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BARE HILL POND WATER QUALITY AND AQUATIC PLANT EVALUATION 1998

Prepared For:

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INTRODUCTION

This study, as initiated and funded by the Town of Harvard, stands as part of the ongoing investigation of Bare Hill Pond in the Town of Harvard, Massachusetts. Its purpose is essentially twofold. First, this study investigates the current conditions of lake chemistry and aquatic plant growths, and adds to the growing database for the pond. Secondly, a management plan is provided with its core intent to provide options intended to maximize the desired uses of the pond in the most efficient and cost-effective manner.

WATER QUALITY

Sampling Methods

A one-time water quality monitoring effort was conducted at Bare Hill Pond on August 17, 1998. Samples were collected from a variety of locations throughout the lake as well as at two of its tributaries. Figure 1 gives the locations of the sampling sites.

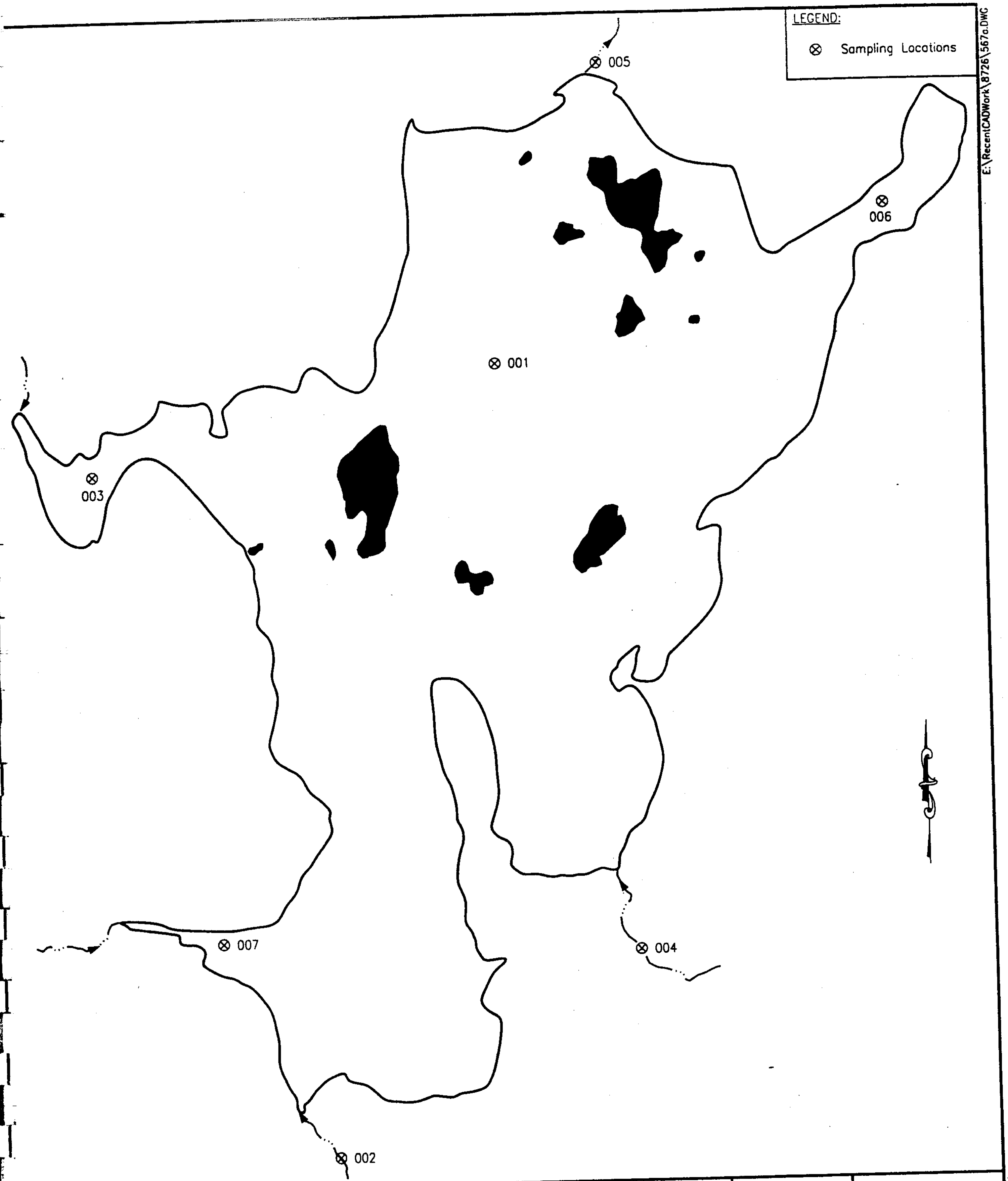
Samples were collected from differing types of areas around the lake including the open water deep-hole, coves, the outlet, and from two tributaries. The open water sample included sample points at the surface, at the thermocline (4.5 meters), and immediately off the lake bottom (6 meters) and were analyzed for the following parameters:

- Total Phosphorus
- Dissolved Phosphorus
- Nitrate
- Ammonium
- Total Kjeldahl Nitrogen
- Chlorophyll a
- Secchi Depth
- Dissolved Oxygen
- Color
- pH
- Alkalinity
- Specific Conductance
- Turbidity
- Iron
- Temperature

This sample point reflects the condition of the open waters of Bare Hill Pond as well as throughout the water column. The outlet was also sampled and analyzed for the same parameters except for iron.

Three of the larger coves of the lakes were sampled as a means of determining the impacts of their representative sub-watersheds. Each of the coves sampled is fed by a stream that drains a sub-basin of the total watershed. Samples from the coves were analyzed for the following parameters:

- Total Phosphorus
- Dissolved Phosphorus
- Nitrate
- Ammonium
- Total Kjeldahl Nitrogen
- Iron
- Chlorophyll a
- Color
- pH
- Alkalinity
- Specific Conductance
- Turbidity
- Fecal Coliform



Client: **Town of Harvard**

Water Monitoring Sites

Bare Hill Pond
Harvard, Massachusetts

November 1998 | Job No. 8726-567

Figure 1

1" = 800'

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Two tributaries, Bower's Brook and Thurston's Brook, were sampled and analyzed for the following parameters:

- Total Phosphorus
- Dissolved Phosphorus
- Nitrate
- Ammonium
- Total Kjeldahl Nitrogen
- Iron
- Detergents (MBAS)
- Color
- pH
- Alkalinity
- Specific Conductance
- Turbidity
- Fecal Coliform

Sampling Results

The results of the 1998 sampling effort are given in Table 1 with the location of the sampling points given in Figure 1. The table of chemical results is broken down into different areas of the lake sampled, including the in-lake sample point at multiple depths, coves, and selected tributaries.

Dissolved Oxygen

Dissolved oxygen was measured at the deep-hole at intervals to a depth of 6 meters. The thermocline was observed at 4.5 meters depth, above which dissolved oxygen was near the saturation point (Figure 2). Below the thermocline, in the colder hypolimnetic waters, dissolved oxygen levels quickly dropped to near zero in the last meter. This is a common occurrence in stratified lakes during the summer months as bacterial decomposition consumes oxygen near the sediment/water interface and replenishment from upper waters is negligible. This condition has been regularly recorded in the deeper waters of Bare Hill Pond during some portion of the summer months in past years.

Plant Nutrients

The primary plant nutrients, phosphorus and to a lesser degree nitrogen compounds, are major contributors to algal productivity in surface waters. When concentrations of these are elevated, the potential for algal blooms rises. However, there are other factors involved that affect algal production independently of nitrogen and phosphorus. These include light, temperature, herbivory and micronutrient availability among others. The availability of phosphorus and nitrogen is also important, as not all forms are equally useable by algae.

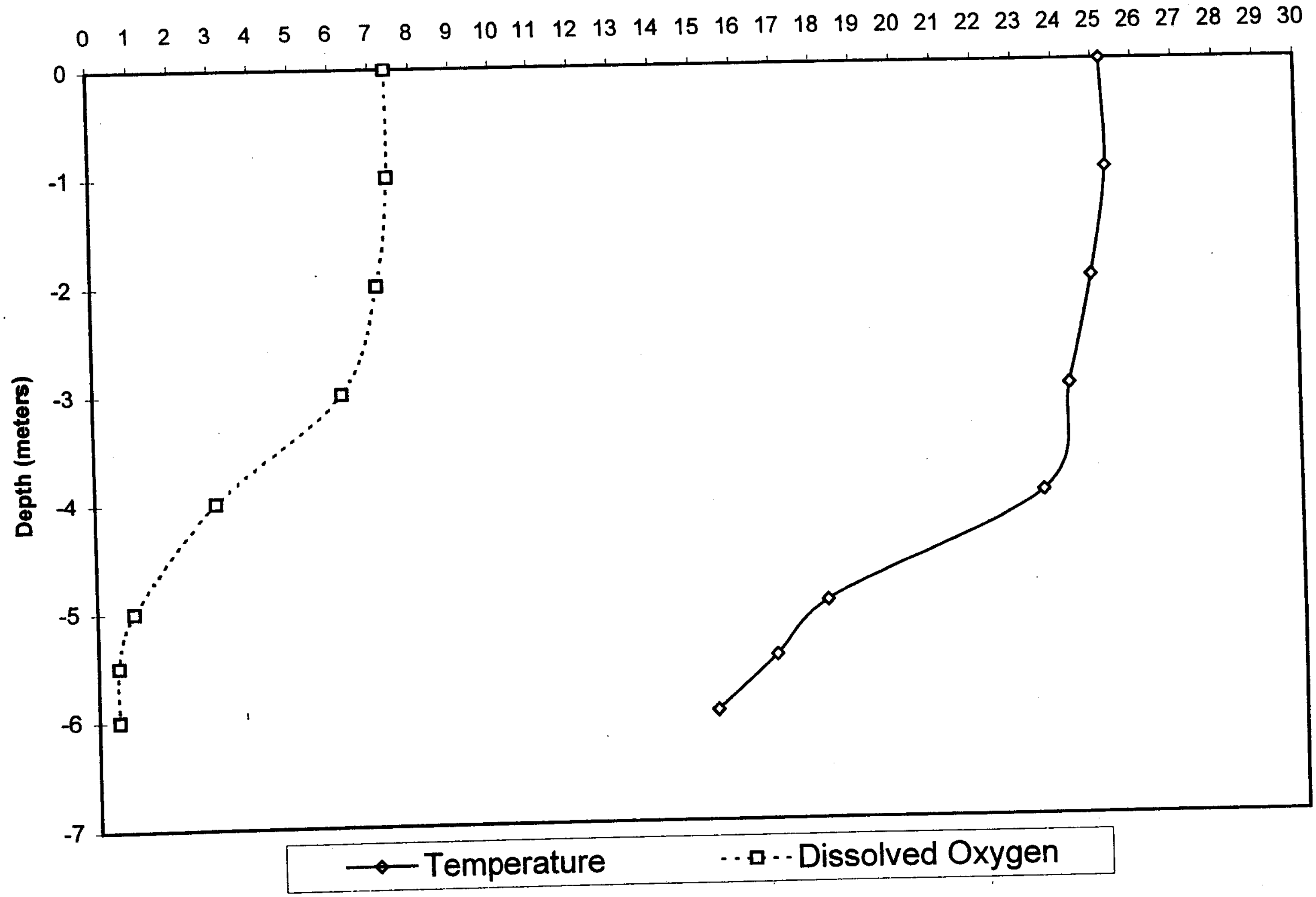
Nutrients present in the open waters of Bare Hill Pond appear to be somewhat elevated from ideal conditions and appear to be able to support substantial algal biomass in the pond. Surface waters exhibited total phosphorus concentrations from 0.04 to 0.05 mg P/L while the hypolimnetic waters provided a concentration of 0.10 mg P/L. This is a typical situation in oxygen depleted waters whereby phosphorus is released from sediments under nearly anaerobic conditions. Levels of dissolved phosphorus, or essentially the "available" phosphorus for plant uptake, were slightly less than the total fraction.

Table 1. Bare Hill Pond - Water Chemistry Data, August 17, 1998.

Sample Site	Depth (meters)	Total Phosphorus (mg P/L)	Dissolved Phosphorus (mg P/L)	Nitrate (mg N/L)	Ammonium (mg N/L)	TKN (mg N/L)	Chlorophyll a (ug/L)	Fecal Coliform (#/100 mls)	M.B.A.S. (mg/L)	Iron (mg/L)	Color (Pt. Unit)	pH (S.U.)	Total Alkalinity (mg/L)	Specific Cond. (μmhos)	Turbidity (NTU)	Secchi (feet)
In-lake Deep Hole																
BHP-001a	surface	0.05	0.03	0.14	0.02	0.9	2.1			0.12	45	6.8	9	117.2	2.55	6.5
BHP-001b	4.5	0.04	0.04	0.04	0.04	1.0	43.3			0.24	50	6.0	12	118.0	1.83	
BHP-001c	6	0.10	0.04	0.34	0.39	1.8				2.2	200	6.4	26	140.9	9.49	
In-Lake Coves																
BHP-003	surface	0.19	0.04	0.02	< 0.01	2.4		30			70	5.8	10	107.7	1.42	
BHP-006	surface	0.04	0.02	0.01	< 0.01	0.6	19.8	< 10			40	6.8	10	119.7	1.77	
BHP-007	surface	0.08	0.03	0.01	< 0.01	0.93	5.3	< 10			60	5.5	7	108.8	1.91	
Tributaries																
BHP-002	surface	0.07	0.04	0.07	0.01	0.7		410	< 0.1		80	6.0	7	143.3	2.13	
BHP-004	surface	0.05	0.03	0.12	0.03	0.35		700	< 0.1		80	6.0	5	215.6	18.2	
Outlet																
BHP-005	surface	0.04	0.02	0.03	0.03	0.56					40	6.5	10	118.1	1.57	

Sample Sites given in Figure 1.

Figure 2. Bare Hill Pond - August 17, 1998



Total phosphorus concentrations in the coves were somewhat higher than in the open waters, ranging 0.04-0.19 mg P/L, while the dissolved fraction was comparable to that of the open waters. This is due mainly to the density of plants in the coves and associated particulate matter present in the water. Samples collected in the coves were observed to contain suspended organic matter which surely increased the total phosphorus values. The actual dissolved phosphorus fraction was similar to the open waters and ranged from 0.02-0.04 mg P/L.

The two tributaries sampled, Bower's and Thurston's Brooks, revealed phosphorus levels comparable to in-lake levels with the same relative amount of dissolved phosphorus. These levels tend to fluctuate more readily than in-lake concentrations because of the significant phosphorus loads often associated with stormwater inputs. These samples were collected at the very start of a precipitation event but reflect dry weather conditions, as runoff conditions had not yet occurred.

Nitrogen compounds are also important components of the potential productivity of surface waters, especially the more readily available nitrate and ammonium, but normally play less of a role than phosphorus. Nitrogen compounds in the open waters and the coves of Bare Hill Pond appear below problematic concentrations. There are, however, slightly elevated levels in the hypolimnetic waters, the result of bacterial decomposition.

In the sampled tributaries, nitrogen compounds were comparable to in-lake concentrations. As with phosphorus, nitrogen loads tend to substantially increase during storm runoff events. This sampling is representative of dry weather conditions, and may therefore underestimate impacts.

Chlorophyll a

In the open waters at the deep-hole, chlorophyll a was measured at the surface and at the theromcline (4.5 meters). The surface water chlorophyll a concentration was 2.1 ug/L, indicative of relatively low algal productivity. In contrast to the surface waters, chlorophyll a at the thermocline was measured at 43.3 ug/L, which indicates a more productive system.

The difference between surface and thermocline results may relate to greater availability of nutrients at greater depth, a common occurrence in many lakes. The sample at the thermocline may also illustrate another common occurrence in stratified lakes whereby algal cells will slowly settle and accumulate on the thermocline. The cooler and denser waters of the hypolimnion prevent further settling of the planktonic algae, and a rather dense community can exist in this region of the water column. Normally these deeper, dense algal growths do not become mixed in the upper waters and therefore do not affect water clarity. The surface water sample represents the mixed condition of the upper waters, the area of the lake where clarity is of the most importance.

The Town Beach Cove (site 006) had a chlorophyll a concentration of 19.8 ug/L and the southwest cove (site 007) had a concentration of 5.3 ug/L. Both of these coves present ideal conditions for algal growth. Because of the dense rooted plant growths, water circulation is minimal and temperatures tend to be warmer and nutrients more plentiful. However, algal production in these coves is probably localized and does not dramatically increase algal concentrations in the surface waters of the open lake. Sometimes rooted plants can interfere with algal growths, but that does not seem to be a major factor in Bare Hill Pond.

Iron

Very small amounts of iron were detected at the surface and at the thermocline, 0.12 and 0.24 mg/L respectively, at the open water sampling site. The hypolimnetic waters had a concentration of 2.2 mg/L. This slight elevation is a result of sediment release of iron during low oxygen conditions. At the time of fall lake overturn, when the bottom waters become re-oxygenated, a portion of this iron is expected to bind with available phosphorus released from the sediments and precipitate. This iron/phosphorus dynamic is common in hypolimnetic waters where iron concentrations are sufficient. This reaction can prevent a large portion of the sediment-released phosphorus from entering the water column and becoming available for algal uptake.

Fecal Coliform

Fecal coliform bacteria were sampled in the 3 cove sites and 2 tributaries in an attempt to identify problematic sources of fecal contamination to the lake. According to Commonwealth of Massachusetts regulations, the concentration of fecal coliform bacteria shall not exceed a log mean of 200 per 100 milliliters of sample for a minimum of 5 samples. Although only a single sample was collected, this concentration is a useful reference point when evaluating data. The actual limit for a single sample is 400 per 100 milliliters of sample.

