GALE

BILLINGTON SEA
DIAGNOSTIC/FEASIBILITY STUDY

FINAL REPORT

NOVEMBER 1990

Prepared For:
The Town of Plymouth
And The
Massachusetts Division of Water Pollution Control
Clean Lakes Program

In Association With
M.G.L. Ch. 628
Massachusetts Clean Lakes Program

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ACKNOWLEDGEMENTS

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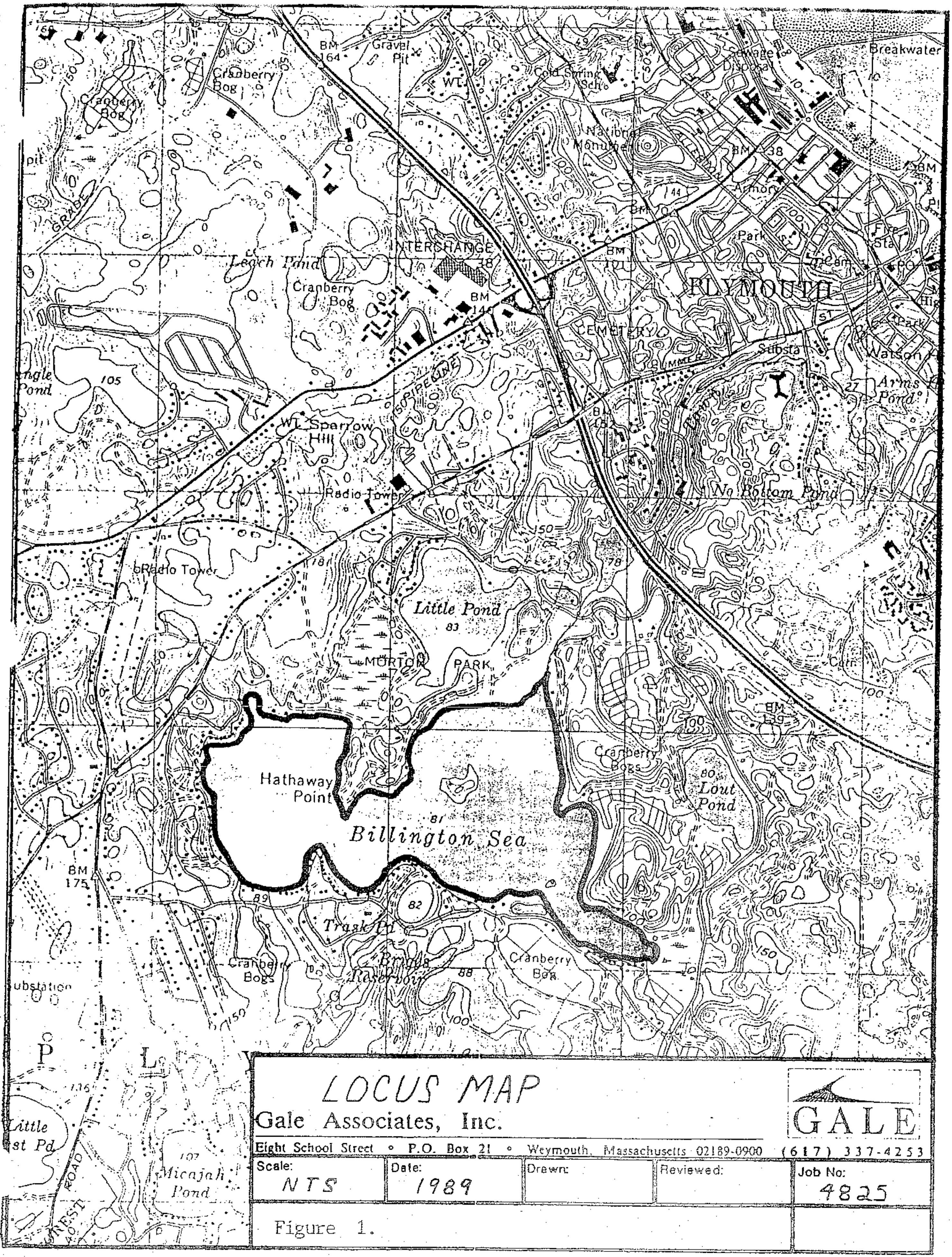
Executive Summary

Conflicting water use demands are currently being placed on the Billington Sea, a shallow 266-acre kettle pond located in Plymouth, Massachusetts (Figure 1). The lake serves as a regionally-important recreational resource, habitat for rare wetland wildlife and as an irrigation source and discharge basin for cranberry bogs. Unsewered residential development is dense along the western and southern shoreline of the lake and aquatic recreational activities occur without regard for their water quality impacts. The eastern portion of the lake is located within the recharge zone of a public water supply well (Lout Pond well).

The recreational, aesthetic, and fisheries and wildlife habitat values of the lake have been reduced as a result of an overabundance of submergent aquatic plant growth and the late summer occurrence of blue-green algal blooms. Thus, a year-round water quality survey of the lake and its tributaries was conducted with funds provided by the Town of Plymouth and the Massachusetts Clean Lakes Program. The physical, chemical and biological characteristics of the lake were assessed, as were the physical, hydrogeological and land use characteristics of the watershed. These data were used to determine the sources of the nutrients which are causing the lake's water quality degradation and to develop a plan for in-lake restoration and watershed management.

Every lake has a limited capacity to assimilate nutrient loading without expressing the undesirable conditions of nuisance algal and aquatic plant growth which are associated with cultural eutrophication. Data collected during the year-round study of the Billington Sea indicate that annual phosphorus inputs to the lake from tributaries (61.3%) and residential wastewater disposal systems (20.0%) are twice as high as the lake's carrying capacity, resulting in the eutrophic state previously described. Tributary and residential wastewater disposal system inputs also account for 16.9% and 63.9% of the annual nitrogen loading to the lake. The shallowness of the lake (mean depth of 2.1m) and low flushing rate (6.3 times per year), as well as the high groundwater velocities which occur along the shoreline of the western basin, make it more susceptible to becoming eutrophic. Approximately 39% of the annual phosphorus load accumulates within the lake, primarily within the sediments, where it can be recycled each year for aquatic plant growth.



LOCUS MAP

Gale Associates, Inc.

GALE

Eight School Street ∘ P.O. Box 21 ∘ Weymouth, Massachusetts 02189-0900 (617) 337-4253

Scale: NTS

Date: 1989

Drawn:

Reviewed:

Job No: 4825

Figure 1.

Recommendations for restoration of the Billington Sea consist of a reduction in phosphorus inputs from cranberry bog tributaries, and secondarily from shoreline wastewater disposal systems, prior to implementing the necessary in-lake restoration measures for reducing phosphorus recycling by aquatic plants. Thus, both in-lake and watershed phosphorus reduction measures will be necessary in order to improve the lake's water quality to a level which will not promote the algal blooms and dense aquatic plant growth which currently exist.

In summary, watershed management plan recommendations include:

(1) tributary phosphorus load reductions which involve the relocation of bog outfalls, in conjunction with the incorporation of "best management practices" for water use and fertilizer applications, and

(2) groundwater phosphorus load reductions which involve the identification and upgrading of subgrade wastewater disposal systems located in the lake's recharge zone.

The latter recommendation involves the implementation of a public education program to teach lakeshore residents about septic system and waterfront maintenance, as well as the adoption of Zoning and Board of Health bylaws which protect groundwater quality in the lake's recharge zone.

The recommended in-lake restoration plan involves the application of an innovative technique called "reverse layering", which is currently being tested as a Research and Development project in Red Lily Pond (Barnstable, MA) with funds provided by the Division Of Water Pollution Control. This long-term, in-lake restoration technique reduces aquatic plant regrowth by depositing sandy lake bottom sediments on top of nutrient-rich muck deposits. Fish spawning habitat and water quality conditions are improved as a result. The implementation of a "lake use plan", which regulates recreational activities on the lake through zoning, is also recommended in order to achieve a balance between the habitat and recreational values of the lake.

1.0 INTRODUCTION

1.1 Background

Plymouth ranks third (1,626-acres in 1989) in terms of the amount of cranberry bog acreage existing in Massachusetts (Jeff Carlson, personal communication). The Billington Sea has been used as a cranberry bog irrigation source and discharge basin since the early 1900's. Since then, some of the bogs in the watershed have been abandoned. Recreational use of the Billington Sea became popular when cottages were built along the western and southern shoreline during the 1920's and 1930's. Many of these summer residences have since been enlarged and converted to year-round dwellings. None of the residences are sewered and a large number of them are not in compliance with the Commonwealth of Massachusetts Title V Sanitary Code.

Deteriorating water quality in the lake was first noticed by lakeshore residents who formed a group in 1971 called "The Association for the Betterment of the Billington Sea". Group members began to contact state and local officials to make them aware of the lake's water quality problems and to determine what could be done about them. Emphasis was placed on controlling the overabundant growth of the aquatic plant, Elodea canadensis, which continues to be a nuisance to date. Six thousand (6,000) gallons of the herbicide, sodium arsenite, were applied to the lake in July of 1970 by the Massachusetts Department of Public Health. This chemical was added at a concentration of 7.5 ppm in order to control the growth of Elodea sp. Less than thirty (30) days later, the lake was treated with 2,500 pounds of copper sulfate, at concentration of 0.3 ppm in order to reduce the algal blooms and improve the water clarity. The fisheries, benthic and plankton communities were sampled by the Division of Fisheries and Wildlife prior to and following these applications. The results indicate that these treatments negatively impacted the lake and may have been the cause of a fish kill and algal blooms which occurred shortly thereafter. Furthermore, beneficial zooplankton species were nearly eradicated probably as a result of copper toxicity (Winner and Farrell, 1976). Elevated arsenic levels which were detected in 1987 in the lake sediments may have also originated from these treatments. Chemical treatments are only short-term improvements and have been associated with major adverse impacts to aquatic ecosystems (Cooke et al., 1986).

A year-round water quality study of the lake and its tributaries was conducted in 1978 (Lyons and Skwarto, 1978) in order to determine the sources of the nutrients causing the abundant Elodea growth. The lake was classified as eutrophic, with total phosphorus concentrations ranging from 0.06-0.09 mg/L and ammonia levels ranging from 0.1-0.3 mg/L during the growing season. Recommendations involved aquatic plant biomass reduction through harvesting out to the 5-ft. contour line. Harvesting is a short-term lake management measure which, although in-lake nutrient levels (plant tissue) are reduced, is only temporary since regrowth occurs rapidly in a eutrophic lake. The watershed pollution control measures recommended included diversion of the bog discharges and the detention of stormwater runoff and/or the installation of catch basins. A voluntary phosphate ban and the installation of non-water using toilets in place of failed systems, to be identified through a septic leachate survey, were also recommended.

Weed harvesting was conducted in 1980, as was a July septic leachate survey (IEP, 1980), with the use of a Septic Snooper leachate detector. Although gross sewage contamination was not implicated, additional water quality testing was recommended for four (4) of the nine (9) leachate plumes identified. Other recommendations included: a ban on phosphate use in the watershed, sampling of tributaries and storm drains during wet weather and following cranberry bog floodwater releases, and an annual shoreline reconaissance to identify additional surface break-out of septic leachate. Since the Billington Sea contains high concentrations of UV-absorbing organics from bog discharges, the use of the septic snooper probably reduced the capacity of the scientists to identify septic leachate infiltration along the southern and western shorelines. Interference from these organics tends to suppress the septic signal (WAPORA, 1982) of this type of leachate detector. The use of the new "Peeper Beeper" leachate detector in the subject study allowed for the detection of bog and septic leachate discharges since this interference does not occur with this model.

A study of the surface and groundwater quality of several of the Plymouth lakes, including the Billington Sea, was conducted in 1981 (Geoscience, 1981). High levels of total phosphorus and nitrate-nitrogen were obtained from groundwater samples collected along the western shoreline of the lake, and in some cases, wells located downgradient from septic systems were noted to be receiving septic leachate inflow. It was suggested that septic inputs of phosphorus and nitrate were directly linked to the density of Elodea sp.

A baseline water quality survey of the Billington Sea was conducted by the Massachusetts Division of Water Pollution

Control on June 9, 1986 (MDWPC, 1986). The results showed a greater concentration of nitrate-nitrogen (0.40 mg/L) present in the western basin than in the eastern basin (0.10 mg/L), which lends support to the contention of a high septic leachate inflow into this basin. Ammonia-nitrogen and total phosphorus concentrations were elevated, consisting of 0.19 mg/L and 0.19 mg/L in bog Tributary A and 0.27 mg/L and 0.26 mg/L in bog Tributary D, respectively.

None of the previous studies of the lake's water quality quantified all of the nutrient and pollutant loading sources to the lake, including the lake sediments. Thus, the Plymouth Conservation Commission was awarded funds from the Massachusetts Division of Water Pollution Control, in conjunction with the Clean Lakes Program, to hire a consultant to conduct a year-round Diagnostic/Feasibility Study of the Billington Sea. The results of this study, conducted by Gale Associates, Inc., are presented herein.

1.2 Scope of Work and Study Objectives

The purpose of the Billington Sea Diagnostic/Feasibility Study was to characterize existing water quality conditions within the lake, identify and quantify the sources of nutrients and pollutants which are causing its degradation, and to recommend cost-effective pollution control measures for its restoration and management.

The first phase of the study, the diagnostic phase, included the year-round collection of water quality data in order to identify existing and potential sources of nutrient and pollutant loading to the Billington Sea. This phase also entailed the assessment of limnological, geological and morphological characteristics of the lake and an evaluation of watershed land use activities and physical features as they relate to in-lake water quality conditions. The data collected during the diagnostic phase were used to prepare budgets of the nitrogen and phosphorus inputs and outputs of the lake. The second phase of the study, the feasibility phase, involves the utilization of the nutrient budget information in order to assess the effectiveness of various pollution control measures on improving in-lake water quality and to recommend a restoration plan for the lake.

The study objectives were as follows:

(1) to fully meet all requirements of the Clean Lakes Program, rules, guidelines and Substate Agreement.

(2) to evaluate the alternatives and recommend long-term solutions for improving in-lake water quality.

(3) to establish a watershed management plan which will mitigate further water quality degradation of the lake.

2.0 DIAGNOSTIC EVALUATION

2.1 Recreational Use and Public Access

The Billington Sea, discovered in 1621 by Francis Billington, is Plymouth's second largest freshwater recreational resource. A survey conducted by members of the Billington Sea Lake Association (Elaine Purdy, personal communication) indicated that in addition to local citizens, residents of neighboring towns as well as tourists visiting the historical Town of Plymouth enjoy swimming, boating, windsurfing, waterskiing and fishing in the Billington Sea. Local citizens and lakeshore residents also engage in icefishing and skating during the winter. During the 1920's, the aesthetically-pleasing nature of the lake attracted summer residents who built cottages around its shoreline. Many of these early cottages have since been enlarged and now serve as year-round homes. The numerous piers and floating docks located along the lakeshore are evidence that the lake is also heavily utilized by lakeshore residents.

As indicated in Figure 2, most of the lake's northern shoreline is accessible to the public via Morton Park. The main access to the park is Morton Park Road, which is located southeast of Summer Street near the Route 44 exit of Route 3. This 240-acre park became established in 1889 when Nathanial Morton purchased the land from Dr. LeBaron Russell for a sum of $1,500.00 which was contributed by local residents for the purchase of a park (Elaine Purdy, personal communication). The parkland ~~west~~ east of Hathaway Point was originally donated to the Town for the construction of a smallpox and contagious disease hospital. As a result, this

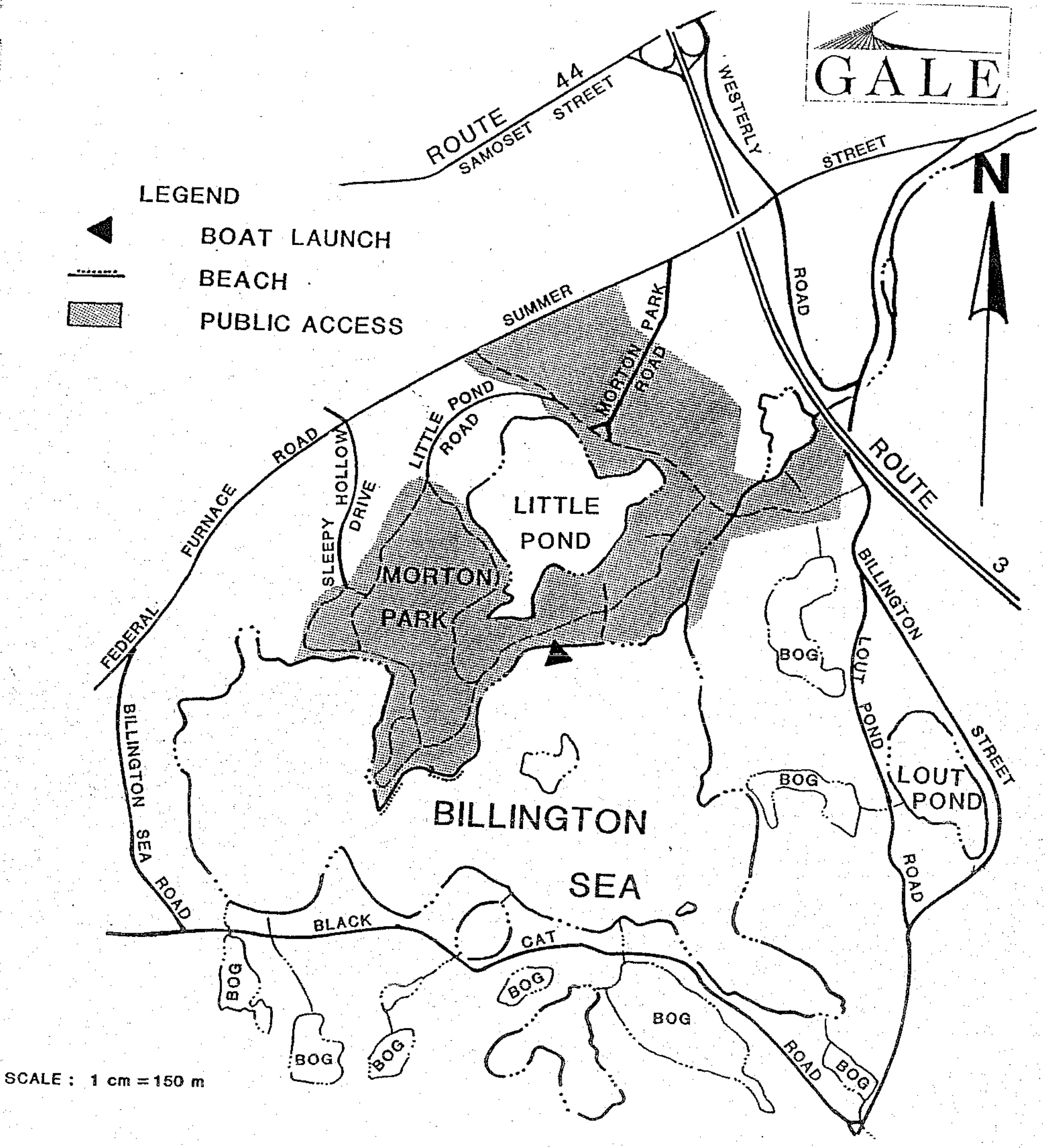


FIGURE 2: PUBLIC ACCESS

BILLINGTON SEA

PLYMOUTH, MASSACHUSETTS

area is now known as "Hospital Cove". The two islands located in the eastern basin of the lake are also owned by the Town. The larger island, called Seymour Island, is now a bird sanctuary. Morton Park contains an undeveloped boat launching area and picnic facilities. Although there is no designated bathing area, most swimmers utilize the shallow,sand bottomed area next to the eastern shore of Hathaway Point. The scenic footpaths which wind through the heavily-wooded park and along the lakeshore are also popular hiking routes (personal observation).

Historically, there have been attempts to adopt a local bylaw which restricts motorboat use to specific weekdays and times, but these efforts have failed. Members of the Plymouth Conservation Commission and some of the lakeshore residents agree that motorboat use on the Billington Sea continues to be a problem, and as a result, do not favor the construction a boat ramp along the northern shoreline. The operation of motorboats at high speed in the shallow western basin is dangerous because two large rock piles are located just below the water's surface. Furthermore, this basin is shallow and the turbulence created by boat propellers can resuspend fine-grained nutrient-rich sediment (Wagner, in press), facilitate algal blooms, increase water column turbidity and can destroy fish spawning habitats. Additionally, propeller cutting may cause an actual increase in the biomass of submergent plants which reproduce by fragmentation. Motorboat use near Hathaway Point also produces a safety hazard for bathers using the area as well as for boaters who are unaware of the sandy shoal which extends lakeward from the end of this peninsula. Therefore, the implementation of a "lake use plan" which minimizes recreational user conflicts and reduces water quality impacts to the lake and fishery resources is recommended.

2.2 Lake and Watershed Description

The Billington Sea is a shallow kettle pond located in Plymouth, Massachusetts (41 degrees 56'4", 70 degrees 41'16"). The lake's watershed (land which drains into the lake) boundary and subdrainage basins are indicated in Figures 3 and 4, respectively. The size of the watershed (4.60 km²) is small in comparison to that of the lake (108 hectares), resulting in a low watershed to lake area ratio of 4.3. Kettle ponds typically have small watersheds since they normally do not have inlets or an outlet. The Billington Sea, however, has five inlets and an outlet (Town Brook, which flows 1.5 miles before discharging into Plymouth Harbor). Five (5) short perennial streams, which receive runoff from cranberry bogs, discharge into the lake along its southern shoreline. Stream flows are highly variable throughout the year since they are regulated by agricultural use, but consistent baseflows are maintained by groundwater recharge.

The physical characteristics of a watershed determine the volume of precipitation that is converted into runoff (direct discharge), groundwater (infiltration) and atmospheric loss (evapotranspiration). The elevation of the lake surface is 81 feet above mean sea-level. The topography of the Billington Sea watershed ranges from flat bog areas (80-90 feet above mean sea-level), located at the base of the hills south of the lake, to steep slopes of up to 35% along the lake's western shoreline. As a result of

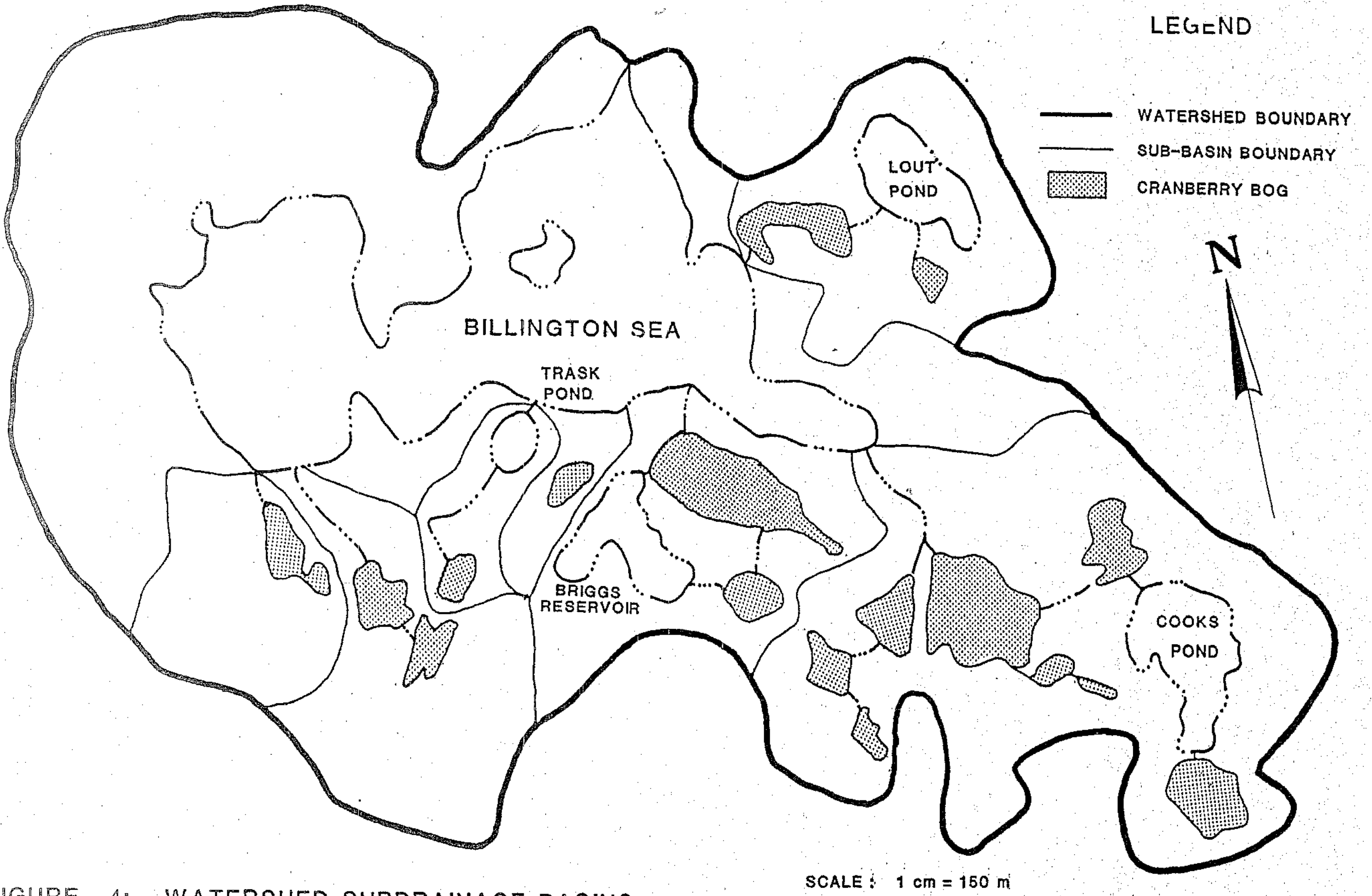


FIGURE 4: WATERSHED SUBDRAINAGE BASINS

BILLINGTON SEA

PLYMOUTH, MASSACHUSETTS

the high infiltration capacity of the sandy watershed soils, surface runoff from the watershed is low and groundwater recharge is the major hydrologic input to the lake. Accelerated groundwater velocities occur along the western shoreline of the lake as a result of a steep groundwater gradient in this area. Consequently, leachate from residential wastewater disposal systems is rapidly transported into the western lake basin.

The majority of the watershed (59%) is undeveloped, consisting predominately of hardwood forests. There is no industrial and only one small commercial development within the watershed. A dense fringe of single family residences, however, exists along the environmentally-sensitive western and southern shorelines. The majority of these dwellings are summer cottages, averaging 40 years of age, which have been enlarged and converted to year-round use. Although road swales direct stormwater runoff from Black Cat Road into several of the lake's tributaries, urban areas generate very little runoff since most of the roads and driveways are unpaved. The northern portion of the watershed contains a large, 240-acre parkland (Morton Park) which is owned and maintained by the Town of Plymouth as a public access to the lake. As a result, this area and the majority of the watershed located south of Black Cat Road are currently undeveloped and not likely to be developed in the future. The latter area is dominated by agricultural open space in the form of cranberry bogs and small, shallow waterbodies which serve as auxiliary irrigation sources. A majority of the land surrounding the cranberry bogs is undeveloped. Since it is owned by the cranberry growers, it is not likely to be developed in the future.

2.3 Watershed Land Uses

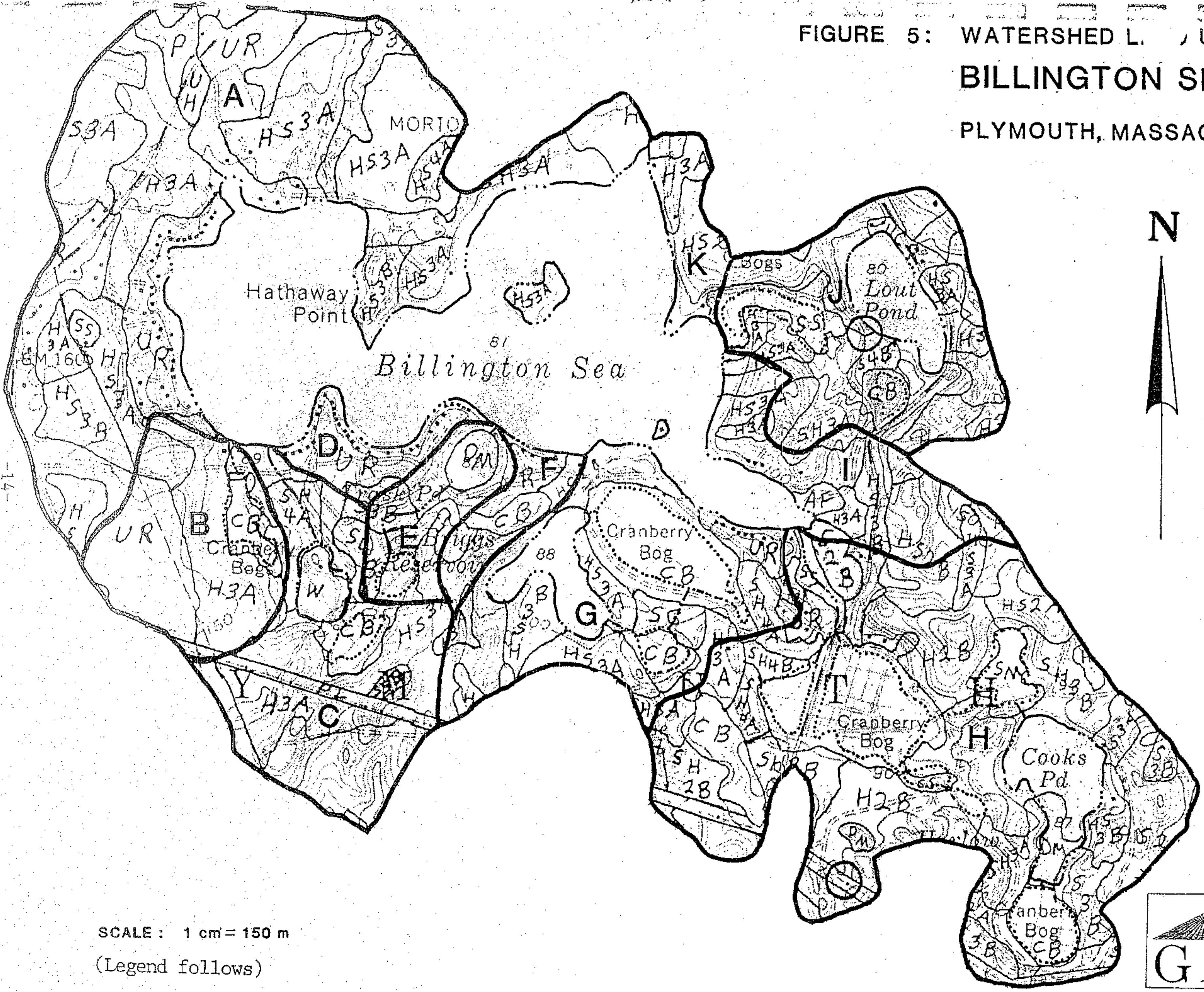
The nature of a lake's drainage basin is influential in determining its water quality for it is primarily the land and its uses which are the loading sources of nutrients, organics and sediment. The most recent land use map of the watershed area available at the time of study is shown in Figure 5 (MacConnell, 1971) and the percent areal cover of Oeach type is presented, by subdrainage basin, in Table 1. Descriptions of each of the land use type codes follow Figure 5. A more recent land use map (1986, available 1989) has indicated no significant change of uses since the 1971 map.

The major watershed land use categories include: wetlands (SS,SM,BM and W), agricultural and open land (P, AF, CB and PL), forests (S, H, SH and HS), mining (SG) and urban land (UH and UR). The majority of the watershed (59%) consists of forested land which is dominated by 41-60ft. hardwood stands. Only fourteen percent (14%) of the watershed consists of urban land. However, these residential areas are concentrated along the environmentally-sensitive western and southern shorelines of the lake. Most of the northern portion of the watershed is undeveloped because it is maintained by the Town of Plymouth as a park (Morton Park) for use as a public access to the Billington Sea and Little Pond. Wetland areas comprise twenty-five percent (25%) of the watershed and are concentrated in the eastern and southern portions of the watershed. Four (4) wetland systems, which occur in subdrainage basins B, E, G and H, have been developed for cranberry production and drain into the Billington Sea through four (4) short, perennial streams. A fifth

FIGURE 5: WATERSHED L. , USE MA

BILLINGTON SEA

PLYMOUTH, MASSACHUSET



SCALE : 1 cm = 150 m

(Legend follows)

LEGEND FOR LAND USE MAP

Agricultural and Open Lands

P – is pasture or wild hay land which is not suitable for tillage due to steepness of slope, poor drainage, stoniness, or lack of fertility. This land has less sharply defined boundaries and often has occasional scattered shade trees for the grazing animals.

AF – is abandoned field which is reverting to wild land. Woody vegetation and grass are abundant but tree crown cover is less than 30%. If the tree crown cover were greater than 30%, the land would be classified as forest. This land is highly productive of wildlife. Most of this land was pasture or wild hay land before abandonment.

CB – is productive cranberry bog. Abandoned cranberry bog soon succeeds to a wetland type usually becoming swamp (SS).

PL – is powerlines or buried telephone lines, gas or oil pipe lines or other right-of-way 100 feet or more in width maintained through wooded areas. Where powerlines cross agricultural or wetland and require no maintenance they are typed as the vegetative type or the land use permitted under them.

Forest Lands

S – softwoods constitute at least 80 percent of the stand.
H – hardwoods constitute at least 80 percent of the stand.
HS – a mixture of hardwoods and softwoods with hardwoods predominating.
SH – a mixture of softwoods and hardwoods with softwoods predominating.

Tree height classes are designated by the numbers 1 through 6.

1. 1 ft. - 20 ft.
2. 21 ft. - 40 ft.
3. 41 ft. - 60 ft.
4. 61 ft. - 80 ft.
5. 81 ft. -100 ft.
6. Uneven heights (three or more height classes represented)

The density classes are designated by letters.

A. High density, 81 percent to 100 percent crown closure.
B. Low density, 30 to 80 percent crown closure.

Wetlands

SS - is shrub swamp. The soil is waterlogged during the growing season and is often covered with as much as six inches of water. Common woody species are alder, buttonbush, dogwood and willow. Sedges are usually present in tussocks.

SM - is shallow marsh. This type is wetter than meadow. The soil is completely waterlogged and often covered with up to six inches of water during the growing season. There is usually some open water and the predominant vegetation is emergent, including such plants as cattails, bulrushes, burreed, pickerelweed and arrowhead with some grasses and sedges present.

DM - is deep marsh. Water depth ranges from six inches to three feet. Fairly large open water areas are bordered by, or interspersed with, emergent vegetation like that found in shallow marsh. Floating and submergent plants such as water lilies, duckweed, watershield and pondweeds are also present.

W - is open water in lakes, rivers and large streams. Water depth is greater than 3 feet during the growing season. The boundary of coastal water is located by drawing a line at the river mouth to connect the edges of the coastline, or man-made features like roads, railroads or bridges crossing rivers or inlets are used to establish it.

Mining

SG - Sand or Gravel - This land is used for the extraction of sand or gravel.

Urban Land

Land classified as urban for the most part encompasses a large number of people living and working in closely ordered structures in a confined land space. Urban limits are at the border of the block street pattern or just beyond it. Each urban type includes the access roads, parking facilities and other features which go with the complex. Industrial, commercial, residential and transportation lands make up the urban type.

UH – is highway commercial land used for merchandising goods and services to the traveling public away from urban centers. Gas stations, motels, restaurants, drive-ins and stores located in strips along major routes of travel make up this type.

UR – is residential land used for homes which are spaced closely and arranged in orderly curved or rectangular patterns and set back from the street.

Table 1: Percent Land Use Types Within the Billington Sea Watershed in 1971/72

Land Use Type (%)

Watershed Subbasin	Area (km^2)	Hardwood	Softwood	Marsh	Open Water	Residential	Cranberry Bog	Urban	Sand Mining	Open Land
A	1.26	50	10			30		5		5
B	0.30	50				35	10			5
C	0.45	50	20		10	5	10			5
D	0.08					100				
E	0.14		20	20		35	25			
F	0.10	60				20	20			
G	0.51	35	5		15		40		5	
H	1.35	40	20	10	5		20			5
I	0.25	85	5							10
J	0.49	40	15	20	25		10			
K	0.08	100								
WATERSHED TOTAL	4.60	46	13	5	6	13	13	1	1	4

Reference: 1971/72 Land Use and Vegetative Cover Map, Plymouth Quadrangle (MacConnell, 1971).

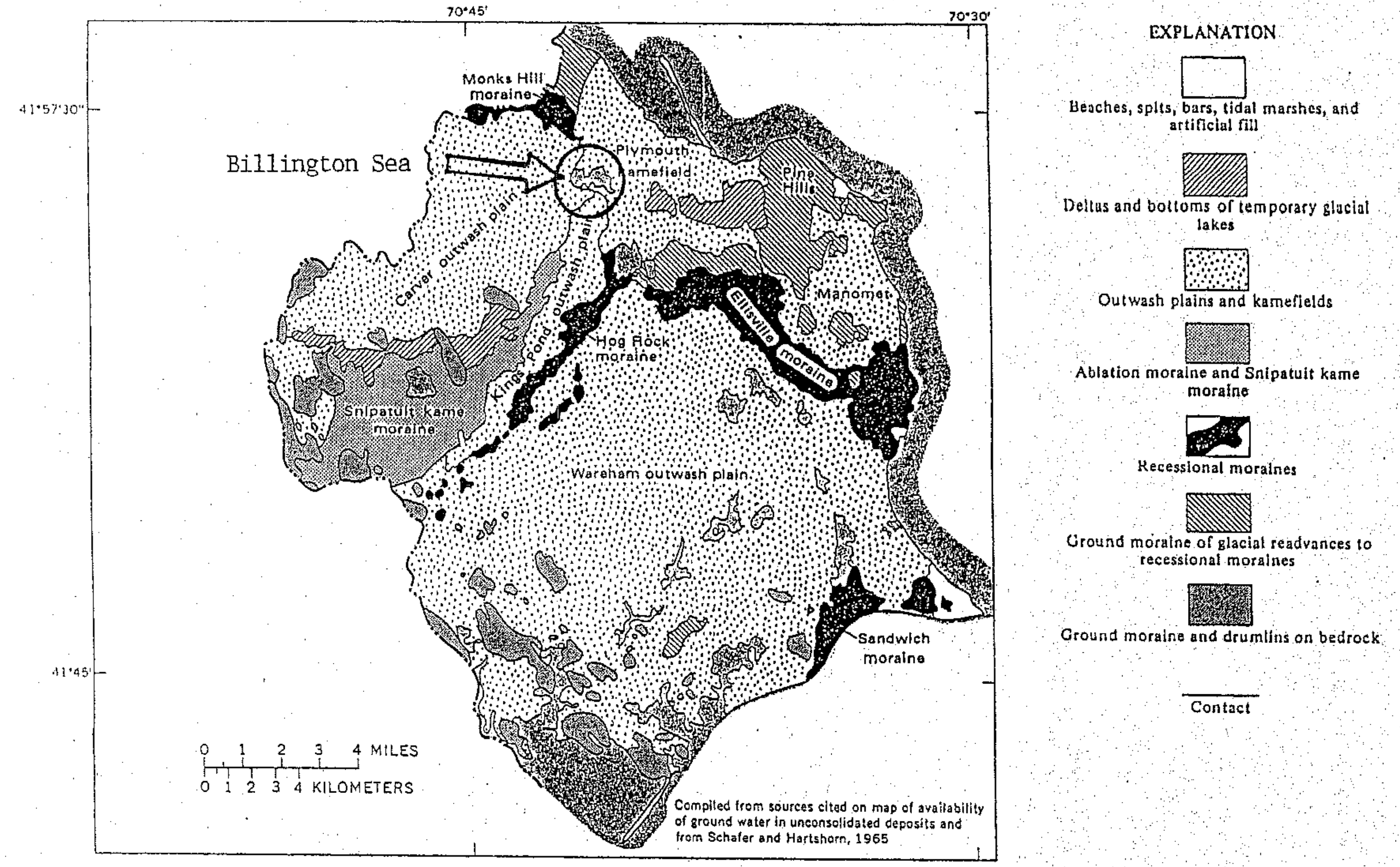
tributary drains an abandoned cranberry bog system in subdrainage basin C. One of these abandoned bogs has been excavated to form a coldwater pond which is used to raise trout and waterfowl. Shallow ponds which serve as auxiliary bog irrigation sources are located in subdrainage basins G and H. Another waterbody, Trask Pond (located in subdrainage basin E), is a small, hypereutrophic pond which serves as an irrigation source for the bog located in subdrainage basin F and receives runoff from the three (3) bogs in subdrainage basin E before discharging into the Billington Sea. The bog in subdrainage basin F discharges into a wetland depression located to its southeast. Lout Pond is located east of the Billington Sea, in the lake's discharge zone and recharges a public water supply well. Most of the land surrounding these bog systems is undeveloped and consists of mixed stands of hard and softwood forests. Several of these forested hillsides have been mined for sand which is applied to the bogs each year. As discussed in the previous section, groundwater recharge rather than watershed runoff is the primary source of inflow to the lake. Therefore, a significant source of nitrogen and phosphorus loading to the lake is septic leachate from residential wastewater disposal systems located in the lake's recharge zone. The boundary of the recharge zone and the quantification of this nonpoint source of nutrient loading are discussed in Section 2.7. Overall, runoff from agricultural land use types has the greatest degree of impact on the lake in terms of nutrient loading.

The amount of phosphorus and nitrogen loading from cranberry bogs is also discussed in Section 2.7. Historically, the magnitude of this impact was probably greater since a larger portion of the watershed formerly consisted of actively managed bogs. These areas are indicated as shrub swamps (ss) on the land use map.

2.4 Watershed Geology

The rolling landscapes of Plymouth and the rest of southeastern Massachusetts were created during the last glacial epoch (Late Wisconsin) by various glacial depositional environments (i.e. glacial meltwaters, glacial lakes and direct glacier contact). Groundwater and surface water quality and flow characteristics in this area are predominately governed by a thick layer of glacial deposits which overlie a relatively deep bedrock layer. The Bedrock Geology Map of Massachusetts (USGS, 1983) indicates that this bedrock layer is between 80 and 150 feet below the ground surface in the vicinity of the Billington Sea. This bedrock layer is composed of either hard granite, gniess or schist and slopes toward the east.

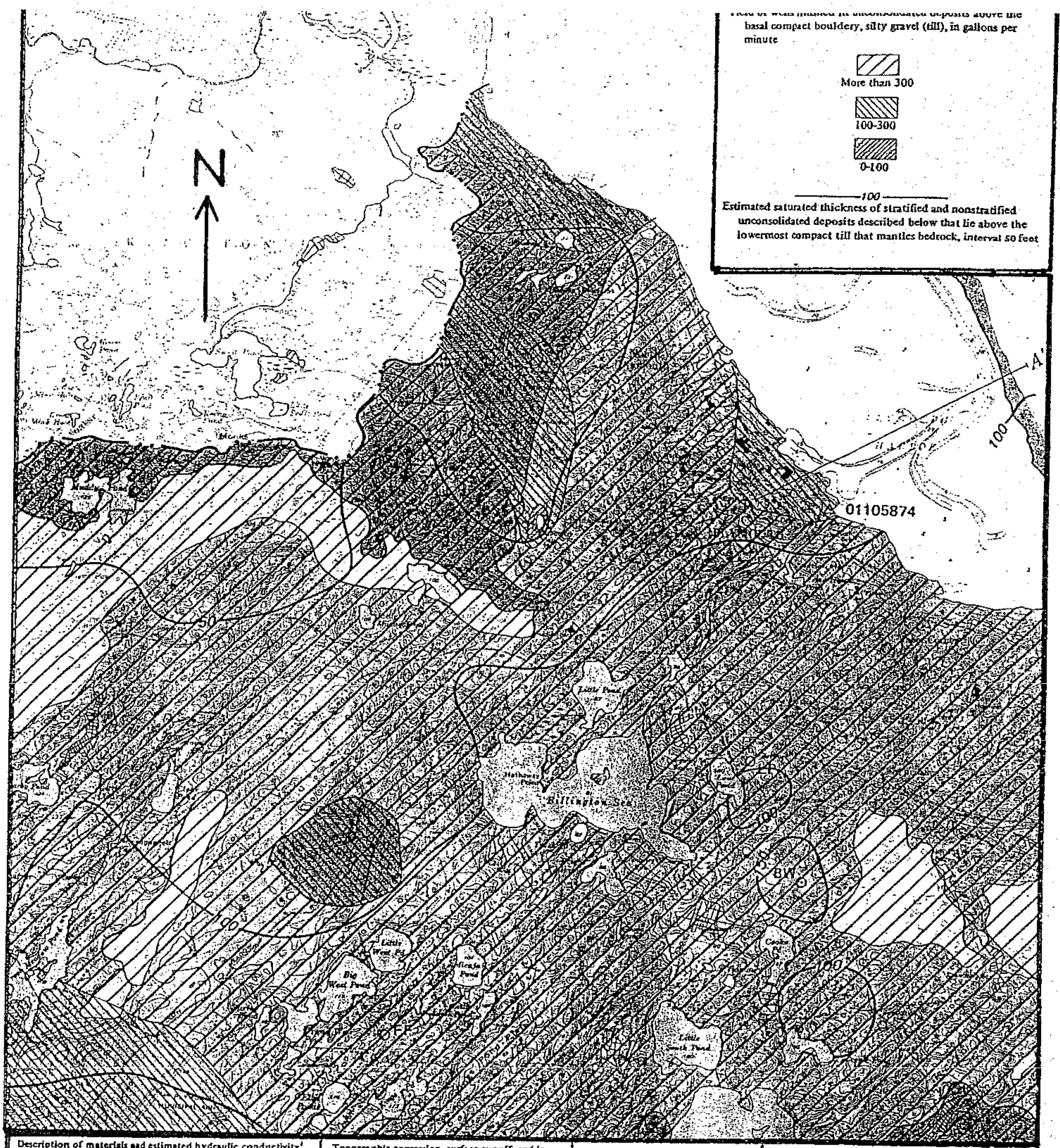
The Billington Sea is a shallow kettle pond which was formed during the retreat of the glaciers. Large blocks of ice, which became buried in the outwash deposits, eventually melted and left large depressions which are referred to as kettles. Some of these kettles became ponds and lakes. As indicated in Figure 6, the western shoreline of the Billington Sea is located at the intersection of two outwash plains and a kamefield. The Carver outwash plain is located to the west, the Kings Pond outwash plain is located to the south and the Plymouth kamefield is located to the east. Outwash plains are created by numerous meltwater rivers and streams which transport, sort and deposit large amounts of sediments. Outwash plains generally radiate in a



Compiled from sources cited on map of availability of ground water in unconsolidated deposits and from Schafer and Hartshorn, 1965

Figure 6. Glacial Landform Map

Source: Williams and Tasker. Water Resources of the Coastal Drainage Basins of Southeastern Massachusetts; Plymouth to Weweantic River, Wareham. 1974

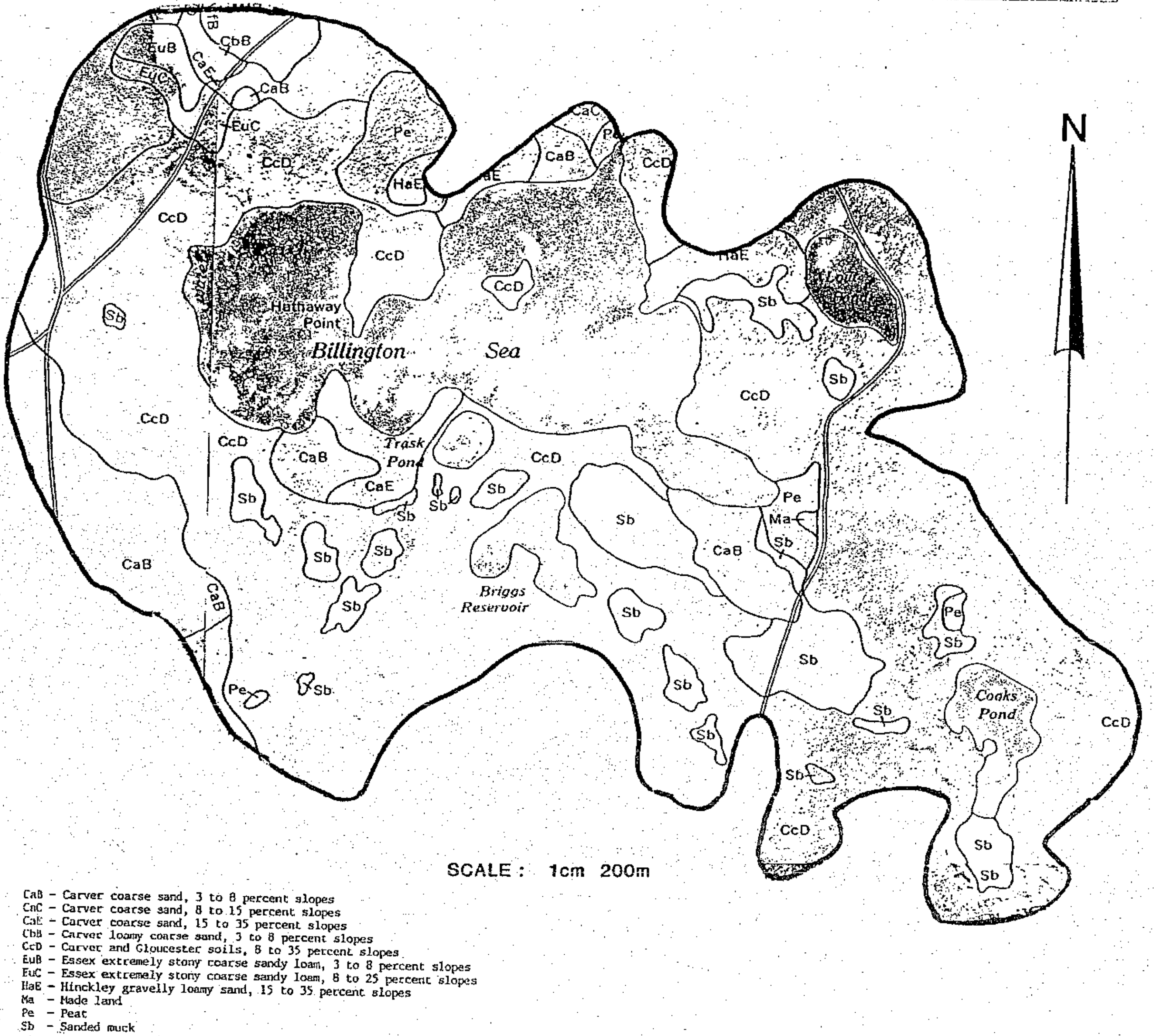


Description of materials and estimated hydraulic conductivity[1] (in parentheses, in feet per day; to convert to coefficient of permeability[2] in gallons per day per square foot, multiply by 7.5).	Topographic expression, surface runoff, and infiltration capacity (See small-scale map for location of named landforms).	Water table	Exploration of ground water
☐ Gravel ▨ Sand Fine to coarse gravel (150-475) and medium to coarse sand (100-150) of northern part of Carver outwash plain, of prominent eskers elsewhere, and a minor constituent of other outwash deposits. Sand of outwash plains generally grades southward from fine to coarse (40-150) in the north to either fine to medium sand (40-100) or to fine sand containing some silt and clay (10-40) in the south. Deposit has relatively little textural change horizontally or with depth in local areas.	Southward sloping Carver, Wareham, and other outwash plains and Plymouth kamefields that are locally heavily pitted or broken by dry furrows. Surface runoff very low; infiltration capacity high in most of area.	As deep as 80 or 90 ft locally near northern boundary of outwash plains, but 10-25 ft near southern margin. Locally within 10 ft near ponds and beneath some furrows and pits.	Generally an excellent source of large supplies of water in areas having more than 50 ft of saturated thickness. With the exception of scattered boulders in some areas, provides easy drilling to light rigs.

Figure 7. Availability of Groundwater in Unconsolidated Deposits.

fan-like conformation in front of glaciers. Kamefields are created when the glacier comes in direct contact with a lake-forming delta or beach. These types of depositional environments allow the sediments to become well-sorted. As indicated in Figure 7, the Carver and Kings Pond outwash plains and the Plymouth kamefield consist predominantly of well-sorted sand with estimated hydraulic conductivities of 40 to 150 feet per day (Williams and Tasker, 1974). These values indicate that the sand is highly permeable and that surface runoff is generally low. The infiltration capacity is high to moderate. Hydraulic conductivity is a property which indicates the velocity and quantity of water that can be transmitted through a material. The estimated saturated thickness of the aquifer in the vicinity of the Billington Sea is 100 feet with transmissivity values ranging from 400 to 15,000 cubic feet per day. Transmissivity is the hydraulic conductivity multiplied by the saturated thickness, a property which indicates the amount of groundwater in an aquifer. Saturated thickness is measured from the top of the water table down to an impermeable boundary (i.e. bedrock or glacial till). This characteristic indicates that the aquifer in the vicinity of the Billington Sea potentially contains a substantial amount of groundwater. Wells installed in this area may yield more than 300 gallons per minute. As a result of the high hydraulic conductivity and infiltration properties of the stratified deposits surrounding the Billington Sea, the major hydrologic input to the pond is recharge rather than surface water inflow.

As indicated in Figure 8 (SCS, 1969), watershed surficial deposits consist predominantly of soils from the Carver Series, mainly the Carver and Gloucester soils (C&D).



CaB - Carver coarse sand, 3 to 8 percent slopes
CnC - Carver coarse sand, 8 to 15 percent slopes
CaE - Carver coarse sand, 15 to 35 percent slopes
CbB - Carver loamy coarse sand, 3 to 8 percent slopes
CcD - Carver and Gloucester soils, 8 to 35 percent slopes
EuB - Essex extremely stony coarse sandy loam, 3 to 8 percent slopes
EuC - Essex extremely stony coarse sandy loam, 8 to 25 percent slopes
HaE - Hinckley gravelly loamy sand, 15 to 35 percent slopes
Ma - Made land
Pe - Peat
Sb - Sanded muck

FIGURE 8: WATERSHED SURFICIAL GEOLOGY

BILLINGTON SEA

PLYMOUTH, MASSACHUSETTS

Approximately two-thirds of this soil type consists of sandy Carver soils and the remainder consists of extremely stony Gloucester soils. The slopes range from eight to thirty five percent. Carver soils are characterized by acidic, excessively-drained coarse sands. As a result of soil droughtiness, forests of pitch pine and scrub oak are the predominant vegetational cover type in the watershed.

Watershed geologic characteristics ultimately affect the water quality of a lake. The physical and chemical composition of the watershed soils determines their suitability for various land use types. The Carver soils have a high hydraulic conductivity (6.3 in/hr) which results in low quantities of watershed runoff. This high hydraulic conductivity also results in aquifer materials that are highly susceptible to contamination. A majority of the Plymouth lakes are kettle lakes which are principally recharged by groundwater rather than surface inflows. Phosphorus and nitrogen from septic leaching fields and fertilizer applications can rapidly leach through the Carver soils and enter the aquifer. This phenomenon is particularly evident in the Billington Sea, along the shoreline of the western basin, where accelerated groundwater velocities rapidly transport these nutrients into the lake and have contributed to the excessive growth of aquatic plants.

South of the lake, patches of acidic, peaty wetland soils (Sb) that have been altered to facilitate cranberry production drain into the Billington Sea. Surface runoff from these poorly-drained soils is rapid, particularly when floodwaters are released, and has resulted in the transport of fine, organic sediments into the lake. As a result of the low permeability of these soils, there is more concern regarding the potential for the transport of fertilizers and chemical applications to the lake via surface inflow rather than groundwater inflow. Furthermore, the short travel distance required for runoff to reach the lake affords little improvement in runoff quality through nutrient uptake. The quality of runoff from these areas is discussed further in Section 2.9.

2.5 Basin Morphometry

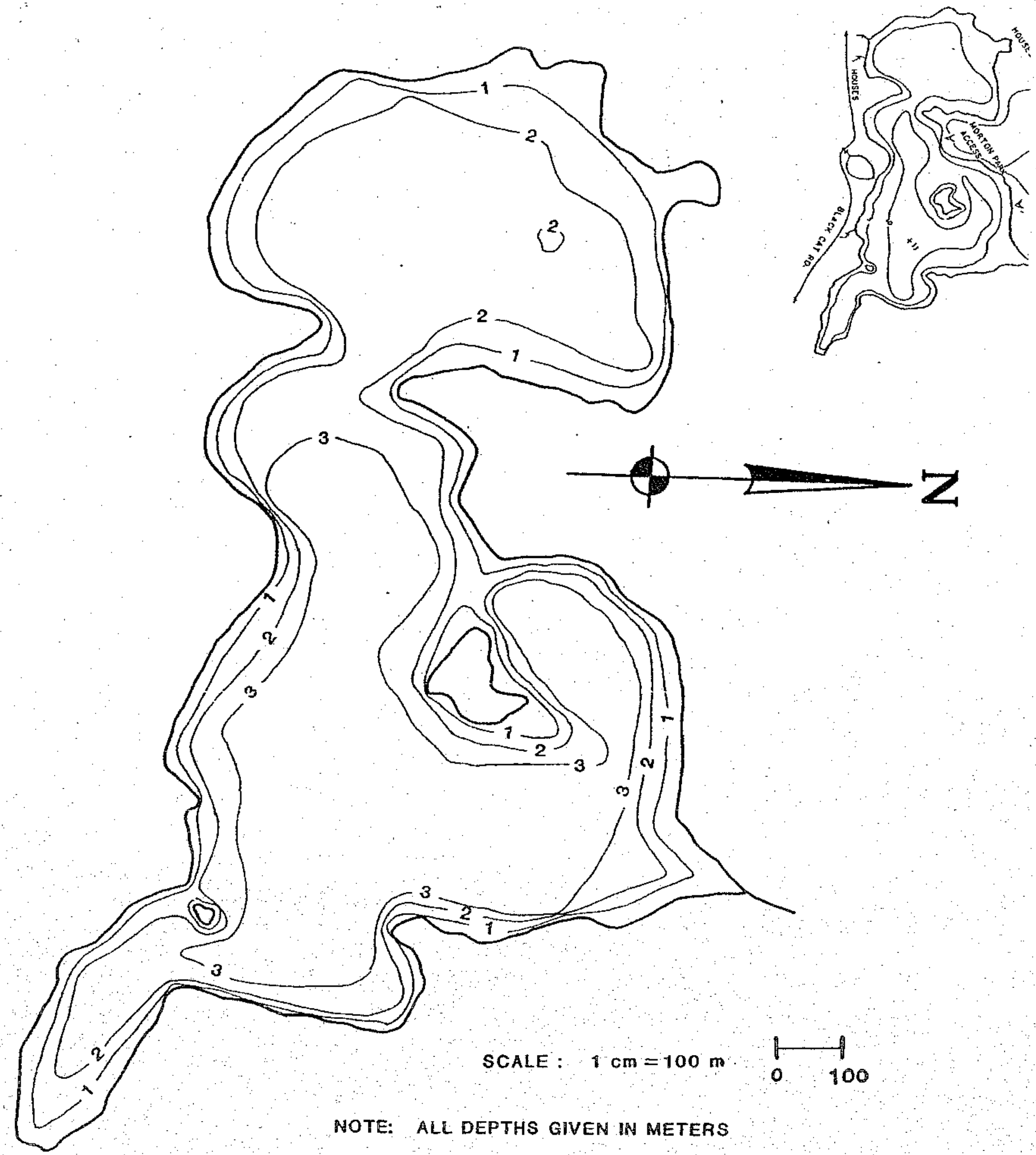
The response of a lake to the hydrologic and nutrient inputs from its watershed is directly related to the area, depth and shape (morphometry) of its basin as well as loading rates. Morphometric characteristics of the Billington Sea basin are presented in Table 2. Lake and watershed surface area measurements were obtained by planimetry from the most recent 7.5-minute series map of the Plymouth Quadrangle (USGS, 1977). Figure 9 is a bathymetric map which shows the water depth contours in the Billington Sea. Note the similarity between this 1987 map and the small scale map, located in upper right-hand corner (depths denoted in feet), which was produced in 1946 by the MA Department of Fisheries and Wildlife (McCann, 1972). Although some shoaling in the coves may have occurred since this time, the two maps are very similar. The 1987 map was generated during ice cover from depth soundings conducted at 50-meter intervals along 54 transects.

