LAKE AND WATERSHED MANAGEMENT PLAN

FOR

STOCKBRIDGE BOWL,

STOCKBRIDGE, MASSACHUSETTS

FUGRO

6 Maple St.
Northboro, MA
01532

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Prepared for
The Stockbridge Board of Selectmen
and
The Stockbridge Bowl Association

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December 1996

TABLE OF CONTENTS

TABLES

FIGURES

SYNOPSIS

Stockbridge Bowl suffers from an infestation of Eurasian watermilfoil and occasional algal blooms, causing navigational and recreational impairment and deterioration of overall habitat quality. Numerous reports and correspondence have been reviewed and summarized in this document. Milfoil has been present in Stockbridge Bowl for about 50 years and dominant for the last 20 years. Harvesting and a slight winter drawdown currently improve recreational utility in some areas, but do not keep milfoil in check. Internal lake processes are more important influences on the short term water chemistry of Stockbridge Bowl than current watershed inputs, and the milfoil problem is largely independent of water chemistry. The current primary objective of a management program for Stockbridge Bowl is the control of milfoil, while the secondary objective is the enhancement of overall water quality for both recreational and habitat purposes.

Evaluation of rooted plant management options reveals that viable alternatives for milfoil control include continued harvesting and greater drawdown facilitated by selective dredging. Greater drawdown is recommended, at least to 4 ft. and possibly to 8 ft., but must be facilitated by a pipe or siphon to bypass four existing pipelines which cross the outlet, deepening of the area between the island and the outlet spillway, and connection of the outlet with deeper lake waters via one or two channels around the island. Implementation of drawdown is further complicated by concerns by regulatory agencies regarding possible impacts on two protected snail species in the lake. Recommendations are made in this report for the alleviation of those concerns. Drawdown provides both expansive and flexible control and is considered the preferred choice for milfoil management in Stockbridge Bowl based on experience elsewhere. Continued harvesting is recommended as a supplementary control technique, primarily to manage growths beyond the drawdown zone.

Actual drawdown carries little operational cost, but the needed pipe to bypass the gas and sewer pipelines had previously been estimated to cost on the order of $100,000. The dredging program necessary to facilitate a 5.5 ft. drawdown depth had been previously estimated to cost approximately $350,000. Drawdown to a depth of 8 ft. may be possible with additional dredging and possibly pumping, at an added capital cost of at least $150,000. These estimates of probable cost may require revision as part of a dredging feasibility assessment. Additional costs for permitting and monitoring should be included.

Realizing that this approach is expensive, costs should be shared in an appropriate manner by all interested parties, including lakefront homeowners on the main lake and those along the outlet channel through the Stockbridge Bowl Association, the Town of Stockbridge, the Commonwealth, and others, including private and institutional donors. Grants from private foundations and public institutions are viewed as potential sources of funds for this project.

A tentative timetable for accomplishing the necessary steps, including arranging for funding, follows this summary for easy reference. The schedule provides for the continuation of harvesting, which complements the control achievable through drawdown. A new harvester has been purchased and the annual operating cost is estimated at approximately $35,000 for two summer harvests of 100 acres of milfoil-infested area.

It is also recommended that a program of detention capacity expansion and maintenance be implemented, centering on former detention areas along Lily Brook and Shadow Brook. Education of watershed residents and eventual control of internal phosphorus recycling are also proposed.

IMPLEMENTATION SCHEDULE

The primary elements of the implementation schedule are obtaining adequate funds, completing the necessary supplementary investigations for design verification and permit application preparation, acquiring the necessary permits, and performing the construction tasks which will facilitate achievement of management goals. Although some overlap is likely, these elements would occur in the order listed.

Funding is critical to any project, and the need to raise over $500,000 will probably cause some attenuation of the project timeline. Supplementary investigations and preparation of permit applications can commence once a modest supply of funding has been generated, while actual implementation will require that virtually all needed funds be in hand. Given limited windows of opportunity and substantial lead time for many grants or public funds, the use of such funds will require an approximately one year timeframe, assuming an acceptable success rate. Funds from private donors or institutions may be obtainable in a shorter period of time, but some number of months is still expected as a lead time. Consequently, funding this project is likely to require at least a year of effort, and could require substantially more time.

The supplementary investigations necessary to move this project forward (see the Additional Information Needs section of this report) will require some months of time to complete, but are not especially influenced by season or administrative constraints. These tasks could therefore be completed within the period of fundraising and should not limit project progress.

The timeframe for the actual permitting process depends on the actions to be permitted, and is not always predictable, as requests for additional information, continuations of hearings, and appeals can extend the process. The most complicated anticipated action, drawdown facilitated by dredging and pipe installation, should require 2 to 3 months to acquire an Order of Conditions from the local Conservation Commission (assuming no appeal at the DEP level), a partly overlapping 4 months to receive the Section 401 Water Quality Certificate (issued by the DEP under authority of Federal Law), a largely overlapping 3 to 4 months to obtain the Section 404 Permit (issued by the Army Corps of Engineers), and a partly overlapping 6 months to be granted a Chapter 91 Waterways License (for work in a Great Pond, issued by the DEP). All totalled, it could take as little as 6 months to move through the permitting process, or as much as 18 months. The actual initiation of these approval processes is often delayed, however, by the MEPA process, under which an Environmental Notification Form must be filed for multi-agency review and through which an Environmental Impact Report is often required for a project of this magnitude. This can add over a year to the permitting timeline, suggesting a possible 2+ year permitting process which would outlast a successful fundraising effort.

Harvesting is minimally controversial and requires only an Order of Conditions from the local Conservation Commission. This action should be permitted separately and could be approved within 2 to 3 months. Other actions, such as the restoration of detention capacity along Lily or Shadow Brook, would have an intermediate timeframe. The timeframe for actual construction is task specific, with the dredging and pipe installation requiring about half of one year to complete. All other tasks would require less time, although tasks such as harvesting would proceed over a 3 to 4 month period on an annual basis.

In summary, some management actions could be implemented for the summer of 1997, but the top priority item, increased drawdown, will require about 2 years lead time if fundraising and permitting processes proceed at the anticipated rates.

SUMMARY OF STOCKBRIDGE BOWL INFORMATION

INTRODUCTION

Stockbridge Bowl, also known as Lake Mahkeenac, is located in the north central portion of the Town of Stockbridge (Figure 1). With a surface area of approximately 370 acres, it is the fifth largest lake in Berkshire County and is part of the Housatonic River Basin. Stockbridge Bowl is bounded to the east by Rattlesnake Mountain, to the north by Bald Head and to the west by Lenox Mountain, and is located at an elevation of 925 feet. General features of Stockbridge Bowl and its watershed are given in Table 1.

Stockbridge Bowl is used heavily by the public for recreational purposes. The lake supports warm and cold water fisheries and is stocked annually with trout. The shoreline contains a number of access points, beaches and a public boat launch. Boaters on the lake utilize a number of vessel types, including motorboats, personal watercraft, rowboats, sailboats, and canoes. Tanglewood Performing Arts Center is located adjacent to the lake, furthering human interaction with the aquatic environment.

The following sections give a brief summary of past lake studies and management practices that have taken place at Stockbridge Bowl and in its surrounding watershed. Over the years, the lake has exhibited a number of problems that have detracted from its usefulness as a valuable recreational resource and as an aquatic habitat in general. Some of these problems include nuisance aquatic vegetation, occurrence of blue-green algal blooms, low water clarity, severe hypolimnetic oxygen depletion, and insufficient cold-water fisheries habitat. Many of these problems are symptomatic of lake eutrophication, a natural process that was undoubtedly exacerbated by man's influence within the watershed. A brief summary of past studies and management practices dealing with these problems will provide context for the formulation of a future comprehensive management plan.

The reported information is based solely on the reviewed reports, and represents the data and interpretations of the authors of those reports. Fugro has refrained from interpretation of the results of past studies in this review beyond what is necessary to clarify excerpts. Interpretative assessment will be provided separately, later in this report. An annotated bibliography of reviewed reports and correspondence can be found in Appendix A.

Figure 1. Stockbridge Bowl Site Location Map.

Table 1. Morphometric and Hydrologic Data for Stockbridge Bowl.

A. General Features

	Metric	English
Watershed Area	2,969 ha	7,336 acres
Maximum Length	2,057 m	6,748 ft
Maximum Width	1,134 m	3,720 ft
Maximum Depth	14.6 m	47.9 ft
Mean Depth	6.8 m	22.3 ft
Area	155 ha	382 acres
Volume	10,540,000 m^3	8,566 ac-ft
Length of Shoreline	5,372 m	17,624 ft
Major Tributaries	5	
Flushing Rate	2.0 /yr	
Residence Time	0.5 yr	

B. Water volume between given depth intervals

depth interval (m)	millions of cubic meters	millions of cubic feet
0-2	2.66	93.9
2-4	2.27	80.2
4-6	1.96	69.2
6-8	1.66	58.6
8-10	1.19	42.0
10-12	0.62	21.9
12-14	0.22	7.8
14-15	0.01	0.4
Total	10.59	374

C. Area of sediment below given water depth

depth (m)	m^2	ft^2
0	1,450,000	15,558,500
2	1,213,000	13,015,490
4	1,053,000	11,298,690
6	909,000	9,753,570
8	750,000	8,047,500
9	595,000	6,384,350
10	440,000	4,721,200
11	313,000	3,358,490
12	186,000	1,995,780
13	108,000	1,158,840
14	31,000	332,630

LYCOTT DIAGNOSTIC / FEASIBILITY STUDY 1991

A Diagnostic / Feasibility Study was conducted for Stockbridge Bowl during the late 1980's by Lycott Environmental Research, Inc., with partial funding from the MA DEP. The final report was submitted to the Town of Stockbridge and the Massachusetts Division of Water Pollution Control in 1991. This document contains a compilation of important data and recommendations concerning Stockbridge Bowl. To date, it represents the seminal characterization of the lake and forms the basis for management efforts by the Town of Stockbridge and the Stockbridge Bowl Association. What follows is a brief summary of the more salient points from that document that are important for future lake management planning.

Watershed

The Stockbridge Bowl watershed lies within the Housatonic River Basin in western Massachusetts. The watershed is predominately located within the Town of Stockbridge, but portions lay within the towns of Richmond, Lee and Lenox. The topography varies throughout the watershed, including steeply sloped mountains at the shoreline and periphery along with moderately sloping areas throughout. Due to the surface layer of low permeability glacial till that covers most of the watershed of Stockbridge Bowl, groundwater flow into the lake was predicted to be relatively low. This is consistent with results of other Berkshire County lakes. Surface runoff from the surrounding watershed reaches the Bowl via 5 major tributaries. Table 2 gives the land uses within the Stockbridge Bowl watershed.

Hydrologic Budget

Two annual hydrologic budgets were developed for Stockbridge Bowl. One used data generated from sample collection and measurements during 1987 and 1988. The other long-term budget depends on average data for the region. The results of each are given in Table 3.

Lake Chemistry

The hypolimnion appears to undergo severe oxygen depletion during the period of summer thermal stratification. During the summer of 1988, hypolimnetic waters exhibited average dissolved oxygen concentrations of 1.0 mg/L over the course of 9 samplings. This low dissolved oxygen concentration could allow for the recycling of phosphorus from the bottom sediments.

Table 4 gives the average values from epilimnetic and hypolimnetic lake chemistry components as measured throughout 1988.

Table 2. Land Use in the Stockbridge Bowl_Watershed.

Land Use	Total Acreage	% of Watershed [1]
Woodland	4477	64.4
Residential	1080	15.5
Open Land	778	11.2
Agricultural	350	5.0
Wetland [2]	246	3.9

[1] Excluding Stockbridge Bowl

[2] Including Lily Pond

Table 3. Annual Water Inputs to Stockbridge Bowl.

A. Calculated inflows from 1988-89 data

	cubic meters	%
Tributary Base Flow	7,890,200	56.5
Storm Runoff	2,531,800	18.1
Direct Subsurface Flow	1,972,500	14.1
Direct Precipitation	1,581,800	11.3
Total Water Input	**13,976,300**	**100**

B. Calculated inflows from long-term data

	cubic meters	%
Tributary Base Flow	12,921,600	60.9
Storm Runoff	3,094,400	14.6
Direct Subsurface Flow	3,230,400	15.2
Direct Precipitation	1,959,800	9.3
Total Water Input	**21,206,200**	**100**

Table 4. Average Lake Chemistry Results for Stockbridge Bowl, 1988-89.

	units	epilimnion	hypolimnion
secchi depth	m	2.4	
chlorophyll a	mg/m^3	7.8	
Total Phosphorus	mg/L	0.038	0.183
Nitrate Nitrogen	mg/L	0.17	0.17
Ammonium Nitrogen	mg/L	0.04	0.99
TKN	mg/L	0.34	1.39
pH	SU	7.7	7.1
Alkalinity	mg/L	120	134
Chloride	mg/L	18	19
Specific Conductance	umhos	245	264
TSS	mg/L	5.0	16.0
Turbidity	NTU	4.0	6.0

Limiting Nutrient

A limiting nutrient analysis was conducted for Stockbridge Bowl by comparing the relative concentrations of the two most commonly limiting nutrients: phosphorus and nitrogen. Total nitrogen and total phosphorus ratios (TN/TP) were used and values below 10 were believed to reflect a nitrogen limited system, while values above 17 suggest a phosphorus limited system. TN/TP ratios between 10 and 17 reflect a phosphorus and/or nitrogen limited system.

Limiting nutrients of the epilimnion and photic zone were considered most important as that is where the majority of the productivity from macrophytes and algae occurs. Fourteen of the 17 surface water samplings that occurred in 1988 suggested TN/TP ratios indicative of phosphorus limited conditions. Thus it was considered that phosphorus was the limiting nutrient in Stockbridge Bowl.

Phosphorus Budget

Two methods were implemented in determining the phosphorus budgets for Stockbridge Bowl, a long-term and a short-term method. The long-term budget was calculated using data from published phosphorus export patterns for the land use types that exist in the watershed. The short-term method involves extrapolation of actual measurements of phosphorus inputs and outputs over the year. The long-term method is more simplistic but is not subject to aberrations that may occur during a single sampling year. Table 5 gives the long-term and short-term phosphorus budgets for Stockbridge Bowl.

Phosphorus Modeling

Table 6 gives the results of phosphorus modeling for both the long and short-term phosphorus budgets. Data collected from 1987 and 1988 revealed an average surface water phosphorus concentration of 0.038 mg/L. This matches closely the value 0.0325 mg/L produced using the Reckhow model for lakes with an anoxic hypolimnion. Using this same model and assuming an oxygenated hypolimnion gives a value of 0.019 mg/L of phosphorus. This suggests that if the hypolimnion of Stockbridge Bowl remained sufficiently oxygenated, the phosphorus levels of the epilimnion would be half of the current actual average value.

Phytoplankton

The phytoplankton community of Stockbridge Bowl is dominated by *Anabaena* in the winter months and *Cyclotella* in the summer months. Blooms of *Oscillatoria rubescens* have reportedly occurred. A composition such as this reflects a eutrophic system where periodic phytoplankton blooms are expected, but does not indicate severe water quality problems often typified by sequential bluegreen blooms throughout the summer.

Table 5. Phosphorus Load Summaries for Stockbridge Bowl.

A. Calculated from 1988-89 data

	P Load (kg/yr)	% of Total
Tributary Base Flow	160.4	14.3
Storm Flow	343.6	30.7
Groundwater	10.5	0.9
Anoxic Sediments		
summer release	438.0	39.1
winter release	117.2	10.5
Wet and Dry Precip.	50.4	4.5
Total	**1120.1**	**100.0**

B. Calculated from average land use phosphorus exports

	P Load (kg/yr)	% of Total
Land Use Exports		
Forested	363.9	26.7
Open	142.6	10.5
Wetland	0.0	0.0
Residential		
Forested	30.2	2.2
Med. Density	3.0	0.2
Light Density	36.2	2.7
Garden Apt.	34.8	2.6
Public Lands	102.1	7.5
Recreat. Land	3.2	0.2
Septic Systems	42.2	3.1
Anoxic Sediments		
summer release	438.0	32.1
winter release	117.2	8.6
Wet and Dry Precip.	50.4	3.7
Total	**1363.7**	**100.0**

Table 6. Model Predictions of Average Phosphorus Concentrations in Stockbridge Bowl.

A. Calculated using long-term data

External P-loading: 808 kg/yr

Flushing Rt.: 1.94/yr

Model	Predicted P (mg/L)
Anoxic hypolimnion	
Reckhow	0.0325
Oxygenated hypolimnion	
Reckhow	0.0190
Vollenweider	0.0225
Dillon-Kirchner	0.0198

B. Calculated using 1988-89 data

External P-loading: 564.9 kg/yr

Flushing Rt.: 1.24/yr

Model	Predicted P (mg/L)
Anoxic hypolimnion	
Reckhow	0.0336
Oxygenated hypolimnion	
Reckhow	0.0167
Vollenweider	0.0196
Dillon-Kirchner	0.0167

Macrophyte Community

From surveys conducted during 1988 and 1989, dense growths of macrophytes were noted throughout the littoral zone of Stockbridge Bowl. The major problem macrophyte was *Myriophyllum spicatum* (Eurasian watermilfoil) which infested approximately 160 acres. The infestation occurs in water depths from 3 to 20 feet. *Potamogeton* species were also detected throughout the littoral zone and found to be at nuisance levels in approximately 50 acres. Plant densities along the majority of the shoreline tended to be moderate to dense, while the outlet channel assemblage was considered very dense. The nearshore areas around the lake (< 2 foot water depth) revealed a low density macrophyte community which was attributed to the annual drawdown of the lake water level since 1981.

This macrophyte situation resembles very closely what was reported in previous studies in 1971, 1980 and 1981. However, surveys during the mid 1970's report a significantly less dense plant community that was dominated by *Chara* species. This change in the plant community makeup was attributed to the use of organic herbicides during the mid-seventies, a practice that ended by the late seventies. In other words, a known problem with macrophytes was controlled for a brief period with herbicides, then allowed to revert to nuisance conditions. The problem of nuisance macrophyte densities was not determined to be the result of recent increased nutrient availability. Actually, the sources of available nutrients from the watershed appear to have decreased with the sewering of the southern shore and a decrease in agriculture. Thus, the methods used for controlling macrophyte growth should not be focused on controlling nutrient inputs from the watershed.

Feasibility and Recommended Management Options

Reducing Internal Phosphorus Loading

Sediment sealing with alum treatments was considered as a possible means to control phosphorus release from sediments. The high alkalinity values of Stockbridge Bowl are substantial enough to keep unwanted dissolved aluminum levels to a minimum. A projected dosage of 37 g of aluminum per square meter would be needed to treat the sediments below a depth of 8 meters in the lake. The surface area of the sediments below 8 meters is approximately 750,000 m^2. This works out to 27,750 kg of aluminum or 75,300 gallons of alum, totaling an estimated $231,000 for a single alum treatment. It is estimated that a single alum treatment would be effective in controlling phosphorus for 8-12 years, after which another treatment would be needed. Over time, alum treatments average approximately $30,000 per year.

After considering the other alternatives for controlling phosphorus release from the sediments, alum treatment was not recommended. Hypolimnetic withdrawal or aeration were seen to be better alternatives because they can also sufficiently control phosphorus release as well as increasing dissolved oxygen levels in the hypolimnion. The oxygen increase would be a benefit to the cold water fishery of Stockbridge Bowl, aiding the solution of another problem.

Hypolimnetic withdrawal was suggested because of a number of positive effects it could have on Stockbridge Bowl. It can improve hypolimnetic oxygen levels by removing oxygen-depleted waters and replacing them with oxygen rich-epilimnetic waters. Hypolimnetic withdrawal can also decrease internal phosphorus loading by decreasing the available P-rich waters that may eventually diffuse or be mixed into the epilimnion. Overall, a net export of phosphorus was calculated for the lake from gathered data, and was perceived as the result of internal P release from sediments. The estimated total cost for hypolimnetic withdrawal, including construction and operation for an unspecified amount of time, was about $650,000.

Hypolimnetic aeration was suggested to add oxygen to bottom waters and suppress internal P loading without destroying thermal stratification. A total yearly cost for hypolimnetic aeration was estimated to be between $33,000 and $68,000, although the initial capital cost would be higher.

In the final analysis, hypolimnetic aeration was suggested as the most appropriate measure for Stockbridge Bowl. Relative to hypolimnetic withdrawal, aeration provides greater benefits to the cold water fishery, potential for decreasing *Oscillatoria rubescens* blooms, and the ability to control turbidity problems associated with iron and manganese; these benefits were seen to outweigh the benefits from hypolimnetic withdrawal.

Controlling Nuisance Plants

The seven methods evaluated for the control of nuisance plants (mainly milfoil) in Stockbridge Bowl were benthic barriers, biological controls, dredging, herbicides, hydroraking, drawdown, and mechanical harvesting. Of these, drawdown was perceived as most effective for the control of nearshore macrophytes. It is not possible to draw the lake down far enough to provide effective drying and freezing of plants, however, as fill materials associated with the Tenneco gas mains had partially blocked the outlet. Assuming that a diversion pipe could be installed, a lake drawdown of six feet would be sufficient to control macrophytes in the shallow waters at minimal operational expense. Based on long term water budgets devised for Stockbridge Bowl, refilling of the lake would be possible during the winter months even during drought conditions.

If the nearshore plants were controlled by drawdown to a depth of 6 feet, control of the remaining plants in the deeper waters might not be essential, although it would be desirable. Herbicides, hydroraking, and harvesting were considered as options for controlling deeper water macrophytes.

The macrophytes between the depths of 5 and 25 feet cover approximately 150 acres. If the remaining deep water macrophytes were to be harvested with the town harvester, a total of 300 acres would be needed to be cut to attain the recommended 2 cuts per season. It was concluded that the town operated harvester would be unable to achieve the total recommended level of harvesting.

The estimated cost of three types of herbicide treatments were considered for Stockbridge Bowl, including Sonar, a combination of 2,4-D and Aquathol K, and treatment with Diquat. Projected annual costs for these methods, if they were to be continued repeatedly when needed, were $70,000, $16,000, and $15,750 respectively. The use of Diquat was seen to be prohibitive for Stockbridge Bowl due to the water use restrictions involved in its usage.

Hydroraking was determined to be unworkable in Stockbridge Bowl due to the large associated cost of managing the 150 acres of littoral zone below 5 feet containing nuisance macrophytes. Also, evidence of past hydroraking in Berkshire County for milfoil control reveals effectiveness for no more than one season.

Due to perceived problems with the restrictions and health concerns related to chemical usage, and the costs associated with hydroraking, these methods were seen as unfit for Stockbridge Bowl. Ultimately, the continuation of harvesting by the town harvester was recommended because the capital investment had already been made and thus future costs could be kept to a minimum.

Watershed Management

Few watershed management options were given, due to the nature of the Stockbridge Bowl problems. The primary lake problems that exist are excessive macrophyte growth and excessive internal nutrient loading, both of which are perceived to be results of internal sources of phosphorus. Management efforts should be focused on in-lake measures rather than watershed considerations. Also, many watershed management efforts have already been implemented, leaving few feasible options left to pursue.

Engineering Recommendations

A number of engineering recommendations were made with regard to structures in the outlet area, mainly dealing with the future ability to draw down Stockbridge Bowl. These include improvements made to the outlet structure, removal of the old dam, construction of a drawdown diversion pipe, and the creation of a drawdown channel.

Of the recommendations, the construction of a drawdown diversion pipe and the creation of a drawdown channel would lead to the most drastic changes to the existing conditions. The proposed diversion pipe would allow greater ability to lower lake levels in the winter, mitigating the current restriction imposed by the installed gas transmission lines across the outlet channel. The pipe would be placed under the gas lines and allow a much greater drawdown. In order to allow the drawdown pipe to function, it is necessary to enhance the channel in the lake sediments leading from the pipe toward the island and out to the deeper waters of the lake. This channel could entail the removal of sediments along the eastern shore of the outlet channel along a distance of nearly 2,000 feet. The estimated cost for the diversion pipe construction is $101,200, while the channel excavation is expected to cost approximately $350,000.

MACROPHYTES

A number of vegetation surveys and scientific studies have been undertaken in Stockbridge Bowl, many dealing specifically with the nuisance macrophyte problem. Most are summarized in the 1991 Lycott report, but the original reports warrant more careful review, in light of the difficulties encountered in gaining approval for plant management actions in Stockbridge Bowl. Some of the larger efforts are summarized below.

1972 Limnology of Stockbridge Bowl, S. Ludlam, K. Hutchinson and G. Henderson, Water Resources Research Center, UMASS, Amherst, MA.

The entire littoral zone of the Bowl was reported to contain dense growths of macrophytes. There appeared to be relatively few plants in the 0-0.5 m (<1.6 ft) water depth, reportedly due to annual water fluctuations. The littoral zone, as defined by the extent of macrophyte growth, reached a depth of 3.5 m (11.5 ft).

Milfoil was the dominant vascular plant and concentrated its growth in the 1-3.5 m depth range. In depths less than 3.5 m, milfoil plants reached the water surface by early summer. *Chara* was the second most abundant plant in the Bowl and was concentrated in the 0.5-1.5 m depth range. It was also observed in deeper waters in the understory of milfoil. It was noted that milfoil was extending its range at the expense of the *Chara* population and that at least one *Chara* bed had been overtaken by milfoil between 1970 and 1972.

1979 Management of Aquatic Weeds in Stockbridge Bowl, Stuart D. Ludlam, Whately, MA

The results of plant surveys of the 1970's were discussed. The confusion over whether the milfoil was *M. spicatum* or *M. exalbescens* was explained, and the convention of calling the dominant plant *M. spicatum* var. *exalbescens* was followed. During 1979 a program of macrophyte harvesting began in Stockbridge Bowl, replacing varied chemical herbicide applications that occurred from 1960 to 1977. This report addresses four considerations for the control of nuisance aquatic macrophytes, including no action, chemical herbicides, harvesting, and drawdown.