Fecal coliform bacteria in the 3 coves sampled did not exceed 30 /100mls in any sample. This may indicate that there is no serious concern for chronic fecal contamination in these cove areas, but this measure is for only one point in time. Fecal contamination tends to be more easily identified during precipitation events when contaminants are washed into tributaries and directly into the lake. Results from this sampling indicate little concern in these coves during this study, but more extensive wet weather data could provide additional insights.

The two tributaries sampled revealed fecal concentrations of 410 and 700/100mls. While these concentrations are somewhat elevated, they do not indicate a significant contamination source. Furthermore, their source is not identifiable, and could be from animal wastes within the mostly forested watershed. Concentrations in the range of thousands to tens of thousands would be cause for concern and warrant further upstream investigations as to their source.

pH

The pH values in Bare Hill Pond, including the coves, open water and the outlet, were found all to be slightly acidic and ranged from 5.5 to 6.8. This appears to be the current natural condition for Bare Hill Pond due to the import of acidic organic compounds from surrounding wetlands. The observed range is substantial, with higher values possibly related to photosynthetic activity and lower values linked to acid release from decomposition. The reported and observed condition of in-lake plants and animals indicates that they are properly suited to the slightly acidic environment.

Alkalinity

Alkalinity is a measure of a water body's ability to buffer against acidic inputs without affecting pH. The surface waters of the lake indicate a relatively low buffering capacity with all values less than 12 mg/L as $CaCO_3$. This condition is indicative of the watershed of Bare Hill Pond which offers limited alkalinity from area soils and continually imports acidic compounds to the lake. Much of the naturally occurring alkalinity is consumed buffering these inputs. The alkalinity of the 2 tributaries sampled was 5 and 7 mg/L. Alkalinity measured 26 mg/L in the deeper waters, primarily the result of buffering capacity associated with materials released from the sediments.

Color

The measurement of color in lakes is an aesthetic measure of water's departure from "clear", but can be indicative of other conditions as well. In the surface and tributary waters of Bare Hill Pond the measure of color ranged from 40 to 80 units, with both of the sampled tributaries at 80 units. This indicates less than clear water and is usually the result of "brown" water inputs from surrounding wetlands. Humic substances, mainly organic acids, are derived from watershed wetlands and sometimes in-lake reactions. This is a naturally occurring event and is common in this region of the country.

Specific Conductance

Specific conductance is a measure of dissolved ionic material or "salts" present in the water. Natural ranges of conductivity for surface waters are generally between 50 and 1,000 umhos/cm, with ranges between 100 and 300 umhos/cm most common. All the waters of Bare Hill Pond, including the tributaries sampled, fall well within this range with results between 107 umhos/cm at site 003 to 215 umhos/cm at Thurston's Brook.

Conductivity is sometimes used as a surrogate field measure for chloride when winter road runoff is expected. Undoubtedly, the tributaries that cross under salted roads in the watershed will have substantially greater conductivity measures during winter and spring runoff events. However, no immediate or lasting problems are indicated by the collected conductivity data.

Turbidity

Turbidity is a measure of suspended particles in the water that tend to scatter penetrating light. Waters with a high turbidity will have a low clarity, but the inverse is not always true, as is the case is with Bare Hill Pond. The measurements of turbidity in the surface waters of the lake are not problematic, being no greater than 2.6 NTU (deep-hole surface), but water clarity is affected by the color of the water. The measure of color in water involves dissolved materials which absorb light while turbidity measures particles that scatter the light.

High turbidity in lakes is often the result of high plankton biomass (the result of algal blooms) or from washed-in or disturbed fine sediments. Neither of these appeared to be substantial during the lake sampling. Thurston's Brook recorded a turbidity of 18.2 NTU, but this is quite normal. The energy of the stream is able to hold particles in suspension, but these particles quickly fall out of suspension when the stream enters the lake.

Detergents
The presence of detergents was measured in the 2 tributaries sampled as Methylene Blue Active Substances (MBAS). This test is often conducted to determine if septic systems in the drainage are failing and thus discharging wash water directly to surface waters. The results show that no detergents were detected in the 2 tributaries sampled.

Previous Water Quality Studies and Trends
It is the intention of this summary section to extract valuable pieces of information from the reports listed below and to present them in a manner that links them in a continuous timeline. The major problem associated with a task such as this is the dependability of the data. A thorough analysis of various methodologies to ensure accuracy was not conducted. For the most part, data were assumed to be reliable unless there appeared to be obvious and unexplainable discrepancies, whereupon the data were disregarded.

The selection of parameters to describe is also difficult because no consistent or coordinated collection pattern was used with regard to stations or parameters over the long term. However, over the years enough data have been collected to allow a comparison over time of some of the more important water quality parameters of primary interest in Bare Hill Pond. The parameters of greatest interest are phosphorus compounds, chlorophyll a and secchi depth measurements, all parameters reflecting the state of algal productivity in the lake and associated clarity. Considering the lake's primary usage for recreation and aesthetics, these parameters can identify trends toward eutrophication and use impairment. Data for pH and alkalinity are also included due to their availability and importance in monitoring acidic effects in this poorly buffered lake.

The studies below were used to obtain past monitoring data:

1. *Weed Control in Bare Hill Pond - 1974: Part 1, State of the Pond; Part2, Methods of Weed Control by A.D. Bliss.*
   This report discusses physical, chemical and biological aspects of Bare Hill Pond with data available at the time. Chemical parameters, primarily those associated with eutrophication (plant nutrients) are examined. Aquatic macrophytes are discussed and estimates of cover and density are provided. Part 2 of this report discusses in detail the sources of nutrients in the watershed and the techniques available for the control of both nutrient concentrations and aquatic plant growths.

2. *Water Quality and Aquatic Vegetation Growths in Bare Hill Pond, Harvard, Massachusetts. 1972-1979 by Steven M. Shapiro.*
   This report is in itself a consolidation of reports concerning Bare Hill Pond through 1979. Numerous reports, sampling data, plant treatments, and generally any work or data collection conducted on Bare Hill Pond is summarized from 1959 – 1979. Data summaries are also provided from previous studies, including aquatic plant data and the principal water quality parameters. A brief analysis of several parameters are given without great detail due to the disparity of the data.

3. *Diagnostic Feasibility Study, Bare Hill Pond, Harvard, Massachusetts, 1987, by Whitman and Howard.*
   This report is a comprehensive 1-year study of all aspects of the pond and its surrounding watershed. Large amounts of data were collected, compiled and analyzed concerning watershed conditions, water quality, sediments, and biological parameters. Hydrologic and nutrient budgets were also constructed. A recommended management plan was developed to address nutrient and aquatic plant problems.

4. *Bare Hill Pond deep-hole testing data, 1995-1997, by M. Hastings.*
   These data represent several years worth of "lay monitoring" data consisting primarily of secchi depth transparency, temperature and dissolved oxygen measurements.

In considering the past and current condition of the lake, a consistent sampling location is needed to track parameters. For this current summary, a single mid-lake surface sampling location was used. From the past studies, several sampling points were used to measure water quality in the pond, but most consistently a mid-lake sample point was used. All data presented in this section represent samples collected from this area of the lake.

Perhaps the single most important parameter for tracking water quality of surface waters is phosphorus. Phosphorus is commonly the least abundant nutrient and therefore controls primary productivity. Several of the past reports identify phosphorus as the limiting nutrient controlling algal growths. Primary productivity in lake systems is a measure of plant growth, including both algae and aquatic vascular plants. Since rooted vascular plants, for the most part, obtain phosphorus from the sediments, phosphorus concentrations in the water essentially control the potential for algal growths. If phosphorus concentrations increase over time, the potential for algal blooms also increases. Although there are other factors controlling algal productivity, phosphorus is principally the most controlling, and can be most easily made to control productivity through management.

Fortunately, the importance of phosphorus was not lost on the investigators of the earlier studies, and fairly regular measurements for the open waters of Bare Hill Pond have been conducted over the years. Figure 3 plots the obtained total phosphorus values over time from 1972 through to the data collected for this investigation. While data for this figure covers the span of time of 26 years, it generally is broken down into 3 groupings. Total phosphorus data was intermittently collected throughout the mid- to late-70s, monthly data collected for the D/F study in the mid-80s, and the single data point from this most recent investigation represents the 1990's. Each point on the graph represents an individual sample.

Figure 3 depicts a somewhat marked increase in total phosphorus concentrations at the mid-lake sample point from the early 1970's to the current time. Several investigations in the 1970's indicate that total phosphorus levels averaged around 0.02 mg P/L with only a few samples registering values greater than this. After a span of several years, the Whitman and Howard Diagnostic/Feasibility study's sampling over the course of a year indicated an average total phosphorus value of 0.044 mg P/L with values ranging from 0.03 to 0.06 mg P/L. The single in-lake total phosphorus measurement from 1998 indicates a concentration of 0.05 mg P/L. Although this single measure in 1998 may not be sufficient to establish a current in-lake average, it does indicate a continuing trend of increasing in-lake phosphorus levels.

Given that the range of phosphorus over which conditions markedly deteriorate is 0.01 to 0.10 mg P/L, the accuracy of measurements is very important. We have no way to evaluate data quality in this case, but the general trend is somewhat alarming and warrants verification.

In general discussions of lake productivity measures, one would expect a substantial increase in algal productivity subsequent to the increase in the observed total phosphorus in Bare Hill Pond over the last 26 years. However, there has been no consistent measure of productivity over this span of years (e.g. chlorophyll or algal biomass counts). A surrogate measure of algal productivity often used in lakes is a water clarity measure such as secchi depth. The measure of secchi depth has been recorded fairly regularly over the years and is presented graphically in Figure 4.

As with phosphorus, three general groupings of secchi depth measurements have occurred over the 26 year period. A series of investigations throughout the 1970's, the Whitman and Howard study in the mid-1980's and monitoring data from the mid-1990's provide a useful view of historical lake clarity. Even though secchi depth transparency can be rather variable within a given year, the overall trend in Bare Hill Pond suggests no major increase or decrease in water clarity and that secchi depth transparency has remained consistently around twelve feet over the course of the data record.

Figure 3. Bare Hill Pond - Historical Total Phosphorus

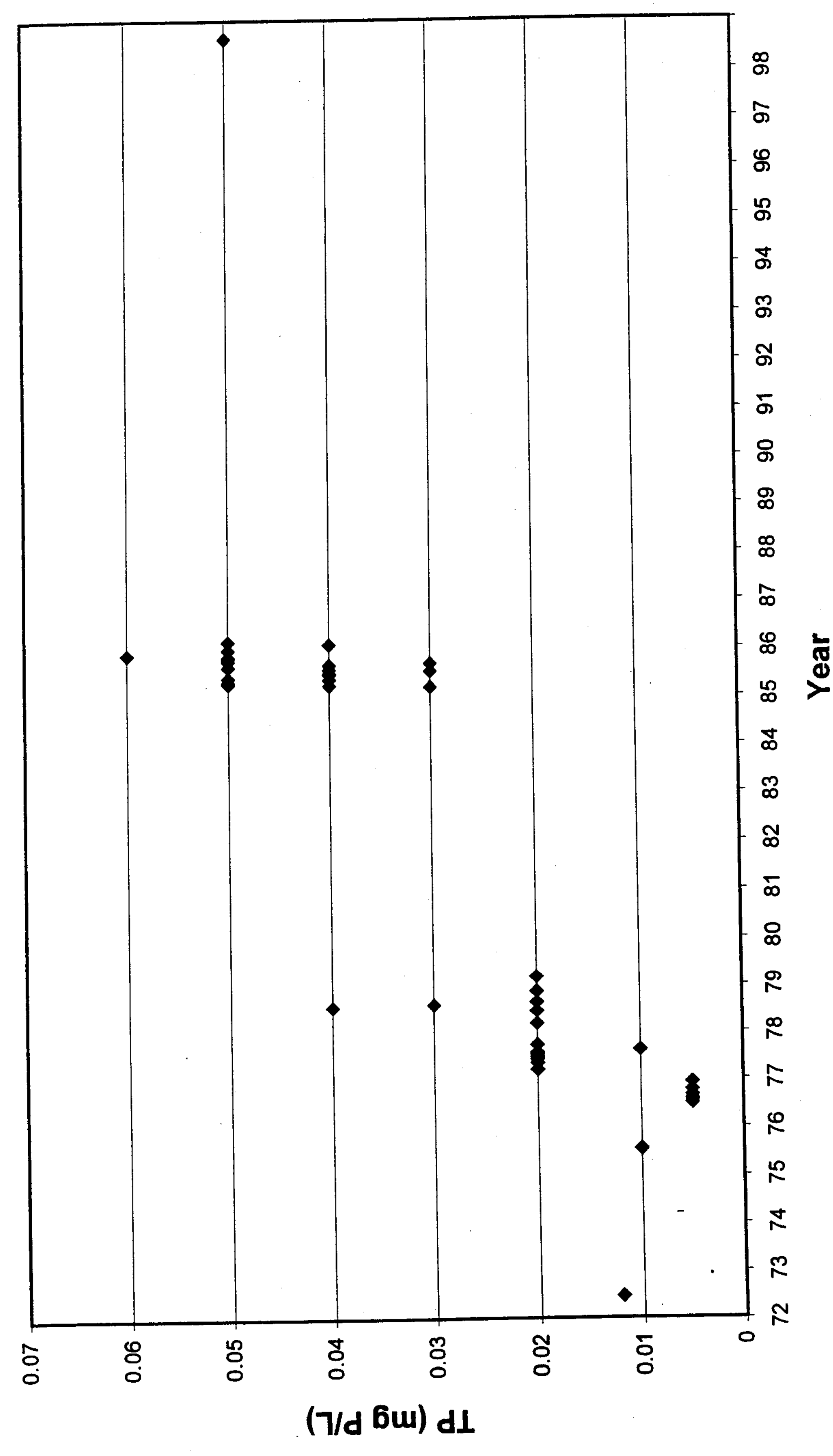
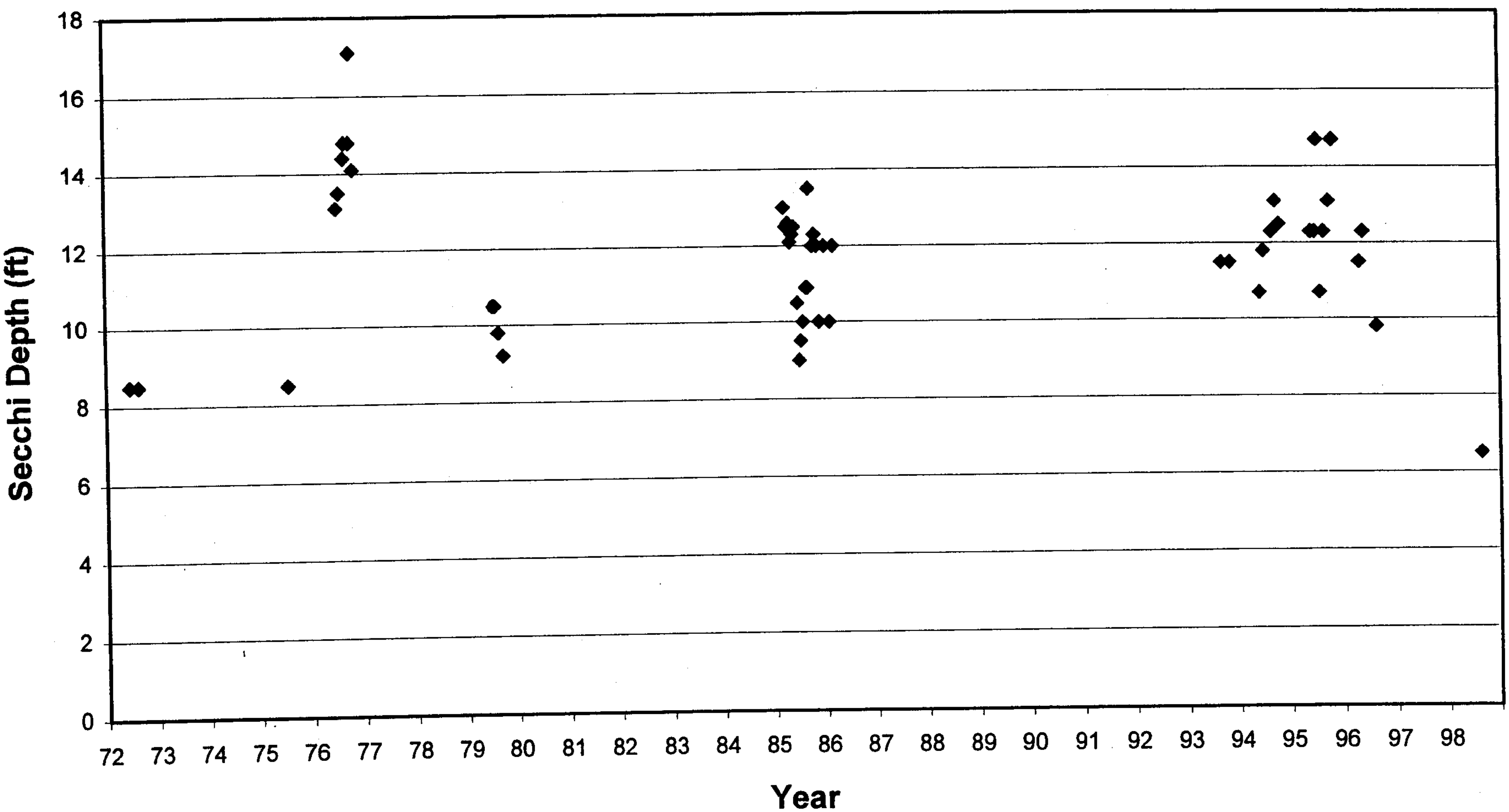


Figure 4. Bare Hill Pond - Historical Secchi Depth Transparency



The apparent steady-state condition of water clarity seems to contradict the increasing trend in total phosphorus. One generally expects decreasing water clarity with increasing phosphorus concentrations. Under most circumstances, this holds true in lakes with moderate productivity to start with, but there can be other factors controlling algal productivity. In the case of Bare Hill Pond, the availability of light may be controlling algal growth. Since the water of the lake is somewhat "brown", light penetration is limited and may not enable the full potential of algal productivity to be expressed. Additionally, the substances which impart this brown color tend to bind phosphorus and make it unavailable to algae. This phosphorus "buffering" capacity appears to be at work in Bare Hill Pond. According to past investigations of the lake, algal blooms are not mentioned as a factor detracting from usage or enjoyment of the lake.