Despite its large surface area of 108 hectares (266 acres), the Billington Sea has an average depth of only 2.1 meters and an average storage capacity of 2.38 million cubic

Table 2. Billington Sea Morphometric & Watershed Measurements

Lake Surface Area	1.08 km^2 (266 acres)
Watershed Area *	4.60 km^2 (1,137 acres)
Watershed/Lake Area	4.3
Shoreline Length	7,114 m (4.4 mi)
Maximum Fetch	1,978 m (1.2 mi)
Maximum Distance Perpendicular To Fetch	986 m (0.61 mi)
Shoreline Development Index	1.9
Maximum Depth	
Western Basin	2.7 m (8.9 ft)
Eastern Basin	3.8 m (12.5 ft)
Mean Depth	2.1 m (6.9 ft)
Volume	2.38 x 10^6 m^3 (1,929 ac-ft)

* Excluding lake surface area



SCALE : 1 cm = 100 m

NOTE: ALL DEPTHS GIVEN IN METERS

NOT TO BE USED FOR NAVIGATIONAL PURPOSES

FIGURE 9: BATHYMETRIC MAP

BILLINGTON SEA

PLYMOUTH, MASSACHUSETTS

meters(1,929 acre-ft.). Maximum depths in the eastern and western basins are 3.8 and 2.7 meters, respectively. The entire western basin and a large portion of the eastern basin are less than three (3) meters deep. These large expanses of shallow water (littoral zones) support the dense growth of aquatic plants and facilitate the resuspension of nutrient-rich lake sediment by wind and motorboat turbulence. A peninsula of land called Hathaway Point juts out into the lake, forming two (2) distinct basins which are interconnected by a shallow, narrow channel. As a result, circulation between water within the shallow, western basin and that exiting the lake from the deeper, eastern basin is poor.

The lake has a shoreline length of 7,114 meters (4.4 mi.), yielding a shoreline development value of 1.9. This value represents the degree to which the shape of the shoreline departs from a circle. Generally, shallow, circular basins are more productive and have a greater tendency to fill in rapidly (Cooke et al, 1986).

In summary, the shallowness and configuration of the two-basin lake increase its susceptibility to algal blooms and the dense growth of aquatic vegetation, making restoration efforts more difficult.

2.6 Hydrologic Budget

A hydrologic budget is an accounting of the inflow, storage, and outflow of water in a hydrologic unit such as a lake. The principle components of the Billington Sea hydrologic budget are: precipitation, evaporation, inlets, the outlet, storm runoff, groundwater and change in the lake storage volume. These components have been estimated utilizing meteorological records, long-term hydrologic data and field data gathered during the diagnostic study. A mass balance approach in limnology, the study of lakes, is used to determine the volume of water entering and exiting the lake and the retention time and flushing rate of the lake.

Table 3 lists the values calculated for each component of the Billington Sea system, and Figure 10 shows the percent contribution of each component. Groundwater entering the lake from the aquifer is the largest input to the system. Sixty percent (60%) of the flow intercepted by the Billington Sea originates from subsurface inflow. Tributary inflow, which constitutes twenty-six percent (26%) of the total lake inflow, is highly variable and dependent upon cranberry bog flooding and irrigation practices in Tributaries A, C, D, and E (Figure 11). Tributary B drains from bogs which have been flooded for the purpose of raising trout and waterfowl. Base flow levels in the bog tributaries are supplied by groundwater discharges which drain from the bog ditches. Flow from these tributaries is impeded by dikes when the bogs are flooded from mid-December through mid-March and for several days in October during the harvest. Discharges from the bog tributaries may increase by several orders of magnitude when these floodwaters are released. Precipitation comprises only eight percent (8%)

TABLE 3. BILLINGTON SEA HYDROLOGIC BUDGET

INPUTS	FLOW (m^3/yr)	% TOTAL
Precipitation	1,180,000	8
Groundwater	9,000,000	60
Tributaries	3,942,000	26
Direct Overland Runoff	351,000	2
Storm Drainage & Pumpage	624,464	4
	+15,097,464	100

OUTPUTS	
the Outlet	14,096,592
Evaporation	688,640
Groundwater	312,232
	-15,097,464

NET INPUT FROM ATMOSPHERE = Direct Precipitation-Evaporation
= 491,360 cubic meters/yr

TOTAL VOLUME FLOWING THROUGH SYSTEM PER YEAR
(Assuming no change in storage volume)
= 15,097,464 cubic meters/yr

RESIDENCE TIME (Time necessary for complete replacement of system volume) = Volume/Flow =
2,380,000 m^3 /15,097,464 m^3 /yr
= .16 yr or 58 days

HYDRAULIC FLUSHING RATE (Number of volume replacements per year) = 6.3 times/yr

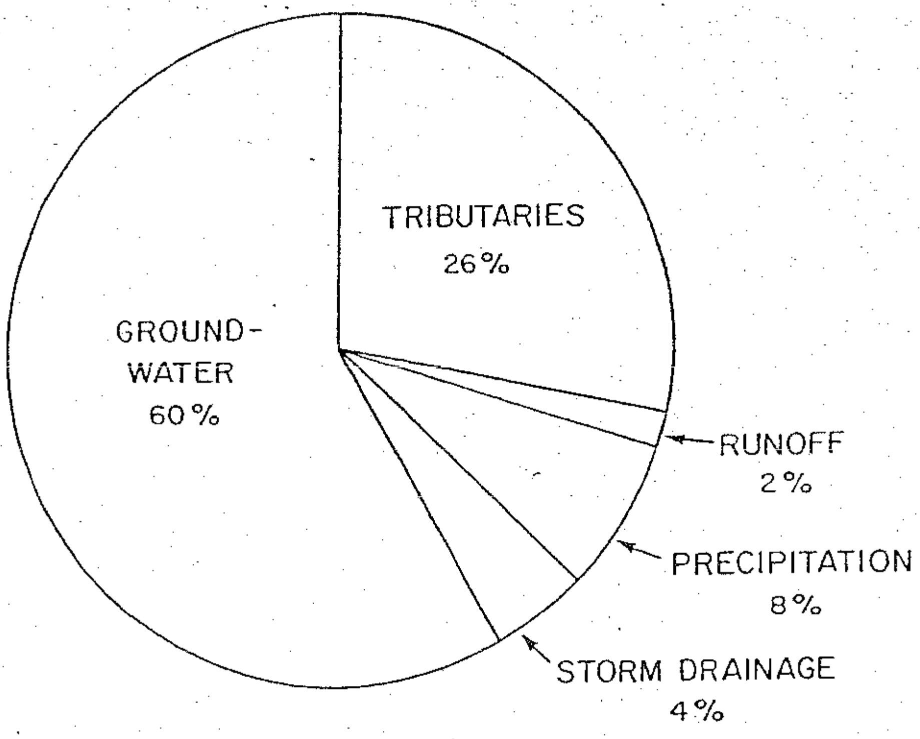
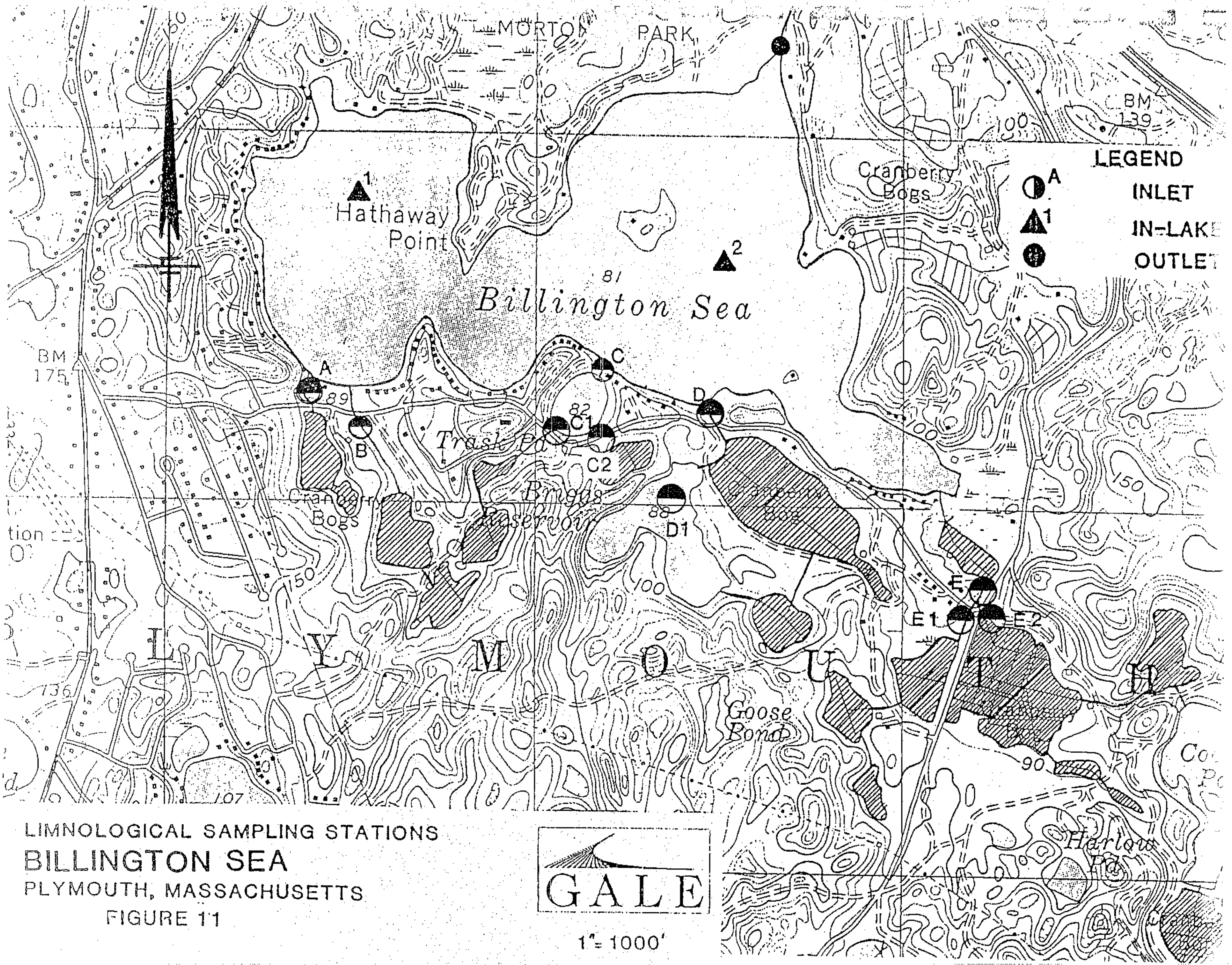


FIGURE 10. COMPONENTS OF THE BILLINGTON SEA HYDROLOGIC BUDGET



LIMNOLOGICAL SAMPLING STATIONS

BILLINGTON SEA

PLYMOUTH, MASSACHUSETTS

FIGURE 11

GALE

1" = 1000'

of the total inflow to the Billington Sea, but when compared to overland runoff (2%) is a significant fraction of the total volume flowing into the system. The amount of overland runoff is low due to the porous nature, or high infiltration rate, of the sandy watershed soils. Only a small fraction (3%) of the total inflow is contributed by road runoff and the importation of water, for the irrigation of cranberry bogs located in the discharge zone, into the recharge zone of the lake.

As a result of the long hydraulic residence time (58 days), the Billington Sea has a low flushing rate of 6.3 times per year.

The derivations of each of the hydrologic budget components are summarized as follows:

<u>Precipitation</u>

An average annual precipitation value of 1.098 m/yr (43.2 inches/year), calculated from long term precipitation records of the area (Williams and Tasker, 1974), was used to compute the inputs to the Billington Sea system from precipitation. The actual amount of precipitation recorded for the twelve (12) month study period (11/87-10/88) was 1.082m (42.6 inches) which is very close to this value.

<u>Tributaries</u>

Tributary inflows were measured directly during the study and are presented with the limnological data in the following section. Inflow from Tributaries A, C, D and E is dependent upon bog flooding and irrigation practices, resulting in high variable flows. Bog tributary flows consist of base flow levels maintained by groundwater recharge and bog runoff following water applications and storm events. Water pumped from the Billington Sea to irrigate upgradient cranberry bogs was considered a transfer within the hydrologic system rather than an import. The volume of water removed from the Billington Sea via pumpage was considered, from a mass balance standpoint, to equal the volume returned to the lake via tributary inflow and groundwater recharge. The consumptive loss of water applied to the bogs was assumed to be negligible. The average annual discharge rates (N=20) of each of the five (5) tributaries were summed and yielded a total tributary inflow value of 3,942,000 m^3/yr. Tributary inflow was assumed to equal tributary outflow.

Groundwater

The groundwater inflow was computed assuming a recharge rate of 0.519 m/yr or 20.4 inches/year (Williams and Tasker, 1974). The area of the recharge zone, determined from a USGS quadrangle map of the area and groundwater flow measurements (refer to the following subsection entitled "Groundwater Inflow to Billington Sea"), is 3,992 acres (16.2 km^2) excluding surface water bodies. A recharge value of approximately 9,000,000 m^3/yr was calculated based on an annual average precipitation value of 1.098 m/yr.

Watershed Runoff

The maximum amount of watershed runoff was estimated at seven percent (7%) of the amount of precipitaion, 1.098 m/yr, falling on land within the 4,601,000 m^2 watershed (McVoy, 1980).

Storm Drainage and Bog Pumpage Imports

The residual term in the hydrologic budget equation includes imputs from storm drainage and cranberry bog pumpage (imports into the recharge zone). Approximately twelve (12) acres of roadway direct 53,323 m^3 of stormwater runoff into the Billington Sea. The residual inflow for this hydrologic budget component was considered to represent the importation of water into the recharge zone for the irrigation of cranberry bogs located in the discharge zone.

Groundwater Inflow to Billington Sea

Groundwater flow directions were measured for Billington Sea around its perimeter during December to January 1987 using K-V Associates, Inc. Model 20 Groundwater Flow Meter. The method and results are described below.

Calibration procedures

For calibration, the 2" mesh-screen packer was filled with 1mm glass beads and the probe inserted into the calibration chamber. The probe-packer combination was then placed into a 6-inch flow chamber which was filled with Billington Sea sand.

By duplicating field conditions in the flow chamber, the calibration procedure corrects for hydraulic conductivity differences between the sand pack (K_o), the packer contact (K_p), and the glass bead packing (K_i). The resistance to flow unique to the natural sand and its configuration were automatically compensated for (Kerfoot and Massard, 1983).

The instrument was calibrated in the flow chamber, and the relative machine readings (RMR) were plotted versus the known velocities. Thus, a conversion constant was determined.

Field measurements

A groundwater flow survey was conducted along the shoreline of Billington Sea at variable intervals (see figure #12). At each shoreline station a hole was augered with a 4-inch earth auger below the water table. The flowmeter probe was lowered into the bore hole and backfilled with sand taken from the bore hole. All measurements performed followed the 180° rotation procedure. The first measurement is conducted with the number 1 sensor oriented toward magnetic north. A second reading is taken with the sensor oriented towards magnetic south. The results are combined to correct for any bias caused by heater tip-sensor deformation.

Figure 12 summarizes the flow measurements taken during the survey in December, 1987-1988. Groundwater was found to flow into the pond at most of the stations, with the exception of stations on the eastern

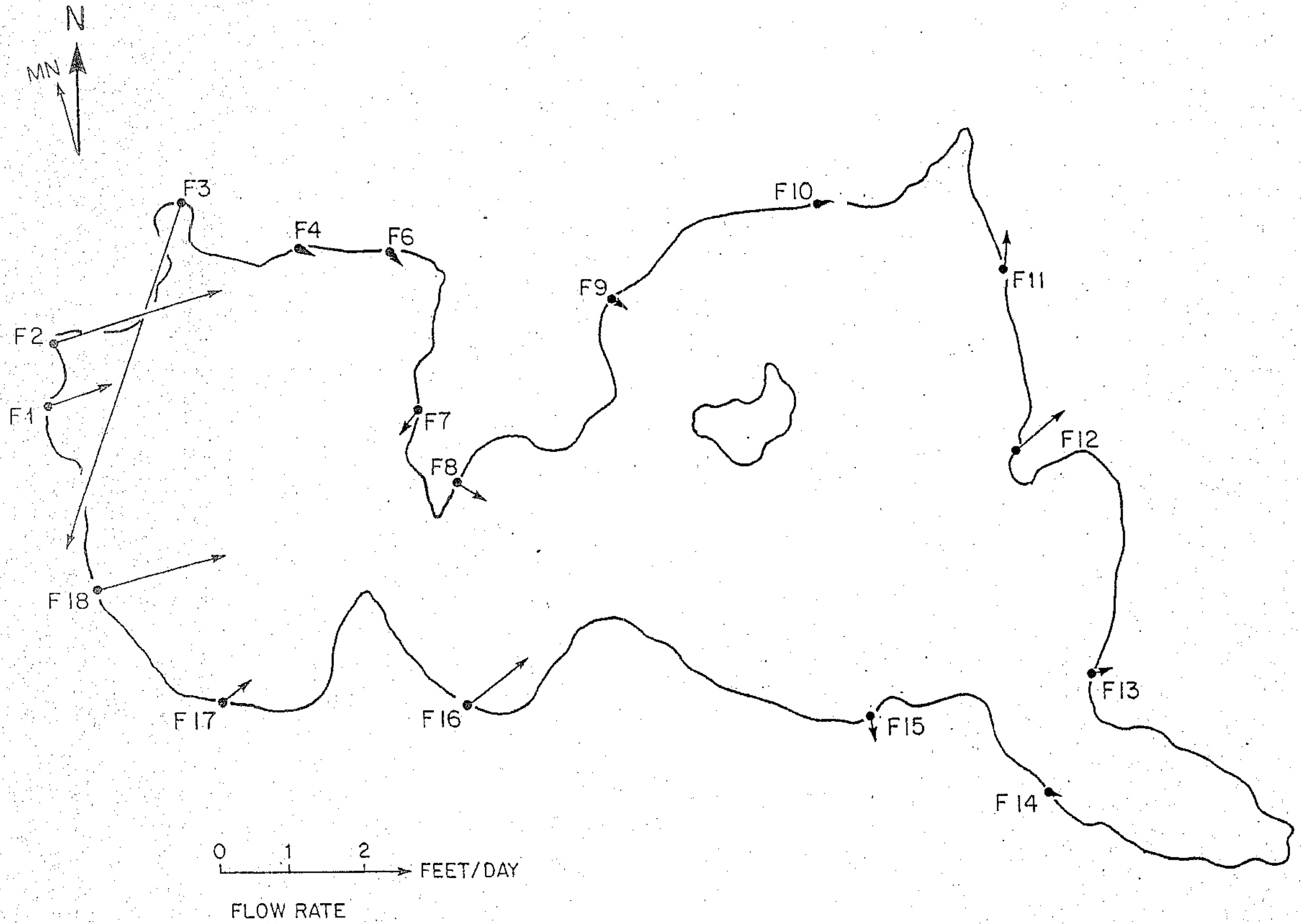


Figure 12. Direction and rate of shoreline groundwater flow.

shoreline where discharge from the pond was observed. Velocity measurements at discharge stations were high (from 3.5 to 8.2 ft/day). At stations where recharge was taking place velocity was generally high and variable ranging from <1 to over 50 feet per day. Groundwater gradients shown on the regional groundwater map also show recharge from the west (see figure 13) (USGS,1987).

Recharge Region of Billington Sea

The recharge area of Billington Sea was defined using groundwater flow measurements inflow and outflow data, precipitation data for southeastern Massachusetts, and U.S.G.S. regional groundwater contour mapping. Figure 14 illustrates the recharge area that was defined for this study.

Groundwater flow measurements show recharge predominantly from the west and south and to a lesser degree along the north.

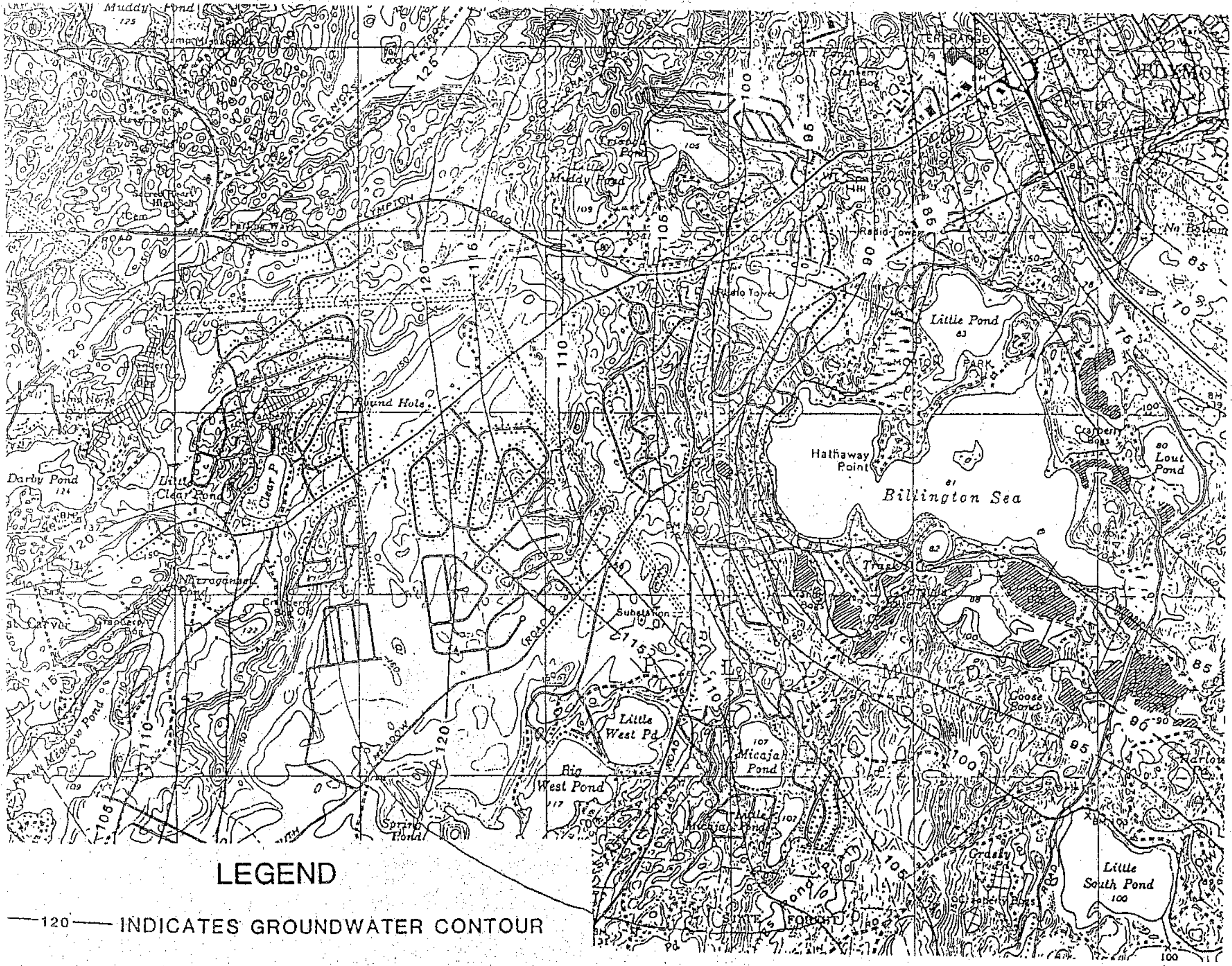


Figure 13. Regional Groundwater Map (U.S.G.S. 1987)

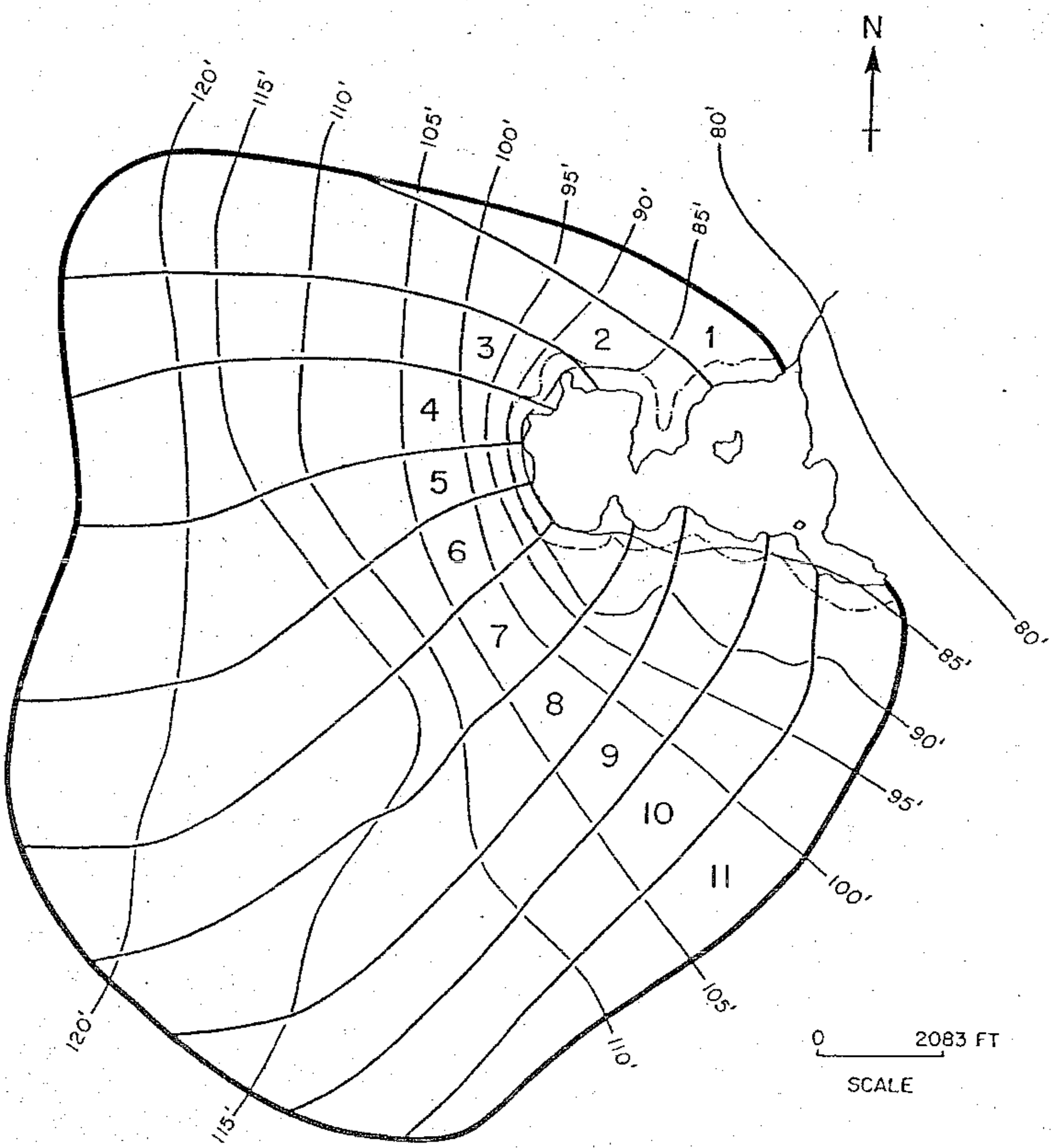


Figure 14. Recharge area of Billington Sea with segmentation into flow cells.

2.7 Nutrient Budget

A nutrient budget is a lake management tool which can be used to quantify the sources of phosphorus and nitrogen loading to a lake in order to develop a plan for managing algal and aquatic plant growth.

The Billington Sea nutrient budgets take into account the amount of phosphorus and nitrogen loading from: 1) tributaries, 2) groundwater, 3) precipitation, 4) watershed runoff, and 5) storm drainage and bog pumpage imports. The budgets also account for losses from the system through: 1) evaporation, 2) groundwater outflow, and 3) the lake outlet.

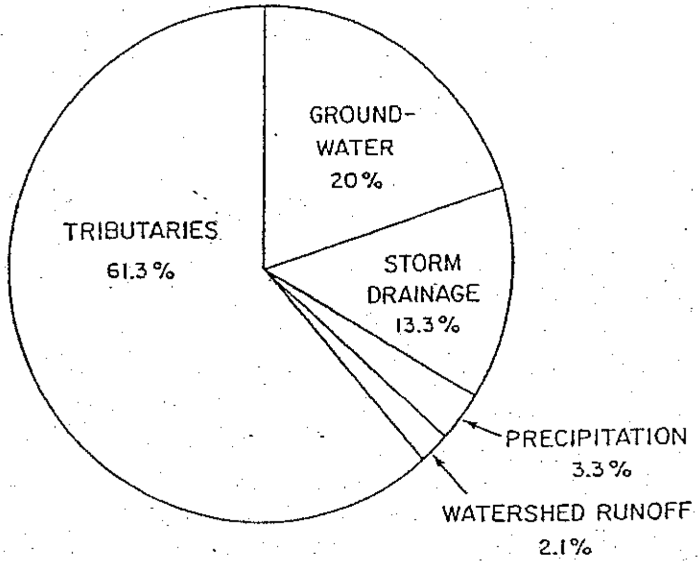
The difference between the inflow and outflow concentrations of these nutrients is retained within the lake, and is considered as in-lake accrual. A small percentage of the phosphorus accrual is stored as aquatic biomass, but the majority is probably deposited in the lake sediments and can be recycled internally. Although a greater percentage of nitrogen constitutes plant biomass, the majority is probably lost from the system as nitrogen gas through the process of denitrification. Table 4 lists the values calculated for each component of the Billington Sea nitrogen and phosphorus budgets and Figure 15 shows the percent contribution of each component. The five tributaries contribute sixty-one percent (61%) of the phosphorus input to the Billington Sea. Considerable variability exists between the magnitude of nutrient loading values were lowest for Tributary B. These values can be considered as background tributary nutrient loading values because Tributary B drains from a bog system which has not been in use for the past thirty (30) years. Phosphorus loading from Tributary B was more than twenty-

TABLE 4. NUTRIENT BUDGET FOR THE BILLINGTON SEA

ADDITIONS	PHOSPHORUS gm/yr	%	NITROGEN gm/yr	
TRIBUTARIES	721,227	61.3	2,372,767	16.9
GROUNDWATER	234,000	20.0	9,000,000	63.9
PRECIPITATION	39,500	3.3	306,800	2.2
WATERSHED RUNOFF	25,272	2.1	838,890	6.0
STORMWATER DRAINAGE, AND PUMPAGE	156,116	13.3	1,561,160	11.0
	1,176,115	100.0	14,079,617	100.0
LOSSES				
EVAPORATION	0		0	
GROUNDWATER	3,435		265,397	
OUTFLOW	719,020		11,132,208	
	722,455	(61%)	11,397,605	(81%)
ACCRUAL	453,660		2,682,012	

Figure 15. Components of the Billington Sea Phosphorus and Nitrogen Budgets.

PHOSPHORUS SOURCES



NITROGEN SOURCES

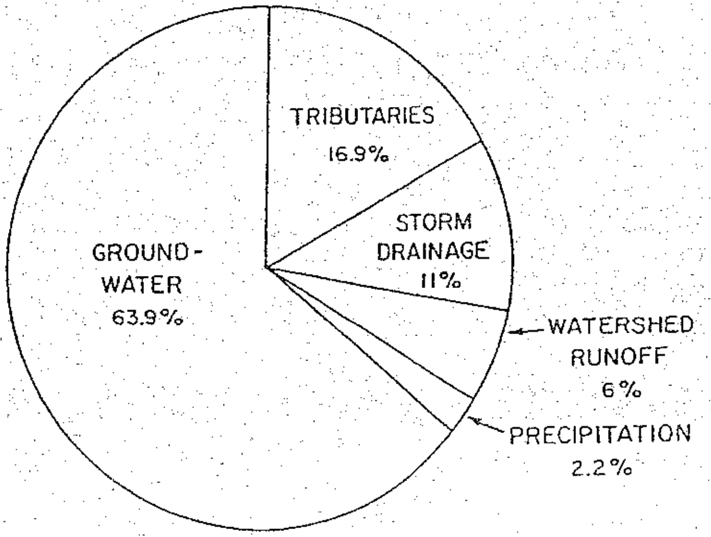


TABLE 5. NUTRIENT LOADING FOR THE BILLINGTON SEA

TRIBUTARIES

TRIBUTARY	MEAN FLOW (m3/sec)	MEAN CONCENTRATION (mg/l)		MEAN LOAD (gm/s x 10 ^{3})		SEASONAL LOAD (gms/yr)	
		P *	N +	P	N	P	N
A	.004	.337	.99	1.35	3.96	42,573	124,882
B	.007	.060	.44	0.42	3.08	13,245	97,130
C	.026	.065	.79	1.69	20.5	53,296	646,488
D	.057	.137	.49	7.81	27.9	246,296	879,854
E	.031	.374	.64	11.60	19.8	365,817	624,413
				TOTAL:		721,227	2,372,767
OUTLET							
	.447	.051	.79	22.8	353	719,020	11,132,208

*P= TP

+N= TKN + NO_3

five (25) orders of magnitude less than phosphorus loading from Tributary E. Eighty-five percent (85%) of the tributary phosphorus loading originates from Tributaries D and E as a result of their higher flow rates and phosphorus concentrations.

Septic leachate transported via the groundwater is the greatest source of nitrogen loading (64%) to the Billington Sea. High shoreline groundwater velocities in the western basin which force nitrogen up through the lake sediments contribute to the occurrence of summer algal blooms. A combination of groundwater nitrogen loading and the availability of phoshorus stored in the lake sediments have probably promoted the dense macrophytic growth in the shallow western basin. Phosphorus is less mobile than nitrogen because of its tendency to combine with iron, flocculate from the water column and be deposited in the lake sediments. This contention is supported by the fact that less phosphorus (61%) is discharged through the outlet of the Billington Sea than nitrogen (81%).

The derivation of each of the nutrient budget components are summarized as follows:

INFLOW

Tributaries

Total phosphorus and nitrogen loadings from the tributaries were computed by multiplying the sum of the average tributary discharges by the concentrations of these nutrients. Both values were based on flow measurements and samples collected at each of the five tributaries. Phosphorus loadings from the tributaries ranked in order from highest to lowest were E, D, C, A and B. The ranking order for nitrogen loading was D, C, E, A and B. Tributary inflow contributed sixty-one percent (61%) and seventeen percent (17%) of the phosphorus and nitrogen loading to the Billington Sea respectively.

Watershed Runoff

The volume of watershed runoff was multipled by the mean concentrations of phosphorus (0.072 mg.1) and nitrogen (2.3 mg/l) present in stormwater runoff samples collected from urbanized watersheds similar to that of the Billington Sea (CCPEDC, 1978).

Groundwater

Groundwater contributions to the phosphorus and nitrogen loads were calculated by multiplying the average groundwater discharge rate, as determined from direct groundwater flow measurements, by the mean background concentrations of phosphorus (N=4) and nitrogen (N=3) present in the Billington Sea shoreline groundwater samples collected with a well point sampler. Groundwater samples characterized by excessively elevated total nitrogen and conductivity values, an indication of septic leachate plume contamination, were excluded from the sample means. Average background concentrations of total phosphorus and total nitrogen were 0.026 mg/l and 1.00 mg/l respectively. These values correspond well with the range of average background total phosphorus concentrations (0.013-0.033 mg/l) reported for groundwater of Cape Cod (Deubert, 1974) and the average nitrate concentration (0.982 mg/l) reported for groundwater samples previously collected from the Billington Sea (Geoscience, 1981). Groundwater is the major source of nitrogen loading (64%) to the Billington Sea.

Precipitation

Phosphorus loading from precipitation was estimated by multiplying the lake surface area by 0.147 kg/P/acre (McVoy, 1980). A nitrogen value of 0.26 mg/l, representing the average concentration of nitrogen present in precipitation falling on Massachusetts from 1983 through 1985 (M. Frimpter, personal communication), was multiplied by the amount of precipitation falling on the lake surface to estimate nitrogen loading from precipitation.

Storm Drainage and Bog Pumpage Imports

Total phosphorus concentrations ranging from 0.04 - 0.56 mg/l and total nitrogen concentrations ranging from 0.020 - 0.540 mg/l have been reported for discharges from cranberry bogs (Gil, 1988). Total phosphorus and nitrogen values of 0.250 mg/l and 2.50 mg/l, respectively, were used to calculate nutrient loading to the Billington Sea from storm drainage and bog pumpage imports. These values are representative of average concentrations present in urban road runoff. Although the nitrogen value may be an overestimate for bog discharges, the total phosphorus value is within the range reported for bog discharges.

OUTFLOW

Evaporation

No net loss of both phosphorus and nitrogen by evaporation was assumed since, in general, the water soluble ionic fractions of both of these elements would not volatize with water.

Groundwater

Mean nitrogen and phosphorus concentrations of water column samples collected at in-lake Station 2 were multiplied by the groundwater discharge rate, as determined from direct groundwater flow measurements collected along the eastern shoreline, to quantify the loss of these nutrients from the system through the groundwater. Nitrogen was assumed to be one hundred percent (100%) mobile in the groundwater. However, only twenty (20%) of the phosphorus was assumed to be mobile. Residual phosphorus was assumed to precipitate into the lake sediment.

Tributaries

The average discharge rate at the outlet was multiplied by the average concentrations of phosphorus and nitrogen present in samples collected from the outlet. The average discharge rate was computed from direct measurements of tributary outflow. The greatest losses of phosphorus (61%) and nitrogen (79%) from the Billington Sea are through the outlet.

Nitrogen and Phosphorus Loading from Residential Sources

Nitrogen and phosphorus loading to Billington Sea were calculated by dividing the recharge zone for the lake into 11 flow segments and calculating the loading for each segment based on the number of residences in each segment. Different weighting values were used for those residences within each segment where they were 300 feet or nearer to the shoreline. The Plymouth U.S.G.S. topographic 7½' quadrangle map was used as a base for these estimates.

Calculations were made within each flow segment for: 1) the zone within 300 ft (or 91.44m) of shore 2) the remaining zone over 300 ft from shore 3) shoreline loading per 100 linear ft (30.48m) of shore 4) total load for the segment (as lbs/yr and as Kg/yr), and 5) loading per acre and per hectare.

A loading value of .75 lbs phosphorus per year was used for each home within 300 ft of the shore and a value of .10 lbs phosphorus per year was used for homes over 300 ft away. Phosphorus attenuation by adsorption requires that an adjustment for distance be made. Nitrogen loading was computed at 24 lbs (10.8862 Kg) per household annually.

The values for phosphorus loading ranged from 3.50 to 47.55 lbs (1.59 to 21.57 Kg) phosphorus per year for each of the eleven segments with a total load of 189.30 lbs (85.87 Kg) phosphorus per year to the lake. An additional 7.5 lbs (3.4 Kg) may be loaded annually from the small islands and immediate eastern shoreline. This amounts to an average of .0468 lbs (.0212 Kg) phosphorus per acre per year within the recharge zone.

Nitrogen loading values for the eleven segments range from 504 lbs (229 Kg) to 8,448 lbs (3832 Kg) per year. Total nitrogen loading in the recharge area is 29,522 lbs (13,392 Kg) per year or a 7.35 lbs (3.33 Kg) per acre per year average. The islands and area immediately on the east shoreline may also contribute 240 lbs (108.8 Kg) nitrogen annually.

The shoreline distance (without the islands) was measured at 4.46 miles (7.17 Km) as shown on the topographic map. Annual phosphorus loading per 100 ft (91.44 m) of shoreline ranged from .2354 lbs (.1068 Kg) to 3.6718 lbs (1.6655 Kg) with an average of 1.3279 lbs (0.6023 Kg). Nitrogen loading per 100 ft of shoreline was from about 39 to 652 lbs (17.8 to 295.9 Kg) with an average of 212 lbs (96.3 Kg).

All nutrient loading values for phosphorus and nitrogen are given in table 6 for each flow segment of the recharge zone which is shown divided into segments in figure 16.

A review of the shoreline loading distribution indicates that flow segments 4 and 5, which occur at the steepest groundwater gradient, would experience vegetative growth problems. Section 9 also has a potential for elevated combined residential and cranberry bog loading. The present loadings are based upon 1979 U.S.G.S. mappings and do not incorporate the most recent residential developments. Generally a 10-20 year period is necessary for groundwater phosphor values to come to equilibrium with source inflow. Monitoring well water quality values tend to under estimate the ultimate impact of residential loading since their values reflect recharge conditions of 10-20 years past.

flow segment number & acreage	no. lots developed within 300' of shoreline	no. lots developed beyond 300' of shoreline	shoreline length for segment	total acres within 300' of shoreline	total acres beyond 300' of shoreline	acres per dwelling within 300' of shoreline	acres per dwelling beyond 300' of shoreline	loading per dwelling within 300' of shoreline (lbs P/ yr)	loading per dwelling beyond 300' of shoreline (lbs P/ yr)	total loading in flow segment (lbs P/ yr)	loading per 100' of shoreline (lbs P/ yr)	loading per acre of flow segment (lbs P/ yr)	nitrogen loading for flow segment (lbs N / yr)	nitrogen loading per acre in flow segment (lbs N /ac/ y
#1 (120ac)	0	46	1954	14	106	no dwellings	2.30	0.00	4.60	4.60	0.2354	0.0383	1104	9.20
#2 (388ac)	6	91	5130	35	352	5.83	3.87	4.50	9.10	13.60	0.2651	0.0351	2328	6.00
#3 (270ac)	4	123	782	13	256	3.25	2.08	3.00	12.30	15.30	1.9565	0.0567	3048	11.29
#4 (326ac)	19	333	1295	8	317	0.42	0.95	14.25	33.30	47.55	3.6718	0.1459	8448	25.91
#5 (401ac)	10	134	977	7	392	0.70	2.93	7.50	13.40	20.90	2.1392	0.0521	3456	8.62
#6 (465ac)	4	66	855	6	457	1.50	6.92	3.00	6.60	9.60	1.1228	0.0206	1680	3.61
#7 (448ac)	22	58	2077	17	429	0.77	7.40	16.50	5.80	22.30	1.0737	0.0498	1920	4.29
#8 (459ac)	14	60	1344	12	445	0.86	7.42	10.50	6.00	16.50	1.2277	0.0359	1776	3.87
#9 (403ac)	10	187	1417	14	387	1.40	2.07	7.50	18.70	26.20	1.8490	0.0650	4728	11.73
#10 (382ac)	2	20	1344	10	371	5.00	18.55	1.50	2.00	3.50	0.2604	0.0092	528	1.38
#11 (345ac)	11	10	1148	11	333	1.00	33.30	8.25	1.00	9.25	0.8057	0.0268	504	1.46
subtotals	102	1128	18323	147	3845			76.50		189.30			25520	7.94 avg.
on islands in lake (3ac)	2		1588+244	3		1.50		1.50		1.50	0.0008	0.5000	48	16.00
east shore within 300' (38.7 ac)	8		5252	38.7		4.84		6.00		6.00	0.1142	0.1550	192	4.96
TOTALS	112	1128	25407					84	112.8					7.35 avg.

Table 6. Phosphorus and Nitrogen Loading to the Billington Sea from Residential Wastewater Disposal Systems.

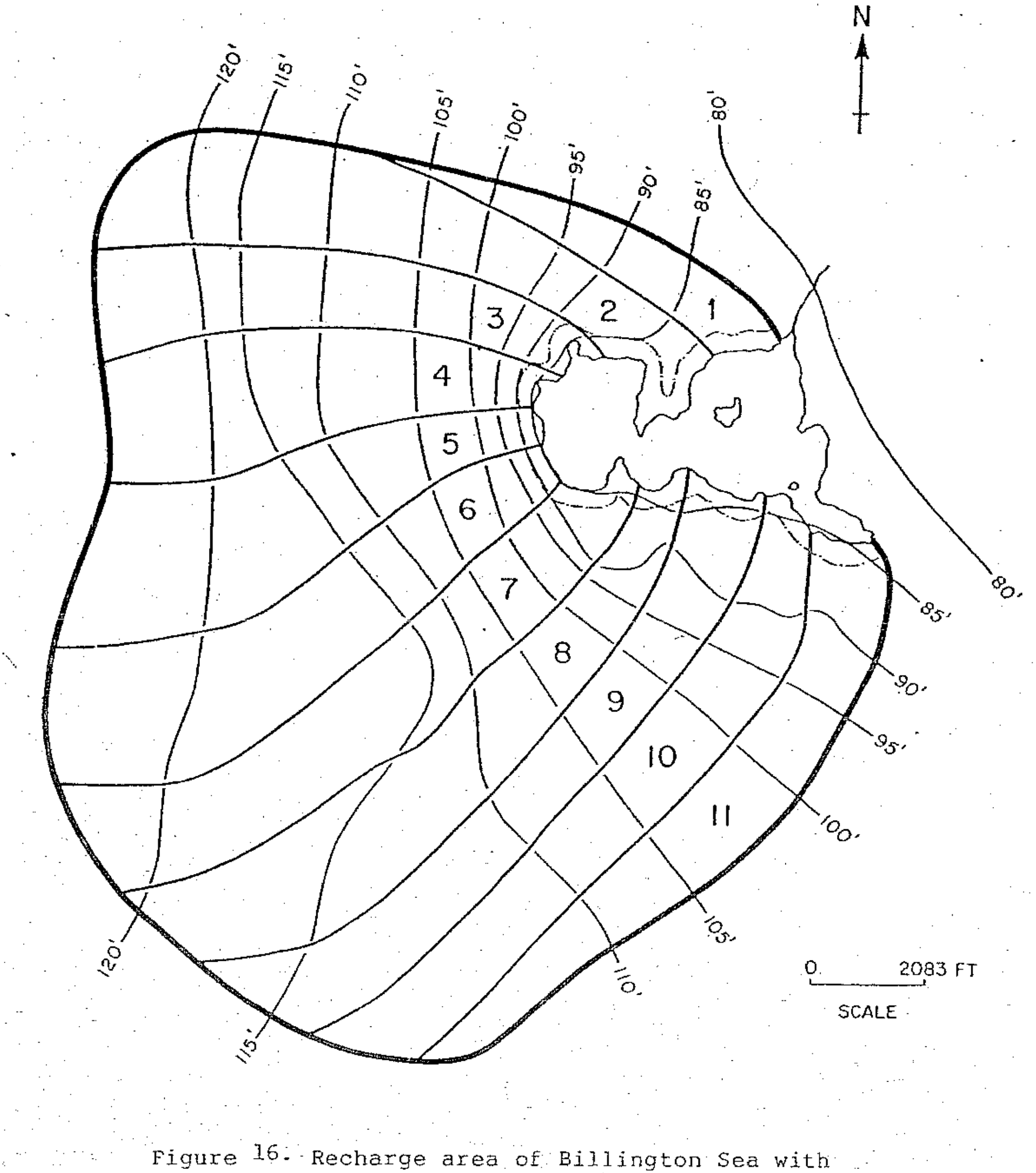
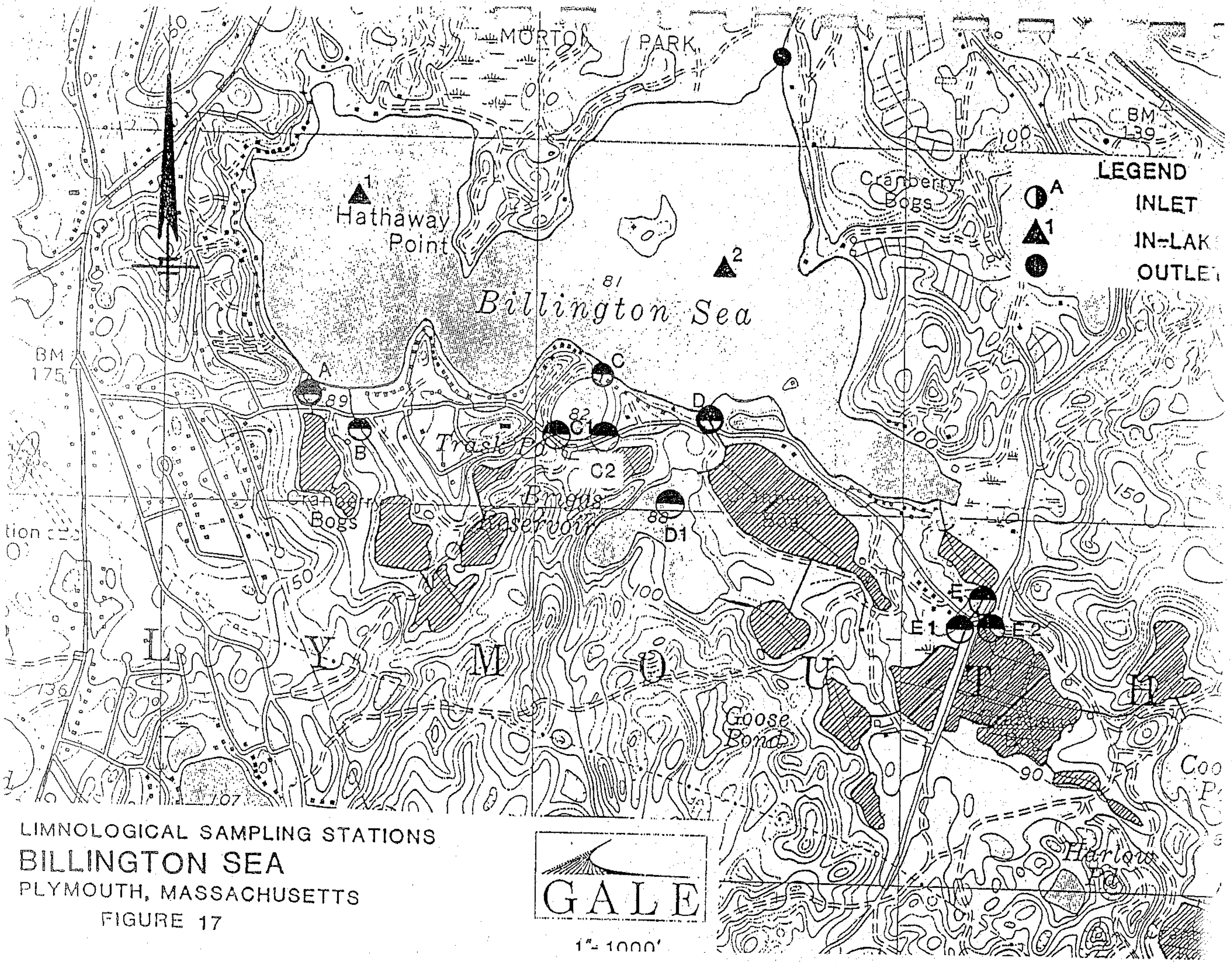


Figure 16. Recharge area of Billington Sea with segmentation into flow cells.

2.8 Limnological Data

A limnological survey of the Billington Sea was conducted from October, 1987 through November, 1988 in order to determine the trophic status of the lake and to identify sources of nutrient and pollutant loading. Samples were collected, on a biweekly basis from April to October and monthly throughout the remainder of the year, at each of the two depressions constituting the major basins in the lake, the five inlets and the outlet (Figure 17). A description of each of the sampling stations is contained in Table 7. Tributary samples were analyzed for the following parameters: temperature, dissolved oxygen, percent saturation of dissolved oxygen, pH, total alkalinity, suspended solids, turbidity, conductivity, chlorides, total Kjeldahl nitrogen, nitrate nitrogen, total phosphorus, fecal coliform bacteria, fecal streptococcus bacteria, and discharge (instantaneous). The tributaries were also sampled for orthophosphorus from June through November; the two in-lake stations were sampled for the same parameters with the exception of discharge. Temperature and dissolved oxygen profiles were measured and instituted, at one meter intervals. Depth-integrated samples of phytoplankton and chlorophyll a were collected down to the limit of the euphotic zone or to 1.0 meter above the lake bottom when the entire water column was euphotic. Sampling did not extend into the anoxic zone at any time. The surface of the water column was sampled for fecal coliform and fecal streptococci bacteria. Secchi disk transparency was also measured at the in-lake stations. Samples from all of the water quality stations were analyzed for alkalinity on a monthly basis throughout the year.



LIMNOLOGICAL SAMPLING STATIONS
BILLINGTON SEA
PLYMOUTH, MASSACHUSETTS
FIGURE 17

GALE

1"=1000'

TABLE 7. BILLINGTON SEA SAMPLING STATION LOCATIONS

Station	Location
A	Two-tiered weir at cranberry bog outlet, on south side of Blackcat Road
B	Weir at outlet of duck pond, on south side of Black Cat Road
C	Weir at outlet of Trask Pond
D	Weir on north side of Black Cat Road, at cranberry bog outlet, near eastern end of Billington Sea
E	Cranberry bog tributary; near intersection of Black Cat and Lout Pond Roads
In-lake 1	Deepest point within western basin; surface and bottom
In-lake 2	Deepest point within eastern basin, between the two islands, at the surface and bottom of the water column
Outlet	Outlet of Billington Sea at footbridge

Sampling, sample preservation and analytical methodologies were conducted in conformance with the standard operating procedures of the Massachusetts Division of Water Pollution Control and *Standard Methods for the Chemical Analysis of Water and Wastewater* (EPA, 1985). A list of the analytical methodologies utilized is included in Appendix A. Laboratory analyses were conducted by Arnold Greene Laboratories, Inc., a state-certified laboratory for all of the parameters tested. Samples were collected in containers provided by Arnold Greene Laboratories, Inc., placed on ice in a cooler then generally transported on the same day of collection to the laboratory for analysis.

In-lake profiles of temperature and conductivity were measured in-situ with a YSI Model 33 meter and dissolved oxygen and percent oxygen saturation profiles were measured with a YSI Model 51B meter. Calibrations of these meters were accomplished according to directions provided by the manufacturer. Water column transparency was measured with a 20 cm Secchi disk utilizing standard procedures. Bacteriological analyses were conducted within six to sixteen hours of field collection and water samples analyzed for orthophosphate were filtered through a 0.45 micron filter immediately following collection then placed in a cooler. These orthophosphate samples were frozen immediately upon their arrival at the laboratory. None of the water quality samples were preserved prior to anaylsis, excluding the phytoplankton samples which were identified to genus and enumerated utilizing a Sedgwick-Rafter cell. The limnological data for in-lake Station 1 and Station 2 are presented in Table 8 and Table 9, respectively. Water quality data for the tributary sampling stations are

ABLE B- IN- LIMNOLOGICAL DATA, BILLINGTON SEA

TATION	SAMPLE DEPTH m	DATE	TEMP oC	DISSOLVED OXYGEN mg/l	pH s.u.	CONDUCT. uhmos/cm	ALKAL. mg/l	T K N mg/l	NITRATE mg/l	AMMONIA mg/l	TOTAL PHOSPH. mg/l	CHLORIDE mg /l	SUSPENDED SOLIDS mg/l	SECCHI m	ORTHO-P mg/l	FECAL COLIFORM #/100 ml	FECAL STREP. #/100 ml	CHLOR a mg/m3	TURBIDITY ntu	OXYGEN SATUR. %
1	0.00	10/28/87	13.0	11.0	6.4	60	9.8	0.28	0.790	-0.100	0.042	19.0	2.00	1.60		10	1080	4.70	-2.0	*
		11/23/87	4.0	14.4	6.1	60	7.4	0.64	0.720	-0.100	0.058	16.3	4.80	2.00		-10	20	9.77	3.0	20.5
		12/16/87	4.5	12.1	6.0	65	9.6	0.30	0.900	-0.100	0.047	17.0	0.40	1.85		20	2000	4.96	-2.0	20.0
		01/27/88	2.0	*	6.5	65	11.1	0.08	1.100	0.050	0.080	14.7	0.80			10	53000	8.65	-2.0	*
		02/24/83	5.0	12.8	6.2	60	8.3	0.41	1.000	0.010	0.027	14.0	0.40	2.25		-10	70	7.97	3.0	21.0
		03/28/88	10.0	11.2	6.8	70	8.0	0.35	0.950	-0.010	0.034	13.0	1.20	2.00		-10	30	12.00	2.0	21.0
		04/13/88	8.0	11.5	6.7	70	8.7	0.27	0.930	-0.010	0.023	21.0	3.20	2.00		-10	1000	5.85	-2.0	20.0
		04/27/88	11.5	10.6	6.9	75		0.19	0.840	-0.010	0.020	17.5	-0.10	2.30		-10	-10	7.50	1.0	22.0
		05/11/88	15.0	9.6	6.1	80	11.1	0.24	0.780	0.020	0.020	22.0	11.00	2.20		0	0	5.31	2.0	20.0
		05/25/88	18.0	8.8	6.5	100		0.68	0.580	0.040	0.082	17.7	-1.00	1.90		0	5	4.08	-2.0	21.5
		06/08/88	21.0	11.9	8.1	100	13.0	0.31	0.710	-0.010	0.050	18.0	5.00	1.60	0.01	0	0	14.00	2.0	25.0
		06/22/88	28.0	9.0	9.4	110	14.0	0.51	0.380	0.020	0.111	10.5	5.00	1.70	0.01	0	0	5.09	2.0	26.0
		07/07/88	25.0	9.4	8.7	110	16.0	0.38	0.400	0.050	0.046	18.0	0.50	1.70	0.01	0	0	0.98	1.0	22.0
		07/21/88	24.5	7.0	6.7	80		0.48	0.180	0.050	0.050	17.0	3.00	1.60	0.03	0	0	10.00	1.6	17.5
		08/02/88	29.0	10.4	9.3	110	18.8	0.56	0.050	0.010	0.030	18.4	1.50	1.30	-0.01	0	0	9.30	1.3	29.0
		08/16/88	27.0	9.0	5.5	115	17.0	1.00	0.060	0.020	0.070	18.0	4.00	0.70	-0.01	8	450	38.00	9.5	24.0
		09/14/88	20.5	9.6	7.6	95	16.2	1.90	0.240	0.030	0.050	18.0	16.00	0.45	0.01	8	26	76.00	16.0	22.5
		09/29/88	18.0	10.3	7.6	90		1.03	0.170	-0.010	0.040	17.0	9.00	0.85	0.02	4	68	77.00	5.0	23.0
		10/24/88	10.5	9.5	6.5	80	14.0	0.57	0.760	0.190	0.030	16.6	2.60	2.40	0.02	40	160	2.50	1.5	18.0
		11/17/88	14.0	9.1	6.5	80	10.0	0.37	0.820	0.020	0.030	15.9	4.00	2.20	0.02	68	122	3.39	0.4	20.0
Average:			15.4	10.4	7.2	84	12.1	0.53	0.618	0.008	0.047	17.0	3.67	1.72	0.01	0.4	1.5	15.35	2.1	21.8
	2.00	10/28/87	13.0	10.5	6.4	80	8.3	0.33	0.750	-0.100	0.053	24.0	6.00							
		11/23/87	3.5	14.2	6.2	65	6.5	0.32	0.760	-0.100	0.032	15.9	4.80						3.0	20.0
		12/16/87	4.5	12.1	6.3	65	9.1	0.49	0.880	-0.100	0.099	17.0	18.40						7.0	20.0
		01/27/88	2.0	12.4	6.4	70	10.2	0.13	1.300	0.100	0.050	17.2	0.80						-2.0	19.0
		02/24/88	5.5	13.2	6.3	60	8.7	0.45	1.000	-0.010	0.016	15.0	0.80						4.0	22.0
		03/28/88	10.0	11.2	7.1	65	9.6	0.36	0.960	-0.010	0.035	15.0	2.00						2.0	21.0
		04/27/88	11.5	10.6	7.1	75		0.22	0.850	-0.010	0.030	13.5	-0.10						2.0	23.0
		05/11/88	15.0	9.8	6.6	85	11.1	0.29	0.760	-0.010	0.030	25.5	10.00						3.0	20.0
		05/25/88	18.0	8.8	6.4	100		0.59	0.580	0.060	0.088	17.7	-1.00						-2.0	21.0
		06/08/88	19.0	11.9	8.5	95	14.0	0.38	0.650	0.010	0.060	18.4	6.00		0.01				3.0	25.0
		06/22/88	25.0	6.2	7.6	110	16.0	0.49	0.400	0.030	0.152	14.1	3.00		0.01				3.0	27.0
		07/07/88	24.0	10.0	7.0	130	26.0	0.49	0.390	-0.010	0.042	18.0	4.00		0.02				0.8	24.0
		07/21/88	23.5	6.2	6.9	100		0.53	0.300	0.080	0.050	17.0	5.00		0.02				1.5	17.0
		08/02/88	26.0	9.7	8.0	105	21.2	0.54	0.070	0.040	0.010	18.0	3.50		0.02				1.6	22.5
		08/16/88	27.0	6.8	9.5	120	17.0	1.00	0.040	0.070	0.090	19.0	7.00		-0.01				8.0	24.5
		09/14/88	19.5	6.1	7.0	95	17.0	1.90	0.230	0.090	0.060	18.0	22.00		-0.01				17.0	15.0
		09/29/88	17.0	8.9	7.3	95		0.93	0.270	-0.010	0.020	17.0	10.00		0.02				5.0	23.5
		10/24/88	10.0	9.4	6.6	80	9.0	0.60	0.790	0.190	0.030	14.4	3.30		0.02				1.8	17.5
		11/17/83	14.0	8.4	6.5	80	8.0	0.53	0.840	-0.010	0.040	17.7	3.00						0.4	18.5
Average:			15.2	9.8	7.0	88	12.8	0.56	0.622	0.016	0.052	17.5	5.71	0.00	0.01			0.00	3.3	21.1
verage:			15.3	10.1	7.1	86	12.4	0.54	0.620	0.012	0.049	17.2	4.66	1.72	0.01			15.35	2.6	21.5

-) Indicates less than detection limits

* data taken at Station 2 on 1/27/88 due to ice cover

TABLE [illegible] LAKE LIMNOLOGICAL DATA, BILLINGTON SEA

STATION	SAMPLE DEPTH m	DATE	TEMP oC	DISSOLVED OXYGEN mg/l	pH s.u.	CONDUCT. uhmos/cm	ALKAL. mg/l	T K N mg/l	NITRATE mg/l	AMMONIA mg/l	TOTAL PHOSPH. mg/l	CHLORIDE mg /l	SUSPENDED SOLIDS mg/l	SECCHI m	ORTHO-P mg/l	FECAL COLIFORM #/100 ml	FECAL STREP. #/100 ml	CHLOR a mg/m3	TURBIDITY ntu
2	0.00	10/28/87	14.0	10.4	6.3	70	9.3	0.41	0.270	-0.100	0.052	18.0	11.00	1.20		0	16000	16.00	4.5
		11/23/87	4.5	11.9	6.2	60	7.4	0.28	0.440	-0.100	0.033	15.3	4.30	2.50		-10	590	9.26	4.0
		12/16/87	1.0	12.5	6.5	60	8.9	0.29	0.550	-0.100	0.037	16.0	0.80	1.35		-10	6000	8.21	3.0
		02/24/88	4.5	13.0	6.4	60	7.8	0.28	0.650	-0.010	0.031	14.0	0.40	1.80		-10	640	6.10	3.0
		03/28/88	6.0	11.7	7.1	65	9.3	0.30	0.590	-0.010	0.031	14.0	0.80	2.50		-10	600	11.00	2.0
		04/13/88	8.5	11.1	6.6	65	7.4	0.24	0.590	0.020	0.029	18.0	2.40	2.80		-10	1000	4.38	-2.0
		04/27/88	11.0	10.2	7.0	70		0.29	0.560	-0.010	0.040	14.5	-0.10	3.10		-10	-10	4.10	1.0
		05/11/88	14.0	9.6	7.1	70	11.1	0.28	0.450	-0.010	0.030	22.0	4.00	1.95		0	0	9.72	-2.0
		05/25/88	19.0	9.6	6.4	120		0.38	0.380	0.030	0.063	17.0	-1.00	-2.40		0	8	4.63	-2.0
		06/08/88	21.0	9.6	9.0	90	14.0	0.39	0.240	-0.010	0.030	17.0	6.00	1.30	-0.01	0	1	24.00	3.0
		06/22/88	28.0	9.3	9.0	100	14.0	0.50	0.060	-0.010	0.112	14.1	3.00	1.80	0.01	0	15	19.50	2.0
		07/07/88	26.0	8.8	8.1	100	18.0	0.37	0.060	-0.010	0.056	16.0	1.00	-2.00	0.01	0	2	1.92	1.2
		07/21/88	25.0	6.3	6.9	100		0.45	0.030	0.030	0.050	17.0	-1.00	1.25	0.02	100	0	12.70	2.0
		08/02/88	30.0	9.1	9.0	110	18.0	0.44	-0.020	0.010	0.020	18.4	1.00	1.45	-0.01	0	2	9.81	1.2
		08/16/88	27.0	7.7	9.3	110	16.0	1.10	0.030	0.040	0.100	17.0	24.00	0.55	-0.01	1	390	57.00	8.4
		09/14/88	21.0	9.2	9.0	90	15.8	1.60	-0.020	0.200	0.080	18.0	24.00	0.45	0.03	2	16	65.00	17.0
		09/29/88	18.0	3.1	7.1	90		1.02	0.060	-0.010	0.050	16.2	12.00	0.80	0.01	0	86	41.00	7.0
		10/24/88	11.5	8.8	6.6	75	11.0	0.74	0.390	0.280	0.070	18.4	-0.10	1.60	0.03	20	20	3.50	3.3
		11/17/88	14.0	9.0	6.5	75	7.0	0.31	0.490	-0.010	0.030	15.9	4.00	1.90	0.02	0	4	5.40	0.5
	Average:		16.2	9.3	7.4	83	11.7	0.52	0.307	0.012	0.050	16.7	5.11	1.75	0.01			16.59	3.0
	4.00	10/28/87	12.5	10.4	6.6	75	10.0	0.43	0.280	-0.100	0.054	17.0	7.50						
		11/23/87	4.0	11.5	6.3	60	7.4	0.28	0.460	-0.100	0.042	15.9	6.80						6.0
		12/16/87	4.0	12.3	6.8	60	10.5	0.39	0.560	-0.100	0.040	18.0	4.00						-2.0
		02/24/88	5.0	13.1	6.5	60	6.3	0.23	0.550	0.020	0.023	14.0	2.80						3.0
		03/23/88	8.5	11.7	7.1	65	8.3	0.31	0.590	-0.010	0.037	22.0	1.60						-2.0
		04/13/88	8.5	11.1	6.7	65	6.3	0.33	0.590	0.010	0.036	17.0	2.00						-2.0
		04/27/88	10.5	10.6	7.0	70		0.23	0.540	-0.010	0.040	14.0	-0.10						1.0
		05/11/88	14.0	9.8	7.1	80	11.1	0.30	0.430	-0.010	0.040	22.0	7.00						3.0
		05/25/88	19.0	9.7	6.9	110		0.43	0.370	0.040	0.043	16.6	-1.00						-2.0
		06/08/88	19.0	9.8	8.8	110	12.0	0.33	0.250	-0.010	0.050	16.6	6.00		-0.01				4.0
		06/22/88	26.0	0.3	7.3	110	14.0	0.66	0.060	0.050	0.135	14.1	5.00		0.01				4.5
		07/07/88	22.0	9.0	7.0	120	20.0	0.56	-0.020	-0.010	0.087	17.0	11.00		0.02				2.7
		07/21/88	24.5	4.5	7.0	100		0.44	0.040	0.060	0.050	16.2	4.00		0.02				2.0
		08/02/88	24.5	0.8	7.0	260	18.4	0.31	-0.020	0.010	0.110	16.6	5.30		-0.01				3.0
		08/16/88	23.0	7.2	9.2	120	17.0	1.10	0.020	-0.010	0.100	19.0	5.00		-0.01				7.0
		09/14/88	19.5	5.1	7.6	90	15.3	1.30	-0.020	0.090	0.090	17.3	15.00		-0.01				16.0
		09/29/88	18.3	5.8	7.0	90		1.03	0.070	0.030	0.050	17.0	12.00		0.01				7.0
		10/24/88	11.5	8.6	6.6	75	8.6	0.83	0.390	0.250	0.060	15.9	3.30		0.03				3.0
		11/17/88	14.0	9.2	6.6	75	8.0	0.32	0.500	-0.010	0.040	15.9	4.30						0.5
	Average:		15.4	8.5	7.1	94	11.8	0.57	0.302	0.010	0.059	16.4	5.33	0.00	0.01			0.00	3.0
Average:			15.8	9.2	7.3	89	11.6	0.55	0.305	0.011	0.054	16.6	5.22	1.75	0.01			16.59	3.0

(-) Indicates less than detection limits

No data taken at Station 2 on 1/27/88 due to ice cover.

