	40				
621.10	0.30	74	1	87	0.20	621.00
621.20	0.40	114				
621.30	0.50	159	2	136	0.40	621.20
621.40	0.60	209				
621.50	0.70	264	5	272	0.60	621.40
621.60	0.80	322				
621.70	0.90	384	10	377	0.80	621.60
621.80	1.00	450				
621.90	1.10	519	25	512	1.10	621.90
622.00	1.20	592				
622.10	1.30	667	50	678	1.30	622.10
622.20	1.40	745				
622.30	1.50	827	100	787	1.40	622.20
622.40	1.60	911				
622.50	1.70	997				
622.60	1.80	1,087				
622.70	1.90	1,179				
622.80	2.00	1,273				
622.90	2.10	1,369				

APPENDIX L

STOCKBRIDGE BOWL

CAPITAL CONSTRUCTION PROGRAMS ITEM		CONSTRUCTION	ENGINEERING	MAINTENANCE	SUBTOTAL	TOTAL
1	DRAWDOWN GATE	33,792	4,264		38,056	
2	DRAWDOWN DIVERSION PIPE	88,001	13,200		101,201	
3	REMOVE OLD DAM	8,032	1,205		9,237	
4	EXCAVATE CHANNEL	133,128	19,969		153,097	
5	LILY BROOK WETLANDS DAM	0	0		0	
6	WETLANDS PROTECTION BARRIER	5,000			5,000	
7	AERATOR COMPRESSOR BUILDING	25,000	3750		28,750	
						$335,342
CAPITAL NON CONSTRUCTION PROGRAMS						
8	HYPOLIMNETIC AERATION	104,700	15,705		120,405	
9	HIGH SPEED HARVESTOR BARGE	0			0	
10	PHASE II MONITORING PROGRAM		13,800		13,800	
						$134,205
ANNUAL OPERATING OR MAINTENANCE PROGRAMS						
11	AERATOR					
	ELECTRICITY			12,000	12,000	
	MAINTENANCE			4,000	4,000	
12	HARVESTING					
	ACRES	300				
	COST PER ACRE	350			105,000	
13	DRAWDOWN					
	OUTLET WATER QUALITY MONITORING			1400	1,400	
						$122,400

STOCKBRIDGE BOWL IMPROVEMENTS
DREDGE CHANNEL

ITEM	DESCRIPTION	UNIT	QUANTITY	COST	SUBTOTAL
	LOWER SECTION				
1	MOBILIZATION	LS	1	7,000.00	7,000
2	DISPOSAL SITE PREPARATION	LS	1	5,000.00	5,000
3	SEDIMENT CONTROL	LS	1	5,000.00	5,000
4	WET DREDGE	CY	18,578	7.45	138,406
5	DEWATER EXCAVATED MATERIAL	LS	1	4,000.00	4,000
6	REMOVE EXCAVATED MATERIAL	CY	9,289	2.50	23,223
7	SITE CLEAN UP	LS	1	5,000.00	5,000
	MIDDLE SECTION				
8	MOBILIZATION	LS	1	7,000.00	7,000
9	DISPOSAL SITE PREPARATION	LS	1	5,000.00	5,000
10	SEDIMENT CONTROL	LS	1	5,000.00	5,000
11	WET DREDGE	CY	77,200	7.45	575,140
12	DEWATER EXCAVATED MATERIAL	LS	1	4,000.00	4,000
13	REMOVE EXCAVATED MATERIAL	CY	38,600	2.50	96,500
14	SITE CLEAN UP	LS	1	5,000.00	5,000
				SUBTOTAL	885,269
	CONTINGENCY	25%			221,317
				SUBTOTAL	1,106,586
	ENGINEERING	15%			165,988
				TOTAL	1,272,574

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STOCKBRIDGE BOWL IMPROVEMENTS
DRAWDOWN DIVERSION PIPE

FERENCE	ITEM	DESCRIPTION	UNIT	QUANTITY	COST	SUBTOTAL
	1	SITE PREPARATION	LS	1	1,500.00	1,500
	2	SITE CLEAN-UP	LS	1	3,000.00	3,000
734-0010	3	COFFER DAM INSTALLATION	SFCA	720	13.60	9,792
110-406	4	EXCAVATION	LF	260	34.50	8,970
-265-0550	5	HAUL EXCAVATION	CY	700	11.85	8,295
-134-2300	6	ROCK EXCAVATION	CY	320	47.00	15,040
34-5460	7	HAUL ROCK	CY	320	3.83	1,226
152-2524	8	CONCRETE PIPE, 26"x43"	LF	260	34.50	8,970
1-404	9	DEWATERING	LS	1	5,000.00	5,000
	10	BEDDING	CY	30	14.85	446
722	11	BACKFILL	CY	400	7.33	2,932
3-750-652	12	HEADWALLS	EA	2	985.00	1,970
	13	REMOVE COFFERDAM	LS	720	4.53	3,261
					SUBTOTAL	70,401
		CONTINGENCY		25%		17,600
					SUBTOTAL	88,001
		ENGINEERING		15%		13,200
					TOTAL	$101,201