With the exception of the Whitman and Howard Study (1987) and this current investigation, very few measures of chlorophyll a have been made (Figure 5). The data from the mid-1980's show a wide range of values over the course of a single year; however, the majority of the data fall below a concentration of 4 ug/L which reveals a low to moderately productive algal community. The single sample from 1998 surface waters of the open lake reveals a concentration of 2.1 ug/L, indicative of low algal productivity. An attempt to identify any trends over time is not possible with the limited amount of data, but conditions suggest that algal blooms are not normally a problem in Bare Hill Pond.

Limited historical data for alkalinity measurements (Figure 6) reveals somewhat variable, but consistently low values for the open waters of Bare Hill Pond. Values at or near 8 mg/L tend to predominate with no discernable trends apparent. Normal seasonal variations could easily account for the variation observed. Low alkalinity values indicate a poorly buffered lake with regard to countering acidic inputs, but there appears to be no trend in decreasing buffering capacity. The low alkalinity values are natural in this system.

Historical pH measurements (Figure 7) exhibit relatively stable conditions with the open waters being slightly acidic. This is consistent with the alkalinity data in that there is little buffering capacity to overcome the continuous acidic inputs from the watershed. This slightly acidic nature of Bare Hill Pond appears to be the natural condition due to the inputs of naturally occurring acids from the breakdown of organic material.

The implementation of a basic monitoring plan is highly recommended so that consistent data can be collected and added to these plots of historical data. An electronic copy of these and other parameters will be provided to the Bare Hill Pond Management Committee (Microsoft Excel™ format) so that future data can be added and continually tracked and plotted for analysis.

Figure 5. Bare Hill Pond - Historical Chlorophyll a

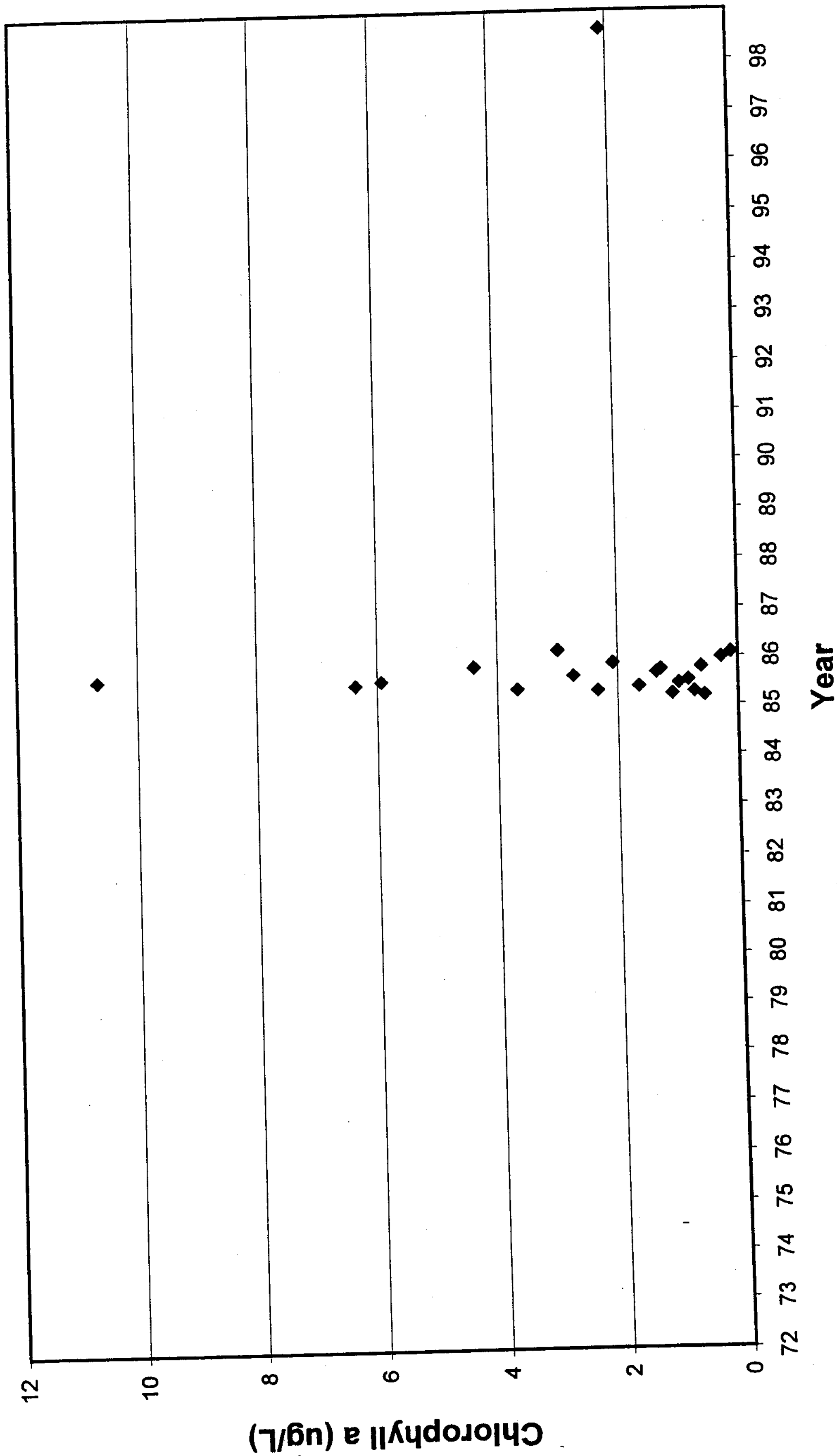


Figure 6. Bare Hill Pond - Historical Alkalinity

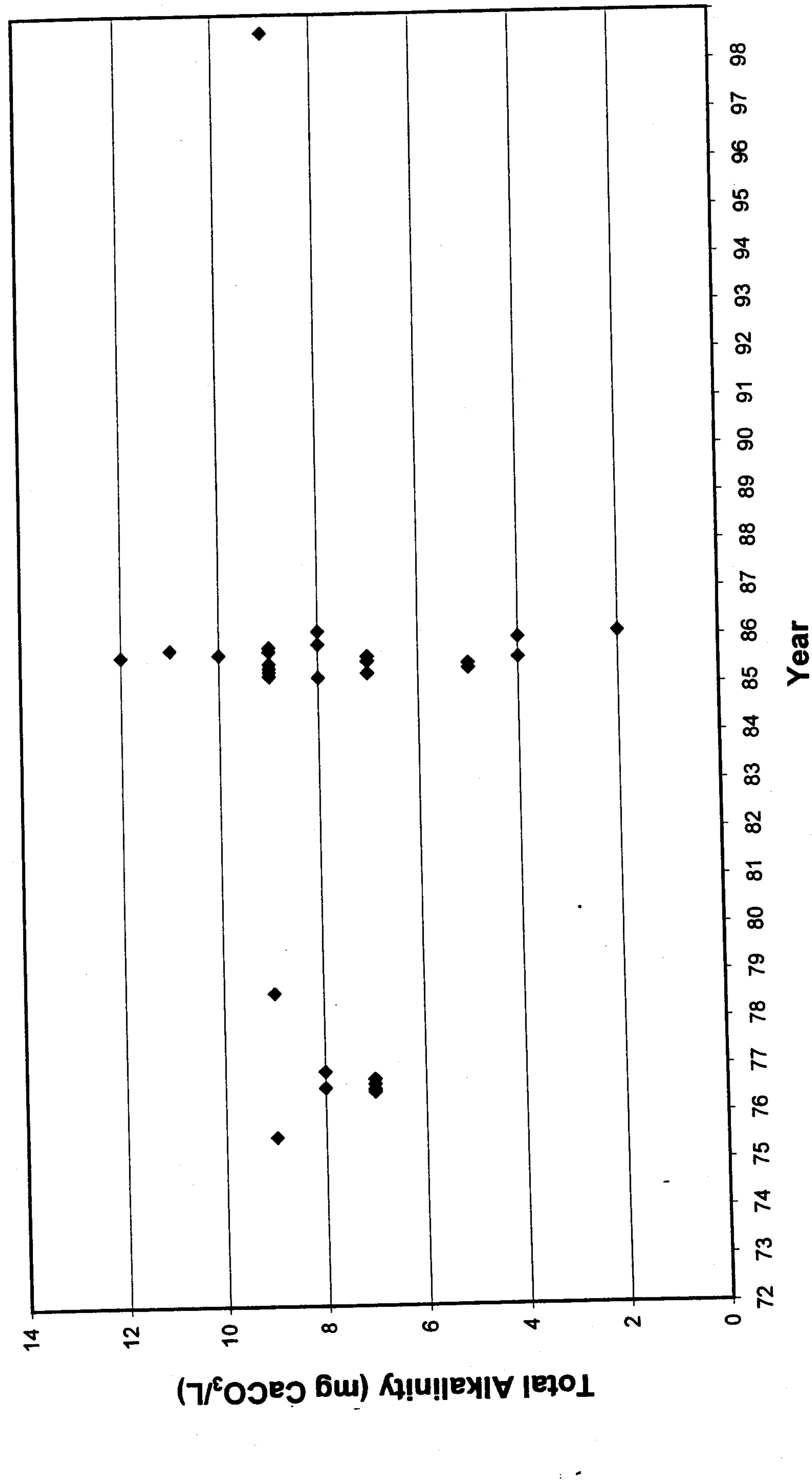
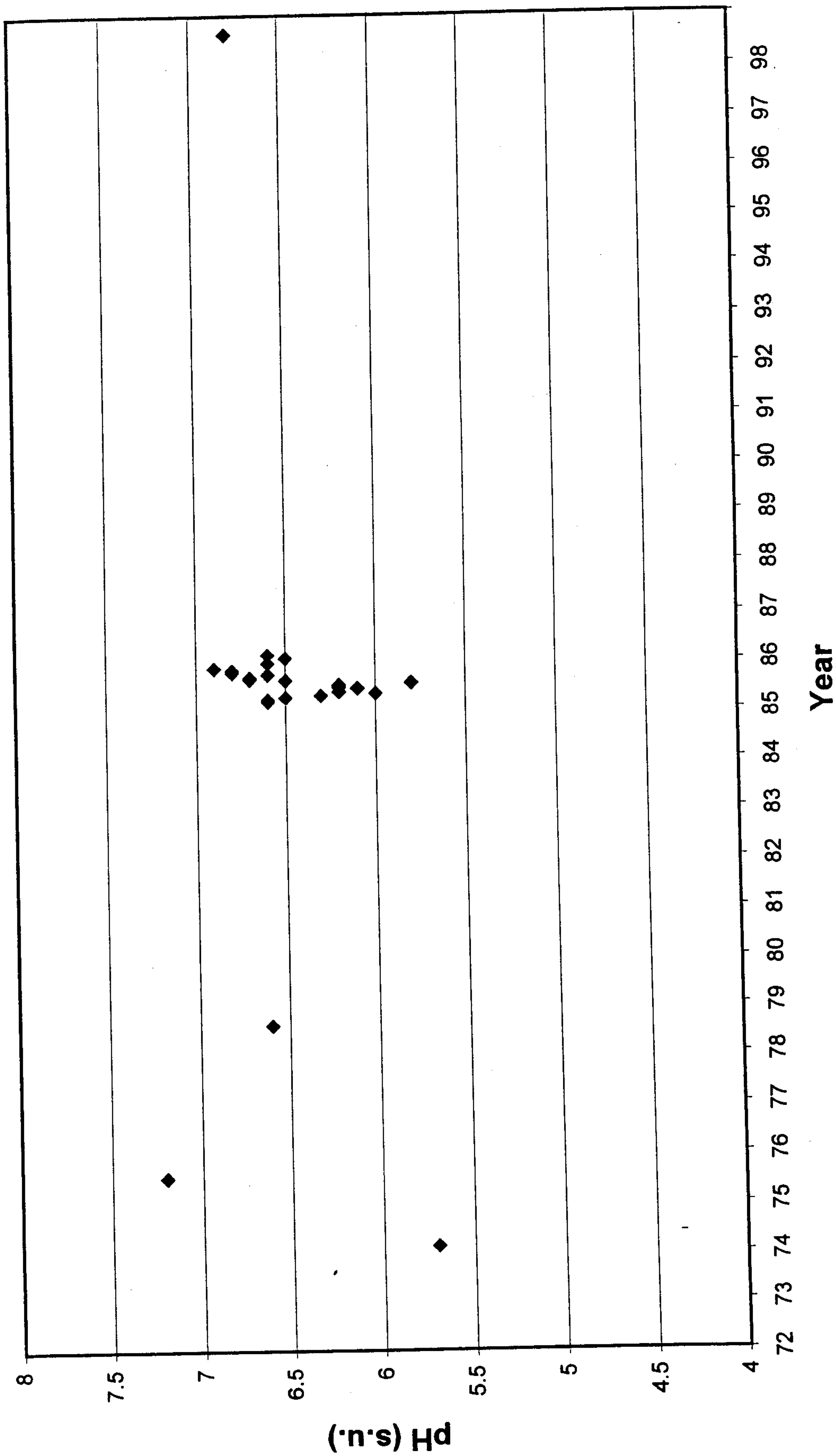


Figure 7. Bare Hill Pond - Historical pH



AQUATIC PLANTS

Plant Mapping Methods

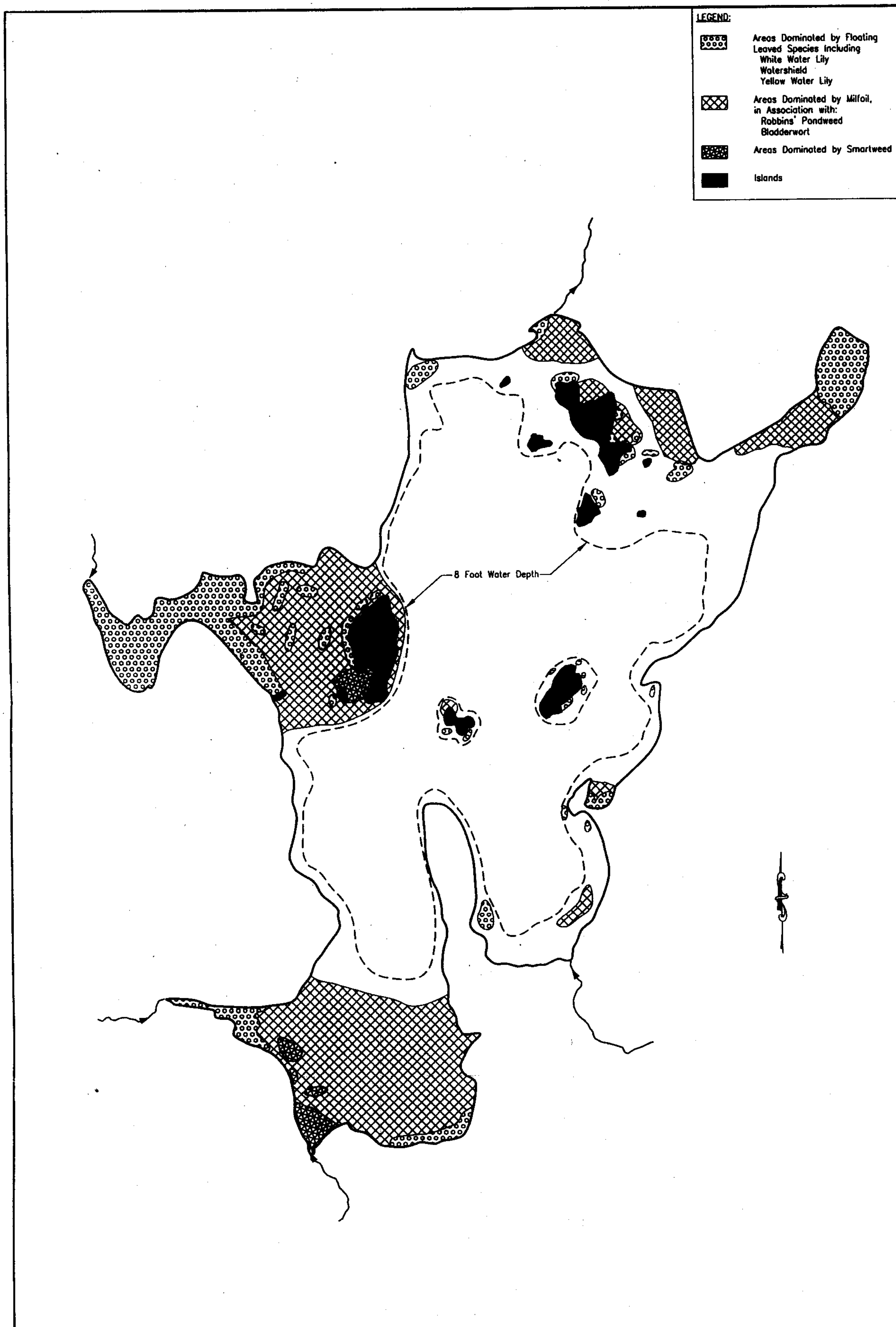
On August 25, 1998 an overall survey was conducted on Bare Hill Pond to determine the areas supporting very dense aquatic plant growths. A shoreline survey was conducted by boat and areas of dense plant growths were mapped. Figure 8 identifies areas across the lake that supported very dense growths of aquatic macrophytes; areas having greater than 75% cover and 75% of the volume of the water column full of plants were noted.

