SUDBURY PLANNING BOARD
FLYNN BUILDING
SUDBURY, MA 01776

HOP BROOK PONDS SYSTEM STUDY
SUDBURY, MASSACHUSETTS

Prepared for:

Board of Health
Town of Sudbury

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A. PURPOSE OF THE STUDY

This study was conducted to determine the current pollutional status of Grist, Carding, and Stearns Millponds in Sudbury. A further purpose was was to identify the sources of the ponds' water quality problems and propose cleanup alternatives.

The study consisted of two phases; a diagnostic phase and a feasibility phase. The diagnostic phase involved collecting data and identifying the existing and potential sources of pollution affecting the Sudbury ponds. The feasibility phase involved analyzing and applying collected data to assess methods for pollution control.

B. SUMMARY OF FINDINGS AND RECOMMENDATIONS

The conclusion of the 12-month diagnostic phase is that the excessive algal and macrophyte growth within the Sudbury ponds is primarily due to the discharge from the Marlborough Easterly Wastewater Treatment Plant (MEWWTP) which has, since 1896, discharged treated effluent to Hop Brook. The treatment plant effluent comprises between 50 and 90 percent of the flow in Hop Brook. The effluent is a rich source of phosphorus, the nutrient determined to be the key influence to aquatic plant growth rates within the ponds.

The gradual filling of the ponds, exacerbated by both the MEWWTP effluent and watershed development, has significantly decreased the water depths within the ponds. This depth decrease has led to an increase in the area available for rooted macrophyte growth. The elevated nutrient levels have provided an ideal media for algal and floating macrophyte growth. The profusion of aquatic plant growth is symptomatic of the hypereutrophic state of the ponds. These problems have further negative impacts to the community because they depreciate many of what are considered the finer characteristics of the ponds and are limiting the ponds uses. Specifically, recreational-uses, such as boating and fishing are becoming impossible due to the excessive aquatic plant growth caused by nutrient loading. Also, the aesthetic beauty once seen in the ponds is diminishing. Repugnant odors from the ponds, unsightly plant growth, and mosquitos have changed the ponds from the once open water area to inland wetlands.

A multi-phased approach to solving the problems of the Sudbury ponds should be undertaken. First, nutrient inputs to the ponds must be curtailed. Since 95 percent of the phosphorus loading to the ponds comes from the MEWWTP, the nutrient levels in the effluent should be reduced. The City of Marlborough should consider additional tertiary treatment techniques, effluent redirection/reduction, and influent controls to achieve a meaningful decrease in nutrient (especially phosphorus) loading to Hop Brook.

Dredging portions of each pond to physically remove phosphorus-laden sediments and decrease the area of the littoral zone should be considered. The dredging alternative involves the mechanical removal of approximately 140,000 cubic yards of soft sediment at an estimated cost of $2.1 million.

Mechanical removal of vegetation (harvesting), or physically limiting the area available for plant growth, show promise as an alternative to dredging. These methods may result in a decrease in rooted plant densities, but do not effectively remove sediments from the ponds or increase pond depths.

Watershed management techniques and pond water-level manipulation should also be part of the restoration plan for the three ponds. Lawn fertilizers, unmonitored septic systems, and improper development techniques add to the nutrient loadings to the ponds. Water-level manipulation can be an effective tool in limiting the growth of aquatic macrophytes by removing a portion of the biomass from the pond system.

In order to achieve the goal of cleaning up these ponds, it is essential for the City of Marlborough and the Town of Sudbury to cooperate in these efforts. This is an effort that can provide a healthy and desirable recreational and aesthetic asset to both communities.

A. BACKGROUND INFORMATION

1. Process of Lake Eutrophication

The natural process of eutrophication (lake aging) has been accelerated in many ponds and lakes throughout the Commonwealth. The primary cause of this has been the uncontrolled addition of nutrients to ponds and lakes. These nutrients stimulate primary production by algae and/or aquatic vascular plants (macrophyton). Nutrient sources can be point or nonpoint in origin and are typically related to watershed development. Accelerated eutrophication due to man's activities is known as cultural eutrophication. Cultural eutrophication, therefore, is the excessive addition of inorganic nutrients, organic matter, and silt to lakes, leading to increased biological production and a corresponding decrease in lake volume (Cooke, et al., 1986).

The grouping of lakes, based on lake metabolism, can be seen as a continuum between oligotrophy and eutrophy. An oligotrophic lake is low in nutrients and organic productivity. Oligotrophic lakes are usually deep, have nutrient-poor sediments, few macrophytes, and large amounts of dissolved oxygen in the deepest water. A eutrophic lake is high in nutrients and organic matter, more shallow, more rich in plankton and macrophyton, and has depleted dissolved oxygen levels in bottom waters.

The cultural eutrophication of the ponds that is found along Hop Brook has occurred for several reasons. In addition to the nutrients emanating from the Marlborough Easterly Wastewater Treatment Facility, nutrients are derived from road runoff, septic leachate, construction practices, and fertilization. There may also be considerable nutrient enrichment from within the ponds. Lake sediments generally contain stockpiles of phosphorus which have accumulated over time. Finally, waterfowl may potentially contribute significant phosphorus loads. This is particularly true of Canada geese, seagulls, and to a lesser degree, common duck species.

2. Previous Studies of the Hop Brook Ponds System

Several studies have previously been conducted of the water resources within the Town of Sudbury. Groundwater resource studies have been conducted by Motts (1977) and H_2O Engineering Consulting Associates, Inc. (1985 and 1986). Several surface water studies have been conducted by the Massachusetts Division of Water Pollution Control (1965, 1977, 1979, and 1986). Presented in these reports are the results of field and laboratory analyses conducted on the waters of the Concord and Sudbury Rivers, including their main tributary, Hop Brook. A synopsis of the MDWPC findings are as follows:

- The limiting nutrient in these water bodies is phosphorus.
- Most (90-99 percent) of the phosphorus comes from the MEWWTP.
- Net phosphorus accumulation in the pond sediments accelerated over the two decades in which the studies were conducted.
- Influent phosphorus levels decreased by a factor of 2-3 since phosphorus removal at MEWWTP began.
- Summer phosphorus flushing has occurred in the ponds since phosphorus removal at MEWWTP began.
- The current rate of phosphorus discharge from MEWWTP into Hop Brook is perhaps 20 times the level needed to reverse the eutrophication process (20 g/m^2/year versus 1/g/m^2/year, respectively).
- Once in-stream phosphorus levels are decreased, it will take some time to realize the benefits since reductions often result in a net release of phosphorus from sediment, prolonging the projected recovery time of the lake.
- "The water quality in Hop Brook has not improved since 1979, although the MEWWTP has continued to be in compliance with its permit limitations for phosphorus and ammonia-nitrogen (MDWPC, 1979)."

The most comprehensive study of of the Hop Brook pond system was conducted by the United States Geological Survey (USGS) in 1984. The purpose of that study was to determine if the pond system "was responding to the reduced concentrations of nitrogen and phosphorus after the initiation of tertiary treatment" at the MEWWTP.

A synopsis of the USGS findings are as follows:

- "Water entering these ponds contains quantities of nitrogen and phosphorus far higher than the levels known to promote excessive growth of aquatic vegetation."
- "During certain summer periods, there appears to be release of some phosphorus from the sediments in Carding and Grist Millponds."
- "No improvement in water quality of the three ponds can be expected until the concentrations of nutrients entering Hager Pond are reduced to levels that will not support excessive growth of vegetation."

3. Hop Brook Ponds System Study

The effort to study the water quality problems facing the ponds system was coordinated by the Sudbury Board of Health. The Board of Health is the local group charged with the management of Hop Brook within Town limits. The Town of Sudbury appropriated funds for the study of the Brook and specifically Grist Millpond, Carding Millpond, and Stearns Millpond.

The Hop Brook Ponds System Study consists of two phases. The first is the diagnostic phase, which includes data collection to identify existing and potential sources of nutrient enrichment affecting the ponds. Included in the diagnostic phase is the analysis of limnological, morphological, demographic, geological, and historical information pertinent to the characterization of the ponds and their watersheds.

The second phase is the feasibility study, during which methods and procedures for controlling accelerated nutrient enrichment of the pond system were investigated. The goals of the feasibility study were to establish on a priority basis:

- Long-term solutions for restoration of the ponds' water quality.
- Methods for long-term preservation of the restored water quality.
- Short-term (remedial) actions to relieve the most severe problems (i.e., aquatic macrophyton growth) in order to maintain the water body in a condition adequate for public recreation and enjoyment.

Feasible methods are presented in terms of their potential effectiveness, their engineering feasibility, costs, improved water quality, and public acceptability. All methods and procedures necessary to implement recommended alternative(s) are included in the study and are directed towards long-term restoration and preservation of Hop Brook and its ponds.

B. HISTORICAL REVIEW OF THE HOP BROOK WATERSHED

The Sudbury portion of the Hop Brook watershed has its origins in colonial times as an agrarian community. Boston Post Road, in use since the 1600's, traverses the watershed in an east-west orientation. Along this road, in 1702, David How build his home in South Sudbury in the vicinity of what are now Grist and Carding Millponds. Licensed in 1716, How's Tavern (How Hotel) was established. It was renamed the Red Horse Inn in 1746 by Colonel Ezekial How and, after publication in 1863 of Henry Wadsworth Longfellow's "Tales of a Wayside Inn," it became know as the Wayside Inn.

Edward Rivers Lemon acquired the Inn in 1897 and officially changed the name to the Wayside Inn. Much of the property surrounding Grist Millpond, Carding Millpond, and the area to the east of Hager Pond (south of Route 20) was owned by Henry Ford. The Grist Mill, fed by Grist Millpond, was built in 1929 for Henry Ford. Likewise, Martha Mary Chapel was built in 1939 by the Fords. The Ford farm occupied the land south of Route 20 in the Grist and Carding Millpond watersheds. The remainder of the Grist and Carding Millpond watersheds remain largely undeveloped to this day.

Because of the extensive wetlands, the Stearns Millpond watershed was largely undeveloped until modern times. Subdivisions, a portion of the U.S. Army Natick Laboratories, cranberry bogs, and the Boston and Maine railroad line which traverses the watershed are all of recent vintage.

The Marlborough Easterly Wastewater Treatment Plant was originally constructed in 1896 in the Hager Pond watershed. The MEWWTP has been discharging to the Hop Brook system since its opening (see Chapter V). Development in the Hop Brook watershed is most intense along Route 20 to the west of Hager Pond.

A. SIZE AND LOCATION

The Hop Brook ponds system study area encompasses the watersheds of Grist, Carding, and Stearns Millponds. These three ponds lie almost entirely within the Town of Sudbury. The exception is approximately 5 percent of the southwestern portion of Grist Millpond. The watersheds of these ponds are within Sudbury, Framingham, Marlborough, and Hudson.

A fourth subwatershed area, Hager Pond in Marlborough, is included in this study since it is the headwaters of Hop Brook. Although no in-pond water quality samples were collected from Hager Pond, both the pond inlet (from the MEWWTP) and the pond outlet were sampled on a regular basis.

The study area, shown on Figure 3-1, is located on the Marlborough/ Sudbury Corporate Boundary, just off Moore Road with the centroid located at latitude 42° 22′ 10" and longitude 71° 28′ 45". The watershed "study area" is approximately 23.8 square kilometers (9.2 square miles) and is located within the north central portion of the Sudbury River Basin. The Sudbury River Basin drains to the Concord River which is tributary to the Merrimack River. The Merrimack River is one of several New England rivers east of the Connecticut River Basin draining to the North Atlantic.

As shown in Table 3-1, about 36.4 percent of the study area lies within Sudbury, 47.6 percent is in Marlborough, 5.3 percent is in Hudson, and 10.7 percent is in Framingham.

1. Hager Pond Watershed

The Hager Pond watershed is 470 hectares (1,160 acres) and located almost entirely within the City of Marlborough. Indian Head Hill (elevation 421), Mount Ward (elevation 411), and an unnamed hill at the Marlborough/Sudbury Corporate Boundary (elevation 438) define the major topographic drainage divides. The central portion of the watershed is almost entirely wetland, from which three intermittent streams feed Hager Pond (elevation 223).

Just north of Hager Pond, effluent from the MEWWTP serves as the major water source to Hop Brook. The Hager Pond watershed is primarily undeveloped due to large wetland areas and steep, hilly terrain.

TABLE 3-1
WATERSHED COVERAGE AREA

Location	Area (hectares)	Percent of Total
Sudbury	868	36.4
Marlborough	1136	47.6
Hudson	126	5.3
Framingham	255	10.7
		100.0

2. Grist Millpond Watershed

The Grist Millpond watershed consists of approximately 280 hectares (690 acres) of lightly populated wetland and rolling hills. Sixty-four percent of the watershed is within Framingham, 25 percent is within Sudbury, and 11 percent is within Marlborough.

Grist Millpond receives drainage from wetlands north and south of the pond, while the predominant flow is from Hop Brook. Steep terrain, with elevations over 500 feet, makes up the southern boundary of the watershed. Drainage from the south and southwestern watershed divides enter a large wetland between Parmenter Road and Wayside Inn Road. The Grist Millpond stillwater elevation is 201 feet.

3. Carding Millpond Watershed

The Carding Millpond watershed is the smallest of the four watersheds studied at 269 hectares (665 acres). Eighty-five percent of the watershed is within Sudbury with the remainder extending into Framingham. This watershed is largely undeveloped. Wetlands within the watershed's central area are the result of large sloping hills in the watershed's southern end. Carding Millpond has a stillwater elevation of 184 feet.

4. Stearns Millpond Watershed

The Stearns Millpond watershed is the largest watershed studied at 1368 hectares (3380 acres). Forty-one percent of the watershed is within Sudbury, 50 percent is within Marlborough, and 9 percent is within Hudson.

HOP BROOK POND STUDY

WATERSHED AREAS

Scale(approx.)

0 2000 4000 feet

0 0.5 1.0 kilometers

Source: USGS 7.5' Topoquads

(Framingham, Hudson, Marlboro, Maynard)

Whitman & Howard, Inc

Figure 3-1

The watershed is best characterized as generally flat, with a large contiguous wetland spreading throughout. Elevations range from an average of about 185 feet to a low point of 154 feet at Stearns Millpond.

B. GENERAL CLIMATOLOGY

The Hop Brook ponds system study area is characterized by frequent and sporadic weather changes throughout the year, wide ranges of daily and annual temperatures, and abundant precipitation. Predominant air flow is from the southwest (warm and moist) during the summer, with cold, dry northerly air flow during the winter.

The mean annual temperature is 9.5°C (49°F). Summer temperatures average between 21°C (70°F) and 23°C (74°F), while winter temperatures average -1°C (30°F). Extremes in temperature occur during summer months with 5 to 15 days exceeding 32°C (90°F). Temperatures below zero occur 5 to 15 days a year. The growing season (frost-free period above a threshold temperature of 0°C (32°F)), averages 140 days per year (NOAA, 1987-1988).

The mean annual precipitation is approximately 107 centimeters (42 inches) and occurs evenly between the four seasons (NOAA, 1987-1988). The mean annual snowfall accumulation varies considerably due to topographic and oceanic effects. Approximately 152 centimeters (60 inches) of snow falls annually on the watershed area.

The Hop Brook watershed is in close proximity to the Framingham Weather Station of the National Oceanic and Atmospheric Administration (NOAA). However, in review of the study year, NOAA records only two months of data. The closest weather station with continuous records of precipitation and temperature is in Bedford, Massachusetts (NOAA Index No. 0551). During the study period (September 1987 - August 1988), approximately 105.6 centimeters (41.57 inches) of precipitation were recorded at the Bedford station (Table 3-2).

C. TOPOGRAPHY AND DRAINAGE

The Hop Brook ponds system study area is characterized by wide valleys, extensive wetlands, and low-rounded hills. Numerous natural drainage swales along hillsides are due to erosional activity by glacial ice and

TABLE 3-2
CLIMATOLOGICAL DATA

Month	Precipitation in. (cm)	Average Temperature °F
September, 1987	6.42 (16.3)	61.5
October	2.46 (6.2)	48.6
November	3.59 (9.1)	40.4
December	2.53 (6.4)	32.3
January, 1988	2.67 (6.8)	23.9
February	4.00 (10.2)	28.8
March	3.42 (8.7)	33.1
April	2.18 (5.5)	45.5
May	3.96 (10.1)	57.3
June	1.61 (4.1)	64.7
July[1]	7.62 (19.4)	73.7
August[1]	1.11 (2.8)	75.5
TOTAL	41.57 (105.6)	

Source: NOAA, 1987-1988.

[1]From R.E. Lautzenheiser - N.E. Climatic Service - Logan Airport.

deposits of glacial till (Motts, 1977). The highest relief in the watershed occur as bedrock and till, traversing from southeast to northwest. The extensive wetland area throughout the watershed plays a critical role in protecting surface and groundwater quality.

Profuse vegetation and the low, flat topography of bordering vegetated wetlands slow down and reduce the passage of flood waters during periods of peak flows. This topography provides temporary flood storage and facilitates water removal through evaporation and transpiration. This occurrence reduces downstream flood crests and resulting damage to private and public property. During dry periods, the water retained in bordering vegetated wetlands is essential to maintain base flow levels in rivers and streams, which, in turn, is important because it protects water quality and water supplies.

Wetland vegetation provides shade that moderates water temperatures important to fish life. Wetlands flooded by adjacent water bodies and waterways provide food, breeding habitat, and cover for fish. However, most river and stream channels do not provide sufficient quantities of food for the microscopic plant and animal life. Thus, fish populations in the larval stage are particularly dependent upon food provided by over-bank flooding which occurs during peak-flow periods (extreme storms).

The plant communities, soils, and associated low, flat topography of bordering vegetated wetland act as sinks, transformers, and/or cleansers which detain sediments, nutrients (such as nitrogen and phosphorus), and toxic substances (such as heavy metal compounds) that occur in runoff and flood waters.

D. GENERAL HYDROLOGY

The hydrologic characteristics of a region are determined largely by the region's physical characteristics, with climate being a dominating factor. Amount and distribution of precipitation, in particular, contribute to the hydrologic features of the region. Physical characteristics (i.e., geology, geography, vegetation) of the watershed dictate (1) the volume of rainfall that is converted into runoff (direct discharge), (2) groundwater (infiltration), and (3) atmospheric loss (evapotranspiration). These three factors are major considerations in the hydrologic budget for the Hop Brook area (discussed in Chapter VIII of this report). The hydrologic budget is also related to the nutrient budget. Hydrologic and nutrient budget calculations were based on a September 1987 to August 1988 study period and were used to assess the overall trophic status of the ponds. The annual budget figures take into account various physical parameters within the watershed that impact its hydrologic cycle and the ponds' subsequent water quality.

As previously noted, the "study area" is divided into four subwatersheds based on surface topography and drainage. Figure 3-1 depicts these subwatershed delineations and Table 3-3 provides pertinent watershed data.

E. GENERAL SOILS INFORMATION

Soil composition in the watershed is important because of erosion potential and absorption of water and nutrients. The following discussion provides background information regarding soil properties, soil groups, and soil mapping, as well as specifics about soil characteristics in the Hop Brook watershed.

1. Soil Properties

Soil properties are important in estimating the total volume of precipitation which may infiltrate, runoff, or evaporate. Soil infiltration and percolation rates indicate their potential to absorb rainfall and thereby reduce the amount of direct runoff. Soils having high infiltration rates (sand, gravel) have low runoff potentials. Conversely, soils having low infiltration rates (clays, muck) exhibit high runoff potentials. Some soils are seasonally wet or subject to flooding. Other soils are unstable and not suitable for use under buildings or roads. Clayey or wet soils are poorly suited to use as septic tank absorption fields.

2. Soil Groups

Hydrologic soils groups are used in estimating runoff from precipitation. Soils are placed in one of four groups on the basis of intake of water after the soils have been wetted and have received precipitation from long-lasting storms. These groups were established by the United States Department of Agriculture Soil Conservation Services (SCS) in 1986.

TABLE 3-3
SUBWATERSHED AREAS WITHIN THE HOP BROOK PONDS STUDY AREA

Subwatersheds	Sudbury		Marlborough		Hudson		Framingham		Total
	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres
Hager Pond	0	0	1020	87.9	0	0	140	12.1	1160
Grist Millpond	174	25.2	74	1.7	0	0	442	64.1	690
Carding Millpond	567	85.3	0	0	0	0	98	14.7	665
Stearns Millpond	1405	4.9	1712	49.9	312	9.2	0	0	3429
Entire Watershed Area	2146	36.4	2806	47.6	312	5.3	680	10.7	5944

The four hydrologic groups are:

Group	Description
A	- Soils having high infiltration rates even when thoroughly wetted, consisting chiefly of deep, excessively-drained sand and/or gravel. These soils have a high rate of water transmission and result in a low runoff potential.
B	- Soils having moderate infiltration rates when thoroughly wetted, consisting chiefly of moderately-well to well-drained soils with coarse-to-medium textures. These soils have a moderate rate of water transmission.
C	- Soils having slow infiltration rates when thoroughly wetted, consisting chiefly of (1) soils with a layer that impedes downward movement of water, or (2) soils with high water table at or near ground surface for 7 to 9 months of the year. These soils have a slow rate of water transmission. This group may include bedrock outcrop.
D	- Soils having very slow infiltration rates when thoroughly wetted, consisting chiefly of (1) soils with a permanent water table for most of the year, or (2) shallow-to-bedrock, extremely rocky at ground surface. These soils have a very slow infiltration rate (high runoff potential). This group may include bedrock outcrop.

3. Soil Mapping

Soil information was assembled by the Middlesex County Office of the Soil Conservation Service (1986). Currently, the data is in its preliminary form and has only been published in an interim Soil Survey Report. Table 3-4 provides an approximate percentage of the soils within each hydrologic group in the four subwatersheds.

The dominant soils in the Hager Pond, Carding, and Grist Millponds subwatersheds are classified as hydrologic group B. In these watersheds, Carlton-Hollis rock outcrop complex (Charlton series) and Narragansett-Hollis rock outcrop complex (Narragansett series) are the most abundant soils in hydrologic group B.

TABLE 3-4
SOIL HYDROLOGIC GROUP BY SUBWATERSHED

	Soil Hydrologic Group				
Subwatershed	A	B	C	C/D	D
Hager Pond	5	60	10	5	20
Grist Millpond	10	50	15	5	20
Carding Millpond	10	60	10	10	10
Stearns Millpond	60	15	5	5	15

NOTE: Numbers in table represent approximate percentages.

The Charlton series consists of gently-sloping to steep, deep, well-drained soils on uplands where the relief is affected by the underlying bedrock. The Narragansett series consists of gently-sloping to very steep, deep, well-drained soils on glacial till plains and ground moraine. Both the Charlton and Narragansett series have a very high or an extremely high degree of stoney surface, except where stones have been removed. The major limitation of these soils is related to slope and stoniness.

The Hollis series also has gentle to very steep slopes, but is more shallow than the other soil series. This complex occurs on ridges and hills. The Hollis complex consists of exposed bedrock and is somewhat excessively drained. The series is made up of shallow, nearly-level to very steep soils. The major limitations that prevent these series from being suitable for septic systems are related to depth-to-bedrock, rockiness, and slope. The overall soil complex has severe limitations (due to impervious bedrock), so it is not suitable for septic systems.

The predominant soils in the Stearns Millpond subwatershed are classified in hydrologic group A. Throughout the watershed the majority of hydrologic group A is composed of Hinckley loamy sand. The Hinckley series consists of nearly-level and gently-rolling, deep, well-drained soils on glacial outwash plains, terraces, and ridges. The surficial soils in the Hinckley series are friable or loose. They are generally gravelly, and sandy loam-to-loamy coarse sand soils. The subsoil is very permeable being composed of loosely stratified sands and gravels. The substratum (hardpan) lies 12 to 30 inches deep and its composition makes it very permeable. The major limitations that prevent these soils from being suitable for development are related to slope and droughtness.

The southwesterly portion of the Stearns Millpond Watershed is predominantly comprised of Windsor soils, which are classified hydrologically in group A. The physical characteristics of Windsor soils mirrors those which describe Hinkley soils and this series is also composed of rapidly permeable soils. The Windsor and Hinkley series differ in that the Windsor has a substratum to a depth of 60 inches or more whereas, as previously mentioned, the Hinckley has a substratum of 10 to 30 inches deep. However, like Hinckley's, Windsor's limitations are also related to slope and droughtness.