STOCKBRIDGE BOWL IMPROVEMENTS
EXCAVATE CHANNEL

ITEM	DESCRIPTION	UNIT	QUANTITY	COST	SUBTOTAL
2	DISPOSAL SITE PREPARATION	LS	1	5,000.00	5,000
3	SEDIMENT CONTROL	LS	1	5,000.00	5,000
4	CONSTRUCT HAUL ROAD, 20'x13', GRAVEL	CY	2230	8.22	19,331
5	GEOTEXTILE	SY	5780	1.64	9,479
6	CONSTRUCT CROSSING, TWIN 42 RCP PIPES	LF	64	43.00	2,752
7	BACKFILL	CY	2230	7.33	16,346
8	INSTALL COFFER DAM, 4'HIGH	SFCA	12000	6.67	80,040
9	EXCAVATE 10'x6' CHANNEL, SEDIMENT	CY	5,556	5.50	30,558
10	BOULDERS	CY	450	28.00	12,600
11	HAUL EXCAVATION	CY	4450	2.23	9,924
11	DEWATER EXCAVATED MATERIAL	LS	1	4,000.00	4,000
12	SPREAD EXCAVATED MATERIAL	CY	1	4,000.00	4,000
13	REMOVE COFFER DAM	SFCA	12000	2.23	26,760
14	REMOVE HAUL ROAD	CY	2230	2.61	5,820
15	STABILIZE EXCAVATED MATERIAL	LS	4000	2.00	8,000
16	SITE CLEAN UP	LS	1	5,000.00	5,000
				SUBTOTAL	243,607
	CONTINGENCY	25%			60,902
				SUBTOTAL	304,509
	ENGINEERING	15%			45,676
				TOTAL	350,185

STOCKBRIDGE BOWL IMPROVEMENTS
EXCAVATE CHANNEL (alternative method)

ITEM	DESCRIPTION	UNIT	QUANTITY	COST	SUBTOTAL
2	DISPOSAL SITE PREPARATION	LS	1	5000	5,000
3	DISPOSAL SITE SEDIMENT CONTROL	LS	1	5000	5,000
4	EXCAVATE 10'x6' CHANNEL, SEDIMENT	CY	5,556	5.5	30,558
	BOULDERS	CY	450	28	12,600
5	HAUL EXCAVATION	CY	4450	4.46	19,847
6	CHANNEL SEDIMENT BARRIER	LS	1	2500	2,500
7	RESTORE HAUL ROADS	EA	4	2500	10,000
8	DEWATER EXCAVATED MATERIAL	LS	1	4000	4,000
9	SPREAD EXCAVATED MATERIAL	CY	1	4000	4,000
10	STABILIZE EXCAVATED MATERIAL	LS	4000	2	8,000
11	SITE CLEAN UP	LS	1	5000	5,000
				SUBTOTAL	106,503
	CONTINGENCY	25%			26,626
				SUBTOTAL	133,129
	ENGINEERING	15%			19,969
				TOTAL	153,098

STOCKBRIDGE BOWL IMPROVEMENTS
DRAWDOWN GATE

ITEM NO	DESCRIPTION	UNIT	QUANTITY	COST	SUBTOTAL
1	SITE PREPARATION	LS	1	500	500
2	SITE CLEAN-UP	LS	1	1000	1,000
3	COFFER DAM INSTALLATION	SF	450	13.6	6,120
4	EXCAVATION	CY	45	23.85	1,073
5	DEMOLITION	LS	1	2000	2,000
6	BEDDING	CY	5.6	14.85	83
7	GEOTEXTILE	SY	50	16.1	805
8	MUD SLAB CONCRETE, 12"	SF	300	5.67	1,701
9	BASE CONCRETE	SF	300	5.67	1,701
10	WALLS CONCRETE	CY	540	5.67	3,062
11	TOP CONCRETE	CY	540	5.67	3,062
12	REINFORCING	TON	2	1142	
13	SLIDE GATE	EA	1	1000	1,000
14	BAR RACK	LS	1	1000	1,000
15	TOP GRATING	LS	1	1000	1,000
16	STRUCTURAL BACKFILL	CY	50	7.33	367
17	COFFER DAM REMOVAL	LS	1	2000	2,000
				SUBTOTAL	26,474
		CONTINGENCY	25%		6,618
				SUBTOTAL	33,092
		ENGINEERING	15%		4,964
				TOTAL	38,056