A no action alternative to weed control in Stockbridge Bowl is predicted to cause very dense weed growths over about 20% of the lake's surface area. This correlates to areas where water depths are less than 7 feet, the maximum observed depth of nuisance plants. This depth interval also corresponds to the area of greatest use for contact recreation. The range of milfoil in the lake will expand, likely replacing *Chara* populations.

The history of herbicide application was considered relatively ineffectual in providing macrophyte-free zones where water based recreation was in greatest demand. In some instances following treatments, dying masses of weeds followed by large filamentous algal blooms remained for weeks in the lake during peak usage periods in the summer. This consequence was viewed as no better than the problem of the macrophytes in the first place. The future use of herbicides was reported to foster herbicide-resistant plants dominating the community at nuisance levels, along with the unknown long-term dangers associated with chemical herbicides.

Mechanical harvesting was reported to specifically select taller plants in the deeper waters. Milfoil may slowly be removed from the system based on its tall stature, while shorter species such as *Chara* and *Heteranthera dubia* may be selectively retained and their range allowed to expand. The nutrient removal from the lake associated with plant harvesting was also noted as a benefit. It was estimated that nearly 8% of the lake's phosphorus load would be removed through harvesting, although much of this phosphorus would actually be from the sediment and not part of the calculated water column load. Also perceived as a benefit to the Bowl was the ability to treat specific areas that needed the most relief from nuisance vegetation. The primary negative effect noted for harvesting was the loss of many small, warm water fish and other fauna contained in the food web of Stockbridge Bowl.

Winter drawdowns of only 2 feet were possible, due to the restrictions imposed by the gas lines crossing the outlet channel. Drawdowns of this level were considered ineffectual in controlling the major weed problems in the lake. Milfoil was considered the major nuisance weed and it occurred in water depths mainly greater than 4 feet.

1980 Final Application for the Eutrophication and Aquatic Vegetation Control Program, Berkshire Enviro-Labs, Inc.

This report identified that both macrophytes and planktonic algae were at nuisance levels during the summer months and the cause of these problems was the extensive phosphorus load to Stockbridge Bowl over the past decades. Even if immediate loads to the lake were eliminated, the macrophyte problem would still remain due to the residual buildup of nutrients in the lake sediments.

The problem areas of macrophyte densities identified in the Bowl are the outlet channel, the southwestern region around the island, the eastern shore, and portions of the north and northeastern shorelines. *Myriophyllum spicatum* was the most dominant problem plant in all these areas in 1980, and was in close association with *Chara* species throughout. Although *Elodea*, *Nuphar*, and *Potamogeton* species were also identified within the lake, milfoil was perceived as the most abundant nuisance species. Maps of aquatic vegetation for the Bowl from 1974 and 1976 were included and milfoil, although present, was not identified a major nuisance species. The community was composed mainly of *Chara* and *Potamogeton* species.

A number of recommendations were made for the control of nuisance aquatic plants. A listing of these include:

- an increase of drawdown capability from 1'9" to 2'6" by excavating fill on top of Tenneco gas lines near the lake outlet.
- winter drawdown to control milfoil and *P. crispus*
- winter drawdown to promote substitution of *Chara* for the nuisance macrophytes
- hydraulic raking of public beaches and access areas
- selective muck removal in very shallow areas.

Winter drawdown of the lake level was proposed as the primary means of plant control based mainly on its cost effectiveness. With an increase in the drawdown level, a greater area of sediments will be exposed, especially near the outlet channel where summertime access to the lake is prohibited due to dense macrophyte growth.

Stockbridge Bowl had been treated with chemical herbicides and algaecides almost annually from 1960 to 1977. Table 7 gives the dates and chemicals used. During the mid-70's the plant community was dominated by Chara with milfoil present, but since the cessation of chemical treatment milfoil has come to replace *Chara* locally throughout much of the lake. It was presumed that this change in the community structure would continue until milfoil dominated the entire littoral zone in the Bowl. The only areas of remaining *Chara* dominance might be the very shallow regions (<2 ft) where water level fluctuations control the more sensitive milfoil.

This report included an appendix from J.F. Moynihan Associates, which detailed the engineering aspects and costs associated with increasing the level of drawdown. The Moynihan report suggests the construction of one or two siphon pipes over the existing covered pipelines, to get water past these obstructions. Dredging of 3600 cubic yards (cy) of material would be necessary to allow a drawdown of 2.7 ft, while dredging of an additional 61,500 cy of material would allow a drawdown of 5.5 ft. Dredging of an additional 14,500 cy and installation of pumps and a checkdam would allow a drawdown of up to 8.5 ft. Associated costs were approximately $90,000 for the 2.7 ft level, $341,000 for the 5.5 ft level, and $238,000 for the 8.5 ft level.

1991 Stockbridge Bowl Diagnostic/Feasibility Study Report, Lycott Environmental Research, Inc.

As described previously, the major problem macrophyte in 1988-89 was *Myriophyllum spicatum* (Eurasian watermilfoil), which infested approximately 160 acres. The infestation occurs in water depths from 3 to 20 feet. *Potamogeton* species were also detected throughout the littoral zone and found to be at nuisance levels in approximately 50 acres. Plant densities along the majority of the shoreline tended to be moderate to dense, while the outlet channel assemblage was considered very dense and included a variety of species, most abundantly milfoil. The shallow nearshore areas around the lake revealed a low density macrophyte community which was attributed to the annual drawdown of the lake water level since 1981. Extensive *Chara* beds were found in some of these shallow areas, but were rarely encountered in deeper water.

Table 7. History of Herbicide and Algaecide Treatments in Stockbridge Bowl.

Year	Chemicals Used	Amount Applied
1960	Sodium Arsenate	1100 gal
1961	Sodium Arsenate	5500 gal
1964	2,4-D Granular	300 lbs
1965	2,4-D Granular	20,000 lbs
1966	Copper Sulfate	2500 lbs
1967	Sodium Arsenate	3000 gal
1968	Sodium Arsenate	3000 gal
1969	Sodium Arsenate	8000 gal
	Copper Sulfate	2500 lbs
1970	Malachite	2500 lbs
1972	Silvex (Kuron)	389 gal
	Aquathol - K	33 gal
	Hydrothol - 47	126 gal
1974	Silvex (Kuron)	104 gal
	Aquathol - K	152 gal
	Citrine G	7000 lbs
1976	Silvex (Kuron)	149 gal
	Aquazine	4000 lbs
1977	Silvex (Kuron)	200 gal

An evaluation of plant control methods concluded that extension of drawdown to a depth of 6 ft would be the best way to control nearshore milfoil infestations, while continuation of harvesting, although inadequate, was the most feasible management tool in deeper waters.

1994 Letter Comments from Robert G. Wetzel, Professor of Biology, University of Alabama.

Dr. Wetzel reports that the most effective way to control the macrophytes would be to remove the excessive phosphorus loading to Stockbridge Bowl, and the milfoil problem will resolve itself through natural decline. Dr. Wetzel has suggested that inputs from septic systems around the lake and throughout the watershed may be a major source of phosphorus, although the Lycott study does not support this contention. Dr. Wetzel asserts that as much as 25% of the annual phosphorus load may be from septic systems. Until nutrient inputs could be controlled, mechanical harvesting and low dose chemical treatment could provide short term relief.

ALGAE

Algal blooms occur on a somewhat irregular basis in Stockbridge Bowl, and documentation has been less detailed than for macrophyte infestations. A few evaluations have been made, however, and are summarized here.

1972 Limnology of Stockbridge Bowl, S. Ludlam, K. Hutchinson and G. Henderson, Water Resources Research Center, UMASS, Amherst, MA.

The most detailed algal assessment was part of the 1971-72 study by Ludlam (1972), which examined both the plankton at that time and the remains of diatom assemblages preserved in the sediment record. Four species of bluegreen algae, four species of diatoms, and one species each of golden algae and dinoflagellates comprised >75% of the algae observed. Dominance shifted over time, with the bluegreen *Oscillatoria* dominating spring samples, the diatom *Fragilaria* most abundant in early summer, and the dinoflagellate *Ceratium* becoming dominant in late summer of 1971. *Oscillatoria* regained dominance in the autumn and remained abundant through the winter. Algae were considered responsible for the low water clarity, with little light penetrating below 7 ft of water depth.

Particularly interesting was the effort to evaluate historic trends in plankton through examination of diatom remains in sediment cores. Although core strata were not precisely aged, it was apparent that there had been a distinct shift in algal composition during the course of this century. Centric diatoms became less abundant, while pennate forms increased in dominance. This trend parallels that of many other systems subjected to human influence, especially from sewage disposal or agriculture. It is hypothesized that a detectable trend toward increased productivity began in the late 1940's, accelerated greatly in the 1960's, and was still in progress in the early 1970's. Increased organic content was also observed in the more recent sediments, supporting the hypothesis of increased productivity. It was further hypothesized that changes in the algal community were paralleled by changes in the plant community, mainly as a function of increased fertility of sediments from which the rooted plants obtain most nutrients.

1980 Final Application for the Eutrophication and Aquatic Vegetation Control Program, Berkshire Enviro-Labs, Inc.

Although details are very sketchy, summer dominance by bluegreen algae (Oscillatoria) is indicated for 1980, with more diatoms during spring and summer turnover. Algal blooms were considered to be a problem.

1991 Stockbridge Bowl Diagnostic/Feasibility Study Report, Lycott Environmental Research, Inc.

Surface sampling on an intermittent basis failed to document blooms which were visually observed, especially in November of 1988, when a red surface slick of *Oscillatoria* was observed along one shoreline segment. The collected algal samples revealed dominance by *Anabaena* during the winter months, a genus not commonly reported for Stockbridge Bowl in previous reports. The centric diatom *Cyclotella* was most abundant in surface samples during the summer; this species was also not frequently encountered in other investigations. Pigment concentrations were moderate on average, but the potential for elevated algal levels near the boundary between the upper and lower water layers during summer was not assessed. Rise of such a "thermoclinal bloom" during autumn mixing was hypothesized as the source of the red surface scum observed in November.

SEDIMENTATION

Sedimentation has been mentioned only sporadically in the written record for Stockbridge bowl, but is of definite interest to lake users as a consequence of resulting access problems and associated rooted plant growth. The most commonly cited problems are sedimentation in the outlet channel, which restricts access and would hinder drawdown in the absence of the pipeline crossing, and sediment accumulation near the inlet of Lily Brook, which has created a large shallow expanse of easily colonized substrate.

Sedimentation in the outlet has been attributed at least partially to the pipeline crossing as a function of slower water movement through the channel, although no detailed investigation of this phenomenon has been conducted. Sedimentation near the inlet from Lily Brook appears to be a result of the conversion of an upstream ponded area into an emergent wetland through prior sedimentation. The degree to which sedimentation of that wetland area has been natural is uncertain, but in the absence of management to maintain or enhance its retention capacity it has ceased to retain sediments from upstream. These sediments now pass into Stockbridge Bowl.

Beyond specifically noted problem areas, the gradual accumulation of organic sediments in shallow portions of the lake is expected to foster greater plant densities. Drawdowns are believed to have minimized this accumulation in very shallow areas, and resuspension is expected to gradually move sediments toward deeper water, but the trapping capability of dense macrophyte stands is promoting more permanent accumulations. Stability of these accumulations is uncertain, potentially leading to highly variable plant communities, both in terms of composition and abundance. Only dredging has been suggested as a means to reclaim areas subject to excessive sedimentation, but permitting problems have discouraged most efforts in this regard.

OXYGEN DEPLETION

Oxygen depletion of bottom waters (the hypolimnion) has been noted in virtually all studies of Stockbridge Bowl, and is suspected as being a long-term problems for the lake, extending back to the early part of this century. The study by Ludlam et al. (1972) detected no oxygen below 9 m (30 ft) during mid- to late summer stratification, and the formation of sulfides was detected in late August. The Lycott study (1991) noted a similar trend. This means that 41% of the lake area, or 13% of its volume, is experiencing severe oxygen depletion during summer stratification. Oxygen depletion is apparently sufficient to cause sulfate metabolism by anaerobic bacteria to become significant, and sulfides are produced in the hypolimnion. A concurrent build up of phosphorus is observed in the hypolimnion as a consequence of release from the sediment under strong reducing conditions. A build up of ammonium is also observed, as sinking particles cannot be completely oxidized in the absence of oxygen. Toxicity and nutrient recycling issues are raised by this situation.

FISHERY FEATURES

Fishery concerns are not often mentioned outside of MA DFW reports for Stockbridge Bowl, but are well known for this lake. Stockbridge Bowl is considered by many to provide valued warm water and cold water fisheries, but populations seem unstable. As of the 1991 Lycott report, the last intensive fish survey of the lake was in 1988. The most recent previous intensive survey had been in 1978. Both surveys indicated numerical dominance by yellow perch, with largemouth bass and pickerel as the primary warm water game fish. Bass and perch abundance declined between the surveys, however, and active trout stocking also began in this time period.

Brown and brook trout are stocked twice per year, and represented almost one third of the total sample weight in 1988. Summer survival of trout has been a concern for the DFW and many anglers, however. Suitable summer trout habitat, which is the volume of the lake where the temperature is below 70°F (21°C) and the oxygen level is above 5 mg/l, was estimated at 20% in 1947 and 8% in 1974. The 1991 Lycott study calculated a summer trout habitat volume of 16%, but the presence of ammonia and sulfides may reduce that volume through toxic effects. A desirable summer habitat volume is 25%.

The condition of the warm water fishery is generally perceived to be linked to macrophyte coverage and density, with moderate amounts desirable (20-40% cover at an intermediate density). The DFW considers the Stockbridge Bowl macrophyte community to be too expansive, too dense, and not diverse enough for optimal warm water gamefish production, based upon the March 1991 letter from Joseph Bergin of the MA DFW to Lee Lyman of Lycott.

RARE SPECIES CONSIDERATIONS

Two species of gastropods have been identified to exist in Stockbridge Bowl that are listed on the Massachusetts rare wetlands species list. These are the Boreal Turret Snail (*Valvata sincera*) and the Pilsbry's Spire Snail (*Pyrgulopsis lustrica*). The Boreal Turret Snail has not recently been reconfirmed to exist in the lake (last confirmed in 1982). However, species are not removed from the list until they have been absent for 25 years or more. Based on correspondence from the MA Division of Fisheries and Wildlife, the Pilsbry's Spire Snail has recently been observed in Stockbridge Bowl and it is commonly accepted that it exists in close association with *Chara* and *Najas* in water depths less than 1.5 meters (<5 ft). It is also commonly accepted that the future of *P. lustrica* depends on the health of *Chara* and *Najas* in Stockbridge Bowl.

The topic of the two rare snails has come into play in a number of questions concerning lake management techniques proposed for Stockbridge Bowl. Generally, the concerns raised deal with preservation of the snail habitat and specifically the *Chara* and *Najas* plant community that supports the Pilsbry's Spire Snail. Most recently, the management techniques involving increased lake level drawdown and the operation of a mechanical harvester for the removal nuisance aquatic macrophytes have been questioned in regard to their impact on the snail habitat.

Fugro is not in possession of either the 1993 study of snail distribution in Stockbridge Bowl by Dr. E. Jokinen or the 1995 summary judgment of an environmental lawyer hired to evaluate the legitimacy of the restrictions imposed under the Endangered Species Act. However, from our discussions with knowledgeable parties and secondary written materials, it appears that although the endangered snails are absent or in decline, protection of their potential habitat will continue on strong legal grounds.

PERMITTING PROBLEMS FOR LAKE MANAGEMENT

Three Tenneco natural gas pipelines and a Town sewer line currently pass under the outlet channel leading to Larrywaug Brook. The fill that was placed over the pipelines during construction at several times since the 1950's is at such a level that it effectively acts as a dam, restricting flow out of Stockbridge Bowl. Prior to this installation, the level of Stockbridge Bowl was controlled by the dam located further down the outlet channel. As this situation now stands, the effective amount of lake drawdown that can be accomplished is approximately 2 feet.

This annual drawdown of 2 feet has been in effect since 1981 for the purpose of minimizing ice damage to structures and the control of nearshore macrophytes. Since the time of the initial pipeline construction, it has been argued that the restricted flow through the outlet channel has lead to an accelerated rate of sedimentation in the outlet channel. This build up of sediments, along with the an extremely dense macrophyte assemblage in the channel, have made it increasingly difficult for residents with homes along the outlet channel to access the main lake waterbody in the summer. The loss of control over the outflow rate from Stockbridge Bowl was considered the reason for the increased sedimentation.

Lycott proposed that a diversion pipe be installed under the gas pipelines as part of its Diagnostic / Feasibility Study, completed in 1991. The construction of the proposed diversion pipe would return the lake to its historic outlet flow pattern and allow for a lake drawdown of 6 feet to be used as part of recommended macrophyte control measures. By 1989, Tenneco was evaluating the Lycott proposal for the construction of the diversion pipe in conjunction with efforts to construct a third pipeline across the Stockbridge Bowl outlet channel. Tenneco agreed to the design and construction of the diversion pipe. Tentative construction of the new pipeline was scheduled for 1991. Tenneco informed the Town that it would file site-specific construction and restoration plans with the state for approval prior to construction. In late 1990 though, Tenneco made it clear that it was willing to design and install the diversion pipe, but that it was concerned with future liability. They stated they wanted the Town to indemnify them against any future operation and maintenance of the diversion pipe.

A letter from the Massachusetts Division of Fisheries and Wildlife dated March 22, 1991, was delivered to Lycott addressing many issues with the planned diversion pipe and its ability to lower the lake by 6 feet. An aquatic biologist for the DFW identified departmental concerns and suggested some modifications to the overall plan. The first concern dealt with the potential effect on the fisheries in Stockbridge Bowl, primarily the shallow water pickerel spawning habitat. The biologist expressed concern that the lake could not be totally filled by March 1 during drought conditions and that this would inhibit pickerel spawning. Concern was also expressed regarding the potential for offshore movement of the exposed sediments during drawdown and the potential for subsequent increased oxygen demand in the hypolimnion. Access was also a concern in the autumn, as the boat launch would be out of the water and recreational use of the lake would be negatively impacted.

The DFW stated that it could not support the proposed drawdown measure of six feet as stated, despite general support for managing rooted aquatic plants and milfoil in particular. The project could be supported, though, if a one year trial drawdown was done with monitoring conducted prior to and following drawdown. Monitoring proposals included surveys of spawning habitat, hypolimnetic chemical monitoring, and protection of noted esocid habitat.

Coinciding with the attempts to permit the diversion pipe construction were harvesting efforts used for the removal of nuisance species, mainly Eurasian watermilfoil. A Notice of Intent for harvesting was filed in 1990 with the MA DEP and was reviewed by MA DFW as required by the Wetlands Protection Act. A return letter from the DFW stated that the rare Pilsbry's Spire Snail and the Boreal Turret Snail reportedly occurred within Stockbridge Bowl and that restrictions would need to be placed on the planned operation of the mechanical harvester. These restrictions included no harvesting of aquatic vegetation to the west or south of the island and that where harvesting did occur, efforts were to be directed specifically toward milfoil and away from observable *Chara* beds. These restrictions were designed to protect snail habitat and to avoid the actual crushing of organisms during harvesting.

All information for the permits for the diversion pipe had been obtained by the end of 1992, and the permitting process was to begin with the filing of an Order of Conditions issued by the Stockbridge Conservation Commission under the Wetlands Protection Act. Unlike the harvesting effort, however, the pipe installation also required permits from the Army Corps of Engineers under Section 404 of the Clean Water Act and from the Massachusetts DEP under Section 401 (Water Quality Certification). It was believed that an existing Letter of Permission issued by the Army Corps to Tenneco for its pipeline operation would suffice to meet the Section 404 requirements, and that the Water Quality Certification would be relatively simple to obtain, as minimal impacts to water quality were expected. It was expected that by early 1993 a Request for Bids could be ready in anticipation of construction beginning in the spring.

The Order of Conditions was filed in February of 1992. Both the MA DEP and the Army Corps responded with requests for additional information, and a year long series of correspondence and meetings ensued. The US EPA recommended in February 1993 that the authorization of the diversion pipe under Section 404 via the Massachusetts Letter of Permission (MALOP) for the Tenneco pipeline construction be revoked by the Corps of Engineers and that the project be reviewed for an Individual Permit. The MA DEP appealed the Order of Conditions and issued its own Superseding Order in March of 1993, which was a denial of the project on environmental grounds.

After consulting with the MA DFW, the EPA stated that although there were no Federally protected species involved, the potential habitat disruption of the endangered snails on the state level list exceeds "minor individual or cumulative impacts on environmental values" as stated in the MALOP. The EPA further noted that the drawdown of Stockbridge Bowl would do little to solve the problem of the nuisance aquatic vegetation, which probably stems from nutrient enrichment from the watershed. Also of concern was the downstream trout fishery that could be negatively impacted by additional water discharged via the diversion pipe. The Army Corps of Engineers contacted the Town to notify it that they could not support the authorization under the MALOP if any state or local concerns about the construction had not been resolved.

The Massachusetts Department of Environmental Protection issued a Denial Superseding Order of Conditions for the proposed diversion pipe installation in March of 1993. The DEP stated that it had not received sufficient information regarding the project to gain a clear understanding of the proposed work. Included were its requests for specific information regarding the intended purpose of the diversion pipe and how the pipe would function to provide that purpose. Also of concern were the measures to be taken to prevent inadvertent drawdown of the lake that may adversely effect the habitat of the endangered Pilsbry's Spire Snail.

Through their consultant, Lycott, the Town contacted the Army Corps of Engineers and MA DEP and countered that the purpose of the diversion pipe installation was not solely to manage macrophytes in Stockbridge Bowl through drawdown, but to return to the historical flow patterns associated with the outlet channel and existing control structure prior to the gas pipeline construction. The Stockbridge Bowl Association (SBA) also contacted the Natural Heritage and Endangered Species Program within the DFW to point out that the administration had misinterpreted the purpose of the diversion pipe and that the NOI did not mention any aspect of lake management. An amended NOI was submitted to clarify that the purpose of the project was to return the lake to historical flow patterns associated with the outlet channel and existing control structure prior to the gas pipeline construction. Although the diversion pipe could clearly be used to draw the lake down, permitting its installation did not constitute permitting a drawdown.

In April 1993, the MA DFW had contacted the MA DEP with regard to the use of the drawdown pipe for control of aquatic vegetation and its potential resulting impact on the endangered snail species. The DFW stated that it had previously commented on the NOI regarding weed harvesting in the lake and had proposed limitations on areas to be harvested. Now the DFW was expressing concern that the use of the diversion pipe would certainly negatively impact the snail species. Its position was that the proposed level of drawdown would be deleterious to the habitat of the endangered Pilsbry's Spire Snail. It was felt that that a 6 foot drawdown would endanger the shallow water *Chara* and *Najas* community which the snail depends on for survival. The report from Ludlum et al. (1974) was referenced, with emphasis on the conclusion that the traditional 2 foot drawdown in Stockbridge Bowl had negatively impacted primary snail habitat. It was suggested that the Town take a new look at problem solving measures which include watershed management to address the root causes of nuisance plant infestation, which were presumed to be linked to excessive nutrient loading.

On behalf of the Town, Lycott contacted the MA DEP to clarify the point that the purpose of the NOI was for construction purposes only and not for lake management. If at a later date it was decided that the diversion pipe was to be used for lake drawdown, it was understood that such action would require a separate set of permits with special consideration given to rare species habitat.

The DEP contacted the Town in June 1993 to state concerns and deficiencies with the submitted amended NOI. It was noted that many concerns were not addressed in the original NOI and repeated attempts to gain information proved less than satisfactory. Of primary concern was the lack of information regarding environmental impacts, namely the potential for inadvertent drawdown that would be possible with the existence of the diversion pipe. It was also noted that the previous annual 2 foot drawdown was conducted without the proper permits and that future lowering of lake levels would require a permit under the Wetlands Protection Act. The Town was urged to submit another NOI containing all requested information to avoid future delays in permitting.

In 1994 the Town submitted an NOI seeking to have the mechanical harvesting restrictions lifted, especially the ability to harvest the areas around the island and the outlet channel. The Natural Heritage and Endangered Species Program upheld the previous restrictions from 1990 to protect endangered snail habitat, and now made further harvesting conditional upon the completion of a watershed management plan for Stockbridge Bowl. The reasoning involved was to get to the underlying problem of advanced lake eutrophication, which was assumed to be caused by elevated nutrient inputs.

The Natural Heritage and Endangered Species Program also stated that it could not support the conclusions of Professor Eileen Jokinen from the "Snail Study, *Pyrgulopsis lustrica* in Stockbridge Bowl," by Lycott (1992). Jokinen had stated that the endangered snails were not present in Stockbridge Bowl based on a single day survey in 1992. It was emphasized that the intent of the Wetlands Protection Act and Endangered Species Act was to protect the habitat of the snails, in this case the *Chara* and *Najas* beds. Also, areas would not be removed from the Estimated Habitat Atlas unless the state could not confirm the presence of a species for a period of 25 years. The DFW reiterated the need to investigate the overall problems of the lake, which would include the formulation of a lake management plan.

At this point there is an Order of Conditions in effect for mechanical harvesting of milfoil, with restrictions on areas which can be managed. There is no Order of Conditions which allows the installation of the diversion pipe and no valid Section 404 or 401 permits at the Federal and State levels. An assessment of the applicability and strength of the regulations by an environmental attorney hired by the SBA in the autumn of 1994 apparently revealed little hope of circumventing another complicated and lengthy permitting process for installation of the diversion pipe. Legislative action to alter the regulations or jurisdiction were contemplated by the SBA, and preparations were made to develop a comprehensive lake and watershed management plan in accordance with the stipulations governing continued harvesting of milfoil in Stockbridge Bowl.