4. Relationship to Subsurface Wastewater Disposal and Aquifer Areas

As noted above, certain soil hydrologic groups function better than others to subsurface wastewater disposal. Clayey or perpetually wet soils do not function well as absorpotion fields for septic systems. The developed portions of the Hop Brook watershed study area generally have high infiltration rates, and, therefore, are well suited to receive septic system contributions.

Most of the study area is not within the aquifer protection district for the groundwater resource that provide potable water to the area (Motts, 1977; H_2O Engineering, 1985 and 1986). The extreme northeastern portion of the Stearns Millpond watershed is the exception. Stearns Millpond is the only one of the four ponds studied that lies within the aquifer protection district.

F. LAND USE

Much of the land use throughout the Hop Brook watershed study area is open space. Industrial and commercial development is confined to a narrow strip surrounding Route 20. Commercial/industrial development in the study area is mainly within Marlborough in the Hager Pond watershed. Commercial establishments, the MEWWTP, and a large Raytheon facility are along this reach of Route 20.

A majority of the Grist Millpond watershed is residentially zoned, with a 5-acre-minimum lot size. The southern third of the watershed is residentially zoned, with a one-acre-minimum lot size. Development in this watershed is minimal.

As with the Grist Millpond area, the Carding Millpond watershed is residentially zoned. The 5-acre-minimum lot size exists throughout most of the watershed.

The Stearns Millpond watershed, the largest of the four watersheds in the study area, has two developed areas. The western corner (in Marlborough) and the northeastern corner (in Sudbury) of the watersheds are one-acre residentially zoned areas. The pond is in the northeastern corner and is flanked by two residential communities. The middle two-thirds of the watershed consists of the Marlborough State Forest, Sudbury Conservation Lands, an undeveloped portion of the Natick Laboratories, and sparse residential development along the few roads that traverse the area.

The watersheds continue to be developed although the restrictive zoning and large conservation areas limit development to the areas previously enumerated. Recent studies (H_2O Engineering, 1985 and 1986) estimate that population trends in the area remain stable and that no substantial population increases are foreseen in the near future.

A. HAGER POND

1. Overview

Hager Pond is a 15.4 hectare (39 acre) pond. The pond is located immediately south of Route 20 at the Marlborough-Framingham Corporate Boundary, within Marlborough City Limits (latitude 42° 20′ 57" and longitude 71° 29′ 14") Hager Pond's major tributary, Hop Brook, is subject to approximately 3.2 million gallons per day (MGD) of treated wastewater from the Marlborough Easterly Wastewater Treatment Plant.

The pond's shoreline had been undeveloped until approximately two years ago. A Raytheon Company building is now situated on the pond's northeast shore. The pond has no developed beach or public access areas. Extensive growths of shoreline weeds, and in-pond waterlilies, along with duckweed and Hydrodictyon (water net), seriously impairs any recreational use of the pond. In addition, during summer months, the pond gives off an odor of chlorine-treated wastewater effluent.

2. Pond Morphology

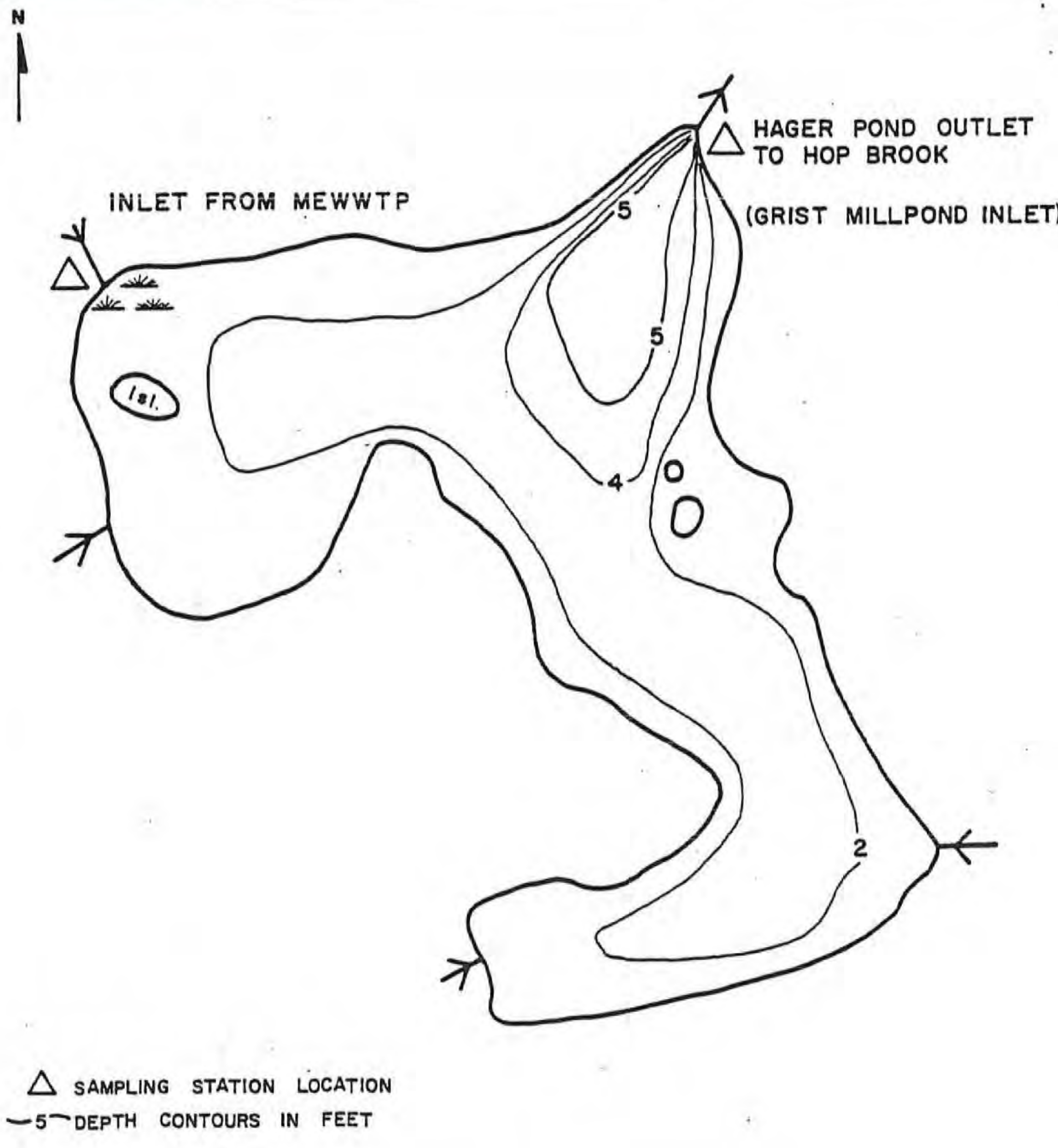
The bathymetric map of Hager Pond (Figure 4-1) was prepared by the MDWPC (1979). Morphological data, information pertaining to the physical dimensions of the ponds, from the MDWPC Report is tabulated in Table 4-1. No in-pond morphometric measurements were taken for this study.

Hager Pond is small, heavily sedimented, and is decreasing in surface area, yet increasing in surrounding wetland area. This change is believed to reflect the pond's cultural eutrophication process. The pond had a mean depth of 0.7 meters (2.5 feet) in 1979 and a maximum depth of 1.8 meters (6.0 feet). The shallowness of the pond is reflected in its small volume.

B. GRIST MILLPOND

1. Overview

Grist Millpond is a 9.4 hectare (24 acre) pond. Grist Millpond was created as a result of damming Hop Brook. Grist Millpond's major tributary, Hop Brook, enters its southwestern-most end within the City of Marlborough. This portion of the pond is impassable and can be



HAGER POND (39 ACRES)
MARLBOROUGH
BATHYMETRIC MAP AND LOCATION
OF SAMPLING STATIONS

Whitman & Howard, Inc.	Figure 4-1

133910

MAKEPEACE

TABLE 4-1
HAGER POND
MORPHOMETRIC DATA

Dimension	Metric	English
1. Surface Area	15.4 hectares	39 acres
2. Maximum Depth	1.8 meters	6.0 feet
3. Mean Depth	0.7 meters	2.5 feet
4. Volume	119,700 cubic meters	97 acre-feet
5. Maximum Length	611 meters	2070 feet
6. Maximum Effective Length	560 meters	1900 feet
7. Maximum Width	398 meters	1350 feet
8. Maximum Effective Width	398 meters	1350 feet
9. Shoreline Length	2025 meters	7974 feet
10. Development of Shoreline[1]	--	1.5
11. Mean to Maximum Depth Ratio	--	0.4
12. Drainage Area[2]	456.7 hectares	1160 acres

[1]The Development of Shoreline Index is used to express the degree of regularity or irregularity of the shoreline. Very circular lakes approach the minimum development of shoreline value of <u>one</u>, the greater the number above one the greater the potential effect of littoral (shoreline) process (wind action, weed growth in shallow embankment areas, etc.) on the pond.

[2]All morphological values, except for the drainage area, were derived from previous MDWPC studies.

considered wetland. The pond is situated immediately north of Route 20 and south of Old Boston Post Road at latitude 42° 21' 17" and longitude 71° 21' 51".

Grist Millpond has two minor tributaries: one which flows south from the Prides Crossing Road area and the other which flows north from Parmenter Road in Framingham. Grist Millpond has two outlets at its northeastern end. A surface outlet powers the Gristmill, while a sub-surface outlet at approximately 3.3 meters (10 feet) below surface level drains the excess water flow. No direct storm drains enter the pond.

Grist Millpond is almost completely covered with Hydrodictyon, a thick algal growth which makes boating difficult, if not impossible, along its dammed northern end. As a result of both wind and water flow, the area closest to the popular Gristmill is choked with macrophyton and algal growth. The southern 3 to 4 acres of the pond have virtually become wetland, while open water is found in the pond's mid-section.

The pond is rarely used for recreational purposes, and thus has no formal public access. However, an occasional angler is seen on shore's edge, and many sightseers walk the elongated man-made dam.

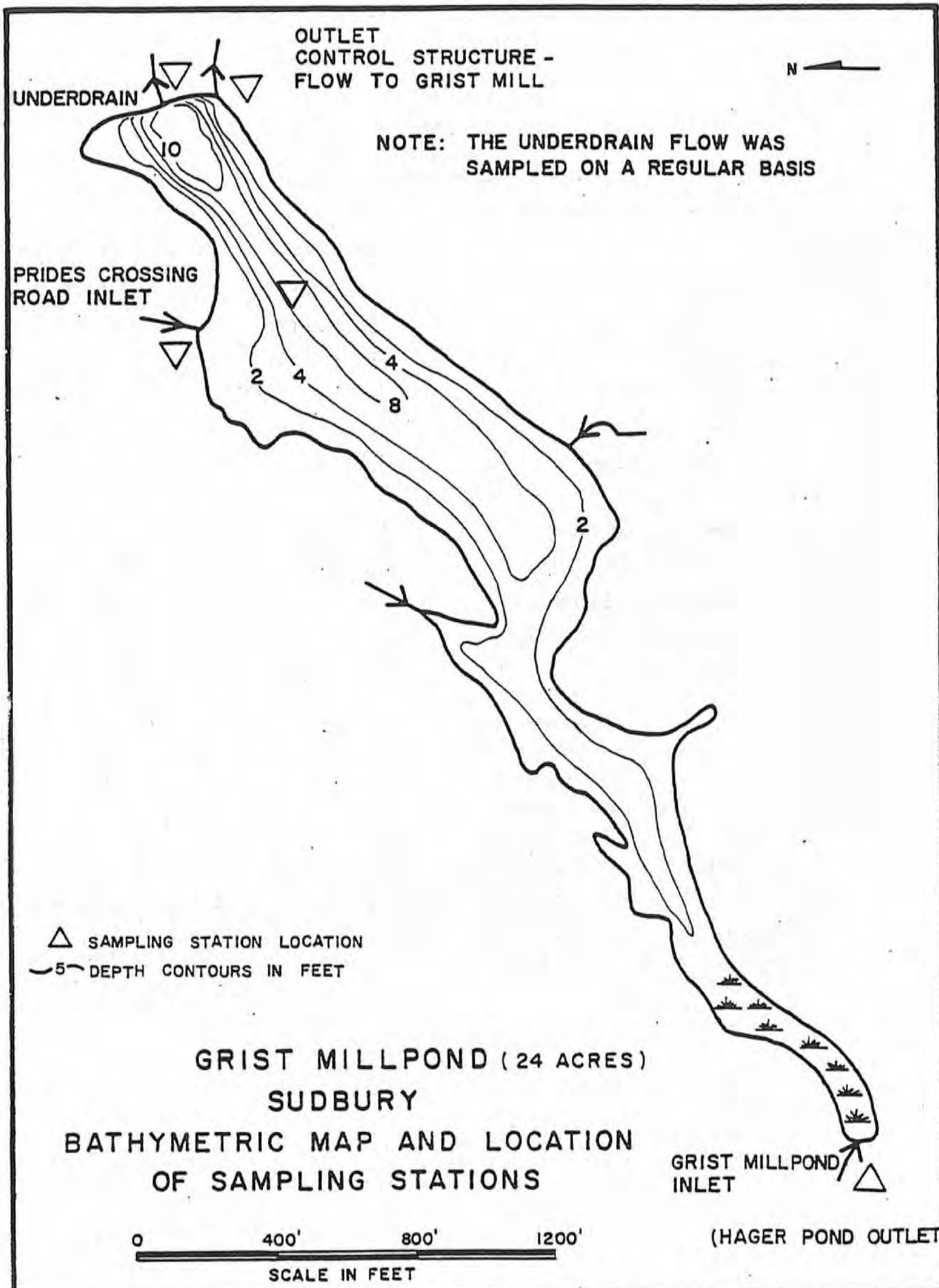
2. Pond Morphology

The bathymetric map of Grist Millpond (Figure 4-2) was developed in June 1987, by use of a sounding chain and a Raytheon DC 200 Fathometer. Transets were run parallel to the dams at widths of approximately 50 meters. Morphometric data were determined from the bathymetric map, the DWPC's studies (as previously noted), and from the USGS (1979). Data from these sources are shown in Table 4-2.

C. CARDING MILLPOND

1. Overview

Carding Millpond is the largest impoundment of Hop Brook in the study area at 15.7 hectares (40 acres). This pond was formed by the damming of Hop Brook. Carding Millpond has virtually no surrounding development and has the most open water available for potential recreation of the ponds studied. This pond has no formal public



Whitman & Howard, Inc.

Figure 4-2

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TABLE 4-2
GRIST MILLPOND
MORPHOMETRIC DATA

Dimension		Metric	English
1.	Surface Area[1]	9.4 hectares	24 acres
2.	Maximum Depth[1]	3.3 meters	10.0 feet
3.	Mean Depth[1]	0.7 meters	2.5 feet
4.	Volume[1]	74,000 cubic meters	60 acre-feet
5.	Maximum Length	789 meters	3100 feet
6.	Maximum Effective Length	767 meters	2600 feet
7.	Maximum Width	171 meters	580 feet
8.	Maximum Effective Width	124 meters	420 feet
9.	Shoreline Length	2181 meters	7392 feet
10.	Development of Shoreline[2]	--	1.9
11.	Mean to Maximum Depth Ratio[1]	--	0.25
12.	Drainage Area[1]	272 hectares	690 acres

[1]Determined by Whitman & Howard, Inc., all other values from MDWPC (1979).

[2]The Development of Shoreline Index is used to express the degree of regularity or irregularity of the shoreline. Very circular lakes approach the minimum development of shoreline value of one, the greater the number above one the greater the potential effect of littoral (shoreline) process (wind action, weed growth in shallow embankment areas, etc.) on the pond.

access, although it may be accessed with permission from the owner of a mill located at its northern end (Dutton Road). It is situated at latitude 42° 21′ 42" and longitude 71° 27′ 57".

Carding Millpond has one tributary, other than Hop Brook, which emanates from the Nobscott Hill area in Framingham. The pond's watershed is the smallest and least developed of those in the study area. The pond has two distinct side-by-side outlets where the water level can be controlled by flashboards.

Carding Millpond's southwestern reaches have become wetland and are therefore inaccessible by boat. East of the islands is considerable open water, although an occasional tree stump is still prevalent. The pond is quite shallow and has extensive soft sediment intermixed with boulders, which is evidence of the once existing field that predates the pond.

2. Pond Morphology

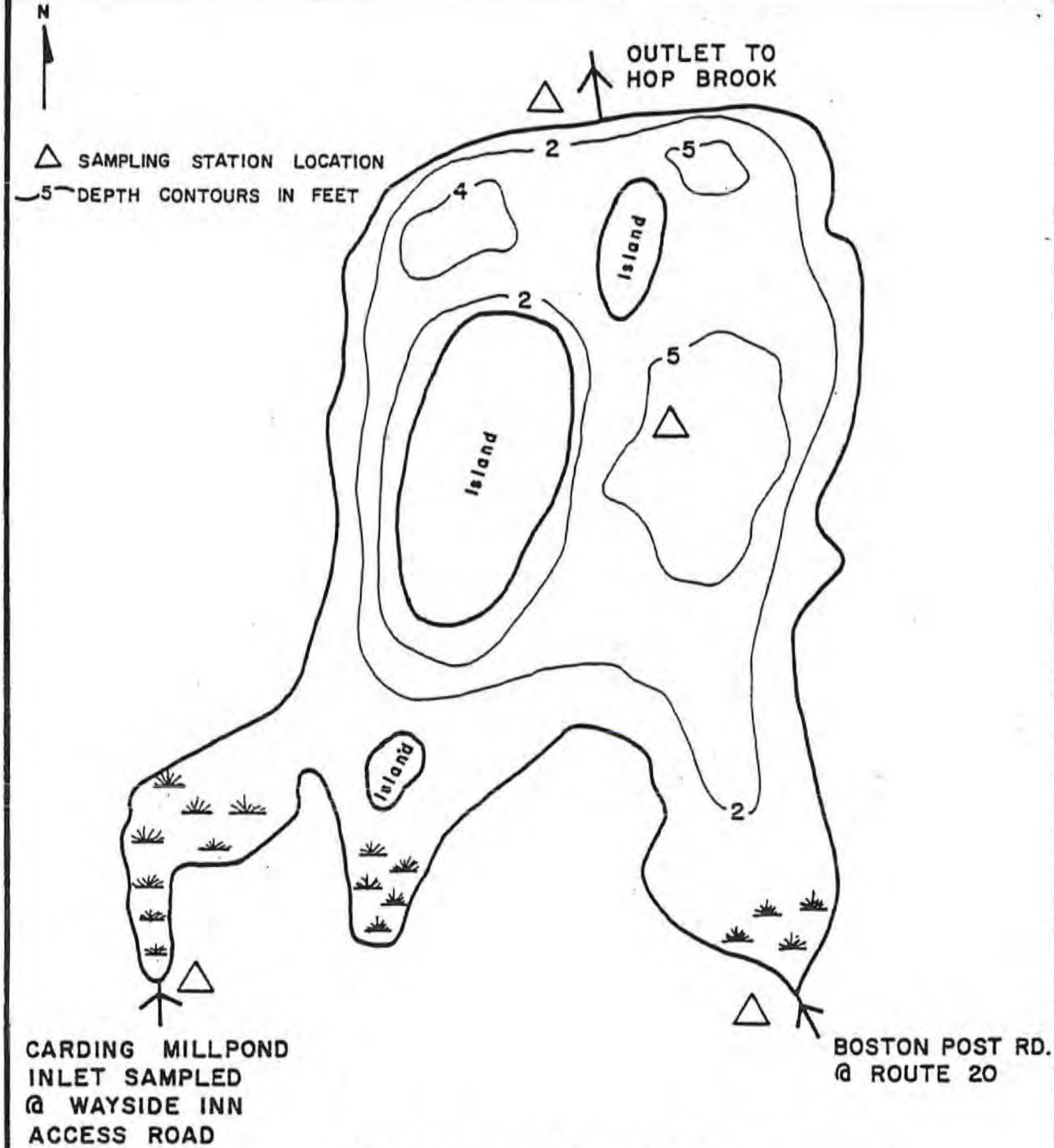
The bathymetric map of Carding Millpond (Figure 4-3) indicates its shallow depth and large islands. Morphometric data were determined from the bathymetric map, the DWPC's studies, and from the USGS (1979). Data from these sources are shown in Table 4-3.

D. STEARNS MILLPOND

1. Overview

Stearns Millpond is a 9.4 hectare (24 acre) pond. Stearns Millpond is the most shallow of the ponds studied, with a maximum depth of 0.9 meters (3 feet), and a mean depth of only 0.3 meters (1 foot). Stearns Millpond is situated in a heavily developed portion of Sudbury. Stearns Millpond's center is at latitude 42° 23′ 10" and longitude 71° 27′ 25". It is most easily accessed from Dutton Road in the vicinity of the pond's outlet structure. No formal public access exists.

Although homes are set back from the pond's immediate shore, over 60 residences are within 1000 feet of Stearns Millpond. All homes in Sudbury rely on on-site wastewater disposal and, although few homes report problematic disposal systems in the vicinity of the ponds, the potential for impact exists.



CARDING MILLPOND (40 ACRES)
SUDBURY
BATHYMETRIC MAP AND LOCATION
OF SAMPLING STATIONS

0 333' 666' 999'
SCALE IN FEET

Whitman & Howard, Inc. | Figure 4-3

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TABLE 4-3
CARDING MILLPOND
MORPHOMETRIC DATA

Dimension	Metric	English
1. Surface Area[1]	15.7 hectares	40 acres
2. Maximum Depth	1.2 meters	4 feet
3. Mean Depth	0.5 meters	1.7 feet
4. Volume[1]	88,000 cubic meters	72 acre-feet
5. Maximum Length	705 meters	2390 feet
6. Maximum Effective Length	614 meters	2080 feet
7. Maximum Width	354 meters	1200 feet
8. Maximum Effective Width	330 meters	1200 feet
9. Shoreline Length	2180 meters	7392 feet
10. Development of Shoreline[2]	--	1.5
11. Mean to Maximum Depth Ratio	--	0.4
12. Drainage Area[1]	217 hectares	665 acres

[1]Determined by Whitman & Howard, Inc., all other values from MDWPC (1979).

[2]The Development of Shoreline Index is used to express the degree of regularity or irregularity of the shoreline. Very circular lakes approach the minimum development of shoreline value of one, the greater the number above one the greater the potential effect of littoral (shoreline) process (wind action, weed growth in shallow embankment areas, etc.) on the pond.

The pond's extremely shallow depth, high nutrient content, and soft sediments support prolific macrophyte and algal growth. Summer recreational activity on the pond is minimal. Anglers are seen on several occasions near the outlet structure. Conversation with the fishermen indicate that Bass is present in the pond, however, the catch is primarily made of small pan fish. In the wintertime, ice-skating on the pond is very popular. Therefore, the gradual filling of the pond will limit this recreational use.

2. Pond Morphology

The bathymetric map of Stearns Millpond (Figure 4-4) shows its overall shallow depth and elongated shoreline. This makes the pond susceptible to littoral weed growth and the impact of shoreline development. Morphometric data were determined from the bathymetric map, the USGS (1979) and the DWPC's studies (Table 4-4).