(*) Meter malfunction

presented in Tables 10 and 11. Data analyses are discussed in the following subsections, on a parameter by parameter basis in relation to the Massachusetts surface water quality criteria for Class B waters (DWPC, 1984) and the EPA surface water quality criteria (EPA, 1986). The data are also compared with that collected during previous limnological studies of the lake. These analyses are based on the desire to achieve Class B water quality and to control cultural eutrophication. Class B waters are designated for the use of protection and propagation of fish, other aquatic life and wildlife and for primary and secondary contact recreation.

Temperature

The seasonal fluctuations exhibited in the annual temperature cycle of Billington Sea are typical for temperate lakes. Surface waters generally freeze during the winter and summer water temperatures are usually below the Massachusetts standard for warmwater fisheries protection (28.3 degrees C). Temperature profiles indicate uniform water column temeratures from late September through May. A slight variability between surface and bottom water temperatures began to occur in both basins in early June and continued through early September. Although a weak summer thermocline developed periodically at Station 2 (3.0 m), it was frequently disrupted by wind action and subsurface currents. As a result of its shallowness, there was never a thermocline present in the western basin at Station 1.

TABLE 10 INLET   LIMNOLOGICAL DATA, BILLINGTON SEA

STATION	DATE	FLOW m3/sec.	TEMP oC	*DISSOLVED OXYGEN mg/l	pH s.u.	CONDUCT. umhos/cm	ALKAL. mg/l	T.K.N mg/l	NITRATE mg/l	AMMONIA mg/l	TOTAL PHOSPH. mg/l	CHLORIDE mg/l	SUSPENDED SOLIDS mg/l	FECAL COLIFORM #/100 ml	ORTHO-P mg/l	FECAL STREP. #/100 ml	TURBIDITY ntu	OXYGEN SATUR. %
A	10/26/87	0.001	13.0	5.6	5.6	70	5.2	0.78	0.170	-0.010	0.767	18.0	13.00	50		28000	16.0	
	11/23/87	0.002	1.0	6.4	5.0	50	1.9	0.79	0.030	-0.100	0.289	17.6	6.00	-10		10000	11.0	9.5
	12/16/87	0.000	5.0	7.9	5.8	40	5.6	0.30	0.600	-0.100	0.170	7.0	5.20	-10		7000	5.0	12.0
	01/27/88	0.001	1.8	9.4	6.0	22	3.7	0.16	0.080	0.060	0.180	7.6	1.60	-10		1600	6.0	14.0
	02/24/88	0.002	5.0	11.4	6.4	50	7.8	0.28	0.360	0.010	0.090	12.0	1.20	-10		1000	3.0	19.0
	03/28/88	0.005	6.0	5.4	5.5	45	4.3	0.59	0.220	0.020	0.104	7.8	1.33	-10		4000	4.0	10.5
	04/13/88	0.003	5.5	10.2	5.6	50	2.8	0.25	0.350	0.070	0.060	19.0	0.40	-10		10000	2.0	17.5
	04/27/88	0.003	9.0	9.2	5.3	55		0.39	0.100	-0.070	0.080	13.5	-0.10	-10		-10	4.0	16.5
	05/11/88	0.003	11.0	5.8	4.7	55	-1.0	0.60	0.220	0.170	0.110	23.7	10.00	0		4	14.0	11.0
	05/25/88	0.005	15.0	5.2	5.4	25		1.60	0.170	0.640	0.339	14.1	25.00	0		76	15.0	12.0
	06/08/88	0.005	19.0	6.2	5.6	80	0.3	3.00	0.360	2.600	1.460	20.6	25.00	80	1.14	14	14.0	15.0
	06/22/88	0.002	19.5	7.4	5.5	70	30.0	0.88	-0.020	0.200	0.271	14.1	5.00	0	0.05	0	6.0	17.0
	07/07/88	0.004	17.0	5.2	5.3	95	2.0	0.89	0.150	0.580	0.154	21.0	8.00	15	0.07	50	2.5	12.5
	07/21/88	0.033	19.5	4.8	5.1	110		0.94	0.080	0.320	0.530	18.0	10.00	30	0.27	270	1.7	11.0
	08/02/88	0.004	20.5	6.0	5.4	70	-1.0	0.69	0.270	0.120	0.140	17.3	3.30	26	0.05	180	1.5	14.0
	08/16/88	0.003	21.0	6.3	5.7	72	3.7	0.67	0.200	0.360	0.290	17.0	6.20	68	0.12	140	2.0	14.0
	09/14/88	0.002	13.5	6.6	5.3	70	2.5	0.97	0.100	0.330	0.130	17.0	9.50	44	0.04	28	1.5	13.5
	09/29/88	0.001	12.0	6.4	5.6	55		0.57	-0.020	0.010	0.450	15.9	17.00	6	0.12	44	2.2	14.0
	10/24/88	0.001	11.0	7.5	5.5	70	3.8	0.54	0.050	0.050	0.290	14.0	8.00	60	0.20	60	1.8	12.0
	11/17/88	0.002	14.0	6.2	5.6	30	8.0	1.60	0.020	0.610	0.840	15.9	27.00	36	0.26	530	5.8	13.0
Average:		0.004	12.0	7.0	5.5	65	5.0	0.52	0.175	0.294	0.337	15.6	9.13		0.23		6.0	13.6
[illegible]	10/28/87	0.011	13.0	7.0	5.9	50	5.6	0.17	0.120	-0.100	0.035	16.0	5.20	110		13000	-2.0	
	11/23/87	0.004	2.0	6.6	5.6	40	2.8	0.19	0.150	-0.100	0.054	14.3	6.00	-10		310	-2.0	10.0
	12/16/87	0.009	4.5	10.3	6.0	40	3.5	0.19	0.170	-0.100	0.039	14.0	2.00	20		3000	-2.0	16.5
	01/27/88	0.006	1.0	11.5	6.2	45	6.5	0.06	0.160	0.060	0.050	14.7	0.40	-10		660	2.0	20.5
	02/24/88	0.015	7.0	11.0	6.3	40	5.2	0.32	0.100	-0.010	0.102	11.0	2.40	10		10000	5.0	19.5
	03/28/88	0.012	9.5	9.6	6.6	50	6.1	0.41	0.080	-0.010	0.049	11.0	2.67	1000		9000	5.0	19.0
	04/13/88	0.011	7.0	9.5	6.4	45	5.9	0.59	0.020	0.100	0.056	15.0	2.80	2000		7000	-2.0	16.5
	04/27/88	0.005	13.0	8.5	6.4	55		0.25	-0.020	-0.010	0.080	13.5	-0.10	-10		-10	1.0	17.0
	05/11/88	0.006	14.0	8.8	6.4	60	6.5	0.47	-0.020	0.100	0.050	16.5	6.00	0		560	5.0	14.0
	05/25/88	0.011	19.0	6.0	6.4	60		0.66	0.120	0.130	0.106	13.4	5.60	360		655	10.0	14.0
	06/08/88	0.034	20.0	9.1	6.9	70	7.0	0.38	-0.020	0.050	0.050	15.2	4.50	236	0.01	122	3.0	20.0
	06/22/88	0.004	23.5	7.9	6.3	80	6.0	0.44	-0.020	-0.010	0.155	14.1	6.00	280	0.02	670	3.0	17.0
	07/07/88	0.002	17.0	6.2	6.5	80	10.0	0.32	0.050	-0.010	0.078	18.0	2.00	52	0.03	64	1.5	10.0
	07/21/88	0.008	22.5	8.9	6.5	70		0.43	0.110	0.090	0.050	11.2	7.00	1340	0.04	3800	1.7	20.0
	08/02/88	0.003	24.0	5.4	6.4	75	4.7	0.79	0.030	0.070	0.040	15.9	-1.00	34	0.01	210	1.6	14.5
	08/16/88	0.003	24.0	4.6	6.2	81	8.2	0.36	0.075	0.090	0.070	17.0	3.50	28	0.02	210	2.2	11.0
	09/14/88	0.002	16.0	6.5	6.9	65	8.2	0.30	0.040	0.010	0.040	14.1	5.00	4	-0.01	22	0.9	14.5
	09/29/88	0.007	12.0	5.7	6.1	60		0.25	0.110	-0.010	-0.010	15.9	2.00	0	-0.01	38	0.6	11.0
	10/24/88	0.002	12.0	10.2	6.3	60	5.0	0.33	0.075	-0.010	0.040	17.0	2.00	340	0.01	1280	0.7	19.5
	11/17/88	0.024	14.5	8.6	6.1	60	5.0	0.25	0.080	0.010	0.060	13.4	3.00	8	0.02	12	0.5	17.0
Average:		0.007	13.8	8.0	6.3	59	5.9	0.37	0.073	0.017	0.060	14.7	3.35		0.01		1.8	15.9

- Indicates less than detection limits

* Meter malfunction

TABLE 11 INLET/OUTLET LIMNOLOGICAL DATA, BILLINGTON SEA

STATION	DATE	FLOW m3/sec.	TEMP oC	DISSOLVED OXYGEN mg/l	pH s.u.	CONDUCT. umhos/cm	ALKAL. mg/l	T K N mg/l	NITRATE mg/l	AMMONIA mg/l	TOTAL PHOSPH. mg/l	CHLORIDE mg/l	SUSPENDED SOLIDS mg/l	FECAL COLIFORM #/100 ml	ORTHO-P mg/l	FECAL STREP. #/100 ml	TURBIDITY ntu	OXYGEN SATUR. %
C	10/28/87	0.001	13.0	9.6	6.2	60	6.3	0.19	0.340	-0.100	0.039	16.0	0.40	0		710	-2.0	
	11/23/87	0.012	3.5	13.3	5.9	50	2.8	0.31	0.410	-0.100	0.034	14.3	4.00	-10		6000	-2.0	20.5
	12/16/87	0.002	5.0	8.5	6.0	45	6.1	0.35	0.420	-0.100	0.050	18.0	3.60	-10		3000	3.0	18.5
	01/27/88	0.013	4.0	10.5	6.1	50	7.0	0.02	0.600	0.020	0.050	15.5	0.80	-10		210	3.0	17.0
	02/24/88	0.023	6.0	13.0	6.4	50	5.7	0.31	0.440	0.030	0.167	12.0	2.00	-10		3000	2.0	22.5
	03/28/88	0.031	11.0	10.4	6.7	50	6.5	0.34	0.340	-0.010	0.035	11.0	0.80	-10		10000	-2.0	19.0
	04/13/88	0.013	8.0	11.7	6.5	55	6.5	0.32	0.430	0.010	0.031	16.0	1.60	-10		4000	-2.0	19.0
	04/27/88	0.100	12.0	10.2	6.7	60		0.21	0.240	0.010	-0.010	17.5	-0.10	-10		-10	1.0	23.0
	05/11/88	0.009	15.0	8.8	6.8	65	7.4	0.41	0.200	0.030	0.040	18.4	10.00	0		0	3.0	18.0
	05/25/88	0.018	19.0	8.3	6.7	75		0.68	0.040	0.070	0.082	16.2	-1.00	0		100	4.0	20.0
	06/03/88	0.003	20.0	8.8	6.7	75	8.0	0.55	0.060	-0.010	0.060	16.6	2.00	2	-0.01	0	6.0	20.5
	06/22/88	0.008	25.0	6.5	6.0	645	14.0	0.98	0.020	0.100	0.149	14.1	4.00	3	0.01	4	3.8	17.0
	07/07/88	0.010	17.0	7.6	6.6	90	12.0	0.67	0.120	0.040	0.055	17.0	3.50	2	0.03	6	1.0	17.5
	07/21/88	0.020	23.0	4.1	6.3	75		1.60	0.030	0.080	0.150	13.7	32.00	130	0.04	620	1.5	9.5
	08/02/88	0.008	24.5	8.0	5.0	80	5.4	1.10	-0.020	0.020	0.060	16.6	10.00	2	-0.01	8	1.0	20.0
	08/16/88	0.008	25.0	4.8	6.2	85	9.2	0.83	0.030	0.170	0.080	18.0	7.00	1	-0.01	24	1.3	11.0
	09/14/88	0.008	16.5	8.4	6.2	70	6.1	0.70	-0.020	0.030	0.050	15.2	10.00	2	-0.01	20	0.7	18.0
	09/29/88	0.157	15.0	6.6	6.3	70		1.08	-0.020	-0.010	0.070	15.5	11.00	0	0.01	12	0.8	14.5
	11/17/88	0.055	15.0	8.8	6.4	65	7.6	0.50	0.260	-0.010	0.040	12.3	3.00	0	0.02	8	0.4	19.5
Average:		0.026	14.6	8.8	6.3	96	7.4	0.59	0.206	0.014	0.065	15.5	5.51		0.01		1.3	18.1
E2	09/29/88	0.023	16.0	7.0	5.8	50		0.27	0.190	-0.010	0.250	8.7	11.00		0.06		2.8	16.0
Average:		0.023	16.0	7.0	5.8	50	0.0	0.27	0.190	-0.010	0.250	8.7	11.00		0.06		2.8	16.0
OUT	10/28/87	0.423	14.0	12.0	6.2	75	10.0	0.47	0.280	-0.100	0.078	16.0	4.00	10		41000	5.0	
	11/23/87	0.377	5.0	12.2	6.4	60	6.5	0.38	0.490	-0.100	0.046	15.1	6.40	20		670	-2.0	19.5
	12/16/87	0.451	5.0	12.4	6.6	65	8.9	0.34	0.540	-0.100	0.041	17.0	5.60	-10		3000	-2.0	20.0
	01/27/88	0.451	4.0	12.4	6.5	65	9.3	0.12	0.690	0.090	0.040	15.9	0.40	-10		2300	2.0	19.0
	02/24/88	0.508	4.0	13.0	6.5	55	8.3	0.31	0.660	-0.010	0.037	14.0	2.00	-10		250	-2.0	21.5
	03/28/88	0.665	9.5	11.4	6.9	65	7.8	0.22	0.620	-0.010	0.026	13.0	1.00	-10		13000	2.0	21.0
	04/13/88	0.455	9.0	9.3	6.7	60	8.3	0.25	0.570	0.020	0.023	14.0	1.60	-10		2000	-2.0	20.0
	04/27/88	0.508	14.5	11.4	7.1	75		0.24	0.510	-0.010	0.030	14.0	-0.01	-10		-10	1.0	24.5
	05/11/88	0.431	14.5	9.7	5.9	75	9.3	0.32	0.410	-0.010	0.040	18.5	22.00	20		0	-2.0	20.5
	05/25/88	0.490	19.0	8.8	6.8	90		0.43	0.350	0.050	0.065	17.3	-1.00	7		136	-2.0	19.0
	06/08/88	0.381	18.5	9.0	7.1	80	11.0	0.36	0.240	-0.010	0.050	16.2	8.00	0	-0.01	0	3.0	20.5
	06/22/88	0.327	21.5	9.8	9.4	100	14.0	0.70	-0.020	-0.010	0.178	14.1	4.00	8	0.01	310	3.0	25.0
	07/07/88	0.608	25.0	9.2	8.3	100	16.0	0.27	0.030	-0.010	0.048	19.0	2.00	2	0.03	1	1.4	23.0
	07/21/88	0.363	25.0	6.5	6.8	90		0.46	0.030	-0.010	0.050	17.0	8.00	0	0.02	100	2.0	25.0
	08/02/88	0.424	29.0	8.4	8.8	105	20.2	0.02	-0.020	0.020	0.020	17.7	2.50	0	-0.01	9	1.2	24.0
	08/16/88	0.375	27.0	8.9	9.4	110	15.0	1.10	0.020	0.180	0.080	18.0	11.00	1	-0.01	90	6.5	24.0
	09/14/88	0.357	21.0	8.9	7.6	90	15.8	1.70	-0.020	-0.010	0.080	18.0	19.00	12	0.02	42	14.0	21.0
	09/29/88	0.322	18.0	7.0	6.6	90		0.80	0.110	0.080	0.020	17.0	7.00	0	-0.01	94	5.8	14.0
	10/24/88	0.390	12.0	9.9	6.6	75	8.0	0.59	0.450	0.190	0.040	14.0	2.00	-20	0.02	-20	2.3	20.0
	11/17/88	0.639	14.0	9.5	6.5	80	8.0	0.30	0.500	-0.010	0.030	14.1	2.00		0.03		0.5	20.0
Average:		0.447	15.5	10.0	7.1	80	11.0	0.47	0.322	0.012	0.051	16.0	5.37		0.01		1.9	21.1

(-) Indicates less than detection limits

(*) Meter malfunction

Dissolved Oxygen

Dissolved oxygen is critical for the sustenance of fish and other aquatic life, as well as for preserving the aesthetic qualities of a waterbody. Class B water quality standards state that a minimum dissolved oxygen concentration of 5.0 mg/L is required to maintain a healthy warmwater fishery. This minimum was not met at depths greater than 3.0 m, in the eastern basin (Station 2), on three sampling events. The dissolved oxygen concentration below 3.0 m was 4.5 mg/L on July 21, 0.9 mg/L on June 22 and 0.8 mg/L on August 22. The latter two occurrences were attributable to the presence of a weak thermocline on these dates which prevented circulation between oxygen-rich surface waters and bottom waters which had been depleted of oxygen. The oxygen demand of bacteria which decompose organic matter is greater during periods of increased temperature and occasionally cause this oxygen depletion. Oxygen depletion may result in the occurrence of fish kills as well as cause the release of sediment-bound phosphorus into the water column. This phosphorus release may then trigger an algal bloom. A comparison between the phosphorus concentrations of the surface and bottom waters indicated the occurrence of such a sediment phosphorus release in the Billington Sea. The data also indicate that periodic increases in the oxygen content of the lake's surface waters are associated with algal blooms.

Tributary dissolved oxygen concentrations were generally lower than lake concentrations, particulary during the summer. The majority of the tributaries exhibited dissolved oxygen concentrations greater than 10.0 mg/L only during the

the winter when bog runoff was not discharged to the tributaries.

Conductivity

Conductivity is a measurement of the capacity of a solution to conduct an electrical current. Measured in umhos/cm, conductivity is proportional to the concentration of dissolved ions, their mobility, valence and solution temperature. Tributary conductivity values were consistently low, with annual averages ranging from 55 - 66 umhos/cm. The conductivity values of Tributaries A, D and E exceeded 100 umhos/cm on only one occasion. These increases were associated with the discharge of stormwater runoff from Black Cat Road. During most of the year, in-lake and tributary conductivity values were similar. During the summer, however, in-lake conductivity values increased from a range of 66-85 umhos/cm to 100-120 umhos/cm. This increase may reflect summer increases of septic leachate inflow from domestic wastewater systems, but was not of a magnitude indicative of heavy pollutant loading.

Chlorides

The chloride content of water is an indicator of the extent of human influences on an aquatic ecosystem. Elevated levels in freshwater may either be associated with road runoff or septic leachate inflow. Values greater than 10 mg/L are generally considered undesirable. However, water quality is generally not impaired at concentrations less than 100 mg/L (McKee and Wolf, 1963). The average annual in-lake concentration of chloride was slightly higher than

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the average tributary concentrations. The latter ranged from 11.9 - 15.6 mg/L in comparison to in-lake concentrations which averaged 17.2 mg/L in the western basin and 16.6 mg/L in the eastern basin. Although in-lake and tributary concentrations were generally greater than 10 mg/L, they never exceeded 30 mg/L.

Turbidity

Turbidity, an indicator of water clarity, can be caused by suspended organic and/or inorganic matter, soluble colored organic compounds and plankton. The turbidity in the Billington Sea was low throughout the year, averaging 2.6 NTU in the western basin and 3.0 NTU in the eastern basin. Slight increases in the turbidity of surface waters were generally associated with increases in chlorophyll a, which occurred in late August and early September during algal blooms. Tributaries B and C were characterized by very low turbidity values, less than 2.0 NTU, in comparison to the other tributaries which ranged from 5.4 - 9.6 NTU. Fluctuations in the turbidity of the bog tributaries did not always vary with total suspended solids. Thus, they probably were attributable to both sporadic releases of suspended particles as well as soluble colored organic compounds.

In summary, increases in in-lake turbidity values appear to represent periods of increased algal productivity and increases of instream turbidity values appear to represent the release of bog tannins and suspended solids.

Total Suspended Solids

Total suspended solids represent the amount of organic and inorganic particulate matter which is suspended in the water column. An increase in the concentration of suspended solids in a lake often follows turbulence created in the water column or is indicative of an abundance of algal cells normally associated with an algal bloom. Preliminary studies have shown high concentrations of suspended solids in the water column of shallow lakes following heavy motorboat activities (Wagner, in press). Although the concentration of suspended solids in the Billington Sea was generally low during the summer, sampling was not conducted on the weekends when motorboat use is generally higher. The highest concentrations of total suspended solids occurred in the surface waters of both basins on September 14 and were associated with a bloom of blue-green algae. The lowest average concentration was measured at the Trask Pond outlet, indicating the particulate retention function of the pond. Observable increases of total suspended solids of the bog tributaries were measured during storm events and floodwater releases. These increases were usually associated with increases in total phosphorus and organic nitrogen concentrations. Streambank erosion was noted during the study as was the transport of cranberries and vegetative matter into the Billington Sea following the October harvest.

Secchi Disk Transparency

The transparency of the water column was measured utilizing a circular plate, 20 cm in diameter, called a Secchi disk.

Factors which can effect the transparency measurements include: water color, dissolved and particulate matter, surface water conditions, sky conditions, time of day and observer bias. Particulate matter may consist of suspended sediment and/or phytoplankton. Thus, all readings were measured by the same individual between the hours of 11:00 a.m. and 2:00 p.m in order to reduce measurement error. Cloud cover and surface water conditions were also recorded. The average Secchi disk transparency of the Billington Sea is 1.7 meters in the western basin and 1.8 meters in the eastern basin. Although these annual averages are above the state standard of 1.2 meters (4 feet) for contact recreational waters, a wide range of values (0.45 - 3.1 m) was obtained. A significant reduction in lake transparency occurred during the growing season and progressively decreased during the summer recreational period to values of 0.45 - 0.85 m, well below the state standard. Substandard transparency values were associated with increased chlorophyll a values, indicating an algal bloom. The reduction in transparency during these algal blooms is obvious since the entire lake turns a pea-green color. Thus, increases in the biomass and size distribution of phytoplankton in the Billington Sea has a negative effect on its water column transparency.

Phytoplankon and Chlorophyll a

Chlorophyll a is an indicator of algal biomass and potential productivity. Chlorophyll is a green plant pigment which transforms sunlight into energy which is usable by phytoplankton (free-floating microscopic algae). Chlorophyll values for the Billington Sea ranged from 0.98

to 77.0 mg/m3 for the western basin and from 1.9 - 65.0 mg/m3 in the eastern basin. Chlorophyll a values increased during the growing season and peaked during late August and early September when blue-green algae blooms occurred in both basins. Average summer chlorophyll a values were 3.5 times greater than the level generally found in mesotrophic lakes (8.0 mg/m^3) (Uttormark and Hutchinson, 1980). Thus, the elevated chlorophyll a levels in the Billington Sea during the growing season are indicative of a high degree of nutrient enrichment. Increases in chlorophyll a values generally corresponded with increases in the standing crop of phytoplankton. The standing crops of phytoplankton present in the Billington Sea are presented for the eastern basin (Station 2) in Tables 12, 13, 14 and 15 and for the western basin (Station 1) in Tables 16, 17, 18 and 19 and are expressed as the number of organisms per unit volume. The monthly relative abundance of phytoplankton genera, as grouped by taxonomic phyla, are presented in Table 20 and Table 21 for in-lake Station 1 and Station 2, respectively. Throughout most of the year, the phytoplankton community is dominated by diatoms (Bacillariophyta) and green algae (Chlorophyta). Both taxonomic groups are characterized by a high species diversity, particularly during the spring and summer growing season. Phytoplankton blooms occurred more frequently in the eastern than in the western basin and were mainly dominated by the diatom, Melosira granulata. These diatom blooms occurred sporadically from late April through late October and were accompanied by blooms of green algae on April 27 and June 8, 1988. Peak biomass in the eastern basin was reached during the June 8 sampling event. Phytoplankton blooms which occurred in the western basin occurred less frequently and were of lower magnitude.

TABLE 12. BILLINGTON SEA PHYTOPLANKTON COMPOSITION AND ABUNDANCE

STATION: IN-LAKE 2

Species	Cells/Liter				
Bacillariophyta	10/28/87	11/23/87	12/16/87	1/27/88**	2/24/88
Fragellaria crotonensis	117,310	93,600	31,418		5,906
* Synedra sp.	7,448	10,800	15,709		9,281
Navicula sp.	5,586	5,400	4,154		4,219
Cymbella sp.	3,724				844
Asterionella formosa	61,448	102,600	5,891		
Melosira granulata	1,080,000	300,600	141,382		92,813
Nitzschia sp.	11,172	19,800	7,855		8,438
Licmorpha sp.	1,862		174,764		
Synedra delicatissima			3,927		
Tabellaria fenestrata			7,855		19,406
Chlorophyta					
Scenedesmus quadricauda	7,448		7,855		
Cosmarium sp.	1,862				
Staurastrum sp.	1,862				
Ankistrodesmus falcatus	242,069				
Scenedesmus bijuga	14,897				
Sphaerocystis sp.	89,379	1,800			
Crucigenia sp.	14,897				
Cinobryon sertularia					118,969
Unidentified green					5,906
Pyrrophyta					
Peridinium cinctum			3,927		
Peridinium sp.					7,594
Total	1,660,964	534,600	404,737		273,376

* Taste and odor-causing alga.
** NO SAMPLE collected at this station.

TABLE 13. BILLINGTON SEA PHYTOPLANKTON SPECIES COMPOSITION AND ABUNDANCE

STATION: IN-LAKE 2

Species	#Cells/Liter				
Bacillariophyta	3/28/88	4/13/88	4/27/88	5/11/88	5/25/88
Fragellaria crotonensis	37,895	79,962	317,647	1,658,618	319,925
Synedra sp.	12,316	2,077	6,353	7,855	4,075
Navicula sp.	6,632	3,115	4,235	3,927	
Cymbella sp.	3,789	5,192	2,118		
Asterionella formosa	18,000	8,308	226,588	10,473	291,396
Melosira granulata	72,000	231,577	116,471	196,364	28,528
Nitzschia sp.	5,684			1,309	
Licmorpha sp.					4,075
Synedra delicatissima					
Tabellaria fenestrata	19,895	36,346	52,941	5,236	
Meridion circulare		1,038	6,353		
Chlorophyta					
Scenedesmus quadricauda			8,471	5,236	
Cosmarium sp.					
Staurastrum sp.					
Ankistrodesmus falcatus				9,164	4,075
Scenedesmus bijuga					
Sphaerocystis sp.	9,474		31,765	123,055	12,226
Crucigenia sp.					
Dinobryon sertularia	39,789	20,769	542,118	218,618	2,038
Unidentified green colony					2,038
Quadrigula sp.	3,789		21,176		
Gonatozygon sp.	947				
Actinastrum sp.	1,895				
Pediastrum boryanum				41,891	
Staurastrum cingulum				2,618	
Closterium lunula				3,927	
Pyrrophyta					
Peridinium cinctum					
Peridinium sp.	17,053	5,192			
Dinoflagellates					
Peridinium				1,309	
Cyanophytes					
Oscillatoria colony				2,618	
Total	249,158	393,576	1,336,236	2,292,218*	668,376

*Note: cells chlorotic

TABLE 14. BILLINGTON SEA PHYTOPLANKTON SPECIES COMPOSITION AND ABUNDANCE

STATION: IN-LAKE 2

Species	#Cells/Liter				
Bacillariophyta	6/8/88	6/22/88	7/7/88	7/21/88	8/2/88
Fragellaria crotonensis	384,000	1,885,457	261,735	674,509	54,000
Synedra sp.	3,000	3,245	60,612	5,891	29,455
Navicula sp.		6,490		5,891	
Cymbella sp.	6,000				
Asterionella formosa	1,788,000	139,543	33,061	35,345	58,909
Melosira granulata	4,536,000	25,962	115,714	444,764	39,273
Nitzschia sp.			41,327	44,182	49,091
Licmorpha sp.					
Synedra delicatissima					
Tabellaria fenestrata				5,891	
Meridion circulare					
Chlorophyta					
Onychonema laeve					49,091
Selenastrum sp.					39,273
Scenedesmus quadricauda	24,000	12,981	11,020	23,564	
Cosmarium circulare	3,000	3,245			2,455
Staurastrum sp.			5,510	5,891	19,636
Ankistrodesmus falcatus	33,000	25,962			12,273
Scenedesmus bijuga		12,981			34,364
Sphaerocystis sp.	345,000	165,505	71,633		
Crucigenia sp.					
Dinobryon sertularia	501,000			2,945	
Unidentified green colony					
Quadrigula chodatii	81,000	25,962			
Gonatozygon sp.					
Actinastrum sp.					
Pediastrum duplex				29,455	
Pediastrum boryanum		103,846			
Staurastrum cingulum	3,000				
Closterium sp.	3,000	3,245	2,755		
Characium sp.	3,000			2,945	
Gleocapsa	12,000				
Psuedostaurastrum			2,755		
Phacus sp.				2,945	
Pyrrophyta					
Peridinium sp.			2,755		9,818
Peridinium cinctum	6,000				
Ceratium hirundinella		3,245		2,945	
Cyanophytes					
Anabaena sp.					2,455
Oscillatoria colony					
Lyngbya sp.				2,945	68,727
Total	7,731,000	2,417,669	608,877	1,290,108	468,820

TABLE 15. BILLINGTON SEA PHYTOPLANKTON SPECIES COMPOSITION AND ABUNDANCE

STATION: IN-LAKE 2

Species	#Cells/Liter				
Bacillariophyta	8/16/88	9/14/88	9/29/88	10/24/88	11/17/88
Fragellaria crotonensis	34,914	27,000	84,000	557,280	274,099
Synedra sp.	32,586	5,400	8,000		7,685
Navicula sp.		5,400		19,440	20,493
Cymbella sp.					
Asterionella formosa	2,328		4,000	19,440	5,123
Melosira granulata	123,362	891,000	760,000	1,062,720	258,729
Nitzschia sp.	62,845				
Licmorpha sp.					
Synedra delicatissima					
Tabellaria fenestrata	4,655		4,000	6,480	5,123
Meridion circulare					
Gyrosigma sp.	9,310				
Chlorophyta					
Scenedesmus quadricauda	4,655		32,000	336,960	51,233
Cosmarium circulare					
Staurastrum sp.	9,310		24,000	6,480	2,562
Ankistrodesmus falcatus					
Scenedesmus bijuga	18,621	21,600	32,000		
Sphaerocystis sp.	6,983			32,400	12,808
Crucigenia sp.					
Dinobryon sertularia					
Unidentified green colony					15,370
Quadrigula chodatii					
Gonatozygon sp.					
Actinastrum sp.					
Pediastrum boryanum					
Staurastrum cingulum					
Closterium sp.	11,638				
Characium sp.					
Gleocapsa					
Phacus sp.	2,328				
Pediastrum sp.					51,233
Pyrrophyta					
Peridinium sp.	41,897			6,480	
Peridinium cinctum					
Ceratium hirundinella					
Cyanophytes					
Anabaena sp.		1,036,800	28,000		35,863
Oscillatoria colony					
Lyngbya sp.	2,328				
Pleurocapsa Minor	46,552				
Total	414,312	1,987,200	976,000	2,047,680	740,321

TABLE 16. BILLINGTON SEA PHYTOPLANKTON COMPOSITION AND ABUNDANCE

STATION: IN-LAKE 1

Species			Cells/Liter		
Bacillariophyta	10/28/87	11/23/87	12/16/87	1/27/88	2/24/88
Fragellaria crotonensis	67,745	95,464	2,077	23,400	
* Synedra sp.		10,125	1,038	5,400	
Navicula sp.	8,836	1,446	4,154	12,600	
Tabellaria fenestrata	19,145	1,446	6,231	7,200	42,058
Asterionella formosa	2,945	40,500	12,462	14,400	7,788
Pleurosigma sp.	1,473				
Melosira granulata	296,018	18,804	69,577	135,000	46,731
Nitzschia sp.	1,473	11,571		19,800	17,135
Licmorpha sp.	2,945				
Synedra rumpens			5,192		
Synedra delicatissima			25,962		
Chlorophyta					
Scenedesmus quadricauda	11,782	5,786	4,154		
Cosmarium sp.	1,473				
Staurastrum sp.	1,473		1,038		
Ankistrodesmus falcatus	32,400			5,400	
Selanastrum sp.	5,891				
Sphaerocystis sp.	88,364				
Closterium sp.		1,446	1,038		
Actimastrum hantzschii					7,200
Cyanophyta					
Lyngbya colonies	142,855		2,077		
Oscillotaria colony				1,800	
Pyrrophyta					
Peridinium sp.				23,400	
Total	684,818	186,588	135,000	255,600	113,712

* Taste and odor-causing alga.

TABLE 17. BILLINGTON SEA PHYTOPLANKTON SPECIES COMPOSITION AND ABUNDANCE

STATION: IN-LAKE 1

Species	#Cells/Liter				
Bacillariophyta	3/28/88	4/13/88	4/27/88	5/11/88	5/25/88
Fragellaria crotonensis	12,316	108,947	63,000	29,455	31,154
*Synedra sp.	2,842	3,789	5,400		1,038
Navicula sp.	3,789	1,895	14,400		1,038
Tabellaria fenestrata	3,789	23,684	3,600	2,945	1,038
Asterionella formosa	3,789	1,895	19,800	8,836	66,462
Pleurosigma sp.					
Melosira granulata	44,526	113,684	36,000	120,764	14,538
Nitzschia sp.	947				
Licmorpha sp.					
Synedra rumpens					
Synedra delicatissima					
Cymbella sp.	1,895	2,842			
Meridion circulate	1,895	3,789	3,600		
Chlorophyta					
Scenedesmus quadricauda		7,579	3,600	5,891	
Cosmarium sp.					
Staurastrum sp.					1,038
Ankistrodesmus falcatus					2,077
Selanastrum sp.					
Sphaerocystis sp.			9,000		
Closterium sp.					
Actimastrum hantzschii					
Dinobryon sertularia	36,000	14,211	18,000	397,636	4,154
Scenedesmus bijuga	3,789				
Gonatozygon sp.	4,737				1,038
Staurastrum protectum					1,038
Cyanophyta					
Lyngbya sp.				2,945	
Oscillataria colony			3,600		
Pyrrophyta					
Peridinium sp.	80,526	286,104			
Total	200,840	568,419	180,000	568,472	124,613

* Taste and odor-causing alga

TABLE 18. BILLINGTON SEA PHYTOPLANKTON SPECIES COMPOSITION AND ABUNDANCE

STATION: IN-LAKE 1

Species	#Cells/Liter				
Bacillariophyta	6/8/88	6/22/88	7/7/88	7/21/88	8/2/88
Fragellaria crotonensis	105,734	955,882	265,846	79,962	
*Synedra sp.		5,882	5,192	3,115	28,929
Navicula sp.			3,115	1,038	
Tabellaria fenestrata		17,647			
Asterionella formosa	1,789,930	32,353	21,808	4,154	
Pleurosigma sp.					
Melosira granulata		5,882	32,192	18,692	57,857
Nitzschia sp.				3,115	52,071
Licmorpha sp.					
Synedra rumpens					
Synedra delicatissima					
Cymbella sp.	3,776		1,038		
Meridion circulare					
Chlorophyta					
Scenedesmus quadricauda	30,210	11,765	2,077	12,462	23,143
Cosmarium sp.					
Staurastrum sp.	3,776				
Ankistrodesmus falcatus	3,776	14,706			
Selanastrum sp.					
Sphaerocystis sp.	64,196	288,235	140,192		40,500
Closterium sp.	3,776				
Actimastrum hantzschii					
Dinobryon sertularia	151,049	8,824			
Scenedesmus bijuga		11,765	-	12,462	
Gonatozygon sp.					
Staurastrum protectum					
Staurastrum cingulum		2,941	4,154	5,192	17,357
Pediastrum		47,059	8,308		
Closterium lunula		2,941			
Unidentified green			2,077		
Phacus sp.				2,077	
Cyanophyta					
Anabaena colony					289,286
Pleurocapsa minor				16,615	
Lyngbya sp.					
Oscillataria colony					
Gleocapsa sp.			8,308		
Pyrrophyta					
Peridinium sp.				1,038	
Ceratium hirundinella				1,038	
Total	2,156,223	1,405,882	494,308	160,960	509,143

* Taste and odor-causing alga

TABLE 19. BILLINGTON SEA PHYTOPLANKTON SPECIES COMPOSITION AND ABUNDANCE

STATION: IN-LAKE 1

Species	#Cells/Liter				
Bacillariophyta	8/16/88	9/14/88	9/29/88	10/24/88	11/17/88
Fragellaria crotonensis	105,195		65,720	8,100	143,591
*Synedra sp.	3,506		3,651	13,500	14,727
Navicula sp.				2,700	3,682
Tabellaria fenestrata			10,953	5,400	
Asterionella formosa		15,882		18,900	44,182
Pleurosigma sp.					
Melosira granulata	63,117	135,000	372,414	178,200	235,636
Nitzschia sp.	98,182				
Licmorpha sp.					
Synedra rumpens					
Synedra delicatissima					
Cymbella sp.					
Meridion circulare			3,651		
Pleurosigma sp.			3,651		
Chlorophyta					
Scenedesmus quadricauda	14,026	31,765	14,604	10,800	29,455
Cosmarium sp.	35,065		3,651		
Staurastrum sp.	14,026	15,882	3,651		
Ankistrodesmus falcatus		39,706			
Selanastrum sp.					
Sphaerocystis sp.	35,065				18,409
Closterium sp.					
Actimastrum hantzschii					
Dinobryon sertularia					
Scenedesmus bijuga	84,156		14,604		
Gonatozygon sp.					
Staurastrum protectum					
Staurastrum cingulum					
Pediastrum					
Closterium lunula					
Unidentified green					
Phacus sp.					
Cyanophyta					
Anabaena sp.		1,945,588	73,022	13,500	
Lyngbya sp.					
Oscillataria colony					
Pyrrophyta					
Peridinium sp.	108,701				
Total	561,039	2,183,823	569,572	251,100	489,682

* Taste and odor-causing alga

TABLE 20. BILLINGTON SEA PHYTOPLANKTON ABUNDANCE SUMMARY

STATION: IN-LAKE 1

Taxon	10/28/87	11/23/87	12/16/87	1/27/88	2/24/88
Bacillariophyta	400,580	179,356	95,539	217,800	113,712
Chlorophyta	141,383	7,232	6,230	5,400	7,200
Cyanophyta	142,855		2,077	1,800	
Pyrrophyta				23,400	

Taxon	3/28/88	4/13/88	4/27/88	5/11/88	5/25/88
Bacillariophyta	75,788	260,525	145,800	162,000	115,268
Chlorophyta	44,526	21,790	27,000	403,527	9,345
Cyanophyta			3,600	2,945	
Pyrrophyta	80,526	286,104			

Taxon	6/8/88	6/22/88	7/7/88	7/21/88	8/2/88
Bacillariophyta	1,899,440	1,017,646	329,192	110,076	138,857
Chlorophyta	256,783	388,236	156,808	32,193	81,000
Cyanophyta			8,308	16,615	289,286
Pyrrophyta				2,076	

Taxon	8/16/88	9/14/88	9/29/88	10/24/88	11/17/88
Bacillariophyta	270,000	150,882	460,040	226,800	441,818
Chlorophyta	182,338	87,353	36,510	10,800	47,864
Cyanophyta		1,945,588	73,022	13,500	
Pyrrophyta	180,701				

TABLE 21. BILLINGTON SEA PHYTOPLANKTON ABUNDANCE SUMMARY

STATION: IN-LAKE 2

Cells/Liter

Taxon	10/28/87	11/23/87	12/16/87	1/27/88	2/24/88
Bacillariophyta	1,288,550	532,800	302,955	NO DATA	140,907
Chlorophyta	372,414	1,800	7,855		124,875
Cyanophyta					
Pyrrophyta			3,927		7,594

Taxon	3/28/88	4/13/88	4/27/88	5/11/88	5/25/88
Bacillariophyta	176,211	367,615	732,706	1,883,782	647,999
Chlorophyta	55,894	20,769	603,530	404,509	20,377
Cyanophyta				2,618	
Pyrrophyta	17,053	5,192		1,309	

Taxon	6/8/88	6/22/88	7/7/88	7/21/88	8/2/88
Bacillariophyta	6,717,000	2,060,697	512,449	1,216,473	230,728
Chlorophyta	1,008,000	353,727	93,673	67,745	157,092
Cyanophyta				2,945	9,818
Pyrrophyta	6,000	3,245	2,755	2,945	71,182

Taxon	8/16/88	9/14/88	9/28/88	10/24/88	11/17/88
Bacillariophyta	270,000	928,800	860,000	1,665,360	571,252
Chlorophyta	53,535	21,600	88,000	375,840	133,206
Cyanophyta	48,880	1,036,800	28,000		35,863
Pyrrophyta	41,897			6,480	

Diatom blooms in this basin occurred on June 8 and June 22, 1988 and were dominated by Asterionella formosa and Fragellaria crotonesis, respectively. A distinct pea-green color was imparted to the Billington Sea on September 14, 1988 in response to a bloom of the planktonic blue-green alga, Anabaena sp. This nuisance alga is pollutant-tolerant which can be toxic to humans, fish and wildlife. Several of the other dominant algal species also produce odor. For example Asterionella sp. produces an aromatic, geranium-like odor that changes to a fishy smell when large numbers are present (Palmer, 1962).

Fecal Coliform and Fecal Streptococcus Bacteria

The normal habitat of fecal coliform and fecal streptococcus bacteria is the intestines of humans and animals. Thus, these organisms can be used to indicate the presence of fecal contamination in a waterbody. The state bathing standard for fecal coliform bacteria, 200/100 ml, was never exceeded at either of the Billington Sea sampling stations. The occasional elevated fecal streptococci densities which occurred in the lake during the fall probably represent wastes deposited by large flocks of migratory waterfowl which were observed on the lake at that time. Similarly high fecal streptococci densities which were obtained from the tributary samples at that time are also probably attributable to wildlife foraging in the bog areas. Fecal streptococci densities obtained in the Tributary B samples were consistantly higher than the other tributaries throughout the year. This is probably attributable to the raising of waterfowl which occurs in the pond upstream from this sampling station. Although the bacteriological data do not indicate the presence of sewage contamination in the Billington Sea, a monitoring program for fecal coliform bacteria and fecal streptococcus should be instituted. Sampling should be conducted in the vicinity of the bathing area, at least on a weekly basis, during the bathing season.

pH and Total Alkalinity

pH is a measurement of the hydrogen ion concentration of a solution, reported on an inverse logarithmic scale from 0 - 14.0, which determines whether a solution is acidic (less than 7.0), neutral (7.0) or alkaline (greater than 7.0). According to Class B water quality standards, pH values within the range of 6.5 - 8.0 are acceptable for the propagation and protection of warmwater fish. The data indicate a general trend toward alkaline conditions during the growing season and acidic conditions throughout the remainder of the year. There were extreme fluctuations in pH levels between acidic and alkaline conditions. The acidic conditions were attributed to stormwater inputs and cranberry bog discharges while alkaline conditions were due to algal blooms. As a result of the latter phenomenon, bottom waters were slightly more acidic than surface waters during the growing season. The effect of acidic stormwater in the lake was evident during the July 21 stormwater sampling event when pH values for the previous two months, which had been greater than 8.0, dropped to a pH of 6.7. This pH reduction also occurred on the October 24 and November 11 stormwater sampling events. These extreme fluctuations in pH occur as a result of the low alkalinity, or poor buffering capacity which is typical of lakes in the northeast United States.

Alkalinity is a measurement of the hydroxyl, carbonate and bicarbonate ions present in a solution which is generally reported as mg/L of calcium carbonate, which determines the buffering capacity of the solution. As a result of the poor buffering capacity of the Billington Sea, extreme fluctuations in pH levels may be stressful to fish and aquatic organisms. These fluctuations may also affect fish and other aquatic organisms indirectly since the toxicity of certain pollutants increases with decreases in pH. Low total alkalinity values in the Billington Sea, averaging 12.4 mg/L in the western basin and 11.8 mg/L eastern basin, make the lake susceptible to acid rain deposition. As expected, the alkalinity values of the bog tributaries were extremely low, ranging from 4.2 - 5.0 mg/L. As a result of this poor buffering capacity, acidic waters which are stressful to fish (pH of 5.5 - 5.9) are discharged into the Billington Sea from Tributaries A, D and E. Tributaries B and C, which drain small ponds, exhibited higher average pH values of 6.3.

Ratio of Total Nitrogen (TKN + $NO^{-3}N$) to Total Phosphorus

The quantity, or biomass, of algae in a lake is an indicator of the degree of eutrophication and is usually limited by the concentration of an essential element or nutrient. The ratio of total nitrogen to total phosphorus can be used to evaluate which nutrient limits phytoplankton growth in the event that other factors such as light, temperature or inhibitory substances do not control growth. Ratios greater than 20 suggest phosphorus limitation and ratios less than 13 often suggest nitrogen limitation (Smith, 1979). Ratios of total nitrogen to total phosphorus in the Billington Sea, averaged 30 and 17 during the year for Station 1 & Station 2

(Table 22), respectively. These ratios are indicative of phosphorus limitation during most of the year. Ratios of less than 13, however, occurred during the summer and were particularly evident at Station 2 (eastern basin). This suggests that nitrogen limitation occurs in the lake during the summer. A significant decrease in the concentration of inorganic nitrogen also occurred during the summer, lending further support to the occurrence of summer nitrogen limitation.

A reduction in phosphorus loading to the lake is the primary objective of the restoration plan. Most of the phosphorus input originates from watershed land use activities. Current lake management technologies focus on phosphorus loading reduction since phosphorus removal from water is more technologically cost-effective than nitrogen removal. Furthermore, even with in-lake nitrogen reduction, blue-green algae can utilize atmospheric nitrogen for their growth.

Phosphorus

Phosphorus, one of the major nutrients required for plant growth (See Appendix D), exists inorganically as orthophosphate and polyphosphates, and as organically bound phosphorus. It occurs in natural waters as well as in stormwater and wastewater, mainly in the form of phosphates. These phosphates occur in dissolved and particulate forms. Orthophosphate concentrations were measured during the growing season in order to determine the amount of this soluble phosphorus fraction which is available for plant growth and to determine watershed loading sources.

TABLE 22. TOTAL NITROGEN/TOTAL PHOSPHORUS IN THE BILLINGTON SEA

DATE	STATION 1	STATION 2
10/28/87	23	12
11/23/87	27	20
12/16/87	18	32
1/27/88	20	No samples
2/24/88	67	34
3/28/88	38	31
4/13/88	52	27
4/27/88	42	20
5/11/88	41	21
5/25/88	14	15
6/08/88	19	15
6/22/88	7	5
7/07/88	19	7
7/21/88	15	10
8/02/88	31	10
8/16/88	13	11
9/14/88	39	21
9/29/88	40	22
10/24/88	45	18
Mean	30	17

Fertilizers applied to agricultural and residential lands contain orthophosphates which can be transported to surface waters in runoff. Total phosphorus is a measurement of organic phosphorus, orthophosphate and polyphosphates and is used by lake managers in nutrient budget calculations rather than orthophosphates.

Total phosphorus concentrations should not exceed 0.05 mg/L in any stream which discharges into a lake and in-lake levels should not exceed 0.025 mg/L in order to prevent the development of nuisance aquatic plant growth and to control cultural eutrophication (EPA, 1986). Average annual in-lake values for total phosphorus ranged from 0.020 - 0.135 mg/L (average 0.054 mg/L) in the eastern basin and ranged from 0.016 - 0.152 mg/L (average 0.049 mg/L) in the western basin. Thus, total phosphorus concentrations in the Billington Sea are twice as high as the maximum levels recommended by EPA. The average annual bottom water concentration was slightly greater than the surface water concentration, primarily as a result of sediment phosphorus release to the water column during anoxic periods. The average annual total phosphorus concentration of the eastern basin was slightly higher than that obtained in the western basin. Phosphorus is recycled in the lake (internal recycling) on an annual basis. Phosphorus is released during decomposition of aquatic vegetation and is then taken up by new plant growth thus completing the cycle.

The average annual total phosphorus concentrations of the tributaries, ranked in order from highest to lowest concentration, were Tributary E (0.374 mg/L), Tributary A (0.337 mg/L), Tributary D (0.137 mg/L), Tributary C (0.065

mg/l) and Tributary B (0.060 mg/l). Thus, all of the tributary phosphorus concentrations exceeded the EPA standard of 0.05 mg/l. The concentration present in Tributary B can be considered as a background concentration since this stream drains from a bog system which has not been in use for more than 30 years. The low average concentration exhibited by Tributary C is probably a result of the detention of bog discharges and stormwater runoff in Trask Pond. This contention is supported by the fact that Trask Pond contains an excessive amount of aquatic plant growth and is hypereutrophic. During high flow periods (2/24, 6/22 and 7/21/88), such as floodwater releases, storm events and snow melts, the detention time in the pond is not long enough to allow for adequate tributary phosphorus reduction through sedimentation and plant uptake before discharging to the Billington Sea. Nevertheless, the average total phosphorus concentration present in Tributary C was much lower than those present in the the other three (3) tributaries. The concentrations in tributaries A, D and E were seven (7), three (3) and seven (7) times greater than the maximum concentration recommended by EPA to prevent the nuisance growth of aquatic plants and algae in receiving waters.