EVENTS DURING THE LAST HALF OF 1995

Through negotiations in 1994 and 1995, the Tenneco Gas Pipeline restated its agreement to fund specified tasks in relation to the design and construction of the diversion pipe. However, Tenneco made it clear that the offer would be extended only through July 26, 1996. Negotiations near the end of 1995 have apparently resulted in a monetary settlement whereby funds have been transferred to the Town of Stockbridge from Tenneco for the purpose of supporting the installation of the diversion pipe. Although Tenneco would retain the right of review and approval on the process, it prefers a less active role at this point in time.

On July 21, 1995, the SBA held a meeting with Patricia Huckery and Thomas French of the Natural Heritage and Endangered Species Program (part of DFW) and Ken Wagner of Fugro East, Inc., acting as a consultant to the SBA. The meeting included a discussion of salient issues and a tour of the lake and outlet channel. The results were summarized in a memorandum from Ken Wagner to the SBA (Appendix B). Ken Wagner addressed a subsequent July meeting of the SBA and discussed management and permitting needs for the future. With the hiring of Fugro East by the Town of Stockbridge in late 1995 and the improvement of communication with the DFW, it is hoped that real progress in the management of Stockbridge Bowl can be made in the coming year.

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LIMITING NUTRIENT

Although nutrient ratios indicate that nitrogen may limit productivity at some times, phosphorus appears to be the limiting nutrient most of the time. Algal data also indicate an adequate supply of nitrogen, leaving phosphorus as the logical choice as the limiting nutrient. Other nutrients may also play a role in limiting productivity or determining algal composition, but phosphorus is the logical choice of management, based both on existing data for the lake and on the potential for successful control. In most cases, management of algal productivity is based on creating or strengthening phosphorus limitation, and such an approach appears appropriate for Stockbridge Bowl as well.

PHOSPHORUS LOADING

The Lycott estimates of total phosphorus loading ranged from 1120 to 1364 kg/yr (Table 5). Although not discussed in the Lycott report, the permissible load (below which no serious problems would be expected) for a lake with the features of Stockbridge Bowl is about 465 kg/yr. The critical load (above which serious problems would be expected) for this lake is about 930 kg/yr. The entire Lycott range for phosphorus loading therefore exceeds the critical limit, suggesting that problems such as algal blooms would be expected with some frequency.

Although algal blooms do occur in Stockbridge Bowl, the record does not suggest the level of severity indicated by the loading analysis above. Furthermore, application of five empirical models relating phosphorus concentration to load suggests that the average observed 1988-89 in-lake concentration of 38 ppb translates into a load of between 428 and 1168 kg/yr, with an average of 912 kg/yr. Although most of the model values are still high, the variability suggests that the situation is complicated by other factors which require assessment. Two factors stand out upon inspection of the Lycott report: there are several very high phosphorus values at the lake surface which bias the data, and the potential for sporadic loading from the hypolimnion compromises the predictive ability of most models.

If the high values are eliminated from consideration, model predictions change substantially. The average predicted load declines to 602 kg/yr, solidly in the transition zone between permissible and critical limits, and similar to the estimated phosphorus load from the watershed (565 kg/yr for the study year, 808 kg/yr from long-term data). If the estimated internal load is subtracted from the total load to the lake, the models indicate that the observed in-lake concentration should be about 23 ppb. In other words, the observed in-lake phosphorus concentration does not appear to be a function of watershed loading alone; internal loading is strongly suspected as an important determinant of in-lake phosphorus concentration.

Lycott used several models to illustrate this situation (Table 6). Models which did not account for potential internal loading predicted in-lake phosphorus levels of 17 to 23 ppb, while a model which included an internal loading term predicted a concentration of 33 to 34 ppb, fairly close to the observed level. Lycott estimated that about 40% of the total phosphorus load was attributable to internal sources (release from sediments), which could account for the discrepancy between observed concentrations and those predicted from models based on loading from the watershed alone.

Several other lines of evidence point towards internal loading as a major factor, and possibly the dominant force, in determining the in-lake phosphorus level. The accumulation of phosphorus in the anoxic bottom waters of many lakes is mitigated by a tendency for that phosphorus to precipitate out with iron, manganese or calcium complexes when exposed to well oxygenated surface waters. This cannot happen, however, if the supply of complexing anions is low, or if the pH allows them to stay in solution, or if other anions preferentially scavenge the potential phosphorus-binders before a reaction with phosphorus occurs. In the case of Stockbridge Bowl, iron and manganese are not continually abundant (<5 times the P level), the pH allows calcium to stay in solution (pH = 7-8), and the periodic production of hydrogen sulfide leads to sulfide scavenging of iron and manganese. The result is that phosphorus may be free, at times, to move across the boundary between the bottom and surface waters in an available form. The discontinuous nature of the conditions for phosphorus movement into surface waters may account for the variability in the data.

Furthermore, the most problematic bloom-forming algae, the bluegreen *Oscillatoria*, is known to form a dense band at the boundary of the surface and bottom water layers, where it has access to phosphorus (and other nutrients) from the bottom waters but still has adequate light from above for growth. Under certain conditions, and often at autumn turnover, these algae move upward in the water column to form surface blooms. Their presence is often indicative of excessive internal loading.

Additionally, mixing induced by summer storms or autumn lake turnover can cause an "erosion" of the upper surface of the bottom water layer, allowing "chunks" of phosphorus-laden water to mix into the upper water layer. In the absence of abundant iron or other complexing anions, algae can make use of this infusion of nutrients. Such sporadic mixing is highly weather dependent and not very predictable, causing further data variability over space and time.

It should also be noted that sediment-water interactions which result in the transfer of phosphorus to the water column can occur even when oxygen is present, albeit at a reduced rate (Nurnberg 1984). Also, macrophytes are known to provide potentially important transfer mechanisms via loss from both live and dead tissues after uptake from the sediment (Barko and Smart 1980). Internal loading can also be facilitated by wave induced resuspension of sediments, although high calcium content in the suspended sediment is believed to reduce transfer of phosphorus from the particles to the water column (Asplundh 1996).

On-site wastewater disposal (septic) systems have been estimated in past studies to provide 100 kg/yr or more of phosphorus to Stockbridge Bowl, and were speculated by Dr. Robert Wetzel (1994) to be a major source of phosphorus to the lake. Septic systems were estimated by Lycott to provide only 42 kg/yr (3% of the total load), with some indication that the actual load from septic systems was even smaller. Based on studies at Lake Mansfield in Great Barrington, Richmond Pond in Richmond and Pittsfield, Lake Garfield in Monterey, and Goose Pond in Lee, septic systems play a minimal role in the loading of phosphorus to Berkshire County lakes. The soils are not very permeable and readily adsorb phosphorus. Substantial contributions would be expected only in rare areas of porous soil, or where there is surface break-out of effluent, or where the ground water table is continually high. The Beachwood community area represents the only obvious threat to Stockbridge Bowl from on-site wastewater disposal, and this area is served by a sanitary sewer which removes wastewater from the watershed of Stockbridge Bowl. We concur with the Lycott report that septic systems are only a minor source of phosphorus to the lake, and disagree with Dr. Robert Wetzel's unsubstantiated claim that septic systems are a primary source.

An assessment of ground water phosphorus contribution to Stockbridge Bowl was conducted in 1995 by Dr. Don Roeder and colleagues of the Berkshire Environmental Research Center under a grant from the MA DEM. In his 1996 report, Dr. Roeder concludes that the maximum input of phosphorus to the lake from ground water is 72 kg, or 6.2% of the yearly total. The study did find larger concentrations of phosphorus in monitoring wells than did the previous Lycott study, accounting for the increase in estimated load from ground water. However, this estimate does not approach the speculative 25% suggested by Dr. Wetzel in late 1994, and Dr. Roeder concludes that lake management should focus on in-lake methods. Continued pursuit of watershed management is certainly encouraged, but is not viewed as sufficient by itself to affect the desired changes in lake condition.

Surface water from developed areas of the watershed were estimated by Lycott to contribute about 210 kg/yr, or about 19% of the total phosphorus load. Although no agricultural inputs were included in this estimate, it appears to accurately reflect the nature of the watershed and likely inputs from development within it. Other sources of phosphorus to Stockbridge Bowl itemized in the Lycott report include forested land (27% of the load), open land (11% of the load) and direct precipitation (4% of the load).

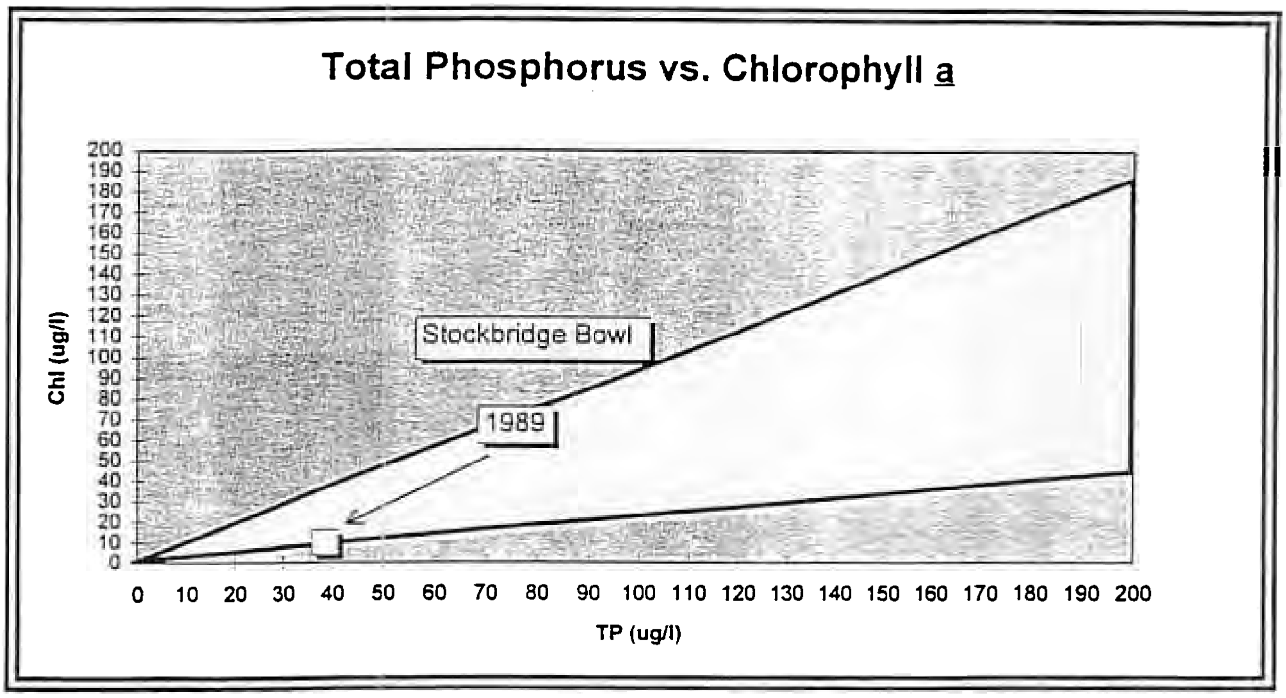
Phosphorus loading can be directly linked to the amount of chlorophyll (green algal pigment) in the water and the water clarity (Figure 2). There is substantial variability in the relationship between total phosphorus and chlorophyll or Secchi disk transparency, but in general it can be assumed that more phosphorus equates with more algae and lower transparency. An interesting threshold occurs with regard to water clarity, however, which declines rapidly until a phosphorus concentration of about 50 ppb, after which the decline is much less noticeable. A phosphorus level of about 25 ppb usually corresponds to the permissible loading limit, while a concentration of about 50 ppb corresponds to the critical limit in most cases. Values for Stockbridge Bowl place this lake solidly in the transition zone, where slight changes in concentration can noticeably alter chlorophyll level and water clarity.

As Stockbridge Bowl is a multi-use lake, consideration should be given to what level of fertility is most appropriate to the variety of uses. As a starting point, maintenance of phosphorus near the permissible level is a reasonable goal, as it would be expected to provide water clarity acceptable to contact users and enough productivity to maintain fish populations. With a target of 465 kg/yr (the permissible loading level), a loading decrease of 58 to 65% would appear desirable. However, this considers loading on an annual basis, and some attention to the seasonal pattern of inputs is warranted. For the following reasons, the internal load would be the logical main target for reduction:

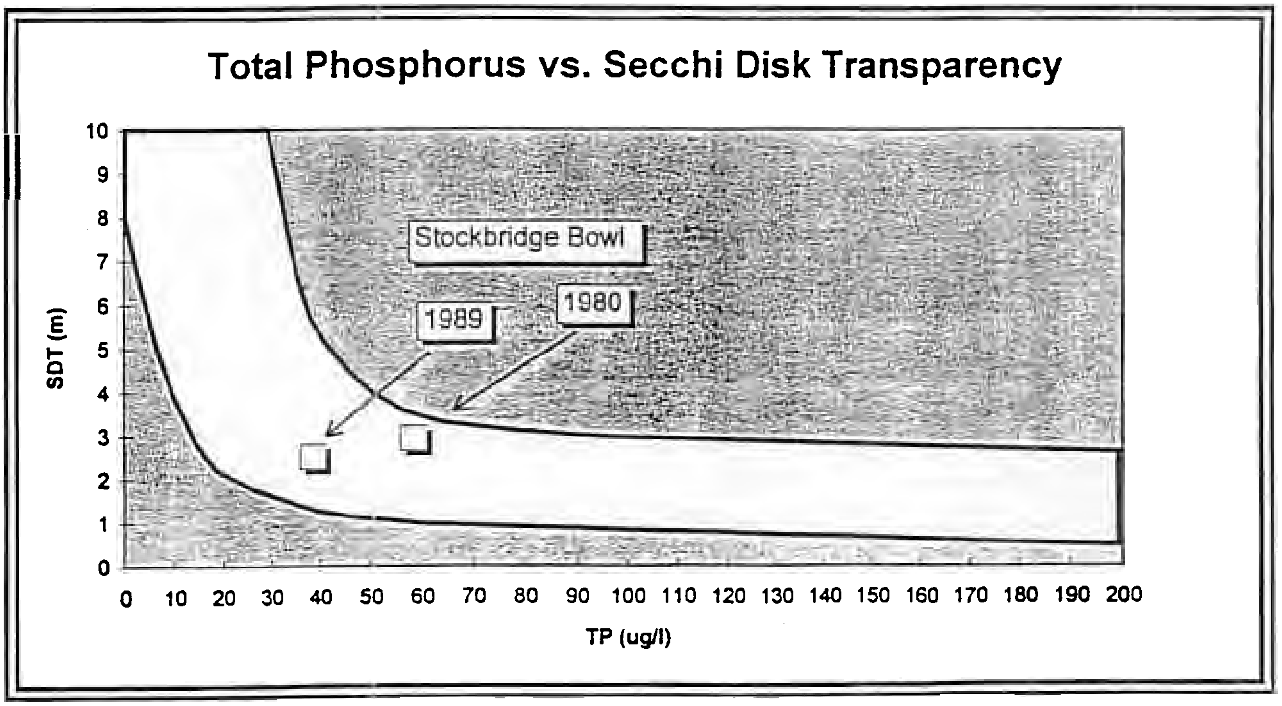
- Internal loading appears to be the largest single source of phosphorus to Stockbridge Bowl.
- Internally loaded phosphorus is more available for algal uptake than phosphorus from the watershed, which is often bound in particulate forms.
- Model results predict acceptable conditions in the lake in the absence of internal loading.
- The internal load is largely a summer-early autumn phenomenon, and could cause water quality problems even with minimal loading from the watershed.
- The twice per year flushing rate suggests that while late autumn-winter loading is not inconsequential, it is less critical than spring-summer loading.

Figure 2. A) The position of Stockbridge Bowl in relation to common ranges of chlorophyll a levels in lakes of various total phosphorus concentrations; B) The position of Stockbridge Bowl in relation to common ranges of secchi depth transparencies in lakes of various total phosphorus concentrations.

A)



B)



Although loading from runoff from developed areas of the watershed could probably be further reduced through education and best management practices, and should be minimized, even the elimination of such loading would not produce the desired overall loading decrease. Most other sources of phosphorus to Stockbridge Bowl are minor or uncontrollable. If a meaningful phosphorus loading reduction is to be achieved, it will have to include amelioration of internal loading. Virtually every approach to estimating the phosphorus load to Stockbridge Bowl yields this same conclusion.

MACROPHYTES

The history of macrophyte growths and management in Stockbridge Bowl has been fairly well documented since the early 1970's. It is not known just when Eurasian watermilfoil entered the lake, but milfoil was present in 1970 and treatments for excessive macrophyte growths date back to 1960 (Table 7). Many of the chemicals used between 1960 and 1977 are no longer on the market, due to either toxicity or registration cost. Although unpleasant side effects such as large masses of decaying weeds were noted, and repeated applications were apparently needed, macrophyte problems were controlled at least temporarily. Milfoil was not the dominant plant in the lake in the mid-1970's.

Despite apparent control of milfoil, Dr. Stuart Ludlam considered the herbicide program ineffectual and encouraged a shift to harvesting in the late 1970's. Although his concerns about the herbicides in use were generally well founded, it is now known that harvesting of milfoil speeds its spread and is not recommended for lakes where milfoil has not reached maximum coverage. Milfoil became dominant within a few years. Although there is reason to believe that harvesting hastened its spread, milfoil has been known to become dominant in some southern New England lakes within 5 years without any human intervention. In the absence of an intensive control effort aimed at killing the whole plant in all areas of occurrence, eventual dominance by milfoil is routinely observed.

Milfoil has remained the dominant macrophyte in water over 3 ft deep since about 1980. Limited milfoil growth in shallower water is related to intolerance of desiccation by this plant. Natural water level fluctuations and intentional drawdowns of up to about 2 ft, with ice damage down to about 3 ft, is believed to be responsible for shallow water control of milfoil in Stockbridge Bowl. Such has been the documented case in other Massachusetts lakes, including nearby Richmond Pond in Richmond and Lost Lake and Knopps Pond in Groton.

There is considerable reference in the correspondence record of the Stockbridge Bowl Association to the role of watershed inputs in the excessive growths of rooted plants. Many individuals, including environmental agency personnel and well known academians, have stated that the milfoil infestation has been caused by watershed inputs and could be counteracted by watershed management. We strongly disagree with the later part of this statement, and see a need to clarify the first part.

Rooted plants such as milfoil gain most of their nutrition from the sediments, not the water column (Barko and Smart 1981). Sediments naturally accumulate in lakes, and although this process can be greatly accelerated by human activities in the watershed, growths of rooted aquatic plants should be expected in all but newly created or intensively managed lakes. Once a sediment base has been established, no amount of watershed management is expected to eliminate rooted plant growths. Although past watershed activities undoubtedly contributed to sediment accumulation in Stockbridge Bowl, current watershed practices are in no way responsible for rooted plant infestation. If the entire watershed could be dissociated from the lake, the infestation could be expected to continue indefinitely.

Eurasian watermilfoil is an invasive, non-native plant which has been in New England for at least 4 decades. It reproduces both vegetatively and by seed, but is best known for its rapid spread through vegetative fragmentation. Fragments can be carried by water currents, waterfowl, or by boats to new areas or lakes, and grow aggressively. Research has demonstrated that this plant is a superior competitor for light and grows more rapidly than most native species (Madsen et al. 1991a, 1991b). Its arrival in Stockbridge Bowl does not appear to have been connected in any way to watershed practices, and no watershed management measure can remove it. In-lake management of this species is the only alternative, through one or more of the seven general methods of plant control.

Milfoil becomes established at the expense of native vegetation. There is frequent reference in the correspondence of the Stockbridge Bowl Association to the value of the native plant assemblage, especially the *Chara* beds known to be prime habitat for protected snail species. Ludlam documented the loss of Chara beds to milfoil growths in the early 1970's, and plant maps produced by Ludlam, Berkshire Enviro-Labs, and Lycott between 1972 and 1989 indicate a progressive expansion of monocultural milfoil stands and commensurate loss of plant diversity during that time. Milfoil is now found at nuisance levels in approximately 160 of the lake's 382 acres. Control of the milfoil is clearly in the best interest of both recreational users and habitat managers.

It should also be noted that species of pondweeds (*Potamogeton* spp.) also achieve nuisance densities in Stockbridge Bowl. Most of these species are native, but Potamogeton crispus, the curly-leafed pondweed, is not and is the primary problem plant in about 50 acres of the lake. Fortunately, this plant is a spring species, disappearing almost entirely by early July. Although management may be warranted at some point, it should not be assigned the level of priority reserved for Eurasian watermilfoil.

ALGAE

Algal problems received considerable attention from Ludlam and his colleagues in the early to mid-1970's, but have been viewed as less of a problem than the milfoil infestation since the late 1970's. To some extent, milfoil dominance has overshadowed a continuing productivity problem, but it does appear that algal growths are somewhat less severe than in the past. Phosphorus inputs from watershed sources are perceived to have declined over the last two decades, mainly as agricultural operations ceased. There is limited chlorophyll data to support such a contention, but rooted plant data do suggest that conditions have improved somewhat. Investigators in the 1970's found few rooted plants at depths greater than 7 ft, and the photic zone (depth to which light could penetrate) extended only to a depth of 11.6 ft. In 1988-89 Lycott found dense milfoil growths at up to 12 ft and plants growing at up to 20 ft of water depth. Even if this "improvement" is only the result of a shift in plant composition to species more tolerant of low light, it is easy to see why attention has focused on the rooted plant community.

The algal community observed in Stockbridge Bowl is indicative of moderate fertility, with productivity peaks which could be considered excessive. These peaks appear linked to internal recycling, and often involve the bluegreen *Oscillatoria*. This alga, or more properly a cyanobacterium, is known to form a dense band near the boundary of the upper and lower water layers during stratification, rising to the surface during periods of mixing or low light. Other bluegreens are also observed at times, but the more common bloom-forming species are rarely abundant. Diatoms remain an important component of the algal community, which is desirable for energy transfer along the food web; these algae are eaten by zooplankton, which in turn are consumed by fish.

Clear water periods have been observed at various times during the summer. The occurrence of these periods of greater water clarity is not very predictable, but may be explained by limited transport of phosphorus from bottom waters into surface waters. Such a limitation may be related to extended periods of calm and/or an abundance of reactive iron or other elements capable of binding phosphorus as it enters the surface waters. Such clear water periods have been observed in a eutrophic pond on Cape Cod after storm events which cause substantial amounts of iron to be flushed into the lake via ground water. Such a mechanism is less likely in the Berkshires, but infusions of calcium with surface runoff could function in much the same way.

Algal abundance in Stockbridge Bowl is a function of phosphorus levels, and is therefore more closely linked to watershed activities than rooted plant growths. However, the importance of internal recycling of phosphorus from anoxic bottom waters minimizes the importance of immediate inputs. It is the long term record of inputs, leading to the internal loading now experienced, which is responsible for algal blooms. This was recognized by William Enser in his 1980 application to the Massachusetts Eutrophication and Aquatic Vegetation Control Program, but has never been acted upon through in-lake efforts to control phosphorus recycling.

SEDIMENTATION

Sedimentation has become a problem as a result of two mechanisms: the gradual infilling and failure to maintain upstream detention areas, and the accelerated deposition of organic matter associated with excessive aquatic plant growths. The infilling of upstream detention areas has largely been a natural process, although development activities may have accelerated sedimentation in some cases. The former pool on Lily Brook just upstream of the inlet to Stockbridge Bowl is a good example of such infilling. Material has accumulated in what was once an open water area along Lily Brook, resulting in expansion of an emergent wetland and loss of open water and detention capacity. Sediment now continues downstream in major storm events, accumulating in the vicinity of the Lily Brook inlet. This area is now very shallow, and could be expected to become emergent wetland at some point in the not too distant future. Similarly, sediment has accumulated in pool areas of Shadow Brook downstream of the Kripalu Center and upstream of the Berkshire County Day School.

Requests for advice from the Stockbridge Bowl Association have met with pessimism from State and Federal agencies, which do not support the restoration of open water and detention capacity within emergent wetlands. A letter from the Army Corps of Engineers expressed sympathy for the plight of the lake, but noted the difficulty of gaining approval for alteration of more than 5000 square feet of wetland, even with replication elsewhere. Easily approved projects which are considered maintenance activities exempt from some permits are often separated from unpermittable projects by only the presence of emergent vegetation. This will remain a regulatory problem until agencies can look beyond the interests of specific laws and view the whole picture of ecosystem management.

The other mechanism of sedimentation, accumulations from plant growth, is an exponentially increasing problem associated with milfoil infestation. Sediment is appearing and remaining in areas where it never did before, fueling greater growths and more sediment deposition the following year. This is quite evident in the outlet channel, where shallow conditions and flows restricted by the gas pipe berm are allowing substantial muck accumulation. Dense plant growths impede boat passage, but even in the absence of such growths, the outlet is reported to be losing depth at a noticeable rate. Fine organic sediments are not accumulating appreciably in most of the roughly 2 vertical foot peripheral region of the lake subject to exposure during drawdown, but just below that water depth the accumulations are evident in any area without at least a 20% slope. This process can be expected to continue, potentially requiring expensive dredging to restore recreational utility and habitat at some future time.

OXYGEN DEPLETION

Loss of oxygen in the bottom waters of Stockbridge Bowl during summer stratification has been occurring for at least 4 decades, and is a natural phenomenon in most deep lakes. Human activities in the watershed greatly accelerate this process, however. Inputs of oxygen-demanding substances cause a direct loss of oxygen, and the addition of nutrients which fuel algae and plant growths lead to deposition of organic matter which then decomposes and uses up oxygen. The evolution of a lake into a body of water which undergoes oxygen depletion is usually a gradual process, even with human involvement. It is a result of long-term inputs, not immediate loading. As such, it becomes an in-lake process independent of watershed management, much like rooted plant infestations.