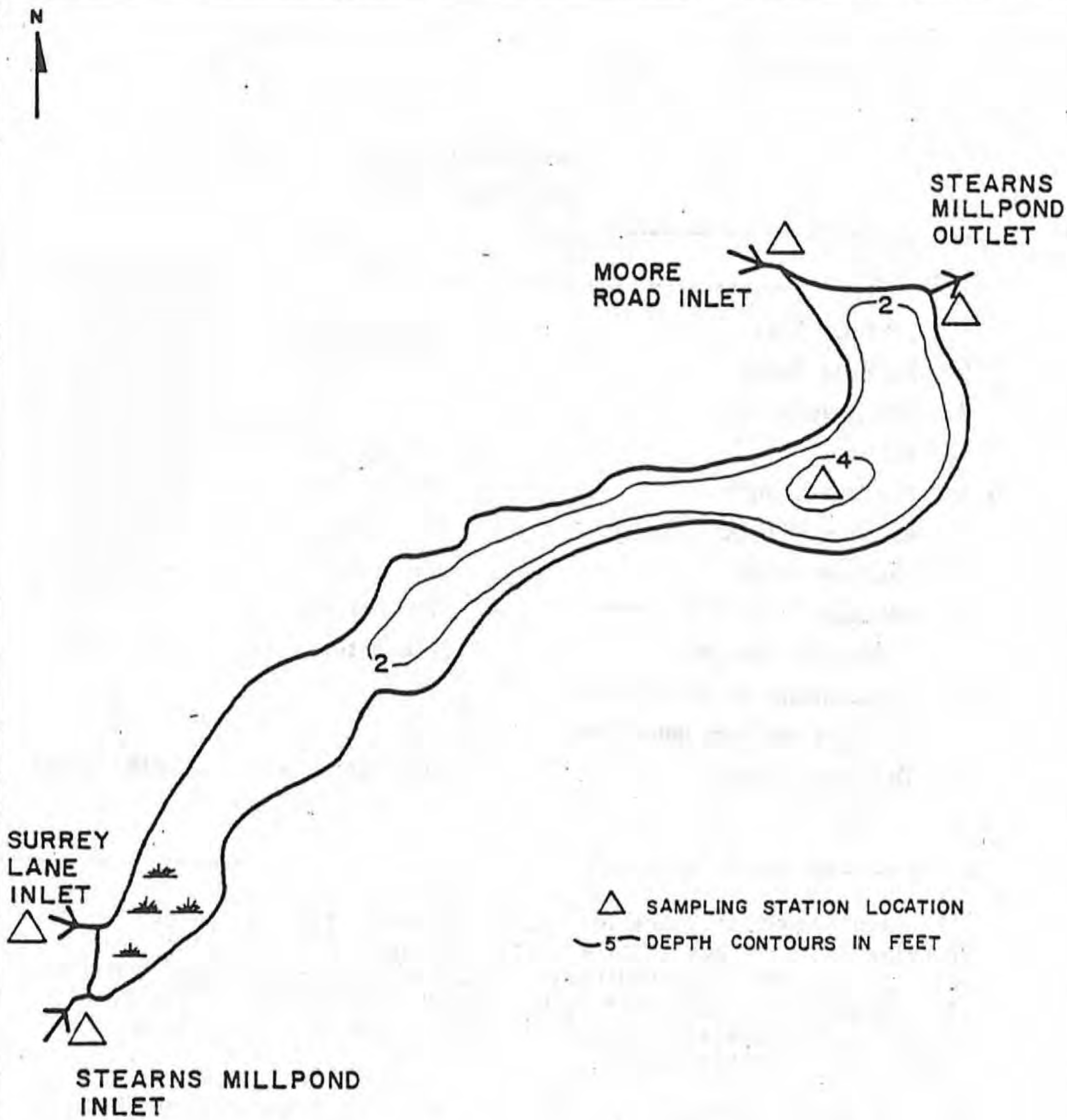
E. POND WATER-LEVEL CONTROLS

Each of the four ponds in the study area are, at least in part, regulated by outlet structures. These structures allow for the manipulation of the water level within the ponds. This capability could be useful in pond management techniques.

Hager Pond is controlled by a 9-foot-high dam with flashboards. The available control height (amount of water-level manipulation that can be attained) with the current structure is 1.9 feet. The structure appears to be operable.

Grist Millpond has two outlets, one to feed the mill and one to manipulate the water level and one to divert excess flows away from the mill sluice. The water-level control is via flashboards, with a control height of 2.2 feet. The structure appears to be operable and in good condition.

There are two spillways along the Carding Millpond dam. At one of these spillways, the water elevation can be controlled by flashboards located adjacent to Dutton Road. The available control height is 4 feet and the structure appears to be operable. The second spillway does not have any means of water-elevation control. A flashboard retainer could be added to the structure for this purpose.



STEARNS MILLPOND (24 ACRES)
SUDBURY
BATHYMETRIC MAP AND LOCATION
OF SAMPLING STATIONS

0 500' 1000' 1500'
SCALE IN FEET

Whitman & Howard, Inc.	Figure 4-4

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TABLE 4-4
STEARNS MILLPOND
MORPHOMETRIC DATA

Dimension		Metric	English
1.	Surface Area	9.4 hectares	24 acres
2.	Maximum Depth	0.9 meters	3 feet
3.	Mean Depth	0.3 meters	1 foot
4.	Volume	29,600 cubic meters	24 acre-feet
5.	Maximum Length	988 meters	3350 feet
6.	Maximum Effective Length	546 meters	1850 feet
7.	Maximum Width	236 meters	800 feet
8.	Maximum Effective Width	227 meters	770 feet
9.	Shoreline Length	2336 meters	7920 feet
10.	Development of Shoreline[1]	--	2.2
11.	Mean to Maximum Depth Ratio	--	0.3
12.	Drainage Area[2]	1331 hectares	3380 acres

[1]The Development of Shoreline Index is used to express the degree of regularity or irregularity of the shoreline. Very circular lakes approach the minimum development of shoreline value of one, the greater the number above one the greater the potential effect of littoral (shoreline) process (wind action, weed growth in shallow embankment areas, etc.) on the pond.

[2]Determined by Whitman & Howard, Inc., all other values from MDWPC (1979).

The Stearns Millpond control structure is in disrepair and currently has no control height available. To control the water level in Stearns Millpond, a new structure would be required. Adequate topographic variations appeared upstream and downstream of the dam and this variation makes control feasible.

V. MARLBOROUGH EASTERLY WASTEWATER TREATMENT PLANT

A. HISTORY OF MEWWTP

Since 1896, when it was first put on-line, the MEWWTP has discharged treated effluent to the headwaters of the Hop Brook ponds system. From 1896 until 1946 the nutrient-rich effluent eminating from the MEWWTP received only primary treatment (Briggs and Silvey, 1984). In 1946, secondary treatment facilities, consisting of trickling filters and Imhoff tanks, were put in operation. Tertiary treatment of the effluent was added between 1973 and 1975. The tertiary treatment consists of the forced aeration conversion of ammonia to nitrate, phosphorous removal, and chlorination of the final effluent (Briggs and Silvey, 1984).

B. CURRENT MEWWTP NPDES PERMIT STATES

The current National Pollutant Discharge Elimination System (NPDES) permit for the MEWWTP was issued in late September, 1988. The permit was issued with the following limitations (average-monthly basis):

- Flow = 5.5 mgd (year-round)
- BOD = 2.0 mg/L (12/1-3/31), 7.0 mg/L (4/1-11/30)
- TSS = 20 mg/L (12/1-3/31), 15 mg/L (4/1-11/31)
- Phosphorous = 0.75 mg/L (year-round)
- Ammonia = 4.4 mg/L (12/1-3/31), 0.50 mg/L (4/1-11/31)

These limitations represented a change from the proposed draft NPDES permit in that phosphorous removal to 0.75 mg/L on an average-monthly basis) was required throughout the year rather than exclusion of the 12/1 to 3/31 period. In addition, the DEQE requires that any future expansion of the treatment facility be permitted only if the increased capacity would not increase the current phosphorous levels (DWPC, 1988). The permit also requires that once the average flow from the facility achieves 70 percent of the design flow, during a 3-month period, that facilities planning efforts for the service area be initiated. The treatment facility is currently at 65 percent of its design flow.

The City of Marlborough appealed the more restrictive permit limitation put forth by the DEQE and, in early December, the USEPA denied the appeal.

C. IMPLICATIONS FOR FUTURE WATER QUALITY IN THE HOP BROOK SYSTEM

The new NPDES permit reinstitutes year-round phosphorous removal at the MEWWTP. The allowable discharge limit (0.75 mg/L average-monthly concentration) for phosphorous represents an improvement over the most recent permit limits. However, this level of phosphorous input to the Hop Brook ponds system is still excessive.

The MEWWTP effluent can, during dry periods, make up 90 percent of the flow into the Hop Brook ponds system. During wetter periods the effluent still constitutes a majority of the flow through Hager Pond, Grist, and Carding Millponds. The USEPA (1976) suggests that to avoid nuisance plant growth in ponds, the influent to the pond should not have a phosphorous concentration in excess of 0.05 mg/L. Attainment of this level (0.05 mg/L) with currently utilized tertiary treatment methods is not practicable. However, the current permit allows an effluent phosphorous concentration of 15 times the USEPA (1976) recommended level.

Even with the high flushing rates exhibited by the ponds, unless the Town of Sudbury and the City of Marlborough can attenuate the phosphorus loading to the ponds, nuisance plant growth within the ponds will continue and be unmanageable.

[illegible]

[illegible]

B. SAMPLE COLLECTION AND ANALYSES

[illegible]

[illegible] shown in Table 4.

[illegible]

[illegible]

A. OBJECTIVE OF STUDY

The purpose of the year-long diagnostic phase of this study was to determine the physical, chemical, and biological characteristics of the three Sudbury ponds. The interactions between these characteristics of each pond yield a picture of the ponds' trophic status. Given this status, and an understanding of the external factors affecting each pond, "clean-up" alternatives were investigated.

B. SAMPLING COLLECTION AND ANALYSES

1. SAMPLING STATIONS

Fifteen sampling stations were established throughout the study area. Station locations are shown on Figures 4-1 through 4-4. The 15 stations are shown in Table 6-1.

2. SAMPLING METHODOLOGY

All samples were taken between 9 A.M. and 4 P.M., on 11 occasions during the study period (September 1987 to August 1988).

Temperature and dissolved oxygen readings were conducted in-situ using a Yellow Springs Instrument Model 5775 meter. In-pond readings were taken at 0.5 meter intervals to a depth of 1.5 meters in Grist and Carding Millponds, and 1.0 meter in Stearns Millpond. Dissolved oxygen and temperatures were also recorded at the inlets and outlets of the ponds.

In-pond transparency measurements were taken using a 20-centimeter-diameter Secchi disk. A Secchi disk transparency was taken as the depth where the disk disappeared when lowered over the shaded side of the boat and then reappeared upon raising the disk.

In-pond surface water samples were collected in pre-rinsed, 2-liter bottles. In-pond deep water samples were collected using a "Polypro" water sampler and were transferred to sample bottles. At the laboratory, 1 liter of each sample was placed in a pre-rinsed glass container and preserved with sulfuric acid. This sample was then analyzed for total phosphorus, total Kjeldahl nitrogen, ammonia nitrogen, and nitrate nitrogen. The remaining sample was refrigerated and analyzed for the following: pH, alkalinity, chlorides, suspended

TABLE 6-1
SAMPLING STATIONS IN SUDBURY PONDS STUDY

Station No.	Location
1	Grist Millpond inlet (Hager Pond outlet)
2	Grist Millpond in-pond
3	Grist Millpond outlet
4	Carding Millpond inlet
5	Carding Millpond in-pond
6	Carding Millpond outlet
7	Stearns Millpond inlet
8	Stearns Millpond in-pond
9	Stearns Millpond outlet
10	Hager Pond inlet
11	Tributary to Hop Brook upstream of MEWWTP
12	Tributary to Carding Millpond near intersection of Old Boston Post Road
13	Tributary to Stearns Millpond near Surrey Lane
14	Tributary to Grist Millpond at Prides Crossing Road
15	Tributary to Stearns Millpond near Moore Road

solids, turbidity, and total dissolved solids. Bacteria (total coliform, fecal coliform, and fecal streptococcus) samples were collected in sterilized 250-milliliter glass bottles. Bacterial samples were collected only from the surface of the in-pond station, inlet, and outlet. These samples were iced in the field, as were all samples, and among the first to be analyzed upon delivery to the laboratory.

Phytoplankton and chlorophyll a samples were collected by lowering a weighted, hollow, polyethylene tube through the water column. Sampling in this way provided a depth-integrated sample of the entire water column. Phytoplankton samples were preserved with a buffered, 10 percent formalin solution.

3. Sample Analyses

All chemical and biological analyses were conducted in accordance with standard methods outlined by APHA (1980). All analyses were performed in the Whitman & Howard, Inc. laboratory in Wellesley, except the following:

- phytoplankton identification was performed by IEP, Inc., Sandwich.
- chlorophyll a was performed by Arnold Green Testing Laboratories, Natick.

4. Comparative Analyses

The results of our analyses of water quality data were compared with study data compiled by state and federal agencies. The results were also compared to the desired Class B water quality level. Water bodies assigned to Class B "are designated for the uses of protection and propagation of fish, or aquatic life and wildlife, and for primary and secondary contact recreation" (MDWPC, 1985). Also, current study data was compared to information compiled from previous water quality data collected by various researchers.

C. ANALYSES OF PHYSICAL DATA

1. Water Temperature

One of the most significant determinants of the physical, chemical, and biological interactions in a pond is its annual temperature cycle (Wetzel, 1983). Temperature readings at the in-pond stations for the Sudbury ponds (Tables 6-2 through 6-4) are characteristic of very shallow, north temperate ponds. Generally, uniform temperatures throughout most of the year indicate that the ponds circulate completely and have a high flow-through rate.

January and February data show slight inverse stratification during periods of ice cover. Inverse stratification (i.e., temperature increases with depth) occurs because the surface waters are the temperature of ice (0.0°C). In contrast, slightly warmer water (up to 4°C) is denser so therefore this water sinks.

Massachusetts surface water quality standards (MDWPC, 1985) state that temperature shall not exceed 83°F (28.3°C) in warm water fisheries or 68°F (20.0°C) in cold water fisheries. The Sudbury ponds' surface water temperatures usually exceeded the cold water fishery criteria during the summer, but did not exceed the warm water fishery criteria.

2. Water Transparency

As previously stated, transparency is routinely measured using a 20-centimeter-diameter Secchi disk. Secchi disk readings offer a subjective estimate of the transparency in the pond. Several factors affect readings. These include apparent water color, dissolved and particulate matter, surface conditions, sky conditions, time of day, and observer bias. Results of Secchi disk readings, water conditions, and apparent water color are shown in Table 6-5.

Overall, the Secchi disk readings were similar within season. The readings were at their high points in the fall when primary production was low and at their low points in the spring when primary production was high.

Apparent water color is a subjective determination of the background color of the water as one looks through the water column at the white portion of the Secchi disk. The apparent water color in the ponds varied from clear in the fall to brown and green in the spring. This color variation is due to variations in the concentration of algae in the water column.

TABLE 6-2
POND TEMPERATURE, DISSOLVED OXYGEN, AND PERCENT SATURATION
GRIST MILLPOND

	September 10, 1987			October 25, 1987			December 9, 1987		
Depth (m)	Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation	Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation	Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation
0.5	21.0	8.1	90	11.0	11.0	99	0.0	10.0	68
1.0	20.0	10.2	111	11.0	11.2	101	1.0	10.6	74
1.5	20.0	9.8	111	11.0	11.0	99	2.0	9.8	71

	March 30, 1988			April 29, 1988			May 31, 1988		
Depth (m)	Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation	Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation	Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation
0.5	4.0	14.4	110	10.5	9.4	84	17.0	5.0	51
1.0	4.0	14.0	110	10.2	8.8	78	17.0	5.0	51
1.5	4.0	14.0	110	10.2	8.4	75	16.0	4.4	44

	June 24, 1988			July 12, 1988			August 30, 1988		
Depth (m)	Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation	Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation	Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation
0.5	22.5	11.0	98	27.0	12.8	140	23.5	11.4	132
1.0	22.0	10.6	94	26.5	10.8	133	23.0	11.0	98
1.5	21.5	8.4	75	25.0	8.5	101	22.5	9.2	82

TABLE 6-3
POND TEMPERATURE, DISSOLVED OXYGEN, AND PERCENT SATURATION
CARDING MILLPOND

	September 10, 1987			October 25, 1987			December 9,1987		
Depth (m)	Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation	Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation	Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation
0.5	21.5	8.8	99	11.0	12.4	112	0.0	10.8	74
1.0	21.0	8.5	95	11.0	12.4	112	0.5	10.4	72
1.5	20.0	7.4	81	11.0	12.4	112	2.0	10.0	72

	March 30, 1988			April 29, 1988			May 31, 1988		
Depth (m)	Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation	Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation	Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation
0.5	4.0	12.5	95	11.0	9.6	87	19.5	5.0	54
1.0	4.0	12.0	91	10.6	8.4	75	19.8	4.8	52
1.5	4.0	12.0	91	9.8	8.2	72	18.5	4.5	48

	June 24, 1988			July 12, 1988			August 30, 1988		
Depth (m)	Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation	Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation	Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation
0.5	23.5	11.0	99	27.5	10.5	131	23.5	9.6	112
1.0	23.0	8.5	98	27.0	10.0	124	23.0	9.3	107
1.5	23.0	6.2	71	27.0	10.0	124	22.0	9.4	107

TABLE 6-4
POND TEMPERATURE, DISSOLVED OXYGEN, AND PERCENT SATURATION
STEARNS MILLPOND

Depth (m)	September 10,1987 Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation	October 25,1987 Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation	December 9,1987 Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation
0.5	21.5	8.8	99	10.0	11.0	97	0.0	10.0	68
1.0	21.0	8.0	89	9.0	10.8	93	2.0	10.4	75

Depth (m)	March 30, 1988 Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation	April 29,1988 Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation	May 31,1988 Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation
0.5	4.5	12.2	94	11.0	9.8	88	16.0	4.5	45
1.0	4.0	12.0	91	10.8	9.6	86	16.0	4.8	48

Depth (m)	June 24, 1988 Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation	July 12, 1988 Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation	August 24, 1988 Temp (Celsius)	Dissolved Oxygen (mg/L)	Percent Saturation
0.5	22.5	5.8	66	23.0	10.2	118	23.5	8.6	100
1.0	21.0	5.0	56	23.0	10.0	115	23.5	8.4	98

TABLE 6-5
SECCHI DISK TRANSPARENCY

Date	Pond	Time	Trans-parency (Feet)	Water Color	Surface
September 10, 1987	Grist	1:55 P	4.9	Clear	Calm
	Carding	2:50 p	4.9	Clear	Calm
	Stearns	11:45 a	3.9	Clear	Calm
October 25, 1987	Grist	11:00 a	4.6	Clear	1/2" Ripples
	Carding	12:15 p	4.9	Clear	1" Ripples
	Stearns	1:30 p	4.6	Clear	1/2" Ripples
March 30, 1988	Grist	11:45 a	N/R*	Green/Brown	Calm
	Carding	1:10 p	3.9	Green	--
	Stearns	2:20 p	3.3	Light Green	Calm
April 29, 1988	Grist	1:55 P	3.9	Brown/Green	1/2" Ripples
	Carding	1:25 p	3.9	Brown/Green	1/2" Ripples
	Stearns	12:30 p	3.6	Brown/Green	1/2" Ripples
May 31, 1988	Grist	8:50 a	3.3	Light Brown	1/2" Ripples
	Carding	--	2.6	Brown	1" Ripples
	Stearns	10:20 a	2.6	Light Brown	1" Ripples
June 24, 1988	Grist	--	N/R	--	--
	Carding	--	N/R	--	--
	Stearns	12:25 p	3.3	Tan/Green	Calm
July 12, 1988	Grist	2:45 p	3.3	--	Calm
	Carding	--	N/R	--	--
	Stearns	--	N/R	--	--
August 30, 1988	Grist	--	4.3	Brown/Green	1/2" Ripples
	Carding	--	N/R	--	--
	Stearns	--	N/R	--	--

*N/R = Not Recorded

D. ANALYSES OF CHEMICAL DATA

1. Dissolved Oxygen

Dissolved oxygen (DO) is critical in the protection of fish and other aquatic life, and in the preservation of aesthetic qualities of water. For aesthetic purposes, particularly to prevent the formation and release of hydrogen sulfide gas, water should contain sufficient dissolved oxygen to maintain aerobic (oxygenated) conditions throughout the water column. Ideally, oxygen should be present at the sediment-water interface. However, the natural respiration and decomposition process within organic sediments may deplete bottom-oxygen concentrations. The MDWPC (1985) stated that a minimum dissolved-oxygen concentration of 5 mg/L is required to maintain a healthy warm water fishery, and a minimum concentration of 6 mg/L is required to sustain a cold water fishery.

Tables 6-2 through 6-4 provide a record of in-pond water temperature, dissolved oxygen, and percent saturation between September 1987 and August 1988. Percent saturations are calculated on the basis of temperature, dissolved oxygen content, and barometric pressure (APHA, 1980). Percent saturations varied greatly throughout the year but were fairly consistent on a pond-to-pond basis.

In general, the water within the ponds was well-oxygenated throughout the water column. Readings taken on May 31, 1988 were the lowest recorded. This day was cloudy with cool temperatures (60^{o}F) and the lower-than-average dissolved oxygen could have been due to respiration by the plants within the ponds. Supersaturated conditions seen on July 12, 1988 reflect the hot, sunny, and calm conditions and the effect of the weather acting in concert with the primary producers in the ponds. Complete anoxia (lack of oxygen) was never recorded in any of the ponds.

Dissolved oxygen readings were also taken at the inlets and outlets of each pond (Table 6-6). The water entering and leaving the ponds was well oxygenated on most sampling dates, with supersaturated conditions common during the cold and warm months. The recording of wintertime supersaturated conditions may, in part, be due to chloride interference with the meter's electrodes. Road salt contains chlorides

TABLE 6-6
INLET AND OUTLET TEMPERATURES, DISSOLVED OXYGEN, AND PERCENTAGE SATURATION

	Hager Pond Inlet			Grist Millpond Inlet			Grist Millpond Outlet			Carding Millpond Inlet		
	Temp (Celcius)	D.O. (mg/L)	% Sat.	Temp (Celcius)	D.O. (mg/l)	% Sat.	Temp (Celcius)	D.O. (mg/L)	% Sat.	Temp (Celcius)	D.o. (mg/l)	% Sat.
September 10	21.5	7.4	83	21.5	11.8	132	20.5	8.2	90	20.5	8.5	94
October 25	14.5	9.1	87	12.0	11.5	106	11.0	11.6	10	11.0	10.3	93
December 9	5.0	10.0	88	1.0	9.6	67	0.0	9.3	64	0.0	10.2	70
February 26	5.0	14.6	114	2.0	16.0	116	1.5	18.0	128	1.5	15.8	113
March 30	7.0	15.4	127	4.0	>20	>140	4.5	16.0	123	5.0	15.6	122
April 29	10.5	8.8	79	11.0	9.3	84	10.5	9.8	87	9.8	12.2	83
May 31	15.5	6.6	66	17.0	6.1	63	18.5	5.3	56	19.0	5.5	59
June	20.0	5.8	63	25.0	8.6	103	23.0	5.8	67	23.5	5.2	60
July 12	22.5	4.0	46	27.5	12.1	>140	24.5	4.5	53	26.0	4.2	51
August 30	23.0	5.3	60	23.5	13.2	>140	22.0	6.2	68	21.5	5.5	61

	Carding Millpond Outlet			Stearns Mill Pond Inlet			Stearns Mill Pond Outlet		
	Temp (Celcius)	D.O. (mg/L)	% Sat.	Temp (Celcius)	D.O. (mg/l)	% Sat.	Temp (Celcius)	D.O. (mg/L)	% Sat.
September 10	22.0	13.6	>140	21.5	6.4	72	21.5	8.5	95
October 25	11.0	12.4	112	10.5	11.0	98	10.0	12.6	111
December 9	0.0	8.9	61	0.5	9.4	65	0.0	10.0	68
February 26	1.0	16.6	117	1.0	16.0	112	2.5	15.6	114
March 30	4.0	13.0	99	4.5	12.8	99	5.0	12.0	94
April 29	11.5	11.2	102	10.8	8.5	76	11.0	9.8	88
May 31	20.0	3.6	39	18.0	5.0	39	18.5	5.3	56
June 24	25.0	12.0	>140	24.0	6.8	80	23.0	6.8	78
July 12	29.5	15.4	>140	26.0	2.4	29	27.5	6.8	85
August 30	24.0	12.8	>140	20.5	5.5	60	21.5	6.7	73

and this ion is a common interference in polargraphic methods. Spring and early fall supersaturated conditions are likely due to plant growth.

2. pH AND ALKALINITY

The pH of water is a measure of its acid or alkaline nature. Specifically, pH is an expression of the hydrogen ion activity in the pond water. pH values are expressed on a scale of 0-14.