Several of the areas identified had apparently been harvested with the plant harvester, but identification of dense growths was still possible. Figure 8 identifies areas of heavy plant infestations and groups them by similar plant associations and not by single species. For example, certain regions may primarily be infested with variable milfoil *(Myriophyllum heterophyllum)* and Robbins' pondweed (*Potamogeton Robbinsii*), species that make up a vast majority of the cover and biomass in that region. However, other plants of lesser cover ratings may also be present but simply weren't a large enough part of the plant community to be considered primary species. The presentation of the transect data (Appendix D) more specifically lists all plant species and their associations encountered in the lake.

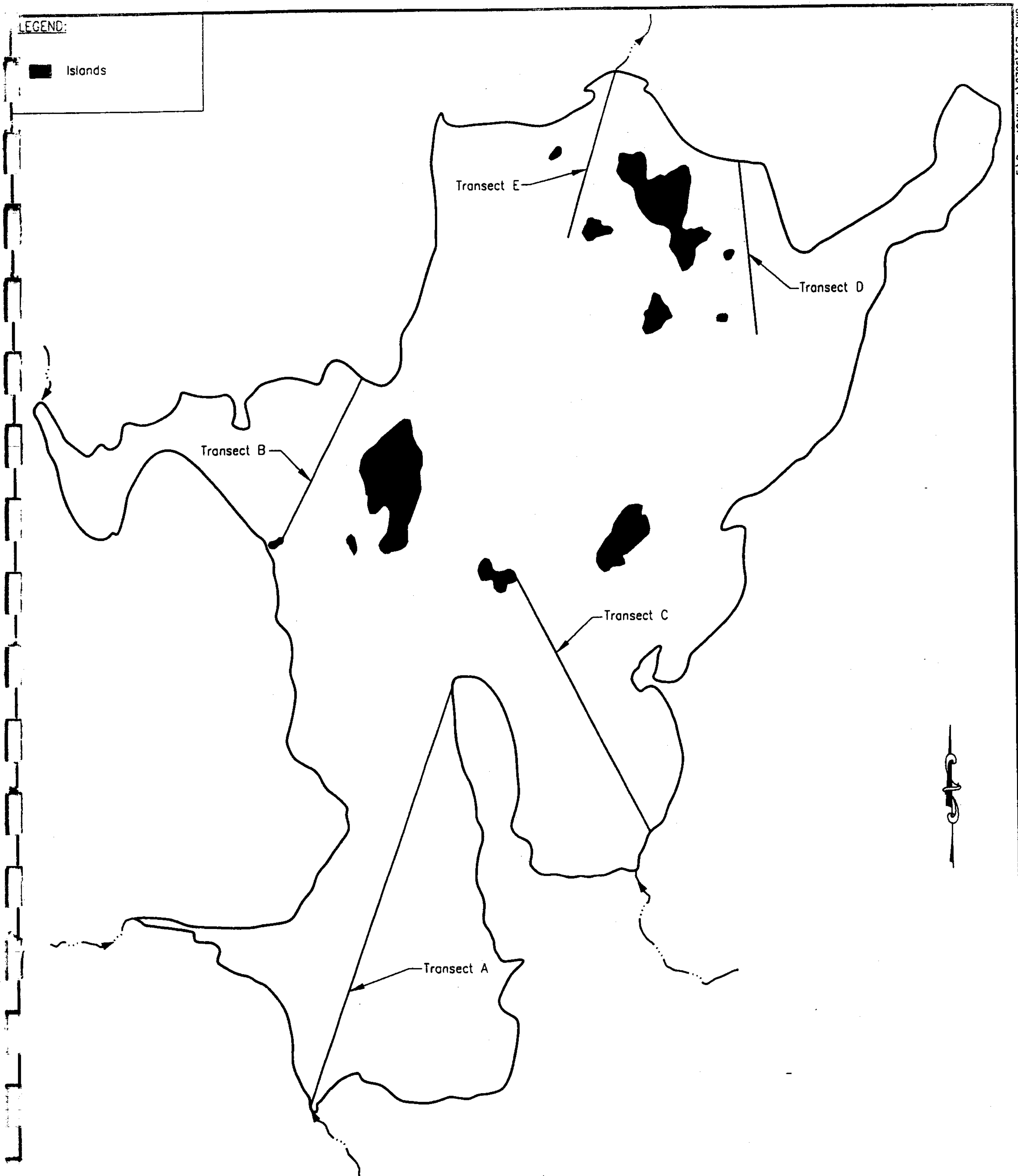
Five plant transect surveys were conducted on September 2nd, 1998 and their locations are given in Figure 9. Various measures for locating and reproducing the transects are given in Tables B-1 through B-5 in Appendix B. Photographs of the beginning and general path of each transect are given in Appendix C.

Each transect was divided into a series of observation points whereby a diver would record the total percent cover of all plants, the total percent biomass (as measured by the amount of the water column filled with plants), and the breakdown of the plant community by species. The approximate percent biomass of each species present in the community was also recorded. These data are given in Tables D-1 through D-5 in Appendix D.

One of the tools used to locate the sample points along each transect was a hand-held Global Positioning System (GPS) unit. The latitude and longitude of each sample point was recorded (Tables B-1 through B-5, Appendix B). Also found in Appendix B are Figures B-1 and B-2. Figure B-1 positions the recorded latitude and longitude of each sample point with a Geographic Information System (GIS) onto a USGS topographic map. Figure B-2 identifies the actual position of the sample points along each transect as recorded at the time of sampling. From Figure B-1, the error associated with the GPS unit becomes apparent and it is recommended that the positions presented in Figure B-2 be used for future replication of the transect surveys.



Client: Town of Harvard	Very Dense Plant Growths (Approximately >75% Cover and Biomass)	Figure 8	ENSR
Bare Hill Pond		1" = 700'	
	November 1998	Job No. 8726-567	



Client: Town of Harvard	Plant Transects Bare Hill Pond Harvard, Massachusetts	Figure 9	ENSR
	November 1998 / Job No. 8726-567	1" = 800'	

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Plant Mapping Results
Figure 8 shows the extent of dense aquatic plant growths as encountered during the overall plant survey. The identified areas of dense growth appear to be similar areas of chronic weed growths over the past several decades.

The areas of the southern cove between 3 and 6 feet experience heavy plant growths dominated primarily by variable milfoil. However, shallower areas were dominated by thick expanses of floating plants such as the lilies, watershield and smartweed (*Polygonum sp.*). The cove at the inlet of Bower's Brook also supports a nearly monotypic stand of smartweed. Even though a large portion of this area is harvested, the shallow conditions and soft sediments continually support high plant densities and promote rapid re-growth.

The cove west of Minister's Island (on the west side of Bare Hill Pond) is also an area of extensive plant growth, similar in species composition and depth regime to the southern cove. Variable milfoil growth dominates and is associated with lower growing plants such as Robbins' pondweed and bladderwort (*Utricularia sp.*). This area also receives significant harvesting attention but continually produces dense plant growths and re-growth. Currently, the harvester is restricted by lack of water depth from operating in the most shallow areas that support the floating-leafed species.

The cove adjacent to the town beach is heavily infested with plants that completely prohibit recreational pursuits during the summer months. The shallow areas support the floating-leafed species while the somewhat deeper areas support dense growth of variable milfoil.

The above three areas support the largest and most extensive plant growths in Bare Hill Pond. However, there are other areas of localized dense plant growths as identified in Figure 8, and any area with a water depth less than 8 ft is susceptible to plant growth.

While the overall plant survey provided a generalized view of heavily infested areas, the transect data measures more precisely the condition of the plant community which can be interpreted for the entire lake. The completion of the 5 plant transect investigations allows a more thorough understanding of the species present in the lake, the depths in which plants are most dominant and provides baseline data to measure the effectiveness of any plant control measures. These transects can be easily repeated in future years to track plant control measures.

Transect A (Figure 9) is a long transect that originates in a cove infested with smartweed at the southern end of the lake (Table D-1, Appendix D). A wide variety of species are soon encountered in water depths from 3-6 feet (points 2-7), an area that is routinely harvested. The area had been harvested during the summer but re-growth had since occurred and biomass was substantial.

In depths from 3-6 feet, percent coverage was at or above 75%, and even though harvesting had recently occurred, the volume of the water column filled with plants, for the most part, was much greater than 50%. Variable milfoil and Robbins' pondweed dominated along with intermittent growths of the floating leafed species. Points 8-12 represent deeper water areas where little plant growth occurred. The end of the transect, point 13, occurred in shallow water but the substrate was not suitable for dense plant growth.

Transect B represents an area heavily infested with variable milfoil. As indicated by Table D-2 (Appendix D), variable milfoil is the dominant plant at each of the 12 sample points and both the average cover and biomass exceed 75%. This area has also been extensively harvested during the summer, but re-growth was substantial. Recreation in this portion of the lake is severely limited during the summer months due to excessive plant growth.

Transect C occurs in an area only moderately impacted by variable milfoil. Shoreline growths of variable milfoil extend into the cove until water depths greater than 8 feet are reached. The far end of the transect (points 7 and 8) reveal plant growths in shallower waters near the island where variable milfoil is present but Robbins' pondweed dominates.

Transect D covers an area of the lake with water depths from 2 to 7 feet with moderate to heavy overall plant growth. In water depths from 2.5 to 4.5 feet (sample points 1-8) both percent cover and plant volume are routinely greater than 50%. Variable milfoil, Robbins' pondweed and bladderwort are the species most encountered, although variable milfoil is the most dominant. In water depths greater than 5 feet (points 9-13), percent cover and plant volume are predominantly less than 50%. At depths greater than 7 feet, only sparse vegetation was encountered and data collection ceased.

Transect E originates at the pond outlet and extends quickly into deeper waters. Transect points 1-5 exhibit moderate to heavy growths dominated by variable milfoil and pondweed. Points 6-8 occur in waters deeper than 8 feet where variable milfoil and pondweed are present at only low densities.

Table 2 breaks down the transect data for the entire lake by two foot depth intervals and gives the average percent cover and average biomass encountered at each interval. The most dominant plant species are also identified for each interval. Species dominance was measured, in this instance, by how many times it was observed in transect sample points. This measure does not take into account cover or biomass, but as applied in Bare Hill Pond, it adequately measures the perceived dominance of the species present.

The presence of substantial aquatic macrophyte growths observed in Bare Hill Pond is primarily limited to a water depth less than 8 feet as shown for the cover and biomass values at depth intervals less than 8 feet in Table 2. Not surprisingly, the concentration of plants decreases with depth as indicated by the decreasing cover and biomass values from

2 feet to 8 feet. Beyond the 8 foot interval, it appears that light is the factor limiting plant growth due to water color, and not substrate. Substrates beyond water depths of 8 feet were similar to those in shallower areas.

Table 2. Summary transect data by depth interval for all transect points observed.

Depth Interval (ft)	# of Transect Points	Average Total % Cover	Average Total % Biomass	Most Dominant Plant Species — Percent Frequency of Occurrence						
				M.h.	P.r.	U.p.	U.v.	N.o.	N.v.	B.s.
2-4	24	76	71	92	92	63	79	42	4	25
4-6	12	66	50	100	100	33	58	8	17	8
6-8	6	46	42	83	67	33	50	0	17	0
8-10	7	13	13	29	43	0	0	0	0	0
> 10	2	0	0	0	0	0	0	0	0	0

M.h.=Myriophyllum heterophyllum; P.r.=Potamogeton Robbinsii; U.p.=Utricularia purpurea; U.v.=Utricularia vulgaris; N.o.=Nymphaea odorata; N.v.=Nuphar variegatum; B.s.=Brasenia Schreberi

The composition of the generalized plant community for the entire lake also changes according to depth interval. The 0-2 foot depth interval reveals a diverse plant community with many species present, but one which is dominated by variable milfoil and Robbins' pondweed. Even though Robbins' pondweed rivals variable milfoil in this dominance measure at all depth intervals, its low growing habit makes it significantly less a nuisance. Where variable milfoil growth is heavy, it grows nearly to the surface and certainly can interfere with recreational pursuits and can pose a significant swimming hazard. Where variable milfoil is less abundant, however, Robbins' pondweed grows close to the bottom in a mat form.

As one moves to deeper waters, the occurrence of species other than variable milfoil and Robbins' pondweed declines. The deeper waters are not the preferred habitat for the floating-leafed lilies and watershield. Even at the 8-10 foot interval variable milfoil and Robbins' pondweed are still present, but at a substantially reduced level. Of the areas sampled by transects, it is clear that in the areas that can support plant growth, variable milfoil is the dominant and most problematic species.

Of the many non-dominant species in Bare Hill Pond, the most notable is the fanwort (*Cabomba caroliniana*). This acidophilic species has only recently been reported from Bare Hill Pond, which provides excellent habitat for this species. It has the potential to become a co-dominant with variable milfoil and is of equal nuisance potential and control difficulty. Also of definite concern in Bare Hill Pond is the water chestnut (*Trapa natans*). This species appears to be on the decline as a consequence of plant harvesting efforts, but has the potential to achieve high coverage and nuisance status if not kept under control.

When combining the overall lake survey with the plant transect data, a clear picture of impacted areas due to excessive plant growth becomes apparent. Heavily impacted areas appear as a function of water depth and to a lesser extent substrate. Dense plant growths rarely occur at depths greater than 8 feet, while extremely dense growths normally occur at depths less than 6 feet.

The lake water surface area is approximately 324 acres. Of that surface area, approximately 185 acres are less than 6 feet deep. According to the lake survey and transect data, approximately 100 acres less than 6 feet deep support dense macrophyte growths. On a relative basis, approximately 55% of the areas that could support dense macrophyte growths actually do. Reasons for lesser growth in some shallow areas include substrate features and past management efforts, including harvesting.

The bulk of the dense plant growths occur in three distinct regions of the lake: the southern cove, the cove behind Minister's Island, and the beach cove. The remaining impacted acreage is spread around the shoreline of the lake and islands. Growths in the above mentioned areas greatly diminish recreational pursuits including boating and may pose dangerous swimming conditions due to possible swimmer entanglement.

BARE HILL POND MANAGEMENT PLAN

Management Goals

Successful management is guided by a clear statement of goals and priorities. What are the intended uses of the lake, and which use has priority over which others? Optimal conditions for swimming, boating, fishing and water supply rarely exist in the same lake, although all uses may be accommodated to some degree. Not all lake management uses are completely compatible and goals must be set accordingly.

There are a variety of human interests associated with Bare Hill Pond, including swimming, canoeing, sailing, rowing, powerboating, fishing, and passive enjoyment of the pond and its wildlife. The pond is not a primary water supply, although there may be some withdrawals for irrigation and the pond might be used to supply drinking water (with treatment) in an emergency. The presence of the large Town recreation complex suggests that pursuits such as swimming, canoeing and sailing will have top priority, while the mooring of motorized watercraft around the lake indicates that powerboating is also a significant use.

There are certainly important non-human uses of Bare Hill Pond as well, and this lake provides substantial habitat for a wide variety of plants and animals. Emergent, floating and submergent plant species are all abundant - too abundant in some areas for the desired human uses, but providing habitat for many non-human lake users. Fish, waterfowl, reptiles, amphibians and many species of insects inhabit the pond. The depth profile for Bare Hill Pond does not suggest that it will support a superior coldwater fishery (e.g., trout), although survival of stocked trout is possible. Warm water fish species such as bass, sunfish, pickerel and perch are all common.

While it would be desirable for the Town to discuss and formalize the management priorities for Bare Hill Pond, we offer the following goals, in perceived order of importance, based on our current understanding of issues at the pond:

1. Maximize recreational utility, enhancing opportunities for swimming, all forms of boating, and fishing. There may be some controversy over the priority of motorized boat use of Bare Hill Pond, but all other recreational uses appear to have roughly equal standing.

2. Maintain a diverse native community of plants and animals in association with the pond, but not at densities which interfere with recreational pursuits.

3. Maintain water quality suitable to recreational and habitat goals.

4. Maximize property values around the pond. This goal is somewhat difficult to quantify, as different people will value different features of the pond, but it seems safe to state that it is not in the best interest of the Town to allow conditions to deteriorate in a manner which significantly reduces the tax base.

Impediments to Achieving Management Goals

Conditions which will inhibit recreational pursuits include poor water quality, algal blooms, dense growths of aquatic vascular plants, and loss of water depth (sediment accumulation). Water quality in Bare Hill Pond is not ideal, but is not an impediment to recreation at this time. Algal blooms are uncommon in this water body. However, rooted aquatic plant nuisances and shallow water depth are problems that impact recreational utility in this pond.

While the plant and animal community of Bare Hill Pond contains many species, a few species dominate the plant community, reducing diversity (note that diversity is not the number of species present, but the distribution of individuals among those species). Although a variety of habitats exist in the pond, invading non-native species limit the abundance of most habitat types. The animal community of Bare Hill Pond was not specifically investigated in this study, but appears healthy overall. Fishing may be sub-optimal as a function of certain aspects of water quality (high color and low bottom dissolved oxygen) and high plant densities.

Water quality generally supports the recreational and habitat uses of the lake, but is not ideal in several regards. Naturally high color, common in lakes which drain extensive wetland areas, restricts light penetration. This can be an aid to controlling algae and rooted plant growths, but impacts the safety of swimming and boating and affects fishing success by some methods.

Low dissolved oxygen near the bottom of the lake is also common in lakes with highly organic bottom sediment deposits. It is not a major problem in shallow water, as overlying waters are well oxygenated, but can reduce fish habitat in deeper areas where exchange with overlying waters is limited. Bare Hill Pond is therefore not especially suitable for coldwater fish species such as trout; shallow waters are too warm and deeper waters have too little oxygen.