Under severe oxygen depletion, anaerobic bacteria flourish and metabolize available substrates. After certain preferred compounds such as nitrate are used up, sulfates are metabolized, producing hydrogen sulfide which is both toxic and greatly aids the recycling of phosphorus into the surface waters. Stockbridge Bowl progresses to this undesirable state by mid- to late summer in most years. Counteraction of this anaerobic process would be beneficial to virtually all uses of the lake.

Currently affected lake area is about 41%, but the volume of impacted water is only about 13% of the lake volume. This means that there is a relatively thin layer of water with highly undesirable quality covering slightly less than half of the lake bottom during the last half of summer and the beginning of autumn. It is created through interaction with the bottom sediments during separation from atmospheric influence, and could be the root of many perceived problems within Stockbridge Bowl.

FISHERY FEATURES

The fish community of Stockbridge Bowl offers substantial recreational opportunity. It is not an entirely natural assemblage, having been subject to a wide range of stocking programs in from the early 1900's until the mid-1960's, when the management emphasis settled on trout. Trout are still stocked in the lake, typically in the spring and fall, despite the limited summer habitat available to these sensitive fish. The Division of Fisheries and Wildlife (or its functional predecessors) at one time avoided stocking lakes without at least 25% suitable trout habitat (temperature <70°F (21°C) and oxygen >5 mg/l), but succumbed to political and public pressure to provide trout angling opportunity in many cases. Stockbridge Bowl has not provided the desired volume of trout habitat since sometime prior to 1947, when the reported trout habitat volume was 20%, and has been reported to have suitable volumes of 8 to 16% over the last 2 decades.

The warmwater fishery of Stockbridge Bowl, while no longer supplemented by stocking, is also highly valued by many anglers. Largemouth bass and pickerel are the primary game species. The presence of rooted plants is desirable for these species, especially pickerel, up to a coverage level of perhaps 40%. Even with the current milfoil infestation, plant coverage does not exceed about 37%. The problem is plant density and the portion of the water column filled with plants, which with milfoil is too high to allow effective foraging. No reduction in plant coverage is necessary for fishery purposes, but alteration of plant assemblage composition and reduction in density would be beneficial. Restoration of the native assemblage of macrophytes identified in past studies would be consistent with proper fishery management.

RARE SPECIES CONSIDERATIONS

Other than the desire to preserve *Chara* and *Najas* beds as habitat for locally rare snail species, we have encountered no record of plant species meriting special protection in Stockbridge Bowl. However, there are a large number of native species present in this lake, at least historically, and the preservation of the native plant assemblage is a worthy goal. Too little attention has been paid to preservation of native plant assemblages through management of non-native species.

Protection of two species of endangered snails, the Boreal Turret Snail (*Valvata sincera*) and Pilsbry's Spire Snail (*Pyrgulopsis lustrica*), has been used to block active management of milfoil in Stockbridge Lake in the 1990's. The former has not been observed in the lake since about 1980, while the latter appears to be in decline. Both are known to prefer shallow beds of *Chara* and *Najas*, each of which may be outcompeted by milfoil in the absence of fluctuating water levels. Only a small portion of the lake is currently suitable habitat for these snails, and much of the lake was never appropriate habitat. All areas of the lake which could be suitable habitat might be considered for restoration and protection, but current classification of the entire lake as protected habitat is inappropriate.

The most substantial remaining *Chara* beds are associated with the shallow area between the island and the shore near the mouth of the outlet channel, and this area is subject to drawdown influence on an annual basis during late autumn and winter. We know of no substantial *Najas* beds in Stockbridge Bowl, but this species is generally a deeper water plant and would be subject to intense pressure from milfoil. Both *Chara* and *Najas* are annual plants which are re-established each year from seed, the germination of which can be stimulated by drawdown (Appendix C).

With what is known of milfoil, agencies devoted to the protection of endangered species and associated habitat should support some program to limit milfoil growth. The rationale for opposing drawdown as a control measure stated in numerous pieces of regulatory agency correspondence (Appendix A) is that the drawdown would directly harm the snails by exposing them along with the milfoil. However, no consideration appears to have been given to the potential to implement a gradual drawdown capable of allowing escape time, or of the apparent long-term consequences of not controlling the milfoil. Dr. Stuart Ludlam is also reported as having indicated that drawdown harms the *Chara* and *Najas* beds, but this is inconsistent with the known ecology of these species. A fresh review of options by all interested parties is needed.

Although the two snail species of interest are rare in Massachusetts, this appears to be a function of the known range of these species instead of habitat destruction, and they are not rare in certain other states. It may be possible to find examples of drawdown or other management techniques for waterbodies containing these snail species, allowing an evaluation of likely impacts. Even if negative impacts are found, the habitat for these snails seems endangered more by not controlling milfoil than by seeking to control it. If suitable habitat could be restored, a re-introduction of the snails would be possible. It is not at all clear why such an effort should be delayed until the protected species have been absent from the a lake for an extended period of time (25 years for removal from the protected list, under current regulations).

RE-EVALUATION OF MANAGEMENT OPTIONS

CONTROL OF MACROPHYTES

Beyond the no action alternative, there are basically seven general approaches to the control of rooted aquatic plants (Table 7), each of which has potential advantages and drawbacks which must be considered in each possible application scenario. Each method is outlined and its applicability to the Stockbridge Bowl milfoil problem is discussed in the following sections.

No Action Alternative

Eurasian milfoil has not been managed in many waterbodies, mostly out of neglect, but in some cases by intent. In its early to middle stages of colonization, milfoil can provide habitat structure of some value to aquatic life forms such as fish and macroinvertebrates, at least in contrast to the absence of plants (Pardue and Webb 1985, Kilgore et al. 1989). Compared to many native species, however, the value of milfoil is inferior, and its tendency to form very dense growths limits its habitat value in later stages of colonization (Keast 1984, Nichols and Shaw 1986). Allowing milfoil to grow uncontrolled has resulted in damage to the native assemblage in most lakes. Additionally, there is distinct potential for uncontrolled milfoil to provide a source of this plant for other, uninfested lakes in the region. If Eurasian milfoil infestation can be considered analogous to a disease, the no action alternative represents a failure to take action against a communicable disease among lakes.

In cases where milfoil has been monitored but no action taken, high densities of this plant are typically achieved within a decade (Carpenter 1980). Expansion throughout the infested lake can occur in as little as 5 years (Wagner 1995). Once dominant, milfoil populations appear to fluctuate in an unstable pattern, and in some cases milfoil has declined substantially for uncertain reasons after reaching peak densities in northern lakes (Carpenter 1980, Painter and McCabe 1988, Smith and Barko 1990, Sheldon 1995a). Smaller scale or temporary declines have been noted in many northern areas (Kimbel 1982, Nichols and Shaw 1986, Pullman 1992). It has been speculated that observed milfoil declines are linked to factors including nutrient depletion, decreased light availability, insect or pathogen attacks, or unauthorized use of herbicides (Carpenter 1980, Sheldon 1995a). Insect herbivory has been of great interest in these declines, but despite substantial research in this regard, insect effects remain unpredictable.

The no action alternative is not a sound strategy for Stockbridge Bowl, primarily because natural declines have not been observed and plant densities have already reached nuisance levels over a large area. Natural declines are unpredictable and not at all guaranteed. The remaining native plant assemblage of Stockbridge Bowl provides far more habitat value than could any stage of milfoil growth, and includes endangered snail habitat. Severe reductions in the native plant assemblage have already been observed. It does not seem prudent to wait any longer before implementing a comprehensive management plan.

TABLE 8. MANAGEMENT OPTIONS FOR CONTROL OF ROOTED AQUATIC PLANTS

Option	Mode of Action	Positive Impacts	Negative Impacts
Drawdown	♦ Lowering of water over winter period allows desiccation, freezing, and physical disruption of plants, roots and seed beds ♦ Duration of exposure and degree of dewatering of exposed areas are important ♦ Variable species tolerance to drawdown; emergent species and seed-bearers are less affected ♦ Most effective on annual to once/3 yr. basis	♦ Control with some flexibility ♦ Opportunity for shoreline clean-up/structure repair. ♦ Flood control utility	♦ Possible impacts on contiguous emergent wetlands ♦ Possible impairment of well production ♦ Reduction in potential water supply and fire fighting capacity ♦ Alteration of downstream flows ♦ Possible overwinter water level variation ♦ Possible effects on overwintering reptiles or amphibians
Chemical treatment	♦ Liquid or pelletized herbicides applied to target area or to plants directly ♦ Contact or systemic poisons kill plants or limit growth ♦ Typically requires application every 1-5 yrs	♦ Wide range of control is possible ♦ May be able to selectively eliminate species ♦ May achieve some algae control as well	♦ Possible toxicity to non-target species of plants/animals ♦ Possible downstream impacts; may affect non-target areas within pond ♦ Restrictions of water use for varying time after treatment ♦ Increased oxygen demand from decaying vegetation ♦ Possible recycling of nutrients to allow other growths
Harvesting/ hydroraking/ rototilling	♦ Plants directly removed by mechanical means, possibly with disturbance of soils ♦ Collected plants placed on shore for composting or other disposal ♦ Wide range of techniques employed, from manual to highly mechanized ♦ Application once or twice/yr. usually needed	♦ Highly flexible control May remove other debris ♦ Can balance habitat and recreational needs	♦ Possible impacts on aquatic fauna ♦ Non-selective removal of plants in treated area ♦ Possible spread of undesirable species by fragmentation ♦ Possible generation of turbidity

TABLE 8. MANAGEMENT OPTIONS FOR CONTROL OF ROOTED AQUATIC PLANTS (Continued)

Option	Mode of Action	Positive Impacts	Negative Impacts
Benthic barriers	♦ Mat of variable composition laid on bottom of target area, preventing plant growth ♦ Can cover area for as little as several months or permanently ♦ Maintenance improves effectiveness ♦ Not really intended for use in large areas, usually applied around docks, boating lanes, and in swimming areas	♦ Highly flexible control ♦ Reduces turbidity from soft bottoms ♦ Can cover undesirable substrate ♦ Often improves fish habitat	♦ May cause anoxia at se[illegible] water interface ♦ May limit benthic invertebrates ♦ Non-selective interferen[illegible] with plants in target area ♦ May inhibit spawning/f[illegible] by some fish species
Dredging	♦ Sediment is physically removed by wet or dry excavation, with deposition in a containment area for dewatering ♦ Dredging can be applied on a limited basis, but is most often a major restructuring of a severely impacted system ♦ Plants are removed and regrowth can be limited by light and/or substrate limitation	♦ Plant removal with some flexibility ♦ Increases water depth ♦ Can reduce pollutant reserves ♦ Can reduce sediment oxygen demand ♦ Can improve spawning habitat for many fish species ♦ Allows complete renovation of aquatic ecosystem	♦ Temporarily removes b[illegible] invertebrates ♦ May create turbidity ♦ May eliminate fish com[illegible] (complete dry dredging on[illegible] ♦ Possible impacts from containment area discharg[illegible] ♦ Possible impacts from d[illegible] material disposal ♦ Interference with recrea[illegible] other uses during dredgin[illegible]
Dyes	♦ Water-soluble dye is mixed with lake water, thereby limiting light penetration and inhibiting plant growth ♦ Dyes remain in solution until washed out of system.	♦ Light limit on plant growth without high turbidity or great depth ♦ May achieve some control of algae as well ♦ May achieve some selectivity for species tolerant of low light	♦ May not control periph[illegible] shallow water rooted plan[illegible] ♦ May cause thermal stratification in shallow p[illegible] ♦ May facilitate anoxia at sediment interface with wa[illegible]
Biological controls	♦ Fish, insects or pathogens which feed on or parasitize plants are added to system to affect control ♦ The most commonly used organism is the grass carp, but the larvae of several insects have been used more recently, and viruses are being tested	♦ Provides potentially continuing control with one treatment ♦ Harnesses nature to produce desired conditions ♦ May produce potentially useful fish biomass as an end product	♦ Typically involves introduction of exotic spe[illegible] ♦ Effects may not be controllable ♦ Plant selectivity may no[illegible] match desired target speci[illegible] ♦ May adversely affect indigenous species

Drawdown

Drawdown is known to provide some degree of control of milfoil through drying and freezing of overwintering vegetative plant parts. Success is linked to sufficient dewatering of exposed sediments and a weather pattern which promotes drying and freezing. Control of milfoil in the drawdown zone has often been observed. Eradication has rarely been achieved, however, mainly due to a common inability to lower the water level to the greatest depth of milfoil occurrence. Nevertheless, if the capability to conduct a drawdown exists or can be economically created, this is a worthwhile tool to have in the arsenal of milfoil management techniques.

Drawdowns have been intensely scrutinized in recent years by regulatory agencies as a consequence of perceived negative impacts on non-target organisms, both plants and animals. Some negative impacts have been documented, while others have simply been postulated. Potential impacts to shallow wells have been observed, and a variety of other hydrologic impairments are possible. A review of drawdown impacts is provided in Appendix C. Most impacts are avoidable and very few are irreversible, suggesting that drawdown is a potentially valuable tool. The key is to provide an appropriately phased program with a concurrent monitoring program to detect and document impacts.

Drawdown has been practiced at Stockbridge Bowl for many years, albeit at a rather minimal level of about 2 ft. Milfoil has been nearly excluded from the drawdown zone, and the primary habitat for the protected snail species occurs in this zone. Although there is some direct threat to the snails, and other impacts are possible, drawdown clearly has merit as a milfoil control technique. If regulatory agencies will consider the full picture of habitat restoration, drawdown may be an allowable means to achieve this end.

Dyes

Dyes are used to limit light penetration and therefore restrict the depth at which rooted plants can grow. In essence, they mimic the effect of light inhibition which might be expected during periods of high turbidity or prolonged ice and snow cover. Natural periods of low light are an important variable in determining plant composition and abundance, and use of dyes can produce similar effects. Dyes tend to reduce the maximum depth of plant growth, but have little effect in shallow water (<6 ft or 1.8 m 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). Although dyes might reduce milfoil growth in Stockbridge Bowl, they would be expected to impact the native pondweeds as well, opening large areas for milfoil colonization at a later date. Although dyes are not especially expensive per unit area or volume treated, treatment of the whole lake would be necessary at substantial expense.

Biological Controls

Biological controls for milfoil include a herbivorous fish (*Ctenopharyngodon idella*, the grass carp), an aquatic weevil (*Eurhychiopsis lecontei*), and viral pathogens. The grass carp, while successful in controlling certain weeds in the southern United States and in small ponds in more northern climates, is not recommended by the State of New York for use in large lakes. Among the problems with this species is selective feeding in which non-target species may become the preferred diet; in Stockbridge Bowl this could result in more available substrate for milfoil growth. The viral pathogens are still in the laboratory test stage, leaving the aquatic weevil as the most viable biological option.

On the positive side, the aquatic weevil in question is a native North American species, so no introduction of an "exotic" species is necessary. The impact of this aquatic weevil on Eurasian watermilfoil has been documented by Sheldon (1995a) through five years of experimentation. In controlled trials, the weevil clearly has the ability to impact milfoil plants through structural damage to stems and is extremely host-specific for Eurasian watermilfoil. Field observations link the weevil to milfoil declines in nine Vermont lakes, but lakewide crashes have not been observed in cases where the weevil has been introduced (Sheldon 1995a, Crosson 1995). Additional anecdotal evidence of weevil-induced crashes has surfaced (Kirschner 1995, Lee 1995), but limited documentation exists. Further field testing has yielded mixed results (Sheldon 1995b, Leamy 1995); the weevils often cause observable damage at introduced sites, but expansion of this damage to lakewide status has not occurred within the time constraints of the research to date.

Several important questions remain unanswered with regard to weevil usage as a valid milfoil control technique. First, how many weevils are necessary to ensure a complete milfoil collapse in a target area? Even at one per stem, the number of weevils needed where the native population is minimal would be quite large. If seeded at a low density, will the weevils reproduce to the extent necessary to control milfoil? If so, why hasn't this happened naturally where weevils are already present? Finally, if control is achieved, will it last? Do the weevils continue to depress milfoil populations, or is a cycle of increase and decrease set up?

Beyond the ecological questions, the practical implementation of this approach is still in the early stages of experience and associated costs are fairly high. The State of Vermont devoted considerable resources to rearing weevils for introduction over a two-year period, using them all for just a few targeted sites (Hanson et al. 1995). Fiscal constraints have since curtailed this effort (Crosson 1995), and a review of the potential for this approach to succeed in Connecticut Lakes (Fredette 1995) concluded that expense would be a limiting factor.

While there are some very appealing aspects to this approach, and it may indeed become a practical methodology at some point in the next decade, it does not appear to hold great immediate promise for Stockbridge Bowl and may not be compatible with other control methods; less than ideal results in some other systems may have been due to interference from competing control techniques (Sheldon 1995c). Without further information, this technique cannot be recommended as a central element for the control of vegetation in Stockbridge Bowl, but it should be considered for future use as developments dictate.

Dredging Approaches
Dredging works as a plant control technique when either a light limitation is imposed through increased water depth or when enough soft sediment is removed to reveal a less hospitable substrate (typically rock or gravel). 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 and most sediment is returned to the lake.

Dredging in Stockbridge Bowl could be an effective milfoil control technique, but would be inordinately expensive and would not work in all areas. All information necessary to assess dredging feasibility (Appendix D) is not available at this time, necessitating substantial further study if this option is to be pursued. Dredging may indeed be necessary to restore depth to some areas, such as the outlet channel and the lake near the Lily Brook inlet, it is unlikely to be applied as a lakewide technique for controlling rooted aquatic plants. More selective and less costly approaches seem available and feasible.

Harvesting Approaches
Harvesting includes a wide range of plant removal techniques; the simplest form is hand pulling of selected plants. Successively more complicated approaches include manual cutting, mechanical cutting, aquatilling (underwater rototilling), mechanical cutting and collection, suction dredging, and hydroraking (mechanical whole plant harvesting with some collection). Harvesting can be an effective longer term control technique when the target plants reproduce by seed and harvesting is timed properly to eliminate annual seed production. Usually several successive years of effort are necessary, as seeds deposited prior to management can be expected to germinate over more than one year. There is some evidence that intense harvesting of plants reproducing by vegetative propagation limits survival over the winter, but the effect varies by species and location. Harvesting can be an effective short term control strategy for any aquatic plant nuisance, analogous to mowing the lawn.

Harvesting techniques which present the opportunity for plant fragments to escape are generally not suited for longer term control of species which reproduce vegetatively, and may actually be counterproductive to control. While short term control may be achieved in the target area, long term control is rare and the escape of fragments often results in colonization of new sites. Any of the cutting techniques without collection, and often even with collection effort, can be expected to result in the spread of vegetatively reproducing species. For that reason, only harvesting approaches with a very low probability of fragments being left in the water are appropriate for longer term control of Eurasian watermilfoil. An exception may exist where milfoil has already become the dominant plant in the system, as spreading by natural means will greatly exceed any harvester-induced dissemination.

In Stockbridge Bowl, harvesting has been applied since 1979 to manage milfoil in water over 3 ft deep. The approach is analogous to mowing the lawn, as the milfoil grows back at rates up to an inch per day. Cutting rarely occurs near the base of the plants, allowing regrowth once a new apical meristem is produced. As milfoil has already spread throughout the lake, there is little danger of further internal spread from current harvesting. There is virtually no likelihood that long-term control will be achieved through harvesting, although growth in some areas appears to have been reduced subsequent to multiple harvesting episodes. Harvesting is therefore a reasonable interim measure for maintaining open water, but is not a substitute for habitat restoration through more permanent means.

Benthic Barriers

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). A variety of solid and porous materials have been used. Commercial production of effective materials has occurred since the late 1970's, although creative lake managers found ways to cover plants long before then. 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 barrier problems of prime concern have been long-term integrity of the barrier, billowing caused by trapped gases, accumulation of sediment on top of barriers, and growth of plants on porous barriers. An additional concern is the non-selective nature of benthic barriers, which kill all plants over which they are applied. One final problem is the tendency of products to come and go without much stability in the market. Few of the barrier materials on the market at any time continue to be available for more than 5-10 years; most need to be made in bulk to keep costs down, yet cost remains high enough to hinder demand and reduce bulk use.

The ability of milfoil fragments to recolonize porous (mesh) benthic barriers has made porous barriers less useful for combating infestations by milfoil on any but the smallest scale, as sheets must be removed and cleaned at least yearly. Solid barriers have been more useful, although gas entrapment has been troublesome; billowing occurs without venting and anchoring, yet appropriate venting and anchoring creates problems for eventual maintenance or redeployment. Expense dictates that only limited areas be treated without re-use of deployed barrier. Nevertheless, 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.

As a result of over a decade of field experience with benthic barriers, several guidelines have been developed:

- 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 at least solid barriers restricts recolonization.

Experience with benthic barriers in Stockbridge Bowl is limited to two attempts in the White Pines Country Estates swimming area. A solid liner was used first, was found to billow unacceptably, and was buried under sand to held hold it down. Organic matter accumulated along with the sand, and milfoil grew on top. A second attempt was made using a porous cover, but this too billowed unacceptably. It was removed after about a month, and temporary control of milfoil was reported for the ensuing summer, but complete regrowth of milfoil has since been reported in the absence of any barrier.

Cost and labor are the main factors limiting the use of benthic barriers in most lakes, and would be prime deterrents in Stockbridge Bowl. Cost per installed square foot is on the order of $1.00 (Table 9), leading to an expense of about $40,000 per acre. Bulk purchase and use of volunteer labor can greatly decrease costs, but use over the 160 acres infested with milfoil is highly unlikely, even if permittable.

The application of solid barriers such as Palco Pond Liner is useful in controlling small (<1 acre) beds of milfoil where the material is left in place and where effort is expended on removing any peripheral growths of milfoil. Redeployment of barrier will reduce the overall cost of this approach and is consistent with the goal of restoring a native plant assemblage to areas infested with milfoil, but is likely to require additional effort at the original application site to prevent recolonization by milfoil. Such effort might include hand harvesting of milfoil for at least two growing seasons after removal of the barrier, or might involve augmentation of the native population in the formerly covered area.

Experiments conducted in Texas (Doyle 1995) indicate that the addition of dried seeds to an exposed area of sediment will result in rapid germination of virtually all viable seeds and rapid cover of the previously exposed area. However, if this is not done early enough in the growing season to allow plants to mature and produce seeds of their own, the population of annual plants will not sustain itself into the second growing season. Transplanting mature growths into exposed areas was found to be a more successful means of establishing a seed producing population. The use of cuttings gathered by a harvester (Helsel et al. 1996) was not successful in establishing native species in areas previously covered by benthic barrier in Wisconsin. More research is needed to establish protocols for restoring native assemblages in concert with benthic barrier use.

Benthic barriers offer definite potential for localized control of milfoil in Stockbridge Bowl. If a comprehensive milfoil management plan does not gain approval by regulatory agencies, use of benthic barriers by individuals or small groups would seem to be a logical if suboptimal approach to milfoil control on a patchwork basis.

Table 9. Current Costs[1] for Available Benthic Barriers

Type of Material	Material Cost ($/sq. ft.)	Anchoring & Installation ($/sq. Ft.)	Total Cost ($/sq. ft.)
Aquatic Weed Net™ - PVC coated fiberglass	$0.60	$0.50	$1.10
Texel™ - Polyester geotextile (needle punched)	$0.30	$0.50	$0.80
Palco™ - PVC pond liner	$0.50	$0.50	$1.00

[1] Retail costs assuming, professional diver installation. Costs may be substantially less for large installation or use of local, less costly labor.

Chemical Control

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. Many pesticides in use even 20 years ago are not commonly used or even approved for use today. The legacy of such books as Rachel Carson's Silent Spring 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.

The Generic Environmental Impact Statement for use of two herbicides (fluridone and glyphosate) in New York (McLaren/Hart 1995) provides a lengthy review of the chemical and non-chemical alternatives for plant management in aquatic habitats. The following discussion of herbicide properties and utility incorporates much of the information supplied in that report, as well as the experience of many researchers, lake managers and environmental agencies in other states. Readers are encouraged to examine the GEIR for further details, but are also cautioned that not everything in that document is an accurate representation of current plant management methodology.

Among the variety of herbicides available today, five have been demonstrated to be successful against Eurasian milfoil, although one is still an experimental herbicide. The first two are endothall (7-oxabicyclo [2.2.1] heptane-2,3-dicarboxylic acid) and diquat (6,7-dihydrodipyrido [1,2-a:2',1-c] pyrazinedium dibromide), which are contact herbicides acting on plant metabolism after adsorption onto outer cell membranes. Salts of endothall are marketed as Aquathol K and Hydrothol 191, but only the Aquathol K formulation is typically used for milfoil control. An Aquathol K concentration of 2-4 mg/l is considered optimal for control of milfoil, but will also result in the death of many native species.

Endothall acts quickly on susceptible plants, but does not kill roots with which it cannot come into contact, and recovery of milfoil is often 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. Endothall compounds break down readily and are not persistent in the aquatic environment. 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.

Diquat is marketed under the tradename Reward. 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). Only portions of the plant with which the herbicide can come into contact are killed. Regrowth of milfoil has been rapid (often within the same year) after treatment with diquat in many cases.

The other three herbicides are systemic chemicals which affect target plants by inhibiting critical metabolic pathways after uptake through roots, leaves or shoots. Included are 2,4-D (2,4-dichlorophenoxyacetic acid), fluridone (1-methyl-3-phenyl-5-[3-(trifluoromethyl)phenyl]-4[1H]-pyridinone) and triclopyr (triclopyr triethylamine), the last of which is still experimental in its aquatic formulation.

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. Aqua-Kleen is the tradename for the butoxyethyl ester granular aquatic formulation which is commonly used. The toxin is absorbed by roots, leaves and shoots and inhibits 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 milfoil early in the season, after growth has become active but before such propagules form.