- At pH 7, the solution is <u>neutral</u>.
- When pH is less than 7 the water is acidic. (This is due to the presence of more hydrogen ions than hydroxyl ions.)
- When pH is greater than 7 the water is alkaline.

Alkalinity represents the buffering capacity of natural water and the capability of water to neutralize acids. It is also an indicator of the productivity potential of a water body. Generally speaking, the higher the alkalinity the higher the potential productivity of the water body.

In fresh water systems, alkalinity is the result of carbonates, bicarbonates and hydroxides in combination with calcium, magnesium, sodium, and other metallic ions. Alkalinity is generally expressed as the concentration (mg/L) of calcium carbonate ($CaCO_3$).

The pH and alkalinity of the water body are therefore closely linked. Poorly buffered systems (low alkalinity) can have greater variations in pH. Water bodies in the northeastern United States tend to be fairly "softwater" (low alkalinity and hardness). The Sudbury ponds exhibit this general character and have alkalinities in the range of 45 to 55 mg/L (Table 6-7). This means that the ponds are susceptible to swings in pH due, primarily, to macrophyte and algal growth. The data shown in Table 6-8 show this effect for Grist and Carding Millponds. Wintertime (nonproductive) pH values are near neutrality (pH=7.0) while warm months (July through September) values are fairly alkaline (pH in the range of 9.0 to 10.0). The lack of such a pH shift in Stearns Millpond is likely due to the influence of the extensive wetlands in the watershed. Wetland areas tend to be high in the concentration of humic substances which are acidic in nature. This acid input may be neutralizing the pH rise normally caused by the in-pond plant communities.

TABLE 6-7
ALKALINITY (mg/L AS CALCIUM CARBONATE)

Station	Sampling Date 9/10/87	12/09/87	5/31/88	7/12/88	Station Average
1	77	27	40	63	52
2	74	24	38	75	53
3	75	24	39	99	59
4	75	33	39	85	58
5	82	24	36	82	56
6	83	32	34	84	58
7	70	26	32	69	49
8	64	28	31	65	47
9	59	27	29	62	44
10	63	99	37	55	64
11	N/R*	57	47	42	49
12	N/R	17	N/R	N/R	17
13	N/R	10	N/R	N/R	10
14	N/R	15	N/R	N/R	15
15	N/R	15	N/R	N/R	15

*N/R = Not Required

Sampling Station Identification

1 - Grist Millpond Inlet
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8 - Stearns Millpond In-Pond
9 - Stearns Millpond Outlet
10 - Hager Pond Inlet
11 - Upstream of MEWWTP
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TABLE 6-8
pH

Station	Sampling Date 9/10/87	12/9/87	5/31/88	7/12/88
1	8.8	7.1	7.2	9.2
2	7.5	7.0	7.1	9.2
3	7.7	7.1	7.1	7.5
4	7.6	8.0	7.1	7.5
5	10.0	7.1	7.0	9.1
6	9.6	8.0	7.0	9.6
7	9.0	7.0	6.9	7.2
8	8.1	7.3	6.6	7.0
9	8.5	7.3	6.8	7.0
10	7.3	7.4	6.9	7.2
11	N/R*	7.0	6.8	7.0
12	N/R	6.6	N/R	N/R
13	N/R	6.6	N/R	N/R
14	N/R	6.6	N/R	N/R
15	N/R	6.6	N/R	N/R

*N/R = Not Required

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In 1969, the European Inland Fisheries Advisory Commission established the following criteria for pH comparison:

pH Range	Effects on Fish
6.0 - 6.5	Unlikely to be harmful to fish unless free carbon dioxide is in excess of 100 PPM.
6.5 - 9.0	Harmless to fish, although the toxicity of other poisons may be affected by changes within this range.

According to Massachusetts surface water quality standards, the pH should be in the range of 6.5 to 8.0 (MDWPC, 1985).

The effects of acid deposition of freshwater systems, has become a paramount concern of water quality scientists throughout the nation. The Massachusetts Division of Fisheries and Wildlife (MDFW, 1984) established the following criteria when analyzing lakes for susceptibility to the effects of acid deposition:

Vulnerable	6-10 mg/L ($CaCO_3$)
Endangered	3-5 mg/L ($CaCO_3$)
Critical	2 mg/L ($CaCO_3$)

According to these criteria the Sudbury Ponds are not as vulnerable to acid deposition as the "average" pond in the state.

3. Chlorides

The concentration of chloride is an indicator of human influence, such as domestic waste disposal and road deicing components.

The sources of chloride are derived from the substrate upon which the water lies and the overground and underground pathways through which the water flows to the pond (i.e., surface runoff, urban drainage, groundwater, and rainfall).

For Class A waters, MDWPC (1985) has established a chloride concentration not to exceed 250 mg/L. Class A water quality standards are generally more stringent than those of Class B waters because they relate to potable water supplies (no specific standards exist for Class B).

In general, however, chloride levels above 50 mg/L probably represent some contamination from human activities. The chloride levels of the three ponds (Table 6-9) are at or slightly above this level, indicating minimal impact from septic system leachate or roadway runoff.

4. Suspended Solids, Dissolved Solids, and Turbidity

Suspended solids concentrations are descriptive of the organic and inorganic particulate matter in water. No distinction is made between living or dead organic matter or inorganic particles. Suspended solids represent those solids retained by a standard glass fiber filter and dried to a constant weight at 103° to 105° Celsius (APHA, 1980). The suspended solids concentrations found in the Sudbury Ponds (Table 6-10) are moderate, comparing favorably with concentrations found in other area water bodies.

Total dissolved solids concentrations can be used as a general indicator of the water's productivity. The USEPA (1984) stated that total dissolved solids concentrations in excess of 100 mg/L indicated eutrophic conditions. The dissolved solids concentrations in the Sudbury Ponds (Table 6-11) are well above this level, indicating hypereutrophied conditions.

Turbidity is a term used to describe the amount of opaqueness produced in water by suspended particulate matter. Turbidity may indicate that primary productivity is limited by light availability within a water body. The range of turbidity seen within the Sudbury Ponds (Table 6-12) is moderate, indicating ample light penetration of the surface water for plant growth.

5. Phosphorus

Phosphorus in the form of phosphate is one of the major nutrients required for plant nutrition and is essential for life. It is known that increased supplies of orthophosphate (PO_4) increase standing crops of aquatic plants and algae (USEPA, 1976). The USEPA (1976) has suggested that in order to prevent the development of biological nuisances and control eutrophication, total phosphorus should not exceed 0.05 mg/L in any stream entering a lake, and in-lake levels should not exceed 0.025 mg/L.

TABLE 6-9
CHLORIDE (mg/L)

Station	Sampling Date 10/24/87	12/09/87	6/24/88	7/12/88	Station Average
1	75	66	66	77	71
2	74	68	60	79	70
3	74	65	64	80	71
4	76	63	60	82	70
5	76	66	55	81	70
6	75	62	49	81	67
7	66	44	37	57	51
8	57	48	35	56	49
9	54	46	35	55	48
10	93	76	92	73	84
11	N/R*	63	48	70	60
12	N/R	21	N/R	N/R	21
13	N/R	10	N/R	N/R	10
14	N/R	29	N/R	N/R	29
15	N/R	31	N/R	N/R	31

*N/R = Not Required

Sampling Station Identification

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6 - Carding Millpond Outlet
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9 - Stearns Millpond Outlet
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TABLE 6-10
TOTAL SUSPENDED SOLIDS (mg/L)

Station	Sampling Date 9/10/87	12/9/87	5/31/88	7/12/88	Station Average
1	1	2	5	7	4
2	2	12	8	7	7
3	1	4	7	8	5
4	9	4	8	4	6
5	2	13	12	9	9
6	2	10	14	13	10
7	3	3	15	12	8
8	1	12	10	10	8
9	1	4	9	8	6
10	5	17	6	9	9
11	N/R*	8	4	9	7
12	N/R	2	N/R	N/R	2
13	N/R	4	N/R	N/R	4
14	N/R	15	N/R	N/R	15
15	N/R	3	N/R	N/R	3

*N/R = Not Required

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9 - Stearns Millpond Outlet
10 - Hager Pond Inlet
11 - Upstream of MEWWTP
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TABLE 6-11
TOTAL DISSOLVED SOLIDS (mg/L)

Station	Sampling Date 9/10/87	12/9/87	5/31/88	7/12/88	Station Average
1	415	275	257	327	319
2	408	298	225	340	318
3	410	269	237	342	315
4	390	255	221	349	304
5	370	264	209	326	292
6	365	260	182	325	283
7	314	197	143	338	248
8	275	200	138	337	238
9	279	197	135	221	208
10	523	291	330	269	353
11	N/R*	216	178	323	239
12	N/R	82	N/R	N/R	82
13	N/R	43	N/R	N/R	43
14	N/R	98	N/R	N/R	98
15	N/R	101	N/R	N/R	101

*N/R = Not Required

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TABLE 6-12
TURBIDITY (NTU)

Station	Sampling Date 9/10/88	12/9/88	5/31/88	7/12/88	Station Average
1	1.0	2.5	3.6	2.3	2.4
2	1.3	3.0	2.4	1.6	2.1
3	1.3	2.3	2.4	4.1	2.5
4	1.3	1.9	2.4	1.2	1.7
5	1.6	3.0	4.7	4.2	3.4
6	1.7	2.6	4.0	5.4	3.4
7	1.8	1.8	3.4	2.6	2.4
8	1.7	1.8	4.3	1.4	2.3
9	1.7	1.9	2.5	1.5	1.9
10	1.8	3.8	2.0	2.5	2.5
11	N/R*	5.1	9.0	4.1	6.1
12	N/R	0.9	N/R	N/R	0.9
13	N/R	1.2	N/R	N/R	1.2
14	N/R	4.0	N/R	N/R	4.0
15	N/R	2.0	N/R	N/R	2.0

*N/R = Not Required

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Vollenweider (1968) demonstrated by several criteria that the amount of total phosphorus generally increases with lake productivity as follows:

General Level of Lake Productivity	Epilimnetic Total Phosphorus (mg/L)
Ultra-Oligotrophic (pristine - low productivity)	<0.005
Oligo-Mesotrophic	0.005 - 0.01
Meso-Eutrophic	0.01 - 0.03
Eutrophic	0.03 - 0.10
Hypereutrophic (polluted - high productivity)	>0.10

Although it is known that phosphorus is not the only cause of eutrophication, there is evidence that it frequently is the key element required by freshwater plants. This is because phosphorus is most often the least abundant nutrient available, relative to aquatic plant growth needs (i.e., limiting nutrient). Also, of all the nutrients required (i.e., carbon dioxide, nitrate, trace nutrients) for aquatic plant growth, phosphorus use, and its introduction to the environment, is the most easily controlled by man.

The most significant form of inorganic phosphorus to primary productivity is soluble reactive phosphorus called orthophosphate (PO_4). In natural waters a small fraction of total phosphorus is orthophosphate which is actually a plant nutrient (Wetzel, 1983). In wastewaters, orthophosphates can be a majority of the forms of phosphorus in the waste stream. Total inorganic and organic phosphorus has often been separated to distinguish reactive orthophosphate from combined phosphorus. However, the most important measure is the total phosphorus content of unfiltered water, which consists of the phosphorus in the particulate and dissolved phases, based on the work by Juday et al. (1927) and Ohle (1938) as cited by Wetzel (1983).

The surface waters of the Sudbury ponds exceeded the 0.025 mg/L total phosphorus EPA criteria throughout the sampling period (Table 6-13). The phosphorus levels in the ponds were heavily influenced by upstream sources, in particular the MEWWTP. As shown in Table 6-13, the

TABLE 6-13
TOTAL PHOSPHORUS (mg/L)

Station	Sampling Date 9/10/87	10/25/87	12/9/87	1/19/88	2/26/88	3/30/88	4/29/88	5/31/88	6/24/8	7/12/88	8/30/88	Station Average
1	0.17	0.49	0.91	1.91	1.19	0.40	0.29	0.36	0.47	0.55	0.33	0.64
2	0.15	0.25	1.10	N/R*	0.67	0.33	0.29	0.26	0.29	0.48	0.27	0.41
3	0.15	0.23	0.93	1.53	0.65	0.35	0.31	0.26	0.31	0.74	0.24	0.52
4	0.19	0.26	0.36	1.59	0.58	0.28	0.26	0.28	0.27	0.43	0.33	0.44
5	0.16	0.17	0.91	N/R	0.55	0.28	0.26	0.30	0.38	0.52	0.33	0.39
6	0.16	0.21	0.35	1.43	0.46	0.29	0.29	0.36	0.38	0.71	0.40	0.46
7	0.25	0.17	0.18	0.81	1.20	0.33	0.27	0.36	0.24	0.43	0.22	0.41
8	0.25	0.14	0.23	N/R	0.09	0.25	0.26	0.31	0.31	0.45	0.36	0.27
9	0.24	0.12	0.20	0.68	0.12	0.25	0.25	0.26	0.31	0.43	0.18	0.28
10	0.29	0.45	1.80	3.76	0.14	0.45	0.36	0.32	0.67	2.00	0.22	0.95
11	0.04	0.05	0.05	0.09	0.09	0.05	0.07	0.09	0.05	0.07	0.07	0.07
12	N/R	N/R	0.02	N/R	0.09	N/R	0.06	0.09	N/R	0.07	0.07	0.07
13	N/R	N/R	0.03	N/R	0.08	N/R	0.17	0.11	N/R	0.09	0.10	0.10
14	N/R	N/R	0.07	N/R	N/R	N/R	0.07	0.14	N/R	N/R	N/A	0.09
15	N/R	N/R	0.03	N/R	N/R	N/R	0.07	0.07	N/R	N/R	0.07	0.06

*N/R = Not Required

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input to Hager Pond (Station 10) had an average phosphorus concentration of 0.95 mg/L. Upstream of the MEWWTP at Station 11, the same brook that serves as the inlet to Hager Pond had an average phosphorus concentration of 0.07 mg/L. Similarly, inputs to the Sudbury ponds, other than the MEWWTP effluent, had concentrations of 0.06 to 0.10 mg P/L versus instream concentrations of 0.41 to 0.64 mg P/L.

Pond sediments and the sediment pore water contain much higher concentrations of phosphorus than does the water. This is evidenced by typically higher bottom phosphorus concentrations (see Chapter VI, Section F for details). Under aerobic conditions, phosphorus is adsorbed in the sediment. Also, under anaerobic conditions (lack of free oxygen), active migration of phosphorus to the water is considerable (Wetzel, 1983). The microflora in sediment is also involved in increasing the concentrations of phosphorus dissolved in interstitial water of the sediments (Fleischer, 1978). In addition, increased water and sediment temperatures increase the microbial activity in the sediment. However, phosphorus movement across the sediment water interface is most significantly controlled by chemical equilibria processes, which is essentially governed by sediment oxygen demand (Hayes, 1964). High amounts of orthophosphate are adsorbed under aerobic conditions (presence of free oxygen) and desorbed under anaerobic conditions, (Ku and Feng, 1975; Fing, 1970).

For the most part, dissolved oxygen concentrations in the bottom waters of the ponds are sufficiently high to control significant sediment phosphorus liberation to overlying water. The increases in bottom water total phosphorus may be due to low dissolved oxygen, sediment disruption, bacterial action, and bioturbation (the activity of benthic organisms in the interstitial water).

The data in Table 6-13 also shows that Grist and Stearns Millponds (and probably Hager Pond) are acting as phosphorus sinks. That is, incoming phosphorus gets bound in organic phosphates, into cellular constituents of organisms (both living and dead), and adsorbed to organic colloids, all of which accumulate in the sediments. Carding Millpond may also be a phosphorus sink, but the data is inconclusive on this point.

6. NITROGEN

Nitrogen exists in several forms within the Hop Brook ponds system: as dissolved gas, as inorganic nitrogen (ammonia, nitrite, and nitrate), and as organically bound nitrogen (nitrogen complexed in carbon-containing molecules formed by plants and animals). Organically-bound nitrogen compounds are broken down by heterotrophic bacteria into ammonia. Ammonia is converted by bacteria to nitrite and then to nitrate in the presence of oxygen. This conversion of organic and inorganic nitrogen from a reduced state to a more oxidized state is known as nitrification.

The most important forms of nitrogen for the growth of phytoplankton and aquatic macrophytes are nitrate and ammonia. The highest growth rates occur with ammonia, followed by nitrate, and then nitrogen (Ward and Wetzel, 1980); ammonia, therefore, is an energy-efficient source of nitrogen for plants (Wetzel, 1983). In waters of high pH, the nitrate form of nitrogen may induce better algal growth rates than ammonia which produces ammonium hydroxide, which in turn increases the water's toxicity to organic organisms. The moderate-to-high pH and oxygen levels of the Sudbury ponds indicate that ammonia is probably the most important form of nitrogen for algal production in the spring, while nitrates induce growth more in the summer.

The oxidation of ammonia-to-nitrite and nitrite-to-nitrate via the action of certain aerobic bacteria is known as nitrification. Oxygen is used during the transformation which contributes to oxygen depletion in bottom waters. Under anaerobic conditions, denitrification occurs whereby nitrite is formed as an intermediary with free nitrogen, which becomes the principal end-product form (Reckhow and Chapra, 1983). Denitrification occurs most rapidly under low oxygen conditions and high water temperatures. Horne and Goldman (1974) estimated that nearly one-half of the available nitrogen in a eutrophic lake is available to the less desirable blue-green algae. If blue-green algae populations are extensive, objectionable floating mats and odors develop. Fortunately, green algae dominated the phytoplankton communities of the Sudbury ponds.

As with phosphorus, there are not definitive criteria for the control of cultural eutrophication caused by nitrogenous compounds. Instead, the MDWPC (1985) stated that "...the discharge of nutrients, primarily phosphorus or nitrogen, to surface waters will be limited or prohibited by the Division as necessary to prevent excessive eutrophication of such waters. There shall be no new or increased discharges of nutrients in lakes and ponds, or tributaries thereto. Existing discharges containing nutrients which encourage eutrophication or growth of weeds or algae shall be treated."

Ammonia nitrogen concentrations are shown in Table 6-14. The in-pond levels exhibited throughout most of the study period were elevated, indicating active decomposition of organic matter within the ponds and sanitary pollution. Active oxidation by microorganisms, along with a decreased load in the MEWWTP waste stream during the summer months, is reflected in the decreased ammonia concentrations during the warm weather sampling trips.

Nitrate nitrogen levels were very high in the ponds throughout the study period. As shown in Table 6-15, the primary source of nitrate into the pond system is from the MEWWTP, rather than oxidation by microorganisms within the ponds or their watersheds. This fact is apparent by comparing the data from Station 11 (upstream of the MEWWTP) and Station 10 (downstream of the MEWWTP). Inputs from the watershed are elevated, but are still an order of magnitude lower than the effluent stream from the MEWWTP.

Organic nitrogen enters the water by the dissolution of once living animal and plant tissue into their constituent parts (amino acids, polypeptides, and proteins). Elevated organic nitrogen levels are usually an indicator of domestic, agricultural, or industrial pollution. Total Kjeldahl nitrogen (TKN) is the term for a method of determining organic nitrogen. TKN also includes ammonia nitrogen, in which the ammonia must be subtracted from TKN to yield organic nitrogen. The TKN values listed in Table 6-16 minus the ammonia values (Table 6-14) show that organic nitrogen in the water of the Sudbury ponds is fairly high (between 0.7 and 1.4 mg/L). This level is indicative of polluted waters.

TABLE 6-14
AMMONIA NITROGEN (mg/L)

Station	Sampling Date 9/10/87	12/9/87	2/26/88	3/30/88	4/29/88	5/31/88	6/24/88	7/12/88	8/30/88	Station Average
1	0.35	0.38	0.75	0.64	0.75	0.50	0.57	0.11	0.16	0.47
2	0.78	0.33	0.73	0.61	0.38	0.58	0.50	0.12	0.15	0.46
3	0.21	0.35	0.70	0.45	0.30	0.57	0.53	1.10	0.16	0.49
4	2.38	0.41	0.51	0.60	0.64	0.40	0.13	0.10	0.21	0.60
5	1.75	0.40	0.36	0.54	0.31	0.05	0.14	0.11	0.50	0.46
6	0.59	0.38	0.31	0.56	0.42	0.50	0.15	0.11	0.14	0.35
7	0.72	0.36	0.85	0.56	0.33	0.46	0.11	0.20	0.14	0.41
8	0.62	0.27	0.27	0.56	0.32	0.50	0.13	0.11	0.42	0.36
9	0.49	0.30	0.31	0.50	0.28	0.53	0.13	0.11	0.12	0.31
10	1.35	0.57	0.29	0.81	0.58	0.48	0.50	0.11	0.15	0.54
11	N/R*	0.25	0.29	0.68	0.45	0.40	0.12	0.12	0.17	0.31
12	N/R	0.16	0.33	N/R	0.32	N/R	N/R	0.13	0.12	0.21
13	N/R	0.16	0.28	N/R	0.26	N/R	N/R	0.17	0.12	0.20
14	N/R	0.18	N/R	N/R	0.30	N/R	N/R	N/R	N/R	0.24
15	N/R	0.15	N/R	N/R	0.31	N/R	N/R	N/R	0.12	0.19

*N/R = Not Required

Sampling Station Identification

1 - Grist Millpond Inlet
2 - Grist Millpond In-Pond
3 - Grist Millpond Outlet
4 - Carding Millpond Inlet
5 - Carding Millpond In-Pond
6 - Carding Millpond Outlet
7 - Stearns Millpond Inlet
8 - Stearns Millpond In-Pond
9 - Stearns Millpond Outlet
10 - Hager Pond Inlet
11 - Upstream of MEWWTP
12 - Carding Millpond - Boston Post Rd. @ Rte. 20
13 - Stearns Millpond - Surrey Lane Inlet
14 - Gristmill Pond - Prides Crossing Road
15 - Stearns Millpond - off Moore Road

TABLE 6-15
NITRATE NITROGEN (mg/L)

Station	Sampling Date 9/10/88	10/25/88	12/9/88	1/19/88	2/26/88	3/30/88	4/29/88	5/31/88	6/24/88	7/12/88	8/30/88	Station Average
1	11.00	8.80	10.20	13.10	6.82	6.10	9.30	10.00	11.90	7.30	11.80	9.67
2	16.00	6.80	10.90	N/R*	5.12	4.70	8.10	7.50	7.70	7.30	8.10	8.22
3	8.20	6.50	10.30	11.30	5.10	4.80	6.70	6.30	7.70	3.30	7.80	7.09
4	7.40	6.80	9.20	10.90	4.60	3.70	6.00	5.30	2.10	3.80	7.80	6.15
5	4.30	4.10	10.30	N/R	4.46	3.70	5.30	4.50	2.50	1.30	3.50	4.40
6	3.20	3.70	9.05	10.60	4.38	3.70	4.00	3.70	2.50	1.00	1.80	4.33
7	2.30	2.90	5.33	8.13	9.54	3.20	3.70	3.30	1.30	0.50	1.60	3.80
8	1.30	1.90	6.10	N/R	0.28	3.00	3.00	2.80	0.77	0.30	1.00	2.05
9	1.70	1.40	5.64	6.56	0.34	3.00	2.80	3.00	0.58	0.50	0.81	2.39
10	17.00	14.10	17.30	14.60	0.32	6.30	12.70	15.30	20.80	11.00	20.00	13.58
11	N/R	0.26	0.83	0.45	0.32	0.20	0.27	0.32	0.46	0.30	0.59	0.40
12	N/R	N/R	0.68	N/R	0.35	N/R	0.10	0.05	N/R	0.20	0.37	0.29
13	N/R	N/R	0.67	N/R	0.29	N/R	0.33	0.28	N/R	0.27	1.30	0.52
14	N/R	N/R	0.79	N/R	N/R	N/R	0.24	0.08	N/R	N/R	N/R	0.37
15	N/R	N/R	0.82	N/R	N/R	N/R	0.93	0.27	N/R	N/R	1.70	0.93

*N/R = Not Required

Sampling Station Identification

1 - Grist Millpond Inlet
2 - Grist Millpond In-Pond
3 - Grist Millpond Outlet
4 - Carding Millpond Inlet
5 - Carding Millpond In-Pond
6 - Carding Millpond Outlet
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8 - Stearns Millpond In-Pond
9 - Stearns Millpond Outlet
10 - Hager Pond Inlet
11 - Upstream of MEWWTP
12 - Carding Millpond - Boston Post Rd. @ Rte. 20
13 - Stearns Millpond - Surrey Lane Inlet
14 - Gristmill Pond - Prides Crossing Road
15 - Stearns Millpond - off Moore Road

TABLE 6-16
TOTAL KJELDAHL NITROGEN (mg/L)

Station	Sampling Date 9/10/88	10/25/88	12/9/88	1/19/88	2/26/88	3/30/88	4/29/88	5/31/88	6/24/88	7/12/8	9/8/88	Station Average
1	0.65	1.15	0.88	2.15	1.85	1.73	1.85	1.80	1.31	1.51	2.60	1.59
2	1.28	1.02	0.86	N/R*	1.74	1.63	1.50	1.68	1.90	1.42	3.20	1.62
3	0.41	0.92	0.89	2.01	1.70	1.45	1.38	1.41	1.65	2.10	1.70	1.42
4	2.98	1.98	0.97	1.94	1.36	1.67	1.84	1.60	1.32	1.20	3.40	1.84
5	3.05	1.54	0.99	N/R	1.16	1.50	1.36	1.70	2.52	2.51	2.10	1.84
6	1.68	1.46	0.94	1.31	1.13	1.61	1.57	1.64	2.74	3.81	3.00	1.90
7	1.47	0.82	0.77	1.24	1.81	1.60	1.42	1.45	1.44	1.50	2.20	1.43
8	1.12	0.86	0.75	N/R	0.75	1.56	1.35	1.36	1.11	0.71	1.33	1.09
9	0.56	0.85	0.75	0.89	0.71	1.35	1.28	1.40	1.25	0.91	1.60	1.05
10	5.25	2.10	1.46	2.43	0.79	2.01	1.42	1.34	1.13	0.71	0.80	1.77
11	N/R	0.36	0.58	0.62	0.56	1.39	0.94	0.98	0.61	0.32	0.80	0.72
12	N/R	N/R	0.43	N/R	0.60	N/R	0.73	1.03	N/R	0.38	0.70	0.65
13	N/R	N/R	0.40	N/R	0.58	N/R	0.52	0.64	N/R	0.34	0.90	0.56
14	N/R	N/R	0.39	N/R	N/R	N/R	0.75	3.17	N/R	N/R	N/R	1.44
15	N/R	N/R	0.35	N/R	N/R	N/R	0.59	0.69	N/R	N/R	0.12	0.44

*N/R = Not Required

Sampling Station Identification

1 - Grist Millpond Inlet
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13 - Stearns Millpond - Surrey Lane Inlet
14 - Gristmill Pond - Prides Crossing Road
15 - Stearns Millpond - off Moore Road

7. Summary of Chemical Analyses

The results of the chemical analyses indicate that the Sudbury ponds are eutrophic systems primarily being influenced by upstream events. Most parameters show higher-than-average concentrations and also nutrient concentrations are excessive. Runoff from their respective watersheds is generally of good quality.