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STOCKBRIDGE BOWL IMPROVEMENTS
REMOVE OLD DAM

ITEM NO.	DESCRIPTION	UNIT	QUANTITY	COST	
1	SITE PREPARATION	LS	1	1000	1000
2	EXCAVATE DAM BOULDERS	CY	200	13.3	2660
3	HAUL FROM SITE	CY	200	3.83	766
4	SITE CLEAN UP	LS	1	2000	2000
					0
				SUBTOTAL	6,426
	CONTINGENCY	25%			1,607
				SUBTOTAL	8,033
	ENGINEERING	15%			1,205
				TOTAL	$9,237

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APPENDIX M

August 30, 1989

Daniel W. Smith
Lycott Environmental Research, Inc.
600 Charlton St.
Southbridge, MA 01550

RE: Stockbridge Bowl Diagnostic Feasibility Study, Stockbridge

Dear Mr. Smith:

My staff has reviewed the materials you submitted, received August 1, 1989, describing the proposed clean lakes program for Stockbridge Bowl.

The project location is located within or adjacent to the Curtisville Historic District which is included in the State Register of Historic Places. After a review of these materials, I concur that this project will have no effect on the significant architectural and historical characteristics of the State Register district.

These comments are provided to assist in compliance with M.G.L. Chapter 9, sections 26-27c, as amended by Chapter 254 of the Acts of 1988 (950 CMR 71.00).

If you should have any questions, please contact Brona Simon of this office.

Sincerely,

for Brona Simon
Valerie A. Talmage
Executive Director
State Historic Preservation Officer
Massachusetts Historical Commission

cc: DWPC - Clean Lakes Program

VAT/BS/kp

Massachusetts Historical Commission, Valerie A. Talmage, *Executive Director, State Historic Preservation Officer*
80 Boylston Street, Boston, Massachusetts 02116 (617) 727-8470
Office of the Secretary of State, Michael J. Connolly, *Secretary*

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Glossary of Lake and Watershed Management Terms

(Modified from US EPA C.L.P.G. Manual 1980)

Aeration - a process in which water is treated with air or other gases, usually oxygen. In lake restoration, aeration is used to prevent anaerobic condition or to provide artificial destratification.

Algal bloom - a high concentration of a specific algal species in a water body, usually caused by nutrient enrichment.

Artificial destratification - the process of inducing water currents in a lake to produce partial or total vertical circulation.

Benthos - organisms living on or in the bottom of a body of water.

Best management practices (BMP) - practices, either structural or non-structural, which are used to control non-point source pollution.

Biochemical/biological oxygen demand (BOD) - the amount of oxygen used by aerobic organisms to decompose organic material. Provides an indirect measure of the concentration of biologically degradable material present in water or wastewater. Additionally, "5-day BOD" is the amount of oxygen required over a period of 5 days to oxidize the organic and inorganic (NH^3, PO^4, etc.) compounds present.

Biomass - the total mass of living organisms in a particular volume or area.

Biota - all living matter in a particular region.

Blue-green algae - the phylum Cyanophyta, characterized by the presence of blue pigment in addition to green chloro-phyll, which usually have the ability to fix nitrogen.

Catch basin - a collection chamber usually built at the curb line of a street, designed to admit surface water to a sewer or subdrain and to retain matter that would block the sewer.

Catchment - surface drainage area.

Chemical control - a method of controlling pest organisms through exposure to specific toxic chemicals.

Chlorophyll ("chlorophyll a") - green pigment in plants and algae necessary for photosynthesis. It is used as an indicator of algal biomass.

Combined sewer - a sewer receiving both stormwater runoff and sewage.

Detention - managing stormwater runoff or sewer flows through temporary holding and controlled release.

Dissolved oxygen (DO) - the quantity of oxygen present in water in a dissolved state, usually expressed as milligrams per liter of water, or as a percent of saturation at a specific temperature.

Diversion - a channel or berm constructed across or at the bottom of a slope for the purpose of intercepting surface runoff.

Drainage basin, watershed, drainage area - a geographical area where surface runoff from streams and other natural watercourses is carried by a single drainage system to a common outlet.

Epilimnion - the upper, circulating layer of a thermally stratified lake.

Erosion - the process by which soils are worn away and carried from one place to another by weathering, corrosion, solution, and transportation.

Euphotic or photic zone - the region in a lake with sufficient light to permit photosynthesis. Defined as extending from the surface to the depth at which 99% of the surface light has disappeared.