Phosphorus levels are somewhat elevated in Bare Hill Pond, but the availability of the phosphorus appears limited by natural organic compounds in the water column which limit light and bind the phosphorus and make it unavailable for algal uptake. Alkalinity is also naturally low in this system, making it susceptible to acidic precipitation, but the aquatic community is comprised of organisms tolerant to such conditions.

Property values are generally enhanced by a pleasant view and high recreational utility, although even degraded lakes often confer higher property value than land away from lakes. As long as one has an appreciation for peripheral emergent vegetation, the view of Bare Hill Pond can be considered pleasant from all but a few vantage points. The problem areas are shallow coves which have become choked with aquatic vegetation. The recreational utility of Bare Hill Pond is still high, but is also clearly diminished by dense aquatic vegetation.

It can be concluded that the primary impediments to achieving the stated management goals are dense growths of aquatic plants, shallow depth, high water color, and low dissolved oxygen near the lake bottom. All of these are to some extent natural features of this lake, which is itself partly artificial as a result of dam construction many years ago. However, the presence of non-native, invasive plant species exacerbates the problem, and the high density of some native species, while "natural", is deleterious to both recreation and overall habitat value. Water quality need not be substantially enhanced to meet recreational and habitat goals, but should be protected from the impacts of continued high development pressure in the watershed.

Therefore, we perceive three major areas of action that should be addressed by a management plan for Bare Hill Pond:

1. Protection and enhancement of water quality
2. Increased water depth in shallow areas impacted by organic muck accumulation
3. Control of aquatic vegetation nuisances

Protection of water quality is most properly achieved through watershed management. Although considerable effort has been devoted in the past to evaluating the watershed (Whitman and Howard 1987), watershed features have not been the subject of the ENSR investigation and we are not in a position to speak authoritatively on watershed management needs. The one water quality sampling conducted as part of this investigation suggested no major problems, but more sampling is needed to update past efforts.

It does seem apparent that any major inputs to the pond from its watershed are a function of storm water influence. Control of the generation of storm water runoff and the quality of runoff reaching the lake is encouraged, and would likely take the form of restrictions on the amount of impervious surface created during new development, maintenance of vegetative buffer zones along stream corridors and the pond itself, and detention and/or infiltration of runoff before it enters the pond. The Town should consider implementing a program to evaluate current inputs and the relative threat of each, with follow up action in each sub-drainage area as warranted.

However, watershed management will not completely protect the pond from deteriorating water quality, and will do virtually nothing about the problems associated with aquatic vegetation and shallowness. Interaction of the pond bottom and plant growths with the water column may affect water quality as much as any inputs from this watershed. Detention time in Bare Hill Pond is substantial, and there is little flushing action during the summer months of greatest human and wildlife interaction with the pond. Watershed management can prevent future problems, but is unlikely to solve any existing ones.

Consequently, in-lake management techniques must be implemented if Bare Hill Pond is to meet the stated management goals. The ecological basis and practical considerations for in-lake management is a complicated subject, and readers are encouraged to examine the extensive literature on this subject before making final judgments on any technique or approach. We have attempted to provide enough background for each method considered here to allow a reasonable level of understanding, but additional insight can be gained from such publications as Restoration and Management of Lakes and Reservoirs (Cooke et al. 1993, the Lake and Reservoir Restoration Guidance Manual (USEPA 1990), Diet for a Small Lake (NYDEC 1990) and a wide variety of primary literature (much of which is contained in either the Journal of the Aquatic Plant Management Society and the Journal of Lake and Reservoir Management). A table of rooted plant management techniques and related considerations is included in Appendix A.

Management Options for Increased Water Depth

There are four possible ways to increase water depth:

1. Raise the water level - Increasing dam height will impound more water and increase average water depth, but the potential for flooding of shoreline properties and the possible damage to peripheral habitats greatly reduces the feasibility of this option.

2. Remove sediments - Dredging all or part of the pond would be a true restoration project, reducing the volume of largely organic material which has accumulated since the pond was formed. Dredging has many potentially negative but largely temporary impacts, but is the one technique that could truly set the pond back in time to a point at which more desirable conditions existed. High cost is a major drawback to this approach on any but the most localized scale.

3. Add microbes and oxygen to decompose accumulated organic sediments - It is theoretically possible to promote more complete decay of organic sediments, resulting in lesser sediment volume. The effectiveness of this approach has not been well documented, and the refractory nature of bottom deposits suggests that large increases in depth are unlikely.

4. Compact the sediments through drawdown - By drying or at least reducing the interstitial water content, organic sediments may compact and remain compressed after re-flooding. For this technique to work, it is essential to lower the water level beyond the existing sediment-water interface in the targeted area, creating significant pressure on the sediments. If the ground water table is high, this may be difficult to accomplish.

Of these methods, compaction by drawdown is least expensive and has some potential to work in the case of Bare Hill Pond. Limitation on the extent of drawdown (up to 4 ft) will restrict the area upon which this technique can operate to areas less than about 2-3 ft deep at full lake level, but some benefit may be derived. Dense water lily root masses may further limit effectiveness by adding structural stability to the otherwise loose sediments, but at minimal cost this approach is worth pursuing. Appendix E contains a listing of planning considerations associated with drawdown.

Dredging is very attractive in this case in terms of potential benefits. Aside from the obvious increase in water depth wherever this technique is used, rooted plant growths would be reduced by both light and substrate limitations and seed banks would be removed. While there are many potential technical difficulties associated with dredging, the greatest impediment is cost. Although dredging costs should be estimated on a case by case basis, considering the many influential factors (Appendix F), a rough rule of thumb is to assume an all-inclusive cost of about $10 per cubic yard (cy) removed.

While we do not know the precise distribution of soft sediment in Bare Hill Pond, deposits are substantial and exceed 10 ft in many areas. Assuming only enough removal to deepen areas with current water depth <8 ft by an average of 3 ft, we have approximately 170 acres times 3 ft = 510 acre-ft = 822,630 cy. This equates to a cost of over $8 million. If only the areas with current water depth <4 ft were dredged, the cost could be cut to around $4 million. Most of this area is in the southern end of the pond, however, away from the primary public use area. If the Town is willing to consider such an expenditure, further analysis is warranted.

Neither raising the water level nor adding engineered microbes and oxygen are recommended for Bare Hill Pond as means to increase water depth.

Management Options for Vegetation Control

There are seven general approaches for controlling rooted aquatic plants (summarized in Table A-1). Useful background information is provided below.

Option #1: Benthic barriers

The use of benthic barriers, or bottom covers, is predicated upon the principles that rooted plants require light and cannot grow through physical barriers. Applications of clay, silt, sand, and gravel have been used for many years, although plants often root in these covers eventually, and current environmental regulations make it difficult to gain approval for such fill deposition. An exception may exist in the reverse layering technique (KVA 1991), in which sand is pumped from underneath a muck or silt layer and deposited as a new layer on top of the muck or silt. This is technically a re-organizing of the sediments, not new filling. Although expensive on a large scale and not applicable where the muck is not underlain by suitable materials, this technique restores the natural pond bottom of some previous time without sediment removal.

Artificial sediment covering materials, including polyethylene, polypropylene, fiberglass, and nylon, have been developed over the last three decades. A variety of solid and porous forms have been used. Manufactured benthic barriers are negatively buoyant materials, usually in sheet form, which can be applied on top of plants to limit light, physically disrupt growth, and allow unfavorable chemical reactions to interfere with further development of plants (Perkins et al. 1980).

In theory, benthic barriers should be a highly effective plant control technique, at least on a localized scale. In practice, however, there have been many difficulties in the deployment and maintenance of benthic barriers, limiting their utility in the broad range of field conditions. Benthic barriers can be effectively used in small areas such as dock spaces and swimming beaches to completely terminate plant growth. The creation of access lanes and structural habitat diversity is also practical. Large areas are not often treated, however, because the cost of materials and application is high and maintenance can be problematic.

Engel (1984) lists the following advantages and disadvantages of benthic barriers:

- Use is confined to a specific area
- Barriers are out of sight and create no disturbance on shore
- Barriers can be installed in areas where harvesters and most boats cannot operate
- No toxic substances are used
- Barriers are easy to install over small areas
- Barriers do not correct the cause of the problem
- Barriers are expensive on a unit area basis
- Barriers are difficult to apply over large areas or over obstructions
- Barriers may slip on steep grades or float to the surface after trapping gases beneath them
- Barriers can be difficult to remove or relocate
- Barriers may tear during application
- Some barrier materials are degraded by sunlight
- A permit is usually required for barrier installation

Successful use is related to selection of materials and the quality of the application. As a result of field experience with benthic barriers in Lake George, New York, several guidelines have been developed (Eichler, pers. comm.):

- Porous barriers will be subject to less billowing, but will allow settling plant fragments to root and growth; annual maintenance is therefore essential
- Solid barriers will generally prevent rooting in the absence of sediment accumulations, but will billow after enough gases accumulate; venting and strong anchoring are essential in most cases
- Plants under the barrier will usually die completely after about a month, with solid barriers more effective than porous ones in killing the whole plant; barriers of sufficient tensile strength can then be moved to a new location, although continued presence of solid barriers restricts recolonization.

Proper application requires that the screens be placed flush with the sediment surface and staked or securely anchored. This may be difficult to accomplish over dense plant growth, and a winter drawdown can provide an ideal opportunity for application. Late spring application has also been effective, however, despite the presence of plant growths at that time, and barriers applied in early May have been removed in mid-June with no substantial plant growth through the summer (Clear and Wagner 1999). Scuba divers normally apply the covers in deeper water, which greatly increases labor costs. Bottom barriers will accumulate sediment deposits in most cases, which allows plant fragments to root. Barriers must then be cleaned, necessitating either removal or laborious in-place maintenance.

Despite application and maintenance issues, benthic barriers are a very effective tool. In northern waters, benthic barriers are capable of providing control of milfoil on at least a localized basis (Engel 1984, Perkins et al. 1980, Helsel et al. 1996), and have such desirable side benefits as creating more edge habitat within dense plant assemblages and minimizing turbidity generation from fine bottom sediments.

Option #2: Dredging

Dredging works as a plant control technique when either a light limitation on growth is imposed through increased water depth or when enough "soft" sediment (muck, clay, silt and fine sand) is removed to reveal a less hospitable substrate (typically rock, gravel or coarse sand). The only exception may be suction dredging, whereby a target species can be reduced or possibly eliminated by removing whole plants and any associated seed banks. Suction dredging might more appropriately be considered a form of harvesting, however, as plants are extracted from the bottom by SCUBA divers operating the suction dredge and sediment is often returned to the lake.

The amount of sediment removed, and hence the new depth and associated light penetration, is critical to successful long-term control of rooted, submerged plants. There appears to be a direct relation between water transparency, as determined with a Secchi disk, and the maximum depth of colonization (MDC) by macrophytes. Examination of a bathymetric map will allow calculation of the likely quantity of sediment which would have to be removed to create a light limitation on macrophyte growth over a target area.

Partial deepening may limit the amount of vegetation which reaches the surface, but may also favor species tolerant of low light, some of which are non-native species with high nuisance potential, such as hydrilla and several species of milfoil. Where funding is insufficient to remove all soft sediment, it is more important to create a depth or substrate limitation in part of the lake than to remove some sediment from all target areas of the lake, if rooted plant control is the primary objective.

If the soft sediment accumulations which are supporting rooted plant nuisances are not especially thick, it may be possible to create a substrate limitation before a light-limiting depth is reached. If dredging exposes rock ledge or cobble, and all soft sediment can be removed, there will be little rooted plant growth. Yet such circumstances are rare to non-existent; either the sediments grade slowly into coarser materials, or it is virtually impossible to remove all fine sediments from the spaces around the rock or cobble. Consequently, some degree of regrowth is to be expected when light penetrates to the bottom. With successful dredging, this regrowth may be only 25% of the pre-dredging density or coverage, and will not contain more recently invading species at a dominant level. Yet some rooted plant regrowth is expected, and is indeed desirable for proper ecological function of the lake as a habitat and for processing of future pollutant inputs.

Experience with dredging for rooted plant control has had mixed results. As with dredging for algal control, failures are invariably linked to incomplete pre-dredging assessment and planning. Control through light limitation appears more successful than control through substrate limitation, largely as a function of the difficulty of removing all soft sediment from shallow areas. Dry dredging projects appear to result in more thorough soft sediment removal, mainly because equipment operators can visually observe the results of dredging as it takes place. Hydraulic dredging in areas with dense weed beds can result in frequent clogging of the pipeline to the slurry discharge area, suggesting the need for some form of temporary plant control (most often herbicides or harvesting) prior to hydraulic dredging.

Option #3: Light Limitation with Dyes and Surface Covers

Dyes are used to limit light penetration and therefore restrict the depth at which rooted plants can grow. They tend to reduce the maximum depth of plant growth, but have little effect in shallow water (<4 ft deep). They are only selective in the sense that they favor species tolerant of low light or with sufficient food reserves to support an extended growth period (during which a stem could reach the lighted zone). In lakes with high transparency but only moderate depth and ample soft sediment accumulations, dyes may provide open water where little would otherwise exist. Repeated treatment will be necessary, as the dye flushes out of the system. Dyes are typically permitted under the same process as herbicides, despite their radically different mode of action.

Surface shading has received little attention as a rooted plant control technique, probably as a function of potential interference with recreational pursuits which are a goal of most rooted plant control programs. Polyethylene sheets, floated on the lake surface, were used by Mayhew and Runkel (1962) to shade weeds. They found that two to three weeks of cover were sufficient to eliminate all species of pondweeds (*Potamogeton* spp.) for the summer if the sheets were applied in spring before plants grew to maturity. Coontail was also controlled, but the macroalga *Chara* was not. This procedure may be a useful alternative to traditional methods of weed control in small areas such as docks and beaches.

Option #4: Mechanical removal

There are many variations on mechanical removal of macrophytes. Table A-1 (Appendix A) breaks these varied techniques into hand pulling, cutting without collection, harvesting with collection, rototilling, and hydroraking. Suction dredging, addressed in the dredging section, could also be included here, as it is primarily intended to remove plant biomass. Other classification systems are undoubtedly applicable; this is a diverse collection of methods linked by the commonality of physically attacking the targeted plants. These techniques are often cited as being analogous to mowing the lawn (cutting or harvesting), weeding the garden (hand pulling), or tilling the soil (rototilling or hydroraking), and these are reasonable comparisons. Mechanical management of aquatic plants is not much different from managing terrestrial plants, except for the complications imposed by the water.

Hand pulling is exactly what it sounds like; a snorkeler or diver surveys an area and selectively pulls out unwanted plants on an individual basis. This is a highly selective technique, and a labor intensive one. It is well suited to vigilant efforts to keep out invasive species which have not yet become established in the lake or area of concern. Hand pulling can also effectively address non-dominant growths of undesirable species in mixed assemblages, or small patches of plants targeted for removal. This technique is not suited to large scale efforts, especially when the target species or assemblage occurs in dense or expansive beds.

Cutting is also exactly what it appears to be. A blade of some kind is applied to plants, severing the active apical meristem (location of growth) and possibly much more of the plant from the remaining rooted portion. Regrowth is expected, and in some species that regrowth is so rapid that it negates the benefits of the cutting in only a week or two. If the plant can be cut close enough to the bottom, or repeatedly, it will sometimes die, but this is more the exception than the rule. Cutting is defined here as an operation which does not involve collecting the plants once they are cut, so impacts to dissolved oxygen are possible in large scale cutting operations.

The most high technology cutting technique involves the use of mechanized barges normally associated with harvesting operations, in which plants are normally collected for out-of-lake disposal. In its use as a cutting technology, the harvester cuts the plants but does not collect them. A recent advance in this technique employs a grinding apparatus which ensures that viable plant fragments are minimized after processing. There is a distinct potential for dissolved oxygen impacts as the plant biomass decays.

Harvesting may involve collection in nets or small boats towed by the person collecting the weeds, or can employ smaller boat-mounted cutting tools which haul the cut biomass into the boat for eventual disposal on land, or can be accomplished with larger, commercial machines with numerous blades, a conveyor system, and a substantial storage area for cut plants. Offloading accessories are available, allowing easy transfer of weeds from the harvester to trucks which haul the weeds to a composting area. Choice of equipment is really a question of scale, with most larger harvesting operations employing commercially manufactured machines built to specifications suited to the job. Some lake associations choose to purchase and operate harvesters, while others prefer to contract harvesting services to a firm which specializes in lake management efforts.

Cutting rates for commercial harvesters tend to range from about 0.2 to 0.6 acres per hour, depending on machine size and operator ability, but the range of possible rates is larger. Even at the highest conceivable rate, harvesting is a slow process which may leave some lake users dissatisfied with progress in controlling aquatic plants. Weed disposal is not usually a problem, in part because lakeshore residents and farmers often will use the weeds as mulch and fertilizer. Also, since aquatic plants are more than 90 percent water, their dry bulk is comparatively small. Key issues in choosing a harvester include depth of operation, volume and weight of plants which can be stored, reliability and ease of maintenance, along with a host of details regarding the hydraulic system and other mechanical design features.

Rototilling and the use of cultivation equipment are newer procedures with a limited track record (Newroth and Soar, 1986). A rototiller is a barge-like machine with a hydraulically operated tillage device that can be lowered to depths of 10 to 12 feet for the purpose of tearing out roots. Also, if the water level in the lake can be drawn down, cultivation equipment pulled behind tractors on firm sediments can achieve 90 percent root removal. Potential impacts to non-target organisms and water quality are substantial, but where severe weed infestations exist, this technique could be appropriate.