The data was used to predict which nutrient is the one limiting growth. This theoretical limitation was used to create a budget for that nutrient (see Chapter IX). In reality, all nutrients needed for plant growth are present in high concentrations. The purpose of the budget is, therefore, not to see what is currently limiting growth but what should be controlled to limit growth.

Any macro- or micro-nutrient can limit growth. Micro-nutrients (boron, manganese, zinc, molybdenum, copper, cobalt, iron, and sodium) are needed in such small quantities and are so readily available, that they rarely limit growth. Of the macro-nutrients (carbon, nitrogen, phosphorous, calcium, magnesium, sulfur, potassium) only carbon, nitrogen, and phosphorous are needed in such quantities that they could be limiting to plant growth.

Vallentyne (1974) reports that typical plant organic matter of aquatic algae and macrophytes contains phosphorus, nitrogen, and carbon in the approximate ratio 1P:7N:40C.

In ponds of moderate alkalinity, like the Sudbury ponds, carbon is usually in sufficient quantity. Also, with the flow rates exhibited by the Sudbury ponds, recarbonation of the water is sufficiently quick to effectively eliminate any carbon limitation potential.

It has been shown that certain ranges of total nitrogen to total phosphorus (N:P) indicate nitrogen or phosphorus limitation. If the N:P ratio is greater than or equal to 10, the limiting nutrient is most likely to be phosphorus (Dillon and Rigler, 1975). However, Wanielista et al. (1981) state that a N:P ratio less than or equal to 5:1 indicates a limiting nutrient of nitrogen. Also, if either phosphorus or nitrogen is reduced during peak biomass production, the nutrient reduced indicates the limiting factor. If neither the phosphorus or nitrogen concentration is reduced during the period of maximum-summer phytoplankton biomass, some other factor, such as light or a micro-nutrient may limit algae growth.

A review of the growing season data for available phosphorus and nitrogen yielded N:P ratios of approximately 34:1, 9:1, and 5:1 for Grist, Carding, and Stearns Millponds, respectively. The Grist Millpond ratio indicates that phosphorous is most likely the limiting nutrient. The ratios for Carding and Stearns Millponds do not conclusively point to a phosphorus limitation.

Current control technology is directed toward the reduction of phosphorus in lakes and ponds. This is due to:

- Phosphorus is added primarily from land sources, and unlike nitrogen, it is not transported in a gaseous state across the air/water interface, nor fixed by blue-green algae or bacteria (Vallentyne, 1974)
- In culturally impacted lakes, the proportion of total phosphorus attributable to man is typically higher than that of any other growth-limiting element (Vallentyne, 1974)
- Phosphorus removal from water is technologically more cost-effective than nitrogen removal
- Nonpoint phosphorus additions may be reduced through proper land-use management (Reckhow and Simpson, 1980)

E. ANALYSES OF BIOLOGICAL DATA

1. Bacteriological Samples

Sampling of surface waters for enteric bacteria was conducted on four occasions during the study. Analyses for coliform bacteria presence are used to indicate the potential for pathogenic contamination of the water by warm-blooded animals. Coliform bacteria are harmless to man but their presence indicates a potential pressure of other pathogenic forms. Likewise, the presence of fecal streptococcus bacteria is indicative of fecal pollution.

The Massachusetts Division of Water Pollution Control (1985) has stated that the occurrence of fecal coliform (FC) bacteria in Class B waters shall not exceed a log mean of 200 per 100 mL. This criterion sets the limit for fecal coliform bacteria based on a concern for public health. The study year in-pond surface grab samples indicate that Class B limits were never exceeded since the yearly averages were below 200/100 mL (Table 6-17).

TABLE 6-17
FECAL COLIFORM BACTERIA (NO./100 mL)

Station	Sampling Date 9/10/87*	12/9/87	5/31/88	7/12/88
1	160	8	32	0
2	92	5	8	12
3	85	10	6	4
4	240	0	22	6
5	5	10	20	0
6	10	0	6	2
7	145	6	62	380
8	75	16	48	12
9	55	51	14	10
10	525	19	26	-
11	--	0	232	-
12	N/R**	0	N/R	N/R
13	N/R	0	N/R	N/R
14	N/R	26	N/R	N/R
15	N/R	2	N/R	N/R

*9/10/87 Results are total coliform analysis (no./100mL)
**N/R = Not Required

Sampling Station Identification

1 - Grist Millpond Inlet
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3 - Grist Millpond Outlet
4 - Carding Millpond Inlet
5 - Carding Millpond In-Pond
6 - Carding Millpond Outlet
7 - Stearns Millpond Inlet
8 - Stearns Millpond In-Pond
9 - Stearns Millpond Outlet
10 - Hager Pond Inlet
11 - Upstream of MEWWTP
12 - Carding Millpond - Boston Post Rd. @ Rte. 20
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14 - Gristmill Pond - Prides Crossing Road
15 - Stearns Millpond - off Moore Road

On several occasions during the summer, samples from inlet waters showed high fecal coliform counts (Table 6-17). This may have been due to many other conditions on the days immediately preceding the sampling dates because rain directly affects the quality of any water body receiving storm drainage. Hence, the "cleaning effect" of rain on streets, fields, etc...will dislodge animal feces, possibly cause septic system ponding and generally increase the potential for increased pollutant loads to receiving streams. Other possible reasons include (1) increased water consumption which introduces more wastewater and (2) freshly deposited waterfowl droppings which cause higher coliform bacteria levels. However, overall health impacts may be minimal.

Fecal streptococcus bacteria counts are presented in Table 6-18. Tchobanoglous (1979) reports that fecal coliform (FC) and fecal streptococcus (FS) counts eminating from human and nonhuman sources differ. Typical FC:FS ratios for humans exceed 4:1, whereas the ratio is usually less than 1:1 for other animals. The data for the Sudbury ponds vary greatly from pond-to-pond and season-to-season. Therefore, no one source or type of fecal pollution was identified.

2. PHYTOPLANKTON AND CHLOROPHYLL A

a. Results of Chlorophyll a Studies

Chlorophyll a is a principle photosynthetic pigment of all oxygen-evolving photosynthetic organisms and is present in all algae (Wetzel, 1975). Chlorophyll a concentration is closely related to the density of algae and rate of production of organic matter in the pond, and is used as an indicator trophic level. As a general guideline, chlorophyll a concentrations greater than 6-10 milligrams per cubic centimeter are indicative of eutrophic conditions (USEPA, 1980).

Chlorophyll a concentrations for the Sudbury ponds are shown in Table 6-19. As with the results of the bacteria analyses, great variation in the data was observed. In general, all three ponds exhibited concentrations typically seen in eutrophic water bodies.

Peak chlorophyll a concentrations did not necessarily correspond to peak periods of counts of phytoplankton. This is evident when comparing chlorophyll a data to phytoplankton sample cell counts (Table 6-20).

TABLE 6-18
FECAL STREPTOCOCCI BACTERIA (NO./100 mL)

Station	Sampling Date 9/10/87	12/9/87	5/31/88	7/12/88
1	10	3	0	5
2	5	0	0	395
3	5	4	0	5
4	42	0	40	60
5	0	2	30	115
6	0	0	10	30
7	45	0	0	995
8	2	0	10	210
9	5	0	10	215
10	160	0	0	-
11	-	0	20	-
12	N/R*	10	N/R	N/R
13	N/R	8	N/R	N/R
14	N/R	9	N/R	N/R
15	N/R	35	N/R	N/R

*N/R = Not Required

Sampling Station Identification

1 - Grist Millpond Inlet
2 - Grist Millpond In-Pond
3 - Grist Millpond Outlet
4 - Carding Millpond Inlet
5 - Carding Millpond In-Pond
6 - Carding Millpond Outlet
7 - Stearns Millpond Inlet
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15 - Stearns Millpond - off Moore Road

TABLE 6-19
CHLOROPHYLL a CONCENTRATION
(milligrams per cubic meter)
SUDBURY, MASSACHUSETTS

Date	Grist Millpond	Stearns Millpond	Carding Millpond
September 10, 1987	5.31	0.9312	61.518
April 29, 1988	192	156	126
May 31, 1988	18	32	9.07
August 30,1988	5.8	4	55

TABLE 6-20
PHYTOPLANKTON (CELLS/mL)

	Grist Millpond				Carding Millpond				Stearns Millpond			
	12/9/88	4/29/88	5/31/88	8/30/88	12/9/88	4/29/88	5/31/88	8/30/88	12/9/88	4/29/88	5/31/88	8/30/88
Diatoms (Bacillariophycae)												
Asterionella	--	Rare	Rare	--	--	--	Rare	--	--	18	--	--
Cocconeis	--	--	--	179	--	--	--	--	--	--	--	161
Cyclotella	--	--	--	--	--	--	--	71	--	--	--	--
Cymbella	--	--	--	--	--	36	--	--	--	--	--	--
Fragilaria	--	36	--	--	--	--	--	--	18	54	48	36
Melosira	18	--	--	36	--	--	--	--	--	--	--	18
Navicula	54	54	36	--	18	107	--	--	36	125	119	519
Pinnularia	Rare	--	--	--	--	--	--	--	Rare	--	--	--
Tabellaria	--	--	--	--	--	--	36	--	--	--	36	--
Subtotals (Diatoms)	72	90	36	215	18	143	36	71	54	197	203	734
Green Algae (Chlorophyceae)												
Ankistrodesmus	18	--	--	--	--	--	--	--	--	--	--	--
Chlamydomonas	--	90	1845	893	36	2321	2035	5962	36	430	298	197
Coelastrum	--	--	202	--	--	--	143	--	--	--	--	--
Eudorina	--	18	--	36	18	1142	--	--	--	1343	--	--
Kircheriella	--	--	--	--	--	--	--	--	--	--	--	18
Pandorina	--	--	--	--	--	428	--	--	--	716	--	--
Pediastrum	90	36	12	2999	36	71	Rare	179	18	--	12	--
Scenedesmus	448	680	119	36	788	1785	536	1021	403	1292	393	376
Schroederia	--	--	262	--	--	--	214	1969	--	--	Rare	--
Subtotals (Green Algae)	556	824	2440	3964	878	5747	2928	9131	484	3581	703	591
Blue-Green Algae (Cyanophyceae)												
Anabaena	--	--	--	--	--	--	--	--	Rare	--	--	--
Gomphosphaeria	--	--	--	--	--	214	--	--	--	--	--	--
Microcysti	--	--	--	--	--	--	--	143	--	--	--	--
Spirulina	90	--	--	--	143	--	--	36	36	36	--	--
Oscillatoria	18	18	--	--	--	--	--	--	--	--	--	--
Subtotals (Blue-Green Algae)	108	18	0	0	143	214	0	179	36	36	0	0
TOTALS	736	932	2476	4179	1039	6104	2964	9381	574	3814	906	1325

B. Results of Phytoplankton Studies

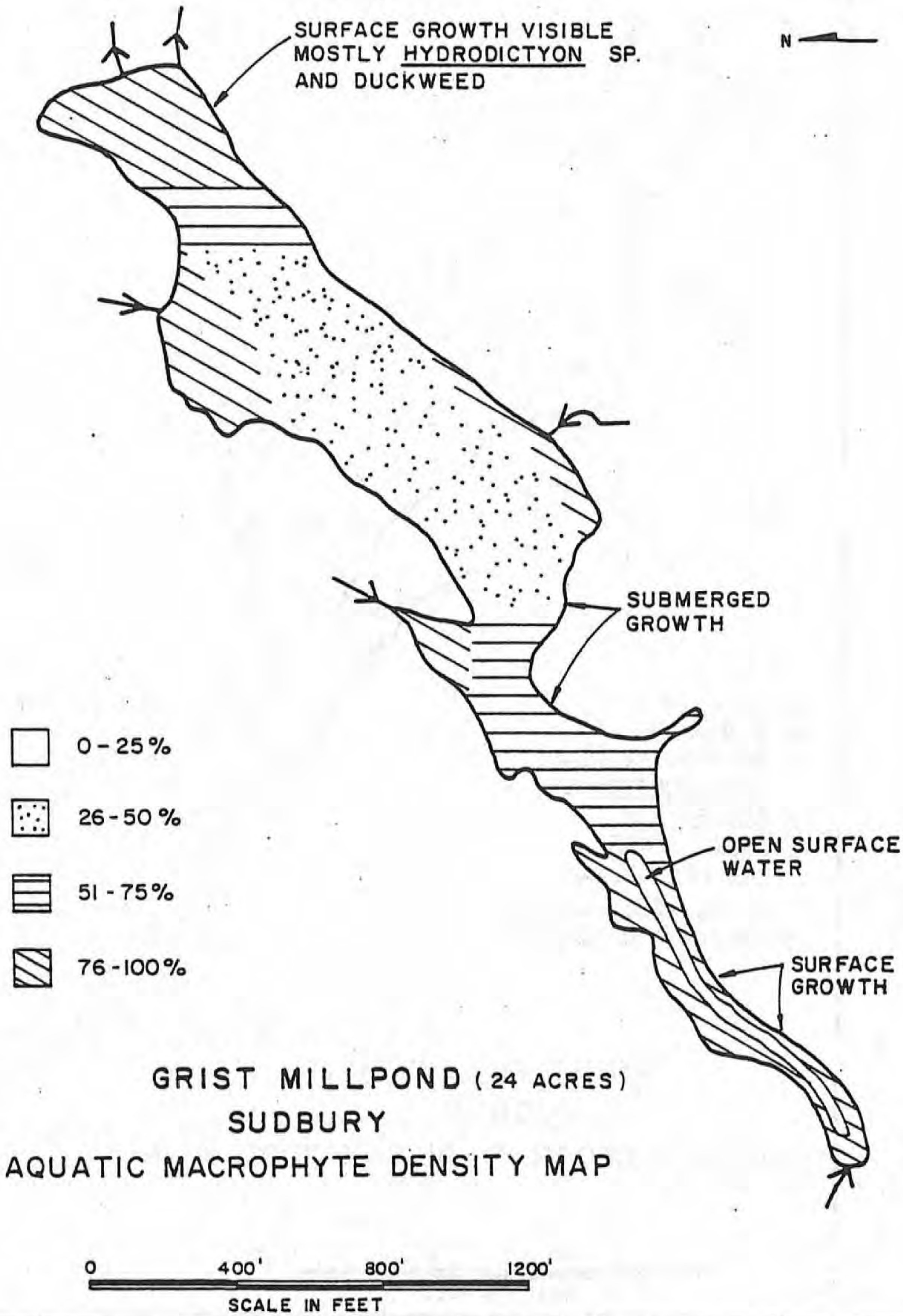
Phytoplankton concentrations within the three ponds (Table 6-20) showed some seasonal variation but not the marked four-season variation which deeper ponds normally exhibit. This is likely due to the general lack of thermal stratification within the ponds and their very high flushing rates. Similarly, class dominance which "normally" would tend to show diatoms dominating in the winter/early spring, green algae dominating in the late spring/mid-summer, and blue-green algae dominating in the late summer/early fall was not pronounced in the Sudbury ponds. Lack of thermal stratification and high flushing rates combined with nutrient availability probably caused this.

The concentrations of algae cells in the water of the ponds was moderate-to-high. Combined with the amount of macroscopic algae and macrophytes present, all three ponds appear to be eutrophic, very productive, systems.

3. Aquatic Macrophytes

On August 29-31, 1988, a macrophyton survey was conducted for the purpose of identifying dominant genera and quantifying the areal extent of aquatic vegetation. Preliminary surveys of the ponds were conducted during preceding limnological sampling trips. The purpose of the preliminary surveys was to improve efficiency during the first portion of the vegetative survey. Plants which were not readily identified in the field were brought back to the laboratory. The taxonomic guide used was Fassett (1957).

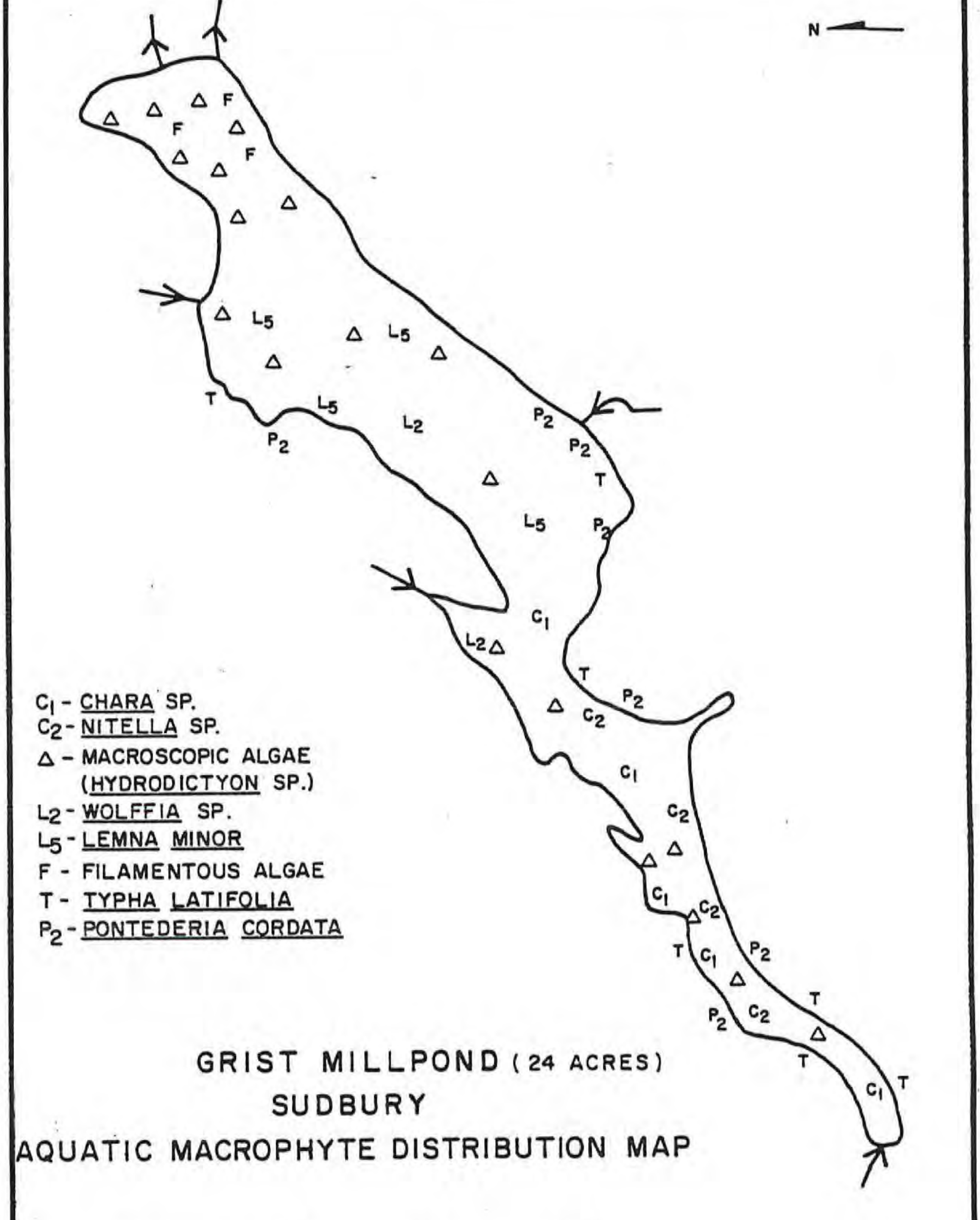
The survey was performed by the line-intercept method. By slowly examining shoreline areas and selecting sampling points at intervals of approximately 50 feet, and then moving perpendicular to these sampling points, transects were made across the pond. Once on the opposite side of the pond, the procedure was repeated. Emergent plants were identified in-situ, while submerged and bottom-growing plants were collected with a grappling hook. Density determinations of overall macrophyte growth for each pond were estimated and individual species type was identified. For each of the three ponds, a macrophyte density and distribution map was compiled (Figures 6-1 to 6-6).