Orthophosphate concentrations were measured in the lake and its tributaries on a biweekly basis during the growing season. The in-lake concentration of orthophosphate was consistently low throughout the growing season due to plant uptake. The average concentration present in both lake basins was 0.01 mg/L and never exceeded 0.03 mg/L. The average orthophosphate concentrations present in the tributaries, however, were highly variable. Tributaries B and C exhibited low concentrations which were similar to those in the lake, ranging from less than 0.01-0.04 mg/L and averaging 0.01 mg/L (Figure 18 and Figure 19). These low concentrations were to be expected given the fact that Tributaries B and C drain ponds which exhibit uptake by aquatic plants during the growing season. Tributary D exhibited an average orthophosphate concentration (0.05 mg/L) which was five (5) times as high as the average background tributary concentration and ranged from 0.01 - 0.22 mg/L (Figure 20). Concentrations present in Tributaries A and E were extremely high, averaging 0.23 mg/L and 0.43 mg/L, respectively. These high averages are reflective of sporadic sharp increases rather than consistently high concentrations of dissolved phosphate. Concentrations in Tributary A ranged from 0.04-1.14 mg/L (Figure 21) and in Tributary E ranged from 0.02-4.0 mg/L (Figure 22). Sharp increases in orthophosphate concentrations occurred in Tributary A on four occasions. The highest concentration (1.14 mg/L) was obtained on a dry sunny day (6/8/88) and occurred simultaneously with the highest values of total phosphorus, ammonia-nitrogen and nitrate nitrogen, suggesting runoff from a prior fertilizer application. The three other increases, ranging from 0.20 - 0.27 mg/L, coincide with storm events. The highest orthophosphate concentration obtained in Tributary D was 0.22 mg/L and represented the last flush of the floodwater released following harvesting. Peak total phosphorus and TKN values, consisting predominately of organic nitrogen (plant tissue), were also obtained on this date. A peak orthophosphate concentration of 4.0 mg/L was obtained in Tributary E on July 7, 1988. This value was obtained on a dry, sunny day concurrently with peak total phosphorus and

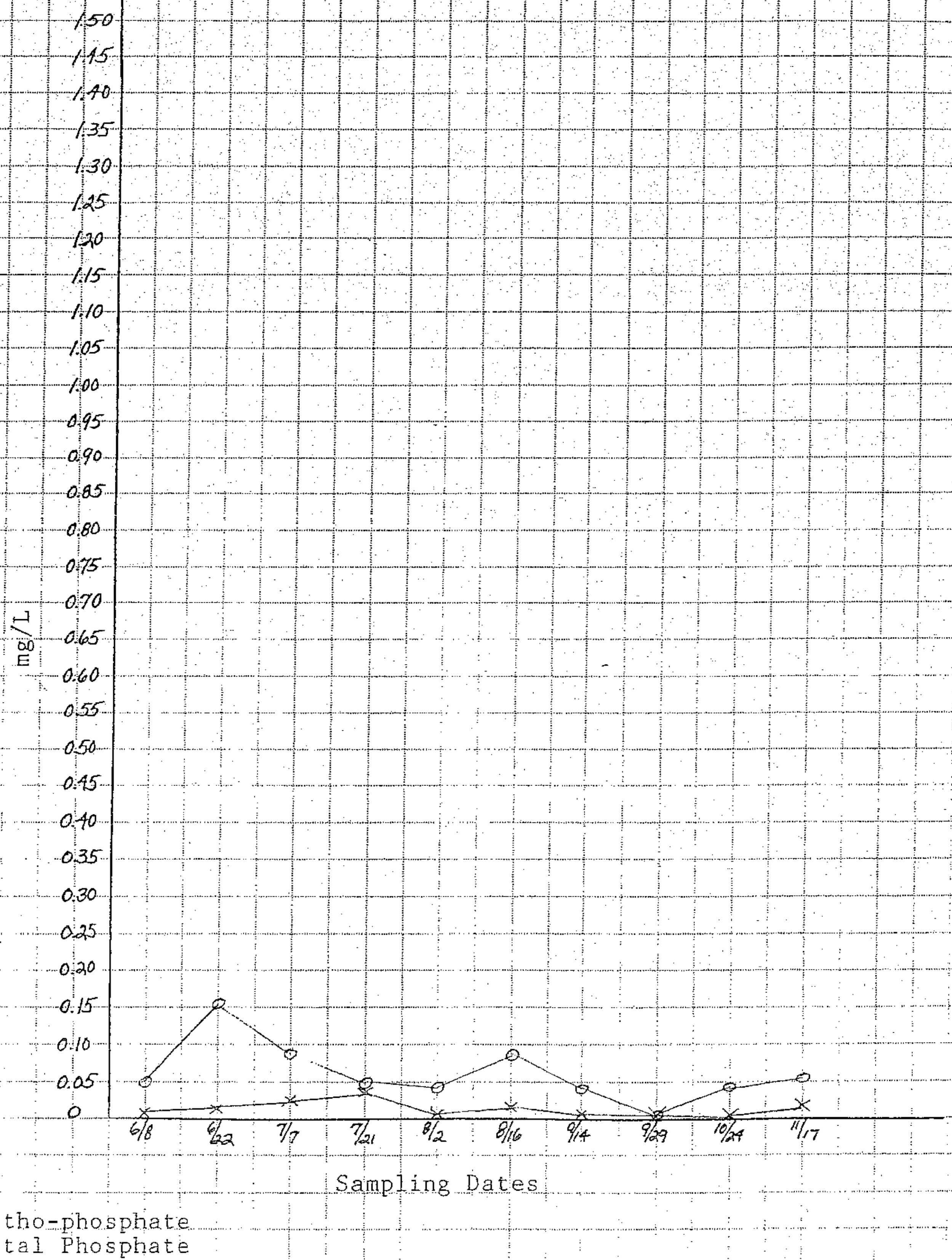


Figure 18. PHOSPHATE CONCENTRATIONS OF BILLINGTON SEA TRIBUTARY B

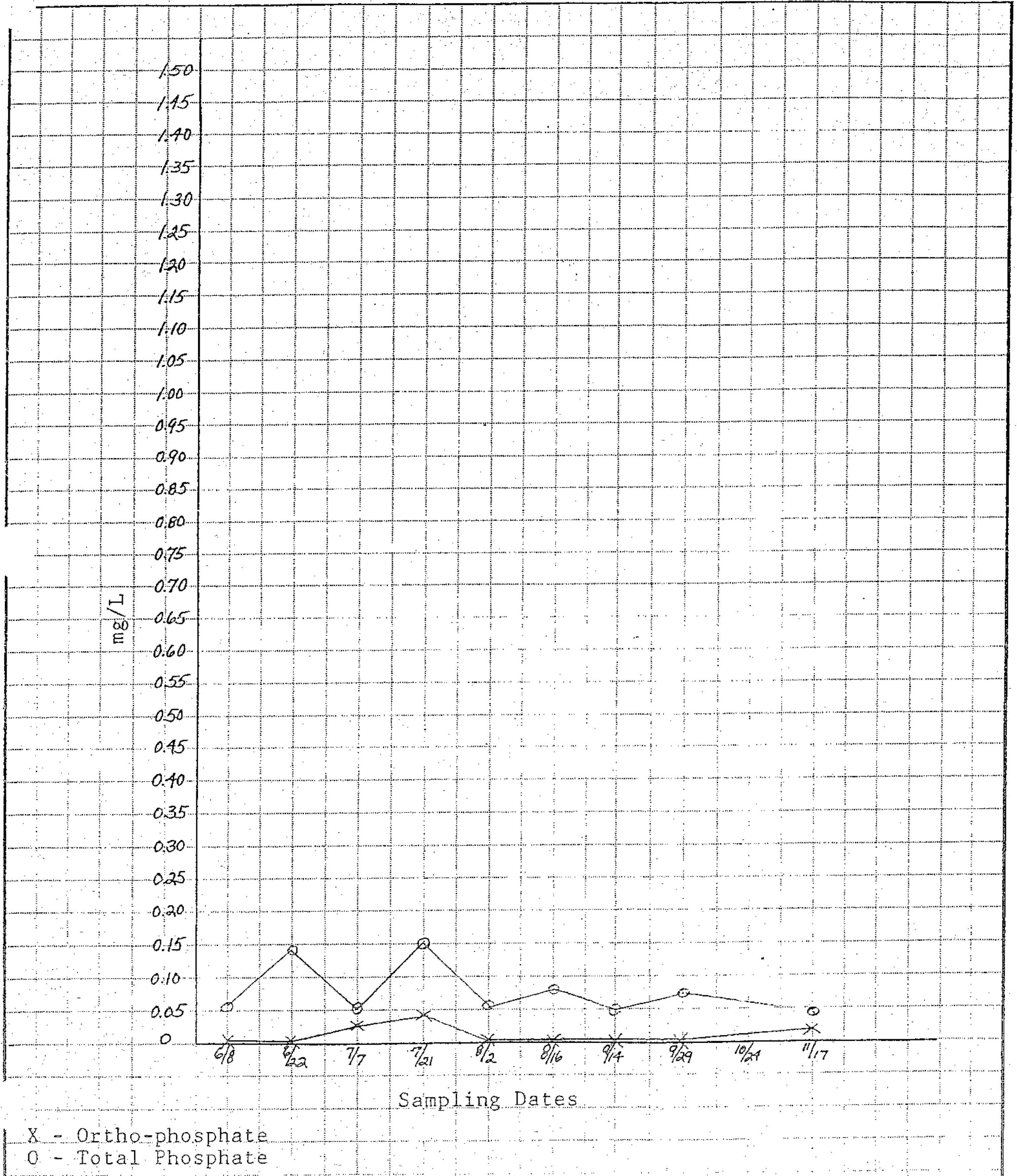
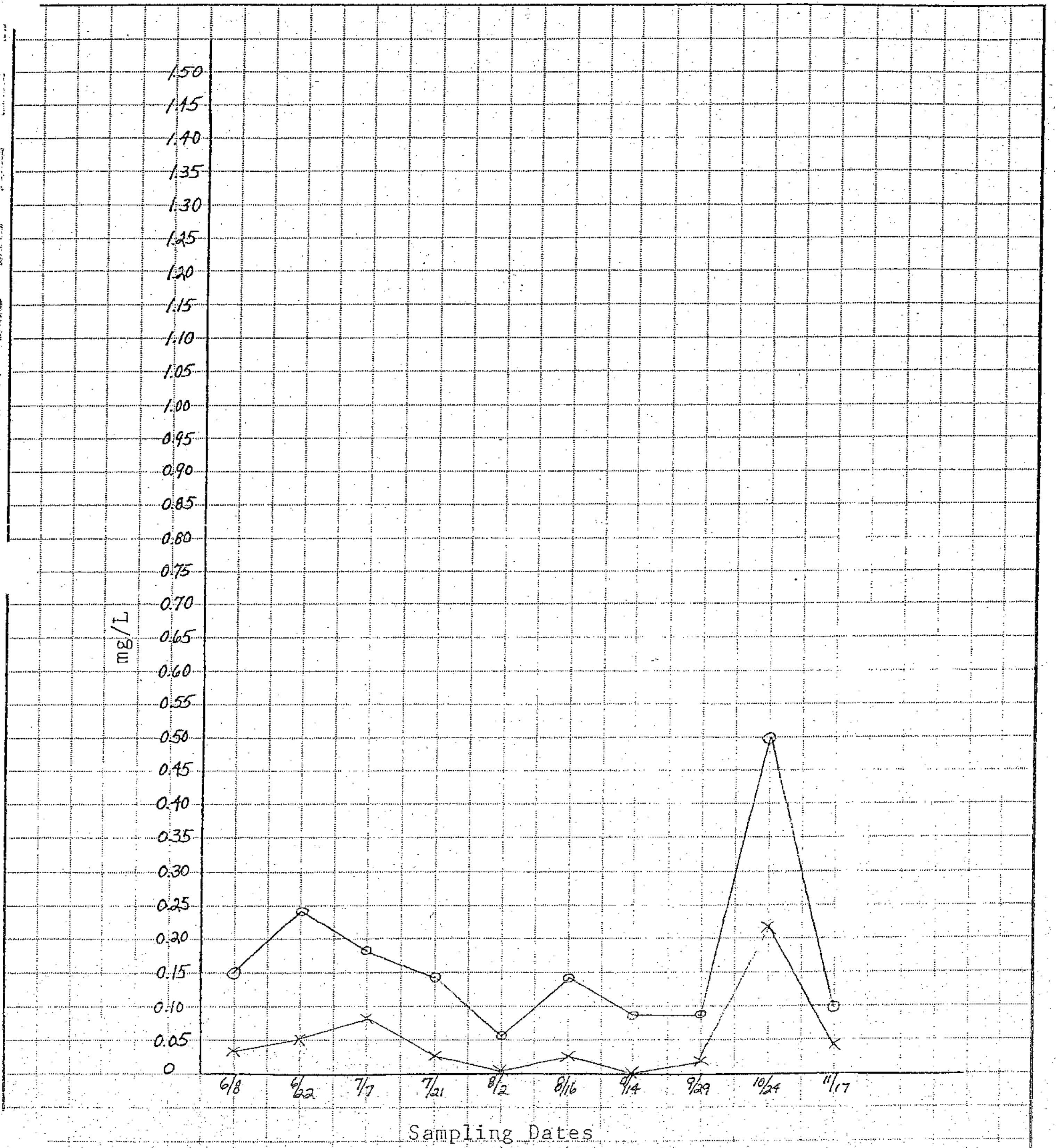


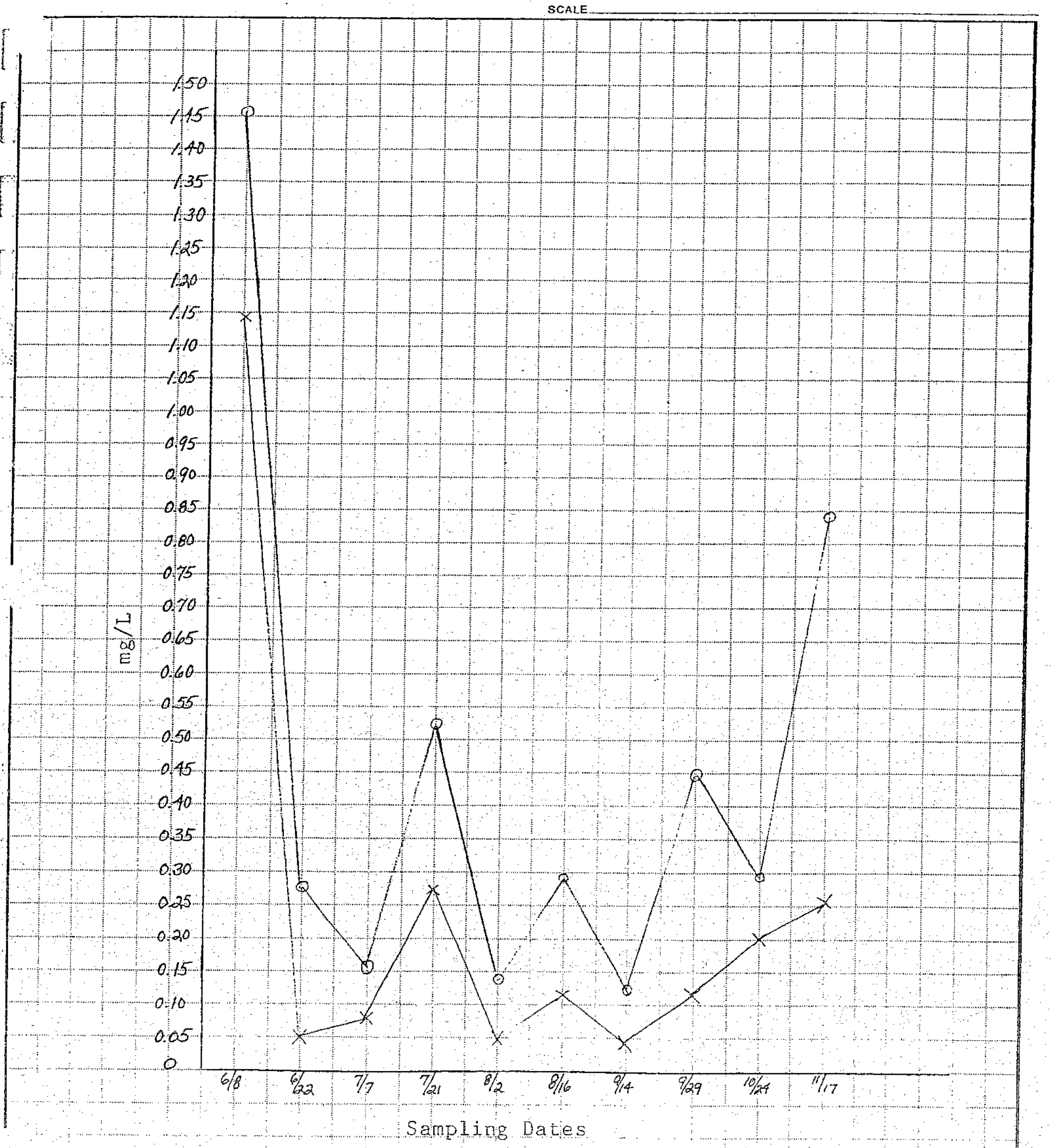
Figure 19. PHOSPHATE CONCENTRATIONS OF BILLINGTON SEA TRIBUTARY C



X - Ortho-phosphate
O - Total Phosphate

Figure 20. PHOSPHATE CONCENTRATIONS OF BILLINGTON SEA TRIBUTARY D

SHEET NO. ______ OF ______
CALCULATED BY ______ DATE ______
CHECKED BY ______ DATE ______
SCALE ______

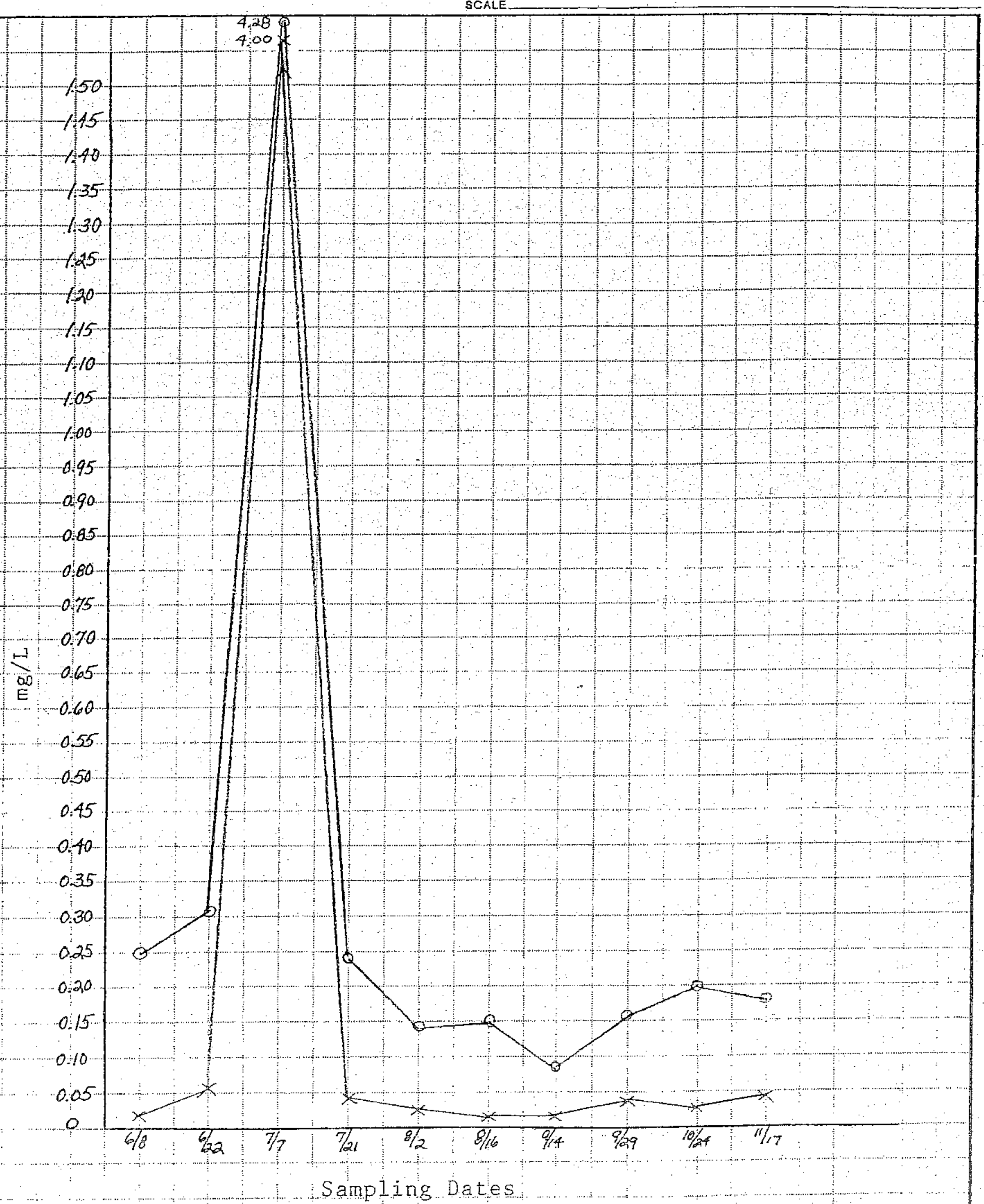


\- Ortho-phosphate
O - Total Phosphate

Figure 21. PHOSPHATE CONCENTRATIONS OF BILLINGTON SEA TRIBUTARY A

GALE ASSOCIATES, INC.
Eight School Street
P.O. Box 21
WEYMOUTH, MASSACHUSETTS 02189-0900
(617) 337-4253

JOB
SHEET NO. OF
CALCULATED BY DATE
CHECKED BY DATE
SCALE



X - Ortho-phosphate
O - Total Phosphate

Figure 22. PHOSPHATE CONCENTRATIONS OF BILLINGTON SEA TRIBUTARY E

ammonia-nitrogen concentrations, also suggesting runoff from a prior fertilizer application. Fluctuations in tributary concentrations of orthophosphate generally coincided with those of total phosphorus.

Nitrogen

Nitrogen cycles in aquatic ecosystems alternate between gaseous and nongaseous organic and inorganic forms. Organic nitrogen, a constituent of plant and animal proteins, can be decomposed by specific types of bacteria to produce inorganic forms of nitrogen which are recycled by plants for growth. Organic nitrogen is converted to ammonia-nitrogen and then to nitrate nitrogen in waters with adequate dissolved oxygen concentrations (aerobic conditions). Both nitrogen forms are utilized by plants and nitrite is the intermediate product which occurs during this nitrification process. The absence of dissolved oxygen levels (anaerobic conditions) causes this cycle to shift to a denitrification process and nitrate-nitrogen is converted to nitrogen gas. Potential sources of inorganic nitrogen loading to the Billington Sea are wastewater, decayed aquatic plant and animal tissues, fertilizers, stormwater runoff and precipitation. Blue-green algae can utilize nitrogen from the atmosphere for growth as well.

The difference between the total Kjeldahl-nitrogen and ammonia-nitrogen concentration is an indication of the organic nitrogen concentration. A comparison of the average concentrations of these two nitrogen forms in the lake indicates a year-round predominance of the organic form. As a result, ammonia-nitrogen concentrations were consistently low throughout the year, averaging 0.012 mg/L in the western basin and 0.011 mg/L in the eastern basin.

Average in-lake nitrate-nitrogen concentrations varied between the two basins. The average concentrations in both basins were high. However, the western basin concentration (0.620 mg/L) was twice as high as that present in the eastern basin (0.305 mg/L). Year-round additions of nitrate from septic systems cause this increase in the western basin. The decrease in nitrate-nitrogen which occurs during the summer, indicates a shift in the limiting nutrient from phosphorus to nitrogen. This nitrogen limitation is particularly evident in the eastern basin, where summer nitrate concentrations are lower because this basin does not receive large amounts of nitrate from wastewater systems during this time period.

Conversely, the average nitrate concentrations of bog Tributaries A (0.175 mg/L), D (0.064 mg/L) and E (0.030 mg/L) were much lower than those in the lake, since the pH of bog soils are generally too acidic for the conversion of ammonium to nitrate to occur. The average concentration present in Tributaries B and C more closely resembled the average in-lake concentrations as a result of the similarity in the nitrogen cycles of eutrophic open water wetlands. In opposition to low average in-lake ammonia concentrations, (0.011 - 0.012 mg/L), bog tributaries exhibited elevated average concentrations of 0.29 mg/L, 0.067 mg/L and 0.338 mg/L for Tributaries A, D and E, respectively. Ammonia concentrations of this magnitude can be chronically, if not acutely toxic to some fish species if a large fraction consists of the un-ionized form. Among non-salmonid fish, 96-hour LC50 values range from 0.14 through 4.60 mg/L for NH3-N (EPA, 1986). These increases in the ammonia concentrations of the bog tributaries during the growing season are probably attributable to runoff from the bogs following fertilizer (ammonium sulfate) applications, as observed in other studies (Teal and Howes, in press). Nitrogen fertilizer applications recommended by the Cranberry Experiment Station are 20-40 lbs/A/yr, depending on yield, growth and bog conditions (Appendices B, E, and F). Under alkaline conditions (pH greater than 9), equilibrium chemistry favors the un-ionized (more toxic) form of ammonia. Except after storm events, alkaline pH values were observed during the summer thus favoring the un-ionizationed form.

2.9 Tributary Water Quality Conditions

The water quality of the five (5) streams which discharge to the Billington Sea were discussed in Sections 2.8 on a parameter-by-parameter basis. Tributaries A, C, D and E drain actively-managed cranberry bogs. Their water quality is primarily determined by cranberry bog management practices (Appendix C), such as water use and fertilizer applications, since these bogs are the source of tributary flow and there is no development upgradient from them within their subdrainage areas. Stormwater runoff from Black Cat Road may also occasionally contribute to poor water quality conditions in Tributaries A, B and C. Tributary B is considered to be representative of background water quality conditions since this tributary drains a pond and an abandoned cranberry bog.

In summary, bog tributary flows are highly variable and dependent on water use practices. Flashboards restrict tributary flow periodically during the winter, when they are installed in the streams in order to flood the bogs for frost protection, and in the fall when the cranberries are harvested. Conversely, highly erosive flows were observed to occur when floodwaters were released. All of the tributaries discharged nutrient-rich water to the Billington Sea throughout most of the year. Concentrations of orthophosphate, total phosphorus, and ammonia present in bog Tributaries A, D and E were at least several times higher than background concentrations of these plant nutrients. Nutrient inputs to Tributary C from stormwaters and bog runoff were substantially reduced by their detention in Trask Pond, and were similar to background levels present in Tributary B. Bog tributaries are also characterized by low pH, dissolved oxygen and alkalinity conditions which can cause direct and indirect impacts to the instream and lake fish communities.

Fluctuations in orthophosphate generally coincided with those for total phosphorus. Peak concentrations of these nutrients generally coincided with the peak ammonia-nitrogen, total phosphorus and occasionally with organic nitrogen concentrations in bog tributaries. The occurrence of these releases during spring and summer dry weather conditions probably represents runoff from the bogs following fertilizer applications. This occurrence during wet weather conditions is probably attributable to nutrient loading from bog runoff and in Tributaries A, B and C from road runoff.

The peak orthophosphate concentration (0.22 mg/L) in Tributary D occurred concurrently with the peak concentration of total phosphorus and organic nitrogen in the last flush of the harvest floodwaters (10-24-88). Peak orthophosphate concentrations of Tributaries A (1.14 mg/L) and E (4.0 mg/L) occurred during dry weather on June 8 and July 7, respectively. On these dates, orthophosphate concentrations peaked concurrently with total phosphorus and ammonia-nitrogen, suggesting fertilizer runoff from these bogs. Elevated orthophosphate concentrations ranging from 0.20 - 0.27 mg/L also occurred in Tributary A concurrently with elevated ammonia-nitrogen and total phosphorus levels on three other occasions (7/21, 10/14 and 11/12). Similar conditions have been shown to occur in bog tributaries following floodwater releases and known fertilizer applications (Teal and Howes, in press; Wagner, in press). It should be noted that tributary sampling was conducted biweekly without prior knowledge of bog applications or water management practices.

Storm events occurred during several of the routine biweekly sampling events. However, composite sampling of the tributaries during 15-minute time intervals was only conducted on July 21 and November 17, 1988. As indicated in Table 23, the tributaries were sampled because base flow levels in Tributaries A, B and C are increased by the discharge of stormwater runoff from bogs and road swales located along Black Cat Road. There are no known storm drains which discharge into the Billington Sea (Plymouth D.P.W., personal communication). Flow-weighted composite sampling was conducted for a cumulative period of two hours in an attempt to sample the first flush through the peak

TABLE 23. BILLINGTON SEA INLET LIMNOLOGICAL DATA - STORM EVENTS

STATION	DATE	FLOW m3/sec.	TEMP oC	DISSOLVED OXYGEN mg/l	pH s.u.	CONDUCT. umhos/cm	ALKAL. mg/l	T K N mg/l	NITRATE mg/l	AMMONIA mg/l	TOTAL PHOSPH. mg/l	CHLORIDE mg/l	SUSPENDED SOLIDS mg/l	FECAL COLIFORM #/100 ml	ORTHO-P mg/l	FECAL STREP. #/100 ml	TURBIDITY ntu	OXYGEN SATUR. %
A	07/21/88	0.033	19.5	4.8	5.1	110		0.94	0.080	0.320	0.530	18.0	10.00	30	0.27	270	1.7	11.0
	11/17/88	0.002	14.0	6.2	5.6	80	8.0	1.60	0.020	0.610	0.840	15.9	27.00	36	0.26	530	5.8	13.0
Average:		0.018	16.8	5.5	5.4	95	8.0	1.27	0.050	0.465	0.685	17.0	18.50		0.27		3.8	12.0
B	07/21/88	0.008	22.5	8.0	6.5	70		0.43	0.110	0.090	0.050	11.2	7.00	1340	0.04	3800	1.7	20.0
	11/17/88	0.024	14.5	8.6	6.1	60	5.0	0.25	0.080	0.010	0.060	13.4	3.00	8	0.02	12	0.5	17.0
Average:		0.016	18.5	8.3	6.3	65	5.0	0.34	0.095	0.050	0.055	12.3	5.00		0.03		1.1	18.5
C	07/21/88	0.020	23.0	4.1	6.3	75		1.60	0.030	0.080	0.150	13.7	32.00	130	0.04	620	1.5	9.5
	11/17/88	0.055	15.0	8.8	6.4	65	7.6	0.50	0.260	-0.010	0.040	12.3	3.00	0	0.02	8	0.4	19.5
Average:		0.038	19.0	6.5	6.4	70	7.6	1.05	0.145	0.035	0.095	13.0	17.50		0.03		1.0	14.5
D	07/21/88	0.122	18.5	4.7	5.3	150		0.73	0.080	0.260	0.140	26.7	21.00	20	0.03	120	3.7	10.0
	11/17/88	0.008	14.5	8.0	6.1	50	12.0	0.45	0.070	0.280	0.100	10.5	7.00	2	0.04	6	2.5	18.0
Average:		0.065	16.5	6.4	5.7	100	12.0	0.59	0.075	0.270	0.120	18.6	14.00		0.04		3.1	14.0
E	07/21/88	0.082	19.5	5.2	4.9	80		0.65	0.030	0.050	0.240	14.8	29.00	300	0.04	940	1.5	12.5
	11/17/88	0.033	14.0	7.5	5.9	50	8.0	0.62	0.050	0.360	0.180	10.5	14.00	10	0.04	650	4.2	17.0
Average:		0.058	16.8	6.4	5.4	65	8.0	0.64	0.040	0.205	0.210	12.7	21.50		0.04		2.9	14.8

Total Precipitation: 7/21/88 - 10.16mm
11/21/88 - 14.00mm

flow. The amount of precipitation deposited during the two-hour sampling period was 10.2 mm on July 21 and 14.0 mm on November 17. Rainfall on July 21 was moderate, but sporadic for the first 1.5 hours and heavy during the last half hour. Rainfall during the November 18 sampling event alternated every 0.5 hours between heavy and light conditions. In general, conductivity and chloride values increased slightly above their annual averages. Dissolved oxygen levels were below their annual average values and the lowest values were associated with the highest values for organic nitrogen and suspended solids. This association suggests that vegetative matter from the bogs is discharged into the tributaries during storm events. Ammonia levels in all of the tributaries exhibited the highest increase above annual average values. Only Tributaries A and C showed increases in phosphorus levels above their annual averages. Overall, Tributary A exhibited the greatest degree of impact from stormwater runoff (Refer to Tables 4 and 5).

2.10 Macrophyton

A survey of the macrophyton community, (plants visible to the naked eye) was conducted in the Billington Sea during the first week of September, 1988. The results were similar to a survey conducted two years prior (DWPC, 1986). As a result of the overall shallowness of the basins, most of the lake bottom constitutes suitable macrophyton habitat. As indicated in Figure 23, most of the western basin (90%) and approximately (15%) of deeper eastern basin are covered by dense vegetative growth. The densest growth occurs in the shallow coves and in the western basin, from the shoreline out to approximately the two (2) meter contour line of the lake bottom. A patch of dense emergent vegetation (plants

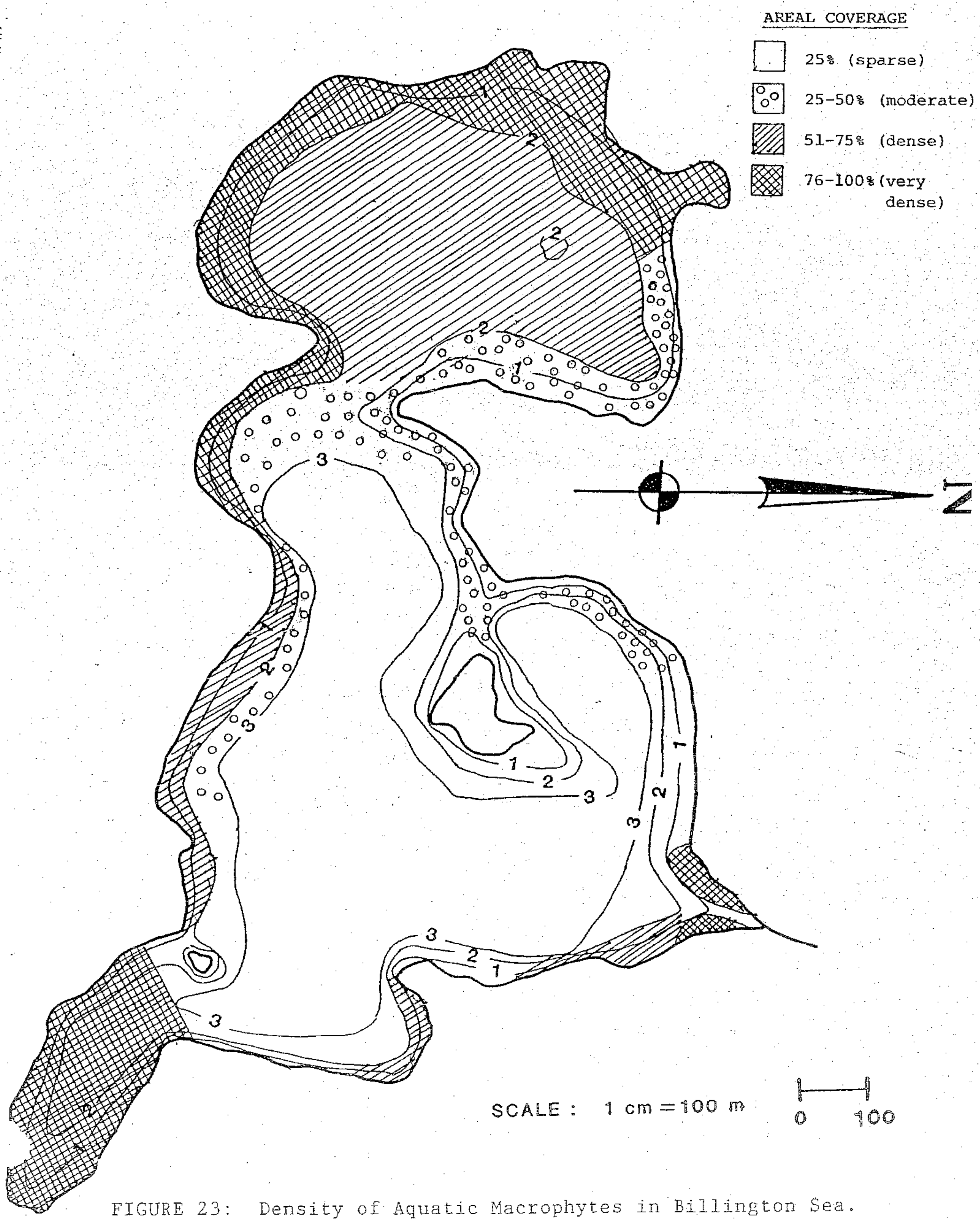
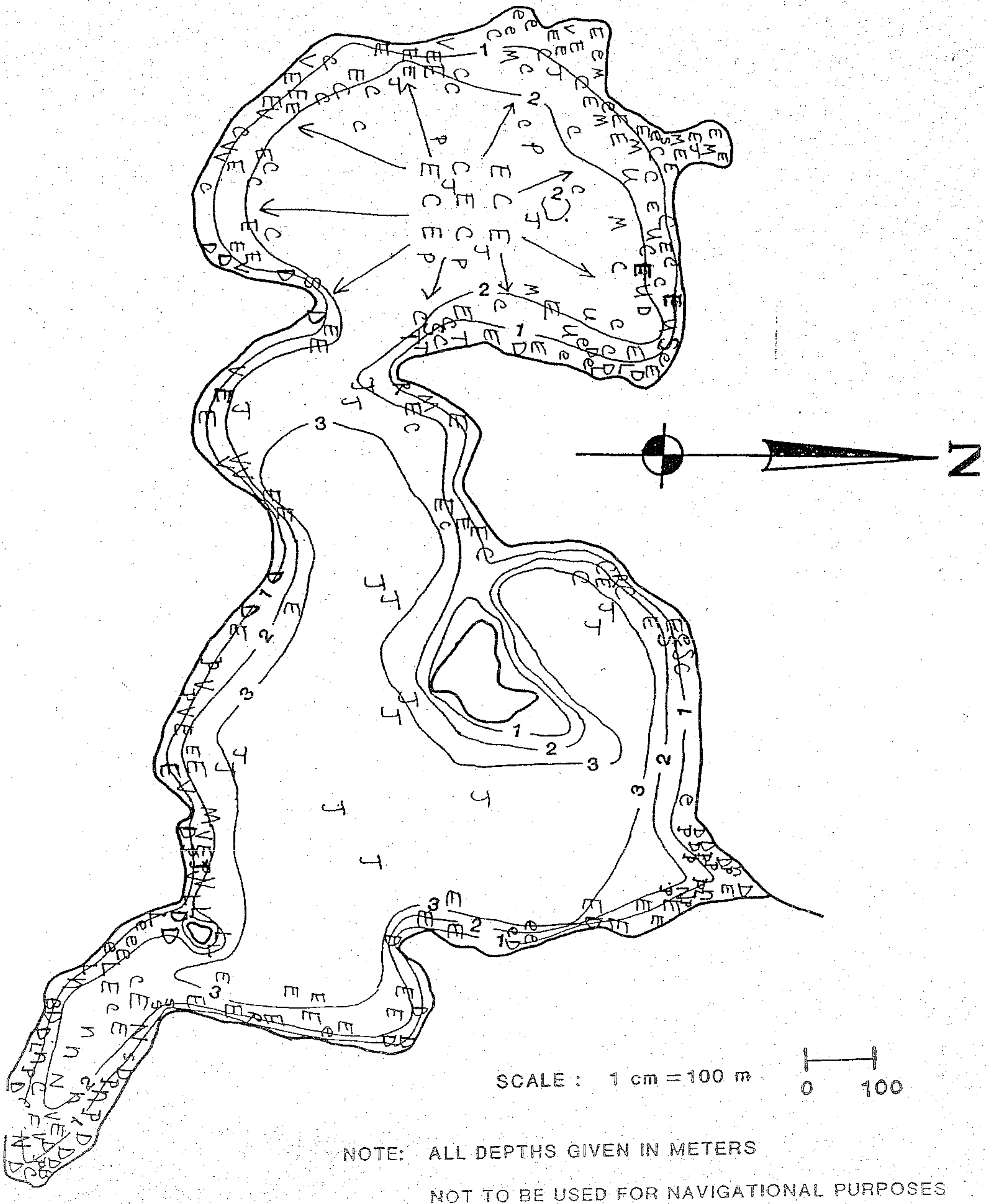


FIGURE 23: Density of Aquatic Macrophytes in Billington Sea.

which grow above the water in shallow areas) is also present along either shore of the lake outlet. As discussed in Section 2.14, these densely vegetated areas are underlain by nutrient-rich, organic sediments which are available for plant uptake through their root systems. Macrophytic growth in the predominant bathing (Hathaway Point) and boat launching areas is only moderate, ranging from 25-50% density. Most of the eastern basin is only sparsely (less than 0-25%) vegetated. Since most of this basin is greater than three (3) meters deep, plant growth is more likely to be controlled by light limitation, particularly during the summer when dense algal blooms occur.

The species distribution of aquatic macrophytes in the lake is shown in Figure 24 and their frequency of occurrence is presented in Table 24. Although the species diversity was greater for emergent rather than submergent plants (plants which grow underwater), the latter category is far more prevalent in the lake and exhibits denser growth. As reported in 1978 (Lyons and Skwarto, 1978), the dense growth of Elodea canadensis (Waterweed) and Ceratophyllum demersum (Coontail) still occurs in the western basin at densities which create a nuisance to lakeshore residents. Although submerged aquatic plants may be utilized by waterfowl and aquatic organisms as spawning habitat, food and cover, the dense coverage which currently exists may cause a shift in the fish community structure. A predominance of panfish, may result, since these fish would be provided with vegetative cover and less visible to predatory gamefish. As

Figure 24. Distribution of Aquatic Macrophytes in the Billington Sea



SCALE : 1 cm = 100 m

NOTE: ALL DEPTHS GIVEN IN METERS

NOT TO BE USED FOR NAVIGATIONAL PURPOSES

Table 24. Frequency of occurence of aquatic macrophyton in the Billingt
Sea (September 6 and 7, 1988).

		* Occurrence Frequency			
Map Code	Species (Common Name)	0-25%	25-50%	51-75%	76-100%
	Submergent Plants				
E	Elodea canadensis (Waterweed)				X
C	Ceratophyllum demersum (Coontail)				X
P	Potamogeton sp. (Pondweed)	X			
M	Myriophyllum sp. (Milfoil)	X			
U	Utricularia sp. (Bladderwort)		X		
J	Najas sp. (Naiad)	X			
	Emergent Plants				
B	Cephalanthus occidentalis (Buttonbush)	X			
S	Sparganium sp. (Burreed)	X			
R	Juncus sp. (Rush)	X			
e	Eriocaulon septangulare (Northern Pipewort)		X		
D	Decodon verticillatum (Water Willow)		X		
p	Pontederia cordata (Pickerelweed)		X		
s	Scirpus sp. (Bulrush)	X			
V	Eleocharis sp. (Spikerush)	X			
T	Typha sp. (Cattail)	X			
L	Chamaedaphne calyculata (Leatherleaf)		X		
	Floating-leaved Plants				
N	Nymphaea odorata (White Water Lily)	X			
n	Nuphar sp. (Yellow Water Lily)	X			

*Number of times observed/total number of observations previously mentioned, this basin is very shallow, rich in organics and nutrient-laden sediment, and is supplied with a constant subsurface inflow of phosphorus and nitrogen from septic systems. Another reason for the success of Elodea sp. and Ceratophyllum sp. may be their ability to reproduce by fragmentation. The motorboat cutting action of propellors operated in the shallow western basin probably aids to increase submergent plant biomass through fragmentation. Although Elodea sp. stems are generally rooted, both species may be found free-floating, allowing for a cosmopolitan range of distribution. Utricularia sp. is also free floating.

Emergent plants tend to grow in stands along the lakeshore since they generally reproduce from seeds and root stocks. They do not usually grow in areas of the lake which are deeper than one meter. Their distribution in the Billington Sea is patchy, but encompasses most of the shoreline. Many of these plant types are utilized by waterfowl for food and nesting. These emergent plants are beneficial at the low densities which they occur in the lake and do not encourage large flocks of waterfowl. Furthermore, their root systems act as lakeshore stabilizers and protect it from erosion. The dense growth of the emergent plants Decodon verticillatum (Water Willow) and Pontederia cordata (Pickerel weed) along either side of the outlet, however, should be managed to allow maximum flushing of the lake.

The third group of aquatic plants, the floating-leaved plants, consist predominantly of water lilies which are rooted by strong, thick tubers to the mucky pond bottom. These plants can become a nuisance at high densities, but their distribution in the lake is limited to the shallow, nutrient-rich southeastern cove and along the lake outlet. In summary, aquatic macrophytes form an essential component of the lake ecosystem by providing spawning habitat, food and cover for waterfowl, fish and other aquatic organisms. An overabundance of plant growth, however, is not only viewed as a nuisance by lakeshore residents and other lake users, but may also lead to poor water quality and an imbalance in the fish community structure. Nutrient releases from the microbial decay of dense beds of submergent plants growing in the western basin are contributing to the algal blooms which occur in the lake each summer. The low dissolved oxygen levels which are also occuring as a result of this process may cause fish kills in the future. Therefore, management and not eradication of vegetative growth is necessary to restore and maintain the desired uses of the Billington Sea.

2.11 Fisheries

As a result of its shallowness, summer water temperatures in the Billington Sea are too high to support a healthy year-round population of coldwater fish. However, the lake does support a diverse year-round warmwater fishery. Additionally, the lake serves as spawning habitat for alewives which migrate upstream through Town Brook each spring (DiCarlo and Reback, 1970).

A 1956 report by the Massachusetts Division of Fisheries and Wildlife (MDFW, 1982) indicated that the following numbers of fish were stocked in the lake between 1905 and 1951: 10,253 smallmouth bass, 100 largemouth bass, 6,600 hornpout, 1,380 bluegills, 60 sunfish, 218 black crappie, 1,522 brook trout and 5,140 yellow perch. There is no record of fish stocking since 1951 (Joe Bergen (MDFW), personal communication) other than with alewife (Joseph DiCarlo (DMF), personal communication). Since the repair and reconstruction of several of the Town Brook fish ladders has been conducted by the MA Division of Marine Fisheries (DMF). Division personnel stocked the lake in 1988 with 1,200 river herring (alewives and bluebacks).

A fishery management plan, focused on increasing the abundance of largemouth bass, yellow perch and chain pickerel, was adopted by the MDFW during the 1950's. Fyke nets and the chemical rotenone were used in 1952 to remove an over abundance of white suckers, golden shiners, bluegills and pumpkinseed sunfish. Fish netted and returned during these operations, in order of abundance by weight, were: yellow perch, brown bullhead, white perch, smallmouth bass, and chain pickerel. A ban which prohibited ice fishing prior to 1950 was removed when a 1955 creel census of 132 fishermen indicated that chain pickerel exhibited rapid growth rates, averaging 20 inches in length. Furthermore, winter fishing pressure on yellow perch was viewed as beneficial in reducing the size of the panfish community.

Electrofishing gear and fyke nets were used to determine the effects of herbicide and algicides, applied in 1970, on the species composition and abundance of the Billington Sea fish community. The results of the fyke net survey, presented in Table 25, indicate a shift in community structure from a pre-treatment codominance of white perch and pumpkinseed

Table 25. Abundance of fish species captured by fykenet in the Billington Sea prior to and following the 1970 applications of copper sulfate and sodium arsenite.

Fish Species	Pre-Treatment Abundance	Post Treatment Abundance
Smallmouth Bass	35	36
Chain Pickerel	6	20
White Perch	1,205	454
Yellow Perch	735	822
Bluegill	270	355
Pumpkinseed Sunfish	545	1,219
Brown Bullhead	224	252
White Sucker	304	926
Golden Shiner	351	8
American Eel	23	34

NOTE: Twelve (12) largemouth bass were collected by electro-shocking prior to treatment.

sunfish to a post-treatment dominance of sunfish. A post-treatment decrease in the relative abundance of white perch and golden shiner and an increase in the relative abundance of white suckers and pumpkinseed sunfish was also evident. Smallmouth bass and chain pickerel each composed less than one percent (1%) of the relative abundance of the pre- and post-treatment fish community at this time. The 1970 report also noted the occurrence of a large fish kill in early September. It is possible that this fish kill occurred as a result of oxygen depletion in the water column which was attributable to the rapid microbial decomposition of algae and aquatic plants following the chemical applications. These applications may have also impacted the fish community indirectly, by reducing the abundance of the food sources of some species. As indicated in Table 26 the post-treatment abundance of zooplankton was nearly eradicated.

Follow-up surveys of the fish community were conducted on August 29 and 30, 1978 (MDFW, 1978) and on July 12, 1982 (MDFW, 1982). The 1978 survey results indicated the existence of a balanced fish population and stated that pumpkinseed sunfish were the most abundant species. Yellow perch declined in relative abundance since 1970 and exhibited reduced growth rates. The white perch population, however, experienced an increase in relative abundance and a reduction in growth rate. The growth rate of chain pickerel was above average and that of largemouth bass was below average for the I-III year classes. Older year classes exhibited above average growth rates. The population stock density (P.S.D.) of largemouth bass was 44%, indicating a low to moderate angler harvest. The management recommendations were to resurvey the lake in five (5) years

Table 26. Invertebrate Benthic Animals Collected in Billington Sea, Plymouth, During 1970, Before and After Sodium Arsenite Application.

	Number of Organisms Collected									
	Pre-treatment					Post-treatment				
	4/30 5/8	5/26	6/15	7/10	Total	8/4	8/24, 25, 26	9/17	11/4	Total
Class Turbellaria										
Other			1*		1					
Tricladida (planarian)		3	13	16	32	23	34			57
Class Oligochaeta										
Other				1*	1					
Plesiopora (Tubifex)	16	57	27	41	141	52	6	2	21	81
Class Hirudinea										
Rynchobdellida (leech)		69	3	62	134	47	25	8	5	85
Class Gastropoda										
Bosmatophora (snail)										
Other							1*			1
Lymnaeidae		19	24	11	54	25	40	14	18	97
Planorbidae		8	9	5	22	16	7			23
Class Pelecypoda										
Eulamellibranchia (mussel)										
Margaritanidae				4	4	5				5
Sphaeriidae	1	11	5	3	20	6	9	2	9	26
Class Crustacea										
Cladocera (water-flea)	1	1	10		12					
Isopoda (Asellus)	5	20		9	34					
Amphipoda (Gammarus)	24	105	113	42	284	1				1
Class Insecta										
Ephemeroptera (May-fly)	3	4	36		43			1		1
Odonata										
Anisoptera (dragon-fly)		6	6		12		1			1
Zygoptera (damsel-fly)		6	2		8			2	10	12
Trichoptera (caddis-fly)	2	2	6	1	11	4	2			6
Coleoptera (beetle)		2			2		1			1
Diptera										
Other		7		1	8			1*	1*	2
Chironomidae (midge)	11	22	32	23	88	11	1	4	150	166
Class Arachnida										
Acarina (water-mite)		2	6		8			4		4
	63	344	293	219	919	190	127	38	214	569

*one sp. unknown

in order to check the P.S.D.of largemouth bass and determine whether the white perch became stunted.

Table 27 presents a synopsis of the 1978 and 1982 survey results for the percent by number and percent by weight of fish species. Although dominant in 1978, no pumpkinseed sunfish were caught in the 1982 sample. Although gillnets, electrofishing gear and a rod and reel were used during this sampling event, the division attributes this result to a poor sunfish sample. The largemouth bass population exhibited an increase in percent by weight and number. The population remained balanced and was characterized by a P.S.D. value of 53%. Bass growth rates were above average and their condition factor was average. The success of the bass population was attributable to an increase in abundance of golden shiners, a bass forage fish. Overall, white perch comprised 48.5% of the total fish population by number and 26.4% by weight. Their growth rates were below the Massachusettes average. Although the growth rate of chain pickerel remained good, this species exhibited a decline in abundance since 1978. The management recommendations in 1982 were relative to resurvey the lake in four (4) years in order to determine whether the white perch reach harvestable size (8-10 inches) or become stunted, to check the largemouth bass P.S.D., recheck the abundance of the pickerel and sunfish populations, and to consider installing artificial cover near the shoreline for the bass population. Although a 1987 follow-up survey was conducted by the MDFW, a report has not yet been generated (Joe Bergen (MDFW), personal communication). The Division catagorizes the Billington Sea as a moderate priority per fisheries surveying and management in comparison to the other 2,500

Table 27. Species composition and percent by weight and number of fish collected from the Billington Sea in 1978 and 1982.

	Percent (%) by Number		Percent (%) by Weight	
	1978	1982	1978	1982
Largemouth Bass	8.8	20.8	22.6	52.1
Smallmouth Bass	----	1.5	----	3.0
Chain Pickerel	16.9	1.5	12.6	3.3
Pumpkinseed Sunfish	27.7	----	10.2	----
Bluegill	7.7	0.5	5.9	0.06
Yellow Perch	8.6	10.9	2.8	3.9
White Perch	24.6	48.5	18.7	26.3
Golden Shiner	2.6	12.9	3.1	7.9
White Sucker	1.8	----	21.2	----
Brown Bullhead	1.2	3.5	2.9	3.5

lakes that are managed by the division. Therefore, the lake's fish community is only likely to be surveyed every ten (10) years. In lieu of this fact, the Division offered the following general recommendations:

1. Encourage the "catch-and-release" of gamefish species (chain pickerel and largemouth bass).

2. Initiate a panfish derby to reduce the abundance of white perch, perhaps involving the elementary school system (the MDFW's "Aquatic Education Program" may be a good resource).

2.12 SEPTIC LEACHATE SURVEY (See Figure 25)

In porous soils, ground water inflows frequently convey wastewaters from nearshore septic units through bottom sediments and into lake waters, causing attached algae growth and algal blooms. The lake shoreline is a particularly sensitive area since: 1) the ground water depth is shallow, encouraging soil water saturation and anaerobic conditions; 2) septic units and leaching fields are frequiently located close to the water's edge, allowing only a short distance for bacterial degradation and soil absorption of potential contaminants: and 3) the recreational attractiveness of the lakeshore often induces temporary overcrowding of homes leading to hydraulically overloaded septic units.

Rather than a passive release from lakeshore bottoms, ground water plumes from nearby on-site treatment units may actively emerge along shorelines, raising sediment nutrient levels and creating local elevated concentrations of nutrients. The contribution of nutrients from subsurface discharges of shoreline septic units has been estimated at 30 to 60 percent of the total nutrient load in certain New Hampshire lakes (LRPC, 1977). Kerfoot and Skinner first used fluorometry to detect lakeshore sewage plumes (1981). Further independent verification of the usefulness of fluorescent analysis was provided by Jourdonnais and Stanford, (1985).

The capillary-like structure of sandy soils and horizontal ground water movement induces a fairly narrow plume from malfunctioning septic units. The point of discharge along the shoreline is often through a small area of lake bottom, commonly forming an oval-shaped area several meters wide when the septic unit is close to the shoreline. In denser subdivisions containing several overloaded units, the discharges may overlap forming a broader increase.

Ground Water Plumes

Three different types of ground water-related wastewater plumes are commonly encountered during a septic leachate survey: 1) erupting plumes, 2) passive plumes, and 3) stream source plumes. As the soil becomes saturated with dissolved solids and organics during the aging process of leaching on-lot septic system, a breakthrough of organics occurs first, followed by inorganic penetration (principally chlorides sodium, and other salts). The active emerging of the combined organic and inorganic residues into the shoreline lake water describes an erupting plume. In seasonal dwellings where wastewater loads vary in time, a plume may be apparent during late summer when shoreline cottages sustain heavy use, but retreat during winter during low flow conditions.

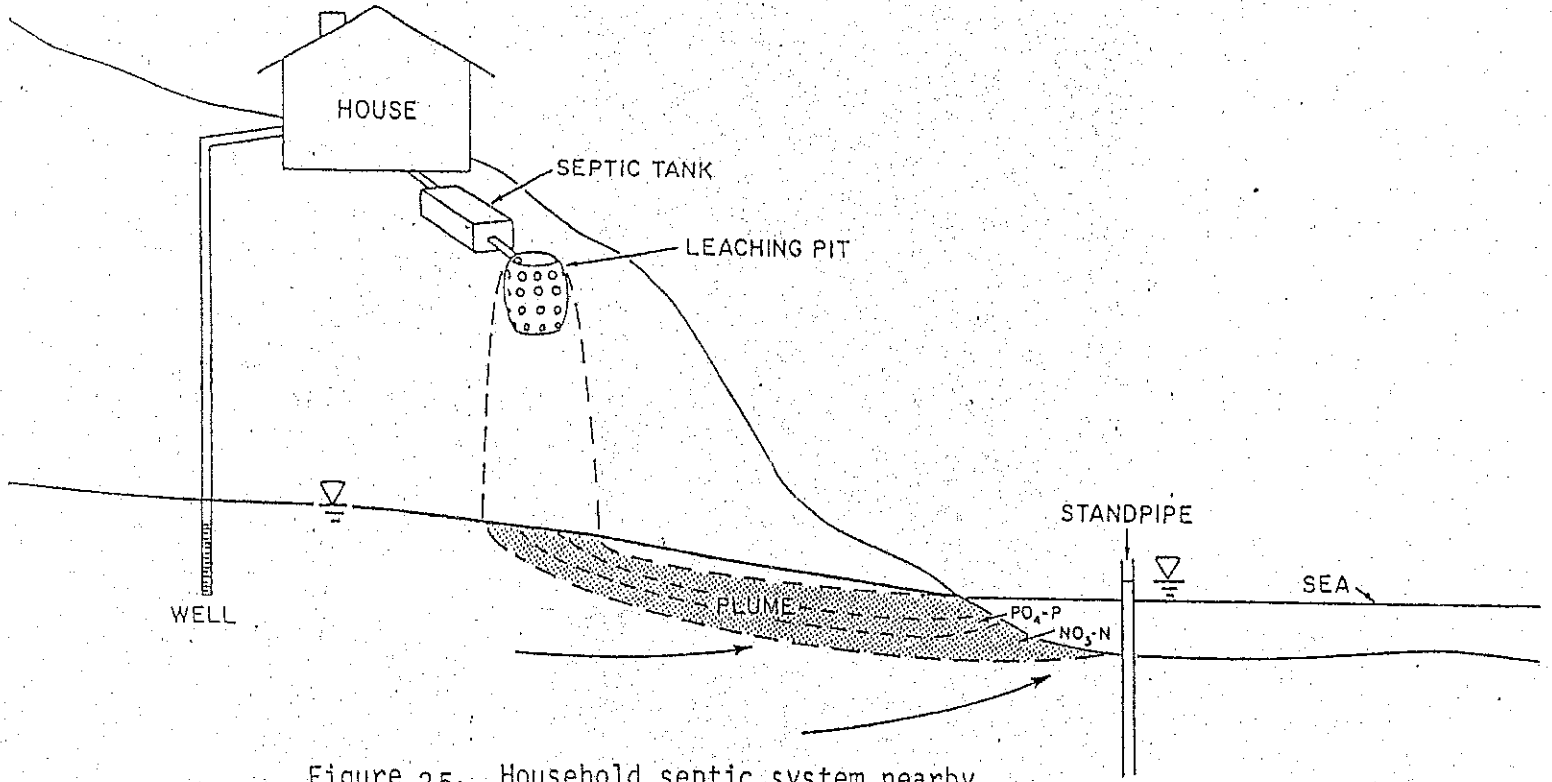


Figure 25. Household septic system nearby Billington Sea.

Residual organics from the wastewater often still remain attached to soil particles in the vicinity of the previous erupting plume, slowly releasing into the shoreline waters. This dormant plume indicates a previous breakthrough, but sufficient treatment of the plume exists under current conditions so that no inorganic discharge is apparent. Stream source plumes refer to either ground water leachings or near-stream septic leaching fields which enter into streams which then empty into the lake.

Runoff Plumes

Traditional failures of septic systems occur in tight soil conditions when the rate of inflow into the unit is greater than the soil percolation can accomodate. Often leakage occurs around the septic tank or leaching unit covers, creating standing pools of poorly-treated effluent. If sufficient drainage is present, the effluent may flow laterally across the surface into nearby waterways. In addition, rainfall or snow melt may also create an excess of surface water which can wash the standing effluent into water courses. In either cause, the poorly treated effluent frequently contains elevated fecal coliform bacteria, indicative of the presence of pathogenic bacteria and, if sufficiently high, must be considered a threat to public health.

Special Survey Technique and Equipment

Wastewater effluent contains a mixture of near-UV fluorescent organics derived from whiteners, surfactants, and natural degradation products which are persistent under the combined conditions of low oxygen and limited microbial activity. The aged effluent percolating through sandy loam soil under anaerobic conditions reaches a stable ratio between the organic content and chlorides which are highly mobile anions. It is this stable ration (conjoint signal) between flourescence and conductivity that allows ready detection of leachate plumes by their conservative tracers. Such identified plumes are an early warning of potential nutrient breakthrough or public health problems. The septic leachate detector utilizes this principle.

Septic surveys for shoreline wastewater discharges are conducted with a septic leachate detector, ENDECO R Type 2100 "Septic Snooper TM" or KVA Model 15 "Peeper Beeper", and the KVA Model 30 Ground Water Flow Meter.

The leachate detector can be operated out of any small boat. It consists of the subsurface probe (water intake system), the analyzer control unit, and an analog stripchart recorder. Initially the unit is calibrated against incremental additions of wastewater effluent of the type to be detected to the background lake water. Nationwide studies have indicated that a mixed effluent from a wastewater plant within the survey area receiving primarily domestic effluent represents the most "average" effluent for calibration (Krause and Peters, 1979). Because of differences in background water supplies and domestic products, the amplitude of conductance and fluorescence changes with geographic area. After calibration, the pump end of the probe unit is submerged in the lake water along the near shoreline. Ground water seeping through the shoreline bottom is drawn into the screened intake of the probe and travels upwards to the analyzer unit. As it passes through the analyzer, separate conductivity and fluorescence signals are genreated. The responses are sent to the signal processor which registers the separate signals on a stripchart recorder as the boat moves forward. The analyzed water is continously discharged from the unit back into the receiving water. The battery-powered unit used for field studies can record individual fluorescence and conductivity or a combination signal. It has been modified to operate under the conductivity conditions encountered in the field.

At locations of observed discharges, small water samples are taken and retained for later laboratory fluorescence. Here a fluorescent scan is employed to segregate "septic discharges from bog" discharges. The wastewater sample is "fingerprinted" and compared to peak locations observed around the lake. The relative magnitude is indicated by mapping in Figure 26 .

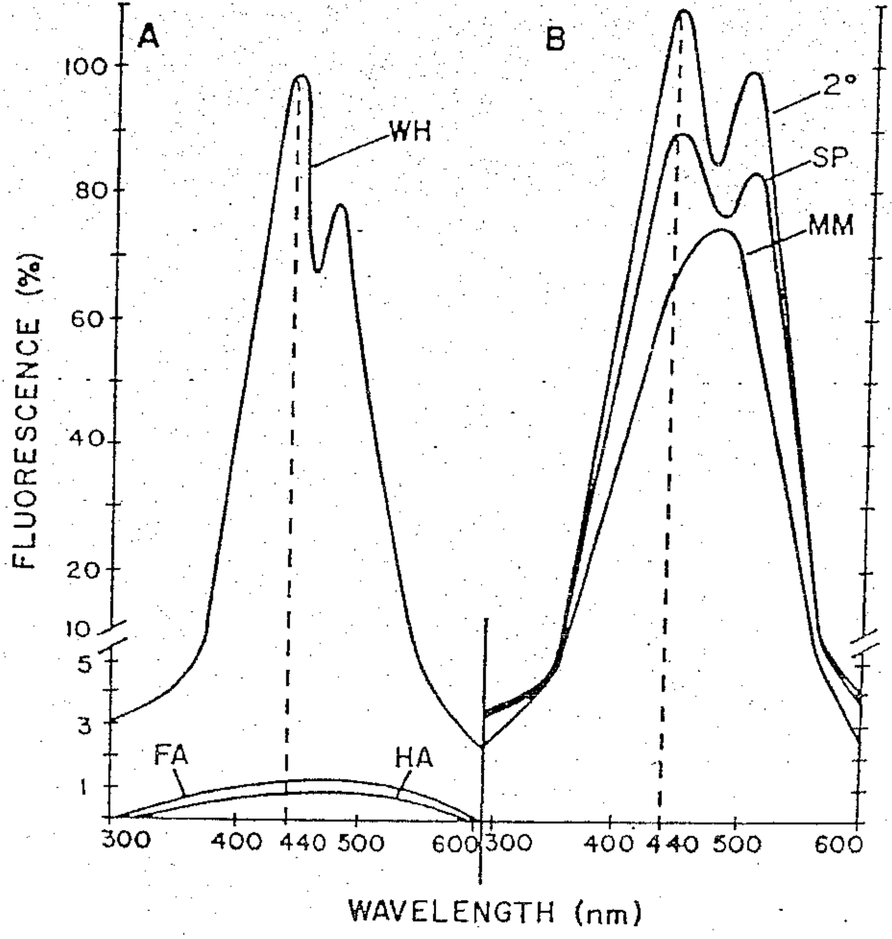


Figure 26. A, Spectral fluorescence pattern for .1 mg/l solutions of purified whitener (WH), fulvic acid (FA) and humic acid (HA). B, Spectral fluorescence patterns observed in samples of secondary sewage (2^{o}), samples from a seep in Big Arm Bay (SP), and samples from a humus bog (MM). In both A and B maximum fluorescence occurred at 440 nm.

Results of Septic Survey

The septic leachate survey identified two major types of plume discharges into the Billington Sea water system: on-site septic system ground water plumes and bog discharges (both surface and ground water). Table 28 shows the results of the survey taken by K-V Associates. Isolated groundwater septic plumes were found around the western and southern Billington Sea (Figure 27). No traditional failures (overflows) were observed. A large number of bog discharges were indicated for the sea region, predominantly on the southern shore.

Several locations along the Billington Sea shoreline showed increased levels of organics, generally without a corresponding conductivity rise. Fluorescent scanning of water samples indicated a bog origin. Some of these sites were not sampled for bacteria or nutrient levels because either the intensity of the reading was not high enough or scanning fluorescence analysis in the lab indicated that they were not septic in origin.