Experience with granular 2,4-D in the control of Eurasian milfoil has been generally positive, with careful dosage management (100 lbs/acre) providing control of Eurasian milfoil with only sublethal damage to many native species (Miller and Trout 1985, Helsel et al. 1996). Recovery of the native community from seed has also been successful. 2,4-D has variable toxicity to fish. There are also claims of carcinogenicity to humans, creating a perceived if not real problem for the use of this herbicide in lakes used for potable water supply. The 2,4-D label does not permit use of this herbicide in water used for drinking or other domestic purposes, or for irrigation or watering of livestock.

Fluridone, which is the active ingredient in Sonar, obtained Federal registration in 1986 has been in widespread use in the United States since the late 1980's. It currently comes in two formulations, an aqueous suspension (Sonar AS) and a slow release pellet (Sonar SRP), 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, including Eurasian watermilfoil, 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.

The plant list of major species from Stockbridge Bowl (Table 10) includes 10 species. Comparison of this list with susceptibility evaluations compiled by the Vermont DEC (1995) and the current supplier of Sonar (SePRO 1995) indicate that at least 4 species of native vegetation are either susceptible or intermediately susceptible to fluridone and information on another 3 is unavailable. The macroalga *Chara* appears to be tolerant of fluridone.

Sonar is considered to have low toxicity to invertebrates, fish, other aquatic wildlife, and humans. It is not known to be a carcinogen, oncogen, mutagen or teratogen. Research on its degradation products initially suggested some possible effects, but further testing indicated no significant threat. Substantial bioaccumulation has been noted in certain plant species, but not to any great extent in animals. The USEPA has designated a tolerance level of 0.5 ppm (mg/l or mg/kg) for fluridone residues or those of its degradation products in fish or crayfish. The USEPA has set a tolerance limit of 0.15 ppm for fluridone or its degradation products in potable water.

The effectiveness of Sonar AS will be limited by dilution. This has been a problem for small area treatments in larger water bodies, leading to the recommendation that Sonar not be used to treat areas less than 5 acres unless the treated area includes the whole water body (i.e., ponds <5 acres). In order for a single Sonar AS treatment to be most effective against milfoil, treated areas must have limited exchange of water during the critical period of herbicide-plant interaction (at least three weeks).

Where dilution is a problematic factor, usually due to water exchange rates which are higher than desirable, Sonar SRP has generally been the formulation of choice. Gradual release of fluridone, which is 5% of pellet content, can yield a relatively stable concentration (Figure 3a). However, Sonar SRP has been less effective in areas with highly organic, loose sediments than over sandy or otherwise firm substrates (Burns 1995, Canfield 1995). A phenomenon termed "plugging" has been observed, resulting in a failure of the active ingredient to be released from the pellet. While some success in soft sediment areas has been achieved (ACT 1994), this approach is likely to be less efficient than the use of Sonar AS in areas with extremely soft sediments. As most of the lake bottom is rather soft sediment, it is not clear that Sonar SRP will be the best choice of application mode. Treatment by some combination of Sonar AS and Sonar SRP may be a worthwhile experiment, given the complementary nature of the concentration vs. time graphs for these formulations (Figure 3).

Table 10. Susceptibility of Common Stockbridge Bowl Plant Species to Fluridone and Triclopyr.

	Susceptibility to Fluridone [2]		Susceptibility to Triclopyr [2]
Species [1]	**VTDEC**	**SePRO**	**VTDEC**
Potamogeton richardsonii	S	S	
Potamogeton amplifolius			T
Potamogeton crispus	S	S	
Potamogeton gramineus			T
Potamogeton pusillus			T
Myriophyllum spicatum	S	S	S
Elodea canadensis	S	S	T
Nymphaea odorata	I-S	I-S	I-S
Chara sp.	T	T	T
Nuphar sp.	I-S	I-S	I-S

[1] Adapted from Stockbridge Bowl Diagnostic/Feasibility Study Report. 1991. Lycott Environmental Research, Inc.

[2] Susceptibility Code: S=Susceptible, I=Intermediate, T=Tolerant

VT DEC has compiled tolerance data from a variety of sources as part of its review for chemical treatment to aid milfoil control in that state.

SePRO is the current supplier of Sonar products.

Acceptably low dilution of Sonar AS may be achieved naturally in certain cove areas, but appropriate conditions may have to be artificially induced in more open areas. Sequestering an area to be treated with a herbicide is not a new idea, but has not been extensively practiced or documented. In recent treatments using 2,4-D, Helsel et al. (1996) used plastic curtains to restrict water exchange between a treated cove and the main body of a lake in Wisconsin. Less than 6% of the herbicide passed the barrier according to their monitoring program. Creation of a curtain made from Palco Pond Liner™ is feasible, but may cost on the order of $15/linear foot, and it would not be unusual to need two 500 ft curtains to provide proper isolation of some likely target areas. However, as such curtains would be indefinitely re-useable and treatment may not be effective in some cases without it, the expense may be justified.

More recently, however, multiple low dose treatments with Sonar AS have been successfully applied in areas where dilution could not be adequately controlled. Sequential treatment with Sonar AS two to four times over a time period of up to a month, as needed to maintain a concentration between 0.01 and 0.03 mg/l (10-30 ppb), can mimic the action of slow release pellets. This approach may be particularly useful in areas with a general pattern of slow throughflow, as treatment could follow a physical pattern which allows tracking of the water movement and maintenance of the desired fluridone concentration.

An immunoassay is currently under development (Burns 1995) which could allow field measurement of the fluridone concentration. When available, this could allow tracking of the fluridone concentration with additive treatment where and when necessary over a multi-week period. A number of flexible treatment regimes are possible with the fluridone formulations currently available, and the potential addition of a time release pellet of longer duration may expand this flexibility.

The cost of fluridone treatments will vary with area treated, water depth, dose and the application mode. Experience elsewhere for areas >10 acres dictates a cost range of $400-750/acre for single treatments, exclusive of any special controls mandated by environmental constraints. Single treatments of smaller areas are expected to cost between $600 and $1500/acre, with multiple treatments resulting in costs of up to about $2000/acre. Costs for sequestering treated areas, educating residents regarding the treatments, and for any preventive activities relating to water intakes could be substantial, and significant monitoring costs associated with early treatments should also be anticipated.

The herbicide Garlon 3A, with triclopyr as its active ingredient, is currently experimental for aquatic habitats. If successfully registered for aquatic use, it will be marketed under the tradename Renovate. It is highly selective and effective against Eurasian milfoil at a dose of 1-2.5 mg/l. Experimental treatments of aquatic environments (Netherland and Getsinger 1993) have revealed little or no effect on most monocotyledonous naiads and pondweeds. 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.

Triclopyr is not known to be a carcinogen, oncogen, mutagen or teratogen, and all lethal effects on tested animal populations have occurred at concentrations over 100 times the recommended dosage rate. The experimental label calls for concentrations in potable water of no more than 0.5 mg/l, suggesting that care must be taken to allow sufficient dilution between the point of application and any potable water intakes. Garlon 3A has been applied to areas as small as 1 acre, with the recommendation that small areas be rectangular in shape. Full Federal registration for use in aquatic habitats is tentatively expected in 1997.

Triclopyr susceptibility by Stockbridge Bowl plants (Table 10) suggests that Triclopyr is less damaging to the native assemblage than fluridone with only 2 native species intermediately susceptible. Chara appears to be tolerant to treatment with Triclopyr.

Given the general public sentiment against the use of herbicides in Stockbridge Bowl, this option may be ruled out based on non-scientific considerations. Certainly there may be reservations about herbicide use on a scientific level as well. However, use of Fluridone or Triclopyr to get control over milfoil has merit, allowing other techniques to be used after initial treatment to keep milfoil from regaining dominance. Consideration of test treatment of a sequestered area of milfoil infestation is warranted, pending a review of results elsewhere in New England and New York.

CONTROL OF ALGAE

Beyond the no action alternative, the control of algae in Stockbridge Bowl could involve any combination of the techniques described in Table 11. It would be most desirable, however, to attack the source of the problem, excessive phosphorus levels, instead of the symptoms, or the algae blooms themselves. This would eliminate algaecides, dyes, settling agents and even biological controls from consideration. Biological controls, especially increasing the abundance of zooplankton which eat algae, would be desirable from the perspective of fueling the food web, but this approach is unlikely to prevent blooms when high levels of available phosphorus are present.

Of the remaining techniques, nutrient input reduction stands out as the most universally agreeable course of action. However, as described previously in this report, achievable control of watershed inputs is not expected to be sufficient to prevent algal blooms as a consequence of the very large internal load of phosphorus. While some effort to minimize watershed inputs is desirable, it cannot be the mainstay of an algal control program.

Of the techniques intended to reduce internal loading, hypolimnetic withdrawal has been discounted by Lycott for reasons of possible downstream impact, and we concur. Circulation does not have a reliable track record, and there is no available source of high quality water for dilution or flushing. Dredging is technically and economically infeasible in the deeper portions of the lake where the sediments influencing internal loading are located. This leaves aeration and inactivation as viable approaches to combating internal phosphorus loading.

No Action Alternative

In the absence of any management action, periodic algal blooms can be expected in Stockbridge Bowl, especially in response to mixing events such as larger storms. Conditions will probably not become appreciably worse than at present, given the relative importance of the internal load, at least in the near future. Conditions would not be expected to improve, however, and would eventually worsen in terms of the frequency of algal blooms. There is a high degree of unpredictability associated with current conditions, again owing to the relative importance of the internal load and the interaction of the two water layers during summer stratification. Blooms will become more frequent and predictable as the overall fertility level of the lake rises, but that may take decades under the current loading scenario.

Aeration

Aeration has great potential in the Stockbridge Bowl system, as it could provide major improvements in water clarity and coldwater fish habitat at a possibly tolerable cost and with relatively little regulatory difficulty. By keeping the hypolimnion from becoming anoxic during stratification, aeration should minimize the release of phosphorus from deep bottom sediments and increase the volume of water suitable for habitation by trout and other fish. The dissolved levels of a number of other contaminants (e.g., metals, ammonium) are likely to decrease markedly in aerated waters. Permitting for aeration can be complicated, but aeration is among the easier lake management processes to get approved in Massachusetts.

TABLE 11. MANAGEMENT OPTIONS FOR CONTROL OF ALGAE

Option	Mode of Action	Positive Impacts	Negative Impacts
Chemical treatment	♦ Liquid or pelletized algaecides applied to target area ♦ Algae killed by direct toxicity or metabolic interference ♦ Typically requires application at least once/yr	♦ Rapid elimination of algae from water column with increased water clarity ♦ May result in net movement of nutrients to bottom of lake	♦ Possible toxicity to non-target areas or species of plants/animals ♦ Restrictions on water use for varying time after treatment ♦ Increased oxygen demand and possible toxicity from decaying algae ♦ Possible recycling of nutrients, allowing other growths
Addition of settling agents	♦ Lime, alum or polymers applied, usually as a liquid slurry ♦ Creates a floc with algae and other suspended particles ♦ Floc settles to bottom of lake ♦ Re-application necessary at least once/yr	♦ Removes algae and increases water clarity without lysing most cells ♦ Reduces nutrient recycling ♦ Removes non-algal particles as well as algae ♦ May reduce dissolved nutrient levels	♦ Possible impacts on aquatic fauna ♦ Resuspension possible ♦ Increased sediment accumulation
Phosphorus inactivation	♦ Typically salts of aluminum, iron or calcium are added in slurry form to the lake ♦ Phosphorus is complexed and settled to the bottom of the lake ♦ Permanence of binding is related mainly to redox potential and pH, with aluminum providing strongest binding ♦ Can be used on inlet streams	♦ May remove other nutrients and contaminants as well as phosphorus ♦ Flexible with regard to depth of application and speed of improvement ♦ If floc is sufficient, phosphorus in surficial sediments will also be inactivated	♦ Possible toxicity to fish and invertebrates by aluminum ♦ Possible resuspension of floc ♦ Possible release of phosphorus under anoxia/low pH ♦ May cause fluctuations in water chemistry, especially pH ♦ May add to sediment build-up
Aeration/ destratification	♦ Addition of air or oxygen at varying depth provides oxic conditions ♦ May maintain or break stratification ♦ Can also withdraw water, oxygenate, then replace	♦ Oxic conditions promote binding/sedimentation of phosphorus ♦ Counteraction of anoxia improves habitat for fish/invertebrates ♦ Deep build-up of ammonia and phosphorus reduced	♦ May disrupt thermal layers important to fish community ♦ May promote supersaturation with gases harmful to fish
Dilution/ flushing	♦ Addition of water of better quality dilutes nutrients ♦ Addition of water of similar or poorer quality flushes system to minimize algal build-up ♦ May be continuous or periodic additions	♦ Dilution reduces nutrient concentrations without altering load ♦ Flushing minimizes detention, response to pollutants may be reduced	♦ Diverts water from other uses ♦ Flushing may wash desirable zooplankton from lake ♦ Use of poorer quality water increases loads ♦ Possible downstream impacts

TABLE 11. MANAGEMENT OPTIONS FOR CONTROL OF ALGAE (Continued)

Option	Mode of Action	Positive Impacts	Negative Impacts
Circulation	♦ Use of water or air to keep water in motion ♦ Often combined with surface aeration or flushing options ♦ Generally driven by mechanical force	♦ Reduces surface build-up of algal scums ♦ Promotes uniform appearance ♦ Can eliminate localized problems without obvious impact on whole lake	♦ May spread localized impacts ♦ May increase oxygen demand at greater depths ♦ May promote downstream impacts
Hypolimnetic withdrawal	♦ Discharge of bottom water which is likely to contain higher nutrient levels and low oxygen ♦ May be pumped or utilize passive head differential	♦ Removes poorer quality water form lake ♦ May increase bottom oxygen levels ♦ May remove initial phase of algal blooms in deep water	♦ Possible downstream impacts ♦ May eliminate colder thermal layer important to certain fish ♦ May promote mixing of some remaining poor quality bottom water with surface waters
Dredging	♦ Sediment is physically removed by wet or dry excavation, with deposition in a containment area for dewatering ♦ Dredging can be applied on a limited basis, but is most often a major restructuring of a severely impacted system ♦ Nutrient reserves are removed and algal growth can be limited by nutrient availability	♦ Can control algae if internal recycling is main nutrient source ♦ Increases water depth ♦ Can reduce pollutant reserves ♦ Can reduce sediment oxygen demand ♦ Can improve spawning habitat for many fish species ♦ Allows complete renovation of aquatic ecosystem	♦ Temporarily removes benthic invertebrates ♦ May create turbidity ♦ May eliminate fish community (complete dry dredging only) ♦ Possible impacts from containment area discharge ♦ Possible impacts from dredged material disposal ♦ Interference with recreation or other uses during dredging
Dyes	♦ Water-soluble dye is mixed with lake water, thereby limiting light penetration and inhibiting algal growth ♦ Dyes remain in solution until washed out of system.	♦ Light limit on algal growth without high turbidity or great depth ♦ May achieve some control of rooted plants as well ♦ Produces appealing color	♦ May not control surface bloom-forming species ♦ May cause thermal stratification in shallow ponds ♦ May facilitate anoxia at sediment interface with water
Biological controls	♦ Manipulation of biological components of system to achieve grazing control over algae ♦ Typically involves alteration of fish community to promote growth of large herbivorous zooplankton ♦ Viruses or other pathogens have been used as well	♦ May increase water clarity by changes in algal biomass or cell size distribution without reduction of nutrient levels ♦ Can convert unwanted biomass into desirable form (fish) ♦ Harnesses natural processes to produce desired conditions	♦May involve introduction of exotic species ♦ Effects may not be controllable or lasting ♦ May foster shifts in algal composition to even less desirable forms
Nutrient input reduction	♦ Includes wide range of watershed activities intended to eliminate nutrient sources or reduce delivery to lake ♦ Includes erosion control measures, agricultural and storm water BMP's, waste water treatment, and land use planning	♦ Acts against the source of algal nutrition ♦ Creates sustainable limitation on algal growth ♦ May control delivery of other unwanted pollutants to lake	♦ May involve considerable lag time before improvement observed ♦ Reduction of overall system fertility may impact fisheries ♦ May cause shift in nutrient ratios which favor less desirable species

Aeration has been successful in reducing available phosphorus in many lakes, but not to the extent or duration expected from theory. Cooke et al. (1986) review a number of examples and note that available phosphorus tends to decline by one to two thirds during aeration, but quickly rises to pre-aeration levels when treatment is ceased. One way to improve and extend results is to add a phosphorus binder such as aluminum or iron to the process; aeration promotes binding activity and bound phosphorus does not necessarily become available after aeration ceases.

Sedimentation of previously available phosphorus in a Canadian lake increased by almost an order of magnitude after aeration with the addition of iron to a Fe:P ratio of 10:1 (McQueen et al. 1986) and the combination of iron and oxygen was similarly successful in a Minnesota Reservoir (Walker et al. 1989). The process of nutrient inactivation is covered separately in this analysis, but where binders are already present it appears that aeration can improve their activity.

There are several types of aeration, but not all are appropriate for Stockbridge Bowl. Surface aerators will do little to reduce the hypolimnetic oxygen deficit. Aerators which use diffusers to destratify a lake could be effective in Stockbridge Bowl, but could eliminate summer trout habitat and might require the addition of phosphorus inactivators (alum, iron or calcium) to reduce internal phosphorus cycling. Systems which bring deep water to the surface can be inexpensive, but unless enough water is brought up to prevent anoxia, the quality of that water which is brought up may cause greater deterioration of surface conditions. Such systems could still be useful if a return mechanism was added to return oxygenated water to the original collection depth. Systems which pump air into the bottom waters without destratifying the lake could be very useful, but tend to be more expensive.

With regard to Stockbridge Bowl, there are three distinct systems with applicability. The first is the "partial air lift system", in which air is pumped into a submerged chamber in which exchange of oxygen is made with the deeper waters. The newly oxygenated waters are released back into the hypolimnion without destratification. A shoreline site for a housed compressor would be needed, but the aeration unit itself would be submerged and would not interfere with pond use or aesthetics. Capital outlay would on the order of $100,000, assuming that one large unit could handle the needed exchange. Operational costs would include mainly electricity, and would be dependent upon the rate of airflow needed. An additional cost of perhaps $2000 should be assumed in maintenance costs.

The second applicable aeration system is a complete water lift approach which would pump hypolimnetic waters to the surface, aerate it, and replace it in the hypolimnion. Bringing the water to the surface could be accomplished with multiple units equipped with small electric pumps or with wind-powered pumping, while return flow to the bottom should be achievable by passive sinking of the colder bottom waters once aerated. To avoid destratification or surface contamination through incomplete treatment, some kind of conduit to the bottom should be provided. Units would be scattered over the surface of the pond, potentially interfering with some recreational pursuits and impairing aesthetic appeal for some users. These units would have to be removed to avoid ice damage if not in use over the winter, adding to annual maintenance costs. The alternative would be to run them all year long, further ameliorating oxygen deficits but possibly eliminating ice cover and doubling operational costs. Despite technical applicability and lower overall cost for this type of approach, it does not appear appropriate for Stockbridge Bowl

The third applicable approach involves a process called layer aeration (Kortmann 1988). It works like the complete water lift system, but aerated water is used to form an oxygenated layer which acts as a barrier to the passage of phosphorus, reduced metals and related contaminants. The layer is stable as a consequence of thermally mediated differences in density. Less of the anoxic portion of the pond would be treated and converted to usable habitat for fish and zooplankton, but such habitat would increase markedly and phosphorus cycling should be reduced. At least one area within the pond would need to be set aside as a surface aeration location, but movement of waters would be through subsurface pipes which should not interfere with pond uses. The capital outlay would be on the order of $60,000, with operational costs slightly less than the partial lift system. This system could reduce internal loading, but would provide less trout habitat.

Any of these three aeration systems could make a marked improvement in Stockbridge Bowl conditions, but it should be noted that practical experience has demonstrated that effects are not uniform or reliably consistent within and among aquatic systems. Zones of minimal interaction will often occur, resulting in at least localized anoxia and possible phosphorus release. Downtime on aerators, especially if wind power is employed, will cause temporal fluctuations in oxygen content. The layer air and partial lift hypolimnetic aeration systems may allow a band of anoxic water to persist near the top of the metalimnion, allowing nutrient cycling and supply to the epilimnion and discouraging vertical migration by fish and zooplankton. Even under oxic conditions, there is some release of phosphorus from the sediments. There is a remote possibility of inducing "gas bubble disease" in fish through supersaturation of nitrogen (not just oxygen is transferred if air is used), and any addition of nitrogen should be viewed cautiously. Negative impacts of nitrogen could be overcome by using pure oxygen in a partial air lift system, but operational costs would increase approximately twofold.

Permitting for aeration systems includes local approval under the Wetlands Protection Act and a Chapter 91 Waterways License from MADEP for installation of structures in a Great Pond. It is not clear whether a permit would be needed from the Army Corps of Engineers under Section 404 of the Federal Clean Water Act for "placing fill in a wetland", but if the installation of aeration equipment in the pond is so construed, a Nationwide Permit (generic, minimum process) should be granted. If the Section 404 Permit is required, the project would also require a Section 401 Water Quality Certificate, issued for compliance with water quality objectives by MADEP; this should not be a problem for a well conceived aeration project.

It should also be noted that the partial lift system will require a land area where a compressor can be housed. Certain layer air options have similar requirements. Either the public beach area or the boat launch would provide suitable areas, with the beach area providing greater security and an existing building and the boat launch area providing the shortest distance to the area of concern. Related details will have to be dealt with in the design stage if this approach is selected.

Phosphorus Inactivation

The theory of phosphorus inactivation is fairly simple: a chemical which is only marginally soluble but has a high affinity for phosphorus is introduced to the water column and allowed to bind existing phosphorus and precipitate out. The bonus in this treatment is that the precipitating flocculant forms a layer on the bottom sediment which retards future phosphorus release. This layer may sink into the soft muck in the deep part of Stockbridge Bowl, but the binding of phosphorus should still be effective (Cooke 1992).

Improved water clarity is almost certain from this technique, and control of algal growths should also be achieved if those growths are dependent on internal sources of phosphorus. Reduced oxygen demand is also expected, but the hypolimnion is still likely to be largely unsuitable for trout without supplementary oxygen inputs. Fishing may be improved somewhat, but reduced fertility will limit fish production and there is some risk of toxicity from certain inactivation treatments. This technique has been permitted in Massachusetts, but requires careful planning and justification.

Alum, or aluminum sulfate, has been the most widely used chemical for this treatment, as it binds phosphorus well under a wide range of conditions. Although alum is not very soluble, concentrations in excess of 50 ug/l may cause toxicity for aquatic fauna and the solubility increases with decreasing pH. A minimum pH of 6.0 virtually ensures that the 50 ug/l limit will not be reached, but alum addition can reduce the pH well below this level in poorly buffered waters. In such cases sodium aluminate, a more pH neutral chemical, has been used with success (Cooke et al. 1993). Other chemicals which have been successfully employed include calcium hydroxide and ferric chloride; the former tends to raise the pH and the latter is relatively neutral.

Phosphorus inactivation has received increasing attention over the last decade as long lasting results have been demonstrated in multiple projects, especially those employing alum. Annabessacook, Cochnewagon and Three Mile Lakes in Maine, Kezar Lake in New Hampshire and Lake Morey in Vermont are examples of successful aluminum-based phosphorus inactivation projects in New England. Annabessacook Lake suffered algal blooms for 40 years prior to the 1978 treatment with aluminum sulfate and sodium aluminate (Cooke et al. 1993). Low buffering capacity necessitated the use of sodium aluminate, as would be the case in Stockbridge Bowl. A 65% decrease in internal phosphorus loading was achieved, cyanobacteria blooms were eliminated, and conditions have remained much improved to date (15 years). Some decline in recent years suggest that another treatment may be needed soon (Monagle 1992). Similarly impressive results have been obtained in the other two Maine Lakes using the two aluminum compounds together (Connor and Martin 1989a).

Kezar Lake was treated with an aluminum sulfate/sodium aluminate mixture in 1984 after a wastewater treatment facility discharge was diverted from the lake. Both algal blooms and oxygen demand were depressed for several years, but began to rise more quickly than expected (Connor and Martin 1989a, 1989b). Additional controls on external loads (wetland treatment of inflow) reversed this trend and conditions have remained markedly improved over pre-treatment conditions for almost a decade (Connor 1992). No adverse impacts on fish or benthic fauna have been observed despite careful monitoring.

Aluminum sulfate and sodium aluminate were again employed at Lake Morey, VT, with great success (Smeltzer 1990). A pretreatment average spring total phosphorus concentration of 37 ug/l was reduced to 9 ug/l after treatment in late spring of 1987. Although values have risen since then, the pretreatment levels have not yet been approached (Smeltzer 1993). Hypolimnetic phosphorus concentrations have not exceeded 50 ug/l. Oxygen levels increased below the epilimnion, with as much as 10 vertical feet of suitable trout habitat reclaimed. Some adverse effects of the treatment on benthic invertebrates and yellow perch were suggested to be temporary phenomena following treatment.

A combined aluminum sulfate and sodium aluminate treatment was conducted at Hamblin Pond in Barnstable, MA in May of 1995. Results in terms of water clarity were excellent, although it is too early to tell if this treatment will have the 10-15 year longevity predicted. On the down side, a fish kill resulted from elevated pH associated with the use of too much sodium aluminate; poor pre-treatment lab work, treatment during inappropriate weather conditions, and insufficient monitoring plagued this project. The need to do the job right is underscored.

Phosphorus inactivation has also been successful in some shallow lakes (Welch et al. 1988, Gibbons 1992), but has been unsuccessful in cases where the external loads have not been controlled prior to inactivation (Barko et al. 1990, Tyning 1992). Successful dose rates have ranged from 18 to 44 g Al/m^2 with pH levels remaining above 6.0. Jar tests are used to evaluate the appropriate dose and optimal mixture of aluminum sulfate and sodium aluminate; the former decreases pH but is less expensive than the latter. Application of the chemical to deep lakes is usually done near the thermocline depth (even before stratification), providing a precautionary refuge for fish and zooplankton which could be affected by dissolved aluminum. Application methods include modified harvesting equipment and specially designed barges made for this purpose.