GRIST MILLPOND (24 ACRES)
SUDBURY
AQUATIC MACROPHYTE DENSITY MAP

Whitman & Howard, Inc. | Figure 6-1

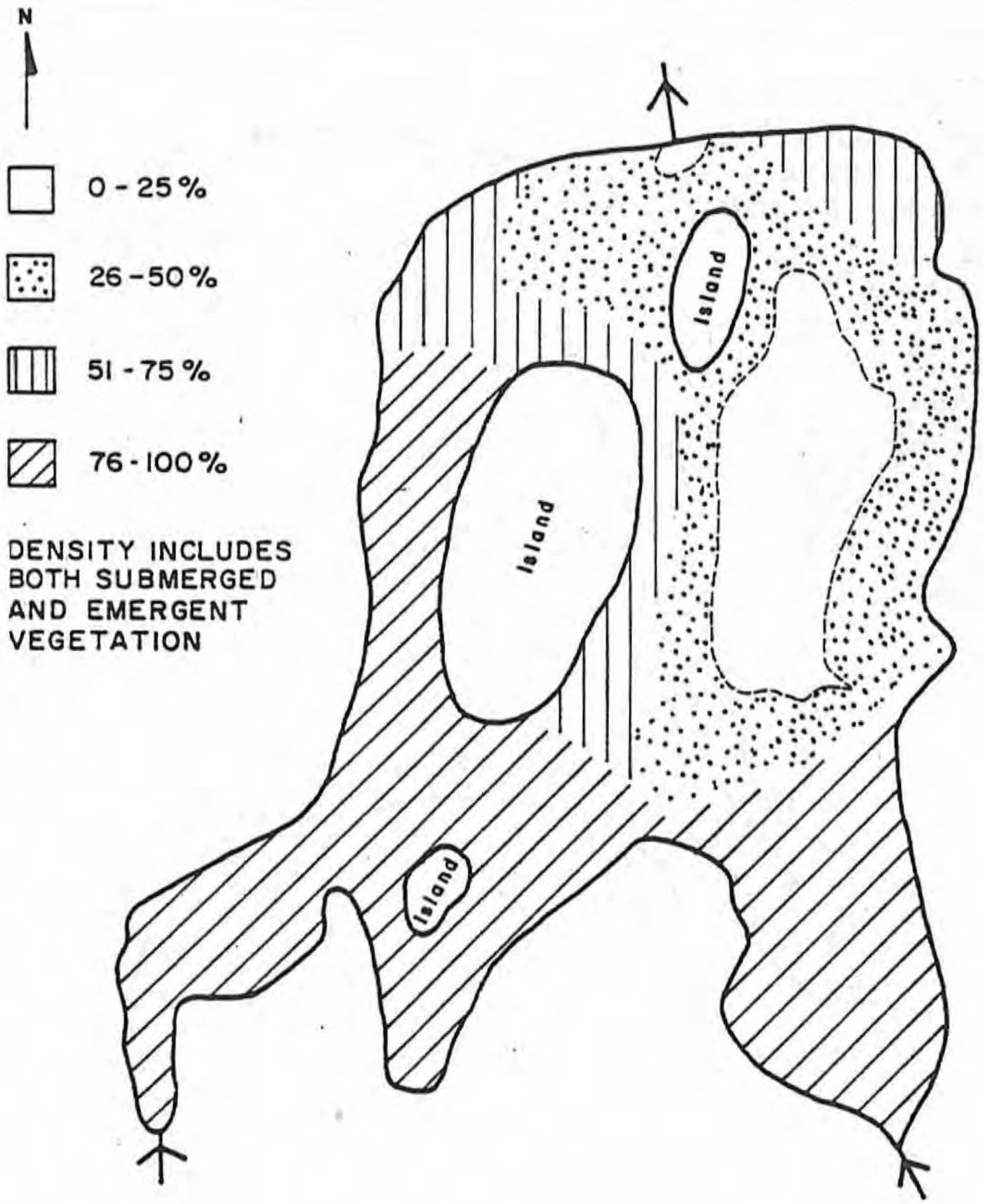
133910



GRIST MILLPOND (24 ACRES)
SUDBURY
AQUATIC MACROPHYTE DISTRIBUTION MAP

Whitman & Howard, Inc. | Figure 6-2

MAKEPEACE



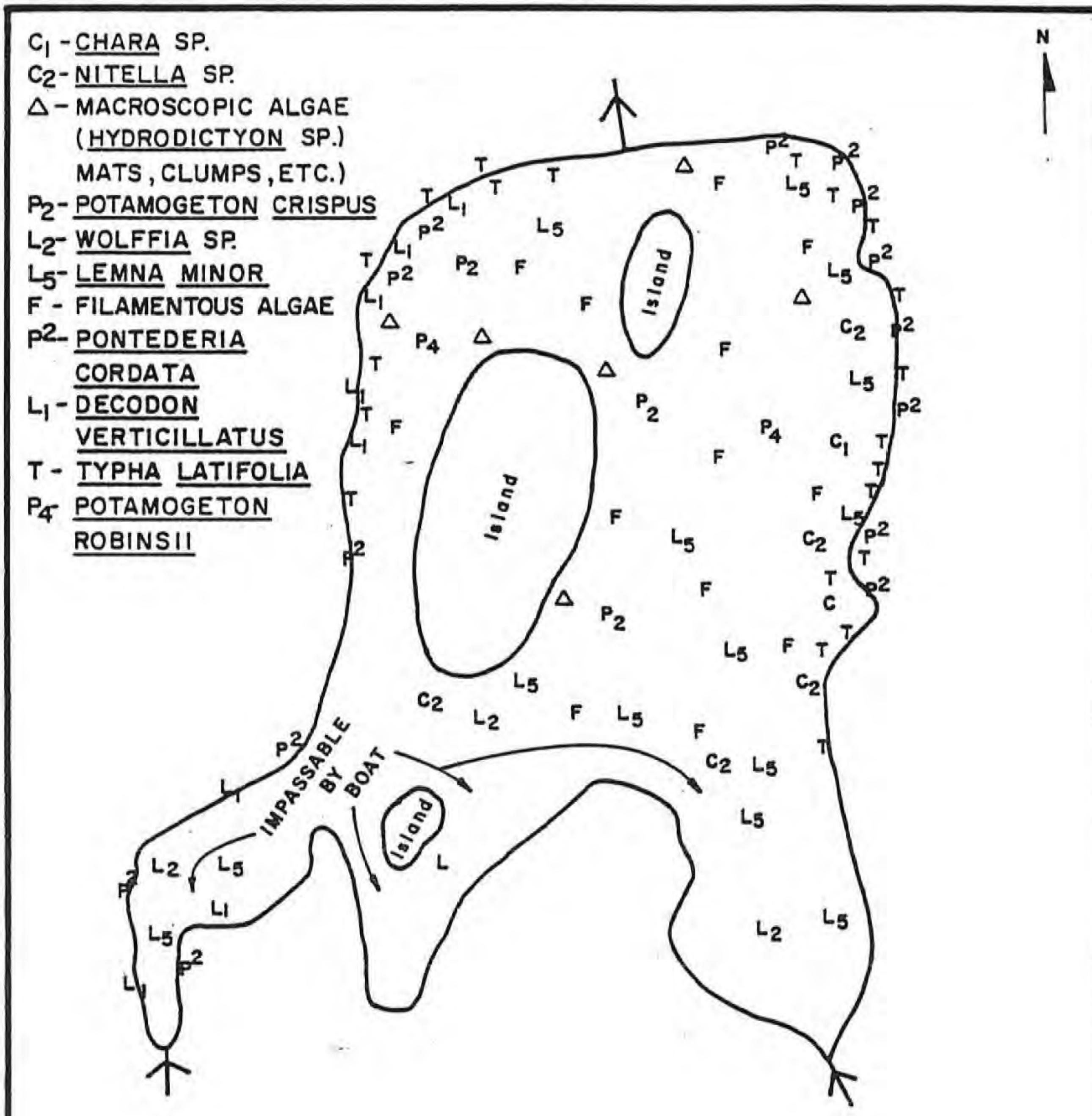
CARDING MILLPOND (40 ACRES)
SUDBURY
AQUATIC MACROPHYTE DENSITY MAP

0 333' 666' 999'
SCALE IN FEET

Whitman & Howard, Inc.	Figure 6 - 3

133910

MAKEPEACE



CARDING MILLPOND (40 ACRES)

SUDBURY

AQUATIC MACROPHYTE DISTRIBUTION MAP

0 333' 666' 999'

SCALE IN FEET

Whitman & Howard, Inc.	Figure 6-4

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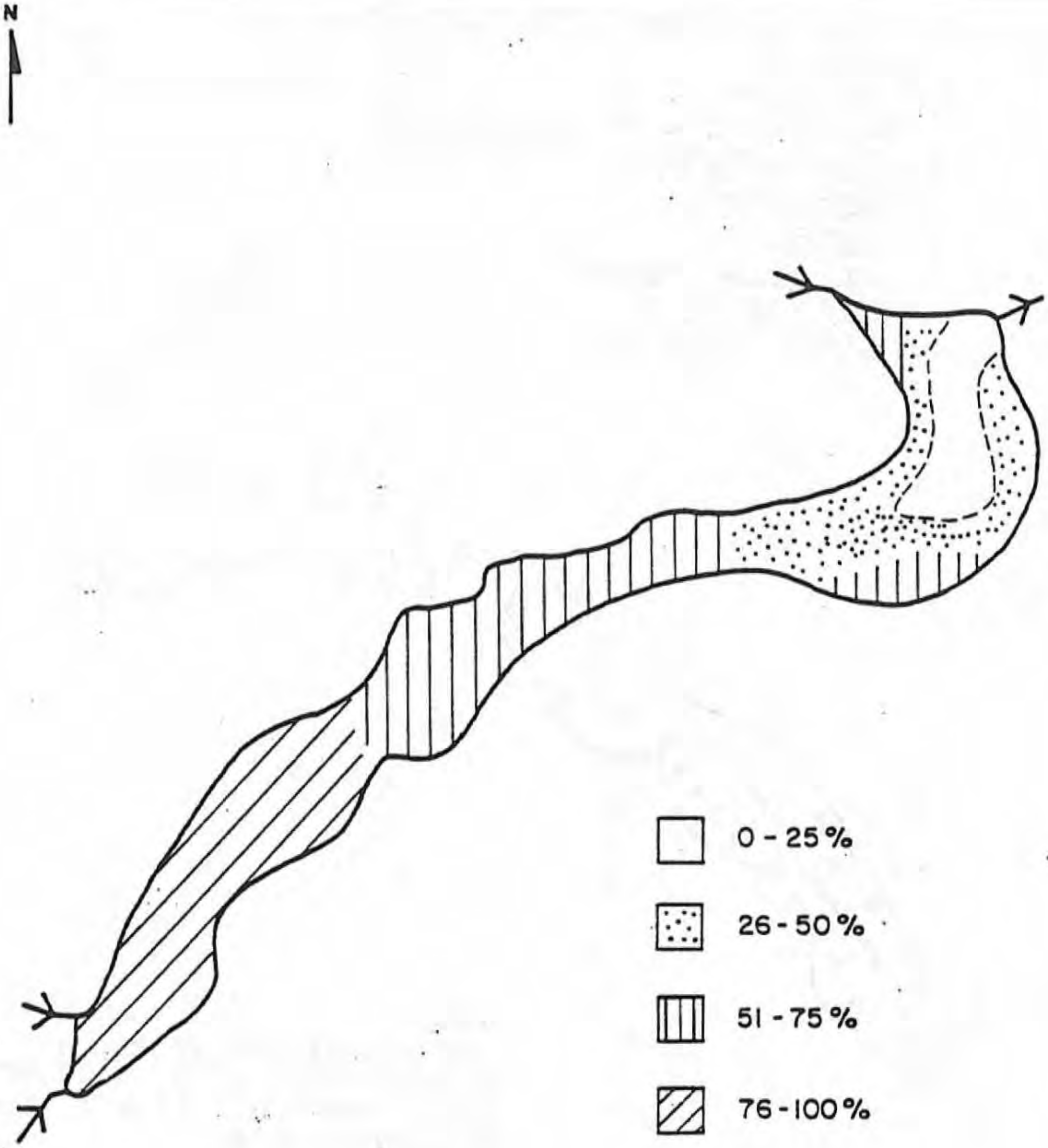


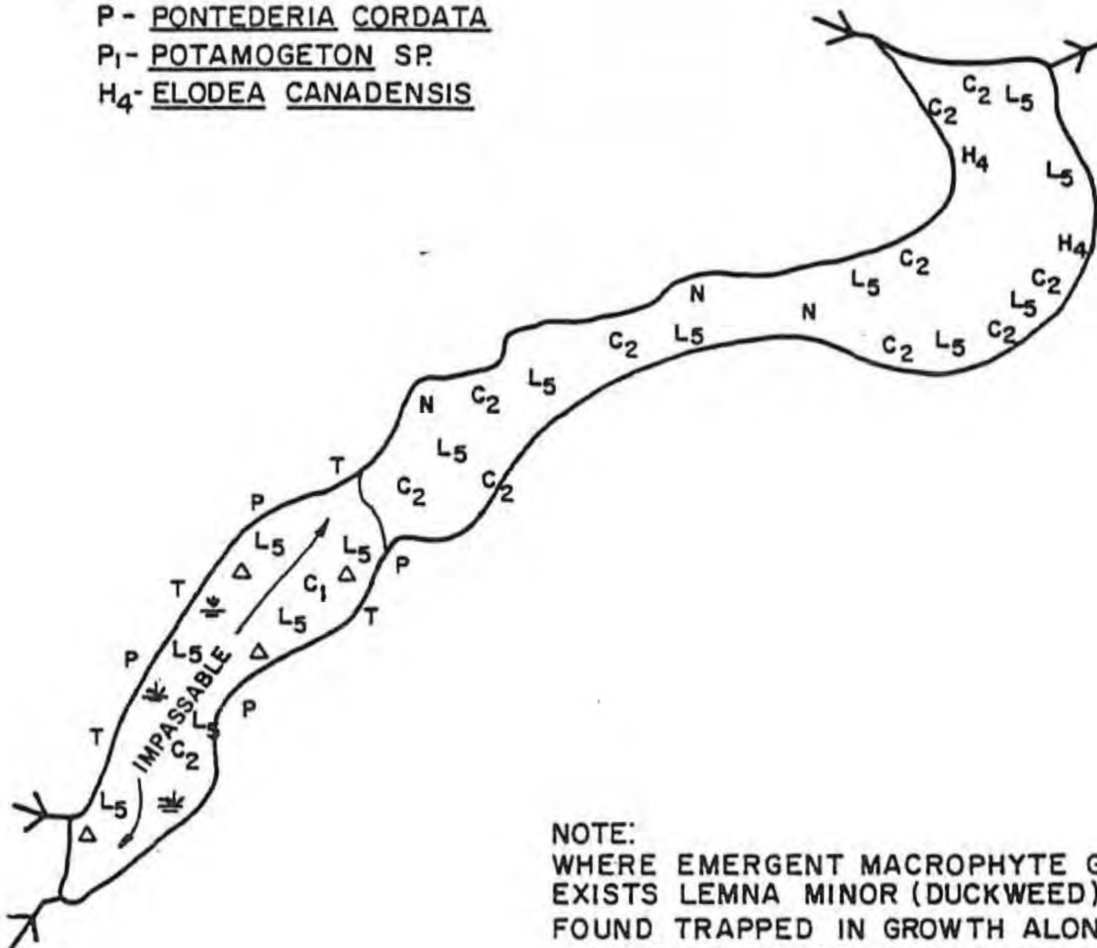
STEARNS MILLPOND (24 ACRES)
SUDBURY
AQUATIC MACROPHYTE DENSITY MAP

0 500' 1000' 1500'
SCALE IN FEET

Whitman & Howard, Inc.	Figure 6 - 5

N

N - *NYMPHEA* SP. (WHITE AND YELLOW WATER LILY)
C_1 - *CHARA* SP.
C_2 - *NITELLA* SP.
△ - MACROSCOPIC ALGAE (*HYDRODICTYON* SP.)
T - *TYPHA LATIOFOLIA*
L_5 - *LEMNA MINOR*
L_2 - *WOLFFIA* SP.
P - *PONTEDERIA CORDATA*
P_1 - *POTAMOGETON* SP.
H_4 - *ELODEA CANADENSIS*



NOTE:
WHERE EMERGENT MACROPHYTE GROWTH EXISTS LEMNA MINOR (DUCKWEED) IS FOUND TRAPPED IN GROWTH ALONG WITH *HYDRODICTYON* SP.

STEARNS MILLPOND (24 ACRES)
SUDBURY
AQUATIC MACROPHYTE DISTRIBUTION MAP

0 500' 1000' 1500'
SCALE IN FEET

Whitman & Howard, Inc.	Figure 6-6

133910
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Nitella were the most dominant plant growing in the three ponds studied. The Nitellas are an advanced form of algae which grow attached to the bottom and have stems and branches. Nitella is similar to Chara, also an advanced algae form, which is bushier, less bristly, and usually not accompanied by a coating of lime. These bottom-growers usually reach a height of only a couple of feet and, therefore, appear not to be a nuisance from casual observation. In most cases, these algae are beneficial to waterfowl because they provide a source of food. Also, the algae are beneficial to fish by providing shelter. Chara and Nitella beds are better left undisturbed due to the potential for introduction of more troublesome aquatic weeds.

During early to mid-summer, the ponds' surfaces were covered by duckweed, both Spirodela polyrhiza (great duckweed) and Lemna minor (lesser duckweed). Great duckweed and lesser duckweed are differentiated by the number of rootlets hanging below the plant body. Great duckweed has numerous rootlets while lesser duckweed has one rootlet. In mid-August, Wolffia began to appear on the ponds' surface, except for a few wind-blown open areas. Wolffia is thick, granular, and lacks rootlets. It is often found in quiet, nutrient-rich waters containing duckweed. Since both Wolffia and duckweed blow and drift, they are difficult to control. The leaves are dormant when dry and during the winter. Both varieties provide food for waterfowl and reproduce rapidly.

Other aquatic macrophytes present, but to a much lesser degree, include scattered bunches of Potamogeton (pondweeds), Nymphea orderata (white water lily), Nuphar (yellow water lily), Pontederia cordata (pickerelweed), and Typha latifolia (broad-leaved cattail). Filamentous algae were also scattered throughout the pond.

Aquatic plants and algae are necessary for the maintenance of nearly all other forms of aquatic life. They consume carbon dioxide and oxygenate the water, provide food for small swimming organisms, and play an important primary production role in the food chain. Aquatic plants also shade and cool waters and provide shelter and breeding areas for the small organisms and fish which feed on them.

Excess aquatic plant growth makes swimming, boating, and fishing unpleasant, and at times, nearly impossible. Fish reproduction is hindered because excess plant growth eliminates spawning areas. Plant decay depletes dissolved oxygen concentrations and water becomes stagnant, providing breeding habitat for mosquitos. Therefore, it is often necessary to control plant growth to the extent the uses of the water body demand.

Aquatic macrophyte control techniques include long-term source reduction measures, mechanical and cultural harvesting, and short-term chemical eradication. One of the most important factors to proper aquatic weed control is realizing the reasons for weed propagation, including the means by which the particular macrophyte reproduces. The factors necessary for aquatic plant growth are present in the Sudbury ponds. These factors are water, light, nutrients (such as nitrogen and phosphorus in the water and sediment), and a suitable bottom substrata for rooted vascular plants.

Filamentous algae grow in long, stringy, hair-like strands that are predominantly attached to other objects. In the case of the millponds, it is often attached to Nitella and Chara. Nutrient-rich waters cause filamentous algal growth, so source reduction of nutrient levels is the best long-term control method. However, another control method is chemical application using copper sulfate or Cutrine(R).

Duckweed and Wolffia, being completely free-floating, are difficult to control. They are most susceptible to chemical control but may also be raked off. They will quickly reinfest an area unless nutrient sources are reduced.

White and yellow water lilies are best controlled by repeated cutting or raking. Eradication of these aquatic plants will not pose any problem to aquatic wildlife since their food value is low. Chemical treatment may be plausible, but their thick fleshy stems are difficult to kill.

The algae which causes a problem within the ponds is a macroscopic algae, Hydrodictyon. Hydrodictyon grows in long, hair-net-like assemblages. It is also sponge-like, in that it holds much water. Hydrodictyon was particularly problematic in Grist Millpond. The remaining aquatic and semi-aquatic plants, such as pickerelweed, broad-leaved cattails, purple loosestrife, and members of the grass family, are found along shore areas and pose no hindrance to recreational uses in the pond.

F. IN-POND SEDIMENT INVESTIGATIONS

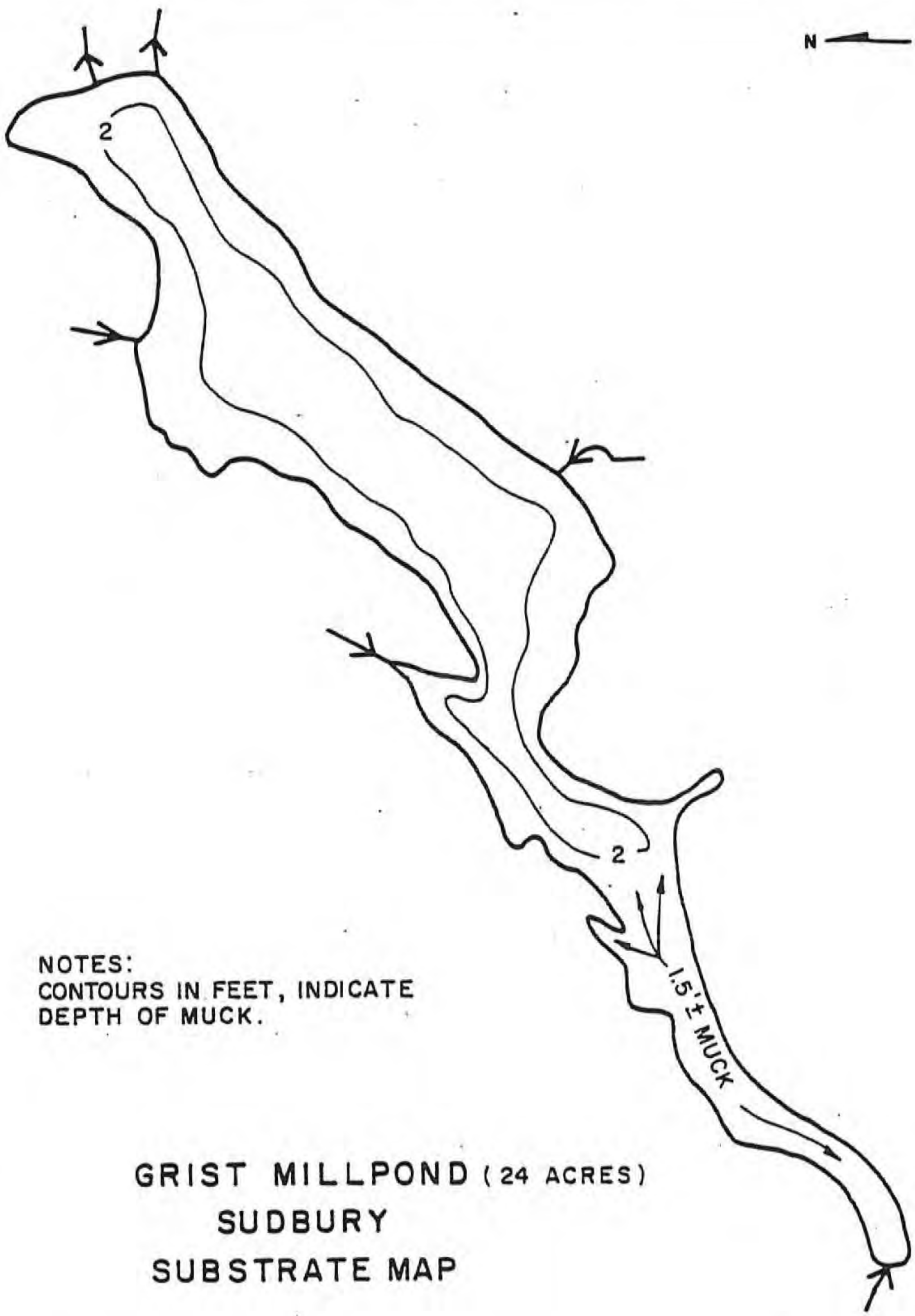
Two types of sediment analyses were conducted in Grist, Carding, and Stearns Millponds. Sediment depth measurements were conducted on August 30, 1988. These measurements were taken by driving a calibrated surveyor's rod to refusal. Transects of the ponds were established by setting pond centerline points at 120-meter (400-feet) intervals upstream from each pond's outlet. Depth measurements were made at 45-meter to 60-meter (150-feet to 200-feet) intervals along these bank-to-bank transects.

Figures 6-7, 6-8, and 6-9 are the resultant sediment depth maps for Grist, Carding, and Stearns Millponds. As shown on these figures, the sediment in all three ponds averaged from 0.5 to 1 meter (2 to 3 feet) in depth. Also, in each pond, the sediment depth distribution was fairly uniform throughout the basin. This is likely due to sluggish water flow and dense macrophyte growth in all of the ponds.

The second type of sediment testing was chemical analyses of grab samples taken from each pond on September 10, 1987 and March 30, 1988. The samples were taken from the deep hole locations shown on Figures 4-2, 4-3, and 4-4. Chemical analyses were conducted to categorize the nature of the sediments for completion of a Certification for Dredging, Dredged Materials Disposal, and Filling in Water (CMR, 1986). These regulations categorize dredge materials by chemical and physical characteristics.