On the western shoreline, septic systems do appear to have a substantial impact on the shoreline. Seasonal heavy vegetative regrowth occurs each summer. Previous sampling of private wells and plume observations show that nitrogen readily penetrates the lakeshore at concentrations up to 10 ppm. The observed high concentration of phosphorus (8 ppm) and nitrogen (5 ppm) during late summer which disappears during late fall likely reflects the high groundwater velocities and summer seasonal loadings. Particularly nitrogen in the form of nitrate - N may readily penetrate the lake bottom deposit. There is some possibility that the shoreline is nitrogen - limited, despite the overall lakewide phosphorus - limited condition. Phosphorus may be released from the lake sediment deposits, combining with the groundwater nitrogen, to result in substantial vegetative growth.

TABLE 28. Sampling Results of Groundwater (g) and Surface Water (s) obtained at locations of observed discharges.

STATION #	CONDUCTIVITY (µmhos/cm)	NO3-N (mg/l)	NH4-N (mg/l)	TP (mg/l)	TC (Counts per 100 ml)	FL	SOURCE
# 1g	140	3.09	.35	8.90	-	-	S
2g	102	1.22	.63	5.36	-	-	S
3g	110	.94	.22	2.58	-	-	S
4s	180	2.35	BDL	.077	-	-	S
4g	180	2.38	BDL	.018	-	-	S
5s	100	1.31	.22	.073	-	-	S
5g	100	1.54	BDL	.021	-	-	S
6s	100	.70	.17	.058	-	-	-
6g	180	0.92	BDL	.022	-	-	-
Standpipe	110 (146)	.58	BDL	.033	-	-	-

BDL - Below Detection Limit

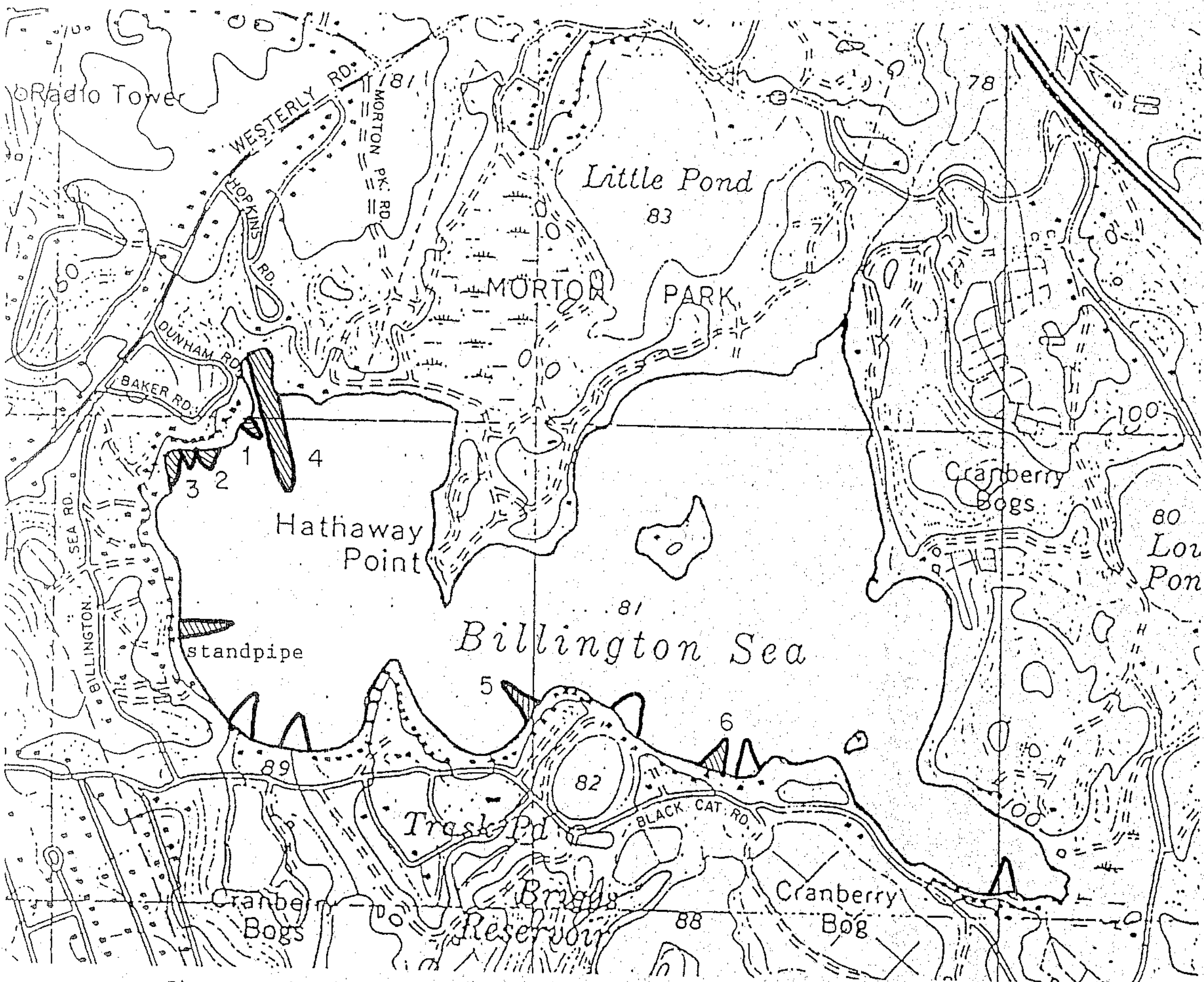


Figure 27 Septic leachate (shaped) and bog (clear) plumes observed around Billington Sea.

2.13 INVENTORY OF ON-SITE WASTEWATER DISPOSAL PRACTICES

An inventory of on-site wastewater and land use practices was conducted for households within 300 meters of the Billington Sea. The questionnaire included the following information:

a. Type of system
b. Distance of system from shoreline
c. Number of occupants per unit
d. Number of days unit is used per year i.e. seasonal (s), vs year round (yr)
e. Age of system
f. Types of appliances used
g. types of additives used
h. Lawn area
i. Type and frequency of lawn fertilizer application

The survey was conducted during August 1988, and January, 1989.

Over 34 homes were visited along the shoreline of Billington Sea with an on-lot survey of septic systems and lawns. (Table 29). Although there was some reluctance of residents to fully answer the questionnaires, most lakeshore owners were vocally supportive of efforts to improve the quality of the sea. Of course, most homes (60%) interviewed during winter were year-round residents. Roughly 40% of the homes are seasonal (7 of the first 16), indicating a progressive change from seasonal cottages to year-round occupancy. In a number of cases, the homes have risen from hunting blinds or summer shacks to two story buildings.

Many of the homesites, even though horizontally close to the water; between 15 and 200 ft., exist at some elevation above the sea (10-35 ft). Flooding of homes or basements is unusual. The average septic system age was 28 years, with older units being cesspools while recently-built homes contained the septic tank-leaching pit combination required by the Title V sanitary code. A number of the residents do annual maintenance pumping of the septic systems.

The average occupancy was 2.3 persons per dwelling for year-round residents. Since seasonal occupancy is significant, even though 6 persons/dwelling is not uncommon, only a 3 month habitation leads to roughly 2 persons per dwelling.

TABLE 29.ON-SITE WASTEWATER AND LAND USE PRACTICES AT THE BILLINGTON SEA.

NUMBER	ADDRESS	SEPTIC/CESSPOOL	PROBLEM	AGE (YR)	DISTANCE (FT)	OCCUPIED	PUMPING INTERVAL	ADDITIVES	FLOODING	# OF RESIDENTS	DISHWASHER	WASHING MACHINE	GARBAGE DISPOSAL	LAWN AREA	FERTILIZER APPLICATIONS	COMMENTS
1	Morton Park	-	-	-	150	s	-	-	-	-	-	-	-	no	-	-
2	Morton Park	-	-	-	100	u	-	-	-	-	-	-	-	no	-	fire damaged
3	Hopkins Rd.	c	-	25	75	s	-	-	-	-	-	-	-	no	-	-
4	Hopkins Rd	s	+	-	200	yr	1yr	-	-	4	+	+	-	200	I	-
5	Hopkins Rd.	-	-	-	150	yr	-	-	-	-	-	-	-	no	-	-
6	Dunham Rd.	s	-	-	50	yr	-	-	-	-	-	-	-	no	-	-
7	Dunham Rd.	c	+	-	15	yr	1yr	-	+	2	+	+	-	no	-	nearby catch basin
8	Dunham Rd.	-	-	-	100	s	-	-	-	3*	-	-	-	200	I	-
9	Dunham Rd.	-	-	42	45	yr	2yr	-	-	1	-	-	-	no	-	40 yrs. on lake
10	Dunham Rd.	s	-	10	100	yr	-	-	-	2	-	-	-	20	-	-
11	Baker Rd.	c	-	-	40	s	-	-	-	2	-	-	-	10	-	-
12	Baker Rd.	c	-	-	50	s	-	-	-	-	-	-	-	-	-	-
13	Schubert Rd.	c	+	50	175	yr	.5	-	-	2	-	+	-	-	-	considering new system
14	Billington SEA	s	-	20	200	yr	.5	-	-	3	-	+	-	+	-	minimal lawn
15	Billington SEA	s	-	.2	200	yr	-	-	-	2*	-	-	-	200	I	new house
16	Billington SEA	c	-	50*	150	s	-	-	-	3	-	+	-	-	-	crawl space
17	Blackcat Rd	s	-	30	60	yr	.5	-	-	2	-	+	-	100	-	small cellar
18	Blackcat Rd	s	-	5	110	yr	-	-	-	2	+	+	-	300	-	1½ story
19	Blackcat Rd	c	-	16	70	yr	1	-	-	2	+	+	-	8400	I	bogs have impact
20	Bumpus Rd.	s	-	20	100	yr	-	+	-	1	-	+	-	-	-	-
21	Bumpus Rd.	s	-	6	50	yr	-	-	-	3	-	+	-	50	-	lawn not maintained
22	Bumpus Rd.	c	-	20	800	yr	2	-	-	2	+	-	-	100	-	-
23	Bumpus Rd.	s	-	1	150	yr	-	-	-	4	+	+	-	100	-	new system
24	Blackcat Rd	s	-	35	50	yr	1	-	-	2	-	+	-	25	-	-
25	Blackcat Rd	c	-	-	60	yr	.5	-	-	2	-	-	-	-	-	-
26	Blackcat Rd	-	-	-	-	yr	-	-	-	3	-	+	-	no	-	-
27	Blackcat Rd	s	-	50*	40	yr	-	-	-	5	-	+	-	+	.5	-
28	Blackcat Rd	s	-	24	40	yr	2	-	-	2	+	+	-	+	.5	shared lawn
29	Blackcat Rd	c	-	50*	40	yr	-	-	-	1	-	+	-	+	.5	-
30	Blackcat Rd	s	-	5	100	yr	-	-	-	2	+	+	-	300	-	new house
31	Blackcat Rd	-	-	-	50	yr	-	-	-	3	-	-	-	100	-	originally duck blind
32	Blackcat Rd	s	-	35	50	yr	.5	-	-	2	-	+	-	100	-	manure
33	Blackcat Rd	-	+	-	-	yr	-	-	-	3	-	-	-	field-		-
34	Knight Pt. Rd.	s	+	60*	50	yr	1	+	-	2	-	+	-	field-		-
Mean Response		s	-	28.5		yr	-	-	-	2.3	-	+	-	field-		-
Range				.2-60	40-200	50I yr	-			1-5				0'-8400'		

Some additional flowage may occur from dishwasher use but most homes only contain washing machines.

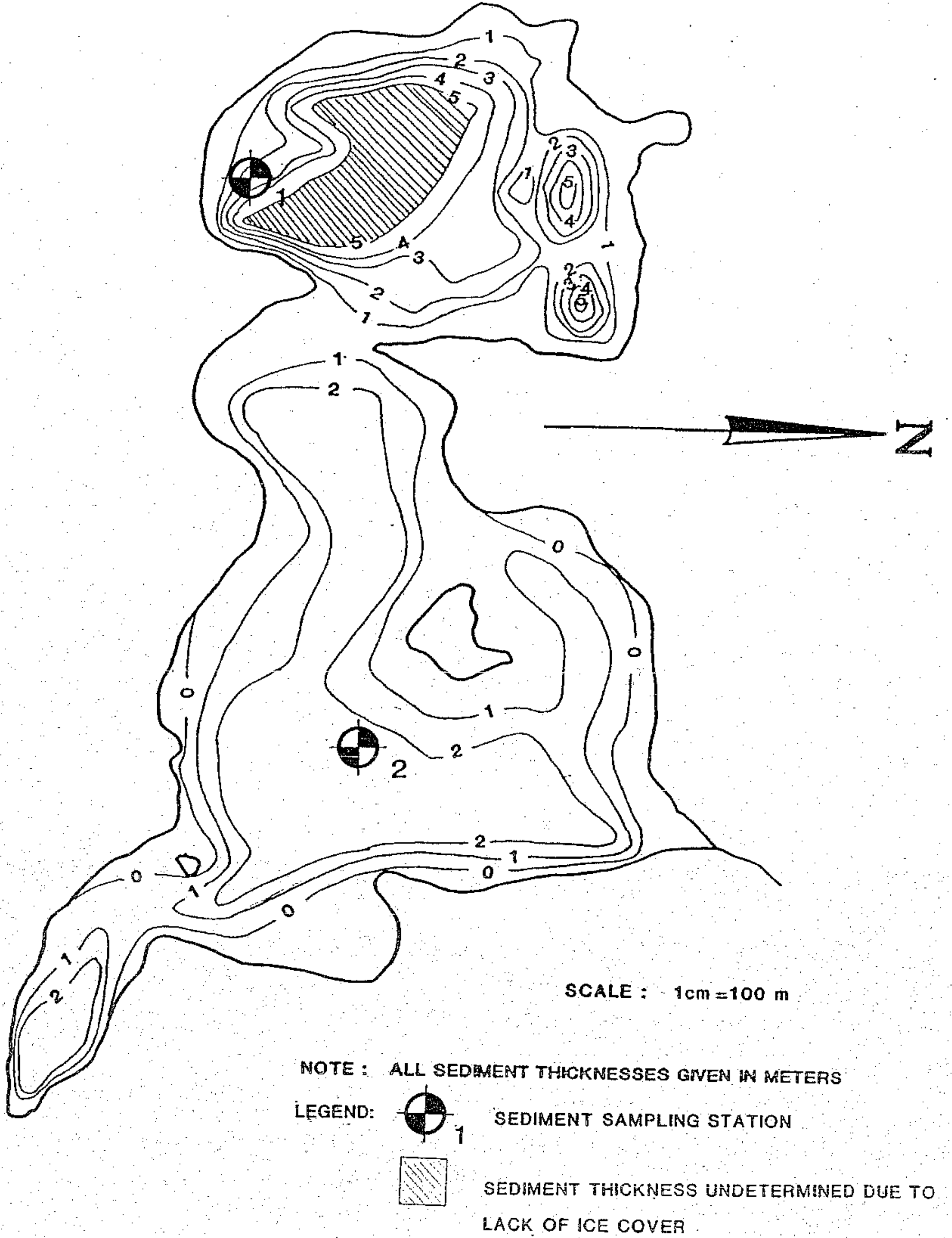
At present, lawns are not a significant factor in nutrient loading to Billington Sea. The average size of observed lawns was 180 square feet. Most homes do not have the manicured lawns of suburban areas. Only one home had a noticeable lawn (8400 sq.ft.). No commercial fertilizing (ChemLawn, Green Lawn, etc.) was observed. Most lawns are not regularly fertilized. In many cases, the mowed areas are natural grass fields which are maintained with only occasional chemical fertilizer use.

2.14 Lake Sediment Characteristics & "Reverse Layering" Feasibility

Lake Sediment Characteristics

Measurements of the thickness of the soft sediment layer in the Billington Sea were conducted, concurrently with the bathymetric survey, by driving a probe to first refusal. As indicated in Figure 28, three 5.0m-thick soft sediment deposits exist in the shallow western basin. The two northernmost deposits are small and located in a shallow cove which is sheltered from wind action, thus reducing the likelihood of sediment transport from this area. A larger deposit is located in the southern portion of the western basin. The sediment thickness within the 5.0m contour was unable to be determined since this portion of the lake was not frozen at the time of the survey. However, this deposit consists of two lobes which appear to extend lakeward from the shoreline discharge points of Tributaries A and B. Channelized flow from these tributaries appears to be redistributing fine-grained lake sediment particles, forcing them to be deposited in the center of the western basin. Redistribution of the soft sediment layer in this basin was noted during the summer. Muck deposits which were observed at the in-lake station during the winter were not evident in the same location during the following summer. As a result of the shallowness of this basin, fine-grained sediments can easily be redistributed by wind action, motorboat activities, and accelerated surface water and/or groundwater inflows.

Sediment samples were collected, on November 11, 1988, at the station shown on the soft sediment thickness map. The



SCALE : 1cm = 100 m

NOTE : ALL SEDIMENT THICKNESSES GIVEN IN METERS

LEGEND: ● 1 SEDIMENT SAMPLING STATION

▨ SEDIMENT THICKNESS UNDETERMINED DUE TO LACK OF ICE COVER

FIGURE 28: SOFT SEDIMENT THICKNESS MAP
BILLINGTON SEA
PLYMOUTH, MASSACHUSETTS

sediment sample collected on the western basin was not obtained at the in-lake station since this area consisted of a homogeneous sand layer. The chemical characteristics of the two sediment samples are presented in Table 30 and the physical characteristics, observed from vertical core samples, are described within the following subsection. Significant variability exists between the chemical composition of the sediments in the two lake basins. Approximately thirty-nine percent (39%) of the phosphorus load and nineteen percent (19%) of the annual nitrogen load were predicted from the nutrient budget calculations to be accrued within the lake. Unexpectedly, higher concentrations of total phosphorus, nitrogen and volatile organics were obtained in the eastern basin rather than the heavily-vegetated western basin. As previously discussed, the sample collected from the western basin was characterized by a greater sand fraction, and thus, contained less organic, nutrient-rich muck. Additional sediment sampling in the western basin is recommended in order to define the distribution of organic sediments during the growing season but is beyond the present scope of work.

A comparison of the lake's sediment quality with the Massachusetts 'Criteria for the Classification of Dredged or Filled Material' (DWPC, 1979) indicates that the Station 1 sample (western basin) would be classified as Category I, Type B material. The Station 2 sample (eastern basin) would be classified as Category III, Type C material.

These designations mean that both of these areas could either be hydraulically or mechanically dredged but that

TABLE 30. BILLINGTON SEA SEDIMENT CHARACTERISTICS

PARAMETER	STATION 1 12/09/88	STATION 2 11/11/88
Arsenic GFAA (mg/kg)	0.22	65.6
Cadmium (mg/kg)	(0.06	(9.7
Chromium (mg/kg)	0.24	14.6
Copper (mg/kg)	0.33	14.6
Iron (mg/kg)	200.70	12,390.0
Lead (mg/kg)	0.73	73.2
Manganese (mg/kg)	1.76	87.8
Mercury (mg/kg)	(0.0182	(0.1
Nickel (mg/kg)	(0.12	19.5
Vanadium (mg/kg)	(0.15	73.2
Zinc (mg/kg)	3.07	102.4
Nitrate Nitrogen (mg/kg)	1.42	108.8
Total Kjeldahl Nitrogen (mg/kg)	823.8	5588.0
Total Phosphate (mg/kg)	67.80	646.8
Percent Water	57.70	89.8
Oil & Grease, Total (%)	0.03	1.20
Total Volatile Solids (%)	1.95	20.00
PCB's (mg/kg)	(0.1	(3.87

(() Indicates less than detection limit which can vary with each sample.

effluent control measures would be required for land disposal. Additionally, sediment removed from Station 2 would require containment throughout the dredging process.

Sediment collected from this Station would be classified as "heavily polluted" in comparison to sediment samples collected from the Great Lakes (Table 31). The elevated concentrations of lead and arsenic in these sediments is of particular concern. The source of lead in the sediments is suspected to be associated with the use of leaded gasoline. Once airborne, the lead would return to the sediment due to wet and dry deposition. The elevated arsenic concentration may have resulted from the herbicide treatments of the lake, conducted in July, 1970, at which time 6,000 gallons of sodium arsenite were added to the lake at a concentration of 7.5 ppm. If dredging of the lake sediments is conducted, in the future, the distribution of arsenic-laden sediments should be further defined.

Table 31. Great Lakes Sediment Rating Criteria

Constituent[1]	Nonpolluted	Moderately Polluted	Heavily Polluted
Volatile Solids (%)	5	5-8	8
COD	<40,000	40,000-80,000	>80,000
TKN	<1,000	1,000-2,000	>2,000
Oil & Grease (Hexane Soluble)	<1,000	1,000-2,000	>2,000
Lead	<40	40-60	>60
Zinc	<90	90-200	>200
Ammonia	<75	75-200	>200
Cyanide	<0.10	0.10-0.25	>0.25
Phosphorus	<420	420-650	>650
Iron	<17,000	17,000-25,000	>25,000
Nickel	<20	20-50	>50
Manganese	<300	300-500	>500
Arsenic	<3	3-8	>8
Cadmium	*	*	>6
Chromium	<25	25-75	>75
Barium	<20	20-60	>60
Copper	<25	25-50	>50
Mercury	*	*	≥1
Polychlorinated Biphenyls(PCB's)	*	*	≥10
SPI	5.3	---	6.3

1. All concentrations given in MG/KG Dry Weight except as otherwise indicated.

*No lower limits defined.

Reverse Layering of Bottom Sediments

The current regrowth of aquatic plants in the western and eastern basins of the Billington Sea demonstrates that without remedial action the lake will continue to be congested with submerged vegetation. The source of the problem may be aided by phosphorus-rich organic sediments. Regardless of reduction in nutrient inputs to the lake, this stored reservoir of plant fertilizer will promote regrowth unless removed by dredging or covered by blanketing. The proposed alternative of blanketing does not attempt to seal the lake sediments (as fly ash treatment does), but to bury the organic layer while maintaining a porous bottom substrate allowing flow to occur.

Sand application is a recognized retardant to establishment and growth of macrophytes. Scientific studies have been conducted on the effectiveness and impact of sand applications as a lake restoration process for over 30 years (Misra, 1938; Peltier and Welch, 1969; Nichols, 1974).

Application of sand/gravel onto existing sediments to thickness of 16-20 cm has been used to control machrophytes (Nichols, 1974). As a restoration technique, it is applicable to small areas, but usually not used in large lakes because costs/unit are high for transport and application (Welch, 1980). On Red Lily Pond, the presence of beach sand underlying the organic sediment layer requires only that the original sand bottom sediments be brought up again to the surface - hence the term "reverse layering" (figure 29).

Corings were conducted during December, 1987 and revealed sandy bottom layers which can be reversed layered. Heavy vegetation resulting from cultural eutrophication is not conducive to pond life or water quality for the following reasons:

1. Low dissolved oxygen levels increase fish mortality and produce nuisance odors.
2. Heavy vegetation limits water circulation and recreational usage such as swimming and fishing.
3. The heavy biomass aids sedimentation which reduces groundwater inflow and flushing.

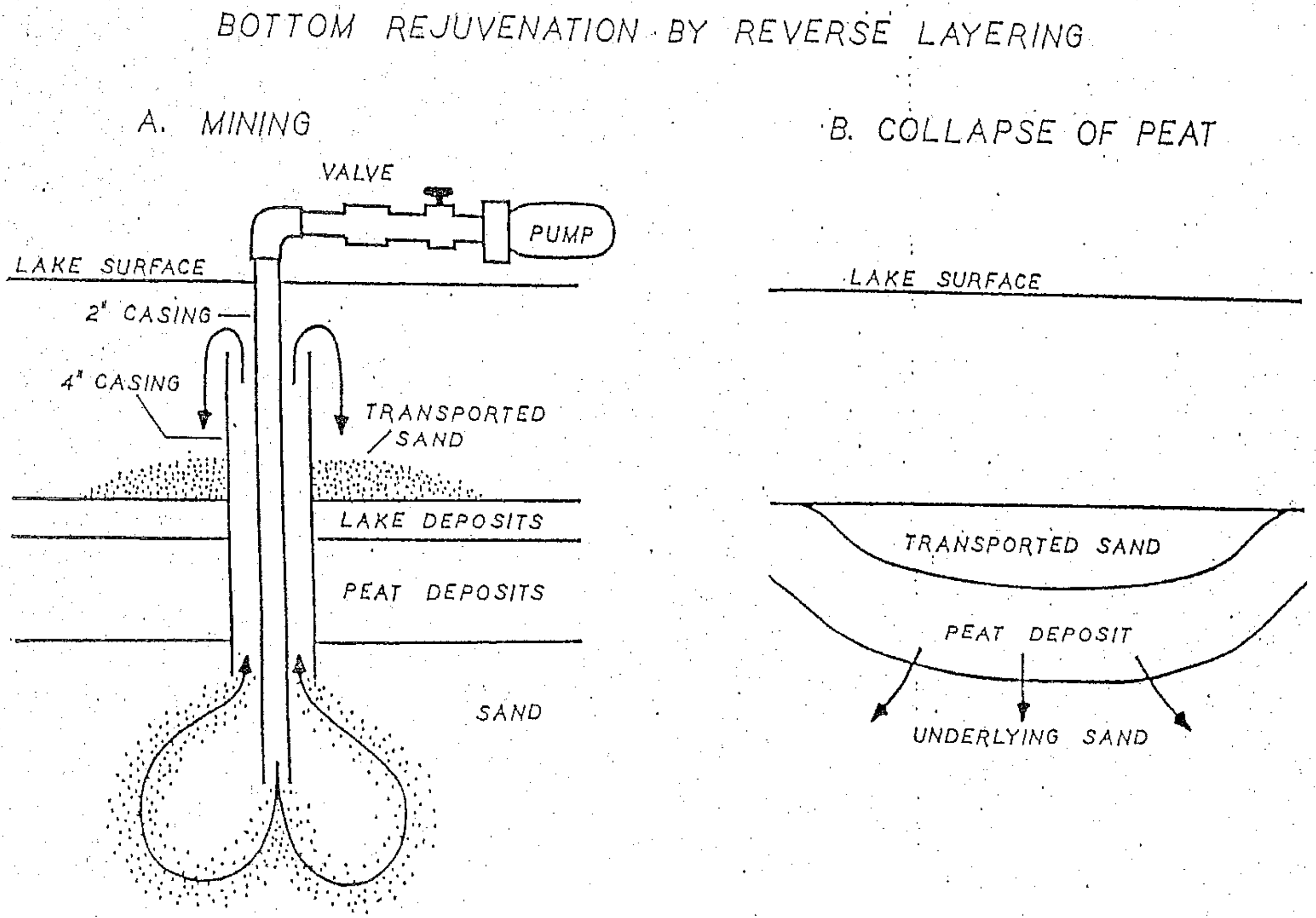


Figure 29. Diagram showing the process of reverse layering.

A test of the procedure was conducted off a dock in the western cove of Billington Sea in December, 1987. A modified centrifugal "mud" pump was connected to a 2-inch ID PVC pipe placed down inside a 4-inch casing. The casing was initially hand-augered to 3 feet below the lake bottom through 2.7 feet of peat deposit. The hydraulic flow was adjusted to sufficient velocity to transport medium sand up the cross-sectional area between the 4-inch casing and 2-inch ID pipe. The transport sand volume was about 2% of water volume. The test showed that the underlying sand can be effectively transported to the surface. (see figure 30 & 31)

A series of corings (1-5) conducted in the western basin all revealed conditions suitable for reverse-layering. The bottom sediments are mainly fine to medium sand with scattered pebbles.

Advantages of application of sand:

1) 15-20 cm (5-8 inches) layer of sand reduces by 400% regrowth of macrophytes (Peltier and Welch, 1969), reduces colonization and species diversity, particularly submerged algae and weeds (Potamogeton, Myriophyllum, and Najas) (Pearsall, 1920, 1929).

2) The porous sand substrate provides aeration to sediments and limits ion exchange with phosphorus.

3) Improves the sandy substrate nesting sites for bluegills and bass. The increase in aerated sediment will decrease mortality by increasing egg and fry survival. Mortality is directly related to oxygen content and water movement.

4) Penetration of the organic sediment layer encourages groundwater inflow.

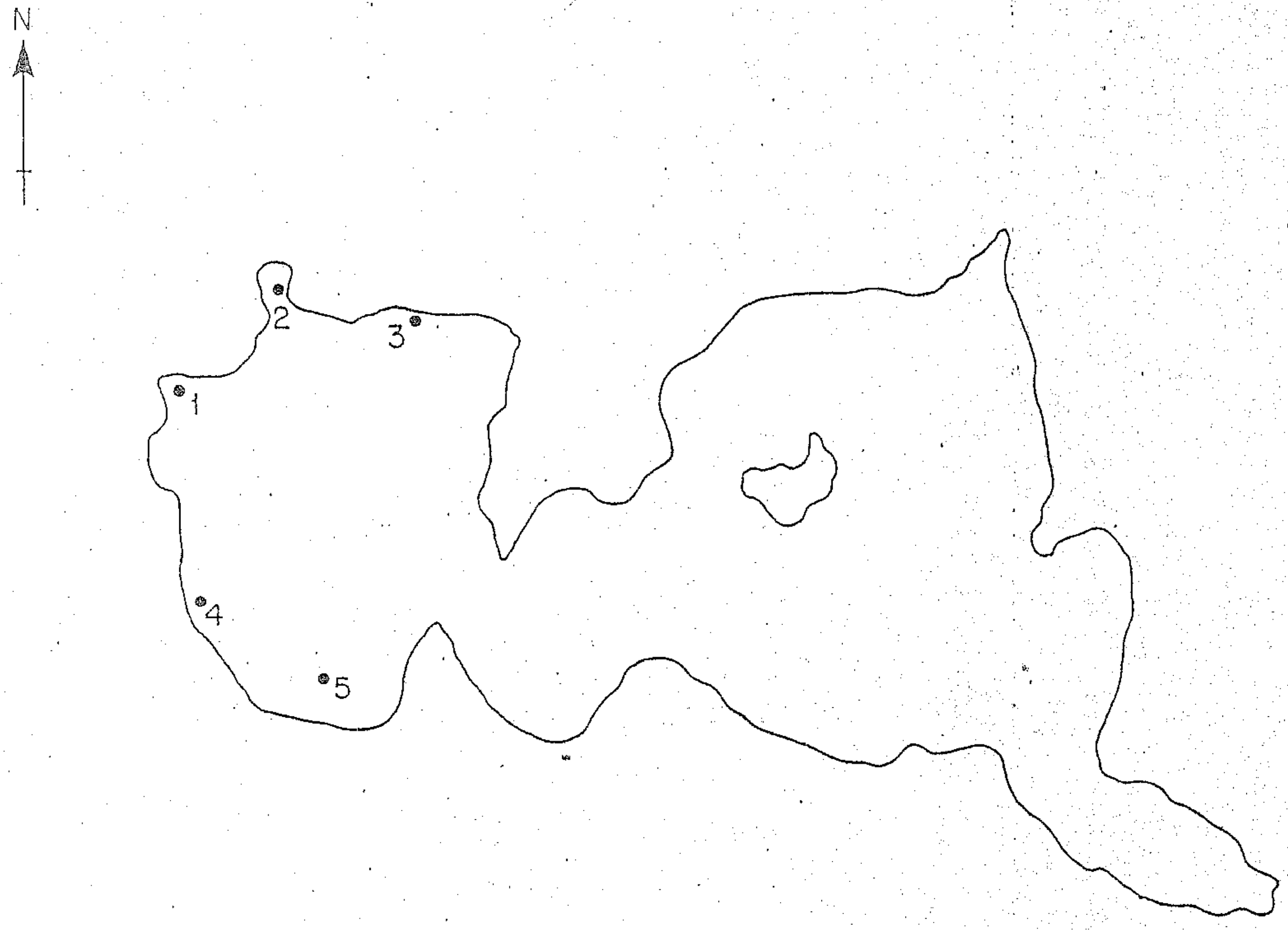


Figure 30. Lake bottom test locations for "Reverse Layering"

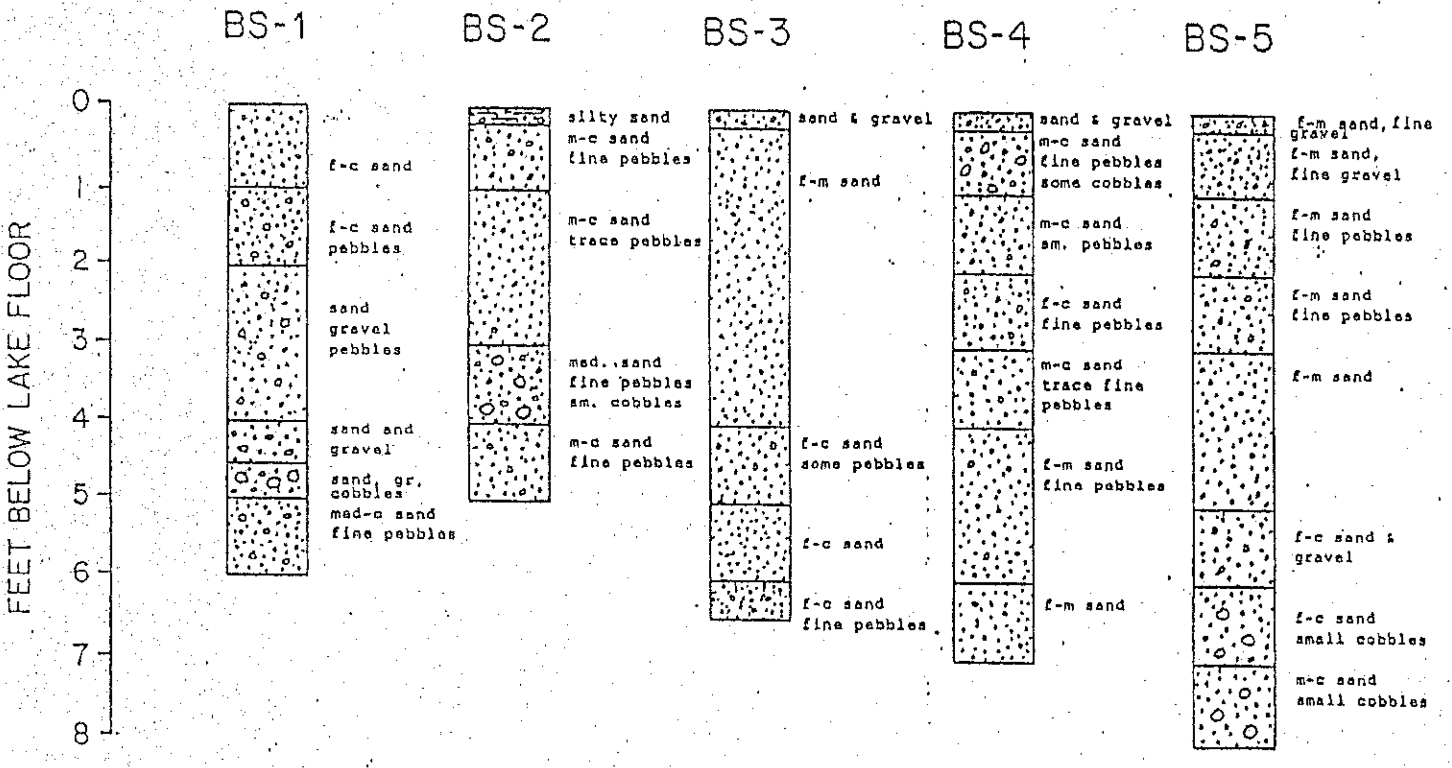


Figure 31. Billington Sea Sediment Profiles (Stations 1-5).
(Detailed description follows - next 2 pages)

BILLINGTON SEA BOTTOM CORINGS

Depth	B.S. #1
1'	dk brn, organic, mod std, f-cse sand, with v cse sand
2'	dk grey, poorly std, f-v cse sand trace fine pebbles
3'	grey brn, poorly std sand & gravel up to lg pebbles
4'	dk grey, poorly sft sand and gravel
4½'	brn, mod std, med-v cse sand and fine pebbles
5'	grey, poorly std sand and gravel up to sm. cobbles
6'	grey, mod std. med-v cse sand and fine pebbles

Depth	B.S. #2
3"	dk grey, mod. std, silty, med-vc sand, some fine pebbles
1'	dk grey, mod-std, med-vc sand, some fine pebbles
2'	lt. tan, mod-std, med-vc sand, tracefine pebbles
3'	lt. tan, mod-std, med-vc sand, trace fine pebbles
3½'	lt. tan, mod-std, med-vc sand and fine pebbles, some sm. cobbles
4'	lt. tan, poorly std, med sand to fine pebbles and sm. cobbles
5'	lt. tan, well std, med-vc sand, trace fine pebbles

Depth	B.S. #3
3"	dk brn, poorly std, sand and gravel
1'	red brn, mod std, vf - med sand, some c and vc sand
2'	red brn, mod std, f-med sand, some c and vc sand
3'	red brn, mod std, f-med sand, some c and vc sand
4'	red brn, well std, f-med sand, some c and vc sand
5'	red brn, mod std, f-c sand with vc sand, trace fine pebbles
6'	red brn, well std, f-c sand
6½	red brn, mod std, f-c sand, trace vc sand and fine pebbles

Depth	B.S. #4
3"	brn, organic, poorly std, sand and gravel
1'	red brn, mod std, med-cse sand, some fine pebbles and cobbles
2'	brn, mod std, med-cse sand, some vc sand and sm. pebbles
3'	brn, poorly std, fine-v cse sand and fine pebbles
4'	brn, mod std, med-v cse sand, trace fine pebbles
6'	brn, well std, f-med sand, trace cse sand and fine pebbles
7'	brn, well std, f-med sand, trace cse sand

Depth	B.S. #5
3"	dk tan, organic, mod std, vf-med sand, some fine gravel
1'	grey, poorly std, silty, vf-med sand and fine gravel
2'	dk grey, mod std, f-med sand, trace cse sand and fine pebbles
3'	grey, mod std, f-med sand, some c and v cse sand and fine pebbles
4'	grey, poorly std, f-v cse sand and gravel
5'	brn, poorly std, f-v cse sand and gravel
6'	brn, poorly std, f-v cse sand, some fine pebbles
7'	brn, mod std, f-cse sand, and small cobbles
8'	brn poorly std, med-v cse sand and small cobbles

3.0 FEASIBILITY ASSESSMENT

The permissible loading rate for a lake defines the carrying capacity of the water body of a critical limiting nutrient. For lakes, the phosphorus concentration should not exceed 0.025 mg/l (EPA, 1986). Beyond this level the lake is overloaded and may result in heavy vegetation growth. The computed annual accrual of phosphorus for Billington Sea stands at 453,660 kg/yr (See Table 4). The accrued phosphorus is potentially equivalent to a concentration of 0.19 mg/l. This inflow pf phosphorus must be reduced to maintain a healthy lake.

Tributary Inflow

Currently, the 12-month monitoring of water quality has shown that 63% of the total phosphorus originates from the stream inflows. The source of the elevated phosphorus appears to be cranberry bog operations. A reduction environment, as occurs during bog operations, favors the release of phosphorus into the stream channels. Teal and Howes (in press) state that "soluble phosphorus in the outflow from the bog is high enough to contribute to fertilization of fresh waters nearly half the time, though if the outflow is processed by a shallow pond before discharge, the phosphorus concentration meets strict standards 94% of the time."

The tributaries alone contribute an estimated 721 kg of phosphorus per year (See Table 4). If the inflows were ceased, the total incoming load would be reduced to 455 kg/yr, well within permissible guidelines (Refer to Figures 32, 33, & 34).

Figure 32. Existing Tributary Phosphorus and Nitrogen Loads Discharge to the Billington Sea.

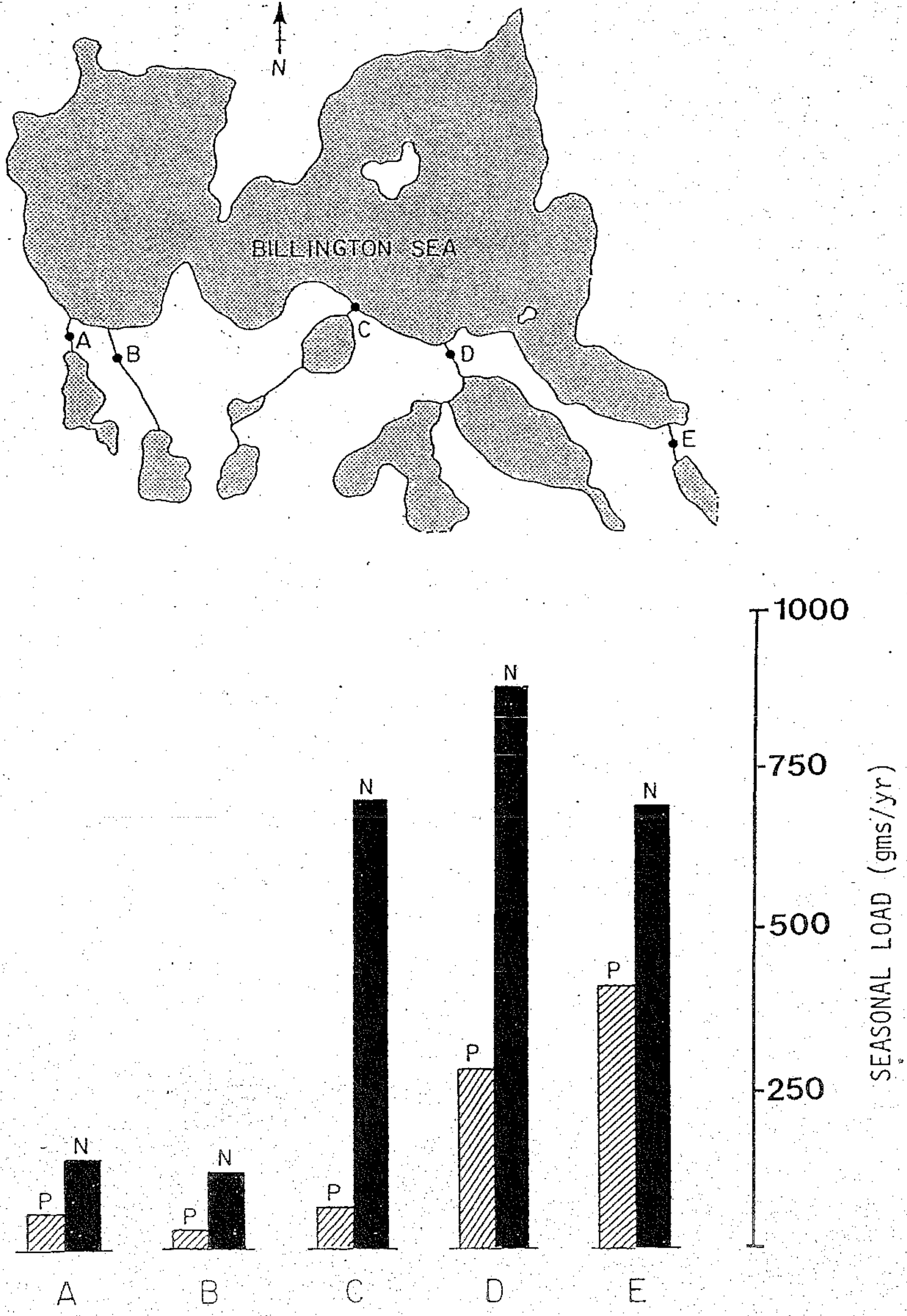


Figure 33. Reduction in Phosphorus and Nitrogen Loading to the Billington Sea following Limited Action and Complete Tributary Cessation.

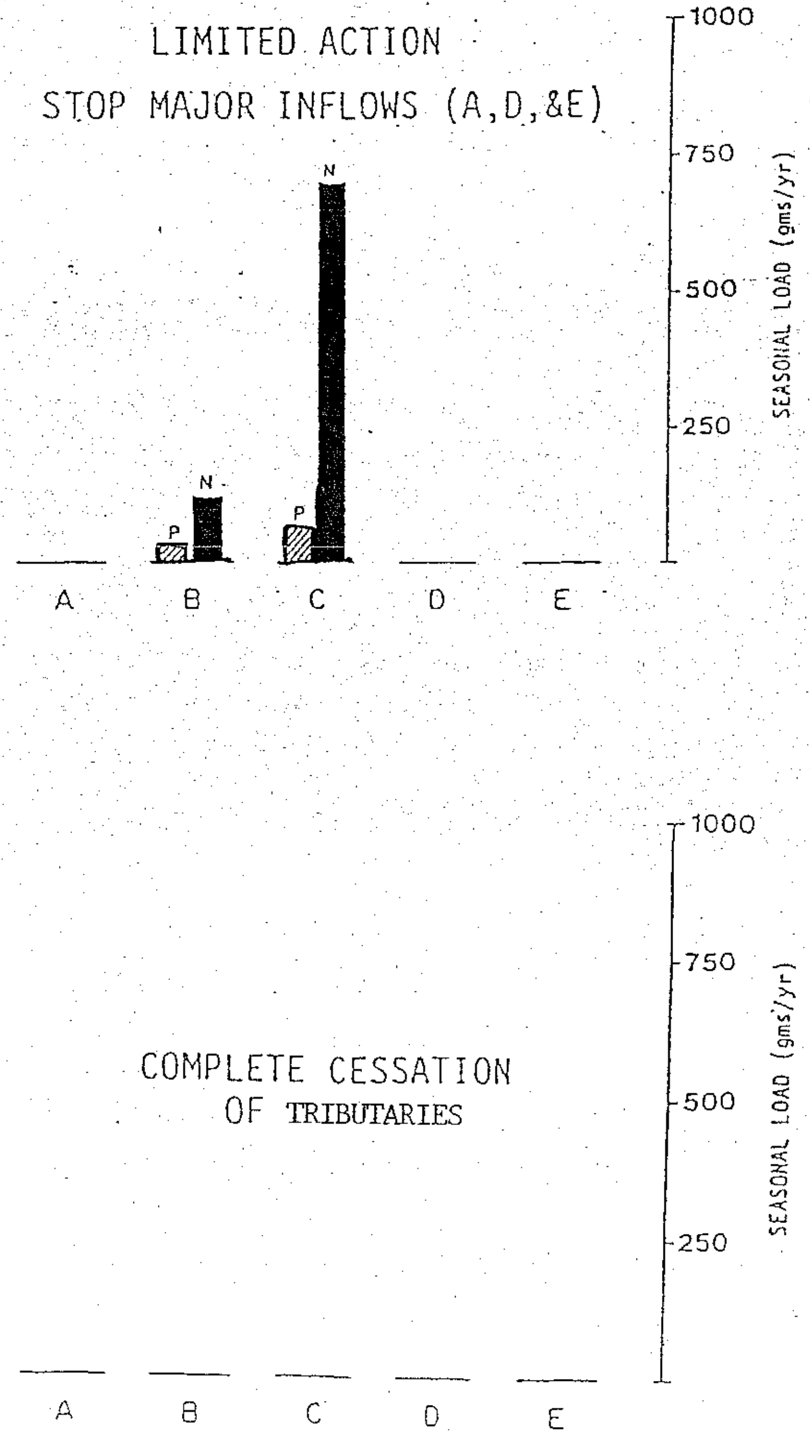
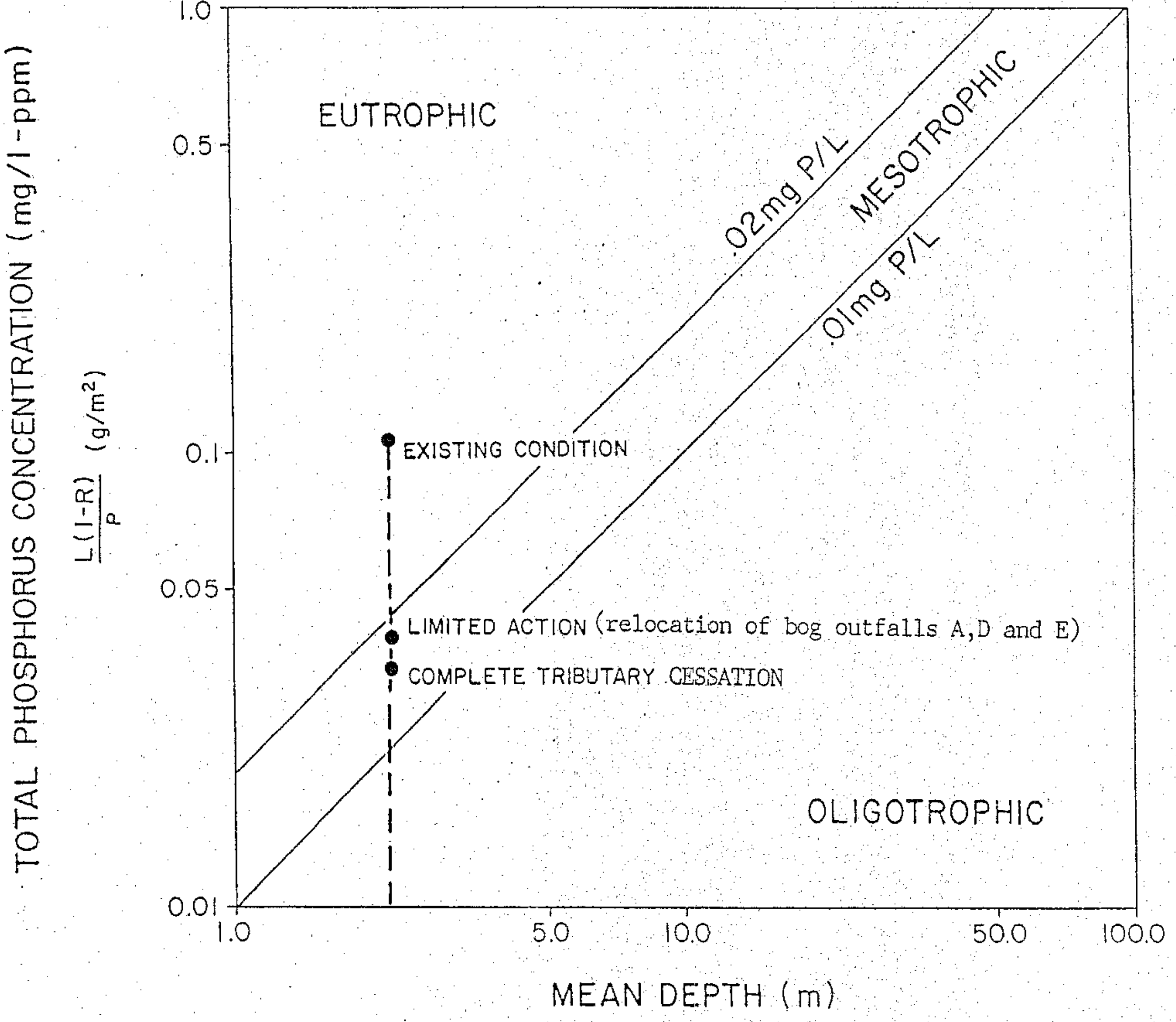


Figure 34. Trophic Condition of the Billington Sea prior to and following Bog Outfall Relocations.



As a practical alternative, phosphorus loading could be lessened by diverting some of the stream inflows of A, D, and E to groundwater discharge.

Septic System Input

Upgrading septic system treatment in the shoreline recharge zones could also benefit the Billington Sea. Requiring upgraded systems for new homes or additions to cottages would be beneficial. Coupling this with upgrading of zoning would reduce future groundwater phosphorus loadings.

Two options exist to upgrade the level of treatment:
1) Increasing leaching field area to double current size and requiring an alternate dousing system.

2) Consider installation of UAF (upflow anaerobic filters) between septic tank and leaching field.

Phosphorus movement is due to low oxygen conditions promoted by organic (BOD) load on the aquifer. Upflow anaerobic filters have shown a removal frequency of 74% of the applied BOD (Mitchell, Univ. of Arkansas). An anaerobic filter consists of a column isolated from contact with air and containing a solid media (1 1/2 to 2 inches in grain size). Anaerobic bacteria grow on the media and uptake nutrients in the waste stream flowing upwards through the filter.

IN-SITU DEPOSITS

Sediment surveys and chemical analyses have revealed a significant store of nutrients in lake bottom sediments. During late summer, low oxygen conditions encourage the release of phosphorus from the sediments. The extent of impact of the lake-bottom recycling can be seen by the mean observed water column content of phosphorus at .050 mg/l, 20% higher than .040 mg/l expected on the basis of existing measured input loading. The increased level is most likely due to the recycling of phosphorus form the lake deposits.

Previous benthic sediment analysis (Lyons and Skwarto, 1978) has shown a phosphorus content above 112 mg/kg. This is considered excessive and a clear indication of enrichment.

Even if the inflow loading of the streams were entirely removed, the insitu deposit recycling would maintain the soluble water column phosphorus level in excess of eutrophic conditions. Lake restoration clearly requires inlake as well as out-of-lake attention.

In-lake management/restoration alternatives are generally divided into two categories, short-term and long-term. The first group includes techniques such as mechanical harvesting or herbicide treatment, which provide short-term weed control and generally must be repeated each year at a recurring expense. Sediment removal (dredging), fall-winter drawdown, and in some cases, mechanical weed raking, are usually considered long-term weed control strategies. The initial cost for design and implementation of these restoration techniques may be high, but the expense for annual maintenance of the waterbody is often reduced or eliminated.

Of particular importance to the evaluation of these different in-lake strategies is first defining the restoration program's goal and objectives. Billington Sea maintains active swimming beaches, fishing and recreational boating activities. The sea should be maintained for primary and secondary contact usages including swimming, fishing, boating, nature study, waterfowl and wildlife habitat, and aesthetics. For the primary and secondary contact usages, the aquatic plant community throughout the sea should be brought into balance, with reduced plant density but maintenance of a high species diversity. Algal blooms should be reduced to periodic occurrences instead of annual occurrences.

Of foremost priority, the current nutrient loading to the sea and the recycling cycle from historical bottom deposits must be reduced. Vascular aquatic plants and nuisance algal populations are currently the primary problem at the Billington Sea, both originate and are maintained by over-fertilization. Therefore, the following discussion of management strategies focuses upon those techniques/methods that are known to be effective for controlling algal blooms and macrophytes. Table 32 summarizes the techniques considered for use at the Billington Sea and their respective costs.

TABLE 32

RECOMMENDED MANAGEMENT PROGRAM

PROGRAM COMPONENTS	COST	BENEFIT
Water Use and fertilizer BMP's		Partial reduction of tributary nutrient load
Bog outfall relocation/ discharge basin construction	**	Major reduction of nutrient loading (P) to Billington Sea
Lake and Land Use Management		
Land Use Zoning	none	Limit/restrict expansionor alterationof existing and future units
Land Acquisition	high	Preserve open space, provide public access
Public Education Program	low	Reduce septic system phosphorus, reduce runoff phosphorus
Lake Use Zoning	none	Reduce sediment resuspension, potential reduction of Elodea sp. and submergent plant biomass,improve user safety andfish/wildlife habitat
Waste Water Management		
Board of Health Regulations	none	Provide better control over on-site waste water disposal
Inspection and Compliance	$30-100K	Maximize efficiency and life expectancy of on-site systems, upgrading of failing leaching systesm to improve phosphorus removal ($3000/home at time of sale).
Reverse Layering	500-700k*	Reduction of recycled phosphorus from in-situ bottom deposits, reduction of vegetation growth

* Current estimate to be refined by DEP R&D Study, preliminary report expected in 1990.

** Site-specific costs must be assessed following Best Management Practices (BMP's) Evaluation (Water Conservation costs are discussed in Appendix E)

3.1 Watershed Management

Tailwater Recovery and Relocation of Bog Outfalls

The major source of phosphorus loading to the Billington Sea is tributary inflow, primarily from cranberry bog tributaries "D" and "E". Prior to implementing any in-lake restoration measures, tailwater recovery and the relocation of discharges from bog tributaries "D" and "E" should be completed. Discharges from bog tributary "A" should be controlled in a similar manner due to their effects on the water quality of the western lake basin. The control of nutrient loading from bog tributary "C", may be accomplished by increasing the detention time of water within Trask Pond through the installation of a water level control structure.

Tailwater recovery is a water conservation measure which involves collection of the water applied to a bog and its transport to a storage basin for future use. The specific tailwater recovery methods to be employed will vary depending upon site-specific conditions and will be determined following a "Best Management Practices" evaluation of each bog operation. This issue was discussed with the Cape Cod Cranberry Growers Association, which is currently devising such an evaluation and may be able to provide technical assistance as well as the U.S. Soil Conservation Service (See Appendix G). As indicated in Figure 35, existing waterbodies may serve as feasible storage basins for some bog outfalls and others may require the excavation of discharge basins which could be shared by several growers. Table 33 summarizes nutrient load reduction measures from bog discharges.

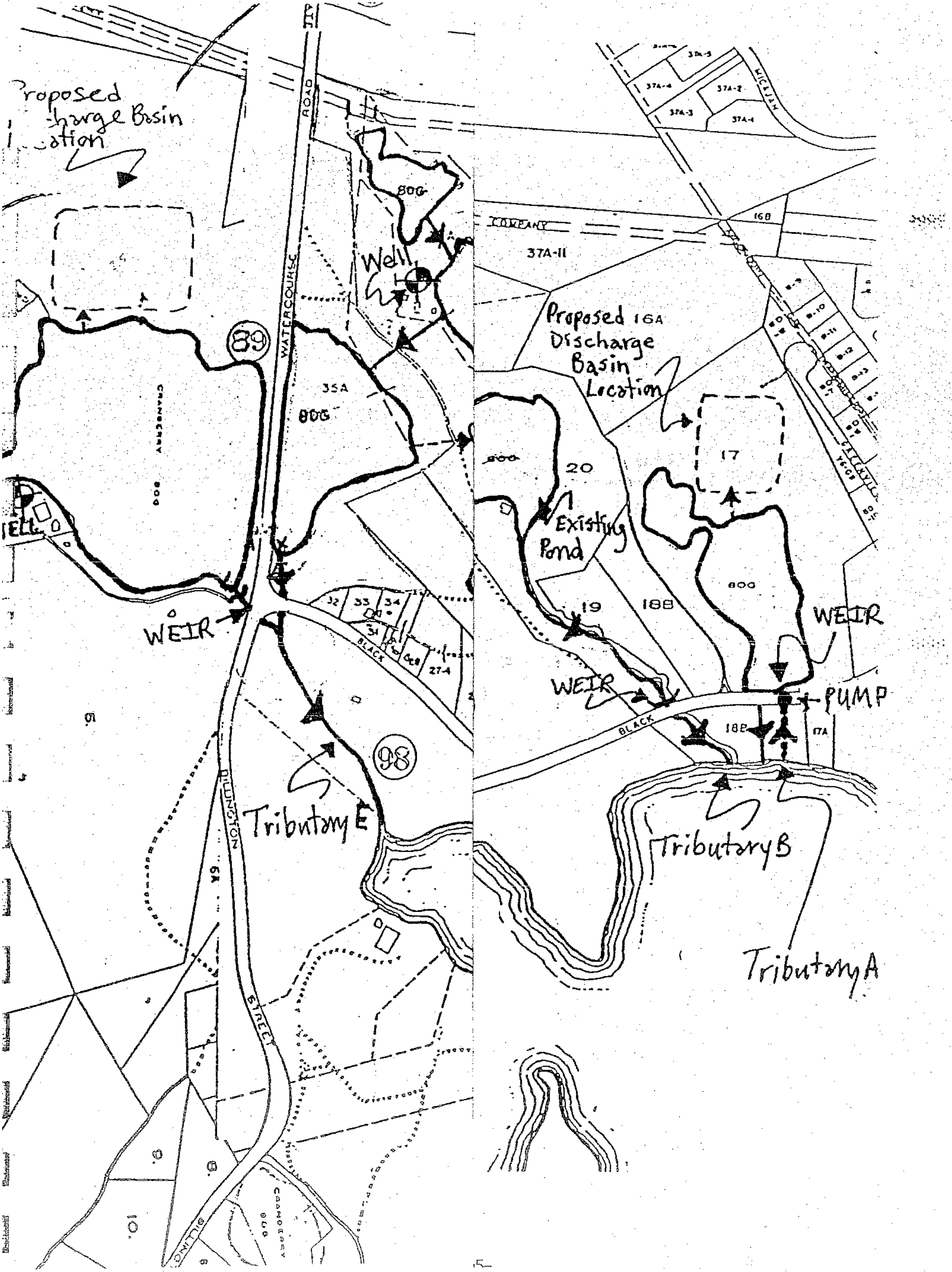

Proposed
Discharge Basin
Location
Well
89
WATERCOURSE ROAD
35A
BOG
CRANBERRY BOG
WELL
WEIR
98
Tributary E
BLACK
32
33
34
31
27-4
DILLINGTON STREET
CRANBERRY BOG
COMPANY
37A-11
37A-3
37A-4
37A-2
37A-1
168
Proposed 16A
Discharge
Basin
Location
17
20
Existing
Pond
19
188
BOG
WEIR
WEIR
PUMP
BLACK
18B
17A
Tributary B
Tributary A

Table 33. Partial listing of BMP's for improving bog discharge water quality and reducing bog operational costs.