Hydroraking involves the equivalent of a floating backhoe, usually outfitted with a York rake which looks like certain farm implements for tilling or moving silage. The tines of the rake attachment are moved through the sediment, ripping out thick root masses and associated sediment and debris. A hydrorake can be a very effective tool for removing submerged stumps, water lily root masses, or floating islands. Use of a hydrorake is not a delicate operation, however, and will create substantial turbidity and plant fragments. Hydroraking in combination with a harvester can remove most forms of vegetation encountered in lakes.

Most mechanical plant removal operations are successful in producing at least temporary relief from nuisance plants and in removing organic matter and nutrients without the addition of a potentially deleterious substance. Plant regrowth can be very rapid (days or weeks), but there is evidence of a carry-over effect (less growth in the subsequent year) in some cases, especially if an area has had multiple harvests in one season.

Some weed species are more sensitive to harvesting than others. Nicholson (1981) has suggested that harvesting was responsible for spreading milfoil in Chautauqua Lake, New York, because the harvester spread fragments of plants from which new growths could begin. On the other hand, milfoil has become the dominant plant in many northeastern lakes without harvesting programs in less than 5 years after initial appearance (Wagner, pers. obs.). Timely harvesting of species which depend upon seeds for annual re-establishment can eventually limit the extent of those species, but the viability of seeds placed in the sediment over years prior to harvesting can minimize impacts for several years to a decade. Extensive harvest of water chestnut in impounded sections of the Charles River in Boston in 1996 had no observable effect on 1997 growths of that plant. Harvesting was repeated in 1997, and growths in 1998 were much reduced, but it is not clear if it was the effect of harvesting or very high spring water level in 1998 which was responsible (Smith, pers. comm.).

There are few data on the actual restorative effects of harvesting, in the sense of removing significant amounts of nutrients or in reducing the release of nutrients and organic matter to the water column from plant senescence. If nutrient inputs are moderate and weed density is high, as much as 40 to 60% of net annual phosphorus loading could be removed with intense harvesting. This would be a significant nutrient removal in many cases. On the other hand, harvesting itself can increase water column phosphorus concentration either through mechanical disturbance of sediments or by enhancing conditions for phosphorus release from sediments.

Option #5: Water level control
Historically, water level drawdown has been used in waterfowl impoundments and wetlands for periods of a year or more, including the growing season, to improve the quality of wetlands for waterfowl breeding and feeding habitat (Kadlek 1962, Harris and Marshall 1963). Until a few decades ago, drawdowns of recreational lakes were primarily for the purpose of flood control and allowing access for clean ups and repairs to structures, with macrophyte control as an auxiliary benefit. While this technique is not effective on all submergent species, it does decrease the abundance of some of the chief nuisance species, particularly those which rely on vegetative propagules for overwintering and expansion (Cooke et al. 1993). If there is an existing drawdown capability, lowering the water level provides an inexpensive means to control some macrophytes. Additional benefits may include opportunities for shoreline maintenance and oxidation or removal of nutrient-rich sediments.

The ability to control the water level in a lake is affected by area precipitation pattern, system hydrology, lake morphometry, and the outlet structure. The base elevation of the outlet or associated subsurface pipe(s) will usually set the maximum drawdown level, while the capacity of the outlet to pass water and the pattern of water inflow to the lake will determine if that base elevation can be achieved and maintained. In some cases, sedimentation of an outlet channel or other obstructions may control the maximum drawdown level.

Several factors affect the success of drawdown with respect to plant control. While drying of plants during drawdowns in southern areas may provide some control, the additional impact of freezing is substantial, making drawdown a more ideal strategy for northern lakes during late fall and winter. However, a mild winter or one with early and persistent snow may not provide the necessary level of drying and freezing. The presence of high levels of groundwater seepage into the lake may mitigate or negate destructive effects on target submergent species by keeping the area moist and unfrozen. The presence of extensive seed beds may result in rapid re-establishment of previously occurring or new and equally undesirable plant species. Recolonization from nearby areas may be rapid, and the response of macrophyte species to drawdown is quite variable. All species which overwinter in a vegetative state (such as milfoils) can be impacted by drawdown, while species which overwinter as seeds (such as most pondweeds) are generally unaffected.

Drawdown has a long and largely successful history, even if not always intended as a plant control technique (Dunst et al. 1974, Wlosinski and Koljord 1996). Winter drawdowns of Candlewood Lake in Connecticut (Siver et al. 1986) reduced nuisance species by as much as 90% after initial drawdown. Drawdowns in Wisconsin lakes have resulted in reductions in plant coverage and biomass of 40 to 92% in targeted areas (Dunst et al. 1974). In one Wisconsin case, Beard (1973) reported that winter drawdown of Murphy Flowage opened 64 out of 75 acres to recreation and improved fishing. Drawdown of Lake Lashaway in Massachusetts during the winter of slightly more than half of the last 15 years has resulted in the elimination of nuisance conditions without eliminating any species of plants (Munyon, pers. comm.).

The effect of drawdown is not always predictable or desirable, however. Reductions in plant biomass of 44 to 57% were observed in Blue Lake in Oregon (Geiger 1983) following drawdown, but certain nuisance species actually increased and herbicides were eventually applied to regain control. Drawdown of Lake Bomoseen in Vermont (VANR 1990) caused a major reduction in many species, many of which were not targeted for biomass reductions. Reviewing drawdown effectiveness in a variety of lakes, Nichols and Shaw (1983) noted the species-specific effects of drawdown, with a number of possible benefits and drawbacks. A system-specific review of likely and potential impacts is highly advisable prior to conducting a drawdown.

Desirable side effects associated with drawdowns include the opportunity to clean up the shoreline, repair previous erosion damage, repair docks and retaining walls, search for septic system breakout, and physically improve fish spawning areas (Nichols and Shaw 1983, Cooke et al. 1993, WDNR 1989). The attendant concentration of forage fish and game fish in the same areas is viewed (Cooke et al. 1993) as a benefit of most drawdowns, although not all fishery professionals agree. Since emergent shoreline vegetation tends to be favored by drawdowns, populations of furbearers are expected to benefit (WDNR 1989). The consolidation of loose sediments and sloughing of soft sediment deposits into deeper water is perceived as a benefit in many cases, at least by shoreline homeowners (Cooke et al. 1993, WDNR 1989).

Undesirable possible side effects of drawdown include loss or reduction of desirable plant species, facilitation of invasion by drawdown-resistant undesirable plants, reduced attractiveness to waterfowl (considered an advantage by some), possible fishkills if oxygen demand exceeds re-aeration during a prolonged drawdown, altered littoral habitat for fish and invertebrates, mortality among hibernating reptiles and amphibians, impacts to connected wetlands, shoreline erosion during drawdown, loss of aesthetic appeal during drawdown, more frequent algal blooms after refill in some cases, reduction in water supply, impairment of recreational access during the drawdown, and downstream flow impacts (Nichols and Shaw 1983, Cooke et al. 1993). Careful planning can often avoid many of these negative side effects, but managers should be aware of the potential consequences of any management action.

Desirable flood storage capacity will increase during a drawdown, but associated alteration of the downstream flow regime may have some negative impacts. Once the target drawdown level is achieved, there should be little alteration of downstream flow. However, downstream flows must necessarily be greater during the actual drawdown than they would be if no drawdown was conducted. The key to managing downstream impacts is to minimize erosion and keep flows within an acceptable natural range.

Inability to rapidly refill a lake after drawdown is a standard concern in evaluating the efficacy of a drawdown. There must be enough water entering the lake to refill it within an appropriate timeframe while maintaining an acceptable downstream flow. In northern lakes, the best time for refill is in early spring, when flows typically peak as the snowpack melts and rainfall on frozen ground yields the maximum runoff.

Impairment of water supply during a drawdown is a primary concern of groups served by that supply. Processing or cooling water intakes may be exposed, reducing or eliminating intake capacity. The water level in wells with hydraulic connections to the lake will decline, with the potential for reduced yield, altered water quality and pumping difficulties. Drawdowns of Cedar Lake and Forge Pond in Massachusetts resulted in impairment of well water supplies (Wagner, pers. obs.), but there is little mention of impairment of well production in the reviewed literature.

Effects of drawdown on amphibians and reptiles have not been well studied, but burrowing species might be expected to be below the zone of freezing or desiccation. The nature of the sediment and the dewatering potential of the drawdown will be key factors in determining impacts. The drawdown of Lake Bomoseen in Vermont was believed to have reduced the bullfrog population through desiccation and freezing of its burrowing areas (VANR 1990), although the evidence is scant.

The impact of drawdowns on wetlands which are hydraulically connected to the lake is often a major concern of environmental agencies. Hydrology is generally considered the master variable of wetland ecosystems (Carter 1986), controlling recruitment, growth and succession of wetland species (Conner et al. 1981). It is apparent that the depth, timing, duration and frequency of water level fluctuations are critical with regard to severity of impacts to adjacent wetlands (Kusler and Brooks 1988). It is also apparent that the specific composition of a wetland plant community prior to drawdown plays an important role in determining impacts.

Carefully planned water level fluctuation can be a useful technique to check nuisance macrophytes and periodically rejuvenate wetland diversity. Planned disturbance is always a threshold phenomenon; a little is beneficial, too much leads to overall ecosystem decline. The depth, duration, timing and frequency of the drawdown are therefore critical elements in devising the most mutually beneficial program.

Option #6: Herbicides

Treating nuisance aquatic weeds with herbicides is perhaps the oldest method used to attempt their management. Other than perhaps drawdown, few alternatives to herbicides were widely practiced until relatively recently. There are few aspects of plant control which breed more controversy than chemical control through the use of herbicides, which are a subset of all chemicals known as pesticides. Part of the problem stems from pesticides which have come on the market, enjoyed widespread use, been linked to environmental or human health problems, and been banned from further use. Some left longer term environmental contamination and toxicity problems behind. Many pesticides in use even 20 years ago are not commonly used or even approved for use today. The legacy of such books as Silent Spring and Our Stolen Future have done much to raise both public consciousness and wariness of chemicals in the environment.

Yet as chemicals are an integral part of life and the environment, it is logical to seek chemical solutions to such problems as infestations of non-native species which grow to nuisance proportions, just as we seek physical and biological solutions. Current pesticide registration procedures are far more rigorous than in the past. While no pesticide is considered unequivocally "safe", a premise of federal pesticide regulation is that the potential benefits derived from use outweigh the risks when the chemical is used according to label restrictions.

There are only six active ingredients currently approved for use in aquatic herbicides in the USA today, with one additional ingredient in the experimental use phase of the approval process. Westerdahl and Getsinger (1988a, 1988b) provide a detailed discussion of herbicides and related plant susceptibilities.

Copper is not typically preferred as a primary herbicide for rooted aquatic plants, but is sometimes part of a broad spectrum formulation intended to reduce the biomass of an entire plant assemblage, especially if it includes a substantial algal component. Copper concentrations should not exceed 1 mg/L in the treated waters.

Endothall is a contact herbicide, attacking plants at the immediate point of contact. Only portions of the plant with which the herbicide can come into contact are killed. It is sold in several formulations: liquid (Aquathol K), granular dipotassium salt (Aquathol), and the di (N, N-dimethyl-alkylanine) salt (Hydrothol) in liquid and granular forms. Effectiveness can range from weeks to months. Most endothall compounds break down readily and are not persistent in the aquatic environment, but the potassium salt forms have been shown to persist in the water for 2 to 46 days.

Endothall acts quickly on susceptible plants, but does not kill roots with which it cannot come into contact, and recovery of many plants is rapid. Rapid death of susceptible plants can cause oxygen depletion if decomposition exceeds re-aeration in the treated area, although this can be mitigated by conducting successive partial treatments. Toxicity to invertebrates, fish or humans is not expected to be a problem at the recommended dose, yet water use restrictions are mandated on the label. Depending upon the formulation, concentrations in treated waters should be limited to 1 to 5 mg/L.

Diquat, like endothall, it is a fast acting contact herbicide, producing results within 2 weeks of application. It is not an especially selective herbicide, and can be toxic to invertebrates, fish, mammals, birds and humans. Domestic water use restrictions are similar to those for endothall products (i.e., 14 days). Regrowth of some species has been rapid (often within the same year) after treatment with diquat in many cases. Concentrations in treated water should not exceed 2 mg/L.

Glyphosate is another contact herbicide. Its aquatic formulation is effective against most emergent or floating-leaved plant species, but not against most submergent species. Its mode of action is not certain, but it appears to disrupt synthesis of necessary compounds within the cell. Rainfall shortly after treatment can negate its effectiveness, and it readily adsorbs to particulates in the water column or to sediments and is inactivated. It is relatively non-toxic to aquatic fauna at recommended doses, and degrades readily into non-toxic components in the aquatic environment. There is no maximum concentration for treated water, but a dose of 0.2 mg/L is recommended.

2,4-D, which is the active ingredient in a variety of commercial herbicide products, has been in use for over 30 years despite claims of undesirable environmental side effects and potential human health effects. This is a systemic herbicide; it is absorbed by roots, leaves and shoots and disrupts cell division throughout the plant. Vegetative propagules such as winter buds, if not connected to the circulatory system of the plant at the time of treatment, are generally unaffected and can grow into new plants. It is therefore important to treat plants early in the season, after growth has become active but before such propagules form.

2,4-D is sold in liquid or granular forms as sodium and potassium salts, as ammonia or amine salts, and as an ester. Doses of 50 to 150 pounds per acre are usual for submersed weeds, most often of the dimethylamine salt or the butoxyethanolester (BEE). This herbicide is effective against a wide range of vegetation, including variable milfoil (granular BEE applied to roots early in the season). Recovery of the native community from seed has often been successful. 2,4-D has a short persistence in the water but can be detected in the mud for months. 2,4-D has variable toxicity to fish and other aquatic fauna, but proper dosages for control of most aquatic vegetation should not cause acute toxicity. While the 2,4-D label does not permit use of this herbicide in water used for drinking, other domestic purposes, or for irrigation or watering of livestock, it is commonly applied to recreational lakes for vegetation control. Concentrations in treated water should not exceed 0.1 mg/L.

Recent experiments with plastic curtains to contain waters treated with 2,4-D revealed a loss of only 2-6% of the herbicide to areas outside the target area (Helsel et al. 1996). This approach may mark the beginning of a new wave of more areally selective treatments and integrated rooted plant management.

Fluridone is a systemic herbicide introduced in 1979 (Arnold 1979) and in widespread use since the mid-1980's, although some states have been slow to approve its use. Fluridone currently comes in two formulations, an aqueous suspension and a slow release pellet, although an even slower release pellet is in the development stage. This chemical inhibits carotene synthesis, which in turn exposes the chlorophyll (active photosynthetic pigment) to photodegradation. Most plants are negatively sensitive to sunlight in the absence of protective carotenes, resulting in chlorosis of tissue and death of the entire plant with prolonged exposure to a sufficient concentration of fluridone. Some plants are more sensitive to fluridone than others, allowing selective control at low dosages.

For susceptible plants, lethal effects are expressed slowly in response to treatment with fluridone. Existing carotenes must degrade and chlorosis must set in before plants die off; this takes several weeks to several months, with 30-90 days given as the observed range of time for die off to occur after treatment. Fluridone concentrations should be maintained in the lethal range for the target species for at least three weeks, and preferably for six weeks. This presents some difficulty for treatment in areas of substantial water exchange, but the slow rate of die off minimizes the risk of oxygen depletion.

Fluridone is considered to have low toxicity to invertebrates, fish, other aquatic wildlife, and humans, and was developed with this consideration in mind. The USEPA has set a tolerance limit of 0.15 ppm for fluridone or its degradation products in potable water supplies, although state restrictions are sometimes lower. Control of aquatic vegetation has been achieved for at least a year without significant impact on non-target species at doses <0.01 mg/L (Netherland et al. 1997, Smith and Pullman 1997), but must be as high as 0.05 mg/L for more resistant vegetation.

If 40 days of contact time can be achieved, the use of the liquid formulation of fluridone in a single treatment has been very effective. Where dilution is potentially significant, the slow release pellet form of fluridone has generally been the formulation of choice. Gradual release of fluridone, which is 5% of pellet content, can yield a relatively stable concentration. However, pellets have been less effective in areas with highly organic, loose sediments than over sandy or otherwise firm substrates (Burns pers. comm., Haller pers. comm.).

In addition to the above six herbicides, there is one more in development which holds and experimental use permit at this time. The active herbicidal ingredient triclopyr is highly selective and effective against most watermilfoil species at a dose of 1 to 2.5 mg/L. Experimental treatments of aquatic environments (Netherland and Getsinger 1993) have revealed little or no effect on most monocotyledonous naiads and pondweeds, which are mostly valued native species. Its mode of action is to prevent synthesis of plant-specific enzymes, resulting in disruption of growth processes. This herbicide is most effective when applied during the active growth phase of young plants.

An herbicide treatment can be an effective short-term management procedure to produce a rapid reduction in vegetation for typical periods of weeks to months. In some cases involving fluridone, as many as five years of control can be gained. The use of herbicides to get a major plant nuisance under control is a valid element of long-term management when other means of keeping plant growths under control are then applied. Failure to apply alternative techniques on a smaller scale once the nuisance has been abated places further herbicide treatments in the cosmetic maintenance category; such techniques have poor cost-benefit ratios over the long-term.

Lake managers who choose herbicidal chemicals need to exercise all proper precautions. Users should follow the herbicide label directions exactly, use only a herbicide registered by EPA for aquatic use, wear protective gear during application, and protect desirable plants. Massachusetts requires applicators to be licensed and to have adequate insurance.

Among the important factors to be considered before adopting a management program with herbicides are the following questions:

- What is the acreage and volume of the area(s) to be treated? Proper dosage is based upon these facts.
- What plant species are to be controlled? This will determine the herbicide and dose to be used.
- What will the long-term costs of this decision be? Most herbicides must be reapplied annually.
- How is this waterbody used? Many herbicides have restrictions of a day to two weeks on water use following application.
- Is the applicator licensed and insured, and has a permit been obtained from the appropriate regulatory agency?