Success has been achieved with calcium (Murphy et al. 1988, Babin et al. 1989) and iron (Walker et al. 1989) salts, but it has become clear that aluminum provides the greatest long-term binding potential for phosphorus inactivation (Harper 1992). Calcium would seem to be most desirable in low pH lakes, while iron seems to be most useful in conjunction with aeration systems. Aluminum salts can be used successfully in any of these cases, however, and would be the chemical of choice unless toxicity becomes a problem.

Cost for nutrient inactivation projects varied substantially in the early years of this technique, but have stabilized in recent years through development of application means and chemical supply markets. A cost of $600 to $800 per acre treated is expected for an aluminum sulfate/sodium aluminate treatment. Given the substantial alkalinity in Stockbridge Bowl and the greater expense of sodium aluminate, only aluminum sulfate may be needed at Stockbridge Bowl. This would about halve the cost. Iron chloride could be applied for as little as $200/acre, but the inability of iron to control phosphorus cycling under current conditions suggests that this approach is only viable if the hypolimnion is aerated.

If the toxicity problem can be avoided in Stockbridge Bowl, a single alum treatment should provide multiple years of greatly improved conditions. Longevity of alum treatments has generally been excellent where external inputs of phosphorus to the system have been controlled (Payne et al. 1991). Inputs from the Stockbridge Bowl watershed are not insignificant, but are predicted to be near the permissible level in the absence of internal recycling. Further tests and calculations are desirable to assess the likely range of longevity, if this approach is to be pursued.

The only other question involves interaction with the soft bottom sediments; just how fast the alum flocculant layer will sink into the soft muck and what level of inactivation can be expected after sinking is uncertain. Jar tests using actual pond sediment may prove useful in this regard.

Permitting for any chemical addition in Massachusetts has become a tedious process, and application of aluminum salts will receive careful scrutiny at state and local levels. A local Order of Conditions under the Wetlands Protection Act is all that should be necessary, but some permitting at the state level (e.g., chemical application permit, possible Water Quality Certificate) should be anticipated. Questions of possible aluminum toxicity in a trout-stocked lake and longevity of effectiveness must be addressed.

An interesting combination of aeration and phosphorus inactivation can be found in the dissolved air flotation systems for water treatment developed by the Lenox Institute of Water Technology in Lenox, MA. Water treated through this process can be made to meet a wide variety of water quality standards, and this technology has been successfully applied in water and waste water treatment. There have been several proposals in recent years to apply this technology to lake management, but no full scale lake operations are known at this time. There is reason to believe that algal blooms could be reduced or prevented through such treatment without adding air or chemicals directly to the lake. Costs are uncertain, but the process is analogous to setting up a water treatment facility for lake water, and is likely to be fairly expensive. The process has been described at times as a possible control strategy for rooted aquatic plants, but appears far more suited to algal control. It would be best to demonstrate its effectiveness on a smaller scale before contemplating any application to Stockbridge Bowl.

COUNTERACTING SEDIMENTATION

Preventing sedimentation of Stockbridge Bowl is an erosion control issue and a detention issue. The erosion issue is not a problem. Proper construction practices should be implemented and enforced, and there is little room for debate in this regard. Natural erosion is to be expected, and can be at least partially managed in accessible areas. Prevention of all erosion is impractical, however, and leads into the detention issue. The use of detention basins is a tried and proven technology for minimizing downstream transport of sediment. In an upland setting, construction and maintenance of detention basins is strongly encouraged. In a wetland setting, however, construction is almost impossible and maintenance is difficult at best.

There is a need to restore all available detention areas within the drainage areas of at least Lily Brook and Shadow Brook. This would include past impoundments of those streams and any associated emergent wetland areas formed from previous open water areas. Just how this can be done under the current regulations or regulatory interpretations is not at all clear.

With regard to the removal of sediment from impacted areas of Stockbridge Bowl, dredging is the only realistic option available. Hydraulic dredging would be feasible in the absence of a drawdown, but most areas of concern are currently quite shallow and could be dredged with conventional equipment in association with a drawdown. A localized drawdown could even be conducted through sequestering and pumping in some areas, but expenses would rise quickly.

Removal of accumulated sediments from the outlet channel appears to have the top priority, followed by extension of that channel past the island and removal of accumulated material near the Lily Brook inlet. All are feasible under a lakewide drawdown of several feet. Further survey and assessment work will be necessary to provide all information needed to address dredging feasibility more fully (Appendix D). A very rough cost estimate of $5 to 10 per cubic yard of material removed is suggested at this time.

PREVENTING OXYGEN DEPLETION

Oxygen depletion can only be prevented by removal of the material demanding the oxygen or addition of sufficient oxygen to offset the demand. Dredging in the deeper parts of Stockbridge Bowl is infeasible. Addition of oxygen through aeration is discussed in the section on Control of Algae. Aeration would provide substantial benefits to multiple uses of the lake.

IMPROVING FISHERY FEATURES

Other than changes in the stocking program or fishing regulations, improvement of the Stockbridge Bowl fishery could be achieved by increasing the oxygen content of deeper waters during the summer. This would best be accomplished through aeration, which is discussed in the section on Algal Control. As noted above, aeration would provide substantial benefits to multiple uses of the lake. Alteration of the macrophyte community, to reduce density and restore a more diverse, native flora, is also appropriate for fishing improvement and is discussed in the section on Control of Macrophytes.

PROTECTING RARE SPECIES

Protection of rare species is a difficult area to deal with in the case of Stockbridge Bowl. If the regulations are interpreted to restrict any activity which has even a short term impact on protected species, it will be very difficult to restore the habitat of those species which is being lost to the milfoil infestation. If, on the other hand, the regulations can be inferred to allow the risk of short-term losses for the sake of long-term gains, there is room to work out an effective program. All parties concerned with Stockbridge Bowl appear to want very similar conditions to result from management actions, albeit for different reasons. There is a need to establish clear goals for restoration and future protection, and to focus on the larger picture instead of the short term impacts. Control of milfoil appears consistent with the known objectives of all concerned parties; it is the manner in which control is achieved and the potential short-term side effects that have caused controversy.

RECOMMENDED MANAGEMENT PLAN

VIABLE OPTIONS

Drawdown

Drawdown has great appeal as a means for controlling rooted plants, particularly vegetative propagators such as the nuisance non-native milfoil. Aside from herbicide application, it is the only technique capable of affecting a large area economically, and is the only technique which can affect a larger area at no more cost than a smaller one. Drawdown would be expected to reduce the density of nuisance species while preserving the native assemblage, which is dominated by seed producing species of *Potamogeton*. Similar effects have been observed elsewhere in many Massachusetts lakes, including Berkshire County lakes. Cessation of drawdown in Onota Lake, Pittsfield, has encouraged rapid expansion and domination by milfoil (Fugro East 1996) despite harvesting efforts. There is little documentation of negative impacts of which we are aware, but many concerns have been raised and not answered by reliable research. If an appropriate monitoring program was devised, a drawdown program might be permitted.

The greatest impediment to drawdown across Massachusetts is impairment of water supply wells, but this is apparently not a major issue at Stockbridge Bowl. In this case, it is the perceived impact on two protected species of aquatic snails and the need to facilitate passage of water under three natural gas pipelines and one sewer pipeline which have precluded drawdown to date. Tenneco, the owner of the gas pipelines, has donated some funds toward a bypass pipe to allow a drawdown to be conducted. Permitting for the drawdown requires that the DEP and NHP be convinced of a lack of negative impacts, or at least of the long term benefit of this approach. We believe that the information provided in this report clearly illustrates the potential for a win-win situation, and recommend a cooperative effort to test drawdown in Stockbridge Bowl as a means to improve snail habitat and control milfoil growth.

The actual cost to bypass the gas and sewer pipelines is uncertain, but the 1991 Lycott study estimated a cost slightly in excess of $100,000. The J.F. Moynihan appendix to the 1980 report by Berkshire Enviro-Labs suggested that two siphons could be constructed for about $75,000. Without a more detailed engineering review, we cannot evaluate these estimates, but they appear to be of the correct order of magnitude. It will cost more than several tens of thousands of dollars to install a bypass for the existing pipelines, but should not be a multiple hundred thousand dollar project.

An additional need involves deepening the outlet channel and its connection to the main body of the lake sufficiently to implement a meaningful drawdown. This will require dredging, which is discussed in the next section. Dredging is typically an expensive endeavor, and requires extensive engineering effort and permitting support.

The drawdown would ideally be as great as spring refill will allow, but would logically start at about 4 ft and increase annually by 1 ft increments until an optimal level was reached. An eventual target of at least 5 ft and possibly 8 ft is appropriate. However, the Moynihan engineering report (BEL 1980) indicated that a pumping system would be necessary to produce a drawdown of more than 5.5 ft. More detailed hydrologic calculations would be necessary in the planning stage, with a re-examination of past engineering estimates. An initial target of 4 to 5 ft is appropriate, although facilitation of greater drawdown is desired if feasible from the viewpoint of engineering and economic constraints. The drawdown would commence in mid-autumn and terminate with ice-out, with downstream discharge held within the natural limit of variation.

Dredging

Dredging accumulated soft sediment from the main body of the lake could reduce nutrient reserves and help control rooted plant densities. However, a very large area would have to be dredged to make a significant difference to the overall plant community by dredging alone. If an average of just one foot of sediment was removed from the roughly 100 acres of milfoil impacted area in the main body of the lake, this would equate to 161,300 cy of sediment and a probable removal cost of between $800,000 and $1,600,000. More sediment might have to be removed to achieve plant control, and the primary nutrient reserves in the sediment under deep water would remain in place. Dredging is therefore not a viable strategy for widespread direct control of rooted plant growth in the main body of Stockbridge Bowl.

Dredging is, however, a viable means of facilitating a drawdown, and could be used in key locations to reverse the effects of lost upstream detention. To allow a drawdown of up to 5.5 ft by gravity, the area between the island and the outlet spillway (known locally as the "outlet") would have to be dredged and a channel around the island would be needed. An existing channel to the south of the island could be deepened, but there is merit to creating an eastern channel as well, most likely along the mainland shoreline away from the island. The drawback in either case is the presence of protected snail habitat all around the island. Dredging of the "outlet" poses less of a problem, as officials of the NHP have agreed that this area does not constitute protected habitat.

Assuming that permitting could be arranged, the actual dredging process would involve roughly 2000 to 2500 linear feet of the outlet. Channel configuration is variable, but the Moynihan report (BEL 1980) indicated that 65,100 cy of material would have to be removed to facilitate a 5.5 ft drawdown. This included primarily muck and loose sediment, but a need to excavate slightly more than 700 cy of ledge was noted. The estimated cost in 1980 was $356,000, including engineering aid. A figure of $350,000 was projected by Lycott several years ago, suggesting little change in costs over more than a decade. It may be possible to create a smaller channel to facilitate drawdown with less dredging and lower cost, but channel stability and creation of access for residences along the "outlet" are important considerations. Complete removal of accumulated sediments from the "outlet" would be preferred, at a previously estimated cost on the order of $350,000. Excavation to allow a drawdown of up to 8 ft was estimated in the Moynihan report to cost about $500,000, but a drawdown to 8 ft may also require pumping. A complete dredging feasibility assessment should be conducted as the first step in the design phase, allowing confirmation of past cost estimation prior to detailed design or permitting work.

Dredging of other areas of the lake may be desirable to remove sediments accumulated as a result of lost upstream detention, most notably near the inlet of Lily Brook. An area of about 5 acres could be dredged to a depth of 4 to 5 ft (currently <2 ft deep), with a removal volume of up to 40,000 cy and a probable cost of over $400,000. Several other areas might be similarly dredged, with a total investment of close to a million dollars. This is not financially realistic, and cannot be considered as a primary management action at this time.

Harvesting

Harvesting has long been practiced at Stockbridge Bowl, and a new harvester has recently been purchased. Harvesting is currently used to control near surface growths in the lake, although use in shallow water is limited. Although harvesting is known to spread milfoil during early stages of infestation, there is no significant harm in cutting and collecting milfoil once the distribution observed in Stockbridge Bowl has been reached. Unless eradication or extreme reduction can be achieved (logically only from chemical means), continued harvesting is a viable means for dealing with milfoil in water about 4 to 15 ft deep. The new harvester, to be in service in 1997, is expected to improve efficiency, but rapid coverage of large areas of the lake will still not be possible. Harvesting will continue to equate with mowing a very large lawn, and several passes per year will be needed to maintain open water in most areas infested with milfoil.

Harvesting costs for Stockbridge Bowl would best be estimated from Town records for purchases and labor, but it is generally assumed that the capital cost of a harvester and various auxiliary equipment is on the order of $75,000 to $100,000, and that operational costs run from $100 to $300 per acre harvested. If 100 acres are harvested twice per summer in Stockbridge Bowl, an annual operating cost of between $20,000 and $60,000 might be assumed. If drawdown or other localized techniques are employed to control milfoil in shallow water, the harvesting program would likely center on deeper waters alone, and might be more efficient, driving the cost toward the low end of the anticipated range.

If eradication or a return to very low densities was achieved, harvesting should probably be abandoned in favor of techniques which provide less risk of plant fragment dispersal for spot control (benthic barriers are a logical choice). Under current conditions, however, and in conjunction with a drawdown, harvesting would be a logical supplemental control technique.

Benthic Barriers

Although not selective, benthic barriers can be an effective means of controlling milfoil or other undesirable plants in small areas. At an initial cost of at least $20,000/ac, with annual labor costs of at least half that amount, this technique is typically reserved for small areas of high use, such as swimming areas or boat launches. Use of benthic barriers would be in direct competition with drawdown as a shallow water milfoil management technique, but could not be used over as extensive an area for as long a time period for economic reasons. This technique would probably be best held in reserve as a back up to drawdown, targeting a few key areas such as the Town beach and other public access points. If private citizens wish to utilize this approach, it would be appropriate to acquire a single joint permit for an well conceived plan covering a greater area.

Herbicides

As discussed in detail previously, the approved herbicide fluridone (trade name of Sonar) or the experimental herbicide triclopyr may be appropriate for the control of milfoil in Stockbridge Bowl. Fluridone is approved for use in Massachusetts waters, including drinking water supplies, having been demonstrated to be a minimal threat to non-target components of the aquatic system or to human health. Triclopyr has the advantage of requiring only about 12 hours of contact time to be effective, while fluridone must be maintained at a concentration of 10-20 ppb for at least 30 days. With high solubility and dispersion rates, fluridone will dissipate too rapidly throughout the lake to be used on a localized basis without an expensive sequestration process (a curtain or other separating device around the treatment area).

At a cost of around $500/ac, a whole lake treatment would cost approximately $185,000, exclusive of permitting and monitoring. Use of triclopyr or sequestered fluridone is still experimental, and may not be appropriate for large scale use at Stockbridge Bowl at this time. There is also considerable resistance to herbicide use among members of the Stockbridge Bowl Association and Town officials, which is understandable in light of the historic use of herbicides at this lake. While this approach may hold future promise, it is not recommended over the implementation of a drawdown at this time for control of milfoil.

Aeration

Aeration could minimize internal recycling of phosphorus, and might make a significant difference in the overall nutrient load to the lake, especially during the critical summer months. Adequate aeration would greatly increase the volume of available trout habitat during the summer, as long as stratification was not destroyed. A hypolimnetic aeration system would be the logical choice for this system, adding oxygen to the hypolimnion without disrupting thermal stratification. Phosphorus, ammonium nitrogen, and other contaminants known to increase under low oxygen conditions would be reduced in the hypolimnion, limiting transport into the epilimnion. The use of hypolimnetic aeration could have virtually no negative consequences, and could minimize algal blooms while maximizing fish habitat.

Aeration is not a rooted plant control technique, however, and could actually increase the area infested by milfoil by allowing deeper light penetration through increased water clarity in response to lowered algal concentrations. While this technique is likely to be viewed favorably by permitting agencies, it will not meet the primary objective of the management program, the control of milfoil. It would be entirely appropriate for implementation in conjunction with a comprehensive milfoil management program, but would not be universally acceptable as a stand-alone option.

The other drawback of aeration is cost. One large aeration unit, at a capital cost of approximately $100,000 with accessories, would be necessary to effectively aerate the hypolimnion of Stockbridge Bowl. A second unit might be necessary to achieve the desired lateral distribution of oxygen. Operational costs would be on the order of $2,000 per year. Although the capital cost is substantial, the potential benefit derived from annual operation would be well worth the operational cost as part of an overall lake management program.

Phosphorus Inactivation

Use of an aluminum, calcium or iron compound to make phosphorus unavailable for algal uptake has definite merit in Stockbridge Bowl, as it could greatly reduce the release of this essential nutrient from the bottom sediments into the hypolimnion or minimize transport of available phosphorus into the epilimnion. Calcium and iron release the phosphorus under low oxygen conditions, making aluminum the preferred choice in most cases. In the absence of an aeration system, aluminum would be the clear choice in this system as well. As this approach competes with aeration as a phosphorus load reduction measure, it is likely that only one or the other would be implemented. However, it would not be inappropriate to add extra iron or calcium to the waters acted upon by an aeration system, so the techniques could be combined. Logically, however, additives would not be used until the aeration system was operational for several years and data indicated a need for additional inactivation.

Inactivation with aluminum tends to be rapid, relatively complete, and lasting for those loads contacted. The settling floc creates a film over the bottom sediments that inhibits release of phosphorus, prolonging the effect. Only when the water column load has been replaced by external inputs or the alum layer becomes buried under new nutrient-rich sediment would the effect be expected to diminish. Negative impacts of aluminum would not be expected to be manifested in Stockbridge Bowl, owing largely to its well buffered pH.

Treatment is typically costed at $600 to $800 per acre treated for aluminum additions. If half the area of Stockbridge Bowl was treated, a cost of between $110,00 and $150,000 could be anticipated for a single treatment. If successful, limitation of sediment phosphorus releases could markedly affect the phosphorus load for a decade or even longer. The effect would be much like that of aeration in terms of phosphorus levels and resultant algal control. Improved clarity could foster expansion of milfoil growths as well. Fish habitat would not be appreciably improved, however, as oxygen levels would still be low in hypolimnetic waters. If inputs to the lake were not controlled, the effects of this treatment would wear off sooner than projected based on current estimation of external loading. While roughly similar to aeration in cost over the expected lifespan of the treatment, aluminum addition would have more immediate and possibly stronger effects, while aeration would have a greater range of beneficial effects.

Watershed Resident Education

Some degree of watershed resident education is already occurring in the watershed of Stockbridge Bowl, but this is a never ending effort which could be organized more fully to target key inputs and raise consciousness about residential practices which affect water quality. Production of a brochure to be distributed throughout the Town is advisable, and should not cost more than about $5,000. There are plenty of sample materials available, most notably through the MA DEM, which also funds lake management programs. Emphasis should be placed on reducing contamination of storm water runoff and maintaining on-site waste water disposal (septic) systems. Storm water runoff is likely to be the main source of sediments, phosphorus and toxic contaminants to watershed streams. Conventional septic systems add considerable nitrogen to the environment, and may cause other contamination problems if not properly managed.

As described previously, educational endeavors are rarely sufficient by themselves, and in this case would do little to control milfoil or reduce the internal loading of phosphorus. While strongly recommended as a public awareness tool, education of watershed residents will not actually meet any of the postulated management objectives. It will surely facilitate management success, but will not suffice alone.

Detention Systems

The loss of detention capacity along at least the two largest tributaries is a legitimate cause for concern, as such detention is valuable for both sediment and nutrient load control. It is becoming increasingly difficult to restore detention capacity unless the basin was recently created for that purpose; cleaning out older basins established in wetland systems is often discouraged by regulatory agencies. The loss of detention within the wetland along Lily Brook just upstream of Stockbridge Bowl is a good case in point. There are several additional basins along Shadow Brook which may fall into the same situation. Effort to get restoration of these detention areas approved is recommended, but may not be easy.

Costs for restoration of detention will be similar to that for dredging projects, at about $5 to $10 per cubic yard of capacity. The lost volume or preferred volume of detention is not currently known for these tributary systems, but could be calculated in a feasibility evaluation. It would not be surprising to find that as much as 500,000 cy of detention capacity should be provided, and that more than half of that volume is non-existent at this time. This would suggest a cost of up to $2.5 million for remediation, if the needed space was available. An effective program could probably be implemented using far less volume by targeting key areas and controlling erosion at the source.

Storm Water Management

Storm water management tends to be a fairly diffuse activity, but is becoming increasingly critical to protecting water quality. Effort expended on storm water management, from source control through transport mitigation techniques, cannot possibly be wasted, but may not provide the greatest benefit per dollar spent in this case. The load of contaminants from the watershed of Stockbridge Bowl, while not insignificant, is not responsible for observed conditions in a direct way except during rare events. Rather, it is the long term accumulation of contaminants in the lake which appears to be controlling water quality, and watershed management bears virtually no relation to the milfoil problem.

Careful review of Town ordinances relating to storm water management is advised, with attention to existing state and federal regulations which continue to evolve. Enforcement of regulations relating to construction projects, routing of storm water, and minimization of peak flows is important, and carries no tangible cost. Consider restricting fertilizer use to situations with documented need, and encourage watershed residents to practice voluntary source control through the education program noted above. Expensive structural improvements are not warranted at this time, although they would have benefits. Restoration of detention capacity, as discussed above, would be the most applicable transport mitigation technique.

RECOMMENDED APPROACH

With regard to the primary objective of management, which is milfoil control, drawdown supplemented with harvesting remains the program of choice. These techniques offer a desirable combination of expansive and flexible control for a nominal operating cost. Capital costs are high, but not insurmountable. Technical drawbacks of drawdown include the need to bypass the gas pipelines, dredge the outlet channel, and to expand or create channels around the island in order to draw the lake down at least 4 ft and perhaps as much as 8 ft. Regulatory constraints revolve around the need to avoid negative impacts to protected species, namely two aquatic snails. Further discussion of short term vs. long term impacts is needed, and will undoubtedly take place during the permitting process. Capital cost to facilitate drawdown have been estimated in previous studies to range from $400,000 to $600,000, including establishment of a bypass for existing pipeline obstructions and dredging to deepen the outlet channel and connect it to the main body of the lake.

Harvesting is a valuable supplementary technique for managing milfoil in waters deeper than the drawdown zone, but cannot be expected to be a completely satisfactory approach by itself. A new harvester has been purchased and will be in service in 1997. Ongoing operational expenses of $20,000 to $60,000 are expected for harvesting.

With regard to the secondary objective of improving water quality and reducing algal blooms, care should be taken not to put too much emphasis on this task until an effective milfoil control strategy has been implemented. Clearer water could translate into milfoil expansion under current conditions, and may also result in higher densities in some areas. Education of watershed residents regarding their role in controlling water quality and supporting overall lake and watershed management initiatives is certainly warranted, and would cost only about $5,000. Restoration of detention capacity along the tributaries is recommended, as the additional input of sediment to the lake provides substrate for milfoil growth as well as nutrients for algal growth. Expense could vary considerably for this element of the management program, but might be set at $50,000 as a start, with Lily and Shadow Brooks targeted as the tributaries to be addressed first.

Aeration or phosphorus inactivation are very attractive techniques for improving water clarity through reduction of internal phosphorus loading, but are not milfoil control techniques. Consequently, application of either should be held in reserve pending the establishment of an effective milfoil control program. After milfoil control has been demonstrated, one or the other should be considered. Aeration seems most desirable at this time, as it has the added advantage of improving fish habitat without substantial additional cost. A capital cost of $120,000 is envisioned for this approach.

ADDITIONAL INFORMATION NEEDS

If the recommended management plan is to be implemented, several tasks should first be accomplished by a competent professional:

- Drawdown impacts on protected species, based on experience elsewhere. The estimated cost for this endeavor is $5,000.
- Dredging feasibility assessment, emphasizing sediment quality, removal technology and disposal options. A template for this evaluation is included in Appendix D. The estimated cost for this endeavor is $15,000.
- Review of the pipeline bypass plan for current applicability and cost. The review cost, exclusive of any necessary re-design, is estimated at $3,000.
- Monitoring program design to meet regulatory needs. The estimated cost for this endeavor is $4,000.
- Evaluation of detention capacity needs and target locations. The estimated cost for this endeavor is $3,500.

If aeration or phosphorus inactivation are to be pursued, one of the following tasks should be accomplished:

- Air volume and power needs for aeration. The estimated cost for this endeavor is $2,000.
- Alum dose for phosphorus inactivation. The estimated cost for this endeavor is $3,000.

TECHNICAL SUMMARY

Stockbridge Bowl suffers from an infestation of Eurasian watermilfoil *(Myriophyllum spicatum)* and occasional algal blooms, causing recreational impairment and deterioration of overall habitat quality. Numerous reports and correspondence were reviewed and the history of the current situation at Stockbridge Bowl was summarized. The native plant assemblage used to be dominated by species of *Potamogeton*, with extensive beds of the advanced alga *Chara* supporting populations of two now protected aquatic snail species (*Pyrgulopsis lustrica* and *Valvata sincera*). Milfoil has been present in Stockbridge Bowl for about 50 years, but has only become dominant in the last 20 years. Harvesting and a slight winter drawdown now improve recreational utility, but are insufficient to keep milfoil in check. Algal blooms are related to elevated phosphorus levels, which appear to be mainly a function of internal releases from bottom sediments and intermittent interaction between upper and lower water layers which exist during the summer. Watershed inputs are not insignificant, but do not control water chemistry on a short term basis. The current primary objective of a management program for Stockbridge Bowl is to control milfoil, while the secondary objective is to enhance overall water quality for both recreational and habitat purposes.