BEST MANAGEMENT PRACTICES (BMP's)	BENEFITS
1. Fertilizer Application Reductions a. conduct soil chemical analyses to determine minimum amount of fertilizers required b. apply low doses more ferquently rather than several large doses less frequently c. maximize use of chemigation (better control of chemical applications through use of irrigation systems)	Reduce discharge nutrient load and fertilizer costs
2. Water Conservation a. repair leaky dikes b. level bog surfaces c. install part-circle sprinkler heads d. recycle floodwater on downgradient bogs e. install tailwater recovery systems f. minimize water use through appropriate sprinkler head spacing	Reduce pumping operations costs, reduce discharge nutrient load, reduce application costs
3. Maximize Harvest Floodwater Retention Time (7 Days) With 3-Day Gradual Release a. retain harvest floodwater on upgradient bog for 7 days then release to downgradient bog, release from downgradient bog over three day period	Reduce discharge nutrient load and downstream erosion as well as reduce pumping operational costs
4. Bog Outfall Relocation Tributary A - excavate basin upgradient from bog for tailwater recovery discharges Tributary B - increase retention time by raising weir elevation Tributary C - increase retention time by raising weir elevation Tributary D - utilize Reservoir Pond for tailwater recovery discharges Tributary E - excavate two basins (refer to Fig. 35) for tailwater recovery discharges	Reduce discharge nutrient load

Upgrading and Maintenance of Subsurface Wastewater Disposal Systems

The results of the septic leachate survey indicated that groundwater plumes of high nitrogen and phosphorus content are being transported through the sandy shoreline soils and leading to the accumulation of these plant nutrients in the lake. The severity of this problem is compounded by the acceleration of this nutrient loading process as a result of high groundwater recharge velocities, particularly along the western basin shoreline. The results of the door-to-door survey of wastewater disposal practices indicated that disposal systems located within 300 meters of the lakeshore averaged twenty eight (28) years in age and many do not meet the standards of the Title V regulations. Twenty percent (20%) and sixty four percent (64%) of the lake's phosphorus and nitrogen loadings, respectively, are attributable to groundwater inflow.

Sewage disposal alternatives are limited to upgrading existing subsurface disposal systems, sewering and the installation of a cluster septic system. The latter alternative requires the dwellings to be clustered together so their wastewater can easily be collected and transported to a centralized location for subsurface disposal. This alternative is not recommended for the Billington Sea watershed since, in addition to potential slope, space and soil restrictions, dwellings are located along the shoreline, rather than clustered. Although sewering of the dwellings located within the recharge zone of Billington Sea would be the most effective, long-term means of reducing nutrient loading to the lake from subsurface wastewater

Although the method of reverse layering is being explored, at present it appears to be less costly than dredging. It also has historic appeal since the original lake bottom is being recovered and transported back to the surface. Depending upon the depth of burial of the bottom sediments, vegetative growth would be substantially reduced. The cost of reverse layering for the Billington Sea basin is estimated to be $500,00--700,000. Funds may be available for a demonstration of the process since it would be applicable to other eutrophic kettle ponds with similar stratigraphy as an alternative to dredging.

low, possibly cost for pilot study

DREDGING

Although selective dredging could serve to greatly improve the sea, the unit costs would be quite high given that the lake/pond cannot be gravity lowered and lack of suitable dredge spoil disposal sites in close proximity to the pond. Wetlands cannot be used as disposal locations. Therefore trucking of the sediment would almost assuredly be required The absence of a suitable land parcel near the pond for sediment disposal heavily weights against the feasibility of hydraulic dredging. To put the estimated cost of dredging in perspective, we have an estimated cost of $8.00/yd^3 for removal and trucking to a containment area within one mile of the pond. For removal of 1,000,000 yd^3, the estimated cost is $8,000,000 plus an additional $200,000 to $300,000 for final engineering design and containment area preparation.

These costs are likely to be conservative and if the total volume of material to be removed were reduced, the unit costs would rapidly escalate.

Because of DWPC (628) Clean Lakes funding availability and application prioritization criteria,The Billington Sea would stand very little chance of receiving funds for a costly dredging project.

DRAWDOWN/WATER LEVEL MANIPULATION

The present outlet structure at the Billington Sea does not allow for lowering of water level by more than 1 to 2 feet. A drawdown of at least four feet would be required to expose the lake bottom for freezing and drying of the aquatic plants. A major lowering of the lake would be very detrimental to fish and further, naiad is one of the most drawdown-resistant plants. Drawdown is not viewed as a viable or effective technique here.

CHEMICAL

Herbicide Treatment

Herbicide or chemical treatment is still the most widely-used method for controlling nuisance aquatic vegetation. Relative to other techniques, herbicides are usually less expensive, equally or more effective and the results are apparent within a few days to several weeks. The Commonwealth of Massachusetts requires that all herbicides applied to public water bodies be preformed by licensed applicators. Naturally, only EPA/State-approved chemicals can be used, with permit approval required form the DEP and the local Conservation Commission.

Herbicide treatment would provide effective short-term control of the naiad, pondweed and waterlilies which are dominant throughout the sea. Either 2, 4-D granular of RODEO (a glycophosphate compound) would be needed to control the white waterlilies and watershield. RODEO is far more effective on yellow lilies or spatterdock. Aquathol K (dipotassium endothol) would provide annual control of the naiad and pondweed. Based upon a treatment of $350/acre, the total cost would be about $3,500, and control of the lilies might be effective for two years. Conditions at the ponds which make herbicide treatment less attractive are: (1) the high density of vegetation which could lead to increased algal growth following plant decomposition, and (2) public acceptance as to the long-term safety of the chemicals to be used. Reducing the total area treated would, in part, help to lessen the potential for increase algae growth. The second concern (long-term risk of the herbicides) is not easily addressed. Base upon review of the literature on the herbicides mentioned above, 2, 4-D is widely used both for aquatic as well as terrestrial weed control, yet there is considerable controversy among the scientific community as to its long-term effects on non-target organisms. RODEO is relatively new, yet its active ingredients have long been used in a terrestrial herbicide called Round-up. The manufacturer of RODEO (Monsanto Chemical) reports low acute and chronic toxicity, no bioaccumulation within the food chain, and fairly complete and rapid biodegradability. The manufacturer cautions against use of the RODEO herbicide within 0.5 mile of a potable water intake, but there are no restrictions on use of the treated water for irrigation of recreational purposes. Aquathol K rapidly degrades form both water and soil within several days to 2 to 3 weeks.

LIGHT SUPRESSION/DYES

Aquashade, an inert dye, has been used in recent years to control both vascular aquatic plants and microscopic algae. The blue color of the dye suppresses weed and algae growth through light reduction. Experience with Aquashade in Massachusetts has been limited to treatment of small, non-flowing ponds. Aquashade or other dyes are not recommended for use at the Billington Sea. The anticipated extent of weed or algal reduction is not well-documented and the ponds are so shallow that effective screening of light may not occur.

BIOLOGICAL CONTROL

The most commonly discussed biological control technique is the use of the grass carp, which is a non-native fish that consumes aquatic vegetation. It is presently illegal to bring this fish into the Commonwealth, although a proposal for a "pilot project" to introduce sterile (triploid) grass carp into Chebacco Lake in Hamilton is pending before the Massachusetts Division of Fisheries and Wildlife Advisory Board. The introduction of the grass carp into Billington Sea is not recommended. The area is a prime sport fisheries region. The carp would be caught and to maintain effective population would impact more desirable species.

Alternatives to Reverse Layering

To address in-lake sources of nutrients should reverse layering prove to be not feasible in the western basin then we would recommend an integrated management approach. The integrated management approach will include selective use of hydroraking and mechanical harvesting. Hydroraking and mechanical harvesting were described previously in this section. Short term aesthetic improvement in the lake can be achieved by herbicide treatment, although nutrient removal will not occur. A relatively non-toxic herbicide that is affective against plants such as Elodea sp. and Ceratophyllum demersum is Fluridone (trade name is Sonar).

Lake Use Plan

The implementation of a lake use plan, shown in Figure 41, can serve as a mechanism for achieving a balance between the fisheries/wildlife habitat and recreational uses of the lake (Engel, 1987). Lake use zoning within the Billington Sea would permit multiple uses to concur by minimizing the current user conflicts which exist as a result of competition for limited space.

The current unrestricted use of power boats on the Billington Sea is dangerous to the boater and bather and may be negatively impacting lake water quality and fisheries/wildlife habitat. The operation of power boats in the heavily vegetated, shallow western basin is advised against because sediment resuspension and increases in plant biomass may occur. Resuspended sediments increase turbidity and may cause increased phosphorus levels in the water column as well as the destruction of fish spawning areas and their benthic food sources. Furthermore, the cutting action of boat propellers may cause an increase in the biomass of _Elodea_ sp., the predominant aquatic plant species in the western basin, which can reproduce by fragmentation. Powerboating also conflicts with windsurfing and the use of other unpowered craft in the western basin. The presence of two submerged rocky shoals (Figure 40) in this basin are dangerous to power boaters as well as is traveling through the shallow channel which connects the two lake basins. Powerboating should not be permitted near the Hathaway Point bathing area for public safety reasons.

The suitability of specific lake zones for fish/wildlife habitat and particular recreational uses were assessed

GALE

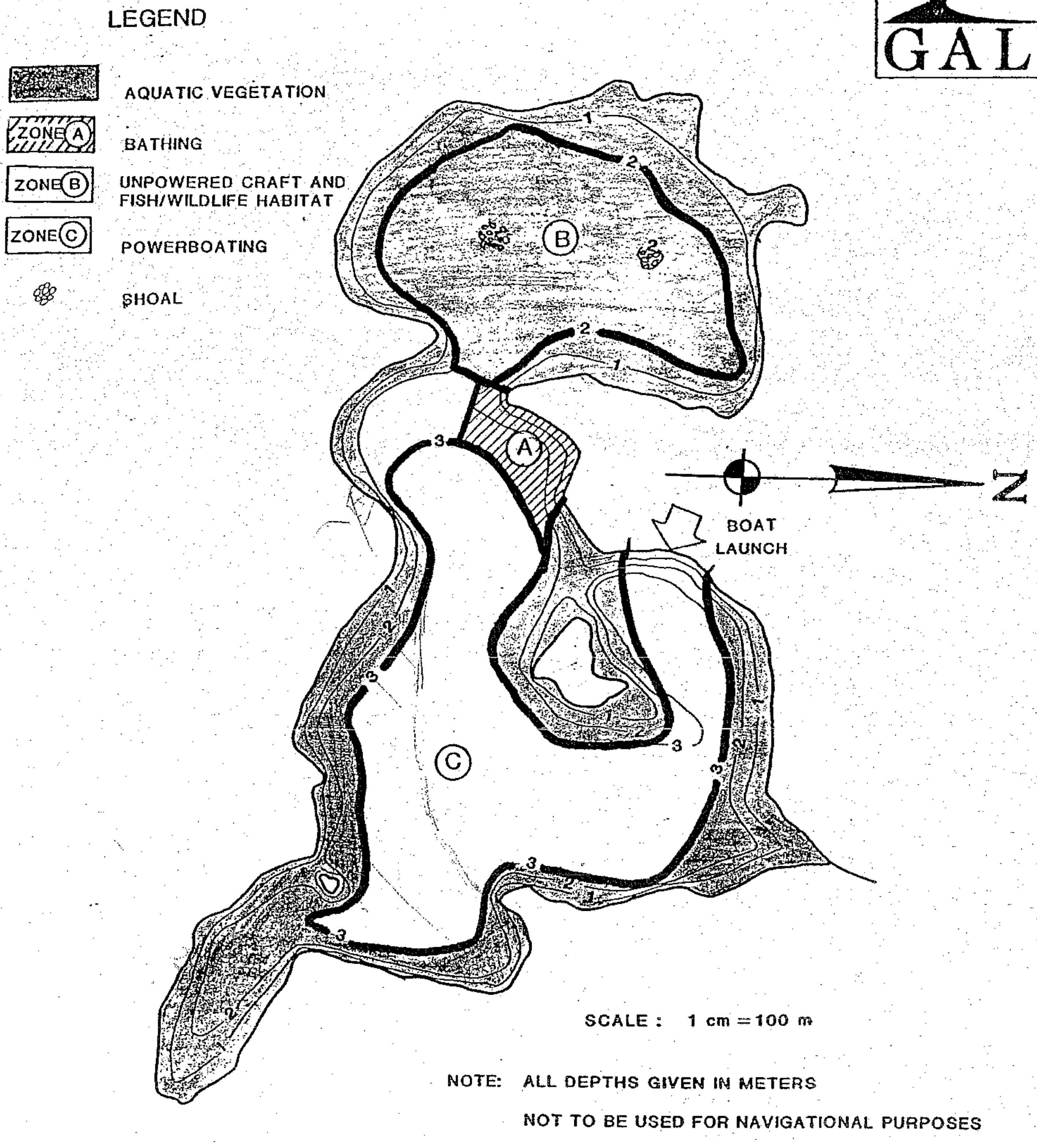


FIGURE 41. LAKE USE MAP

BILLINGTON SEA

PLYMOUTH, MASSACHUSETTS

according to lake hydrology (water depths) and vegetative cover. Zone A, which currently is a bathing area, appears to be the best location for this type of use in that this is shallow and characterized by sandy sediment and sparse vegetative growth. The boundaries of this bathing zone should be delineated with a float line and possibly a buoy sign warning powerboat operators to steer clear of this area. Weekly monitoring of fecal coliform bacterial densities and Secchi Disk depth, which indicates water column transparency, should be conducted in this area during the bathing season. Zone B, which includes most of the western basin, is shallow and heavily vegetated. This area is best suited for fisheries and wildlife habitat and recreational activities utilizing unpowered craft. Motorboating activities should be restricted to Zone C, which includes the largest amount of deep water area available in the lake, including a long stretch of deep water for water skiing. This basin supports less vegetative growth and contains the boat launch area.

Implementation of the proposed lake use plan will require public education and enforcement measures. Since many of the recreational users of the Billington Sea are not local residents, signs designating the uses of each zone are recommended. A permanent buoy sign, indicating "Danger no power allowed beyond this point", would, be beneficial if installed in the channel between the two basins. Boaters who are lakeshore residents can be set a good example by only utilizing the western basin of the lake for access to the eastern basin (Zone C).

3.3 Implementation of Recommendations

Implementation of the lake restoration project may be more effective if it is overseen by a Watershed Management Committee composed of at least one representative from the Conservation Commission, Board of Health and Planning Board, a Plymouth citizen from outside the watershed, a member from the Billington Sea Lake Association and a local cranberry grower. This committee would be charged with establishing a timetable and methodology for implementing the various restoration components. The committee would work with the Board of Health to implement the wastewater management recommendations and the planning board to implement the lake and land use zoning recommendations. This committee may establish a subcommittee to set up a public education program or gather and disseminate educational brochures and publicize seminars given by the Massachusetts Congress of Lake and Pond Associations themselves. This committee would work with the various lake user groups to see that each group's needs are met and concerns addressed. In particular, this group would work as a cooperative effort with the Cape Cod Cranberry Growers Association and the U.S. Soil Conservation Service to assist the growers with implementing the agricultural management practices.

Table 34 summarizes the permits required for implementing the watershed management and lake restoration recommendations, the potential impacts and possible funding sources for the project. Table 35 describes the various funding programs.

TABLE 34 Summary of Impacts, Permits, and Funding Sources for Recommended Management Alternatives

○ Maybe applicable

● Definitely Applicable

Program Components	Potential Impacts					Permits/Actions Required										Funding Sources					
	Noise	Traffic	Water Quality	Erosion/Siltation	Wildlife	Town Meeting	Planning Board Hearing	MA Natural Heritage Prog.-Appendix A	Notice of Intent (Ch. 131, S. 40)	DEP Water Quality Cert.	Army Corps 404	Chapter 91 Waterways License	MEPA (ENF/EIR)	Cooperative effort-Watershed Man.^Comm. & Cranberry Growers Assoc.	Board of Health Vote	Town of Plymouth	Clean Lakes Ch. 628, Phase II	ALA (310 CMR 24.00) (Aquifer Land Acquisition, DEP)	Self Help (Division of Conservation Services)	PL-566 Small Watershed Protection Program, SCS, USDA	Agricultural Conservation Program (ASCS, USDA)
Lake and Land Use Management																					
Land Use Zoning		○	●	●	●	●	●									●					
Lake Use Zoning			●	●	●	●	●	○	○							●					
Land Acquisition			●		●	●												●	●		
Public Education Program			●	●												●	●				
Wastewater Management																					
Board of Health Regulations			●												●						
Septic System Inspection and Compliance Documentation			●			○		●	●						●						
Agricultural Management																					
Bog Outfall Relocation/ Discharge Basin Construction			●	●	●			●	●	○	○	●	○	●						●	●
Best Management Practices			●	●	●			○	○					●						●	●
Reverse Layering			●	●	●	○		●	●	●	●	●	●			●	●				

TABLE 35. POTENTIAL FUNDING SOURCES

FUNDING SOURCE	TYPE OF WORK FUNDED	% FUNDED	1989 STATUS
Rivers and Harbors Program-Department of Environmental Management, Division of Waterways	Restoration & Preservation of Massachusetts Waterways	75%	No funds available until FY 1992
Public Access Board Dept. of Fisheries, Wildlife Law Enforcement Division	Design & Construction of public use access to ponds, lakes and coastal areas	100%	Applications taken presently. They work with legislature to aquire funds
Small Watersheds Protection Program(PL-566)	Agricultural Soil and Water Conservation Measures	60:40 Fed./Grower match, up to $100,000/grower	Long-term implementation, (approx. 4 years)
Aquifer Land Aquisition Program, Ch 286 Sec 5.20. DEQE	Purchase of land for water protection	For studies 100% to $50,000. Grants to $250,000 including purchase of land. $15,000,000 authorized.	No new grants until FY 1991
Agricultural Preservation Restoration Program		100% of purchase	Restricted. Probably nothing available until FY 1991
Feasibility Study Grants Executive Office of Community and Development	Grants made to towns w/less than 50,000 pop. for dredging projects	$30,000 limit per project	Future funding uncertain.

disposal systems, it does not appear to be a viable alternative in the near future. Upgrading of the overloaded Plymouth wastewater treatment facility is in the planning stages. An interim action plan for reducing wastewater loading to the lake is needed.

An interim plan for mitigating wastewater impacts to the Billington Sea involves the upgrading of failed and subgrade systems to meet Title V standards and local health bylaws. Sewage disposal systems located upgradient of leachate plumes identified from the septic leachate survey should be inspected in an attempt to identify operational failures and/or subgrade systems. Additional information regarding the condition of a disposal system may be available through the review of installation, repairs and tank pumping records, as well as through consultation with the Plymouth Health Agent. Proper septic system maintenance practices should be a component of a public education program initiated for watershed residents. The use of non-phosphate detergents, implementation of household water conservation measures, septic tank pumping frequency and the elimination of garbage disposals are among the issues which should be addressed.

The effectiveness of this mitigation measure is dependent upon the stringency of local bylaws and enforcement efforts. For example, the adoption of bylaws which require the upgrade of a system upon resale of a dwelling or the conversion from a seasonal to a year-round dwelling are useful enforcement tools.

Zoning/Land Use Planning

Land within the lake watershed and recharge zone should be managed in such a way as to minimize future impacts to the water quality of Billington Sea. The adoption and enforcement of zoning bylaws which establish watershed and aquifer protection zones would complement the use of existing land use control regulations to reduce nutrient loading. Delineation of the Billington Sea recharge zone, on Zoning Map Number 4 of the Aquifer Protection District (See Figure 36), would aid in enforcing the Plymouth aquifer protection bylaw for recreational waterbodies (401.17(C)(3)(A)). Undeveloped parcels of land located within critical nutrient loading zones may be earmarked for land aquisition and nutrient loading controls may be placed on future land development projects through the adoption of bylaws which regulate stormwater, wastewater, and agricultural discharges.

An example of a zoning bylaw that would contribute toward easing the nutrient loading to Billington Sea would be to require that any future residential development within 300 feet of the shoreline utilize pump-out holding tanks for septic waste. In addition, any existing system that has failed must be replaced by a holding tank.

Existing regulations such as 310 CMR 10.00 which pertain to wetlands protection, may also aid in the mitigation of land use impacts to the Billington Sea. The entire watershed is located within an area which contains habitat for rare wetland wildlife species (Figure 37), which means that even "limited projects" require the filing of an Appendix "A" form. Furthermore, the primary recharge zone for the Lout

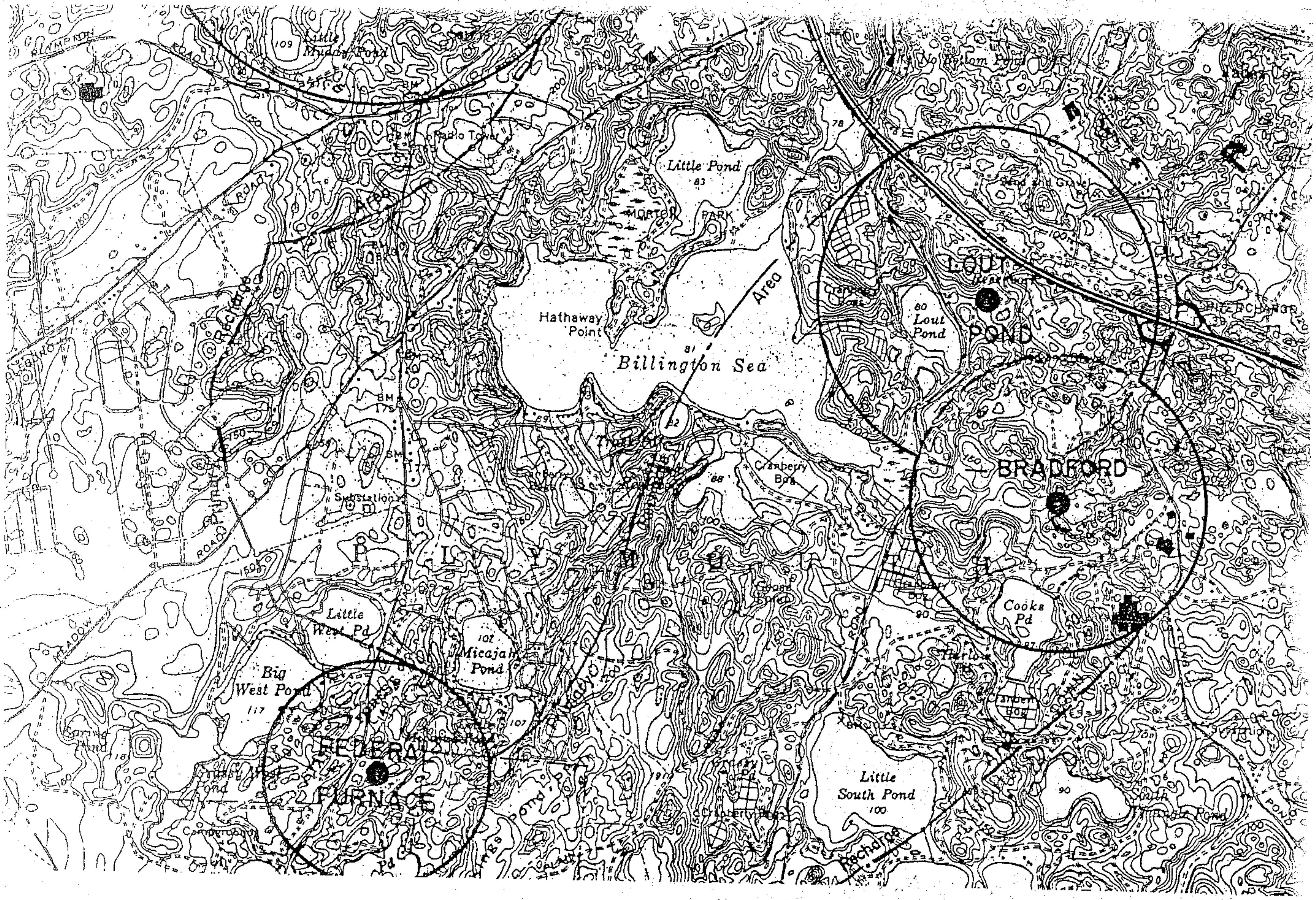


Figure 36. Aquifer Protection District-Zoning Map No. 4.

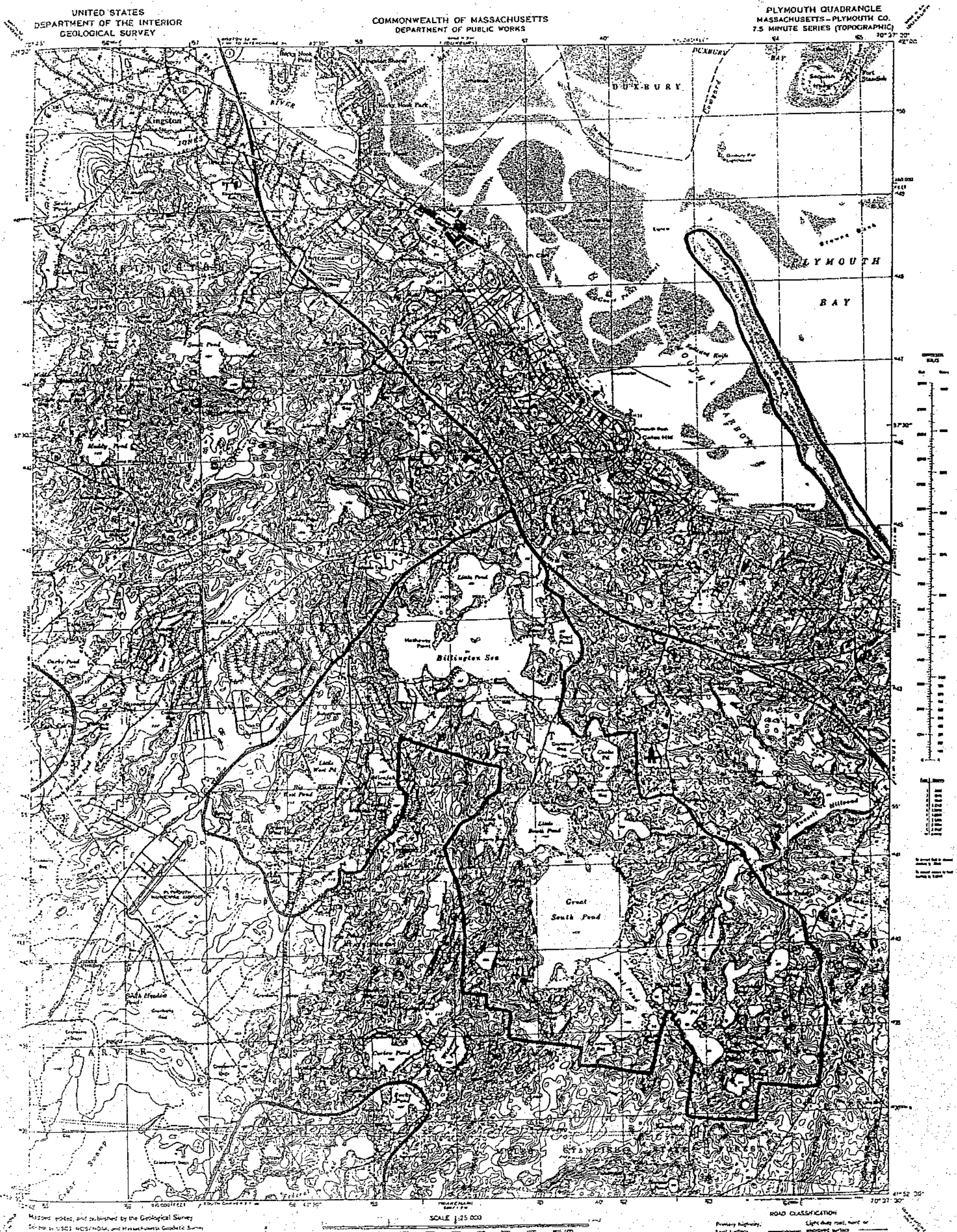


Figure 37

ESTIMATED HABITAT MAPS

Of State-listed Rare Wildlife Species that Occur in Wetlands

NOTE: ONLY FOR USE WITH THE WETLANDS PROTECTION ACT

Prepared by the Natural Heritage & Endangered Species Program

Massachusetts Division of Fisheries and Wildlife

[illegible] 1987

Pond well includes the Billington Sea and a large portion of the lake's recharge zone. Special restrictions apply to development projects in these areas.

Public Education Program

A public education program on the impacts of human activities on the Billington Sea would encourage public participation in the lake management and restoration efforts. Residents would be encouraged to implement "best management practices" for septic system maintenance, lakeshore lawncare, shoreline stabilization and the adoption of a lake use plan. Sources of information for this project include the Soil Conservation Service, the Plymouth County Cooperative Extension Service, the Old Colony Planning Counsel, and the Massachusetts Audubon Society.

3.2 In-Lake Restoration

Approximately thirty-nine percent (39%) of the phosphorus input and nineteen percent (19%) of the nitrogen input to the Billington Sea is accrued in the lake. Although some of this nutrient accrual is contained within the water column and plant biomass, the majority is contained within the uppermost layer of the lake sediment where it is available for aquatic plant and algal growth. Thick nutrient-rich deposits in the western basin of the Billington Sea have promoted excessive vegetation growth in this area. This plant growth may increase sedimentation, which reduces groundwater inflow and flushing, as well as impede in-lake water circulation and recreational usage of the lake for swimming and boating. Low dissolved oxygen levels in the lake, resulting from the high oxygen demand of these nutrient-rich deposits during the summer, may cause fish kills and the release of sediment phosphorus. This release can subsequently trigger algal blooms. Data collected during this study suggest that this internal nutrient recycling is occurring within the Billington Sea and that without its control the lake will continue to sustain dense aquatic plant growth and algal blooms.

The objective of the following in-lake mitigation measures are to control internal nutrient recycling, primarily by reducing the amount of nutrient-rich sediment which remains in contact with the overlying water column. Long-term in-lake restoration measures must be implemented following the relocation of bog discharges in order to improve and maintain the fisheries habitat, recreational and aesthethic values of the Billington Sea.

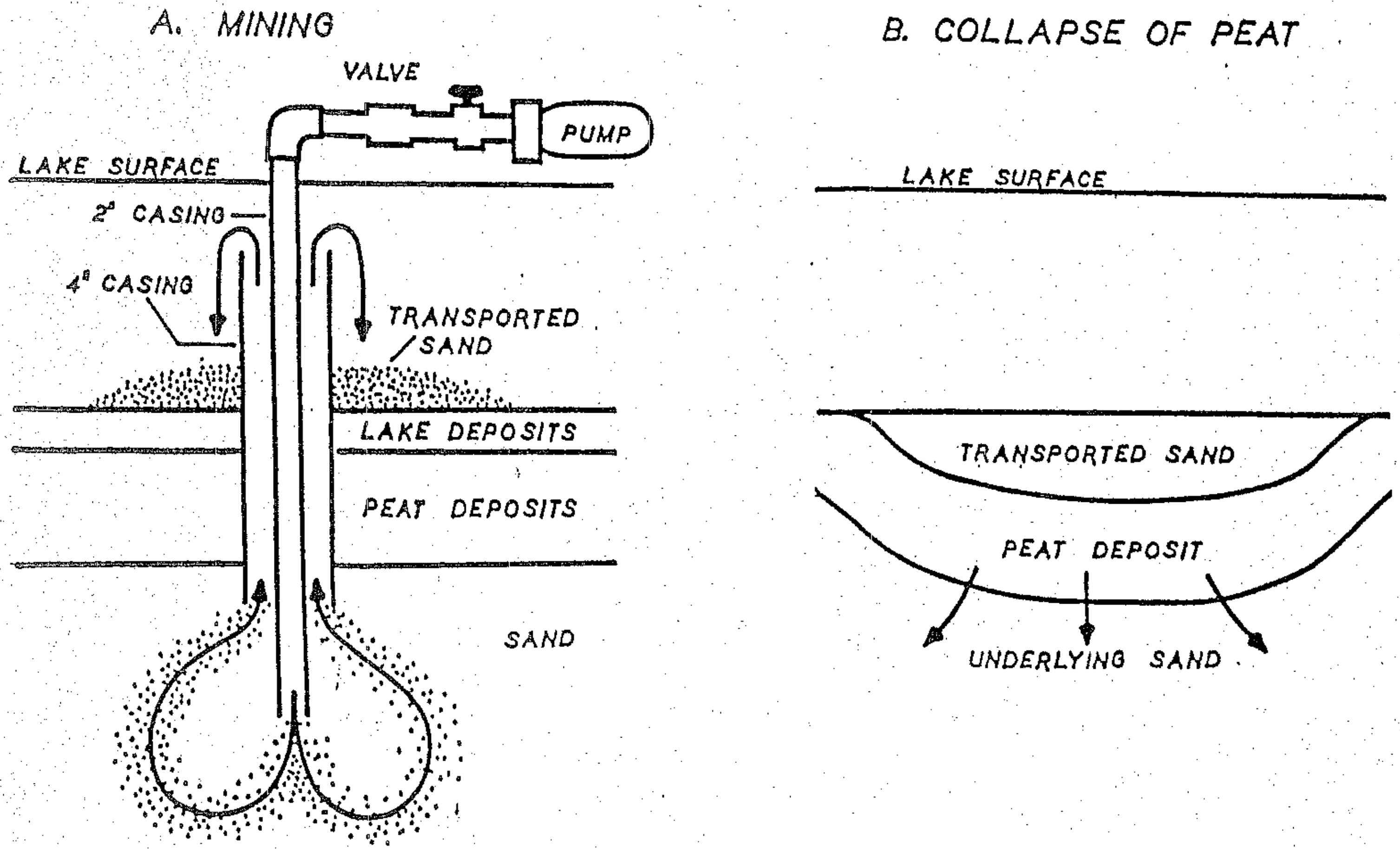
Sediment Cover (Reverse Layering)

Reverse Layering is an in-lake restoration technique which is currently being investigated with funds from the Clean Lakes Program for its effectiveness in reducing internal nutrient loading in Red Lily Pond (Barnstable) which is a euthrophic kettle lake such as the Billington Sea. (KV Associates, Inc., 1988). The process is based on conclusions derived from previous studies which demonstrate that sand applications of 15-20 cm. in depth can reduce the regrowth of aquatic plants by as much as 400% (Nichols, 1974, Peltier and Welch, 1969).

The procedure employs the use of a modified centrifugal "mud" pump to transport sand deposits located beneath the lake's nutrient-rich organic sediment and deposit them on top of this upper layer of sediment (Figure 38). Harvesting of aquatic plant biomass prior to conducting reverse layering would further retard plant regrowth. In addition to retarding plant regrowth, reverse layering may control internal nutrient loading by reducing the amount of nutrient-rich organic sediment remaining in contact with the water column and thus reducing the liklihood of sediment phosphorus release. Reverse layering is less costly than sediment removal and does not require the design and construction of a sediment disposal area. Environmental impacts from reverse layering may be reduced by conducting the procedure in alternating squares within a 100 ft. by 100 ft. grid to allow for recolonization of the lake bottom by benthic organisms. The resultant siltation is controlled with booms constructed of filter cloth and the use of a cyclone separator. Reverse layering may allow for some deepening of the lake by redepositing a portion of the mined sand in another location. This technique, however, should not be substituted as an alternative for sediment removal when the objective of the latter restoration technique is to remove contaminated lake sediments and to significantly deepen a lake.

Pump tests were conducted in order to determine the feasibility of employing reverse layering in the western basin (Figure 39) of the Billington Sea. This testing indicated that adequate sand deposits are located beneath the nutrient-rich organic sediments in the lake and that these deposits can be readily transported to the sediment surface. The dense beds of submerged aquatic vegetation and thick nutrient-rich organic deposits, located primarily within the western basin (Figure 40), are targeted for conducting reverse layering. The installation of

FIGURE 38. BOTTOM REJUVENATION BY REVERSE LAYERING



A. MINING

B. COLLAPSE OF PEAT

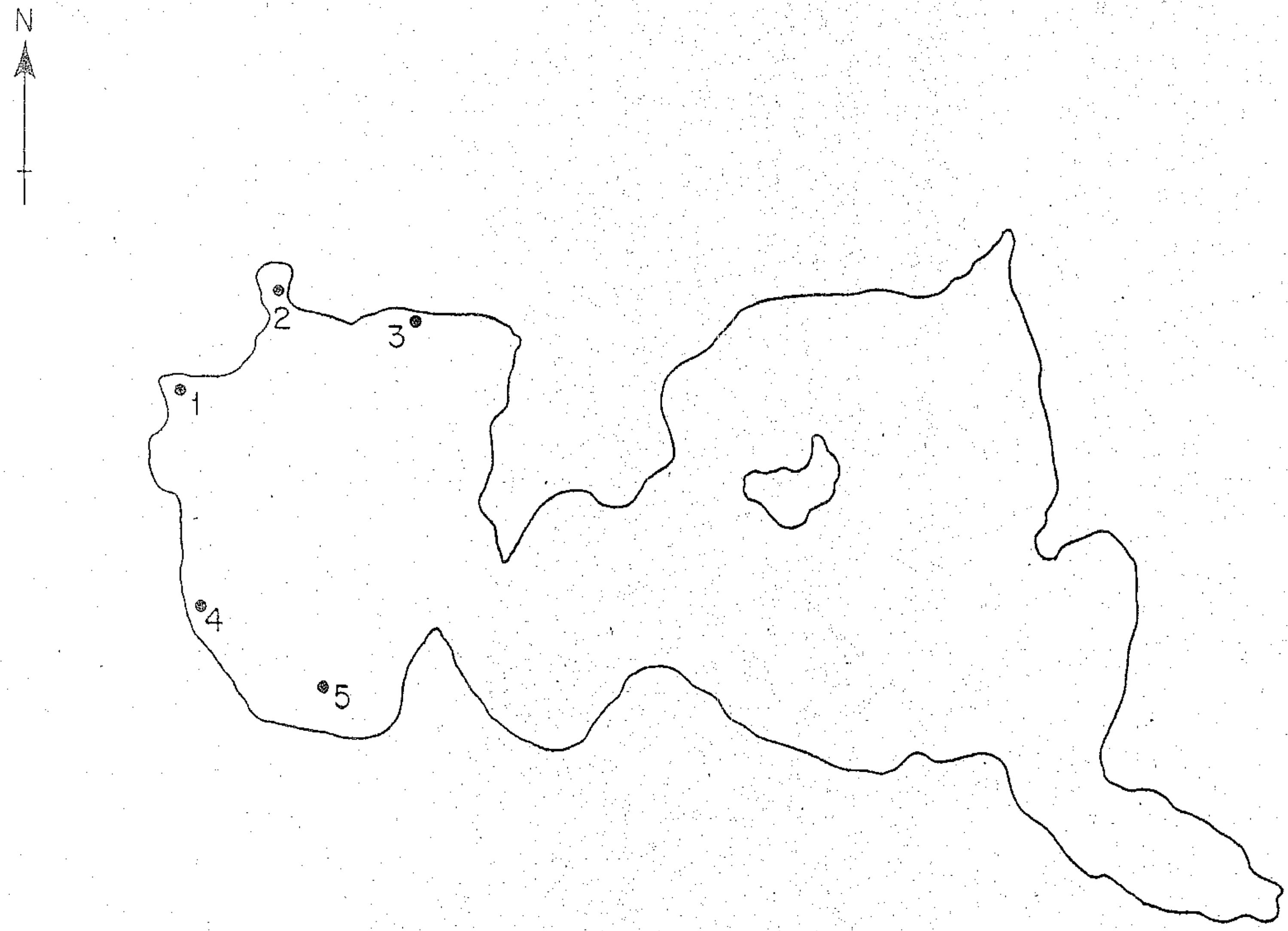


Figure 39. Lake bottom test locations for "Reverse Layering"

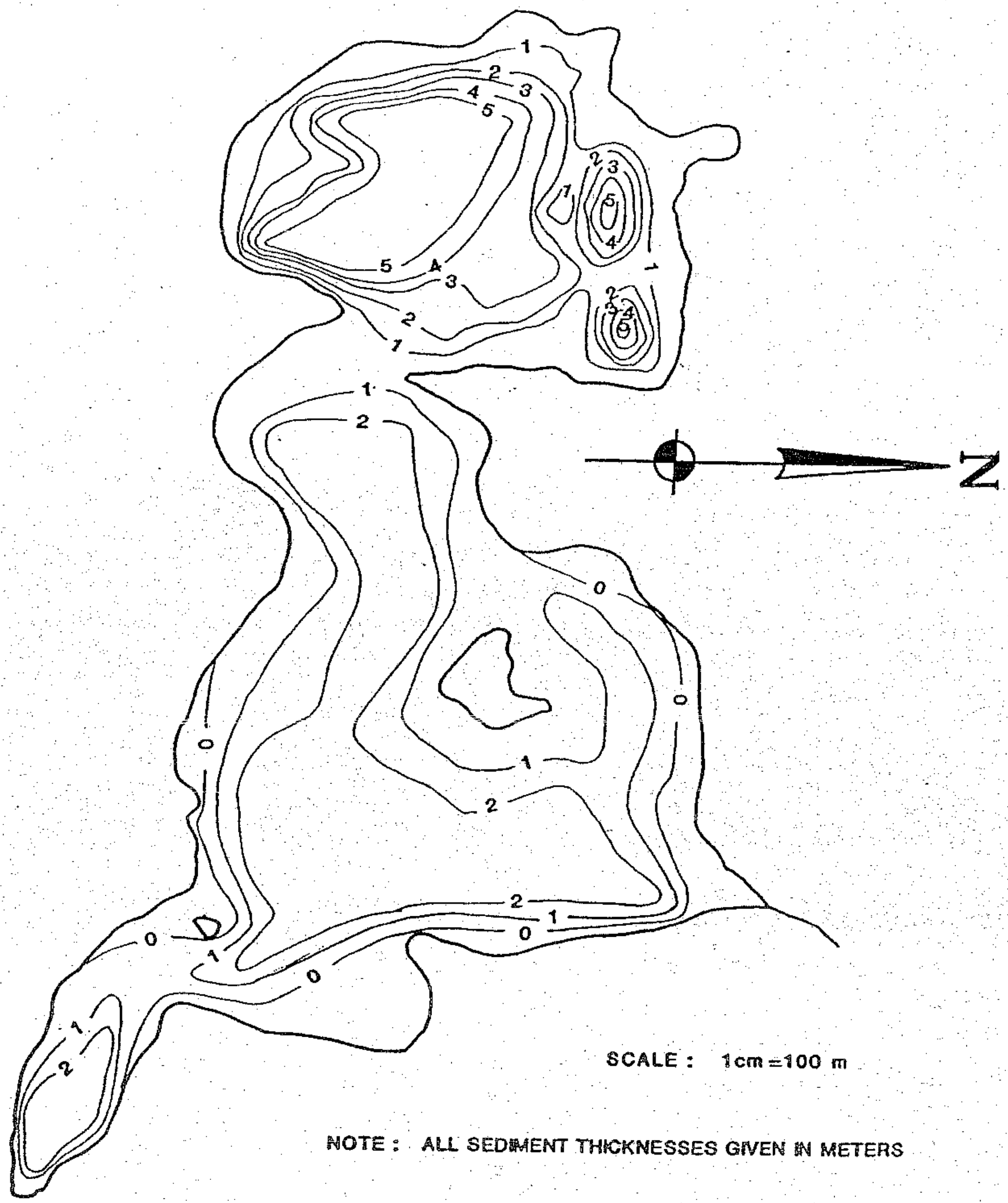


FIGURE 40. SOFT SEDIMENT THICKNESS MAP
BILLINGTON SEA
PLYMOUTH, MASSACHUSETTS

interception wells along the western shoreline of the lake may be neccessary in order to reduce the velocity of groundwater flow up through the buried nutrient-rich deposits. Secondly, the implementation of a lake use plan which restricts motorboat usage in the western basin is recommended in order to curtail the resuspension and transportation of silt in this shallow basin.

MECHANICAL

Harvesting. In recent years the use of commercially manufactured weed cutters/harvesters has become prevalent. There are several Massachusetts-based companies that provide contract weed harvesting services to municipalities and pond associations. Recently, several municipalities have purchased their own equipment for operation by Town DPW personnel. These machines range in cost from about $20,000 to $80,000, depending upon width of cut and load capacity. A small model harvester (i.e., Aquamarine H4-100) suitable for residential shorelines has a productivity of approximately 0.1 to 0.2 acres/hour. If the capital cost were $40,000 and written off over a period of 10 years, the annual cost would be $4,000.00. Assuming base labor costs were equivalent, the cost of operation runs about $200/acre with commercial companies, compared to about $100/acre, where a town owns its own harvester. Roughly 40 acres would have to be harvested annually for the break even point to be reached where income received balances cost of equipment.

The mechanical harvesters have sickle-bar type cutters which cut the weeds from a variable depth from the pond surface to a maximum of about five feet. Behind the horizontal/vertical cutter bars is a conveyor system which simultaneously collects the vegetation for on-board storage.

When a full load has been obtained, the harvester backs into shore and automatically empties it contents on shore. The vegetation may be trucked directly away by the contractor or else allowed to dewater for a day or two and then be picked up by the Town DPW for disposal.

Harvesting has the advantage over chemical because the vegetation is removed from the water body rather than decomposing. Harvesting projects are seldom followed by algal blooms and no potentially toxic materials are added to the water. However, waterlilies are controlled by harvesting for a period of only 2 to 3 weeks before complete regrowth occurs.

The direct purchase and operation of a small harvester by the Town of Plymouth for use at these and other public water bodies may make economic sense. The unit cost of weed harvesting with Town-owned equipment sharply declines as the machine is utilized to its capacity.

Most harvesting contractors charge hourly for their equipment plus a "lump sum" mobilization fee. The costs for harvesting a the Billington Sea are likely to be approximately $450/acre, including trucking of the cut vegetation. Harvesting should be directed at priority areas, such as access points used for shoreline fishing and secondly within areas of greatest plant biomass. Based upon 100 acres, the cost of one harvesting would probably run about $45,000.00. Two and preferable three harvests per summer would be desirable.

Unfortunately, at the current level of nutrient input, the beneficial effect would be short-lived. After 2-3 years, harvesting would have to be repeated to maintain clear shorelines.

HYDRO-RAKING

The hydro-raking consists of a barge propelled through the water by paddle wheels. On the barge is mounted a backhoe with a six-foot wide York-Rake digging attachment. Unlike a weed harvester, the Hydro-Rake is capable of scraping or digging soft bottom materials to a depth of 12 to 14 feet. The Hydro-Rake has no on-board storage capacity. Therefore, each rake-full (500 to 600 pounds) must be deposited either on-shore or else onto a separate transport barge.

The Hydro-Rake will effectively remove virtually all common types of aquatic vegetation but works best with tuberous rooted rhizome plants. Hydro-raking is not cost-effective on aquatic plants with fine root systems such as naiad and thin-leaved pondweeds. These species will fully regrow, usually within a year or two of raking. Hydroraking is not recommended for the Billington Sea since the dominant vegetation does not possess rhizomes or tubular roots.

BENTHIC BARRIERS

There are several types of commercially available benthic barriers that have specifically been developed to control nuisance aquatic vegetation. One such product, Aquascreen, is a coated fiberglass material that has the appearance of window screen. The mesh size has been developed to preclude sufficient light beneath the screening such that rooted aquatic plants cannot survive. The screening lies on the pond or pond bottom. Gases from the sediments or from decomposing vegetation can escape through the screen, in contrast to black plastic sheeting which often balloons when used for this purpose.

Aquascreen is usually ordered in panels 14 feet wide by 50 or 100 feet in length. The screening is priced at about $0.24/ft^2$ and pins to anchor the screening and installation are added costs. Screening is quite expensive when used to cover large areas. Material costs alone run approximately $10,454/acre, and installation is likely to cost an additional $3,000 or so. The manufacturer projects a minimum life expectancy of 10 years for the material. Screening may become ineffective within a year or two if used in proximity to storm drain outfalls or where tributaries enter a pond since sediment may accumulate on the screening. Plants may start to grow on top of the screening if it is covered with even a thin layer of sediment. Within the sea, sediment movement has been observed under strong wind conditions. Aquascreen or even lower-cost barriers such as Dartek (a black nylon material) are not recommended for large-scale use at the ponds. Decomposing weeds/algae and other suspended material which settles to the bottom would probably soon cover the screening. Further, it would not be desirable to cover all benthic life beneath the screen.

REVERSE LAYERING OF BOTTOM SEDIMENTS

The current regrowth of aquatic plants in the middle basin of Billington Sea demonstrates that without remedial action the lake will again become congested with submerged vegetation within a short period of time. The source of the problem is phosphorus-rich organic sediments. Regardless of reduction in nutrient inputs to the lake, this stored reservoir of plant fertilizer will promote regrowth unless removed by dredging or covered by blanketing. the proposed alternative of blanketing does not attempt to seal the lake sediments (as fly ash treatment does), but to bury the organic layer while maintaining a porous bottom substrate allowing flow to occur.

Sand application is a recognized retardant to establishment and growth of macrophytes. Scientific studies have been conducted on the effectiveness and impact of sand applications as a lake restoration process for over 30 years (Misra, 1938; Peltier and Welch, 1969; Nichols, 1974).

Application of sand/gravel onto existing sediments to thickness of 16-20 cm has been used to control macrophytes (Nichols, 1974). As a restoration technique, it is applicable to small areas, but usually not used in large lakes because costs/unit are high for transport and application (Welch, 1980). On Red Lily Pond in Barnstable where a test program is underway, the presence of beach sand underlying the organic sediment layer requires only that the original sand bottom sediments be brought up again to the surface - hence the term "reverse layering".

A test of the procedure was conducted off the Gavitt's dock at the base of Lake Elizabeth in April, 1986. A modified centrifugal "mud" pump was connected to a 2-inch ID PVC pipe placed down inside a 4-inch casing. The casing was initially hand-augered to 3 feet below the lake bottom through 2.7 feet of peat deposit. The hydraulic flow was adjusted to sufficient velocity to transport medium sand up the cross-sectional area between the 4-inch casing and 2-inch ID pipe. The transport sand volume was about 1% of water volume. The test showed that the underlying sand can be effectively transported to the surface. Similar testing has shown success of transport at the Billington Sea.

Advantages of application of sand:

1.) 15-20 cm (5-8 inches) layer of sand reduces by 400% regrowth of macrophytes (Peltier and Welch, 1969). Reduces colonization and species diversity, particularly submerged algae and weeds (Potamogeton, Myriophyllum, and Najas) (Pearsall, 1920, 1929).

2.) The porous sand substrate provides aeration to sediment and limits ion exchange with phosphorus.

3.) Improves the sandy substrate nesting sites for bluegills and bass. The increase in aerated sediment will decrease mortality by increasing egg and fry survival. Mortality is directly related to oxygen content and water movement.

4.) Penetration of the organic sediment layer encourages groundwater inflow.

Reduction of negative impacts during layering process:

1.) Circular booms would limit turbidity to working area. A cyclone separator may be used to segregate silt from the sand fraction.

2.) Patchwork approach allows macrophyte stands to be present outside working areas during sand application within confined working areas. Work could be staggered to allow recolonization of benthic (bottom) organisms during restoration activities.

3.) Vegetative harvesting would precede sand application to reduce regrowth.

4.) Bottom restoration work would involve a notice-of-intent proceeding and monitoring of impacts prior to, during, and after sand application.

5.) A research and development phase for defining most cost-effective and environmentally suitable procedure is being conducted initially on a limited area (3 acres) of Lake Elizabeth in the Town of Barnstable prior to conducting full-lake activities. A report on the results will be available in 1990 from the DEP.

TABLE 35. POTENTIAL FUNDING SOURCES(cont.)

Mass. Small Cities Program Executive Office of Community and Development	Dredging when it is associated with providing public service and improvements.	varies	Uncertain.
Federal Clean Lakes Program Sec 314 of PL 92-500, U.S. Environmental Protection Agency.	Restoration of lakes and ponds	50%	All funding is through state run programs.
Mass Clean Lakes Program, Ch 628 DEQE	Restoration of lakes and ponds		No grant program currently in existence
Pilgrim Resource Conservation and Developement Program,SCS,USDA	Agricultural Soil and Water Conservation Measures	100%	Technical assistance and funding referrals
Agricultural Conservation Program, ASCS, USDA	Agricultural Soil and Water Conservation Measures	75:25 Fed./Grower * $3,500/grower/yr	Highly recommended Fast implementation

* $30,000 has been requested by ASCS to be earmarked specifically for the funding of soil and water conservation measures on bogs in the Billington Sea watershed ("Special Project"), a long-term agreement may be signed by a grower which could entitle him to $35,000 to be awarded up front, or $3,500 per grower per year for up to ten (10) years

Only contribute
to Cranberry Growers
& agriculture not
to pond.

Implementation Monitoring Program

The following baseline water quality monitoring program should be conducted during the implementation period in order to ensure that the desired water quality improvement objectives are achieved. This monitoring program should also be conducted for a period of three (3) years following implementation of the recommendations in order to evaluate the effectiveness of the project. Additionally, programs which monitor water quality improvements from bog outfall relocations, on-site wastewater disposal system inspections and upgrading and "reverse layering" should also be conducted for this three (3) year period.

A. Baseline Water Quality Monitoring

Sampling Stations: In-lake Stations 1 (surface and 1.5m) and 2 (surface and 3.5m), Inlets A-E, and the Outlet

Sampling Frequency: First and third week of April, July, October and January (sample during two (2) storm events)

Water Quality Parameters:

- orthophosphate
- total phosphorus
- TKN
- nitrate-nitrogen
- ammonia-nitrogen
- dissolved oxygen (1-meter profiles at in-lake stations)
- conductivity
- pH
- total alkalinity
- total suspended solids
- chlorophyll a (in-lake stations only)
- Secchi disk (in-lake stations only)
- fecal coliform bacteria
- fecal streptococcus bacteria
- temperature (1-m profiles in-lake)
- phytoplankton composition and abundance (in-lake stations only, depth-integrated samples)
- discharge (Inlets A-E and outlet)

Other Sampling: macrophyton density and distribution during August (verify 1987 maps)

The estimated yearly cost would be approximately $100,000.00.

B. Bog Outfall Relocations

Sampling Stations: Tributaries A-E

Sampling Frequency: First and third week of April, July, October and January (sample during two (2) storm events which exceed 0.5 inches of rainfall)

Water Quality Parameters:

- discharge (use dye to detect low flow movement from bog into tributary)
- orthophosphate
- total phosphorus
- TKN
- nitrate-nitrogen
- chlorophyll a
- settleable solids
- dissolved oxygen
- pH
- conductivity
- total alkalinity
- total suspended solids

Other Sampling:	Well-point sampling of groundwater at three locations downgradient from each new discharge basin on one occasion for: orthophosphate total phosphorus TKN nitrate-nitrogen ammonia-nitrogen Groundwater flow direction and velocity at each of these three stations

C. On-site Wastewater Disposal System Inspections and Upgrading

Sampling Stations:	Septic leachate survey with Peeper Beeper Model 15 septic leachate detector along the western and southern lakeshore.
Sampling Frequency:	Once during late August
Water Quality Parameters:	Any leachate plumes shall be mapped and sampled for: fecal coliforms total phosphorus conductivity nitrate-nitrogen ammonia-nitrogen

D. "Reverse Layering"

Sampling Stations: In-lake Stations 1 and 2 (surface and bottom of water column) and the outlet.

Sampling Frequency: Weekly from two weeks prior through two weeks following "reverse layering".

Water Quality Parameters:
total suspended solids
total phosphorus
orthophosphate
chlorophyll a
settleable solids
dissolved oxygen

Other sampling prior to "reverse layering":

Contact Natural Heritage Program to map habitat of wetlands wildlife species. Verify distribution of organic lake sediments. Sample each "reverse layering" station for arsenic. Conduct a benthic faunal survey - sample four (4) square-meter quadrats for species abundance and diversity within each "reverse layering" area. Other sampling prior to and following "reverse layering":

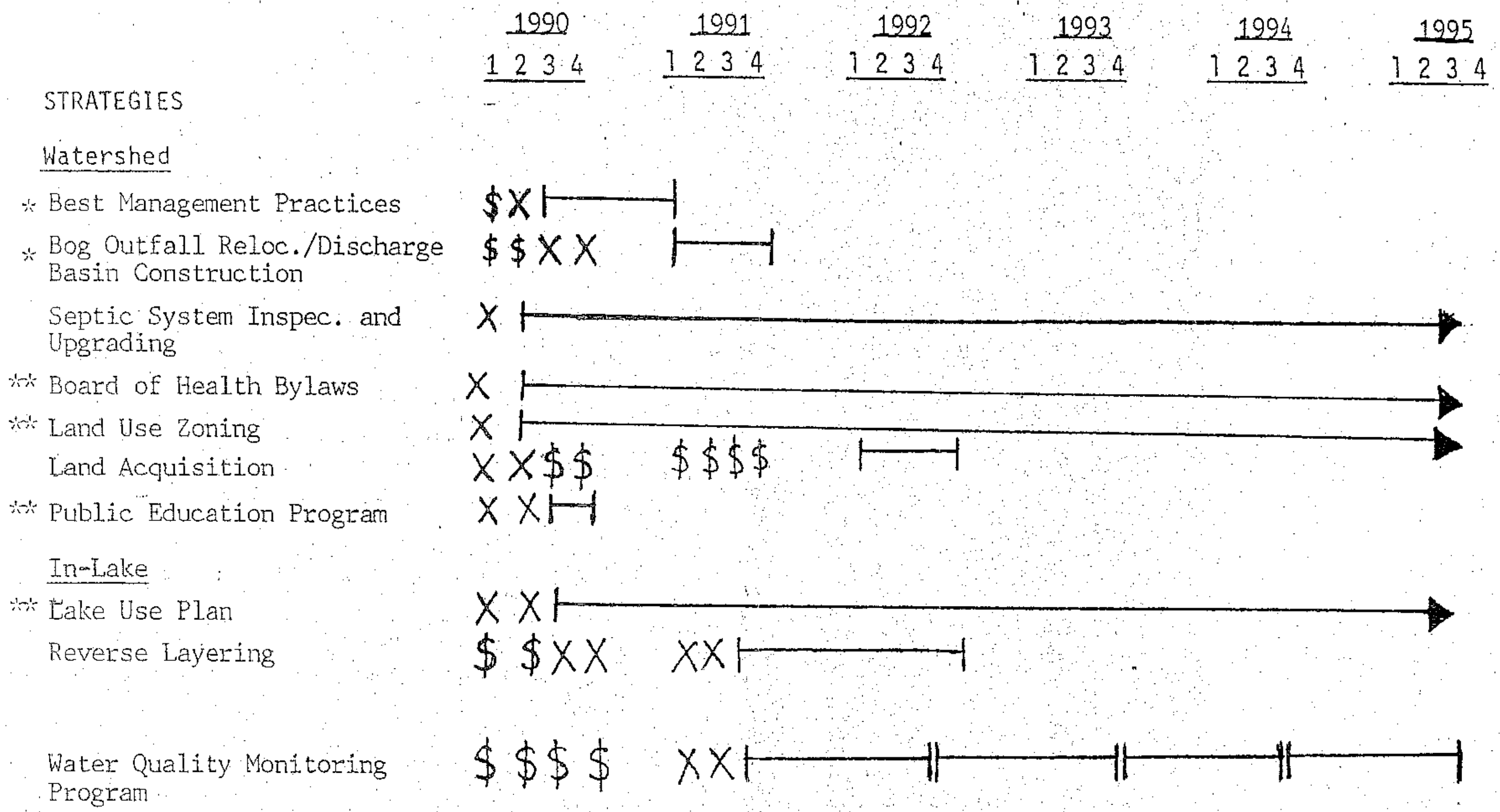
Fisheries survey (conducted by MDFW prior to and following "reverse layering") of relative abundance and species diversity, bass and pickerel P.S.D.

Fisheries survey (conducted by MDFW prior to and following "reverse layering") of relative abundance and species diversity, bass and pickerel P.S.D.

Macrophyton species distribution and density (prior to and following "reverse layering").

Table 36 presents the milestone schedule for implementing the monitoring and the other restoration recommendations.

Table 36. Milestone Schedule for the Restoration of the Billington Sea.



$$$$ Grant Application/Appropriation Municipal Funds

XXXX Final Engineering/Design

├─┤ Implementation/Construction

* Low or No Cost Measure with Immediate Water Quality Benefits (Maximize floodwater retention time on all bogs; Relocate Tributary D outfall to Reservoir Pond)

** Low or No Cost Measure with Long-term Water Quality Benefits

3.4 Public Hearing

PUBLIC COMMENTS – BILLINGTON SEA STUDY FINAL PUBLIC MEETING
January 25, 1990

Q: "How do you know which septic systems are discharging into the lake?"

A: "Additional investigations of septic systems located upgradient of the leachate plumes detected during the shoreline septic leachate survey are nesessary. The Plymouth Board of Health must conduct inspections and dye testing of these systems to detect operational failures and subgrade septic systems.

Q: "How will the lake use plan be enforced? It will be difficult to control motorboat use on the lake."