Shireman et al. (1982) caution that the following lake characteristics almost invariably produce undesirable water quality changes after treatment with a herbicide for weed control:

- High water temperature
- High plant biomass to be controlled
- Shallow, nutrient-rich water
- High percentage of lake area treated
- Closed or non-flowing system

Competent applicators will be cautious in treating a lake with these conditions.

Option #7: Biological introductions

Significant improvement in our future ability to achieve lasting control of nuisance aquatic vegetation may come from plant-eating or plant-pathogenic biocontrol organisms, or from a combination of current procedures such as harvesting, drawdown, and herbicides with these organisms. Biological control has the objective of achieving control of plants without introducing toxic chemicals or using machinery. It suffers from one ecological drawback; in predator-prey (or parasite-host) relationships, it is rare for the predator to completely eliminate the prey. Consequently, population cycles or oscillations are typically induced for both predator and prey. It is not clear that the magnitude of the upside oscillations in plant populations will be acceptable to human users, and it seems likely that a combination of other techniques with biocontrols may be necessary to achieve lasting, predictable results.

Biological controls include herbivorous fish such as *Ctenopharyngidon idella* (the grass carp), insects such as the aquatic weevil (*Euhrychiopsis lecontei*), and experimental fungal pathogens. Aside from consumptive approaches (grazing, parasitism), it is also possible to exert competitive pressures, limiting invasive species by maintaining a healthy native assemblage.

The grass carp is an non-native fish known to be a voracious consumer of many forms of macrophytes. It has a very high growth rate (about 6 pounds per year at the maximum rate; Smith and Shireman, 1983). This combination of broad diet and high growth rate can produce control or even eradication of plants within several seasons. However, grass carp do not consume aquatic plant species without preference. Generally, they avoid alligatorweed, water hyacinth, cattails, spatterdock, and water lily. These fish prefer plant species such as elodea, pondweeds and hydrilla. Low stocking densities can produce selective grazing on the preferred plant species while other less preferred species, including milfoil, may even increase. Overstocking, on the other hand, may eliminate all plants, contrary to the ecological axiom of oscillating population cycles described previously. Feeding preferences are listed in Nall and Schardt (1980), Van Dyke et al. (1984), and Cooke and Kennedy (1989).

Critical controls include restrictions on the ability of the fish to reproduce (sterile triploid fish vs. reproductive diploid fish) and inlet and/or outlet controls to prevent emigration. Stocking rate calculations are based primarily on qualitative and quantitative characteristics of the lake, with adjustment by region. Rates of up to 70 fish per acre have been used for intended removal of dense assemblages of unpalatable plants, while rates of only 1-2 fish per acre have been used in lakes with a low density of more palatable vegetation. Stocked fish are normally 10-12 inches in length to avoid predation losses. Stocking is typically performed on a 6-year cycle linked to fish mortality.

Grass carp are not approved for introduction in Massachusetts, so additional discussion is not warranted; use of these fish is not a legal option in the Commonwealth.

The use of insects to control rooted plants has historically centered on introduced, non-native species. Ten insect species have been imported to the United States under quarantine and have received U.S. Department of Agriculture approval for release to U.S. waters. These insects are confined to the waters of southern states, specifically to control alligatorweed, hydrilla, water lettuce and water hyacinth, and include aquatic larvae of moths, beetles and thrips (Cooke et al. 1993). These 10 species have life histories that are specific to the host plants and are therefore confined in their distribution to infested areas. They also appear climate-limited to southern states, with the northern range being Georgia and North Carolina. Their reproductive rates are slower than their target plants. Therefore, control is slow, although it can be enhanced by integrated techniques whereby plant densities are reduced at a site with harvesting or herbicides, and insects are concentrated on the remaining plants.

Despite some successes, the track record for biological problem-solving through introduced, non-native species is poor (as many problems seem to have been created as solved), and governmental agencies tend to prefer alternative controls unless there is no practical choice. However, the use of native species in a biomanipulative approach is usually acceptable. Combining biological, chemical and mechanical controls is the basis of integrated pest control, and takes advantage of as many avenues of control as possible for maximum effectiveness. The development of native insects as aquatic plant controls is still in its infancy, but several promising developments have occurred in the last decade, mainly in northern states. The use of larvae of midgeflies, caddisflies, beetles and moths have been explored with some promise (Cooke et al. 1993). However, the activities of the aquatic weevil *Euhrychiopsis lecontei* have received the most attention in recent years.

Euhrychiopsis lecontei is a native North American species believed to have been associated with northern watermilfoil (*Myriophyllum sibericum*), a species largely replaced by non-native, Eurasian watermilfoil (*M. spicatum*) since the 1940's. The weevil is able to switch plant hosts within the milfoil genus, although to varying degrees and at varying rates depending upon genetic stock and host history (Solarz and Newman 1996). It does not utilize non-milfoil species, and does not attack variable milfoil. Its impact on Eurasian watermilfoil was been documented (Creed and Sheldon 1995, Sheldon and Creed 1995, Sheldon and O'Bryan 1996a) through five years of experimentation under USEPA sponsorship. In controlled trials, the weevil clearly has the ability to impact milfoil plants through structural damage to apical meristems (growth points) and basal stems (plant support). Adults and larvae feed on milfoil, eggs are laid on it, and pupation occurs in burrows in the stem.

Plant pathogens remain largely experimental, despite a long history of interest from researchers. Properties of plant pathogens which make them attractive (Freeman 1977) include:

- High abundance and diversity
- High host specificity
- Non-pathogenicity to non-target organisms
- Ease of dissemination and self-maintenance
- Ability to limit host population without elimination

Fungi are the most common plant pathogens investigated, and control of water hyacinth, hydrilla or Eurasian watermilfoil by this method has been extensively evaluated (Charudattan et al. 1989, Theriot 1989, Gunner et al. 1990, Joye 1990). Results have not been consistent or predictable in most cases, and problems with isolating effective pathogens, overcoming evolutionary advantages of host plants, and delivering sufficient inoculum have limited the utility of this approach to date. However, combination of fungal pathogens and herbicides has shown some recent promise as an integrated technique (Nelson et al. 1998).

Summarizing the above information within the context of Bare Hill Pond, we can conclude the following about each potential rooted plant control technique:

1. Benthic barriers - Application of natural (sand) or artificial (screens or sheets) materials to cover plants and prevent growth. This works well on a localized basis, but is very expensive on a larger scale and requires labor-intensive maintenance. For areas such as the public swimming area or private boat docks, this is an appropriate approach.

2. Dredging - As described previously as a depth increase technique, removal of sediments is a true restoration method and has many benefits in plant control. There are many potential negative impacts as well, however, and the cost is typically very high. It does not appear to be a cost-effective option for Bare Hill Pond at this time.

3. Dyes and surface covers - Application of chemical dyes or physical covers will create a light limitation on plant growth. Surface covers will interfere with recreation, however, and currently high natural water color in Bare Hill Pond provides all the benefits which would be expected from chemical dyes. This approach is inappropriate for Bare Hill Pond.

4. Mechanical removal - Cutting, pulling, harvesting, hydroraking, rototilling or otherwise physically damaging plants will reduce plant density and coverage for a few weeks to a few years, depending upon the plant species and technique. On a large scale, expensive machinery is generally necessary to affect results in a reasonable amount of time, as is the case for the Bare Hill Pond harvesting program. With the right equipment and a well-devised plan of operation, however, this is a valid maintenance approach. With modification, the current harvesting program could be far more effective than it has been recently.

5. Water level control - Flooding is unlikely to be effective or appropriate at Bare Hill Pond, so water level control equates with drawdown in this case. Drawdown affects some species more than others, mainly based on whether the species depends on seeds or vegetative propagation for overwinter survival. Most of the problem species in Bare Hill Pond would be impacted by drawdown, but the height of the dam limits the depth of drawdown to slightly less than 4 ft. This approach is highly cost effective, and should be pursued to the extent possible at Bare Hill Pond, but will probably not be sufficient by itself.

6. Herbicides - There are 6 active ingredients on the market today, comprising two general groups: contact and systemic herbicides. Contact herbicides kill only the portion of the plant into which they come in contact, and are unlikely to provide lasting relief. Systemic herbicides can kill the whole plant and may provide benefits for up to 5 years. Fluridone, a systemic herbicide, was developed to have virtually no adverse long-term effects on non-target organisms, but has not been routinely successful in controlling variable milfoil, the primary problem species in Bare Hill Pond. 2,4-D, another systemic herbicide, has greater potential for impact to non-target organisms, but is routinely effective against variable milfoil and can be used in a manner which minimizes risk to non-target organisms. Pilot testing with each appears desirable.

7. Biological introductions - Herbivorous fish (grass carp), herbivorous insects (the milfoil weevil) and pathogenic microbes (mostly fungi) have been used in other lakes with varied success. Grass carp are illegal in Massachusetts, none of the plant species in the pond are significantly affected by herbivorous insects (the milfoil weevil does not attack the species in Bare Hill Pond), and pathogenic microbes appropriate to the Bare Hill Pond plant community are not commercially available. This is therefore not a viable approach in this case.

Based on the above insight and the detail provided here, dyes/surface covers and biological introductions are not deemed applicable to Bare Hill Pond. Benthic barriers are potentially useful on a small scale, especially in the Town swimming area where we are told they have been applied in the past. Dredging is appropriate on a localized or lake-wide basis, but carries a cost in the millions of dollars and will not be considered in greater detail unless the Town expresses a willingness to consider such an expenditure. This leaves drawdown, mechanical removal, and herbicides as the viable means to affect lakewide control over rooted aquatic vegetation.

Drawdown

A drawdown of up to 47 inches is currently underway, and careful monitoring of results is warranted. In terms of long-term control at limited cost, this is the most advantageous technique available when an appropriate outlet structure is already in place. Drawdown has the potential to compact loose, organic sediments, dry and/or freeze out aquatic vegetation which depends on vegetative forms to overwinter, and allows nearshore access for other permittable management actions (e.g., laying benthic barriers, removing debris). Aside from minor costs associated with permitting, managing the outlet and monitoring the drawdown, there is little expense anticipated for the drawdown of Bare Hill Pond.

Common concerns about drawdown revolve around possible impacts on water supply, the ability to refill the lake in the late winter and spring, and possible impacts on overwintering fauna, especially reptiles and amphibians. Wells in the area of Bare Hill Pond tend to be deep, although no detailed analysis has been conducted in this investigation. Flow from a 2675 acre watershed in the early spring in this part of Massachusetts should exceed 12 cfs, suggesting refill from a drawdown of 4 ft in under two months, even allowing some downstream flow during refill.

However, at a drawdown depth of 4 ft, only about 60 acres of Bare Hill Pond bottom will be exposed, leaving plenty of overwintering habitat for aquatic fauna. There is some controversy over the timing of the start of drawdown, with current regulatory policy leaning toward initiation early enough to achieve the targeted drawdown depth before reptiles and amphibians become dormant. This poses no major problem at Bare Hill Pond, although access for some shoreline property owners may be reduced with an early drawdown.

The greatest technical concern about the drawdown of Bare Hill Pond is whether 4 ft will be enough to make a significant difference in water depth or plant community features. Low light penetration limits plant growths at depths >8 ft in this pond, and at depths of >6 ft the plant growths rarely reach the surface, but a drawdown of 4 ft will expose only about 60 acres, leaving 70 to 125 additional acres of potential problem area untreated. The outlet is not constructed to allow a greater drawdown, and a large downstream wetland further limits additional drawdown. Careful tracking of the 1998-99 drawdown in terms of both logistical considerations and effects is strongly advised.

Another limit to drawdown effectiveness is weather. The outlet is not large enough to pass higher flows associated with larger storms or winter thaws, so the average depth of drawdown may be as little as 2-3 ft in a warm, wet winter. Early snow will insulate areas which would otherwise be exposed, limiting both freezing and drying effects. Drawdown is usually recommended as an every-other-year effort, but plans must typically be made to conduct a drawdown every year in order to achieve suitable conditions once every two to three years.

The duration of drawdown can be as little as 1-2 months if conditions are suitable, but it is difficult to refill a lake during sub-freezing winter conditions, and changes in water level once the ice has formed may render the lake surface unsafe for winter recreational pursuits. It is more common to terminate the drawdown in late February or early March, in time to capture the high runoff of the thaw period.

Mechanical Plant Removal

Mechanical removal is currently practiced in the form of harvesting, whereby plants are cut and collected for disposal outside the pond. This is preferable to cutting them without collection, as the pond currently experiences slight oxygen stress and the added decomposition of organic matter could create a more severe problem in this system. Hand pulling is not practical on such a large scale. Rototilling would create too much turbidity in this pond to be acceptable. Other than the current harvesting program, hydroraking would be appropriate in areas of dense water lily coverage, as this technique would disrupt the root system.

If hydroraking were employed, the cost would be expected to be on the order of $6000-10,000/acre, and might provide acceptable results for several years. For a few acres in a cove severely impacted by water lilies, or to remove floating islands resulting from decaying lily root masses, this may be a viable technique. It would not be cost-effective on a large scale in Bare Hill Pond, however.

For larger scale plant control, therefore, the current harvesting approach is most appropriate. Maximizing efficiency is critical to a successful harvesting program, and this generally translates into maximizing actual cutting time. This can be done by:

- Implementing a scheduled maintenance program to repair or replace parts which typically fail after a threshold of use time
- Inspecting all equipment at the end of the day and performing preventive maintenance before the next use instead of waiting for a breakdown
- Having spare parts on hand and readily accessible
- Providing multiple offloading sites to minimize travel distance
- Providing a barge which can make offloading runs while the harvester continues to cut weeds
- Cutting in a pattern which minimizes overlap or passage through "no-cut" areas

Normal harvester lifespan is about 10 to 15 years. While many older harvesters can still be successfully operated after that time, the downtime associated with more frequent repairs becomes a major factor in inefficiency. Additionally, advances in harvester technology have been made; a new harvester should be more effective than an older one, not just less prone to breakdowns. The harvester at Bare Hill Pond is of an older variety, and replacement should be considered. The cost of new harvesters is about $50,000 to $90,000, depending upon the size and features. Auxiliary equipment, such as offloading conveyors, can raise the price to the $120,000 mark, but can greatly increase efficiency.

In contrast, contract harvesting will cost a minimum of $200/acre, with dense areas costing as much as $1500/acre as a function of increased cutting time and the need to offload more often. Harvesting 100 acres of Bare Hill Pond twice per season could carry a contract cost on the order of $100,000 to $150,000 per year. While there are other costs associated with owning and operating a harvester (e.g., labor, insurance, fuel, maintenance), it should be obvious that for a lake such as Bare Hill Pond, the owner-operator route is preferable to contract harvesting.

A harvesting program can also be implemented to maximize impact on the target plants by:

- Harvesting seed-producing annual plants before they can produce and drop their seeds; this is especially true for water chestnut (*Trapa natans*), most pondweeds (*Potamogeton* spp.), and naiad (*Najas* spp.)
- Cutting vegetatively propagating species as close to the bottom as possible; in some cases it may be possible to skim the bottom and disrupt roots as well; this works well for milfoil (*Myriophyllum* spp.), fanwort (*Cabomba caroliniana*), and water celery (*Vallisneria americana*)
- Cutting stems and leaves of species which rely on root stocks, tubers or other root structures to overwinter (and provide nourishment the next spring) at least twice, minimizing food storage; this may work with many species, but is especially suited to water lilies (*Nymphaea* spp., *Nuphar* spp.)

The pattern of harvesting should therefore be designed with the dominant plant species of each area in mind. Some combination of maximized cutting time and a priority order of areas based on plant community composition is needed to attain the greatest impact. It is a useful exercise to get all interested and knowledgeable parties to participate in a strategy session in which the pond would be divided into "harvesting units" (typically representing several days to a week of work) and prioritized for the coming season.

Herbicides

Herbicides have a generally negative connotation in the northeastern USA, but are much more commonly used in the south where large scale control of invasive non-native species is essential to maintaining open water. Historic impacts of herbicides produce some valid concerns, but modern herbicides tend to have far less impact on the aquatic environment that their predecessors. There is always a concern that we will find problems with current herbicides at some future date, but most currently available herbicides have been fairly thoroughly tested. Some consideration of herbicide use is therefore in order.

Of the active herbicide ingredients available, copper is generally not used for vascular plants, and both endothall and diquat (contact herbicides) would have only short-term impact on the plant community of Bare Hill Pond. This leaves glyphosate, 2,4-D and fluridone as possible herbicides. Glyphosate is also a contact herbicide, but is sprayed directly onto targeted floating or emergent vegetation and is not used in the water column. It is very effective on water lilies and smartweed and could be a means to open up some cove areas in Bare Hill Pond. Results will not last much longer than a year, however, and repeat treatments or other means would be necessary to maintain open water. Treatment costs are typically on the order of $500-1000/acre treated.

2,4-D is a systemic herbicide which has a particularly negative connotation for many people as a consequence of its association with defoliants of the Vietnam War era. It is a common ingredient in lawn care products, however, and is a very effective aquatic weed control agent. It has been reported that 2,4-D was the active ingredient in herbicides applied to Bare Hill Pond in the 1960's, and that treatments were successful. This assertion could not be verified by written documents, and no one involved in the actual treatments could be located.

Virtually all current problem species in Bare Hill Pond could be controlled with 2,4-D, although increased growth by fanwort would not be checked by this herbicide. Toxicity to non-target organisms at proper doses is considered low, but this will not assuage the fears of some people. The USEPA has recently reported favorably on the prospects for upcoming re-registration of 2,4-D, citing no unacceptable impacts in numerous studies. It could be used to control variable milfoil and several other Bare Hill Pond problem plants at a cost of about $300-800/acre treated. Duration of impact should be at least a year, and could be as great as 5 years. The primary problem with the use of 2,4-D will be public acceptance.