The results of the sediment analyses for the Sudbury ponds are shown in Table 6-21. The sediment in all three ponds exhibits elevated levels of zinc and volatile solids. Grist and Stearns Millponds had elevated levels of cadmium, and Stearns and Carding Millponds had slightly elevated levels of lead. None of the values of these parameters were unusually high. The elevated levels of the metals could be related to upstream inputs to the ponds as well as roadway runoff. Volatile solids values could be due to upstream inputs as well as autochthonous sources (algae and macrophytes).

In relative terms, sediments can be classified according to their pollutional status. One such classification scheme is presented in Table 6-22. When compared to other pond sediments, the sediments of the Sudbury



GRIST MILLPOND (24 ACRES)
SUDBURY
SUBSTRATE MAP

Whitman & Howard, Inc.

Figure 6-7

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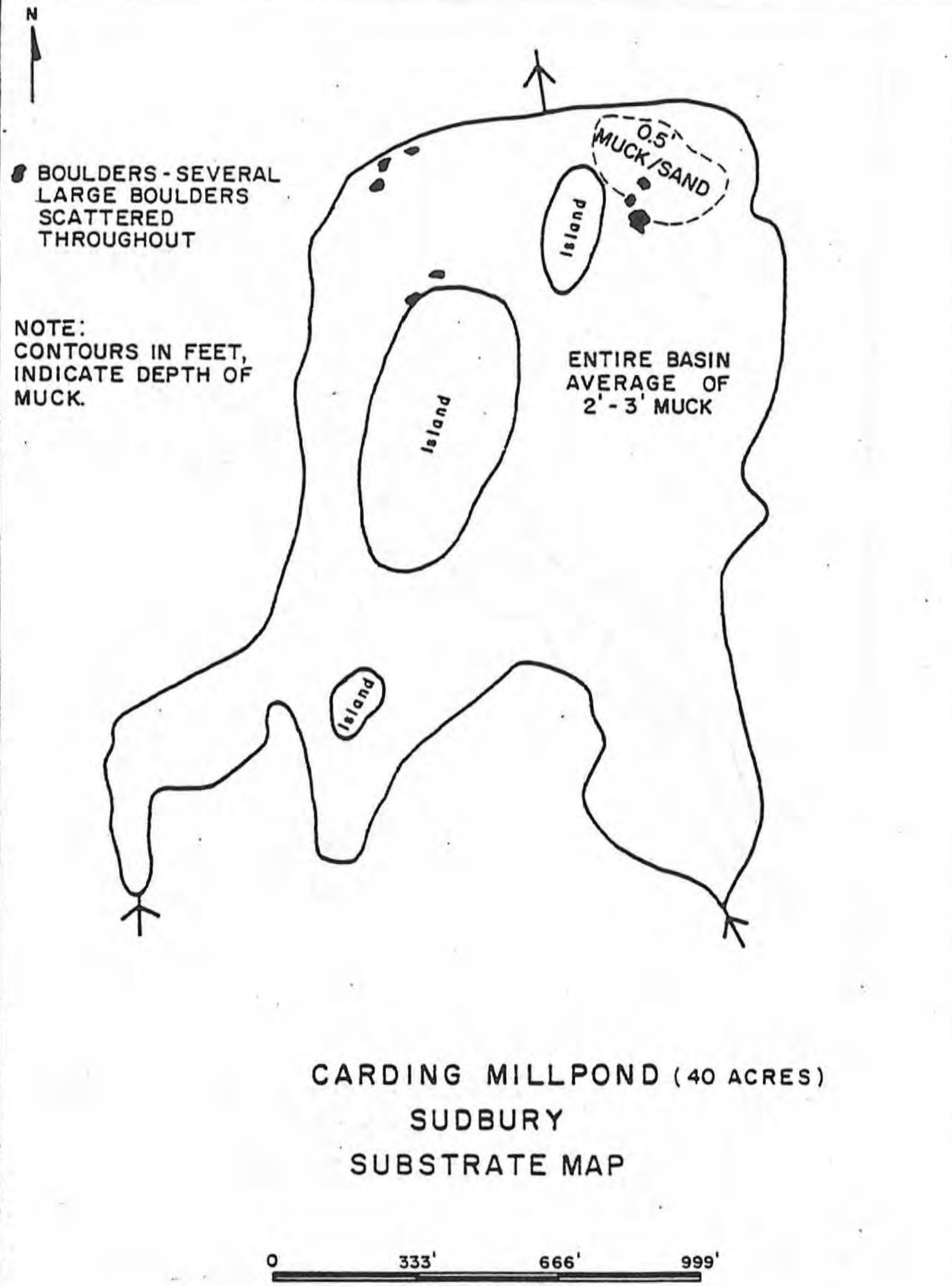

CARDING MILLPOND (40 ACRES)
SUDBURY
SUBSTRATE MAP

Whitman & Howard, Inc.

Figure 6-8

133910

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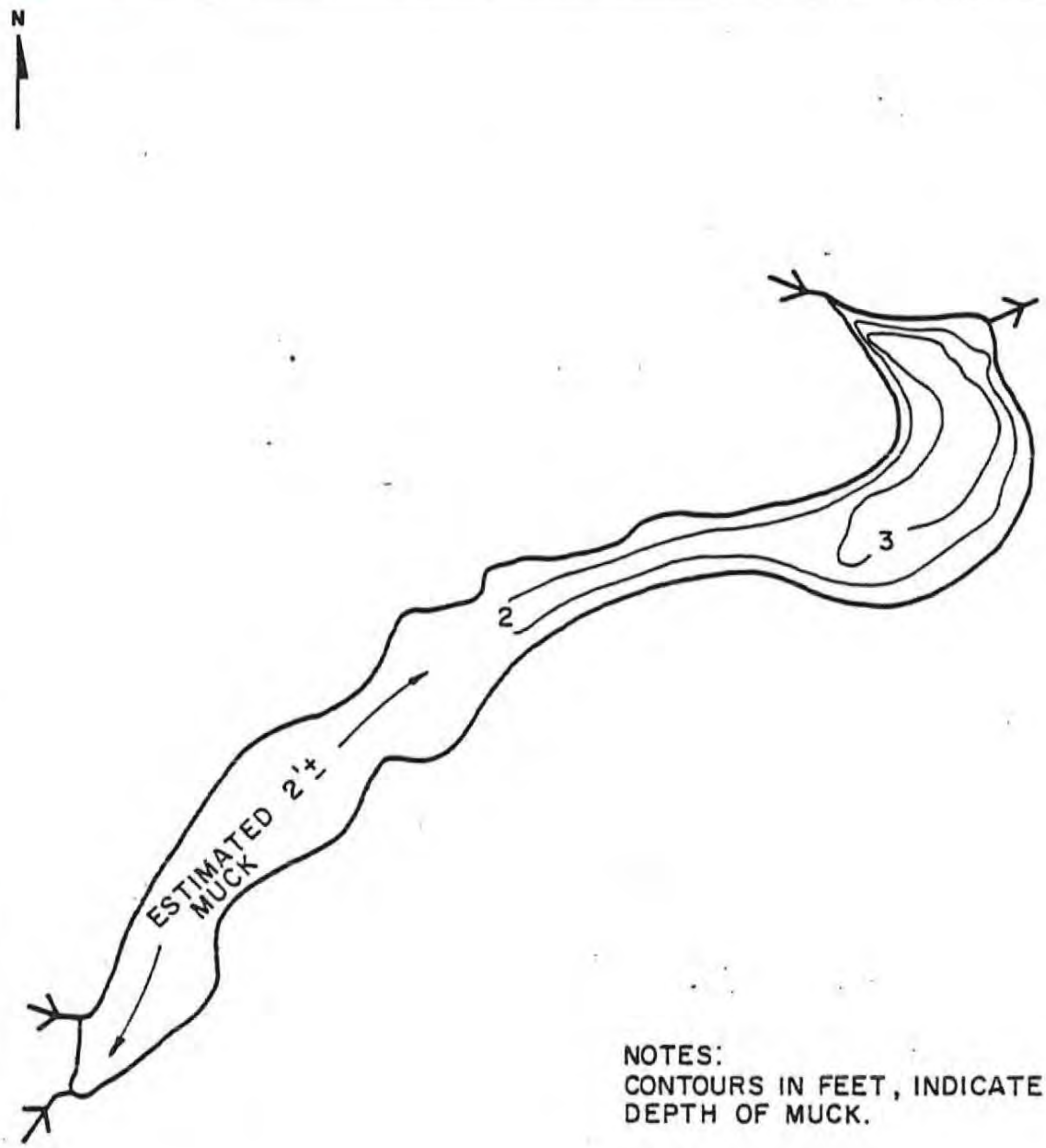

NOTES:
CONTOURS IN FEET, INDICATE DEPTH OF MUCK.

STEARNS MILLPOND (24 ACRES)
SUDBURY
SUBSTRATE MAP

0 500' 1000' 1500'
SCALE IN FEET

Whitman & Howard, Inc.

Figure 6-9

133910

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ponds are moderately-to-heavily polluted (Table 6-23). In particular, the Sudbury ponds' sediments have high concentrations of kjeldahl (ammonia plus organic) nitrogen, and phosphorus. Both of these parameters are indicators of cultural enrichment of the sediment, probably due to wastewater effluent nutrient loads. As previously indicated, cadmium, lead, and zinc concentrations in the Sudbury ponds' sediments are also elevated.

The results of the analyses confirm the eutrophic state of the Sudbury ponds. Given the depth of both the water and the sediments, and the high nutrient concentrations in the sediments, dredging should be considered as a remedial measure.

Either hydraulic or mechanical dredging with land disposal would be a method normally approved by the Massachusetts Department of Environmental Quality Engineering (DEQE). Land disposal would probably require effluent controls and timing constraints to avoid environmental impacts associated with disposal.

TABLE 6-21
IN-POND SEDIMENT DATA

Parameter*	Grist Millpond 1/10/87	Grist Millpond 3/30/88	Carding Millpond 9/10/87	Carding Millpond 3/30/88	Stearns Millpond 9/10/87	Stearns Millpond 3/30/88
Oil and Grease	N/A	585	N/A	735	N/A	429
Volatile Solids (%)	N/A	33.3	N/A	37.8	N/A	36.5
Total Kjeldahl Nitrogen	17,600	N/A	16,410	N/A	21,030	N/A
Nitrogen (Total)	N/A	22,810	N/A	21,960	N/A	23,380
Phosphorus (Total)	2,710	3,870	2,270	2,580	2,410	2,340
Arsenic	N/A	1.12	N/A	0.86	N/A	0.79
Cadmium	2.1	9.6	3.9	3.5	9.3	6.7
Chromium	7.9	9.8	13	7.5	12.8	8.2
Copper	29.5	45.2	51	57.4	115	43.5
Iron	N/A	3,850	1,890	2,870	4,210	3,030
Lead	53	98	99.5	110	139	105
Manganese	142	201	105	109	455	220
Mercury	N/A	0.25	N/A	0.18	N/A	0.20
Nickel	N/A	6.5	N/A	4.5	N/A	5.6
Vanadium	N/A	0.15	N/A	0.12	N/A	<0.10
Zinc	112	220	206	218	310	190

*All values in milligrams of the parameter per kilogram of dry sediment (mg/kg).

TABLE 6-22
GREAT LAKES SEDIMENT RATING CRITERIA
(dry weight basis; mg/kg[1])

Parameter	Nonpolluted	Moderately Polluted	Heavily Polluted
Ammonia Nitrogen	< 75	75 - 200	> 200
Total Kjeldahl Nitrogen	< 1,000	1,000 - 2,000	> 2,000
Phosphorus (Total)	< 420	420 - 650	> 650
Arsenic	< 3	3 - 8	> 8
Cadmium	NLD	NLD	> 6
Chromium	< 25	25 - 75	> 75
Copper	< 25	25 - 50	> 50
Iron	<17,000	17,000 - 25,000	>25,000
Lead	> 40	40 - 60	> 60
Manganese	< 300	300 - 500	> 500
Mercury	NLD	NLD	≥ 1
Nickel	< 20	20 - 50	> 50
Zinc	< 90	90 - 200	> 200

Source: USEPA, 1982.

[1]mg/kg = milligrams of the parameter per kilogram of dry sediment.

NLD = No lower limits defined.

TABLE 6-23
COMPARATIVE POLLUTIONAL STATUS
OF THE SUDBURY PONDS' SEDIMENTS
(USING THE GREAT LAKES SEDIMENT RATING CRITERIA)

Parameter	Grist Millpond	Carding Millpond	Stearns Millpond
Total Kjeldahl Nitrogen	H	H	H
Phosphorus (Total)	H	H	H
Arsenic	N	N	N
Cadmium	M-H	M	H
Chromium	N	N	N
Copper	M	H	M-H
Iron	N	N	N
Lead	H	H	H
Manganese	N	N	N-M
Mercury	N-M	N-M	N-M
Nickel	N	N	N
Zinc	M	H	M-H

H = Heavily polluted
N = Nonpolluted
M = Moderately polluted

VII. SANITARY QUESTIONNAIRE SURVEY RESULTS

A. OBJECTIVE OF STUDY

The purpose of the Hop Brook watershed "Wastewater Disposal Questionnaire" was to assess the magnitude of water-intensive household appliance use and their potential impact on on-site wastewater disposal systems. Additionally, it was our intention to obtain an approximation of the number and type of faulty wastewater systems and the types of maintenance techniques practiced by watershed residents. The Sudbury Board of Health was solicited for their concerns with problem areas within the vicinity of the study ponds. Board of Health records indicate that no apparent problems exist in the immediate vicinity of the ponds.

B. RESULTS OF HOP BROOK WATERSHED WASTEWATER QUESTIONNAIRE SURVEY

A total of 125 questionnaires were hand-delivered to selected Hop Brook watershed residents. There was 36 percent participation, providing a sampling size of 45. The distribution of return location is as follows:

Closest Location	Returned	Percent Participation
Grist Millpond	2	4.4
Carding Millpond	3	6.7
Stearns Millpond	23	51.0
Hop Brook	17	37.8

Questionnaire results indicate that 100 percent of the households surveyed in Sudbury have subsurface wastewater disposal systems consisting of septic tanks. The system distances from the shoreline are as follows:

Distance	Distribution	Percent
10-50 ft	1	2.2
50-100 ft	5	11.1
100-200 ft	6	13.3
200-300 ft	18	40.0
Over 300 ft	15	33.4

Regularity of septic system maintenance of those responding to the questionnaire ranged from never to every year. The average system was maintained every 3.5 years. Eighty-two percent of the maintenance performed was pumping, while six homes had new leach beds, one home had chemical treatment to the system and one home had installed a new septic system.

Twenty-two percent of those surveyed have storm drains located on or near their property. Most of these people thought that the storm drains were cleaned once or twice a year. Eleven percent of those responding believe that their stormwater drainage is directly connected or discharges to the pond, stream, or stormwater pipe.

Twenty-two percent of those replying to the survey have experienced problems with aquatic vegetation. Fertilizers are used by 67 percent of the respondents. Fifty-three percent of those surveyed using fertilizers use Scott products. Herbicides were used by 9 percent and pesticides were used by 31 percent.

A. INTRODUCTION

The purpose of a hydrologic budget is to numerically depict the cyclical process of water movement through a watershed. The cycle consists of three primary components; precipitation, evapotranspiration, and surface/subsurface water movement. Figure 8-1 is a pictorial representation of the hydrologic cycle.

Precipitation on a watershed can evaporate, be transpired by plants, travel over the land to streams and wetlands, or infiltrate to the groundwater. As much as 50 to 80 percent of precipitation is eventually returned to the atmosphere through transpiration and evaporation. Collectively, these two transport mechanisms are referred to as evapotranspiration. Infiltrated water may be stored as soil moisture or may percolate to deeper groundwater areas. In sandy and gravely areas, groundwater is plentiful. In clayey or bedrock areas groundwater is minimal. Groundwater can be transpired by plants, flow out to springs or wetlands, or provide base flow in streams.

A hydrologic budget for a pond assumes that water inputs must equal water outputs. The water balance for a pond is evaluated by a hydrological equation in which the change in storage volume of water is equal to the rate of inflow from all sources minus the rate of all outflows.

The inputs to the Hop Brook system ponds include surface water runoff (R), flow from upstream sources (U), and groundwater inflow (Gi). The outputs are outflow (O), direct evaporation (E), and groundwater exfiltration (Ge).

For the Hop Brook system subwatersheds, several assumptions were made. First, it was assumed that equal quantities of groundwater entered and exited each pond. Secondly, it was assumed that the amount of groundwater withdrawn for water supply equals the amount of water returned to the groundwater through subsurface wastewater disposal.

The equation for flow through the Hop Brook system ponds is, therefore:

$$R + U = O + E.$$

B. HAGER POND CALCULATIONS

Hager Pond is the headwaters of the Hop Brook system. To estimate hydrologic budgets for Grist, Carding, and Stearns Millponds, an estimate of the outflow from Hager Pond (inflow to Grist Millpond) had to be derived. Due to a lack of gauged flow data from the Hager Pond outlet, a series of calculations were made utilizing data from several sources. These sources included: data previously collected by the United States Geological Survey (USGS, 1977-1979) from the Hager Pond outlet for the period September 1977 through August 1979; a correlation of average stream flows from the gauging station and the average percentage of MEWWTP effluent in the stream at the Hager Pond outlet (Briggs and Silvey, 1984); and, the average daily flow (monthly basis) from MEWWTP during the study period (City of Marlborough, 1987-1988). The results of the latter of these three sources are presented in Table 8-1. The purpose of this exercise was to calculate Hager Pond outflow and determine the contribution of flow from sources other than the MEWWTP.

The findings of this approach and the details of the methodology used are shown in Table 8-2. From these calculations it was determined that, on a yearly basis, approximately 71 percent of the flow through Hager Pond was contributed by the MEWWTP. To check the validity of these calculations, the hydraulic retention time in Hager Pond was determined and compared to values previously determined by the Massachusetts Division of Water Pollution Control (MDWPC, 1986). Hager Pond received 1072 million gallons of MEWWTP effluent during the study year. Using the literature values of the ratio of effluent to streamflow (USGS, 1984), and the historically measured flow (USGS, 1977-1979), it was determined that Hager Pond received 449 million gallons of water from sources other than MEWWTP during the study year. The total flow through the pond was approximately 1521 million gallons. The volume of Hager Pond is approximately 94 acre-feet; therefore, the hydraulic residence time is about 7.6 days (0.021 year). The value reported by the MDWPC (1986) was 6.6 days.

C. GRIST MILLPOND CALCULATIONS

Runoff from watersheds in New England averages 2.1 inches per year (Sopper and Lull, 1970; Linsley and Franzini, 1979). Runoff production can be affected by a variety of watershed characteristics including soil types,

TABLE 8-1
MARLBOROUGH EASTERLY WASTEWATER TREATMENT PLANT EFFLUENT VOLUMES

Month	Average Daily Flow (MGD)	Average Daily Flow (cfs)	Total Flow MG/Month
September 1987	2.5	3.88	75.0
October	2.6	4.03	80.6
November	2.6	4.03	78.0
December	2.8	4.34	86.8
January 1988	2.6	4.03	80.6
February	3.7	5.74	103.6
March	3.5	5.43	108.5
April	3.3	5.12	99.0
May	3.8	5.89	117.8
June	2.8	4.34	84.0
July	2.6	4.03	80.6
August	2.5	3.88	77.5
	Average = 2.94	Average = 4.56	Total = 1,072.0

Source: City of Marlborough, 1988.

TABLE 8-2
DETERMINATION OF WASTEWATER FLOW
VS
CONTRIBUTIONS FROM OTHER SOURCES ENTERING HAGER POND

Month	Measured Flow (cfs)[1]	% of Total Flow Contributed From WWTP[2]	Actual WW Flow (cfs)[3]	Contributions From Other Sources (cfs)[4]	Total Flow (cfs)[5]
September	3.79	88	3.88	0.47	4.35
October	4.89	79	4.03	0.85	4.88
November	6.00	66	4.03	1.37	5.40
December	7.82	59	4.34	1.78	6.12
January	14.25	18	4.03	2.90	6.93
February	8.51	55	5.74	2.58	8.32
March	11.20	29	5.43	3.86	9.29
April	10.85	35	5.12	3.33	8.45
May	8.50	55	5.89	2.65	8.54
June	5.48	69	4.34	1.35	5.69
July	4.09	81	4.03	0.77	4.80
August	5.68	77	3.88	0.89	4.77
Averages			4.56	1.90	

[1]Measured Flow by USGS September 1977 through August 1979 at Station No. 01098710.

[2]Percent of Total Flow Contributed by the MEWWTP Based on USGS Report No. 84-4017 (1984) Figure 2, Page 7.

[3]Actual Wastewater Flow from MEWWTP from September 1987 through August 1988 (City of Marlborough, 1987-1988).

[4]Column 3 + (1.0 - Column 4, Column 3)

i.e., September

= (1.0 - 0.88) (3.88)
= (0.12) (3.88)
= 0.4656 cfs.

[5]Total Flow = 3.88 cfs + 0.47 cfs = 4.35 cfs.

vegetative cover, watershed shape, slopes, and evapotranspiration. Using the average value of 21 inches per year, the Grist Millpond watershed runoff production was estimated to be 393 million gallons per year. To check the validity and this average value, precipitation data were gathered from the period from September 1987 to August 1988 (NOAA, 1987-1988). Precipitation for this period totaled 41.57 inches. The precipitation input to the Grist Millpond watershed was, therefore, approximately 779 million gallons (based on a watershed area of 690 acres). Since evapotranspiration can account for up to a 50 to 80 percent loss of precipitation, and the watershed has moderate slopes and limited wetland areas, and the predominant soil classification is in hydrologic Group B (See Chapter III, Section E), a runoff return equal to 50 percent of the precipitation input was viewed as reasonable.

The upstream input to Grist Millpond is equal to the outflow from Hager Pond since these ponds are in close proximity to one another. Because of the limited distance between the ponds, evapotranspiration between ponds is likely to be insignificant.

Direct evaporation from shallow lakes averages 27 inches per year (Linsley et. al., 1975). Based on a surface area of 24 acres, the direct evaporation from Grist Millpond is approximately 18 million gallons per year.

The rearranged equation to solve for outflow from the pond is:

$$O = R + U - E$$

or $O = 393 + 1521 - 18 = 1896$ million gallons per year.

The retention time for Grist Millpond, based on a pond volume of 60 acre-feet, is approximately 0.010 years (3.8 days). The value derived by the MDWPC (1986) was 4.0 days. Flushing rate is the number of times per year that a water body will have a complete exchange of water volume. This rate is calculated by taking the reciprocal of the retention time. In general, the more flushings per year, the higher the benefit to a water body because of self-cleansing. The flushing rate for Grist Millpond is approximately 97 times per year. This high flushing rate shows the influence of high inflows from upstream sources, the pond's shallow depth, and the pond's small acreage.

D. CARDING MILLPOND CALCULATIONS

Runoff production from the Carding Millpond watershed to the pond was estimated to be 379 million gallons per year, based on the average of 21 inches per year reported in the literature. To check this, precipitation input to the watershed was calculated and watershed characteristics checked. Precipitation for the study year was approximately 751 million gallons, based on a watershed area of 665 aces. As with the Grist Millpond watershed, the slopes in this watershed are moderate and the dominant soil types are classified as hydrologic Group B. Therefore, a runoff return equal to 50 percent of the precipitation input was viewed as reasonable.

It was assumed that the small wetland area between the Grist Millpond outlet and the Carding Millpond inlet could cause a loss of 10 percent of the upstream flow input to Carding Millpond. This loss would be due to evapotranspiration in the wetland. Therefore, the upstream flow input was reduced by 190 million gallons to a value of 1706 million gallons per year.

Direct evaporation losses from the pond surface equaled 29 million gallons per year, based on a surface area of 40 acres. Therefore, the outflow equation for Carding Millpond is:

$O = 379 + 1706 - 29 = 2056$ million gallons per year.

The retention time for Carding Millpond, based on a pond volume of 72 acre-feet, is 0.011 years (4.2 days). The MDWPC (1986) calculated the retention time of Carding Millpond to be 5.1 days. The flushing rate for Carding Millpond is approximately 88 times per year. As with Grist Millpond, this high rate shows the influence of the inflow to the pond and the small size of the pond.