Eutrophic lake - a lake with an abundant supply of plant nutrients producing a high concentration of biomass.

Eutrophication - a natural enrichment process of a lake, which may be accelerated by man's activities. Usually manifested by one or more of the following characteristics: a) excessive biomass accumulations of primary producers; b) rapid organic and/or inorganic sedimentation and shallowing; or c) seasonal and/or diurnal dissolved oxygen deficiencies.

Grassed waterway - a natural or constructed waterway covered with erosion-resistant grasses, used to conduct surface water from an area at a reduced flow rate.

Green algae - algae characterized by the presence of photosynthetic pigments similar in color to those of the higher green plants.

Hydraulic residence time - the time (in years) it would take to replace all of the water in a lake. Calculated by taking lake volume/total annual discharge. Its reciprocal is flushing rate.

Hyper-eutrophic lake - a lake with extremely high levels of nutrient enrichment caused by human activities. Nuisance algal blooms and aquatic macrophyte growths are common.

Hypolimnion - the lower layer of a thermally stratified lake which does not mix with the upper layer (epilimnion) while the lake is stratified.

Internal loading - release of dissolved phosphorus or other nutrients from sediments.

Limiting nutrient - the substance that limits growth due to its short supply relative to other essential substances.

Littoral - the area along the shore which contains major aquatic plant growth.

Macrophytes - large vascular, aquatic plants which are either rooted or floating.

Mesotrophic lake - a trophic condition between an oligotrophic and a eutrophic water body. A moderately clean lake.

Metalimnion - the middle layer of a thermally stratified lake in which temperature rapidly decreases with depth (also called the thermocline).

Nitrogen fixation - the biological process of incorporating elemental nitrogen into organic compounds.

Non-point source - non-point source pollutants are not traceable to a discrete origin, but generally result from land runoff, precipitation, drainage, or seepage.

Nutrient budget - an accounting of the nutrients entering and leaving the lake, and accumulating in the lake and its sediment (e.g., input minus output = accumulation).

Nutrient inactivation - the process of rendering nutrients inactive by one of three methods: 1) changing the form of a nutrient to make it unavailable to plants, 2) removing the nutrient from the euphotic zone, or 3) preventing the release or recycling of potentially available nutrients within a lake.

Oligotrophic lake - a lake with a small supply of nutrients, and consequently a low concentration of biomass.

Outfall - the point where wastewater or drainage discharges from a sewer to a receiving body of water.

Overturn, turnovers - the complete mixing of a previously thermally stratified lake. This occurs in the spring and fall when water temperatures become uniform.

Phosphorus, available - phosphorus which is readily available for plant growth. Usually in the form of soluble orthophosphates.

Phosphorus, total (TP) - all of the phosphorus present in a sample regardless of form. Usually measured by the persulfate digestion procedure.

Photosynthesis - the process occurring in green plants in which light energy is used to convert inorganic compounds to carbohydrates. In this process, carbon dioxide is consumed and oxygen is released.

Phytoplankton - plant microorganisms, such as algae, living suspended in the water.

Plankton - unattached aquatic microorganisms which drift passively through water.

Point source - a discreet pollutant discharge such as a pipe, ditch channel, or concentrated animal feed operation.

Primary production - the production of organic matter from light energy and inorganic materials, by autotrophic organisms (algae and macrophytes).

Respiration - process occurring in all organisms where fixed carbon is oxidized to produce energy to sustain life. They consume oxygen and produce CO_2.

Secchi depth - a measure of optical water clarity as determined by lowering a weighted Secchi disk into a water body to the point where it is no longer visible.

Sediment basin - a structure designed to slow the velocity of runoff water and facilitate the settling and retention of sediment and debris.

Sub-basin - a physical division of a larger basin, associated with one reach of the storm drainage system.

Suspended solids - refers to the particulate matter in a sample, including the material that settles readily as well as the material that remains dispersed.

Thermal stratification - the layering of water bodies due to a temperature-induced density differences.

Trophic status - a relative description of a lake's biological productivity. The range of trophic conditions is characterized by the terms oligotrophic for the least bio-logically productive, to eutrophic for the most biologically productive.

Turbidity - a measure of the cloudiness of a liquid. Turbidity provides an indirect measure of the suspended solids concentration in water.

Urban runoff - surface runoff from an urban drainage area.

Water quality - a term used to describe the chemical, physical, and biological characteristics of water, usually with respect to its suitability for a particular purpose.

Water quality standards - state-enforced standards describing the required physical and chemical properties of water according to its designated uses.

Watershed - see drainage basin.