Evaluation of rooted plant management options reveals that possible alternatives for milfoil control include greater drawdown, selective dredging, continued harvesting, two specialized herbicides, and localized use of benthic barriers. Herbicides and benthic barriers have been eliminated from final consideration at this time as a consequence of constraints on use and cost factors. Greater drawdown, at least to 4 ft and possibly to 8 ft, is recommended, but must be facilitated by a channel, pipe or siphon to bypass four existing pipelines which cross the outlet channel, deepening of the area between the island and the outlet spillway (the "outlet"), and connection of the outlet with deeper lake waters via one or two channels around the island. Application of drawdown is further complicated by concern by regulatory agencies that the protected snail species may be harmed by drawdown. In order to protect the habitat of the snails from further loss and to restore lost habitat through drawdown, it may be necessary to present a short term risk of direct impact to the snails themselves. Alleviation of concerns may be possible, however, through evaluation of impacts at other lakes and through an overall habitat restoration program which could include population enhancement. Drawdown provides both expansive and flexible control and is considered the preferred choice for milfoil control in this case based on experience elsewhere. Continued harvesting is recommended as a supplementary control technique, primarily to manage growths beyond the drawdown zone.

Actual drawdown carries little operational cost, but the needed pipe or channel to bypass the gas and sewer pipelines has previously been estimated to cost on the order of $100,000, and the dredging program necessary to facilitate a 5.5 ft drawdown depth has previously been estimated to cost approximately $350,000. Drawdown to a depth of 8 ft may be possible with additional dredging and possibly pumping, at an added cost of at least $150,000. These estimates of probable cost may require revision as part of a dredging feasibility assessment, but appear to be of the proper order of magnitude.

A new harvester has recently been purchased, and the annual operating cost is estimated at $20,000 to $60,000, based on two summer harvests of 100 acres of milfoil-infested area at a cost of $100 to $300 per acre. This technique complements the control achievable through drawdown.

Evaluation of water quality improvement options suggests that no action is essential outside of the lake, as control of the internal load of phosphorus may be sufficient to prevent algal blooms and maintain acceptable water clarity. Although inactivation with an aluminum compound should provide lasting relief, aeration of bottom waters will provide similar relief and greatly expand useable fisheries habitat for a similar capital cost on the order of $120,000. As increased water clarity may foster expanded milfoil coverage, however, substantial effort to reduce the phosphorus load is not recommended until an effective milfoil control program is in place.

Although not essential to meeting stated management objectives, it would be desirable to manage the watershed to minimize contaminant inputs to Stockbridge Bowl. An education program for watershed residents is recommended at a cost of approximately $5,000, to make watershed residents aware of how their land-based activities affect water quality and to generate support for other components of the management plan. It is also recommended that a program of detention capacity expansion and maintenance be implemented, centering on former detention areas along Lily and Shadow Brooks. An initial cost estimate of $50,000 has been set for detention improvements. Review of existing ordinances and enforcement of local, state and federal storm water management regulations is also advised, but no tangible cost is anticipated.

Additional information needs include assessment of known impacts on protected species by drawdown in other lakes, a dredging feasibility evaluation with review of previous cost estimates, review of the pipeline bypass plan and cost estimate, analysis of detention needs and potential locations, and development of a monitoring program to track and guide the management plan. Once milfoil control has been achieved, consideration of the details of either aeration or phosphorus inactivation should be undertaken.

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APPENDIX A

ANNOTATED STOCKBRIDGE BOWL REFERENCE LIST

ANNOTATED STOCKBRIDGE BOWL REFERENCE LIST
(A Summary of Materials Supplied to Fugro for Review)

The following reference materials are presented in reverse chronological order. Materials were collected by Mr. David Hoadley of the Stockbridge Bowl Association and reviewed by three Fugro staff members. Clearly extraneous references have been deleted.

10/11/95 Stockbridge Bowl Association Update, from D.A. Hoadley. Addresses Directors' meeting held August 26, 1995, Selectmen's meeting held August 28, 1995, meeting with Selectmen on Sept. 11, 1995, Directors' meeting Sept. 10, 1995, meeting with Jane Swift and Senator Richard Durand on Sept. 11, 1995, meeting with Selectmen on Sept. 18, 1995, and update as of Sept. 18, 1995.

9/25/95 To James D. Hartman, Right of Way Agent, Tennessee Gas Pipeline (TGP), from J.A. Beacco, Chairman, Board of Selectmen. Asking for a meeting so that construction of a bypass of the three gas lines which obstruct the natural flow of the outlet can begin.

9/13/95 Visit to Stockbridge Bowl from the following state officials: Senator Jane Swift, (R. North Adams), Senator Robert A. Durand, (D. Marlboro), and Rep. Barbara Grey (sent an aide)

8/27/95 To Selectmen from Cris Raymond, President, Stockbridge Bowl Association. SBA is urging Selectmen to hire a Lake Management Consultant

8/24/95 To Patricia Huckery, DFW, from R.J. McDonald, SBA. RE: Forwarding Ken Wagner's "Reflections on Stockbridge Bowl" memo from 7/21/95 meeting. Summarizes problem, possible courses of action, and areas of agreement.

8/6/95 To Selectmen from Cris Raymond, President, Stockbridge Bowl Association. RE: Sept. 1, 1995 meeting among John Beacco, Gene Talbot, Tom Stokes, R.J. , Richard Seltzer, David Hoadley, Chris Raymond. Concerning release of Town monies for a lake management plan.

4/8/95 Minutes of the SBA Director's meeting

I. Request the town vote on a sum for continuing lake care.
II. Cost of harvester, harvesting schedule, harvesting fund.
III. Tom Stokes reports that the Berkshire Regional Planning Commission is working on a project to reduce pollution entering the county lakes.
IV. Construction projects around lake should be closely monitored.
V. Concern over environmental lawyer fee.
VI. Wells to be drilled to determine if phosphates are coming into the lake from shallow groundwater.
VII. Suggestion to submit one-page recommendation to state legislators for a positive lake management policy.

3/14/95 To Patricia Huckery, DFW, from R.J. McDonald, SBA. RE: groundwater phosphorus monitoring project. Work to be funded 1/2 grant, 1/2 Town of Stockbridge, with total of $7000. They believe monitoring must be completed prior to setting forth a lake management plan. Request for Huckery to reiterate her approval in writing to the Town of Stockbridge that the harvesting program can be continued with the restrictions herein indicated.

1/17/95 Notes for SBA file from Edward C. Darrin, Jr. Concerning fall 1994 meeting with Laurie Suda, Project Manager of Regional Division of the Army Corps of Engineers. Suggestion to apply for wet dredging of the outlet (application time 2-3 months and cost of $30,000). Mr. Suda asked to view the inlet area for the possibility of dredging under 5,000 sq. ft. as a settling pond; he thought it would probably not be enough to provide effective settling, but would check and get back.

10/20/94 To Mr. Richard Seltzer, from Ken Wagner, Fugro East. Description of services which may be necessary to improve and protect Stockbridge Bowl. Tasks include review of selected existing information, lake and watershed management plan, septic system survey, macrophyte control, monitoring program development and implementation, selective dredging, and meetings and correspondence.

5/31/94 To Stockbridge Conservation Commissioners, from Patricia Huckery, Wetlands Environmental Reviewer (DFW). RE: Weed harvesting. The NOI which Clint Schneyer, Jr. filed asked to relax some of the restrictions imposed by DFW under the Endangered Species Act. Pat reiterates need for those restrictions and once again recommends a watershed management plan for the Town. Suggests cooperation with the DEP lake program to perform a sanitary survey (Editorial Note: DEP Lake Program transferred to DEM in 1993). She also points out that the 1995 estimated habitat map will show all of SB as aquatic habitat for endangered snails. She rejects Eileen Jokinen's findings and reiterates that it is the habitat which is being protected, not existing snail populations. She acknowledges SBA effort to address the problem of phosphorus loading but notes that efforts to permit enhanced drawdown are at a stalemate.

3/27/94 To Mr. R.J. McDonald, Stockbridge Bowl Association, from Robert G. Wetzel, Bishop Professor of Biology, U. of Alabama. RE: Reflections on the problems of Stockbridge Bowl and remedial actions. Eutrophic conditions results from excessive loading of nutrients, especially phosphorus, which leads to high production and excessive decomposition. This in turn depletes dissolved oxygen which eliminates this region from use by fishes and other organisms. Addresses milfoil, excessive productivity of both planktonic algae and macrophytes and how it has led to high rates of deposition of organic matter, sediment accumulation, and both short and long term remediation activities.

3/94?

The Reversal of Lake Eutrophication Or...How to Turn Back the Clock on the Weeds of Time. An Innovative Approach to Phosphate Control. Lenox Institute of Water Technology, Inc., Lenox, MA

1.0 Summary: 3 Year Plan
2.0 Stockbridge Bowl Cross-section
3.0 Top View Diagram of Krofta Type SPC-24-LF Floating Cell
4.0 Section 'A'-'A' Diagram of Krofta Type SPC-24-LF Floating Cell
5.0 3-Dimensional View Diagram of Krofta Type SPC-24-LF Floating Cell
6.0 Diagram of Krofta Double Floatation Sand Filtration Process
7.0 Stockbridge Bowl Map with Boat Ramp County Access and Access to Stockbridge Town Beach

3/19/94 To Dr. Robert Wetzel, U. Of Alabama, from R.J. McDonald, SBA. RE: Summaries of 3/15/94 facts and concerns regarding Wetzel's 3/15/94 summary: **1)** Sewer System installed in area known as Beechwood (5 years ago), and southern end of lake has denser human population than northern end. **2)** Silt build-up west of island and through the outlet up to the TGP pipes and town sewer pipe. **3)** Controversial diversion pipe. **4)** Endangered snails (would opinion on drawdown be different if snail not endangered)? **5)** Can Stockbridge Bowl be related to another similar lake? **6)** Can he recommend other short term solutions? **7)** Most cottages on lake are used May-Sept., but several large institutions are within immediate watershed and have sub-surface septic systems.

3/15/94 To R.J. McDonald, SBA, from Robert G. Wetzel, Prof. of Biology, U. of Alabama. Apology for slow response, will discuss various options for Stockbridge Bowl during his visit.

3/15/94 To SBA, from Robert G. Wetzel, U. Of Alabama. RE: Summary of lake conditions and remedial actions. General and long-term prophylactic methods of lake restoration. Discussion of internal loading and how to keep P in the sediments by hypolimnetic aeration, chemical precipitation of P, and macrophyte removal.
Appendix 1 Stockbridge Bowl Outlet Modifications
Appendix 2 Water Quality Management Plan for the Upper Housatonic River (Final Plan/Environmental Impact Statement)

1/20/94 To John Beacco, Chairman, Board of Selectmen, from W.B. Arcese, Jr., Division Right of Way Supervisor, TGP. Acknowledges receipt of 12/20/93 letter to Mr. Michael Walsh regarding the drawdown capability of Stockbridge Bowl. In compliance with Mitigation Measure No. 50, and after consultation between TGP and Stockbridge, result has been a mutual agreement that TGP would fund specified tasks at specified costs relating to the design and construction of the Town's proposed diversion pipe in the outlet channel. As part of its 1993 construction, TGP installed its pipeline at a depth that accommodates the proposed elevation of the diversion pipe. TGP has extended its agreement relating to the diversion pipe through July 26, 1996, but no further.

10/15/93 To SBA Task Force, from Richard Seltzer & R.J. McDonald, SBA. RE: Past Studies of Stockbridge Bowl. Discusses "The Limnology of Stockbridge Bowl" by Ludlam, Hutchinson & Henderson, 1973, "The Upper Housatonic '208' Water Quality Management Draft Plan" by Berkshire County Regional Planning Commission, 1976, "Water Quality Management Plan for the Upper Housatonic River" by Berkshire County Regional Planning Commission, 1978, "Stockbridge Summary--Water Quality Management Plan" by BCRPC, 1978, "Stockbridge Bowl Diagnostic/ Feasibility Study Report" by Lycott Environmental Research, Inc., 1991, and "Study of the Snail, *Pyrgulopsis lustrica,* in Stockbridge Bowl" by Lycott Environmental and Dr. Eileen Jokinen of the Univ. of CT at Storrs, 1992.

8/30/93 To John Beacco, Chairman Selectmen, from J.D. Hartman, Senior Right of Way Agent, TGP. RE: Terms of 8/16/93 letter requesting addition funding unacceptable.

8/20/93 Department of the Army Programmatic General Permit, Commonwealth of Massachusetts, Effective Date: 8/24/93, Expiration Date: 5/31/94, with Amendment -- The expiration date of the PGP shall be extended to 12/31/94

8/6/93 To Stockbridge Conservation Commissioners, from Patricia Huckery, Wetlands Environmental Reviewer (DFW). Refers to the 5/14/90 recommendation and again suggests watershed management. Again refers to nutrients going into the lake and also refers to Lycott study of 1989 for confirmation. Approval of activities contingent upon previous guidelines being followed and completion of a watershed management plan.

7/23/93 To R.J. McDonald, SBA, from Thomas French, Ph.D., Assistant Director, DFW. Comments on Lycott's "Study of the Snail, *Pyrgulopsis lustrica* in Stockbridge Bowl, MA. Believes habitat of *P. lustrica* has been adversely affected by past actions. Restrictions are necessary to prevent adverse effects: 1) No mechanical harvesting of aquatic vegetation to west or south of island at southwest end of lake 2) Mechanical harvesting around perimeter of lake should be directed toward water milfoil to avoid impacts to *Chara* and *Najas* beds. 3) No drawdowns in excess of traditional 2 feet.

7/23/93 To R.J. McDonald, Stockbridge Bowl Association, from Carlos Carranza, President, Baystate Environmental Consultants, Inc. RE Diversion pipe (Editorial Note: This comes after apparent "non-compliance order" issued by DEP and is intended to propose a new strategy for proceeding). This letter tries to analyze the problem and lay out a procedure for dealing with the DEP. It includes a contract for proposed services and estimates a total cost of 25K. This letter describes the impasse with the DEP and need for professional help.

7/7/93 To R.J. McDonald, President SBA, from Carlos Carranza, Ph.D., BEC, Inc. Prepared to present strategy regarding Stockbridge Bowl Diversion Pipe. There appears to be an impasse with a DEP non-compliance order for alleged violations of the Wetlands Protection Act and other statutory laws. BEC favors new approach with DEP, but technical issues must be clarified, including nature of the Stockbridge Bowl operation, the post-1959 history of Stockbridge Bowl, and issues of the endangered snail. There must be clear-cut common ground established between parties regarding impact and a restatement and reassessment of the diversion pipe approach. Also notes legal/administrative issues.

6/25/93 To Mr. R.J. McDonald, SBA, from Robert McCollum, Section Chief, Bureau of Resource Protection, Springfield Office of MADEP. RE: DEP file number 296-127, Appeal of Order of Conditions for Diversion Pipe. Enclosed the Department's Denial Superseding Order of Conditions. Project denied because information requested in four instances was not submitted. Refers to letter received from Lycott on 5/19/93. States that DEP has no preconceived notion of what the applicant may or may not be intending. Concerned that if pipe not properly designed and operation not monitored adequately, result could be increased draw down of the Bowl, which is not part of the applicant's proposal. Applicant and their representative have not yet described potential environmental impacts of project and how they would be minimized. If Town intends to draw the Bowl down again in 94 as done previously, advised to file NOI. A 3/26/93 Department meeting concerning installation of diversion pipe found several deficiencies with the NOI. Refers to 4/1/93 DEP request for specific info to document potential wetland impacts of proposal, with deadline of 5/1/93. States that DEP has attended additional meeting to assist Town (4/16/93), but to date 55 days have passed since the 4/1/93 request for information. The Dept. finds it inappropriate to spend additional time on project until objectives and impacts have been defined. Applicant urged to submit a new NOI.

6/23/93 To Mr. Lee Lyman, Lycott Environmental Research, Inc. from R.J. McDonald, SBA. Lycott directed to stop any and all work on behalf of SBA, including Tenneco Diversion pipe and other issues; Board would like time to review and consider other options.

6/21/93 Petition to MA State Legislators Senator Jan M. Swift and Rep. Christopher J. Hodgkins to help get the MA DEP NOI #296-127 approved.

6/7/93 Draft of news on the Tenneco sponsored diversion drain pipe for the SBA Newsletter from Don Deno, VP SBA

5/19/93 To Robert McCollum, Section Chief, DEP, from Lycott. Re-draft of 5/5/93 letter. States that Lycott was not involved with filing the original NOI #296-127 or amendment to Order of Conditions, which was approved by the Town, but appealed by Springfield DEP. Would like to make it clear that Town or SBA do not have permission to conduct drawdown of SB any greater than 2 feet. When and if community moves forward with permitting process for drawdown to manage milfoil, endangered snails, among other issues, must be addressed.

5/13/93 To Robert McCollum, Section Chief, DEP from John Beacco, Chairman, Stockbridge Board of Selectmen. Due to rain and snow melt, Stockbridge Bowl has returned to its natural level and gates were closed to maintain the spillway level. In process of preparing necessary documentation in anticipation of a fall draw down.

5/5/93 To R. McCollum, DEP, from Lee Lyman, Lycott. To clarify Stockbridge Bowl pipe installation project for all state and federal agencies involved. Explains Lycott's retention by Town, and states they were not involved in filing original NOI #296-127 or amendment to the Order of Conditions. States that Town and SBA do not have permission to conduct a drawdown of the Bowl any greater than 2 feet. Community will attain proper permits if decide to move forward. Installation of pipe under Tenneco pipes is a completely separate project. Final permit needed by Town for pipe installation project is a Water Quality Certificate from DEP.

4/28/93 To Robert McCollum, Dept. of Environmental Protection, from Patricia Huckery, Wetlands Environmental Reviewer, DFW. RE: Diversion pipe. Concerned about pipe because of drawdown which could affect snails. Suggests nutrient inputs are the real problem. Watershed management measures are recommended to Town, such as identifying and upgrading failing and substandard septic systems.

4/27/93 To R.J. McDonald, SBA, from R. McCollum, Section Chief, Bureau of Resource Protection, DEP. Refers to Dept. meeting on 4/16/93 to discuss proposed installation of diversion pipe. States that drawdown of Bowl is in non-compliance with 310 CMR 10.59 (no project permitted to have short or long term adverse impacts to habitat of local populations of rare and endangered species). Proposed project described now would be difficult to permit under the Wetlands Protection Act. To obtain an issuance of a Variance, would have to show how proposed pipe could never be used to allow increased drawdown. Notice of Non-compliance enclosed. Requests provision of additional info by deadline.

4/9/93 To Town of Stockbridge from R. McCollum, DEP. RE: DEP file #296-127 and 4/1/93 letter. Town meeting on 3/26/93 discussed proposed Diversion Pipe and NOI with Tim McKenna, DEP. States that DEP's 4/1/93 letter inadequately addresses content of meeting and goes off the subject, which has led to confusion. Discusses 6 items that were listed to satisfy the DEP in approving the NOI. Enclosed prospectus of the Diversion Drain project.

4/1/93 To R.J. McDonald, SBA, from R. McCollum, DEP. RE: DEP file #296-127 and Appeal of Order of Conditions Refers to 3/26/93 meeting, at which deficiencies in NOI discussed. DEP will provide applicant with the opportunity to determine if the proposed project could ever receive and Order of Conditions. Requests description of the intended purpose and proposed site. In addition, requests copy of the Order of Conditions that permits current annual 2 foot drawdown in state jurisdictional wetlands within one week of issuance of this notification.

3/29/93 To Patricia Huckery, DFW, from Don Deno, VP SBA Deno believes the Natural Heritage & Endangered Species Program has misinterpreted the Bowl Diversion Drain Project. Enclosed an amendment to the NOI to more strongly emphasize the purpose, and a historical perspective of the present degradation.

3/25/93 To R. McCollum, DEP, from Patricia Huckery, DFW. Concern expressed over proposed diversion pipe and weed harvesting contributing to decline of snail populations. Appears to be same as letter dated 4/28/93.

3/24/93 To R.J. McDonald, President, SBA, from Don Deno, VP SBA RE: Purpose of the Diversion Drain Project.

3/23/93 FAX To R.J. McDonald, SBA, from Don Deno, SBA. Recommendation to have political representation from Senator Swift and Rep. Hodgkins at the Friday meeting.

3/23/93 Appendix A, Project Description, to go with Amended Order of Conditions.

3/23/93 Revised Amendment to Order of Conditions, Town of Stockbridge, for Diversion Pipe Project.

3/22/93 To Karen Kirk Adams, Chief, Permits Branch Regulatory Division, Dept. of the Army, from Lee Lyman, Lycott. Response to letter on 3/17/93 which indicated concern about proposed Stockbridge Bowl project. Lyman assures Adams that project does not involve lake level drawdown, but rather installation of a pipe under existing utilities. States awareness of snail controversy and associated restrictions on lake management, and desire to obtain a Water Quality Certificate in a timely fashion.

3/17/93 To Town of Stockbridge from Karen Kirk Adams, Permits Branch Regulatory Division. In regard to recently issued MA Letter of Permission (MALOP) for diversion pipe, there is concern over endangered snail species. Suggests consideration of enclosed (EPA) alternatives.

3/17/93 FAX To Don Deno, SBA, from R.J. McDonald, SBA. Confirmation of 3/26 meeting with Tim McKenna, DEP.

3/14/93 To R.J. McDonald, President. SBA, from Don Deno, VP SBA. Proposal of meeting to be called by Stockbridge Board of Selectmen to: 1) Refute the content of the DEP letter describing reasons for the appeal order. 2) Propose to MA State Legislature action to reverse the Denial issued after appeal of the Order of Conditions (DEP file # 296-127, relating to the Diversion Pipe Project). 3) Propose to the MA State Legislature a correction to DEP procedures and/or regulations.

3/9/93 To Town of Stockbridge from R. McCollum, Bureau of Resource Protection, DEP. RE: DEP file #296-127, Appeal of Order of Conditions. Proposed work remains incompletely described. Will appeal the Order of Conditions. Notice that a representative of the office will conduct an informal on-site meeting to be held 4/1/93. No work may proceed until DEP has issued a Superseding Order of Conditions.

3/8/93 To William Lawless, P.E., Chief, Regulatory Division, U.S. Army Corps of Engineers. RE: 1993-00307 Northeast Settlement Project (PDN)1992-00428. Town of Stockbridge addresses concern over the pre-discharge notification (PDN) of TGP that MALOP may not be valid in this case. As they have gathered info on the Diversion Pipe Project, EPA has concluded that this authorization should be revoked and the project reviewed as an Individual Permit by the Corps of Engineers. Also addresses concern over snails in the lake and brown and brook trout downstream.

2/25/93 To Lee Lyman, Lycott, from Michael Amaral, Endangered Species Specialist, US Fish and Wildlife Service. The proposed project will not impact Federally listed species; however, there are state species to be concerned with.

2/24/93 To Frederick Wallhausser, from Don Deno, VP SBA. Proposed easement for diversion pipe to cross outlet next to Wallhausser's property. Enclosed construction diagrams.

2/11/93 To Commissioner Daniel Greenbaum, DEP, from Lee Lyman, Lycott. Thanks Greenbaum for meeting, and expresses frustration with DEP over permitting process. Requests assistance and direction with regard to Stockbridge Bowl.

2/4/93 To R.J. McDonald, President, SBA, from Richard Seltzer, SBA. States that Lee Lyman, Lycott, confirmed they could have a Request For Bids within 2 weeks. Lyman is confident that fabrication of precast pipe will be fairly routine, and will soon have the necessary permit from the Army Corp. Engineers and the Water Quality Certificate from MA DEP.

1/15/93 To R.J. McDonald, SBA, from Richard Seltzer, SBA. Waiting to hear from Lycott about bid package in time to have pipe installed this spring.

12/28/92 To Henry Woolsey, DFW, from R.J. McDonald, SBA. RE: Aquatic weed harvesting. Expresses support for a redesignation of the restricted area for harvesting on Stockbridge Bowl.

12/11/92 To Lee Lyman, Lycott, from Don Deno, VP SBA. Deno states they need a tight schedule to meet Tenneco's requirements of construction. Attached letter from J.L. Grabiec, TGP. Order of Conditions should be signed at 12/22 meeting. Describes tentative schedule resulting in May 93 completion of Diversion Pipe. Enclosures

12/7/92 To Don Deno, SBA, from Lee Lyman, Lycott. Prepared to move forward with filing Army Corps of Engineers permit and DEP Water Quality Certificate applications. Before these are submitted, need: 1) Order of Conditions for piped diversion, 2) Copies of FEMA maps, 3) DEP file # for project.

12/1/92 To Don Deno, VP SBA, from J.L. Grabiec, Associate Engineer, Tenneco. Request for copy of bid package for review and an estimate of total cost. Also includes request for items to be incorporated into construction contract. Attachment.

11/25/92 To DEP, from John Beacco, Chairman, Stockbridge Board of Selectmen. RE: DEP file #296-127. Comments relative to NOI and subsequent hearing on 2/25/92.

11/13/92 To Henry Woolsey, DFW, from Mary Flynn, Selectman. RE: Aquatic Weed Harvesting. Since area could not be viewed in Oct., Flynn sending photographs.

11/9/92 To Lee Lyman, Lycott, from Don Deno, VP SBA. Tentative progress schedule, request for Task IIA copies

10/28/92 Report on permit scheduling for the Diversion Pipe under the Tenneco pipeline. Site visit held at Tenneco pipeline crossing on 10/28/92. Big issue is special permits. Attachment.

9/23/92 To Hamer Clarke, Lycott, from John Beacco, Chairman, Board of Selectmen. Authorization for Lycott to complete Task IIA--MEPA, Chapter 91 and completion of Army Corps of Engineers filing.

9/4/92 To Henry Woolsey, DFW, from Mary Flynn, Selectman. Referring to designation of certain areas as "zone #8" where harvesting is not allowed, including the shoreline across from the island. Stockbridge would like that area to be reconsidered because it is a place where many cottages have been built, and access is a concern.