E. STEARNS MILLPOND CALCULATIONS

Runoff production from the Stearns Millpond watershed to the pond was estimated to be 1927 million gallons per year, based on the average value of 21 inches per year reported in the literature. Precipitation input to the watershed was estimated to be 3816 millions gallons per year, based on a watershed area of 3380 acres. The groundslopes in the watershed vary from moderate to gentle and there are extensive wetland areas throughout the watershed. The dominant soil types are classified as hydrologic Group A. This group has characteristically low runoff potential. Because of these factors, a runoff return equal to 50 percent of the precipitation input is too high. A value equal to 30 percent of precipitation would be more reasonable. Therefore, the runoff production was estimated to be 1156 million gallons per year.

The large wetland area between the Carding Millpond outlet and the Stearns Millpond inlet also causes evapotranspiration losses from the upstream inflow to the pond. As much as 50 percent of the flow is liable to be "lost" to the atmosphere. Therefore, the upstream flow input to the pond was reduced to 1.028 million gallons per year.

Direct evaporation losses from the ponds surface equaled 18 million gallons per year based on a surface area of 24 acres. Thereafter, the outflow from Stearns Millpond is:

$$O = 1156 + 1028 - 18 = 2166 \text{ million gallons per year.}$$

The retention time for Stearns Millpond, based on a pond volume of 24 acre-feet, is 0.004 years (1.3 days). This compares to a value of 1.6 days derived by MDWPC (1986). The flushing rate for Stearns Millpond is approximately 280 times per year. This very high rate shows that Stearns Millpond is, at this point in time, little more than a widening in Hop Brook.

IX. LIMITING NUTRIENT (PHOSPHORUS) BUDGET

A water body nutrient budget is an attempt at quantifying the sources and losses of nutrients as they move through the water body. One method of determining this budget is based on the hydrologic budget of a pond and the results of a sampling program for the nutrient in question.

For the Hop Brook system ponds, the nutrient which limits primary production is phosphorus. Total phosphorus concentration data were collected over a period of a year at 15 locations in the Hop Brook watershed. Calculations of phosphorus loadings were based on the average concentrations found at specific locations from this sampling program and elements of the hydrologic budget for each pond. Atmospheric fallout of phosphorus onto the surface of the pond was estimated from literative values (Wells et. al, 1972; Richardson and Merva, 1976; Frissel, 1978).

These calculations are shown in Tables 9-1, 9-2, and 9-3 for Grist, Carding, and Stearns Millponds, respectively. The results of the phosphorus-loading calculations show that most of the load to each pond comes from upstream sources. The total load entering Grist Millpond is the highest of the three ponds, followed by Carding and then Stearns Millponds. Therefore, each pond in the system is serving as a "sink" for upstream phosphorus. Some of this phosphorus is removed by plants in the pond (macrophytes and algae) and a portion is directly deposited to the pond sediments. All three ponds have very high phosphorus loading rates. For example, the annual phosphorus load entering Grist Millpond was calculated to be 3820 kilograms. An annual load of approximately 200 kilograms of phosphorus would be a more appropriate load.

In terms of surface areal-weighted loading rates, Grist Millpond's loading rate is twice that of either Carding or Stearns Millponds. The areal-loading rates are used in spatial models of lake water quality. One such model, which is extensively used in Clean Lakes programs throughout the country, is Vollenweider's Model.

A version of this model (1974) is as follows:

$$Cp = Lp\ tw/^{2}\ (1 + tw^{0.5})$$

where:

C_p = mean phosphorus concentration (mg/L)

L_p = phosphorus loading ($g/m^2/yr$)

t_w = hydraulic residence time (yr)

z = mean pond depth (m)

and where the key assumptions are:

- Phosphorus is the limiting nutrient.
- The average sedimentation rate is 10 to 20 m/yr.
- The pond is completely mixed.
- The pond is at a hydraulic steady state (inflow equals outflow).

The model is used to predict areal loadings, maximum permissible loadings and excessive levels of loadings of phosphorus. In practice, the model is solved for the pond in question and the results are compared to plots of areal loading as a function of the mean pond depth divided by the hydraulic residence time. These plots are available in the literature (Vollenweider, 1975; Rast and Lee, 1978).

Table 9-4 presents a comparison of areal loading from empirically derived modeling, the loading predictions from Vollenweider's model and the maximum permissible and excessive loading rates derived from past studies. The results of the empirical and Vollenweider modeling efforts for the ponds reveal many similarities. Both methods show that all four ponds are hypereutrophic, having phosphorus loading rates at least an order of magnitude higher than levels which are considered to be excessive.

Pollution from on-site wastewater disposal systems (septic systems) was not incorporated into the phosphorus budget. The potential impact from the five systems within 300 feet of the pond shores is negligible. There were no reports of septic system problems from our wastewater disposal questionnaire survey (Chapter VII) or reports to the Sudbury Board of Health.

TABLE 9-1
GRIST MILLPOND
EXISTING PHOSPHORUS LOADING RATES

ιam Sources:

ι21 MG/yr x 0.64 mg/L = 3680 kg/yr

ϝ:

ι3 MG/yr x 0.09 mg/L = 130 kg/yr

ιitation:

ι acres x 1.00 kg/ha/yr = 10 kg/yr

Loading:

ι80 + 130 + 10 = 3820 kg/yr

·Weighted Loading:

$\frac{\text{320 kg/yr}}{\text{24 acres}}$ = 39 $gm/m^2/yr$

TABLE 9-3
STEARNS MILLPOND
EXISTING PHOSPHORUS LOADING RATES

Upstream Sources:

1028 MG/yr x 0.41 mg/L - 1600 kg/yr

Runoff:

1156 MG/yr x 0.08 mg/L = 350 kg/yr

Precipitation:

24 acres x 1.00 kg/ha/yr = 10 kg/yr

Total Loading:

1600 + 350 + 10 = 1960 kg/yr

Areal-Weighted Loading:

$$\frac{1960\ \text{kg/yr}}{24\ \text{acres}} = 20\ \text{gm/m}^2\text{/yr}$$

TABLE 9-4
PHOSPHORUS LOADING RESULTS

Pond	Predicted L^1	Predicted L^2	Permissible L^3	Excessive L^4
Hager Pond[5]	N/A	31.4	0.5	1.0
Grist Millpond	39	30.7	1.0	2.0
Carding Millpond	18	18.9	0.7	1.5
Stearns Millpond	20	23.9	1.1	2.5

[1]Empirically Derived Value

[2]Vollenweider Model Calculated Value

[3]Rast and Lee, 1978

[4]Rast and Lee, 1978

[5]Based on MEWWTP DATA:

$$\frac{\text{average daily Cp} \times \text{average daily flow} \times 365 \text{ days}}{\text{Hager Pond surface area}}$$

A. INTRODUCTION

The analysis of the data shows that the existing condition of the Hop Brook ponds system is directly related to external nutrient and internal nutrient/sediment sources. Nutrient loading associated with the Marlborough Easterly Wastewater Treatment Plant is the major source of elevated nutrient levels within the ponds system. Because of these elevated nutrient loadings there is excessive nutrient availability in the ponds. The long-term effect of this availability is the accelerated sedimentation of the ponds and the loss of their use for recreation and flood attenuation. Furthermore, the ponds have a reserve of nutrients within the sediment from which rooted aquatic plants receive a majority of their phosphorus.

Continued sedimentation and associated aquatic macrophyte growth has resulted in the degradation of the aesthetic quality of the ponds. Odor and visual complaints from neighbors of the ponds, along with complaints from visitor's to the historically significant Wayside Inn, have caused active participation by Sudbury's citizenry. Sudbury's Board of Health, other Town Boards, and the Hop Brook Protection Association through public meetings and active participation in this study show both a concern for the problem and a willingness to support restoration of the ponds.

The goal of this study is to present both a restoration and management solution to restore the aesthetic qualities of the ponds and thereafter preserve their water quality. To approach this goal, reductions in nutrient loadings into the Hop Brook ponds system is the first task. Next, in-pond restoration techniques should be implemented. Last, pond and watershed management techniques must be implemented to continue the renewed aesthetic quality of the ponds and their water quality preservation. Without these measures, Grist, Carding, and Stearns Millponds will quickly change from open water systems to swamps.

B. REDUCTION IN NUTRIENT LOADINGS INTO THE PONDS SYSTEM

As shown earlier in the report the major contributor of phosphorous into the Hop Brook ponds system is the Marlborough Easterly Wastewater

Treatment Plant. Since the effluent from this facility contributes up to 90 percent of the flow coming into the ponds system, the characteristics of its flow have a great effect on the quality of the pond's water. The USEPA has stated (1976) that in order to prevent cultural eutrophication of ponds, phosphorous levels must be below 0.05 milligrams per liter (mg/L). Reaching this level may not be practicable; however, phosphorous levels must be reduced to the minimum practicable levels in order to restore and maintain the ponds aesthetic qualities.

In order to accomplish the goal, the following alternatives should be evaluated by the City of Marlborough:

1. Increase treatment efficiency. Marlborough's current discharge permit (NPDES) issued by the EPA and DEQE requires that the average weekly discharge from the plant maintain a total phosphorous level of 1.0 mg/L. This discharge limit must be met on a yearly basis. This 1.0 mg/L limit is an industry standard for advanced wastewater treatment plants. Very few conventional wastewater treatment facilities have limits which are more strict. However, other methods of treatment should be studied to see if a more stringent limits can be consistently met.
2. Relocate the discharge point of the treatment facility. MEWWTP currently discharges into a small stream which flows into Hager Pond. Hager Pond, in turn, serves as the headwaters for Sudbury's Hop Brook. By diverting the discharge to another location, the source of the nutrient addition would be eliminated. Since during dry months 90 percent of the flow to the Sudbury ponds is MEWWTP effluent, the effect of reducing the flow to the ponds by such a significant amount must be evaluated.
3. Limit the flow into MEWWTP. By limiting the number of connections, and therefore the amount of flow into the Marlborough Easterly Wastewater Treatment Plant, the total amount of phosphorous entering the ponds system will be reduced. At the present time, Marlborough is allowed to discharge 320,000 pounds of phosphorous per year into the ponds system. With growth to full capacity of the plant (i.e., 5.5 mgd) the levels of phosphorous into the plant could be increased by 57 percent.
4. Use Hager Pond for treatment. As previously stated, all flow enters Hager Pond prior to entering Sudbury's ponds system. By using Hager

Pond, or another man-made detention area, as a treatment system, the phosphorous levels leaving Hager Pond and entering the Sudbury ponds, could be reduced. This could be accomplished by aerating Hager Pond, allowing rapid macrophyte growth, and harvesting the plants for off-site disposal. The aesthetic concerns of using such an alternative at Hager Pond should be further evaluated.

By using one or all of these, or other alternatives, the phosphorous levels entering the Sudbury ponds would be reduced. The levels to which phosphorous must be reduced, the detailed evaluation of the available alternatives, and their side effects are beyond the scope of this report.

On August 15, 1988, DEQE wrote the EPA concerning the NPDES permit for Marlborough's Easterly Wastewater Treatment Facility. In that letter, DEQE recommended that when the flow at the Easterly Plant reached 70 percent of design capacity, the City should be required to submit a schedule to the DEQE and EPA for upgrading the facility. This would be required so that the treatment levels attained will be consistent with approved water quality management plans. Since the MEWWTP is currently operating at 65 percent of its capacity, it is our recommendation that the preliminary steps needed for this effort be initiated as soon as practicable.

C. IN-POND RESTORATION TECHNIQUES

1. Dredging

The high productivity of macrophytes and algae in the ponds is, in part, due to the shallow depths of the ponds, sediment resuspension and nutrient recycling. The physical removal of sediment and associated rooted plants from the ponds could result in an immediate improvement in the ponds' usage, since sediment and weed density is a major restraint to use. To restore a portion of each pond, the volumes of sediments which would need to be removed would be as follows:

o	Grist Millpond	28,900 cubic yards
o	Carding Millpond	72,800 cubic yards
o	Stearns Millpond	37,500 cubic yards
	Total	139,200 cubic yards

The primary drawback to the removal of such large volumes of sediment is the availability of a disposal site in the area. Ideally, a disposal site close to the ponds would be advantageous because the further the distance from the disposal site from the ponds, the higher the costs. Typical costs for dredging of this type is approximately $15 per cubic yard making the costs for the three ponds:

o	Grist Millpond	$ 432,800
o	Carding Millpond	1,091,400
o	Stearns Millpond	562,500
	Total	$2,086,700

Besides the cost and proper disposal of spoils issues, dredging can also involve adverse environmental impacts. Short-term water quality impacts in the water body being dredged are common. Sediment suspension in the water column, removal of beneficial benthic organisms, reduction of fish populations and downstream sedimentation are all possible impacts of dredging.

The implementation of a dredging program would result in an improved water body with increased depth and decreased macrophyte and algal densities.

2. Chemical Treatment

The use of various chemicals for the control of aquatic plants, algae, and nutrients is commonly practiced. Chemical treatment is considered a maintenance function with a short-term benefit of "improved" water quality. However, chemical treatment does not eliminate the problem, but it temporarily eliminates the symptoms. Also, chemical treatment of any kind is a regulated activity under the jurisdiction of both local and state agencies due to its potentially adverse environmental impacts. Because of the potential for environmental impacts with chemical treatment, and the short-term benefit of their use, chemical treatment is not recommended for the Sudbury ponds.

D. POND MANAGEMENT TECHNIQUES

1. Water-Level Manipulation

Water-level controls are available at Grist and Carding Millponds. These structures have "stop logs" that can be used to regulate the water level at the pond. Stearns Millpond does not have adequate water-level controls and the dam at the end of the pond would require modification or replacement to improve the water-level controls.

By lowering the water levels of the ponds during the winter months, freezing and desiccation of the weeds will reduce their abundance in the spring and the summer. A secondary benefit of the water-level drawdown would be to allow for maintenance improvements to the shoreline area. Drawdown should commence in mid to late November (prior to ice formation) and refill should commence after the spring thaw.

As with most restoration techniques, negative impacts from drawdown exist. Winter recreational use of the ponds would be curtailed. Any private wells in the area should be surveyed to ascertain the degree of impact. Fish kills and odor would also be of concern, but could be minimized with a controlled drawdown.

2. WATERSHED MANAGEMENT

Although the nutrient loading impact from within the ponds' watershed's is small in comparison to the impact of the MEWWTP and the sediment in the ponds, regulation of the ponds' watersheds should be considered. Nutrients that enter the ponds via runoff and groundwater provide a source of nutrients for the growth of aquatic vegetation. A management program to reduce the phosphorus levels from these sources can be implemented with minimal cost and manpower effort. The success of such a program will depend on the willingness of the residents to participate. However, cooperation is possible if public education is provided to the residents.

The components of a watershed management plan are:

a. Septic Tank Maintenance/Septage Disposal Program - Home Owners should be educated, especially those in close proximity to the pond and its tributaries, of the need for an annual cleaning and inspection of septic tanks.
b. Land-Use Regulation - The watershed surrounding the ponds is currently made up of conservation land and lightly-populated residential areas. Future development in the area should be closely monitored to ensure that nutrient loads from septic tanks, lawn fertilizers, and drainage discharges are controlled. Existing Town

bylaws and procedures should be reviewed to see if they adequately address these items.

c. Fertilizer Substitution Program - Fertilizing of lakeshore lawns, in turn, fertilizes the ponds. While the complete abolition of common fertilizers is not practicable, minimization of fertilizer applications or the use of special fertilizers designed specifically for lawns in close proximity to water bodies is encouraged.

d. Erosion Control Program - The Town should continue to strictly enforce the requirements of the Wetlands Protection Act as it relates to erosion control. Sediments entering the ponds through tributaries or wetlands will accelerate the degradation of the ponds.

e. Maintenance Practices - The three Sudbury ponds are controlled by outlet structures. Keeping these structures free of debris and operable will provide short-term relief from some of the aesthetic concerns which befall the ponds during the summer months. Likewise, street sweeping and an aggressive stormwater catch basin maintenance program will help to minimize nutrient and sediment inputs to the ponds.

   While it is difficult to quantatively assess nutrient loading reductions due to watershed maintenance programs, it is our belief that such a program will help extend the life of the ponds.

3. AQUATIC MACROPHYTE HARVESTING

Mechanical aquatic macrophyte control measures such as raking or harvesting can be very effective in reducing the amount of rooted vegetation in a pond. Harvesting methods can be as simple as hand weeding or as mechanized as motorized boat/barge harvesters. These methods are not effective at removing floating species such as Wolfia or Lemma or at removing phytoplankton. The different mechanical means have varying success at Hydrodictyon or filamentous algae removal.

Surrounding productive macrophyte beds and other shallow areas with booms and turbidity curtains can help contain the spreading of floating macrophytes to adjacent areas. Occasional seining of the epilimnion can help reduce floating macrophytes and algal mats. Sheeting of the littoral-zone sediments in localized areas with plastic sheeting or geotextiles can curtail growth in those areas. The sheeting can be moved around ponds' littoral zones during the growing season.

In general, there are a variety of in-pond mechanical controls that are effective in controlling algae and macrophytes. These mechanical controls can be almost as effective as dredging, usually at a significantly lower cost. These types of controls may also be more environmentally acceptable than dredging operations. Harvesting and other mechanical controls, should, therefore, be considered along with dredging, nutrient reductions, and watershed management.

XI. RECOMMENDATIONS

In the preceding chapter, restoration alternatives for the ponds were discussed and evaluated. As a result of the evaluation, the following recommendations are made:

1. The City of Marlborough should initiate a study to evaluate the various methods available to reduce the phosphorous levels from MEWWTP to as close to 0.05 mg/L as possible, prior to discharge into the Hop Brook Ponds System.
2. Dredging of Grist, Carding, and Stearns Millponds should be considered. The cost of dredging a portion of each pond is estimated to be $2.1 million. Because of the cost and potential for environmental impact, a phased approach to the dredging operations should be considered.
3. If dredging is considered to be as economically infeasible, mechanical control measures should be evaluated. These measures may prove to be as effective as dredging for the control of rooted aquatic macrophytes.
4. Initiate the pond management techniques outlined in the previous chapter, including water-level manipulation of Grist and Carding Millponds. Combined with mechanical removal of vegetation, water-level manipulation is an effective means of controlling aquatic plants. Implementation of a watershed management plan for the Hop Brook Watershed, and the maintenance of outlet control structures on a regular basis during the summer months of the year should be undertaken.

   By implementing the measures above, and cooperation between the City of Marlborough and the Town of Sudbury, the goal of cleanup can be realized.

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APPENDIX A
HOP BROOK POND SYSTEM QUESTIONNAIRE

THE QUESTIONNAIRE AND COMPILATION OF RESULTS

The following two pages are a reproduction of the questionnaire delivered to area residents. A compilation of the responses to the questionnaire and specific comments made by the residents follows.

HOP BROOK POND SYSTEM STUDY
CONDUCTED BY WHITMAN & HOWARD, INC.
FOR THE
TOWN OF SUDBURY

WASTEWATER DISPOSAL QUESTIONNAIRE
APRIL, 1988

As part of the long-term environmental management of Hop Brook, the Sudbury Board of Health has appropriated funds for the study of the Hop Brook Pond System from the Marlborough Easterly Wastewater Treatment Facility to the outlet of Stearns Millpond. The study is being conducted by Whitman & Howard, Inc. of Wellesley under the direction of the Sudbury Board of Health.

The main purpose of this study is to investigate the causes for the accelerated aging process of the Ponds and to make appropriate recommendations for inhibiting such cultural eutrophication. The gradual filling in of a lake -- from pond, to marsh, to swamp, to dry land -- that takes place over hundreds or even thousands of years, is a natural process called eutrophication. Artificial, or cultural eutrophication, occurs due to the increasing influx of nutrients from human activities. One of the most visible and disagreeable aspects of such nutrient enhancement is the rapid proliferation of weeds and algae.

The diagnostic portion of the study, now in progress, involves a detailed description of the Pond and its watershed along with a year-long intensive water quality testing program. This information is used to estimate the level of nutrients in the Pond System and how they affect the eutrophication process.

To this end, it is crucial to determine the potential impact on the nutrient balance of the Ponds from such factors as wastewater disposal, road runoff, and general land use. The following questionnaire is intended to obtain some of this information and will be used to develop a representative model of the present-day condition of the Hop Brook Pond System. The model will then be used for planning appropriate alternatives for preservation and/or restoration of the Pond.

This questionnaire is being circulated to residents within close proximity of the Pond and/or the brook. The information will only be used to arrive at a composite model for the express purpose of preserving and protecting one of Sudbury's greatest environmental assets, Hop Brook.

All information will be kept confidential and will only be used anonymously.

We urge your timely cooperation.

RESPONSES TO THE
HOP BROOK POND SYSTEM STUDY
WASTEWATER DISPOSAL QUESTIONNAIRE

1. If your property is used for dwelling:

   Number of Family Units in Dwelling 1
   Total Number of People 3.178

2. What kind of wastewater disposal system do you have?

   Cesspool ____, Septic Tank 45 (100%), Town Sewerage ____,
   Unknown ____.

3. To which body of water is your dwelling nearest?

   Grist Millpond 2/44%, Stearns Millpond 23/51%,
   Carding Millpond 3/67%, Hop Brook 17/37.8%.

4. How far is/are your system(s) from the shoreline of the Pond or tributary to the Pond?

   1/13.3% 10-50 ft, 5/11% 50-100 ft, 6/13% 100-200 ft, 18/40% 200-300 ft, 15/33% Over 300 ft

5. When was the last maintenance done on your system? 3.5 yrs ago (40 answered)
   Please indicate regularity of maintenance needs. 3.5 (29 answered)

6. Type of maintenance performed? Pumping 36, New Leach Bed 6, Unclog Leach Lines ___, Chemical Treatments 1, Bacterial Aids ___, New Septic Tank 1.

7. Do you have water-saving devices on any of the following?
   Shower Heads 33, Bath Tub Spigots 1, Toilets 5.

8. Do you have any problems with your wastewater disposal system?
   Yes 3 No 42.

9. If the answer to question 8 is "Yes" please check the items below that best describe your problem. Check as many blocks as are appropriate.

	Spring	Summer	Fall	Winter
Slow Drainage from Sinks and Tubs				
Toilet Backups				
Odors Outside of Residence		1	1	1
Standing Water on Property	1			

10. Does any part of your disposal system (or any other system you may know of) have any direct connections or discharges to the ponds, streams, or to any stormwater pipes?
Location: 37 - No. See comments on attached sheet.

11. If storm drains are located by your property, please give approximate location and approximate cleaning schedule by Town trucks. See attached sheet.

12. Do you have an aquatic weed problem in the immediate area of your lakeshore home? Yes 10 (22%) No 17 (38%). If Yes, how do you deal with it? NA = 18 (40%). See attached sheet for comments.

13. Do you use any of the following agricultural products?

    Fertilizer; types or brands: See attached sheet.
    Herbicide; types or brands: See attached sheet.
    Pesticide; types or brands: See attached sheet.

14. How far is your well located from the shoreline of the previously indicated pond or Hop Brook?

    10-50 ft.___, 50-100 ft. 3/21.4%, 100-200 ft. 1/2.2%, 200-300 ft. ___, Over 300 ft. 10/71.4%.

    Total = 14 (31% of total respondents)

COMMENTS MADE ON
HOP BROOK POND SYSTEM STUDY
WASTEWATER DISPOSAL QUESTIONNAIRE

10. Direct Connections or Discharge

- The drain on the street carries water into a pipe which feeds into the pond.

11. Storm Drain Locations

- Directly fronting on property. They have to call the Town to clean the drain.
- One drain across the street (30 feet away).
- At edge of property next to the road. Cleaned once or twice a year.
- Corner Barton Drive and Winter Street. No cleaning done to my knowledge.
- The drain is located between us and our neighbors to the east. Cleaned by the Town once or twice a year.
- Drain runs to property from at least three street drains. Directly into Stearns Millpond.
- Two times in ten years.
- Cleaning schedule unknown.
- Storm drain at edge of property. Don't know cleaning schedule.
- Street side. Yearly.

12. Deal with Aquatic Weeds

- Not well, sometime is just swamp depending on rainfall. Can't control that problem.
- Not only the immediate area but most of the pond.
- We hold our nose and look the other way.
- Curtail canoeing on pond due to weeds and due to green scum on pond during summer months.
- Last two years have been worst in 25 years. Very heavy layer of weeds. Cannot paddle canoe through.
- We watch it envelop the pond and take it over by August - September.