Fluridone is the newest registered aquatic herbicide available, and acts as a systemic agent to inhibit critical pigment synthesis in plants. Not all plant species are equally affected, facilitating more selective removal of target species with greater sensitivity to fluridone at lower doses. Fluridone is also the only herbicide with demonstrated effectiveness against fanwort, a seemingly new species in Bare Hill Pond that could eventually rival variable milfoil for dominance. No toxicity to aquatic fauna has been observed in actual treatments in this geographic area, to the best of our knowledge.

It should be noted that control of variable milfoil (*Myriophyllum heterophyllum,* the milfoil species in Bare Hill Pond) by fluridone has not been consistent. Successful control of variable milfoil has been accomplished at Flanagans Pond in Ayer and at Pond Meadow and Eatons Ponds in Braintree, while treatment in a number of other lakes has not provided the desired level of control. Dose appears to be a major factor. Eurasian milfoil, fanwort and most other targeted aquatic plants will be affected at a dose of <30 ppb, but control of variable milfoil may require doses of 35 to 70 ug/L.

Use of fluridone to control variable milfoil will therefore not allow selective control. Recovery by any seed producing species would be expected the following year, and water lilies are also expected to recover to some extent, but most aquatic vegetation would be eliminated at these higher doses during the treatment year. There may be other factors in the success or failure of fluridone for variable milfoil control which have not yet been discovered.

The advantages of fluridone, which is marketed under the tradename "Sonar", include very low toxicity to non-target organisms, slow elimination of target plants such that oxygen depression is minimized, and longer lasting control by virtue of elimination of the entire plant (i.e., roots, shoots and leaves). High initial treatment cost is a negative factor in the use of fluridone; typical costs are $500-1000/acre treated for single liquid treatment, up to $2000/acre for sequential liquid treatments, and $800-1200/acre for slow release pellet applications. However, if 3-5 years of control are achieved, the total cost is no more than for other herbicides. Also, the slow rate of action becomes a drawback in combination with high solubility; the herbicide will move throughout the treated system rapidly and may be diluted or flushed out of the system before it can be absorbed to the extent necessary to be effective. The central question is whether or not fluridone will work on variable milfoil in Bare Hill Pond.

In a case such as Bare Hill Pond, where less than a third of the pond area and even less of the pond volume has a plant problem, it would not be cost-effective to treat the entire pond area. Sequestering selected areas with impermeable curtains (the prime manufacturer of which is located in Massachusetts) is an attractive option, but has not yet been attempted with a fluridone treatment. Preparatory dye tests have been conducted in several lakes, however, with acceptable results, and such an approach has been applied with 2,4-D in a lake in Wisconsin. It is not essential to sequester areas to be treated with 2,4-D to gain effectiveness, but this will limit the impact zone.

Some combination of glyphosate, 2,4-D and fluridone could be used to achieve control of rooted vegetation in Bare Hill Pond, and a pilot program would be desirable to develop the most appropriate approach in this case. Public acceptance may play a large role in whether or not herbicides are applied, but a pilot scale program represents an opportunity to evaluate effectiveness and non-target impacts on a small area with minimal risk to the lake ecosystem as a whole. There is no need to test glyphosate, as it may not be needed at all and its impacts and side effects are well understood. The key would be to demonstrate the effectiveness of fluridone and/or the lack of negative side effects by 2,4-D in a controlled test which all interested residents of Harvard could observe.

Recommended Approach
The following management recommendations are offered for in-lake management of Bare Hill Pond:

1. **Implement and closely monitor the current drawdown.** Attempt to achieve the full 47-inch water level decline, and monitor water level and flow on at least a weekly basis at the outlet through refill of the pond next spring. Estimate the duration and degree of exposure of the pond bottom at each elevational gradient (0.5 ft increments recommended). It would be desirable to measure sediment elevation relative to some stationary objects (e.g., dock surface, rock outcrop) for later comparison to assess any compaction. Locate a suitable weather station (most likely via the internet) to obtain records for temperature and precipitation, or begin a local weather tracking program.

   Allow at least 10-20% of the spring flow to pass through the outlet during the refill period; a flashboard with holes in it works well in this regard. Re-assess plant community features along the transects set up in this study next summer and evaluate drawdown impacts. Provide a working guidance manual for future drawdowns. A cost of $10,000 to $15,000 could be incurred for outside help, but the pond committee and other interested parties may be able to manage this program at no cost to the Town.

   Plan to conduct the drawdown again in 1999-2000. A lack of major change after only one year of drawdown should not be construed as a failure of the technique, given the importance of weather and sediment conditions. As many as 3 to 4 consecutive years of drawdown may be necessary to achieve maximal impact.

2. **Adjust the current harvesting program to maximize efficiency.** Virtually all of the suggestions made in the discussion of harvesting efficiency and maximizing impact are applicable to the program at Bare Hill Pond:
   - Implement a scheduled maintenance program
   - Inspect all equipment at the end of the day
   - Have parts available and make repairs as needed
   - Provide multiple offloading sites to minimize travel distance
   - Provide a barge for hauling weeds from the harvester to the off-laoding area(s)
   - Cut in a pattern which minimizes overlap or passage through "no-cut" areas
   - Harvest seed-producing annual plants before they can release seeds
   - Cut vegetatively propagating species as close to the bottom as possible
   - Cut areas of non-seed producing species at least twice per season

   Convene a meeting of appropriate parties to develop a detailed harvesting plan, with contingencies. Plan for the acquisition of a new harvester and accessory equipment. The harvesting plan would have no cost if done by a Town committee, but some professional aid might be desirable at a cost of $1000 to $2000. New equipment could cost as much as $150,000, but it may be possible to acquire at least a new harvester for as little as $50,000 to $75,000.

3. **Perform a pilot herbicide treatment program.** Use an impermeable curtain to sequester a cove or other target area with dense rooted plant growths, sub-divide it into two roughly equal parts, then treat with fluridone or 2,4-D (one in each part) at a level appropriate to eliminate most vegetation. Response of variable milfoil to fluridone has not been consistent in other lakes; neither SePro (the distributor) nor reputable applicators will guarantee its success with this species. At least temporary success is very likely with 2,4-D, but this herbicide was developed with less concern for non-target organisms than fluridone. No adverse impacts are expected at the proper 2,4-D dose, and sequestering the area would localize any unanticipated impacts. This side-by-side test will demonstrate the impacts of each herbicide in a controlled manner with no risk to the lake as a whole.

   Treatment should occur in mid- to late spring. Monitor the plant community the summer before the treatment and for one to three years afterward. It would also be desirable to monitor other biological components during this period, including use of the area by populations of invertebrates, fish, reptiles and amphibians. Cost will depend upon the size of the chosen treatment area, herbicide(s) applied, and the details of the monitoring program. Assuming a roughly 10-acre area, a cost of up to $40,000 is envisioned. This would include permitting, the curtain, treatment, and monitoring of plants, invertebrates, fish, reptiles and amphibians in the target area. Minimizing contracted costs to just the curtain and treatment, the cost could be as little as $10,000-$15,000, but the monitoring would appear to be essential for demonstration purposes.

4. **Use benthic barriers to ensure acceptable plant densities in the Town swimming area.** If the previously installed barriers are useable, maintain them. Otherwise, install and maintain a benthic barrier if rooted aquatic plants are a nuisance in this area. This may not be a necessity in the near future, but a large number of lake users could be accommodated by such a program if the swimming area is seriously impacted by plant growths. An initial cost of up to $50,000 is expected, with annual maintenance costs of about $4000.

5. **Be mindful of opportunities to get selected areas of the pond dredged.** Although a major program would seem out of the fiscal picture, grant programs or contractors in need of material could make at least partial dredging a possibility on an opportunistic basis. At least two lakes in Massachusetts have been dredged at minimal cost to the respective Towns in the last decade, and another was partially dredged at limited cost, all because a contractor had a need for the material. It is not worth spending a substantial amount of money on plans or permits at this stage, but do not assume that there is no possibility of any dredging taking place at Bare Hill Pond at some future date.

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Table D-1. Transect A - Plant Community Data, September 2, 1998.

A - 1	---																							
A - 2	3.0	5	5			95			1	1	1			1	1									
A - 3	3.9	3H	2	15	15			15		15	15					25								
A - 4	4.0	4H	3	30	15			10		10	10					25								
A - 5	4.3	4H	4	75	10			10		3	2													
A - 6	4.8	5H	4	40	40					10	10													
A - 7	6.0	4H	3	40	40				t	t							10							
A - 8	6.5	2	2	20	60		5			5							10							
A - 9	8.5	0	0		t																			
A - 10	10.0	0	0																					
A - 11	12.0	0	0																					
A - 12	7.0	1	1		60					10							30							
A - 13	2.0	2	2									20					10	20	50					

Plant Species:

B.s.	Brasenia Schreberi	M.h.	Myriophyllum heterophyllum	P.sp.	Potamogeton sp.
C.car.	Cabomba caroliniana	Ni.f.	Nitella flexilis	P.spir.	Potamogeton Spirillus
C.d.	Ceratophyllum demersum	N.v.	Nuphar variegatum	S.g.	Sagittaria graminea
El.ac.	Eleocharis acicularis	N.o.	Nymphaea odorata	Ut.p.	Utricularia purpurea
FG/BG	Filementous Green alga	Poly	Polygonum sp.	Ut.v.	Utricularia vulgaris
	Blue Green algae	P.amp.	Potamogeton amplifolius	W.c.	Wolffia columbiana
Iso.	Isoetes spp.	P.epi.	Potamogeton epihydrus		
L.m.	Lemna minor	P.rob.	Potamogeton Robbinsii		

Cover Rating:
0 = 0%; 1 = 1 - 25%; 2 = 26 - 50%; 3 = 51 - 75%; 4 = 76 - 99; 5 = 100%

H = Harvested area
t = Trace amount

Volume Rating:
0 = 0%; 1 = 1 - 25%; 2 = 26 - 50%; 3 = 51 - 75%; 4 = 76 - 99; 5 = 100%

Table D-2. Transect B - Plant Community Data, September 2, 1998.

																					P.amp.	P.sp.	P.spir.
B - 1	2.5	4	4	20	20			10	30	10	10												
B - 2	3.5	4	4	80	20																		
B - 3	3.0	5	5	40	10			40		5	5												
B - 4	3.0	4H	4	80	20																		
B - 5	3.5	4H	4	80	5			5		5	5												
B - 6	3.5	4H	4	70	15			5		5	5												
B - 7	4.0	4H	3	70	15			5	t	5	5												
B - 8	4.0	4H	4	75	10			5	t	5	5	t											
B - 9	4.0	4H	4	75	5			5	5	5		5											
B - 10	3.0	4	4	50	20	10		5	5	5											5	t	

<u>Plant Species:</u>

B.s.	Brasenia Schreberi	M.h.	Myriophyllum heterophyllum	P.sp.	Potamogeton sp.
C.car.	Cabomba caroliniana	Ni.f.	Nitella flexilis	P.spir.	Potamogeton Spirillus
C.d.	Ceratophyllum demersum	N.v.	Nuphar variegatum	S.g.	Sagittaria graminea
El.ac.	Eleocharis acicularis	N.o.	Nymphaea odorata	Ut.p.	Utricularia purpurea
FG/BG	Filementous Green alga Blue Green algae	Poly	Polygonum sp.	Ut.v.	Utricularia vulgaris
		P.amp.	Potamogeton amplifolius	W.c.	Wolffia columbiana
Iso.	Isoetes spp.	P.epi.	Potamogeton epihydrus		
L.m.	Lemna minor	P.rob.	Potamogeton Robbinsii		

H = Harvested area
t = Trace amount

<u>Cover Rating:</u>
0 = 0%; 1 = 1 - 25%; 2 = 26 - 50%; 3 = 51 - 75%; 4 = 76 - 99; 5 = 100%

<u>Volume Rating:</u>
0 = 0%; 1 = 1 - 25%; 2 = 26 - 50%; 3 = 51 - 75%; 4 = 76 - 99; 5 = 100%

Table D-3. Transect C - Plant Community Data, September 2, 1998.

C - 1	4.0	2	3	25	25						25									25				
C - 2	6.0	4	3	20	70						10													t
C - 3	7.5	3	3	90							10													
C - 4	9.0	0	0														t							
C - 5	12.0	0	0																					
C - 6	10.0	0	0														t							
C - 7	5.5	3	2	10	90												t							
C - 8	5.0	2	2	10	70							10									10			

Plant Species:

B.s.	Brasenia Schreberi	M.h.	Myriophyllum heterophyllum	P.sp.	Potamogeton sp.
C.car.	Cabomba caroliniana	Ni.f.	Nitella flexilis	P.spir.	Potamogeton Spirillus
C.d.	Ceratophyllum demersum	N.v.	Nuphar variegatum	S.g.	Sagittaria graminea
El.ac.	Eleocharis acicularis	N.o.	Nymphaea odorata	Ut.p.	Utricularia purpurea
FG/BG	Filementous Green alga	Poly	Polygonum sp.	Ut.v.	Utricularia vulgaris
	Blue Green algae	P.amp.	Potamogeton amplifolius	W.c.	Wolffia columbiana
Iso.	Isoetes spp.	P.epi.	Potamogeton epihydrus		
L.m.	Lemna minor	P.rob.	Potamogeton Robbinsii		

Cover Rating:
0 = 0%; 1 = 1 - 25%; 2 = 26 - 50%; 3 = 51 - 75%; 4 = 76 - 99; 5 = 100%

H = Harvested area
t = Trace amount

Volume Rating:
0 = 0%; 1 = 1 - 25%; 2 = 26 - 50%; 3 = 51 - 75%; 4 = 76 - 99; 5 = 100%

Table D-4. Transect D - Plant Community Data, September 2, 1998.

Transect	Depth (ft)	Cover Rating	Volume Rating	Plant Species and Approximate Percent Coverage																				
				M.h.	P.rob.	Poly	N.v.	Ni.f.	B.s.	Ut.p.	Ut.v.	S.g.	N.o.	L.m.	W.c.	C.d.	FG/BG	P.epi.	El.ac.	C.car.	Iso.	P.amp.	P.sp.	P. spir.
D - 1	2.5	3	3	40	40						10	10												
D - 2	3.0	3	3	40	40						10	10												
D - 3	3.0	3	3	45	45						5	5												
D - 4	3.5	3	3	40	40						10	10												
D - 5	4.0	4	3	60	5					5	30													
D - 6	4.0	4	4	75	10		5				10													
D - 7	4.0	3	3	45	45					t	t	10												
D - 8	4.5	3	3	40	40						10						t							
D - 9	5.0	1	1	15	60		15										t							
D - 10	5.0	2	1	50	15		10				10	10					t							
D - 11	6.0	4	3	80	10						10	15					t							
D - 12	6.0	2	2	10	90												t							
D - 13	7.0	1	1	25	25						25	25					t							

Plant Species:

B.s.	Brasenia Schreberi	M.h.	Myriophyllum heterophyllum	P.sp.	Potamogeton sp.
C.car.	Cabomba caroliniana	Ni.f.	Nitella flexilis	P.spir.	Potamogeton Spirillus
C.d.	Ceratophyllum demersum	N.v.	Nuphar variegatum	S.g.	Sagittaria graminea
El.ac.	Eleocharis acicularis	N.o.	Nymphaea odorata	Ut.p.	Utricularia purpurea
FG/BG	Filementous Green alga	Poly	Polygonum sp.	Ut.v.	Utricularia vulgaris
	Blue Green algae	P.amp.	Potamogeton amplifolius	W.c.	Wolffia columbiana
Iso.	Isoetes spp.	P.epi.	Potamogeton epihydrus		
L.m.	Lemna minor	P.rob.	Potamogeton Robbinsii		

H = Harvested area
t = Trace amount

Cover Rating:
0 = 0%; 1 = 1 - 25%; 2 = 26 - 50%; 3 = 51 - 75%; 4 = 76 - 99; 5 = 100%

Volume Rating:
0 = 0%; 1 = 1 - 25%; 2 = 26 - 50%; 3 = 51 - 75%; 4 = 76 - 99; 5 = 100%

Table D-5. Transect E - Plant Community Data, September 2, 1998.

																							P.spir
E - 1	4.0	2	2	20	20					20	20	20											
E - 2	4.0	4	2	10	75					5	5	5											
E - 3	6.0	4	2	10	75					5	5	5											
E - 4	6.5	4	3	40	40						10								10				
E - 5	8.0	3	3	100																			
E - 6	9.0	1	1	80	20																		
E - 7	9.0	1	1	100																			
E - 8	10.0	1	1		100																		

Plant Species:

B.s.	Brasenia Schreberi
C.car.	Cabomba caroliniana
C.d.	Ceratophyllum demersum
El.ac.	Eleocharis acicularis
FG/BG	Filementous Green alga Blue Green algae
Iso.	Isoetes spp.
L.m.	Lemna minor
M.h.	Myriophyllum heterophyllum
Ni.f.	Nitella flexilis
N.v.	Nuphar variegatum
N.o.	Nymphaea odorata
Poly	Polygonum sp.
P.amp.	Potamogeton amplifolius
P.epi.	Potamogeton epihydrus
P.rob.	Potamogeton Robbinsii
P.sp.	Potamogeton sp.
P.spir.	Potamogeton Spirillus
S.g.	Sagittaria graminea
Ut.p.	Utricularia purpurea
Ut.v.	Utricularia vulgaris
W.c.	Wolffia columbiana

H = Harvested area
t = Trace amount

Cover Rating:
0 = 0%; 1 = 1 - 25%; 2 = 26 - 50%; 3 = 51 - 75%; 4 = 76 - 99; 5 = 100%

Volume Rating:
0 = 0%; 1 = 1 - 25%; 2 = 26 - 50%; 3 = 51 - 75%; 4 = 76 - 99; 5 = 100%