A: "The Department of Fisheries, Wildlife, and Environmental Law Enforcement has the authority to regulate motorboat activity on Great Ponds in Massachusetts. It is suggested that the Town contact them to request assistance in drafting a bylaw to regulate motorboat use on the Town's lakes and ponds. The lake use plan relies on visual signs and the honor system since no enforceable boating bylaws currently exist in Plymouth. The signs should emphasize public safety and be posted in key locations. Bathing areas should be posted as such and their boundaries designated by floating markers. Posting the word 'DANGER' on the sign located at Hathaway Point should prevent most visitors from operating their motorboats in the restricted area, the western basin. The western shoreline residents should set a good example by only operating their motorboats in this area to get to and from docks and moorings."

Q: Were the copper sulphate and sodium arsenate treatments of the lake beneficial?"

A: "Both treatments consisted of herbicides applied to control the lake's algae blooms, however they may have caused more harm than good. Data collected before and after the sodium arsenate treatments indicate a post-treatment reduction in the species diversity of the benthic invertebrate community and elimination of important fish food sources. Additionally, elevated arsenic levels were detected in the sediments at in-lake station 2 in the eastern basin."

Q: "Will homeowners be able to have 'reverse-layering' conducted along their shorelines and docks?"

A: "'Reverse-layering' is still being tested as a lake restoration measure in a Research and Development Program. If public funds are awarded through a state grant program to conduct 'reverse-layering', public bathing areas and densely vegetated portions of the western basin will likely be given top priority."

Q: "Isn't 'reverse-layering' just a way of burying the problem so that the next generation will have to deal with it?"

A: "No, the permits necessary to conduct 'reverse-layering' require tesing of the sediments for pollutants. During the permit process it would be determined whether sediment removal is necessary depending on the concentration and type of pollutant detected."

Q: "How do you know which direction the groundwater flows in relation to the lake?"

A: "A K-V Associates, Inc. flowmeter was inserted into 17 holes augered into the shoreline sediment of the lake perimeter. This flowmeter was calibrated to the shoreline sediments and was used to measure groundwater flow directions and velocity. Groundwater moves into the lake or recharges it along all shorelines except the eastern shoreline where it discharges in the direction of Lout Pond."

Q: "Who will fund the work needed to improve the water quality of the cranberry bog discharges?"

A: "Several funding sources, mainly Federal cost-share programs currently exist. A cost-share program administered by the ASCS, entitled the Agricultural Conservation Program, is still available to cranberry growers who agree to pay 25% of their costs to install soil and water conservation measures in their bogs. Approximately $30,000.00 has been earmarked for such improvements to bogs in the Billington Sea watershed and is available to cranberry growers who volunteer to make these improvements. Additional funding sources are the PL-566, Small Watersheds Protection Program, which will fund up to 60% of such improvements to cranberry bogs and the Massachusetts Nonpoint Source Pollution Control

Program grant for controlling agricultural runoff. Technical assistance is also available from the regional Soil Conservation Service office and the Cape Cod Cranberry Growers Association. The Growers Association is in the process of establishing criteria and methods for assessing soil and water conservation needs on bogs. Perhaps the Billington Sea cranberry bogs could be used in a pilot program for these assessments."

Q: "What can lakeshore residents do on their own to improve the lake's water quality? I harvest the weeds growing around my dock and beach."

A: "Lakeshore residents can reduce Environmental impacts to the lake by: 1) upgrading their septic system if it is subgrade and/or it has failed, 2) utilizing no phosphate fertilizers and detergents, 3) not utilizing gargage disposals, 4) not disposing of oil, paint and/or other household hazardous materials in household drains or street drains, 5) enforcing the lake use plan, and 6) applying for permits to conduct work on or within 100 feet of the lake."

Q: "Did you sample all of the drinking water wells around the lake's shoreline? If so, what is the general water quality in these wells?"

A: "No, but shoreline wells were sampled in 1981 by GeoScience and the results indicated that several wells are receiving septic leachate discharges. K-V Associates, Inc. found similar results when they analyzed groundwater samples collected with a well point sampler. Shoreline residents should periodically have the water quality of their well supplies tested by a State-certified laboratory."

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APPENDICES

Appendix A

November, 1988

LIMITS OF DETECTION

~TEST~	~METHODOLOGY~	~LIMITS OF DETECTION~
pH	Method NO. 423	0-14
Total Alkalinity	Method No. 403	1 mg/l
Nitrate	*Method No. 353.1	.02 mg/l
Ammonia	*Method No. 350.2	.01 mg/l
Total Kjeldahl Nitrogen	*Method No. 351.2	.04 mg/l
Total Phosphate	Method No. 424(C) & 424(E)	.01 mg/l
Ortho Phosphate	Method 424(E)	.01 mg/l
Chloride	Method No. 407(A)	1 mg/l
Manganese	Method No. 303(A)	.02 mg/l
Cadmium	" "	0.02
Chromium	" "	0.02
Copper	" "	0.02
Iron	" "	0.02
Lead	" "	0.10
Nickel	" "	0.04
Zinc	" "	0.02
Vanadium	Method No. 305	0.02
Arsenic	Method No. 304	0.005
Mercury	Method No. 320(A)	0.0005
Turbidity	Method No. 214(A)	.1 NTU
Total Suspended Solids	Method No. 209(C)	1 mg/l

Appendix B

CRANBERRY FERTILIZER CHART

I.E. DEMORANVILLE
C.J. DEMORANVILLE

CRANBERRY EXPERIMENT STATION, MASS. AGRICULTURAL EXPERIMENT STATION,
COOPERATIVE EXTENSION
REVISED January 28, 1986

This chart is intended to furnish general treatments: Detailed information may be obtained from the Cranberry Experiment Station, East Wareham, Mass.

NOTICE: The Cranberry Experiment Station and its staff does not assume any responsibility for personal injury or property damage.

NOTES

1. **GOOD DRAINAGE AND ADEQUATE IRRIGATION** are essential for best response to fertilizer. Soil Moisture in the top inch should be checked twice a week with a soil sampler during the growing season. One inch of water per week from rain or irrigation is ample. If no rainfall occurs, ½ inch applications by sprinkler at 3 or 4 day intervals are best.
2. **DISCOLORATION** similar to nitrogen deficiency may be caused by insect, red mite or disease injury.
3. **FERTILIZER RATIOS** of 1:2:1 and 1:2:2 can be expected to produce a better response than a 1:1:1 ratio. Balanced applications of NPK plus minor elements can be expected to produce better results than NPK alone.
4. **SUSCEPTIBILITY TO SPRING FROST INJURY** may be increased by fertilizer applied in the fall or early spring. Fall fertilizer application (Oct.-Nov.) increases resistance of vines to winterkill injury.
5. **KEEPING QUALITY AND COLOR** may be impaired by excessive use of nitrogen because of increased shading and higher moisture.
6. Sprinkler systems may be used to apply fertilizer but unless distribution is uniform fertilization will not be uniform. The system should be checked before using it to apply fertilizer. Foliar feeding is used to supplement a balanced soil fertilizer program, not to replace it.
7. A calcium-boron combination (CaB, Leffingwell; no other product was tested) at 2 qt/A improved set. Application in full bloom three years in a row had no adverse effects. Application by aircraft is more effective than sprinkler application. If possible, apply early in the morning. May not work on bogs treated with maneb or mancozeb, or with a micronutrient package containing manganese.
   One application in early bloom (about 10%) is suggested. *Do not use more than indicated and do not use CaB if the leaf analysis (samples taken in May) shows boron levels above 75 ppm.* The combination should be more effective than the individual nutrients.
8. Avoid manganese on bogs treated with maneb or mancozeb. Manganese may lower yields.
9. Use soil and tissue analyses only to help you make decisions. Your experience is more important than a computer printout.

FERTILIZER FOR CRANBERRY BOGS

	RECOMMENDATION	TIMING	
PRODUCTIVE VINES			
Yields above 100-120 bbl/A.	20-40 lb/A nitrogen per year depending on yield, growth and bog condition.	Early bud elongation (Roughneck)	10-20% of total
Early Black New Growth 2-3½ inches			
Howes New Growth 2½-4 inches	Formulation used should be based on soil analysis.	Early (10%) bloom	See Note 7.
		Full bloom	60-70% of total
		August 5-15	10-20% of total
		October-November	2-4 lb/A nitrogen See Note 4.
OVER VEGETATIVE VINES			
Early Black New Growth over 3½ inches	If excessive runner growth and uprights use NO nitrogen. Use P and K according to soil analysis.	as for productive vines	
Howes New Growth over 4 inches	If runner growth and uprights not excessive use 50% of normal nitrogen dosage.	NO nitrogen before bloom	
WEAK VINES			
Early Black New Growth less than 2 inches	40 lb/A nitrogen	as for productive vines	
Howes New Growth less than 2½ inches			
NEW OR REBUILT BOGS			
Vines should be pushed during the first two years. Transition towards production in the third year.			

lb/A nitrogen

first year	second year	third year	
20	20	5	April
10	10	10	Roughneck
10	10	15	Full bloom
10	10	5	August

Complete fertilizer may be used.
Use micronutrients where deficiencies have been diagnosed.

FERTILIZER NEEDED PER ACRE

GRADE	RATIO*	FOR 20 lb/A N	FOR 40 lb/A N
10-20-20	1:2:2	200	400
10-20-10	1:2:1	200	400
12-24-12	1:2:1	167	334
13-34-10	1:2.6:0.8	154	308
14-14-14	1:1:1	143	286

~TEST~	~METHODOLOGY~	~LIMITS OF DETECTION~
Total Volatile Solids	Method No. 209(F)	1 mg/l
Oil & Grease (Sediment)	Method No. 503(A)	0.1 mg/l
Chlorophyll a	Method NO. 1002(G)	.05 mg/m^3
Pcb's	*Method No. 608	Dependent upon sample
Fecal Coliform Bacteria	Method No. 909(C)	1 - 100 colonies/100 ml Dependent upon sample
Fecal Streptococcus "	Method No. 910(B)	1 - 100 colonies/100 ml Dependent upon sample

Referenced procedures were taken from "Standard Methods for the Examination of Water and Wastewater, 16th Edition, 1985".

*All procedures referenced with an asterisk were taken from: EPA-600/4-83 Edition "Methods For Chemical Analysis of Water and Wastes".

Appendix C

CRANBERRY CULTURE AND THE ENVIRONMENT CONFERENCE

SPONSORED BY:

Cape Cod Conservation District
Cape Cod Cranberry Growers Association
Ocean Spray Cranberries, Inc.
USDA-Soil Conservation Service
Cape Cod Cooperative Extension

Daniel Webster Inn
Sandwich, Massachusetts

January 22, 1987

General Cranberry Cultural Practices....Irving Demoranville, Director
Cranberry Experiment Station

Generally, cultural practices have been divided into seasons of the year beginning with winter management which is December through early March. We begin with winter flood for the protection of the dormant cranberry plants against wind and low temperatures. The cranberry plant is shallow-rooted with most of the roots being in the top four inches of soil. When temperatures are below freezing and the ground is frozen with winds blowing consistently for at least seventy-two hours, plants are extremely susceptible to drying out. This condition is winter dessication or "winterkill". This winterkill process begins with the terminal, or tip, bud being killed and proceeding to kill leaves and stem of the plant. To my knowledge, there has never been an instance where the roots are killed. The roots will remain alive and will regenerate the plant, but there will be no crop that year. What is visible and evident is that everything above ground turns brown and dies. The usual time for beginning winter flood is the first half of December. It will be left on until early March if other complications are not experienced.

One complication in winter management is oxygen deficiency injury which may occur if there is snow cover on top of the ice or a melting/freezing situation. This creates opaque ice or snow ice which blocks the sunlight causing the plants to deplete the oxygen in the water. The cranberry plant is alive but dormant and when sunlight cannot get through to replenish oxygen, oxygen-deficiency injury occurs. The plant survives by breaking down its food reserves which results in a stress situation. Oxygen-deficiency injury is very, very difficult to assess. There are various stages and some bogs are more prone to injury than others. Commonly, there are signs ranging from a minor loss of leaves to complete defoliation with a resulting reduction in crop. But the plant does not die. This occurs in the early spring after removal of the winter flood when the plants start to "green up" and grow. The old leaves will fall off and the bog resembles a field of dead twigs. This condition can be avoided by draining the water from under the ice and leaving the snow and ice cover which affords protection. If there are conditions, such as a January thaw, the bog must be reflooded if possible, because winterkill can occur through the first week of March.

Cranberry bogs are sanded in the winter to protect from breakage, friction burns, and other winter-related injuries. The cranberry plant requires a thin (1/2") layer of sand spread over the bog surface every three to five years. Besides being an injury preventive, sanding also renourishes the bogs. It is a necessary cultural practice and should be performed when the ice is thick enough to hold the weight of the spreading equipment and the load of sand. Ice thickness should be at least five to six inches.

Spring management usually begins in early March and lasts to mid-June. We begin with the re-assembling of the sprinkler systems which should have been disassembled in early winter. Generally speaking, the sprinkler lines are buried, but risers and sprinkler heads are above the bog surface and must be taken out and brought in r the winter or ice breakage will occur. Sanding can also be done in the spring but only if absolutely necessary and then only from mid-March to late April. Sprinkling as a cultural practice is vital to crop protection because of the very crucial danger of crop loss from frost. Almost any amount of crop can be lost in just one night of frost on unprotected bogs. The general time to take preventive measures against frost begins in late April and runs until mid-June. There are exceptions, but this is the general time. The purpose is to prevent injury from cold temperatures or frost to the blossom buds and from the vegetative material. The cranberry vine has what are called "uprights" right in the tip where there is the terminal bud. This is where the flower buds and all future growth of the plant is located and this is what is being protected in the spring. Fortunately, there is a certain amount of natural hardiness. At the beginning of the season, in late April, the terminal bud will withstand temperatures of 20°F and even a little colder. As the season progresses and approaches mid-May, the bud will only withstand temperatures of approximately 30°F. We don't worry about 32°F. This hardiness tolerance is the tolerance of the bud to withstand temperatures.

Weed control begins with spring management and there are many, many weeds on bogs. They cannot be controlled by conventional agricultural practices such as cultivating or harrowing as there is a mplete groundcover. Handweeding is expensive and finding labor to the job is difficult. We rely on chemicals which are applied in spring during the dormant or semi-dormant period of the plants. All of the herbicides used during this period are granular.

Regarding fertilization, there are differing ideas and recommendations. We recommend having a first application in late May with a complete application of fertilizer-nitrogen, phosphorous, potassium as a granular formulation. Cranberries do not use as much fertilizer as most other plants. As a general rule, use about one-fifth of the total amount of fertilizer during the first application in late May.

Insect control gets into the IPM program and to me, it is the second most important practice in cranberry growing right behind frost control. I tell people that if they can control frost and insects, they stand a good chance of raising a crop of cranberries. The bogs should be monitored weekly beginning in the latter part of May. Sweep nets or long-handled insect or butterfly nets are used. The procedure is to walk across the bogs, swinging the nets across the tips of the vines and using a certain number of sweeps - 25, 50 - whatever. Then fold up the net so that nothing gets out of it and then count the insects that are in the net that are injurious to cranberry plants, flowers, or fruit. If there is an insect pest that exceeds a specified number listed on our spray recommendations, eatment is necessary. This is called the "economic threshhold" and used in the IPM program now, but has been in use by cranberry growers for many, many years. Simply stated, it means the number of insects per acre that will cause more damage than the cost of the treatment. If the number is below the "economic threshhold", we do not recommend treatment.

The summer management period is from mid-June to mid-September. Insects should be monitored as is done in the spring using the IPM practices, etc. By early July, the fruit worm or berry worm appears against which the sweep-net method of insect control cannot be used because the moth emerges, lays the egg in the calex end of the berry, whereupon the worm hatches, enters the berry and eats the inside going from one berry to another. Monitoring for fruitworm means picking green berries at random and using a magnifying glass, look for the eggs in the calex end. If two eggs per 100 berries are found, it's time to treat. There is a more recent method where the cranberry flowers are monitored. The cranberry blooms over a period of about four weeks (the flowers open up over this period of time) where there are approximately as many open flowers as small berries and unopened flowers - the bog is 50% in bloom. Seven days after that, the first treatment is applied. This method seems to be working out very well.

Disease control is usually necessary to control fungi that cause uit rots either in the field or in storage. There have been more stances of plant diseases in recent years. Current and future treatment will have to include keeping the plants disease-free as well as the berries. Disease control applications are over by early August.

Most weed control is done in the spring. For cleaning up summer weeds, we make a herbicide solution for use with a sponge-type applicator and swab the weeds being careful not to touch the vines. This practice is generally begun in mid-July with a minimum time interval before harvest which is usually thirty days. Some weed-control substances will have a shorter interval and some will have a longer one.

Fertilizing should begin in late June with a minor element spray of a calcium-boron mixture which increases the set of the berries. In early July, complete fertilization should be done again being about three-fourths of the total fertilization. In late July and early August the other one-fifth should be applied. We work toward a total of thirty pounds of nitrogen per acre per season. This is our recommendation. Some bogs will not require that much fertilizer. They become over-vegetative and the fruit quality declines.

Even though the cranberry flower is botanically considered to be a perfect flower (having both male and female components), it must be cross-pollinated. The pollen is heavy and the orientation of the blossom is such that never "the twain shall meet". Bees carrying the pollen from one flower to another are really the only method that works. Most growers will rent bees which are delivered in mid-June and stay for about five or six weeks. We recommend one healthy hive per acre or per two acres, depending on the situation. There are an average of fifty million flowers per acre. Generally speaking, a flowering upright will have one to five blossoms although two to four is the common number. Try as we may, we haven't been able to come up with much better than a twenty to twenty-five percent of fruit set which is one flower of five sets a berry. Sometimes a grower can do better.

The sprinkler system comes into play again with irrigation. From mid-June to early September, or about ten weeks, is the growing season when the plant needs an inch of water per week. If it does not rain, use the sprinkler system. We recommend a half-inch per application twice a week when necessary.

Fall management begins in mid-September and proceeds to November and primarily consists of protecting the crop from frost prior to harvest and then harvesting. Frost protection at this time means protecting the fruit, not the plant, as the fruit is not frost hardy. The grower begins his frost protection in early September and continues until the harvest is finished.

There are two types of harvest. Dry harvest has been the method from the very beginning of cranberry growing. The method includes everything from picking the berries by hand; picking them with small, one-handed scoops which are called "snap machines" which are seen probably only in museums now; the regular scoop for which two hands are needed and which is seen in pictures or used as magazine racks; and the mechanical harvest machines. In Massachusetts we must have the dry-harvested berries for fresh fruit. The dry berries are delivered in one-third barrel boxes. A barrel equals 100 pounds and the boxes hold 33-35 pounds of berries. The berries can also be delivered in bulk bins which hold about ten barrels each.

The other type of harvest is wet and most berries will not stand up as fresh fruit. They don't have the shelf life. This wet harvest is a relatively new process in Massachusetts having been initiated only in the past fifteen years or so. Now, ninety percent of the crop is harvested in water. In Wisconsin this has been common practice for eighty to one hundred years or perhaps more. The whole secret of water harvest and the way it works is that the cranberry floats and everything is harvested, as opposed to dry harvested operations where a conservative estimate is that twenty percent are lost. Water harvest is faster and uses less labor; however, the berries must be dried and de-trashed after harvest because everything on the bog floats! - dead leaves, pieces of weeds, everything - so the berries have to be separated. Trailer trucks are used with a capacity of four hundred barrels to deliver the berries to whomever will be selling them.

It is interesting to note that water-harvested berries, which are brought in and dried and then put in a freezer, can be used for any processed product. But if the berries freeze on the vines, they are of no value.

***

Fate of Chemicals in Cranberry Bog Systems..............Karl Deubert
Cranberry Experiment Station

Residues of pesticides used in agricultural operations have been detected in groundwater in areas with intensive agricultural roduction (primarily midwestern United States and California). In Massachusetts, pesticide residues have been found in groundwater in the Connecticut River Valley, also an area with intensive agriculture.

Most pesticides used in cranberry production are sprayed on the plants where 50-80% of the used amounts are intercepted by leaves and washed off later. Chemicals that reach the ground are largely absorbed and retained by soil organic matter and broken down by soil micro-organisms. Both processes occur simultaneously and their duration depends on the nature of the chemical involved.

Experiments have shown that 1 inch of simulated precipitation applied 15 minutes after the application of three chemicals, left approximately 98% of the three chemicals in the top 2 inch soil layer. In other words, the chemicals did not move as freely as the water did. Field samples have shown little or no chemicals at >18 inches. Modern chemicals are short-lived in contrast to the old ones (>90% breakdown in 1-2 weeks on the average), and the chances for a residue to move >12 inches are remote.

Most chemicals are used during the peak of the growing season (June - July) where evaporation from the soil surface and transpiration by plants remove more water from the top soil than atural precipitation supplies. This results in little or no replenishment of the groundwater supply during the summer months and even water soluble chemicals hardly move past the root zone at this time of the year. Loss of water makes it necessary to irrigate a bog during the summer. The amounts of water used for this purpose are about equal to the amounts of water lost to the atmosphere.

Cranberry bogs are built on wetland, that is, in areas with poor drainage. One of our studies has shown that under cranberry bogs there is an impervious layer which probably separates cranberry bogs from groundwater supplies used for human consumption.

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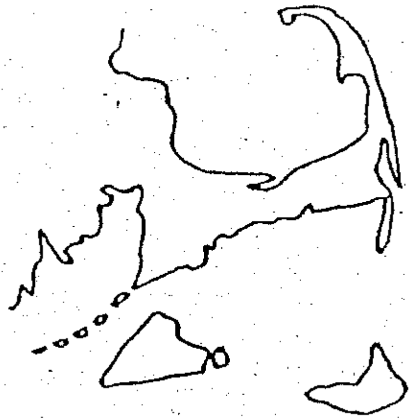
INFORMATION SHEET



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PHOSPHORUS

GENERAL

Phosphorus (P) is present in larger quantities in seeds than in any other part of the plant. Young growing parts contain considerable amounts of P.

The efficiency of P uptake by the plant is increased in the presence of nitrogen.

FUNCTIONS AND EFFECTS

P is used to store and transfer energy within the plant. It is utilized in the formation of nucleic acids (DNA, RNA).

P stimulates early growth and flowering, promotes fruiting and seed production, encourages root development, balances the effects of excess nitrogen. P stimulates more vigorous plant growth thus making plants more resistant to most diseases.

DEFICIENCY SYMPTOMS

Deficiency symptoms can easily go unnoticed. The following symptoms have been observed on plants other than cranberries: slow growth, stunted plants, delayed maturity, poor grain, fruit or seed development, reddish-purple or pinkish coloration of leaves and/or stems.

Cranberries show "a slight reddening of all upright leaves. Severe shortage changes the color to purplish red" (Pacific Northwest Coop. Ext. Bull. 247).

It may be difficult to observe these symptoms on the bog because of the extensive use of fertilizer. In case of doubt a tissue analysis is indicated (see TISSUE ANALYSIS).

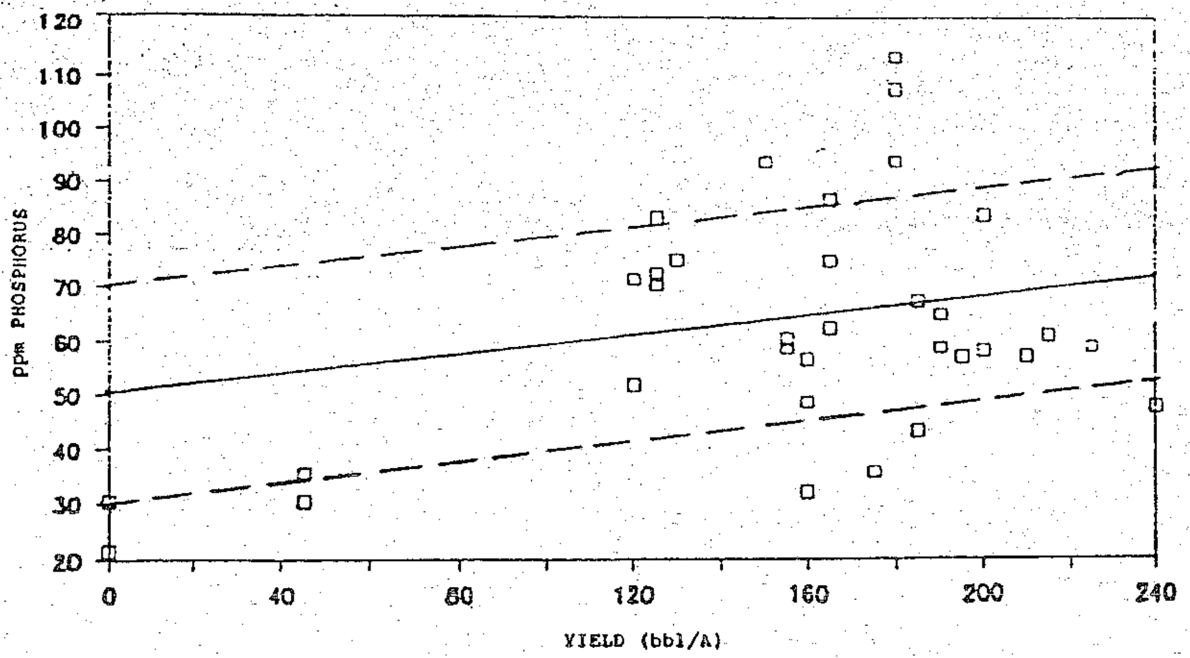
Table 2. Soil P using Bray (note 1, last page). To convert to lb/A, see CONVERSION FACTORS.

Phosphorus (ppm)	No. of Bogs (Per Cent)
<20.1	12
20.1-40.0	25
40.1-60.0	27
60.1-80.0	15
>80.0	21

The smaller the amount of soil used in the analysis, the larger the variation of the results regardless of the extraction method. Therefore, good judgement is needed in the evaluation of soil P tests.

A comparison of soil P (Bray, note 1, last page) with productivity shows that more productive bogs contain more P than less productive bogs (Fig. 1).

Fig. 1. Soil P (Bray, note 1, last page) and productivity of Howes. The area between the broken lines (standard deviation) contains data which are considered of equal importance when compared to yield data, e.g., there is no significant difference between the two P levels associated with 200 bbl/A.



TISSUE ANALYSIS

Foliar P levels vary according to the developmental stage of the plant (Fig. 2), temperature and soil moisture.

REMOVAL OF NUTRIENTS

A crop of 100 bbl fruit or one ton of leaves remove about the same amount of P (1-1.2 lb/A P each, or about 2.3-2.8 lb/A P_2O_5). These data may vary considerably.

To replace P removed with one crop including leaves apply 4.6-5.6 lbs P_2O_5 for a 100 bbl/A crop, 6.9-8.4 lb P_2O_5 for a 200 bbl/A crop, and 9.2-11.2 lb/A P_2O_5 for a 300 bbl/A crop. For fertilizer equivalents see Table 3.

Table 3. Maintenance fertilizer dosages in lb/A (approximate) according to removal by crop and leaves (note 2, last page).

lb/A Fertilizer if the crop was			
100 bbl/A	200 bbl/A	300 bbl/A	Grade
46-56	69-84	92-112	10-10-10
33-40	49-60	66-80	14-14-14
29-35	43-53	58-70	16-16-16
24-29	36-44	48-59	19-19-19
23-28	35-42	46-56	0-20-0
23-28	35-42	46-56	5-20-20
23-28	35-42	46-56	10-20-10
23-28	35-42	46-56	10-20-20
19-23	29-35	38-47	12-24-12
14-16	20-25	27-33	13-34-10

TO RAISE SOIL P

Raising the soil P level is a long term project because of the amounts of fertilizer P needed. To raise the P level in the top 5 in. soil layer by 1 ppm, 3.45 lb/A P_2O_5 is needed. To find the amounts of fertilizers to raise the soil P in the top 5 in. by 10 ppm see Table 4.

Table 4. Fertilizer in lb/A (approximate) required to raise soil P by 10 ppm (Bray, note 1, last page) in the top 5 in. soil layer (note 2, last page). P_2O_5 requirement: 34.5 lb/A.

lb/A Fertilizer	Grade
345	10-10-10
246	14-14-14
216	16-16-16
182	19-19-19
173	0-20-0
173	5-20-20
173	10-20-10
173	10-20-20
144	12-24-12
101	13-34-10

APPENDIX E

INFORMATION SHEET

UNIVERSITY OF MASSACHUSETTS
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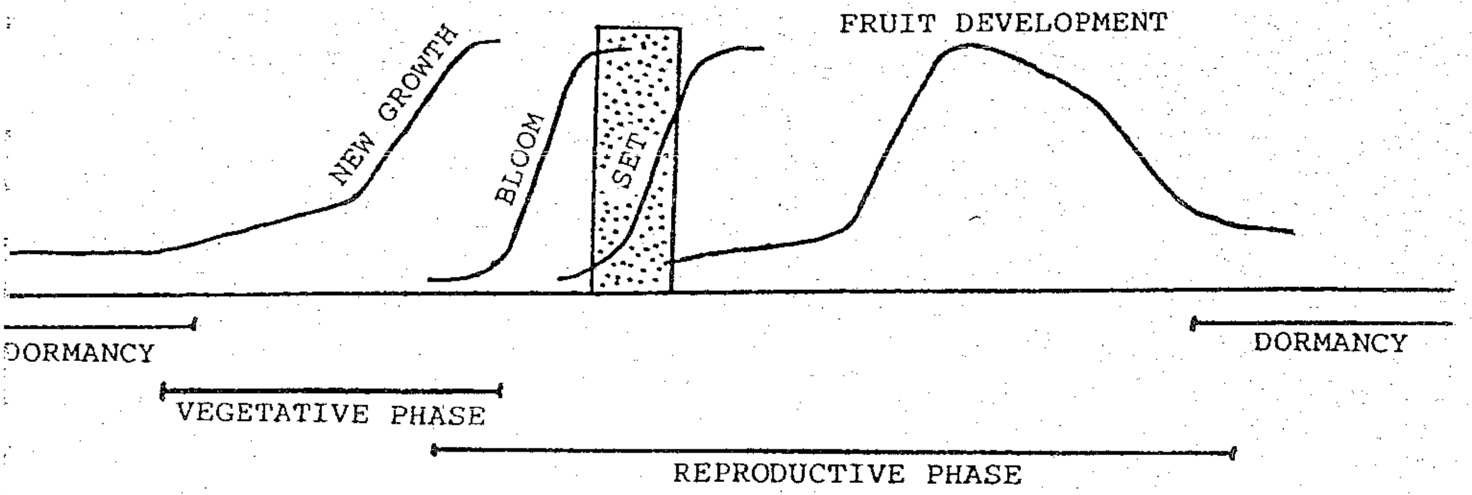
DEVELOPMENTAL STAGES AND SUGGESTED FERTILIZER TIMING

Based on the results of our studies on foliar nutrient levels we present a graph that may be useful in timing fertilizer applications. The graph presents various developmental stages which start slowly, then progress strongly and level off. The developmental stages are fit into a general growth pattern (dormancy, vegetative phase, reproductive phase) to facilitate the selection of fertilizers and the timing of applications.



DORMANCY

During dormancy the physiological activities of the plant are slow and nutrient requirements are low. The duration of dormancy is influenced by nitrogen doses applied at the end of the growing season. In general, large to moderate nitrogen doses (>10 lb/A N) applied in the second half of the growing season (after early in August) and moderate doses (>5 lb/A N) after harvest tend to prolong the growing season thus shortening dormancy. Furthermore, after a big foliar calcium, boron and manganese levels drop to a seasonal low which suggests a stress situation which could affect set and, therefore, yield. Based on this observation, calcium, boron and manganese sprays were tested in 3-year field experiments. The best effects of calcium-boron on set (average 30% increase on 11 bogs- hand, sprinkler and helicopter applications) were obtained with split applications early in June and in full bloom. Applications late in bloom and after bloom were less effective. Manganese sprays had little or no effect alone and negated the effect of calcium-boron when the two were used together.

An adequate NPK supply is necessary to provide nutrients for the early development of the fruit. Application of a 1:2:2 during early fruit growth (early in August) should supply enough nutrients to insure good growth of berries provided the weather cooperates.

Nitrogen doses applied later in the season may delay the ripening process, and problems with early frost become a good possibility.

After harvest, a small N dose (<4-5 lb/A N) may restore the vigor of the plants. A well-fed bog may not need more fertilizer. An overdose will delay dormancy and result in early development in spring with increased susceptibility to frost.

SUMMARY

1. Nitrogen during the vegetative phase (April-June) tends to push vegetative growth.

2. The use of high phosphorus grades is suggested for bloom fertilizer applications.

3. Calcium and boron are needed in full bloom because foliar levels at this time are at their lowest (see Information sheets on calcium and boron). The plants probably get all the manganese they need from that available in the soil.

4. A 1:2:2 during early fruit growth (early in August) will help berries to grow if the weather is favorable.

6. After harvest, if a bog needs it, a small dose of a 1:1:1 or 1:2:2 (<5 lb/A N) may be helpful.

September 26, 1986

INFORMATION SHEET

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295-2212, 295-2213

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CAPE COD CRANBERRY GROWERS ASSOCIATION

NITROGEN

GENERAL

Nitrogen (N) is the "Big Guy" among the plant nutrients. Although N has been studied more than the PROCESS nutrients, effective N management still presents a greater challenge than does that of any other nutrient.

Most of the other nutrients have certain residual values (depending on soil conditions) and build up in the soil, whereas N fertilizer is applied on a crop-by-crop basis. Since the availability of soil N in bog soil depends on soil temperature and moisture, weather conditions along with plant growth are the most important factors determining the amounts of fertilizer N to be used.

FUNCTIONS AND EFFECTS

Plants utilize N to form amino acids needed in the synthesis of proteins. N is required in the formation of chlorophyll, it governs to a certain extent the utilization of other nutrients, and it encourages vegetative growth.

If applied in excess, maturation may be delayed by excessive vegetative growth (delayed ripening, increased susceptibility to frost damage). Fruit quality may be impaired and resistance to most diseases is reduced.

N is used to maintain optimal vegetative growth to support best possible fruit production.

DEFICIENCY SYMPTOMS

In general, N deficiency affects vegetative growth and stunted plants with small leaves may be the result. Lack of N

SOIL ANALYSIS

Soil analysis for total N estimates the presence of both fixed and available N. Since there is a correlation between soil N and organic matter, soil N can be predicted if organic matter has been determined (Table 1). Approximately 10-40% of the soil N is available during the season.

Table 1. Soil N in lb/A in the 0-5 in. soil layer based on organic matter.

Organic Matter Per Cent	Soil N lb/A
1.0	15.0
1.5	22.5
2.0	30.0
2.5	37.5

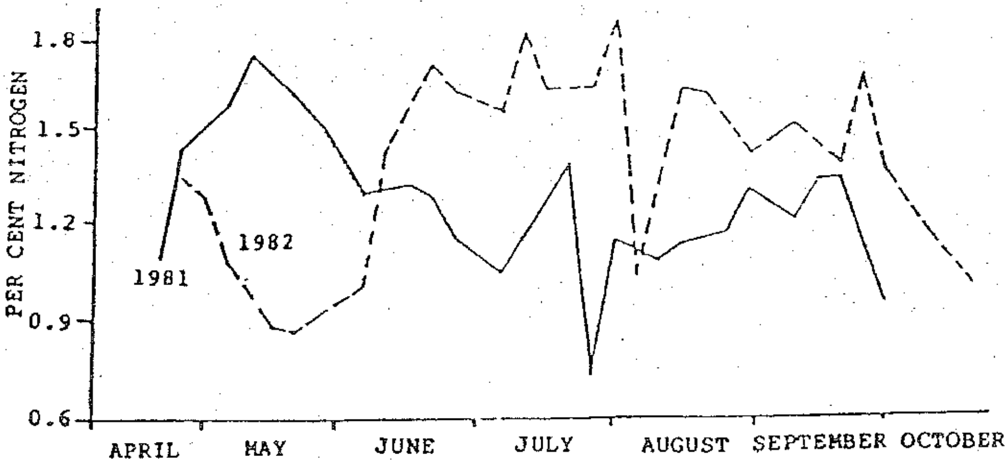
No guidelines have been established yet to interprete the amounts of ammonium determined in soil analyses.

Most of the nitrate contained in fertilizer will leach into the ground.

TISSUE ANALYSIS

Foliar N levels vary according to the developmental stage of the plant (Fig. 1), temperature and soil moisture.

Figure 1. Foliar N levels throughout the 1981 and 1982 seasons. Howes, 9 bogs, sampled weekly.



Factors affecting foliar N levels:

1. Developmental stage (Fig. 1): Comparable patterns in

Table 3. N in lb/A recommended according to the length of the new growth.

Early Black	Howes		
New Growth (inch)	New Growth (inch)	N lb/A	Condition
<2.0	<2.5	40	Weak vines
2.0-3.5	2.5-4.0	20-40	Producing vines
>3.5	>4.0	0-20	Overvegetative vines

In the case of overvegetative vines (>400-500 uprights/sq.foot and light runner growth) one should not increase the presently used amounts of nitrogen. Where there is above average runner growth, lowering of the nitrogen dosage is indicated. If runner growth is excessive, omit N at least in the pre-bloom application. During and after bloom small amounts to support set, bud formation and fruit development may be indicated. The reason for this is to reduce vegetative growth without hurting the crop unduely.

In productive vines the N fertilizer should contain at leaast the amounts of N removed with the last crop. For example, Early Black with about 3 in. new growth on a bog that had a crop of about 200 bbl/A (see Table 3, 2-3.5 in.), the recommended amount is between 20 and 40 lb/A N ; then go to REMOVAL OF NUTRIENTS (paragraph 2) and find 25 lb/A N for a 200 bbl/A crop. The recommended dosage would be 25-30 lb/A N. The final adjustment must be made using the grower's experience with the bog.

Weak vines need vegetative growth to support an adequate crop, and the removal of N with the last crop is of minor importance.

Overdosages impair quality and color of the fruit, favor runner growth and most diseases, and make plants susceptible to frost damage (early use of sprinklers for frost protection).

Timing: Regular pre-bloom dosages may produce runner growth. The probable reason is that when temperatures in spring, particularly in April and June, are above average, more soil N is released. At average spring temperatures the amounts of soil N are lower. Therefore, the N dosage that caused runner growth in one year may not produce runners in the next year and vice cersa. The pre-bloom N dosage should be small and can be supplied in May or early in June to support the new growth. Where the vines are weak, a first pre-bloom application in April followed by a second pre-bloom application late in May may be of advantage. About 10-20% of the total dosage may be applied before bloom.

Appendix G

DRAFT

WATER CONSERVATION
AND
UTILIZATION STUDY

Southeastern Massachusetts

U.S. Department of Agriculture

Soil Conservation Service

February 1986

Introduction

It has been said many times that water is the life blood of the cranberry industry in southeastern Massachusetts. Cranberry plants require a plentiful supply of water for frost protection of the buds and berries in the spring and fall as well as for summer irrigation to meet crop needs. Most growers harvest the crop by flooding the bogs and floating the berries for collection. Water is needed to flood the bogs in the winter to protect the vines from "winter kill". In comparison with other crops that utilize water only for plant growth needs, the water needs of the cranberry bog are several times higher on a per-acre basis. An adequate supply of water is necessary nearly year around if cranberry production i to be optimized. Most of the cranberry grower's need for water is for non-consumptive use for a short period of time before returning the wate to the groundwater or surface water system. Many of the ponds and reservoirs in the cranberry growing areas were developed by growers to assure themselves of a dependable source of water.

In Massachusetts, cranberry growing is concentrated in Plymouth County with significant but lesser acreage in Barnstable, Bristol, Nantucket, Dukes, Norfolk, and Worcester Counties. The cranberry growing area lies south of Boston and east of Providence, Rhode Island. Newly completed additions to the Interstate Highway System are making this once somewhat isolated rural area into a more attractive residential area for city workers. High technology industries which have concentrated along Massachusetts Route 128 are now expanding outward and a new high tech manufacturing boom is occurring along Interstate Route 495, the outer beltway around Boston.

As demands for municipal water supply increase, state government has responded with a series of programs intended to bring additional order and long range thought to water resource planning in the Commonwealth. Municipalities are required to develop plan for meeting long term water supply needs. Guidelines are being developed to encourage communities to implement water conservation stategies to control demand growth and waste of water. Of special interest to cranberry growers has been the effort t pass legislation to require large-scale users of water to register their water use with state government and to ultimately develop a permit system and allocation plan for water resources in river basins that are experiencing chronic water shortages.

With the situation of increasing urbanization of the cranberry growing region of Massachusetts, statewide needs for water, and greater state and local government control of water resources, cranberry growers have been concerned about protecting the water supplies that are so vital to their enterprise. Of special interest to the cranberry growers is documentatic of present water use and needs to support applications for withdrawal permits should this become necessary. Growers are also interested in determining measures to conserve water and reduce water use to the minim required to efficiently produce a crop. State government agencies are interested in developing accurate agricultural water use estimates for various river basins in the state in order to develop present water need data and to develop components for a future allocation plan if such is dictated by increasing demand.

This Water Conservation and Utilization Study was instituted to address some of the needs for water use data in the cranberry growing region Massachusetts and to evaluate the potentials and benefits for installation of measures to reduce water needs in cranberry production.

Data Gathering

In order to obtain accurate information concerning the water needs of the cranberry growers, a questionnaire form was developed by the Cape Cod Cranberry Growers Association in cooperation with the USDA, Soil Conservation Service (SCS) and the U.S. Geological Survey (USGS).

Cranberry bog locations were delineated on USGS 1:25000 scale topographic quadrangle sheets by SCS personnel. Bog locations were identified from several sources including bog symbols on the USGS quads, aerial photographic interpretation, Massachusetts Map Down cover and land u maps, and local knowledge possessed by SCS employees. A unique identification number was assigned to each bog. Ownership information fo each bog was determined from the data in the file of the county SCS and Agricultural Stabilization and Conservation Service offices. After bog ownership was determined, a questionnaire with the owner's name and bog identification number was attached to a photocopy of the USGS quad sheet indicating the location of the bog. Questionnaires and attached maps wer mailed to growers with a cover letter explaining the need for accurate data and requesting the grower to complete the survey and return the questionnaire. THe Cape Cod Cranberry Growers Association provided postage for mailing questionnaires and The Massachusetts Cranberry Experiment Station performed the functions necessary to mail the survey.

The Pilgrim Resource Conservation and Development office personnel tabulated returned surveys. After three months, growers who had not returned questionnaires were contacted by telephone and asked to return the completed questionnaire. After two additional months, SCS personnel made field visits to accessible bogs to obtain basic water management data(acres of bog, sprinkler situation, and readily apparently needed measures to promote water conservation).

All of the information obtained from the questionnaires and SCS field visits was entered into an electronic data base. This was done to put the information into a format that could be manipulated to analyse various portions of the data. For bogs where no questionnaires were returned or where field visits were not made, only the bog number,owners name, and bo acreage was entered into the data base.

Questionnaires and field visits generated data for 546 cranberry bogs covering 7566 acres. Data was thus obtained for 63.4% of the 11,939 acr of the identified producing bogs in the study area counties of Massachusetts. Average size of the bogs with water use data collected (13.9 acres) was higher than the average size bog (7.2 acres) for which questionnaire data was not obtained. This may have been due to the fact that small bogs were not visited by SCS employees in order to maximize t acreage that could be visited in a limited period of time. In addition, more concerted effort was expended to obtain data from owners with large acreages who ,coincidently, had larger average size bogs.

Utilizing the portion of the data base for bogs represented by returned questionnaires or SCS field visits, a number of numerical summaries wer made. This data is presented in Table 1.

Table 1

Summary of Data From Bog Owner Questionnaires and SCS Field Visits

Item	Number	Acres	Item as % of Number of bogs	Item as Acres of bogs
--Bogs With Data--	546	7565	100	100
--Sprinkler Systems--				
Sprinklered Acreage		7341		97.
Unsprinklered Acreage		224		3.
--Harvest Method--				
Wet Harvested Acreage		5921		76.
Dry Harvested Acreage		1634		21.
--Bogs Reusing Harvest Water--	26[illegible]	4615	47.8	61.
--Waterholding Capability--				
Bogs with Poor Waterholding	35	250	6.4	3.
Bogs with Fair Waterholding	122	1674	22.3	22.
Bogs with Good Waterholding	303	4027	55.5	53.
--Source of Water--				
Stream as Sole Source	71	829	13.0	11.
Reservoir or Pond as Sole Source	278	4273	50.[illegible] 56.5	[illegible]
Well as Sole Source	3	64	0.5	[illegible]
Municipal Water as Sole Source	3	3	0.5	0.
Stream and Pond as Source	92	1242	16.8	16.
Stream and Well as Source	17	316	3.1	4.
Pond and Well as Source	70	891	12.8	11.
Municipal and Well as Source	1	3	0.2	0.
Municipal and Pond as Source	1	14	0.2	0
--Stream Flows Through Bog--	183	2552.7	29.9	33
--Stream Bypasses Bog--	117	1735.5	21.4	22
--Adequate Supply of Water--	272	3065.8	49.8	40
--Inadequate Supply of Water--	155	2316.1	28.4	30
--Inadequate Water in Droughts--	157	2377	28.8	31
--Well Interference Reported--	10	120	1.8	[illegible]
--Well Interference Suspected--	4	258.4	1.3	[illegible]
--Bog Levelness--				
Bog 6" to 1' out of level	44	609.5	8.1	[illegible]
Bog 1' to 2' out of level	37	599.8	6.8	[illegible]
Bogs over 2'. out of level	16	275.3	2.9	[illegible]

Note: In some categories, the sum of percentages may exceed 100 % du
fact that some bogs are included in more than one category. Some categ
may total less than 100 % due to lack of response by growers to specifi
questions.

Water Needs Estimates

A distinction must be made regarding the term "water need" as opposed to "water use". Water need as calculated for this study is the volume of wat necessary to adequately provide for cranberry raising as practiced by the average prudent grower. Except for water used during the growing season plant requirements, most cranberry water use is primarily non-comosumptiv and water is returned to the groundwater/surface water regime close to th point where it was temporarily remove and in essentially the same quantit

Cranberry water needs estimates were determined as described fully in Appendix A. Table 2 indicates the estimated water needs for various combinations of parameters affecting water use.

Table 2

Water Needs

Bog Physical Parameters			Water Needs (acres feet per acre of bog)	
Levelness	Waterholding	Tailwater	Sprinklered	Unsprinklered
Level	Good	No	8.3	12.5
Level	Fair	No	10.3	15.1
Level	Poor	No	12.3	17.8
Level	Good	Yes	6.8	9.5
Level	Fair	Yes	8.8	12.1
Level	Poor	Yes	10.8	14.8
1' Out	Good	No	9.8	20.2
1' Out	Fair	No	11.8	22.8
1' Out	Poor	No	13.8	25.5
1' Out	Good	Yes	7.9	11.6
1' Out	Fair	Yes	9.9	14.2
1' Out	Poor	Yes	11.9	16.9
2' Out	Good	No	11.3	21.7
2' Out	Fair	No	13.3	23.3
2' Out	Poor	NO	15.3	27.0
2' Out	Good	Yes	9.0	12.7
2' Out	Fair	Yes	11.0	15.3
2' Out	Poor	Yes	13.0	18.0

The water needs rates presented in Table 2 were assigned to individual bogs in the electronic data base to compute the estimated water needs for the 7,565 acres of bogs where detailed physical data was available. These bogs need 67,643 acre feet of water per year or an average of 8.9 acre feet per acre of bog. Average water need figures, adjusted for differences in bog size, were assigned to the remaining bogs where only size information was available.

Each cranberry bog was identified as to the subwatershed that it was located in. Subwatershed locations and designations are indicated on Figure 1.

Water needs estimates were developed for each subwatershed and are presented in Table 3.

Table 3
Water Needs Aggregated by Subwatershed

Subwatershed	Acres of Bogs	Water Need (acre feet/yr)	Average (acre feet per acre)
BB41	1,935	17,508	8.8
BB42	2,175	20,128	9.3
BB43	1,209	11,587	9.6
BB44	1,148	10,594	9.2
BB45	165	1,583	9.6
BB46	46	476	10.3
CC	,1156	11,096	9.6
IS	244	1,991	8.2
SS26	5	53	10.6
SS27	324	2,601	8.0
SS28	249	2,364	9.5
SS29	423	4,116	9.7
SS30	505	4,663	9.2
SS31	62	689	11.1
TA47	39	332	8.5
TA49	719	5,293	7.4
TA50	656	5,779	8.8
TA51	8	93	11.6
TA52	81	778	9.7
TA53	479	4,381	9.1
TA54	96	799	8.3
TA56	5	61	12.2
TA58	152	1,126	7.4

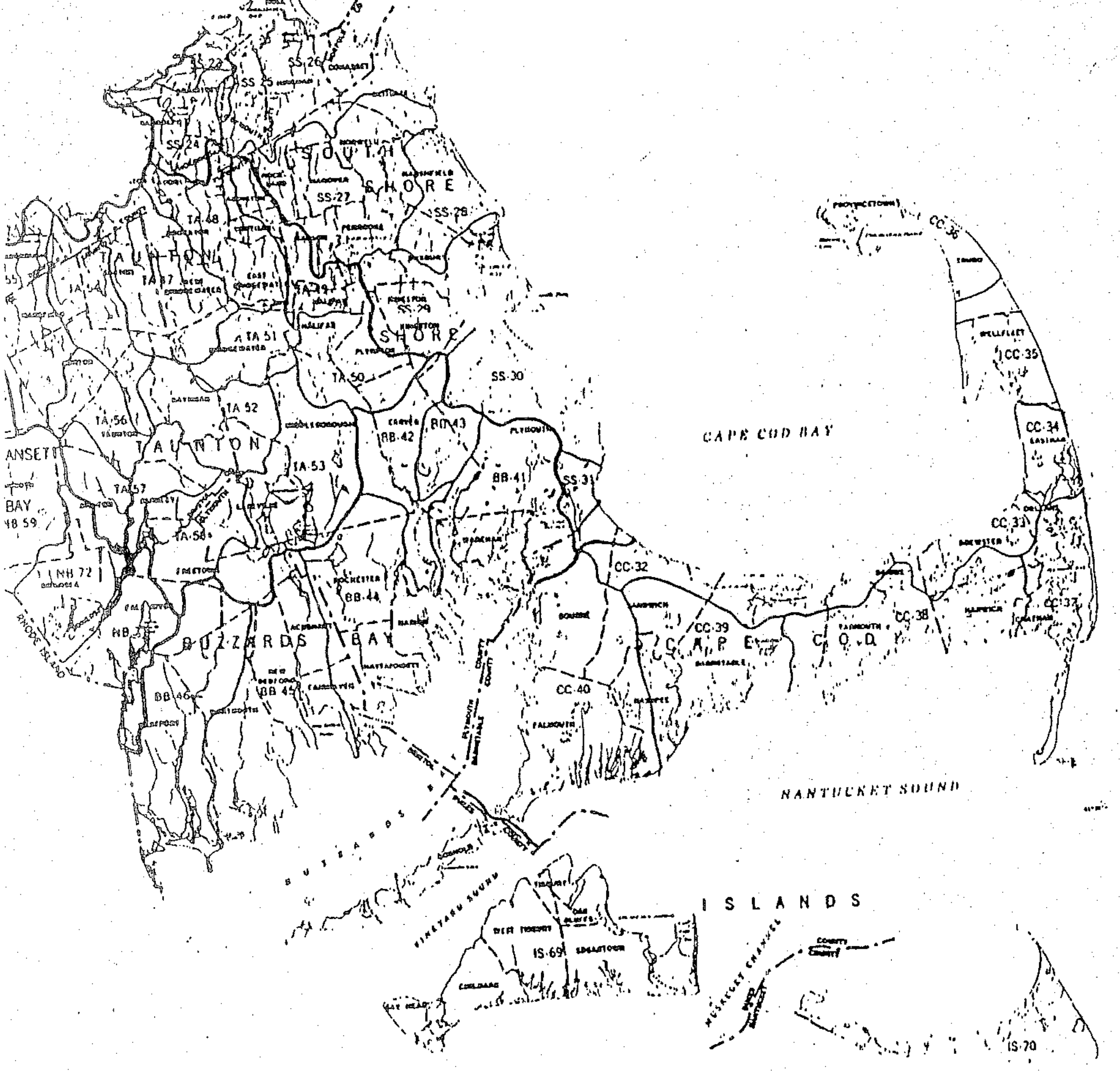


Figure 1
SUBWATERSHED LOCATIONS

Water Conservation Measures

Water conservation measures were analysed to determine the potential water need reduction in the individual subwatersheds. The water conservation measures used in the analysis were: 1) rehabilitation of leak perimeter dikes, 2) replacement of water control structures, 3) installati of sprinkler systems, and 4) development of tailwater recovery systems. I was felt that measures to improve waterholding capability of bogs or levelling of unlevel bogs were prohibitively expensive and would not be acceptable to many growers. This is because these two measures would require re-establishment of the bogs with the accompanying loss of income for two or three seasons in addition to the cost of levelling or bog sealing. The other measures included in the analysis do not require that the bog be taken out of production and would be more likely to be acceptal to growers.

Table 4 summarizes the water conservation measures reported as needed by growers on returned questionnaires or noted by SCS employees during field visits. The water conservation measures indicated in Table 4 are based o questionnaires and field visits representing 7,565 acres of cranberry bog or approximately 63 percent of the identified cranberry bog acreage in Massachusetts.

Table 4
Water Conservation Measures Reported as Needed in Bog Owner Questionnaires and SCS Site Visits

Dike Rehabilitation Needed: 30,975 linear feet

Water Control Structures Needed: 111 structures

Sprinkler Rehabilitation Needed: 254.5 acres

Sprinkler Installation Needed: 144 acres

Tailwater Recovery Needed: 533.8 acres

--Bog Levelness--
Bog 6" to 1' out of level 610 acres
Bog 1' to 2' out of level 500 acres
Bogs over 2' out of level 275 acres

Mathematical factors were developed to estimate the water conservation measures needed for bogs that did not have grower questionnaires or field visits. Table 5 indicates the water conservation measures that were calculated to be needed in each subwatershed.

Table 5
Water Conservation Measures

Subwatershed	Dike Rehabilitation (linear feet)	Water Control Structures	Sprinkler Systems	Tailwate Recovery Systems
BB41	5100	14	18	12
BB42	10100	35	31	17
BB43	4600	34	11	10
BB44	6500	33	29	13
BB45	1200	2	1	3
BB46	100	1	0	0
CC	5000	11	91	7
IS	1200	4	6	2
SS26	0	0	0	0
SS27	700	2	4	1
SS28	1500	9	3	2
SS29	1900	5	7	3
SS30	4100	8	28	4
SS31	600	2	0	0
TA47	200	1	1	0
TA49	800	3	4	2
TA50	2100	5	5	3
TA51	0	0	0	0
TA52	300	2	1	1
TA53	2500	10	13	3
TA54	500	1	2	1
TA56	0	0	0	0
TA58	400	0	0	1

The data from Table 2 Water Needs were utilized to develop Table 6 detailing the water need reductions expected from water conservation measures.

Table 6

Expected Effects of Water Conservation Measures

Bog Physical Parameters			Measure Evaluated	Expected Water Savings (acre feet per bog acre)
Levelness	Waterholding	Tailwater		
Level	Good	No	Sprinkler Install.	4.2
Level	Fair	No	"	4.9
Level	Poor	No	"	5.5
Level	Good	Yes	"	2.7
Level	Fair	Yes	"	3.4
Level	Poor	Yes	"	4.0
1' Out	Good	No	"	10.4
1' Out	Fair	No	"	11.1
1' Out	Poor	No	"	11.7
1' Out	Good	Yes	"	3.7
1' Out	Fair	Yes	"	4.4
1' Out	Poor	Yes	"	5.0
2' Out	Good	No	"	10.4
2' Out	Fair	No	"	11.1
2' Out	Poor	No	"	11.7
2' Out	Good	Yes	"	3.6
2' Out	Fair	Yes	"	4.3
2' Out	Poor	Yes	"	4.9
1' Out	Good	No	Levelling	1.5-7.7
1' Out	Fair	No	"	1.5-7.8
1' Out	Poor	No	"	1.5-7.8
1' Out	Good	Yes	"	1.1-2.1
1' Out	Fair	Yes	"	1.1-2.1
1' Out	Poor	Yes	"	1.1-2.1
2' Out	Good	No	"	3.0-9.2
2' Out	Fair	No	"	3.0-9.2
2' Out	Poor	No	"	3.0-9.2
2' Out	Good	Yes	"	2.3-3.2
2' Out	Fair	Yes	"	2.3-3.2
2' Out	Poor	Yes	"	2.3-3.2

Table 6
Expected Effects of Water Conservation Measures

Bog Physical Parameters			Measure Evaluated	Expected Water Savings (acre feet per bog acre)
Levelness	Waterholding	Sprinkler		
Level	Good	No	Tailwater Recovery	3.0
Level	Fair	No	"	3.0
Level	Poor	No	"	3.0
Level	Good	Yes	"	1.5
Level	Fair	Yes	"	1.5
Level	Poor	Yes	"	1.5
1' Out	Good	No	"	9.6
1' Out	Fair	No	"	8.6
1' Out	Poor	No	"	8.6
1' Out	Good	Yes	"	1.9
1' Out	Fair	Yes	"	1.9
1' Out	Poor	Yes	"	1.9
2' Out	Good	No	"	9.0
2' Out	Fair	No	"	9.0
2' Out	Poor	No	"	9.0
2' Out	Good	Yes	"	2.2
2' Out	Fair	Yes	"	2.2
2' Out	Poor	Yes	"	2.2

Levelness	Waterholding	Tailwater Rec.		
Level	Fair	No	Improve Waterholding	2.0-2.7
Level	Poor	No	"	4.0-5.3

Table 7 indicates the potential reduction in water need that could be accomplished if water conservation measures were installed in bogs.

Table 7

Potential Reduction in Water Needs That Might Be Achieved With Water Conservation Measures

Subwatershed	Present Water Need (acre feet)	Potential Reduction (acre feet)	Percent Reduction
BB41	17,508	1,318	7.7
BB42	20,128	2,192	10.9
BB43	11,587	1,273	11.0
BB44	10,594	1,695	16.0
BB45	1,583	259	16.3
BB46	476	19	3.9
CC	11,096	1,587	14.3
IS	1,991	277	13.9
SS26	53	0	0
SS27	2,601	155	5.9
SS28	2,364	330	14.0
SS29	4,116	396	9.6
SS30	4,663	820	17.6
SS31	689	68	9.9
TA47	332	35	10.5
TA49	5,293	219	4.1
TA50	5,779	394	6.8
TA51	93	0	0
TA52	778	99	12.7
TA53	4,381	547	12.5
TA54	799	112	14.0
TA56	61	0	0
TA58	1,126	76	6.8

Cost estimates were prepared for each of the water conservation measures indicated in Table 7. Costs included the actual construction cost to install the measure plus 15% for contingencies, 15% for engineering' and 15% for project administration. Total project costs and a comparison wi expected water savings is presented in Table 8.

Table 8
Cost of Water Conservation Measures and Comparison with Estimated Water Needs Reductions

Subwatershed	Cost of Conservation Measures	Potential Savings of Water (acre feet per year)	Cost per acre foot saved	Annual Cost ($ per acr foot)*
BB41	$291,000	1,318	221	22
BB42	$475,000	2,192	217	21
BB43	$301,000	1,273	237	23
BB44	$387,000	1,695	228	23
BB45	$ 63,000	259	242	24
BB46	7,000	19	352	35
CC	$334,000	1,587	210	21
IS	$ 63,000	277	225	22
SS26	$ 3,000	< 1		
SS27	$ 35,000	155	227	22
SS28	74,000	330	223	22
SS29	$ 86,000	396	217	21
SS30	$160,000	820	195	19
SS31	$ 12,000	68	178	18
TA47	$ 8,900	35	256	25
TA49	$ 54,000	219	246	24
TA50	$ 83,000	394	211	21
TA51	$ 3,000	< 1		
TA52	$ 28,000	99	280	28
TA53	$115,000	547	210	21
TA54	$ 27,000	112	246	24
TA56	$ 3,000	< 1		
TA58	$ 20,000	76	26	26

* Project installation is amortized at 8 5/8 % (the current discount rate for federally assisted water resources projects) for 25 years.

Comparison of Costs and Benefits of Water Conservation

The average annual costs of installing water conservation measures as indicated in Table 8 varies from $18 to $35 per acre foot of water need reduction.

The value of the water need reduction or the benefit from the need reduction is more difficult to assign a dollar value to. The benefit in some measure depends on what the water would be used for if it were no longer needed for cranberry culture. Since most of the water needed by cranberry growers is not a consumptive use but merely a temporary diversion of the water, if the water is not utilized for some purpose downstream or upstream from the bog the benefit to the water conservatio measures is quite low.

If the water need reduction were to be utilized for municpal water suppl the benefit from water conservation would equal the cost of providing th same volume of water from the next least costly source. The cost of providing an acre foot per year of municpal water supply from groundwater varies from $11 to $20. Surface water development has a cost of fror to $35 per acre foot. Comparing these benefits against the $18 to $. cost of water conservation measures indicates that water conservation in the cranberry growing industry might be a cost effective means of reallocating water resources to municipal use. The actual economic analysis would depend on cost factors specific to a particular bog and municipal water supply situation. Factors such as distance to existing mains, elevations, and water quality would need to be considered on an individual basis. The point that is important to note at this level of study is that the cost of installing water conservation measures in cranberry bogs has the potential of returning similar dollar values in municipal water supply benefits.

Cranberries are a relatively high value crop. Gross returns per acre of bog can easily exceed $6,000. As a result, the value of an acre foot of water to the grower may be quite high. Although cranberry culture requires a high volume of water, there is also an important timing factor that needs to be considered. When frost warnings are issued, the grower needs to have sufficient water available to run the sprinkler system at that time. If the water is not available, 50 to 90% of the crop can be lost in one night. Even if the lack of water occurs once in 100 years, the average annual cost of such an event can exceed $200 per acre foot of water that was not available when it was needed. Thus, if water conservation measures reduce water needs to the point where water will be available when it might otherwise not be, the benefits to the grower can greatly execeed the average annual cost of installing such measures.

Alternatives for Installation of Water Conservation Measures

Water conservation measures for cranberry bogs also benefit the growers making a more efficient operation that results in lower total costs. Growers have long recognized the economic benefits of installing sprinkl systems to replace the old practice of flooding the bogs for frost protection and for providing growing season water. Over 97 percent of th cranberry acreage in Massachusetts has sprinkler systems installed. Between 250 and 400 acres of sprinkler system are installed or rehabilitated each year in the state.

Federal cost sharing for water conservation measures in cranberry bogs i available through the U. S. Department of Agriculture, Agricultural Stabilization and Conservation Service. Cost sharing is normally limite to 50% of the cost of installation of eligible measures with an annual limit of $3,500 per year for each grower.

Agricultural water management measures to improve the efficiency of wate use are eligible components of a watershed protection plan under provisions of Public Law 83-566, the Watershed Protection and Flood Prevention Act. In order to develop a watershed plan under P.L. 566, a qualified local sponsoring organization must file an application for assistance to the U. S. Department of Agriculture, Soil Conservation Service. In Massachusetts, the Division of Water Resources is the s agency that is designated to receive P.L. 566 applications and assis in determining priorities for servicing of applications for assistance. Applications must cover an entire hydrologic unit, usually the watershed of a river, of less than 250,000 acres in size.

Cost sharing for water conservation measures under P.L. 566 is 50% federal funds and 50% "other" non-P.L. 566 funds.

A preliminary screening of watersheds that might be logical candidates for project action to install water conservation measures under P.L. 566 was undertaken.

Some of the watersheds were eliminated from further consideration because the project actions would benefit fewer than four individuals. Although there is no program criteria specifying a minimum number of project beneficiaries. practical considerations do not favor projects that appear to give windfall benefits to a select group of individuals. It is also difficult to establish support from a qualified sponsoring organization for projects with few beneficiaries.

The following watersheds have fewer than three potential project beneficiaries.

Table 9

Watersheds with Fewer than Three Bog Owners

Watershed	Number of Bog Owners
BB46	3
IS	1 *
SS26	1 *
TA47	1 *
TA51	1 *
TA54	1 *
TA56	1

None of these owners indicated with an asterisk responded to the Cape Cod Cranberry Growers Association request for water use information.

From the watersheds and costs indicated in Table 8, the following watersheds listed in TAble 10 have estimated installation costs of less than $75,000.

Table 10

Watersheds with Conservation Measures Costing Less Than $75,000

Watershed	Estimated Cost of Water Conservation Measures
BB45	$63,000
BB46	$7,000
IS	$63,000
SS26	$3,000
SS27	$35,000
SS28	$74,000
SS31	$12,000
TA47	$ 9,000
TA49	$54,000
TA51	$ 3,000
TA52	$28,000
TA54	$27,000
TA56	$ 3,000
TA58	$20,000

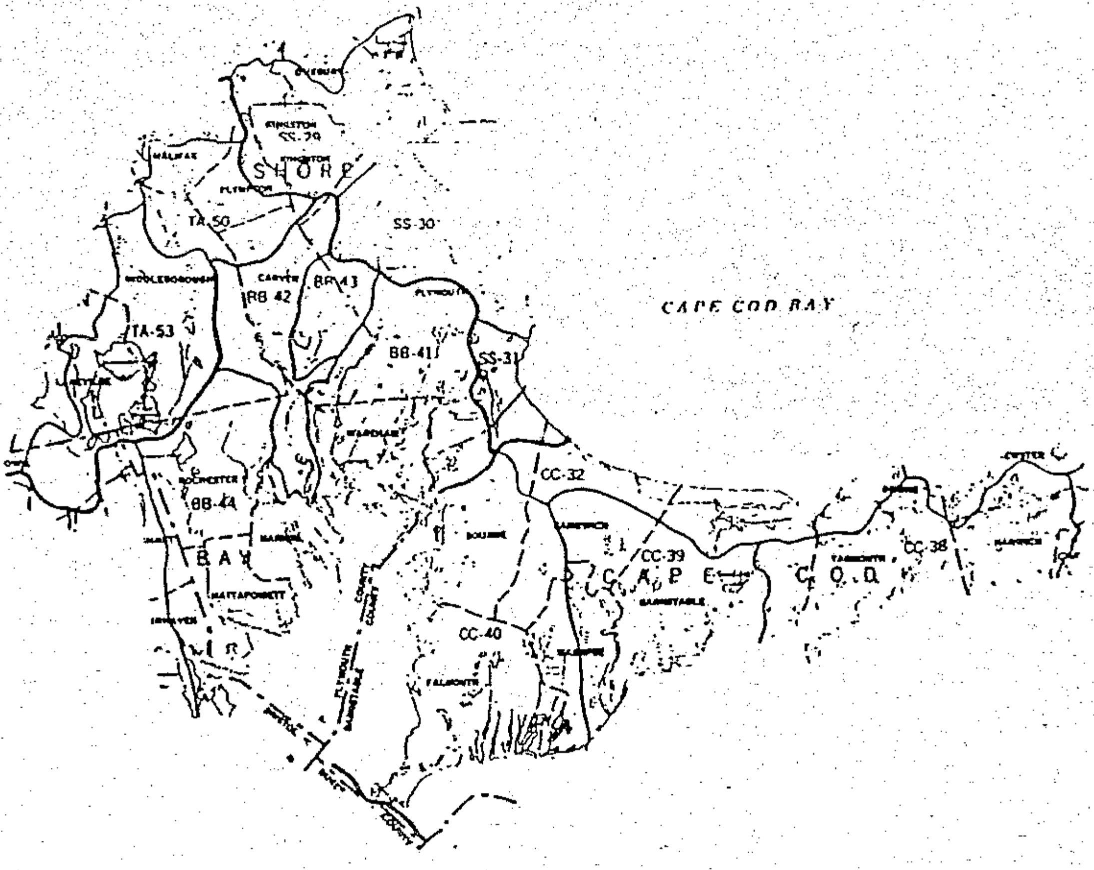


Figure 2

Subwatersheds with Apparent Potential for Project Type Action To Install Water Conservation Measures in Cranberry Bogs

APPENDIX H

ENVIRONMENTAL NOTIFICATION FORM

I. SUMMARY

A. Project Identification

1. Project Name Billington Sea Reverse Layering
Address/Location Black Cat Road
City/Town Plymouth
2. Project Proponent Town of Plymouth
Address Plymouth, MA
3. Est. Commencement unknown . Est. Completion .
Approx. Cost $500,000-700,000 Status of Project Design 20 % 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.

The Billington Sea, a 266 acre Great Pond, is located off Black Cat Road in Plymouth. This lake is a major recreational resource for the town but has experienced an ongoing problem with nuisance vegetation since the early 1970's. It is recommended that a process called "reverse-layering" be employed in order to rid the pond of excess plant growth and delay the recurrence of same.

Please see enclosed narrative and plans for further description.

ALL INFORMATION IN THIS FORM IS TAKEN FROM "BILLINGTON SEA DIAGNOSTIC FEASIBILITY STUDY, FINAL REPORT", NOVEMBER, 1990, BY GALE ASSOCIATES, INC.

Copies of the complete ENF may be obtained from (proponent or agent):
Name: Irwin Silverstein Firm/Agency: Gale Associates, Inc.
Address: 8 School St., Weymouth 02189 Phone No. 617-337-4253

1986 THIS IS AN IMPORTANT NOTICE. COMMENT PERIOD IS LIMITED.
For Information, call (617) 727-5830

11.28: continued

P.3

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 X .

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: 266 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 266 acres
3. Wetlands .... ____ acres
4. Floodplain .... ____ acres
5. Coastal Area .... ____ acres
6. Tidelands .... ____ acres
7. Productive Resources
   Agriculture .... ____ acres
   Forestry .... ____ acres
8. Other .... ____ acres

C. Provide the following dimensions, if applicable: N/A

	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).

N/A

11.28: continued

P.5

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: ______________) YES
Explanation and Source:

The project is proposed to reduce the amount of nuisance vegetation in the pond. The site is located in an area or rare wetland wildlife habitat.

3. Agricultural Land. Has any portion of the site been in agricultural use within the last 15 years? If yes, specify use and acreage. NO
Explanation and Source:

D. Water Quality and Quantity

1. Might the project result in significant changes in drainage patterns? NO
Explanation and Source:

2. Might the project result in the introduction of any pollutants, including sediments, into marine waters, surface fresh waters or ground water? YES
Explanation and Source:

The reverse-layering process by its nature will disturb the sediment in the pond, but will not increase the amount of sediment already present. During reverse-layering, metals such as copper, arsenic and lead may get resuspended into the water column. Therefore, before full implementation of this process, it is recommended that the sediment be disturbed and the water column tested for these metals in a limited area.

3. Does the project involve any dredging? No __X__ Yes ______ Volume ______. 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).

11.28: continued

P.7

9. Does the operation of the project result in any increased consumption of water? NO

Approximate consumption ________ gallons per day. Likely water source(s) ________

Explanation and Source:

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? NONE

Explanation and Source:

2. Might the project involve the generation, use, transportation, storage, release, or disposal of potentially hazardous materials? NO

Explanation and Source:

3. Has the site previously been used for the use, generation, transportation, storage, release, or disposal of potentially hazardous materials? NO

Explanation and Source:

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. NO

Explanation and Source:

11.28: continued

P.10

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.

The purpose of the proposed project is to allow greater use of the Billington Sea as a recreation source for the town. It is currently used for boating, fishing and swimming. The project is designed to increase the usage of these activities by town residents. Therefore, consistency with the questioned plans and policies is ensured.

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 ________

11.29: FORMS OF NOTICE

(1) PUBLIC NOTICE OF ENVIRONMENTAL REVIEW PROJECT:

FORMS OF NOTICE

(1) PUBLIC NOTICE OF ENVIRONMENTAL REVIEW

PROJECT: Billington Sea Reverse Layering
(Brief description of project)

LOCATION: Plymouth, MA

PROPONENT: Town of Plymouth

The undersigned is submitting an Environmental Notification Form ("ENF") to the Secretary of Environmental Affairs on or before ______.
(Date)

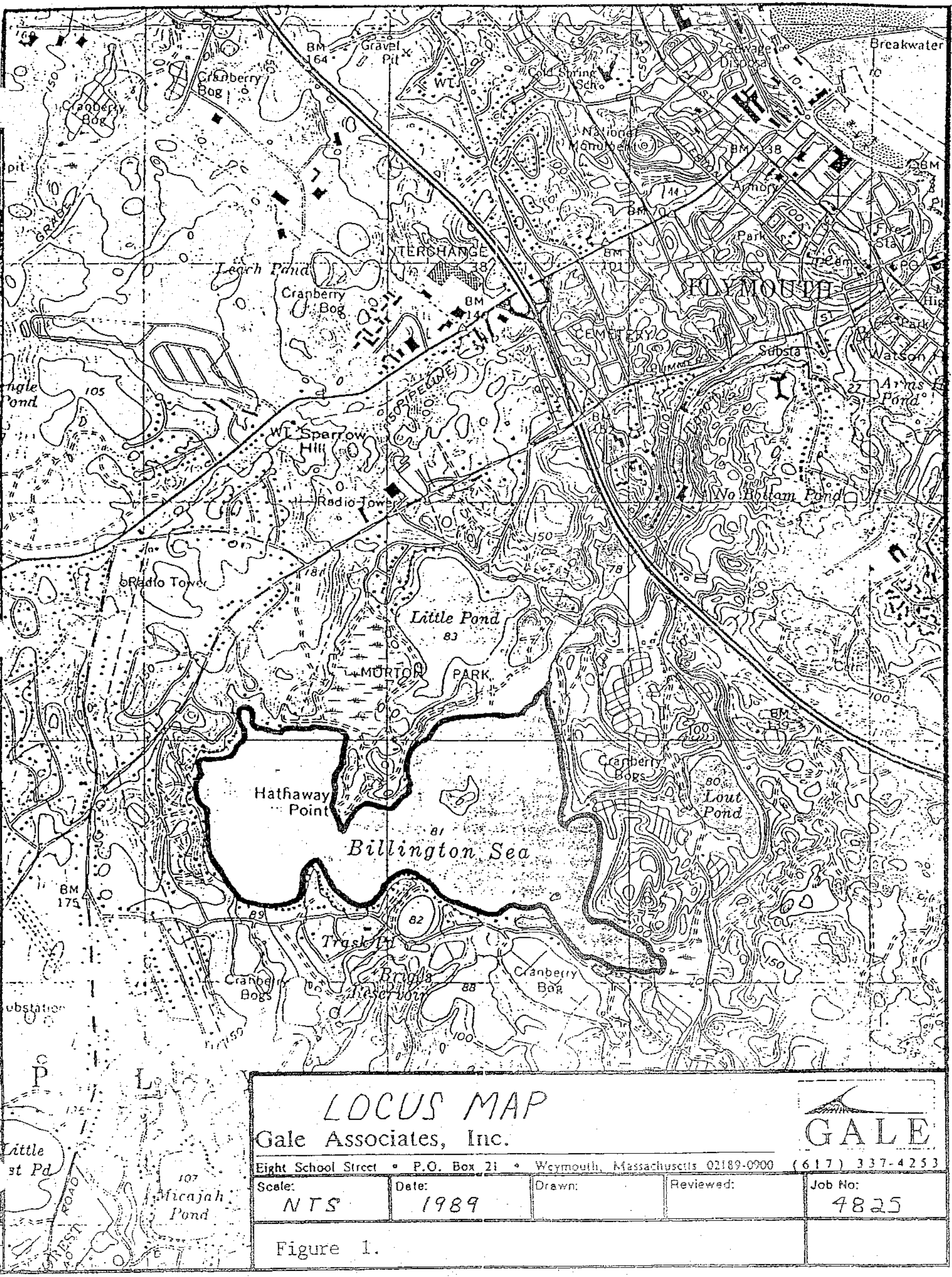
This will initiate review of the above project pursuant to the Massachusetts Environmental Policy Act ("MEPA", G.L. c. 30, secs. 61, 62-62H). Copies of the ENF may be obtained from:

Gale Associates, Inc., 8 School Street, Weymouth, MA 02189.
(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 Plymouth (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)



LOCUS MAP

Gale Associates, Inc.

GALE

Eight School Street • P.O. Box 21 • Weymouth, Massachusetts 02189-0900 (617) 337-4253

Scale:	Date:	Drawn:	Reviewed:	Job No:
NTS	1989			4825

Figure 1.

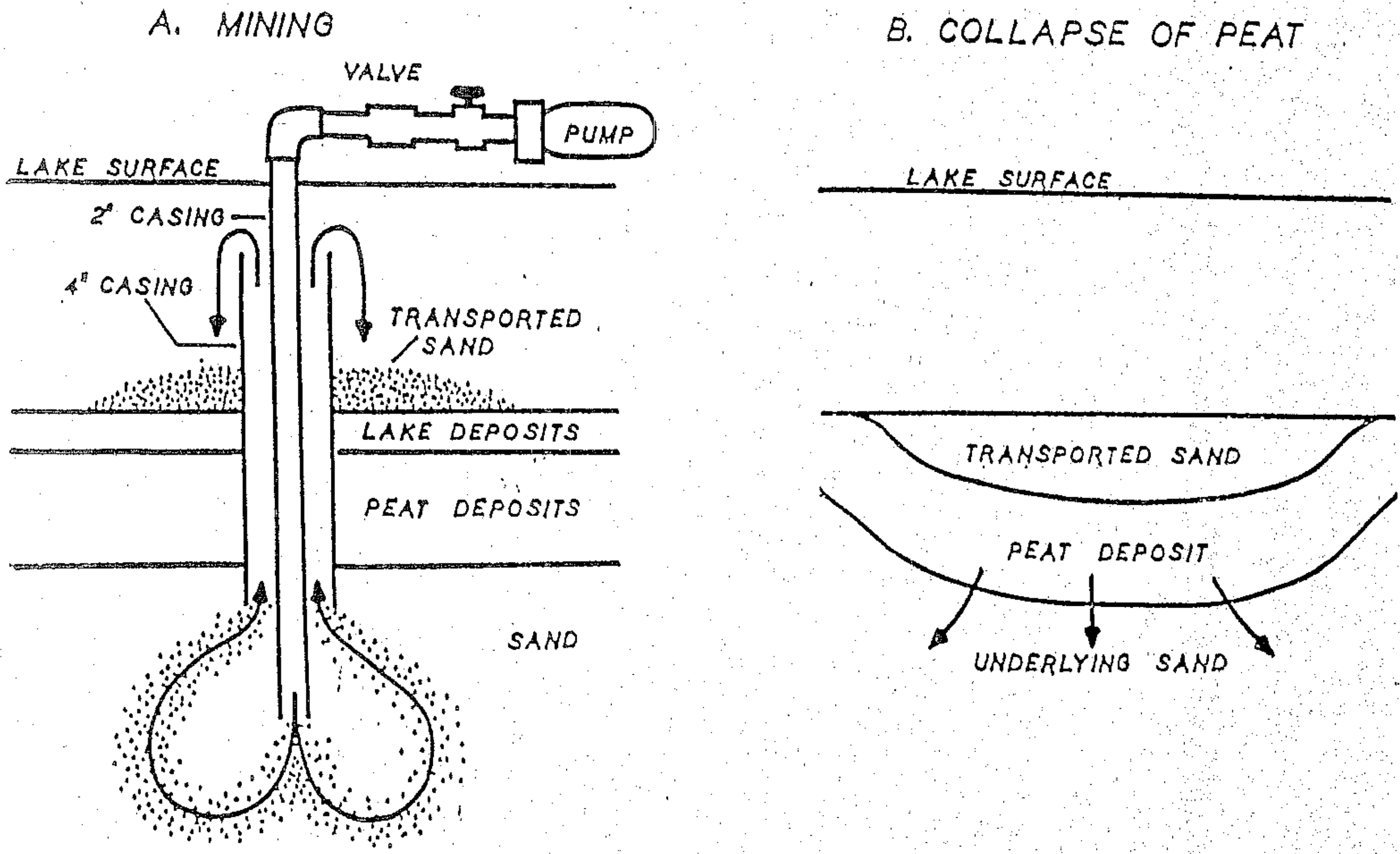
Sediment Cover (Reverse Layering)

Reverse Layering is an in-lake restoration technique which is currently being investigated with funds from the Clean Lakes Program for its effectiveness in reducing internal nutrient loading in Red Lily Pond (Barnstable) which is a euthrophic kettle lake such as the Billington Sea. (KV Associates, Inc., 1988). The process is based on conclusions derived from previous studies which demonstrate that sand applications of 15-20 cm. in depth can reduce the regrowth of aquatic plants by as much as 400% (Nichols, 1974, Peltier and Welch, 1969).

The procedure employs the use of a modified centrifugal "mud" pump to transport sand deposits located beneath the lake's nutrient-rich organic sediment and deposit them on top of this upper layer of sediment (Figure 38). Harvesting of aquatic plant biomass prior to conducting reverse layering would further retard plant regrowth. In addition to retarding plant regrowth, reverse layering may control internal nutrient loading by reducing the amount of nutrient-rich organic sediment remaining in contact with the water column and thus reducing the liklihood of sediment phosphorus release. Reverse layering is less costly than sediment removal and does not require the design and construction of a sediment disposal area. Environmental impacts from reverse layering may be reduced by conducting the procedure in alternating squares within a 100 ft. by 100 ft. grid to allow for recolonization of the lake bottom by benthic organisms. The resultant siltation is controlled with booms constructed of filter cloth and the use of a cyclone separator. Reverse layering may allow for some deepening of the lake by redepositing a portion of the mined sand in another location. This technique, however, should not be substituted as an alternative for sediment removal when the objective of the latter restoration technique is to remove contaminated lake sediments and to significantly deepen a lake.

Pump tests were conducted in order to determine the feasibility of employing reverse layering in the western basin (Figure 39) of the Billington Sea. This testing indicated that adequate sand deposits are located beneath the nutrient-rich organic sediments in the lake and that these deposits can be readily transported to the sediment surface. The dense beds of submerged aquatic vegetation and thick nutrient-rich organic deposits, located primarily within the western basin (Figure 40), are targeted for conducting reverse layering. The installation of

FIGURE 38. BOTTOM REJUVENATION BY REVERSE LAYERING


A. MINING

B. COLLAPSE OF PEAT

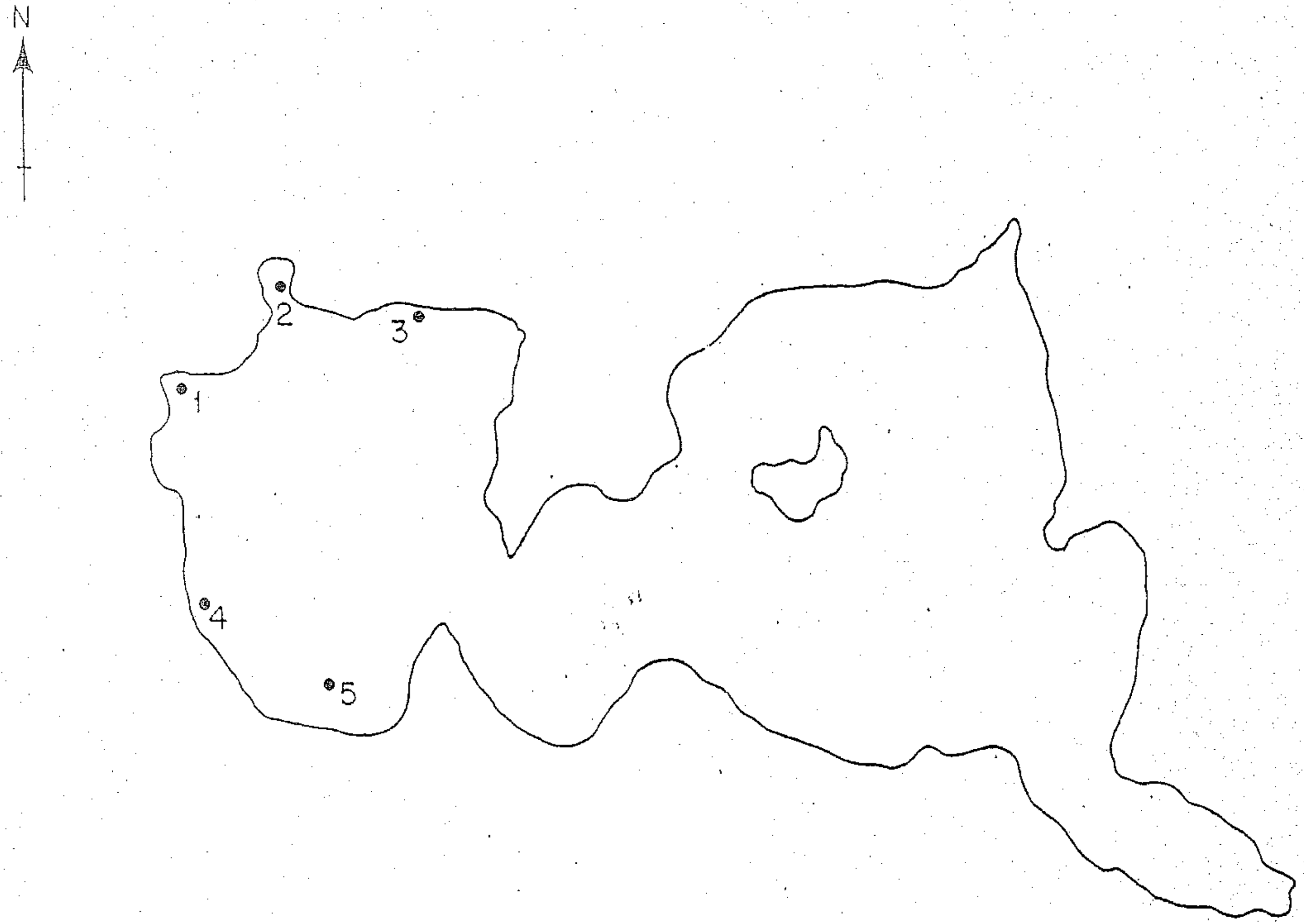
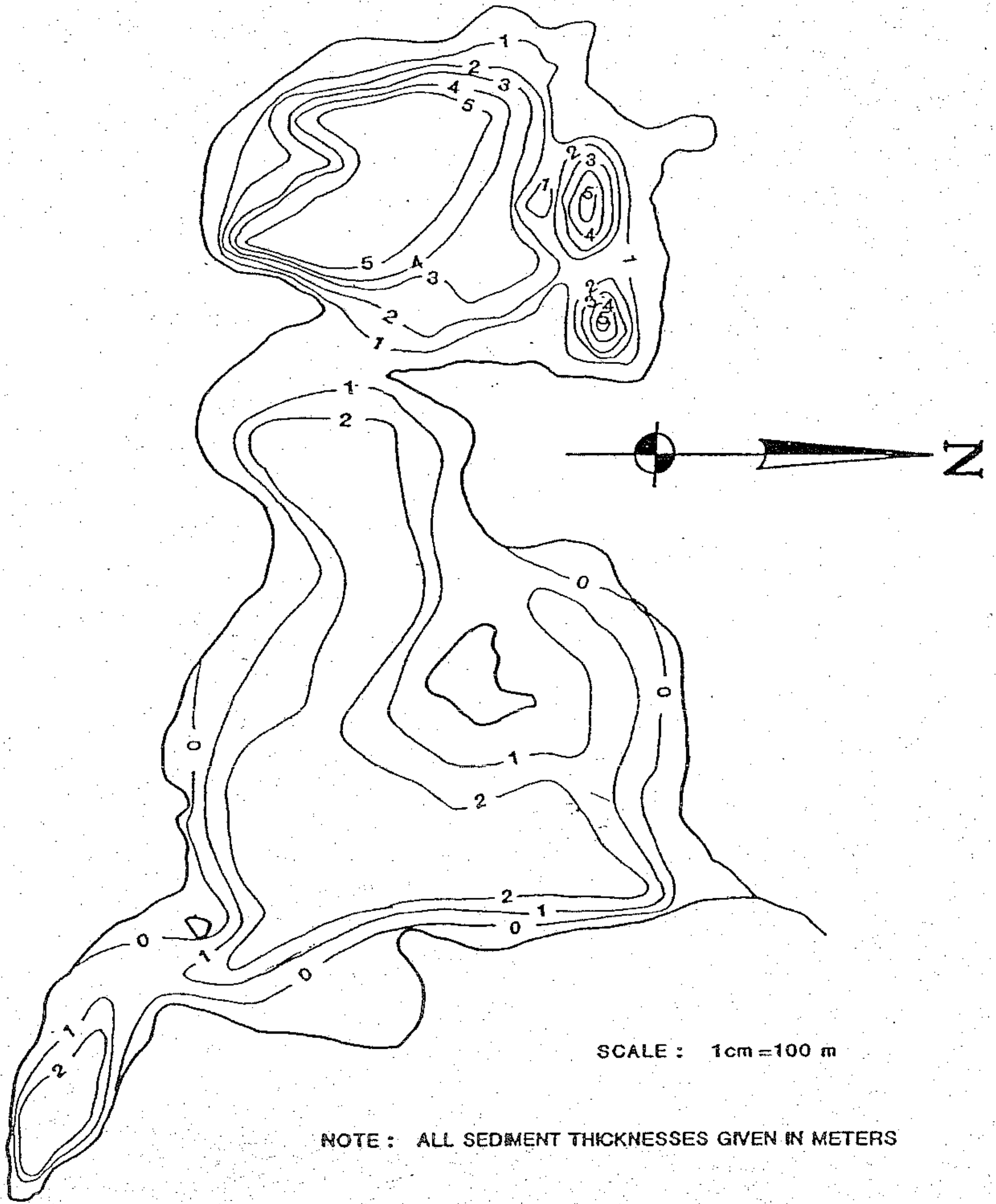


Figure 39. Lake bottom test locations for "Reverse Layering"



SCALE : 1cm = 100 m

NOTE : ALL SEDIMENT THICKNESSES GIVEN IN METERS

FIGURE 40. SOFT SEDIMENT THICKNESS MAP

BILLINGTON SEA

PLYMOUTH, MASSACHUSETTS

interception wells along the western shoreline of the lake may be neccessary in order to reduce the velocity of groundwater flow up through the buried nutrient-rich deposits. Secondly, the implementation of a lake use plan which restricts motorboat usage in the western basin is recommended in order to curtail the resuspension and transportation of silt in this shallow basin.

From another practical standpoint, it is unlikely that 100 percent of the growers in a watershed would be interested in installing needed water conservation measures. Participation rates of 50 to 75 percent are probably more realistic. Over a five year period if 75% of the growe in the watershed indicated in Table 10 participated in installing water conservation measures, $150,000 in cost sharing would be required or an average of $30,000 per year. In the past few years, this amount would have been available for cost sharing through the Agricultural Stabilization and Conservation Service. Hence, there would be no real benefit to project type action in these watersheds where the on-going program could effectively meet grower needs.

Table 11 presents a summary of the watersheds that appear to have good potential for P.L. 566 project action to install water conservation measures from the standpoint of reasonable project size, a realistic benefit to cost picture, and the opportunity to make a significant contribution to water conservation in the local area. These watersheds on TAble 11 are also indicated in Figure 2. In retrospect, it is not too surprising that the greatest potential for project type action to install water conservation measures is in a fairly contiguous part of Massachusetts that is in the heart of the cranberry growing area.

Table 11

Watersheds With Apparent Potential

For Project Type Action To Install Water Conservation Measures

Watershed	Estimated Cost of Measures
BB41	$291,000
BB42	$475,000
BB43	$301,000
BB44	$387,000
CC	$334,000
SS29	$ 86,000
SS30	$160,000
TA50	$ 83,000
TA53	$115,000

The important factor remaining to be assessed is grower interest in persuing project type action and interest in installing water conservatic measures in cooperation with other growers. Conservation Districts, growers, grower organizations and other groups and individuals are encouraged to review the findings presented in this report and, if sufficient interest is generated, to consult with the local Soil Conservation Service office concerning procedures to initiate a P.L. 566 application.

Continuation Appendix 6

The Cape Cod, Martha's Vineyard,, Nantucket, and Plymouth County shorelin areas have been becoming more and more popular as a summer vacation destination and it is not unusual for some communities to experience two to four fold increases in population during July and August. During the rest of the year, local officials have noted a lengthening of the tourist season and the construction of condominiums and second homes has added to the number of people living in the cranberry growing region of Massachusetts.

Communities in southeastern Massachusetts have been experiencing municipa water supply shortages and water emergencies on a relatively frequent basis. The municipalities have responded to the recurring water shor[illegible]ge by a variety of means including demand management techniques such as [illegible]ns on the outside use of water, water conservation education programs, and water saving devices. Activity is also underway to locate and develop sources of groundwater and surface water supplies. Most small communitie in the region rely upon groundwater aquifers while some of the larger systems utilize surface water sources.

Municipal water supply is receiving attention throughout Massachusetts d to a combination of increasing population (and water demand) and periods of low rainfall. The system supplying the Boston metropolitan area has been experiencing demands that exceed the safe yield of the supply watersheds. A range of alternatives to bring demand and supply into balance is being evaluated. One possible alternative is the expansic the Boston system's sources of water supply to other regions of the state, including the Plymouth-Carver aquifer in Plymouth County.

**Below is the Executive Summary
from the Billington Sea
Diagnostic / Feasibility Study done in Nov. 1990.
It shows exactly what is wrong with Billington
Sea and where the excess
nutrients are coming from.**

GALE

Executive Summary

Conflicting water use demands are currently being placed on the Billington Sea, a shallow 266-acre kettle pond located in Plymouth, Massachusetts (Figure 1). The lake serves as a regionally-important recreational resource, habitat for rare wetland wildlife and as an irrigation source and discharge basin for cranberry bogs. Unsewered residential development is dense along the western and southern shoreline of the lake and aquatic recreational activities occur without regard for their water quality impacts. The eastern portion of the lake is located within the recharge zone of a public water supply well (Lout Pond well).

The recreational, aesthetic, and fisheries and wildlife habitat values of the lake have been reduced as a result of an overabundance of submergent aquatic plant growth and the late summer occurrence of blue-green algal blooms. Thus, a year-round water quality survey of the lake and its tributaries was conducted with funds provided by the Town of Plymouth and the Massachusetts Clean Lakes Program. The physical, chemical and biological characteristics of the lake were assessed, as were the physical, hydrogeological and land use characteristics of the watershed. These data were used to determine the sources of the nutrients which are causing the lake's water quality degradation and to develop a plan for in-lake restoration and watershed management.

Every lake has a limited capacity to assimilate nutrient loading without expressing the undesirable conditions of nuisance algal and aquatic plant growth which are associated with cultural eutrophication. Data collected during the year-round study of the Billington Sea indicate that annual phosphorus inputs to the lake from tributaries (61.3%) and residential wastewater disposal systems (20.0%) are twice as high as the lake's carrying capacity, resulting in the eutrophic state previously described. Tributary and residential wastewater disposal system inputs also account for 16.9% and 63.9% of the annual nitrogen loading to the lake. The shallowness of the lake (mean depth of 2.1m) and low flushing rate (6.3 times per year), as well as the high groundwater velocities which occur along the shoreline of the western basin, make it more susceptible to becoming eutrophic. Approximately 39% of the annual phosphorus load accumulates within the lake, primarily within the sediments, where it can be recycled each year for aquatic plant growth.

(OVER)

DRAFT

Billington Sea Project Update
Review of 1990 Recommendations for Bog Nutrient Load Reductions

Prepared by:
Fugro East, Inc.
6 Maple Street
Northboro, MA 01532

April 1997

Introduction

The Town of Plymouth Department of Public Works has contracted Aquatic Control Technology, Inc. (ACT) to review the recommendations in the 1990 Diagnostic/Feasibility (D/F) Study prepared by Gale Associates, regarding cranberry bog operations. ENSR (formerly Fugro East, Inc) was subcontracted to conduct this review.

The 1990 D/F study identified commercial cranberry operations as the primary source of phosphorus (63%) to Billington Sea. The study made recommendations for reducing the phosphorus loads from cranberry bogs. These recommendations included the use of Best Management Practices (BMPs) for fertilizer application reductions, increasing bog water detention time, and tailwater recovery (storage and re-use of bog flood waters). However, the quantification of nutrient load reductions possible with the implementation of these recommendations was limited to a cursory analysis. The Gale report only identified load reductions with the complete elimination of discharges from tributaries A, D, and E (limitation action -- stop major inflows) or all tributaries (complete cessation of tributary inflows).

The objective of this update is to review the D/F Study recommendations (and supporting data), and further examine the feasibility and potential benefits of the recommended actions. This evaluation included:

- an independent review of nutrient budgets prepared by Gale Associates;
- "limited" field inspections of various bog operations in the watershed;
- an analysis of the anticipated benefits of the recommended management actions;
- an identification of likely permit requirements; and
- a preliminary opinion of improvement costs.

Review of 1990 Gale Associates Nutrient Budget

Hydrologic and nutrient budgets are developed to provide an estimate of the relative contribution of water and nutrients from various sources. Gale Associates prepared hydrologic and nutrient budgets for Billington Sea. Meteorological records, watershed characteristics, groundwater measurements, and surface water monitoring and flow data (samples taken every 14 to 28 days) collected during the one year diagnostic study were used. The hydrologic and nutrient budgets presented in the D/F study report were completed using generally accepted practices, although uncertainty (error) associated with the calculated hydrologic and nutrient budgets was not presented. As it is impossible to eliminate uncertainty it is desirable to quantify the uncertainty (where possible) and consider it when making decisions based on such estimates.

A number of assumptions and estimates are used when developing hydrologic and nutrient budgets. The accuracy of data used and the assumptions made contribute to the uncertainty (error) of calculated hydrologic and nutrient budgets. Each contributing term (e.g., tributaries, precipitation, ground water, evaporation) within the hydrologic or nutrient budget will contain a certain amount of error.

Tributaries (and their associated bogs) were identified in the Gale study as a significant source of phosphorus to the lake. Typically the error associated with estimates of annual tributary loads based on biweekly to monthly sampling of tributaries is about 10 - 20 percent (Reckhow and Chapra, 1983). However, the extreme variability of tributary flows associated with bog operations in the Billington Sea watershed suggests that even greater uncertainty can be expected for the estimates contained in the D/F report. Based on the observed variability of tributary flow and phosphorus concentrations more than 100 samples would be required to accurately estimate mean flow and concentration (with 95% certainty) in some of the tributaries. Generally speaking, the more variable something is, the more samples that are required to estimated the average with certainty. Cost, however, often limits the number of samples that can be taken and often requires that we work with a limited number of samples or make estimates from other published data sources.

Table 1 provides modified hydrologic and phosphorus budgets for Billington Sea. Average, low and high estimates were calculated based on the study data. Our review of the Gale hydrologic and nutrient budgets identified some possible double counting of watershed runoff and septic loads. Adjustments were made to the direct watershed runoff and septic load terms as well as minor adjustments in precipitation to reflect actual precipitation for the period of study. In addition, the single anomalous peak phosphorus concentration recorded for Tributary E on July 7, 1988, was omitted, as it greatly skewed the resultant load. That sample alone nearly doubles the annual load for Tributary E. This peak becomes inappropriately emphasized when calculating the average tributary value.

High and low tributary estimates represent the 90% confidence limits for the data used to derive annual water and phosphorus load (Table 1). That is, with 90% certainty we can expect that the annual water and phosphorus loads falls between these two estimates. High and low estimates for other terms in the hydrologic and nutrient budgets represent the likely range of error based on professional judgment and published literature error values. Phosphorus loads are likely to range from 719 to 1,519 kg/yr, with a likely load of 1,095 for the year of study based on our analysis. This "likely" estimate does not differ greatly from the 1,176 kg/yr in the Gale report, and reasonably predicted the observed in-lake concentration. However, the range clearly illustrates the uncertainty of the load estimates for the period of study. It is important to note that there is some additional uncertainty introduced when we attempt to extrapolate to other years or some future conditions. Variations from year to year are to be expected.

Billington Sea Nutrient Load Reduction Goal

Vollenwieder (1975) developed equations that estimate permissible and critical loads based on the volume and flushing rate of a lake. The calculated permissible and critical loads for Billington Sea are 402 and 804 kg/yr, respectively. Phosphorus loads above the Vollenweider critical load are fully expected to cause eutrophication problems (poor water clarity and algae blooms), whereas loads below the permissible level are not likely to result in problems. The estimated load to Billington Sea exceeds the critical load threshold. At least a 30% reduction in phosphorus load is needed to reduce the phosphorus load below the critical level. Greater reductions are needed if actual loads are closer to the high-end loading estimate (about a 600 - 700 kg/yr or 50% reduction). A 30%-50% reduction in load is expected to improve water clarity an average of 1.2 feet (0.4 meters). In our opinion, the 30% reduction in load is the minimum acceptable reduction likely to produce visible improvements in water clarity and a reduction in the frequency of algae blooms.

Analysis of Current Bog Operations

As part of our review, we completed site visits to many of the bogs within the watershed, except the Crimson Cove bogs (Tributary A). During the site visit we had an opportunity to briefly discuss the bog operations with the owners/operators.

A summary of the information gained from our site visits to each of the bog operations is attached. Most of the bogs located in the Billington Sea watershed are headwater bogs. That is there is no upstream surface water discharge flowing through the bog. Groundwater discharge to the bogs creating a base flow in the bogs is however likely for many of the bogs. In general, the bogs visited appear to be well managed. Fertilizer applications appear to be consistent with guidelines provided by the SCS and the Umass Cranberry Experiment Station. Most of the bogs visitied are out of level to some extent, requiring higher volumes of water to flood the bogs for harvest and frost protection. Our site visits and discussions with the bog operators clearly revealed that each operation is unique; tailored to the specific characteristics of their bogs. Therefore, it is difficult to make generalized statements about bog operations or to fully anticipate the potential opportunities and limitations of recommended controls without a full and detailed investigation of each operation. Such investigations were beyond the scope of this review.

As an industry, bog operators have invested considerable effort in developing and adopting sound management practices for their bogs to not only reduce the cost of production but minimize environmental impacts. For example, Black Cat Cranberry has constructed and put into operation a tailwater recovery system. In addition, they have constructed a dike within their largest bog to reduce water volumes required for flooding of the severely out-of-level bog. In addition, a new weir equipped with a slot for a charcoal filter was installed at the Kapell bogs, and excess summer water is infiltrated in a retention pond at the Meharg bogs. All of these actions serve to reduce water usage and discharge while improving the quality of discharges.

Water conservation represents the single largest opportunity to reduce nutrient loads from bogs to receiving water resources. Likewise, there may be an economic benefit to some commercial bog operations associated with water conservation. Pumping of water to irrigate and flood bogs may range in cost from $11 - $35 per acre-foot of water (SCS, 1986). Water conservation costs are generally balanced against these costs.

It should be noted that all of the bogs visited use sprinkler systems for irrigation. The use of sprinkler systems is one of the most significant water conservation measure bogs can employ reducing water needs by 30 - 50% (SCS, 1986). Other measures such as improved water holding (dike repair) and tailwater recovery systems may reduce water needs by about 20 - 25%. Leveling of bogs probably has the greatest potential to reduce water need. However, leveling is not typically feasible unless bog reconstruction is planned for other reasons. Leveling and sealing the bottom of high leakage bogs would result in the loss of income for 2-3 growing seasons along with the cost of leveling or sealing.

Review of Recommendations

The Gale D/F study made several recommendations to reduce phosphorus loads from the bogs. However, the projected reductions in load included in the report (elimination of loads from certain tributaries or all tributaries) are not realistic. It is not possible to eliminate the tributary loads, even were all bog operations to cease. A certain base load associated with watershed surface runoff and groundwater baseflow would persist. While the recommended measure may reduce the bog loads, they will fall well short of eliminating all phosphorus loads from the bogs. Table 2 provides a summary of the recommended controls (per the D/F Study; Gale & Associates, 1990) and our estimate of the anticipated load reduction of such controls.

Bog loads were estimated based on the volume of water required to flood the bog areas to an average depth of 3 feet for fall harvest and twice during the winter/spring. A second winter or early spring flooding is often required to prevent frost damage or damage from anoxia (lack of oxygen) that may develop under the ice formed on flooded bogs (Demoranville, 1987). The amount of water required to provide 1 inch of irrigation per week over a 4 month period was added to the flood volume. A phosphorus concentration of 0.25 mg/l was assumed for the flood water releases (BEC, 1993, Gale, 1990). Flow-weighted average concentrations, excluding apparent harvest and winter flood releases were used for the irrigation discharges. It was assumed that 100% of the irrigation water is discharged from the bog, though very little probably discharges. This assumption in part compensates for discharges that may occur associated with excess stormwater runoff during the growing season.

TO: Leighton F. Peck, D.P.W. Director

FROM: Douglass C Gray, Park Superintendent

RE: Billington Sea Remediation Meeting

DATE: September 30, 1997

Enclosed please find a proposal from Nancy Palmstrom of ENSR entitled "Cranberry Bog Discharge Treatment Feasibility Assessment." This proposal was requested after discussion at a meeting held in Town Hall on July 8, 1997. This meeting was attended by Nancy Palmstrom-ENSR, Gerald Smith-Aquatic Control Technology, Inc., Elaine Purdy and Lorna Hardy-Billington Sea Association, Leighton Peck- Director of Public Works and Douglass Gray-Parks & Forestry. Others including cranberry bog owners had been invited but were unable to attend.

This proposal seeks to define monitoring programs designed to "document the benefits and to assess the feasibility of applying various treatment strategies to commercial cranberry operations" that release into Billington Sea.

There will be a meeting on Tuesday, October 21, 1997 at 10:00 AM in the Mayflower I Hearing Room to discuss this proposal. Please look over this proposal and note any questions, comments or suggestions in this matter, so that these issues can be discussed at the meeting.

Please advise our office (508-830-4095) of your ability to attend this meeting.

c.c. Town Manager's Office
Plymouth Conservation Commission
Nancy Palmstrom
Gerald Smith
Elaine Purdy
Lorna Hardy
Jeffrey Kapell
Black Cat Cranberry Corp.
Eugene D. Cobb
Susan Meharg
George R. Holmes, Jr.
Donald V. Holmes
Crimson Cove Cranberry Trust

Table 3 provides a summary of the likely improvements from existing conditions associated with the implementation of recommended controls on other bogs. Construction of a tailwater recovery system for the Black Cat bogs (Tributary D) and the replacement of the Kapell Bog weir have been completed, and their associated benefits already realized.

Based on our review of the available information and site visits we have drawn the following conclusions:

1. The extreme peak phosphorus concentration observed in Tributary E (7/7/88) occurred shortly after a helicopter application of fertilizer (pers. comm., Jeff Kapell). However, it is unclear whether the observed concentration was a result of overspray (or drift), actual discharge from the bog, or possible contamination of the sampling containers. As bog discharges during the mid summer are limited due to evapotranspiration, it seems unlikely that this concentration was associated with discharge from the bog. An elevated (>1.0 mg/l) concentration was also noted at Tributary A during the summer. However, we do not know whether this corresponded with a fertilizer application. While fertilizer applications are made several times (typically 3 - 5 times) throughout the growing season, peaks of such magnitude are not routinely observed (Gale Associates, 1990; BEC, 1993, Davenport, 1990). Follow-up investigations to determine the cause of such peaks should be made.
2. At least a 30% reduction in phosphorus loading is needed to produce visible improvements in water quality in Billington Sea.
3. About 30-50% of the total phosphorus bog load is likely discharged in harvest and winter flood water. Given the rapid flushing rate of Billington Sea, fall releases probably have only a limited immediate impact to recreational water uses. Sedimentation of phosphorus from these discharges may contribute to long-term internal loading. However, at present internal loading is a relatively small contribution to the nutrient budget.
4. The recommended tailwater recovery system for the Black Cat Cranberry bogs has been constructed and is in use. Construction of a bypass to prevent flow through the bog when Briggs Reservoir overtops should be investigated further.
5. There is little data available documenting the actual benefits of tailwater systems for the reduction of nutrient loads. Implementation of a monitoring program on the Black Cat system would provide valuable information for evaluating the benefits of this alternative for other bogs.
6. The raising of the outlet of Trask Pond to improve detention times is not feasible as at its current levels the pond is causing flooding of neighboring yards.
7. Construction of a tailwater recovery system to serve the Kapell bogs will provide only limited benefit. At least 1/2 of the area identified for the construction of a storage reservoir is now an active bog. In addition, shallow depth to ground water (<5 feet) at the proposed location would severely reduce the available storage volume. The available storage volume is less than 25% of the water needed to flood the bog and about 1/2 the amount needed for summer irrigation. Without better documentation of the potential load reduction associated with tailwater recovery systems, this alternative is not recommended for nutrient load reduction purposes alone.

8. Construction of a tailwater recovery system to serve the Meharg/Holmes bogs will provide only modest benefit. In addition, shallow depth to ground water (<10 feet) at the proposed location would severely reduce the available storage volume. The available storage is less than 50% of the water needed to flood the bog, but probably sufficient to meet summer irrigation needs.. Without better documentation of the potential load reduction associated with tailwater recovery systems, this alternative is not recommended for nutrient load reduction purposes alone.
9. No site visit was made to the Crimson Cove bogs, and little is known about their operations. Construction of a storage basin for tailwater recovery appears potentially feasible based on our review of aerial photos and groundwater elevations. The total load contributed by these bogs is fairly small. Therefore, even with maximum effectiveness, the benefits to overall load reduction to the lake will be small. This alternative is not recommended without better documentation of the potential load reduction associated with tailwater recovery systems and more detailed information about the operations.
10. The recommended modification to increase detention times within the Tributary B system do not appear warranted as there are no active cranberry operations on this tributary.
11. In general, we believe that the growers probably exercise prudent use of fertilizers, though some additional reductions may be possible on a case-by-case basis. The Town should work with the each grower to explore opportunities for further reducing or better managing fertilizer applications.
12. Encouraging the detention (7 days) and slow release (3+ days) of harvest flood waters will result in little additional cost to growers while providing minor reductions (<5%) to phosphorus loads. Even an additional one day holding time can provide some reduction in discharge concentrations. In some cases, extended holding may not be possible due to water needs of downstream growers. The Town should work with the each grower to explore opportunities for increasing harvest water detention times.
13. The cost of water conservation measures such as dike and weir repair will vary considerably, but are only likely to reduce phosphorus loads from the bogs by about 10%. It is assumed that the replacement of the weir at the Kapell bogs has largely acheived this reduction for Tributary E. Such measures should be explored on a case-by-case basis with the bog owners.
14. Innovative and site-specific approaches (i.e., the weir filter fitting use at the Kapell Bogs and infiltration of excess water from the Meharg bogs) are recommended for further investigation. The charcoal filter system developed for the Kapell bog could be modified to include iron shavings and peat to enhance the removal phosphorus and nitrogen. To our knowledge there is no data available quantifying the potential benefits of such a filter. Even without modification, the charcoal filter system will at a minimum reduce the particulate portion of total phosphorus (which in some cases can be a significant portion of the total, particularly in harvest waters). Other possible innovative alternatives would include mechanisms to aerate discharge waters to facilitate phosphorus precipitation and the use of constructed or enhanced wetlands downstream of bog discharges to remove phosphorus. Constructed wetlands have been demonstrated to remove 70 - 90% of the phosphorus in stormwater runoff.

Conclusions and Recommendations

Cranberry bog operations probably contribute about 50 - 60 percent of the total estimated tributary phosphorus load where bogs are present. Total tributary loads (including Tributary B) are estimated at 735 kg/yr, representing about 60% of the total load to Billington Sea. Bog loads would need to be reduced by more than 50% overall to reduce the total load to the lake to the established goal. While lesser reductions in load will provide some level of improvement to the lake visible improvement (improved water clarity and reduced algal bloom frequency) are unlikely. The maximum likely load reduction associated with feasible control measures is about 105 kg/yr compared with the 300 - 350 kg/yr reduction needed to the nutrient load reduction goal. Given the limited benefits and high cost of some actions, not all potentially feasible actions are recommended at this time. The following provides a summary of recommended actions:

1. Develop and conduct a monitoring program of the Black Cat bog to demonstrate water quality benefits associated with tailwater recovery systems. In conjunction with this, examine the feasibility and potential benefits of constructing a bypass channel to avoid unnecessary discharge from Briggs Reservoir through the bog. Given the complexity of bog operations, such a monitoring program is likely to cost $8,000 - $12,000.
2. No immediate action to construct additional tailwater recovery systems are recommended at this time for nutrient load reduction purposes alone. The anticipated cost for the construction of tailwater systems will vary depending on site conditions and bog characteristics. However, a reasonable estimated cost for a system may range from $40,000 to $80,000. Further evidence (data) quantifying the benefits of tailwater systems for load reduction, is needed to justify the cost of construction.
3. Work with watershed growers on a case-by-case basis to develop or refine fertilizer application programs to minimize potential nutrient discharge.
4. Work with watershed growers on a case-by-case basis to evaluate opportunities for improved water holding through repair of leaky dikes or weirs.
5. Work with watershed growers on a case-by-case basis to evaluate opportunities for increasing the detention time of fall harvest water prior to release.
6. Explore other innovative mechanisms to reduce nutrient loads associated with bog discharges (see item 13 above for partial list of possible alternatives). A more detailed feasibility analysis of innovative and/or site specific alternatives is estimated to cost $10,000- $25,000, including the development of conceptual alternatives.

None of the above recommended actions require permits at this time. The construction of tailwater recover systems, and the repair, replacement, or modification of dikes and weirs may require various permits including:

Massachusetts Natural Heritage Program
Notice of Intent or Request for Determination (Wetlands Protection Act)
DEP Water Quality (Section 401) Certificate

Army Corps of Engineers Section 404 permit
Chapter 91 Waterways License
MEPA (ENF/EIR)

Other permits or approvals may be required depending on the specific location and scope of the proposed work.

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Table 1. Billington Sea Hydrologic and Nutrient Budgets

HYDROLOGIC BUDGET **Inputs (m^3/yr x10^6)**	**Mean**	**Lower Limit**	**Upper Limit**	**Mean % of Total**
Precip	1.2	1.2	1.2	8%
Groundwater (per Gale)	9.5	10.3	8.8	64%
Tribs (including Bog Discharge)				
Trib A	0.1	0.0	0.2	1%
Trib B	0.2	0.2	0.3	2%
Trib C	0.8	0.4	1.3	5%
Trib D	1.9	0.9	2.9	13%
Trib E	1.0	0.7	1.2	6%
Direct Overland Runoff	0.1	0.0	0.1	0%
Import/Discharge (direct watershed)	0.2	0.1	0.2	1%
Total Input	15.0	13.8	16.1	100%
Outputs m^3/yr x10^6				
Outlet	14.1	13.0	15.3	94%
Evaporation	0.5	0.5	0.5	4%
Groundwater	0.3	0.3	0.3	2%
Total Output	15.0	13.8	16.1	100%
Residence Time (Years)	0.16	0.17	0.15	
Flushing Rate (times/year)	6	6	7	
Areal Water Load (m/yr)	13.9	12.8	14.9	

PHOSPHORUS BUDGET **Inputs (kg/yr)**	**Mean**	**Lower Limit**	**Upper Limit**	**Mean % of Total**
Precip	32	16	65	3%
Septic Systems (<300 ft only)	80	40	120	7%
Groundwater (non-septic system)	248	267	228	23%
Tribs (Including Bog Discharge)				
Trib A	55	20	93	5%
Trib B	14	10	19	1%
Trib C	51	21	82	5%
Trib D	393	184	622	36%
Trib E	165	119	212	15%
Direct Overland Runoff	34	9	62	3%
Internal Sediment Release	23	32	16	2%
Total Input	1095	719	1519	100%
Outputs (kg/yr)				
Outlet	619	467	814	99%
Evaporation	0	0	0	0%
Groundwater Discharge	4	2	6	1%
Total Output	622	469	820	100%
Net Retention (kg/yr)	473	250	699	43%
Areal Load (gm/m^2/yr)	1.01	0.67	1.41	

Predicted In-Lake Concentration	Lake Model Predicted Values			Actual
Predicted In-Lake P Concentration (mg/l)	0.05	0.03	0.06	0.05
Predicted Secchi Depth (m)	1.2	1.5	1.0	1.3
Predicted Chlorophyll (mg/m^3)	23.8	14.5	34.5	24.5
Carlson Trophic State Index				
TSI tp	60	55	64	61
TSI sd	58	54	61	57
TSI chl	62	57	65	62

Table 2. Recommended Controls and Anticipated Load Reduction

	Trib A	Trib C[b]	Trib D	Trib E
Existing Total Load (kg/yr)	55	51	393	165
Existing Bog Load (kg/yr)[a]	26	36	152	102
Gale Recommended Controls				
Tailwater Recovery	X		X	X
Increased Harvest Detention Time		X		
Fertilizer Management	X	X	X	X
Water Conservation	X	X	X	X
Estimated Reduction Efficiency				
Tailwater Recovery[c]	34%	0%	25%	25%
Increased Harvest Detention Time[c]	15%	9%	5%	15%
Fertilizer Management	5%	5%	5%	5%
Water Conservation	10%	10%	5%	10%
Estimated Load Reduction (kg/yr)				
Tailwater Recovery	9	0	38	26
Increased Harvest Detention Time	4	3	8	15
Fertilizer Management	1	2	8	5
Water Conservation	3	4	8	10
Total Possible Load Reduction	16	9	61	56
Likely Feasible Load Reduction	8	5	61	31
Feasible Recommended Controls				
Tailwater Recovery**	?	NA	X	?
Increased Harvest Detention Time	X	NF	X	X
Fertilizer Management	X	X	X	X
Water Conservation	X	X	X	X

a Bog load consistent with estimates based on unit area load per bog acre derived from (BEC, 1993) as well as estimates made based on water usage and outflow concentrations

b Bog load for Tributary C does not account for existing removals provided by Trask Pond (about 60%)

c Varying load reduction efficiency based on storage volume relative to the demand, and diminished benefits of harvest detention or other water conservation measures w/ Tailwater systems

** Implementation benefits of tailwater system requires further documentation; potential load reduction not included in likely feasible load reductions

NF = not feasible

NA = not applicable

Table 3. Load Reduction Analysis

PHOSPHORUS BUDGET	1988 Conditions	With Prior Actions*	With All Recommended Controls	With Feasible Recommended Controls	
Inputs (kg/yr)					
Precip	32	32	32	32	
Septic Systems (<300 ft only)	80	80	80	80	
Groundwater (non-septic system)	248	250	254	254	
Tribs (Including Bog Discharge)					
Trib A	55	55	38	47	
Trib B	14	14	14	14	
Trib C	51	51	42	46	
Trib D	393	355	332	332	
Trib E	165	160	109	134	
Direct Overland Runoff	34	34	34	34	
Internal Sediment Release	23	23	23	23	
Total Input	1095	1054	959	997	
Outputs (kg/yr)					
Outlet	619	619	619	619	
Evaporation	0	0	0	0	
Groundwater Discharge	4	4	4	4	
Total Output	622	622	622	622	
Net Retention (kg/yr)	473	432	337	375	
Areal Load (gm/m^2/yr)	1.01	0.98	0.89	0.92	
Predicted In-Lake Concentration		**Lake Model Predicted Values**			**Goal**
Predicted In-Lake P Concentration (mg/l)	0.05	0.05	0.04	0.04	0.03
Predicted Secchi Depth (m)	1.17	1.20	1.29	1.26	1.54
Predicted Chlorophyll (mg/m^3)	23.8	22.6	19.7	20.8	14.2
Carlson Trophic State Index					
TSI tp	60	60	58	59	55
TSI sd	58	57	56	57	54
TSI chl	62	61	60	60	57
Vollenweider Load Thresholds	**kg/yr**	**gm/m2/yr**			
Permissible Load	402	0.37			
Critical Load	804	0.74			

BOG SITE VISIT SUMMARY

Owner/Operator: **Black Cat Cranberry Bogs**
Total Acreage: 31.5±
Acreage in Production: 31.5
Harvest Method: Wet
Water Source: Billington Sea/Briggs Res.
Discharges to: Billington Sea
Fertilizer Management: Consistent w/ SCS application rates; helicopter application
Levelness: fair; was >5 feet out of level prior to dike construction*
Water Holding: good
Notes: Tailwater recovery system constructed to pump water to Briggs Reservoir for storage and re-use (insufficient storage for harvest use); 100 % recycled during summer; system construction cost = $35,000±
Has trouble preventing discharge;groundwater discharges into bogs
Installed dike (15 acre/8 acre split) to reduce water volume required for flooding
Briggs reservoir overflow flows through bog; bypass would avoid this flow through when Reservoir overtops

Owner/Operator: **G. Holmes Bogs**
Total Acreage: 4±
Acreage in Production: 4
Harvest Method: Wet
Water Source: Well.
Discharges to: Trask Pond
Fertilizer Management: Consistent w/ SCS application rates and methods; hand application
Levelness: fair
Water Holding: good
Notes: Once drawn down in spring/early summer bog doesn't generally discharge
Discharges winter flood waters over 2 day period

Owner/Operator: **Kapell Bogs**
Total Acreage: 22±
Acreage in Production: 22
Harvest Method: Wet
Water Source: Wells
Discharges to: Tributary E
Fertilizer Management: Consistent w/ SCS application rates; helicopter application
Levelness: poor; was 3 feet out of level
Water Holding: good* (possibly improved with new weir construction)
Notes: New weir installed for improved water control; probably has help to reduce leakage
New weir equipped with fitting for charcoal filter (used primary after pesticide applications, but probably also filters out particulate and some dissolved phosphorus)
Recently upgraded sprinkler system

BOG SITE VISIT SUMMARY

Owner/Operator: **Meharg Bogs**
Total Acreage: 5.7±
Acreage in Production: 5.7
Harvest Method: Wet
Water Source: Wells
Discharges to: To downstream bogs (D. Holmes) and Tributary E
Fertilizer Management: Consistent w/ SCS application rates
Levelness: good
Water Holding: poor (primarily infiltration losses)
Notes: Infiltrates summer excess water in small detention area next to bog

Owner/Operator: **Cobb Bogs**
Total Acreage: 3.4±
Acreage in Production: 3.4
Harvest Method: Wet
Water Source: Trask Pond
Discharges to: Trask Pond to Tributary C
Fertilizer Management: Consistent w/ SCS application rates; hand application
Levelness: good; about 1 foot out of level
Water Holding: good
Notes: Use of and recycling to Trask Pond serves similar purpose as a tailwater recovery system.
Neighbor abutting Trask Pond has requested that Trask Pond be maintained 6 inches lower than historic levels as higher water levels result in saturation of the homeowners lawn.