8/31/92 To Helen Pigott, Secretary of Town of Stockbridge, from Don Deno, VP SBA. States that 15 copies of final contract package for Diversion Pipe Project have been delivered to Deno, who has tentative schedule for selecting a contractor.

8/31/92 To James Hartman, Senior ROW Agent, Tenneco, from Don Deno, VP SBA. Enclosed copies of correspondence concerning the contractual status of the Diversion Pipe Project. Request for Tenneco's support on next step, which is implementation of permitting process.

8/31/92 Draft of news on the Tenneco sponsored diversion drain pipe for SBA Newsletter by Don Deno, VP SBA

8/31/92 To Lee Lyman, Lycott, from Don Deno, VP SBA. Believes DEP dedicated to stop the Diversion Pipe Project; Deno does not believe negotiation will lead to useful conclusions. More useful to approach problem through Legislators.

8/24/92 To Selectmen from Lee Lyman, Lycott. Refers to 4/22/91 Lycott proposal and tasks for Diversion Project. 5/15/91-Tenneco authorized Lycott to proceed with only preparation of design plans. R. Seltzer of SBA prepared the NOI. In 2/92 the Corps of Engineers notified the Town that a permit would be required. On 2/26/92 Karen Adams of Corps outlined process for submission of info and assigned # to project (07-92-00428). Outlines steps needed to comply with Corps of Engineers request for additional info.

3/16/89-7/1/92 Summary of the Diversion Pipe Project Sponsorship by Tenneco.

6/26/92 To Lee Lyman, Lycott, from Hamer Clarke, Lycott. Contract documents have not been completed, but are relatively easy. Estimates time for review and arrangements. Permitting will include, at minimum, a Corps of Engineers (404) permit and Water Quality Certificate (401) from DEP. No Chapter 91 Waterways License required. Believes no Individual Permit required from Corps.

4/21/92 To Lee Lyman, Lycott, from Don Deno, VP SBA. Refers to 4/16/93 meeting at Stockbridge Town Hall. Upset that drawings were not accepted by DEP and feels Tim McKenna, MA DEP is being unfair. Details the four additional submissions required by Tim McKenna. Enclosures.

3/26/92 To Don Deno, SBA, from Robert Grass, Tenneco. Refers to speaking with Stone & Webster, Tenneco's environmental consultants, who informed Grass of Tenneco's requirement to make a submission separate from its NOI to obtain a permit from the Corps of Engineers. States that Town will probably have to engage Hamer Clarke (Lycott) to prepare a response to Corps' questions. Tenneco permit # 90-03560L2.

2/26/92 To John Beacco, Board of Selectmen, from Karen Kirk Adams, Permits Branch, Regulatory Division, Army Corps of Engineers. Receipt of application for Dept. of Army permit, assigned #07-92-000428. Insufficient info for processing, and may require a Water Quality Certification from the state. No work may be started until permit received.

2/24/92 Order of Conditions, MA Wetlands Protection Act, for Diversion Pipe installation.

2/13/92 Notification of File Number (296-127) from DEP.

2/4/92

Notice of Intent for Diversion Pipe

1.0 Notice of Intent, Stockbridge Bowl Diversion Pipe, Stockbridge Conservation Commission Applicant: Town of Stockbridge, February, 1992

2.0 Appendix A: Project Description: Intro., Location, Objectives, Timing of Construction, Plan and Profile Sheet.

3.0 Appendix B: Description of Work, Details Sheet.

4.0 Appendix C: Stream and Wetland Construction and Mitigation Procedures: Perennial Stream Crossings, Federally Delineated Wetland Crossings, Hydrostatic Testing

5.0 Appendix D: Notice of Intent Fee Transmittal Form Department of Environmental Protection, Division of Wetlands and Waterways

1/23/92 To Don Deno and R.J. McDonald, SBA, from Alan Berk, Stockbridge resident. Enclosed correspondence concerning Tenneco pipeline.

1/17/92 To W.B. Arcese, Tennessee Gas Pipeline, from Alan Berk, Stockbridge resident. Receipt of 1/14/92 letter. Berk's well is within 200 feet of possible blast zone and expects restoration if damaged during blasting.

1/14/92 To Alan Berk, Stockbridge resident, from W.B. Arcese, Division Right of Way Supervisor, Tenneco. Receipt of 1/10/92 letter. If well and house is within 200 feet of pipeline, and if blasting is required, a pre-blast inspection will be arranged.

1/10/92 To Susan Tierney, Secretary, Office of Environmental Affairs, from Alan Berk, Stockbridge resident. Comments on the Draft Env. Impact Report (EOEA #8660).

12/17/91 To Bill Ledbetter, TGP, from Richard Seltzer, SBA Appreciation for Tenneco's commitment to install diversion pipe. Would like to confer to review plans. Will obtain an easement from the property owner beneath whose land the pipe will pass.

12/13/91 To R.J. McDonald, SBA, from Hamer Clarke, Lycott. Enclosed final copies of plans for Stockbridge drawdown diversion pipe.

11/27/91 To Chairmen Moffat & Socha, Stockbridge Conservation Commission, from Alan Berk, Stockbridge resident. Concerned with potential effects of blasting on well water at home on Lake Dr.

5/15/91 To Selectmen, from JD Hartman, Right of Way Agent, TGP RE: Northeast/Phase I/ 255 Section, MKA (1) (2) & (3) 48. Consent to cover the costs of proposal submitted 4/22/91 by Lycott. This letter authorizes Task I.

4/22/91 To Selectmen, from Hamer Clarke, Lycott. **Task proposal--I.**-Design Plans, **II.**-Support Services, **IIA.**-Permitting (NOI, MEPA, Chapter 91 filing), **IIB.**-Bid Process, **IIC.**-Construction Review, **III.**-Any work required by the town not listed in the Scope of Services in Tasks I or II, for a fee.

3/21/91
Stockbridge Bowl Diagnostic/Feasibility Study Report
Lycott Environmental Research, Inc.
1.0 Disclaimer
2.0 Project Summary
3.0 Diagnostic Study Historical Lake Uses, Review of Reports, Watershed and Sub-Basins, Land Use, Geological Description of Drainage Basin, Soils, Hydrogeology and Groundwater Monitoring, Hydrologic Budget, Morphometric Data, Limnological Data, Storm Drain Mapping, Wastewater Inventory, Limiting Nutrient Analysis, Annual Phosphorus Budget, Modeling of Phosphorus Compounds, Interconversion of Nitrogen Compounds, Fisheries Data, Macrophyte Evaluation, Sediment Sampling, Wetland Evaluation.
4.0 Feasibility Study Summary, Preliminary Screening of Alternatives, Recommended Option--Hypolimnetic Aeration, Summary: Hypolimnetic Withdrawal vs. Hypolimnetic Aeration, Drawdown for Control of Nearshore Macrophytes, Harvesting to Control Deep-Water Macrophytes, Watershed Management, Engineering Recommendations, Cost Analysis, Implementation of Engineering Recommendations, Sources of Funding, Predicted Effects of Remediation, Effects on Fish and Wildlife, Effects Upon Associated Wetlands, Phase II Monitoring Program, Public Participation, Necessary Permits and Licenses, Historical Commissions.

5.0 Appendix A Site Location Map, Watershed Sub-Basins, Land Use Map, Detail of Shoreline Development, Bedrock Geology, Surficial Geology, Watershed Soils Map, Monitoring Well Location, Bathymetric Profile, Sampling Station Locations, Temp, D.O., & RTR vs. Depth (6/28/88, 8/15/88, 10/8/88), Total Phosphorus vs. Time, Total Nitrogen vs. Time, Storm Drain Locations, Leachate Sampling Locations, Total Nitrogen/Total Phosphorus, Sources of Phosphorus, The Aquatic Nitrogen Cycle, Aquatic Macrophyte Survey, Aquatic Macrophyte Densities, Aquatic Macrophyte Survey, Sediment Depths, Bordering Wetlands.

6.0 Appendix B	Boring Logs
7.0 Appendix C	Hydrologic Budget Calculations
8.0 Appendix D	Temperature, Dissolved Oxygen, and Relative Thermal Resistance (RTR)
9.0 Appendix E	Water Quality Data: Tributaries and In-lake Sampling
10.0 Appendix F	Water Quality Data: Groundwater Sampling
11.0 Appendix G	Calculation of Averages
12.0 Appendix H	Laboratory Methods
13.0 Appendix I	Hypolimnetic Aeration
14.0 Appendix J	Environmental Notification Form
15.0 Appendix K	Runoff and Hydraulic Computations
16.0 Appendix L	Cost Analysis
17.0 Appendix M	Historical Commissions
18.0 Drawings	Site Plan & Profile, Outlet Structure and Drawdown Pipe, Wetlands Protection Barriers.

3/22/91 To Lee Lyman, Lycott Environmental Research Inc., from Joseph Bergin, Aquatic Biologist, DFW. Refers to meeting held 3/5/91, includes response to proposal, concerns, and modifications. States DFW support for the goal of controlling the excessive macrophyte levels in a manner that will minimize impacts to the resource.

11/19/90 To John Beacco, Selectmen, from Tenneco. Confirms 12/16 meeting with Selectmen, SBA, and TGP regarding pipeline. TGP has filed with the Federal Energy Regulatory Commission (FERC). TGP is willing to cover engineering design costs for the proposed drain; Town will utilize Lycott.

11/17/90 To James Hartman, Tenneco, from Don Deno, Secretary, SBA Minutes of 12/16/90 meeting including summary, dialog of meeting, and general plan for diversion pipe.

10/27/90 SBA invitation to attend 12/16/90 meeting at Town Hall with representatives from TGP, SBA and Selectmen. The Town of Stockbridge requests the flume pipe and a drawdown diversion pipe. Attachment #1 discusses status of the Stockbridge Bowl Outlet Channel Flow Restriction.

9/10/90 To R.J. McDonald/Don Deno with cc: Henry Williams and Richard Seltzer, SBA, from Tenneco. Discusses Condition 50 and Tenneco's agreement that a drawdown pipe should be installed at the same time Tenneco installs its 36 inch pipe. Tenneco would work on design and install drawdown pipe, but concerned about future liability. Tenneco wants Town to indemnify them against any liability in future operation and maintenance. Also discussion of specifics of pipe (i.e., placement, materials, possible erosion), installation of trash rack, sluice gate, and future meeting. Tenneco has not yet received FERC permit.

8/29/90 To Don Deno/R.J. McDonald, SBA, from Richard Seltzer, SBA. Regarding 8/23/90 memorandum. Discusses issues which must be coordinated in year 1. Attachments include a proposed program and possible budget.

8/23/90 To SBA Clean Lakes Committee, from Don Deno, SBA. Tenneco will develop and file site-specific construction and restoration plans for review and approval by Director OPPR prior to construction. Tenneco will consult with SBA to ensure there are no adverse effects on Stockbridge Bowl. States that construction of diversion pipe under gas lines is essential to implement any long range goals of SB lake management. Request that flume pipe and diversion pipe be one in the same.

5/14/90 To Stockbridge Board of Selectmen from Steven M. Roble, Ph.D., Wetlands Wildlife Biologist, Division of Fisheries and Wildlife. RE: Proposed aquatic weed harvesting of Stockbridge Bowl. Certain areas must be protected because of state endangered species, and therefore no harvesting will be allowed in these areas. No problems expected if guidelines are followed.

1988

321 CMR: Division of Fisheries and Wildlife, Massachusetts Endangered Species Act Regulations

1987

Select Stockbridge Bowl Study Reports and Applications 1972-1987

*****Note: Only the asterisked reports were included*****

1.0* Chapter 628 Application, Town of Stockbridge, September 26, 1986.
2.0* Stockbridge Bowl Map--Its Residences and Sewered Areas; Residences were revised in 1985 and Sewered Areas were revised in 1987.
3.0* Mass DEQE Division of Water Pollution Control, Massachusetts. Lake Classification Program, January 1984. Excerpts.
4.0 Mass DEQE Division of Water Pollution Control, Six Ponds Dioxin Survey, June 1984.
5.0 Mass DEQE Division of Water Pollution Control, Massachusetts. Lake Classification Program, January 1982. Excerpts.
6.0* Berkshire Enviro-Labs, Inc., Stockbridge Bowl Water Quality and General Aquatic Macrophyte Maps, 1980 and 1981.

7.0* Berkshire Enviro-Labs, Inc., Stockbridge Bowl Eutrophication and Aquatic Vegetation Control Program, Final Application, October 1980.
8.0* Berkshire County Regional Planning Commission, Water Quality Plan for the Upper Housatonic River, Final Plan/Environmental Impact Statement, September 1978. Excerpts.
9.0* Mass DEQE Division of Water Pollution Control, 1976 Baseline Water Quality Studies of Selected Lakes and Ponds, Housatonic River Basin, December 1976. Excerpts.
10.0 Mass DEQE Division of Water Pollution Control, Berkshire County 208 Program Inlet Survey Data, May 1976.
11.0* Mass DEQE Division of Water Pollution Control, 1974 Baseline Water Quality Studies of Selected Lakes and Ponds, Housatonic River Basin, September 1975. Excerpts.
12.0* S. Ludlam, K. Hutchinson and G Henderson, The Limnology of Stockbridge Bowl, Stockbridge, Massachusetts, 1972.
13.0 Curran Associates, Inc., Wastewater Collection and Disposal at Stockbridge Bowl, Stockbridge, Massachusetts, December 1971.
14.0 J. McCann and L. Daly, An Inventory of the Ponds, Lakes and Reservoirs of Massachusetts, Berkshire and Franklin Counties, February 1972, excerpts.

1979
Management of Aquatic Weeds in Stockbridge Bowl
Stuart D. Ludlam Box 48 Whately, MA

APPENDIX B

REFLECTIONS ON STOCKBRIDGE BOWL, JULY 1995

REFLECTIONS ON STOCKBRIDGE BOWL FROM THE JULY 21, 1995 MEETING OF SBA AND NHP REPRESENTATIVES
Submitted by K. Wagner, 7/29/95

As this collection of thoughts is a recollection made one week later, it has not been labeled as "minutes" of the meeting. It is intended as a summary, but is open to interpretation and clarification by any involved party. It is meant primarily for purposes of laying the ground work for project planning and projection of permitting needs.

A. On Friday, July 21, 1995, R.J. McDonald, Ed Darrin, Richard Seltzer, Cris Raymond and several other members of the Stockbridge Bowl Association met with Tom French and Pat Huckery of the Massachusetts Natural Heritage Program to discuss the potential for lake management actions in light of the designation of the lake as protected habitat for two aquatic gastropod (snail) species (*Pyrgulopsis lustrica* and *Valvata sincera*). Also present was Ken Wagner, consultant to the SBA for lake management efforts.

B. Prior to the arrival of the NHP personnel, members of the SBA and Ken Wagner discussed preferred options and the restrictions which might be imposed by the protected habitat designation. Major concerns include:
   1. The presence of dense milfoil (*Myriophyllum spicatum*) stands around much of the lake perimeter, typically at water depths of 4-15 ft, is of great concern and warrants control.
   2. Other species, most notably species of native pondweeds (*Potamogeton*) and water lilies (*Nymphaea*), are also sometimes a nuisance, but not to the extent of the milfoil in the lake itself.
   3. The outlet channel is choked with nuisance vegetation of several species, along with boulders of both natural origin and human placement.
   4. Shallow water depth is a problem for boat passage and general recreational use in several areas, most notably southwest of the island and in the outlet channel. Both natural bathymetry and deposition enhanced by human activities is considered responsible.
   5. The installation of several pipelines under the outlet channel over the years, especially by the Tenneco gas company, has promoted sedimentation in that area and limited drawdown capability.
   6. The gradual sedimentation of the former pool just upstream of the main inlet (from Lily Brook and Pond) has resulted in much organic material and sands moving under the causeway road via culverts and accumulating in the lake in that area.

C. Possible in-lake management actions include:
   1. Installation of a diversion pipe to allow drawdown to levels lower than currently possible with the Tenneco gas pipeline in place.
   2. Dredging of the outlet channel to improve access for riparian landowners and to facilitate drawdown to a greater level than now possible.
   3. Dredging of channels on the south and west (close to shore) sides of the island to allow boat traffic and drawdown of the lake.
   4. Dredging of the former sedimentation pool area upstream of the main inlet and the causeway to restore its sedimentation function.

5. Dredging of the inlet area to restore water depth and control colonization by nuisance plant growths.
6. Drawdown to a greater level than currently possible to control vegetatively reproducing plants such as milfoil.
7. Continued harvesting to maintain plant densities at levels desired for recreational utility, especially as relates to milfoil infestations.
8. Use of bottom barriers to restrict plant growths in localized areas.
9. Introduction of weevils which selectively damage milfoil at densities high enough to cause the collapse of this species in the lake, as is currently being tested at Lake Mansfield in Great Barrington and Goose Pond in Lee.
10. Use of controlled substances to selectively damage milfoil plants.
11. Phosphorus inactivation to control internal recycling of this essential plant nutrient.

Not all of these techniques would necessarily be applied, but all have potential applicability in this case.

D. Possible impediments for implementation include:

1. Restriction of activities anywhere in the lake as a consequence of the whole lake being designated a protected habitat.
2. The presence of snail habitat in shallow water areas which might be affected by several of the management techniques.
3. Failure of the Wetlands Protection Act regulations to recognize public safety, recreational utility, or property value as interests of the Act.
4. The pressure through the wetlands protection regulations on Conservation Commissions to limit coverage of lake management projects under the limited status afforded by the "control of eutrophication and nuisance vegetation" clause.
5. Funding of major capital expenses, most notably the diversion pipe and dredging necessary to affect a drawdown, a portion of which has been promised by Tenneco if action is taken soon.

E. When the NHP personnel arrived a tour of the lake was conducted, emphasizing problem areas and habitat types. A wide variety of plants were identified, and areas of apparent optimal snail habitat were pointed out. Lake management techniques were discussed and the potential for developing a management plan which would reduce plant problems while preserving or improving snail habitat was explored. There were no major points of disagreement. Points of agreement and further evaluation needs included:

1. Milfoil does threaten protected habitat and other interests of the Wetlands Protection Act, and its management is consistent with proper environmental stewardship. Just how to manage the milfoil is a subject for further evaluation.
2. The outlet channel does not contain protected habitat and is a viable candidate for dredging; the process would need to ensure no significant downstream transport of sediment to be permitted.

3. A barely existing channel south of the island to the Beechwood side could also be reasonably considered for dredging, up to the point where it transitions to high quality snail habitat. The necessary width of the channel and relation to protected habitat needs further elucidation, but some form of channel deepening and widening appears feasible, and it would be desirable to include access channels from shoreline areas.
4. The channel to the west of the island is more problematic, crossing an expanse of shallow water with apparent snail habitat and only limited evidence of boat use or utility. A channel near the shoreline may be feasible, but would most likely have to follow work in the other channel which was demonstrated to benefit or at least not negatively impact protected habitat.
5. Drawdown may be a viable technique for milfoil control, but the impact on both the protected snails and their habitat should be researched from other lakes before proceeding; if results are favorable, and incrementally increasing drawdown could be implemented with proper monitoring.
6. The use of a variety of techniques to improve recreational utility may indeed be permissible, but must not have negative impacts on protected habitat. A phased approach is recommended, whereby a technique is employed on a limited basis and monitored to demonstrate its benefits, then expanded in an incremental fashion with continued monitoring to achieve desired results.
7. There is considerable potential for a "win-win" scenario with respect to all interests at Stockbridge Bowl. It will be necessary to work within the existing regulatory framework, which can be slow and frustrating, but successful management of plant nuisances and sedimentation does appear possible within the regulatory constraints imposed.

The tour was followed up by a brief meeting on land to discuss the process from this point forward, and the need to take relatively prompt action if funds from Tenneco were to be made available. Members of the SBA left the meeting encouraged that at least the NHP would be willing to work with them for better lake conditions.

APPENDIX C

LITERATURE REVIEW OF DRAWDOWN IMPACTS

LITERATURE REVIEW OF DRAWDOWN IMPACTS

General Information:
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). More recently lake drawdown has been successfully used to control submerged aquatic macrophytes, considered nuisance weeds in the littoral zone (Mitchell and Titlow 1989). Although drawdown is known to be a potentially effective tool for lake management, potential conflicts with other lake uses and functions are of concern.

For a lake, water depth is critical to aspects of the fish, benthic invertebrate and macrophyte communities and to water quality (Cooke et al. 1993). Water level is an important determinant of recreation through maintenance of depth of bathing areas, limiting the activity or size of boats, and affecting shoreline facilities (e.g., docks and retaining walls). Water level may also be critical at industrial intakes for processing or cooling water supply purposes. Water level in a lake is related to flood storage capacity and regulation of downstream flow variation. Outside of the lake, changing lake water level may affect water levels in nearby supply wells and the hydrology of hydraulically connected wetlands.

Water level in a lake may be kept relatively constant, fluctuate seasonally or vary in a rapid or seasonally unsynchronized fashion. Respective examples of these types of water level fluctuations would be: (1) an impoundment where the level is determined by the elevation of a large capacity control structure, (2) a natural lake where the level rises with the spring floods but eventually falls with declining summer water table, and (3) a hydroelectric reservoir where release rates are dictated by economic supply and demand. Conflicts with wetlands occur when water level is manipulated principally to the benefit of one purpose without regard to competing uses (O'Neil and Witmer 1988). Management conflicts between lake recreation and wetland protection are most likely to arise in the first category above, since the water level can be regulated for specific purposes. Disagreement over water use priorities or lack of a unified lake management plan (Wagner and Oglesby 1984) can easily result in such conflicts.

In-lake Considerations:
One of the common problems of recreational lakes is the overabundance of submerged macrophytes impacting recreational uses such as swimming, fishing and boating. Many lakes are pre-disposed to plant nuisances, but human activities have resulted in excess sedimentation and overfertilization which promote such growths. In the many cases these problems have been exacerbated by invasions of exotic species. To treat the problem, lake managers may resort to a water level drawdown. While this technique is not effective on all submerged species, it does decrease abundance of some of the chief nuisance species, particularly those which rely on vegetative propagules for expansion (Cooke et al. 1993). If there is an existing drawdown capability, lowering the water level provides an inexpensive means to control macrophytes. Additional benefits may include opportunities for shoreline maintenance and oxidation or removal of nutrient-rich sediments.

The desired depth of drawdown should be determined by lake morphometry and the location of target nuisance species, although many other factors will enter into determining the allowable or achievable depth of drawdown. From experiences with several Massachusetts Lakes, suggested drawdowns were generally restricted to less than six feet. More often than not, it is the elevation of the outlet structure, such as a spillway or bottom drain, which determines the practical limits of drawdown. The duration of drawdown should be determined by the time necessary to sufficiently desiccate or freeze vegetation to the point of the desired density reduction. As this cannot usually be determined during the drawdown, several years of experimentation in a given system are often needed. The actual period of drawdown is often determined by watershed size (tributary inflows), weather (storms) and size of the dam opening (maximum outflow).

The typically intended effects of a drawdown are to reduce the density of rooted aquatic plants in the exposed area and to provide an opportunity for clean-up and repairs by shoreline property owners. If the water level declines, there is little that will interfere with maintenance efforts, but several factors may affect the success of drawdown with respect to plant control. The presence of high levels of groundwater seepage into the lake may mitigate or negate destructive effects on both target submergents and adjoining emergents 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 some macrophyte species to drawdown is quite variable (Cooke et al. 1993, EPA 1988, Table 1).

Drawdowns of many lakes have controlled macrophyte growths to the satisfaction of users and managers, and have been employed for longer than most other lake management techniques (Dunst et al. 1974). Winter drawdowns of Candlewood Lake in Connecticut (Siver et al. 1986) reduced nuisance species by as much as 90% after initial drawdown. Reductions in plant biomass of 44 to 57% were observed in Blue Lake in Oregon (Geiger 1983) following drawdown. Certain species have been reduced or eliminated from shallow water in Richmond Pond in Massachusetts by annual winter drawdown (Enser, pers. comm.). Drawdown of Lake Bomoseen in Vermont (VANR 1990) caused a major reduction in many species, many of which were not targeted for biomass reductions. About a decade of experience with drawdown at Lake Lashaway in Massachusetts has resulted in the elimination of nuisance conditions without eliminating any species of plants (Munyon, pers. comm.). Drawdowns in Wisconsin lakes have resulted in from 40 to 92% reductions in plant coverage/biomass in targeted areas (Dunst et al. 1974). 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 is highly advisable prior to conducting a drawdown (Cooke et al. 1993, WDNR 1989).

TABLE 1
ANTICIPATED RESPONSES OF SOME WETLAND PLANTS TO WINTER WATER LEVEL DRAWDOWN

	Change in Relative Abundance		
	Increase	**No Change**	**Decrease**
Acorus calamus (sweet flag)	E		
Alternanthera philoxeroides (alligator weed)	E		
Asclepias incarnata (swamp milkweed)			E
Brasenia schreberi (watershield)			S
Cabomba caroliniana (fanwort)			S
Cephalanthus occidentalis (buttonbush)	E		
Ceratophyllum demersum (coontail)			S
Egeria densa (Brazilian Elodea)			S
Eichhornia crassipes (water hyacinth)		E/S	
Eleocharis acicularis (needle spikerush)	S	S	S
Elodea canadensis (waterweed)	S	S	S
Glyceria borealis (mannagrass)	E		
Hydrilla verticillata (hydrilla)	S		
Leersia oryzoides (rice cutgrass)	E		
Myrica gale (sweetgale)		E	
Myriophyllum spp. (milfoil)			S
Najas flexilis (bushy pondweed)	S		
Najas guadalupensis (southern naiad)			S
Nuphar spp. (yellow water lily)			E/S
*Nymphaea odorata (*water lily)			S
Polygonum amphibium (water smartweed)		E/S	
Polygonum coccineum (smartweed)	E		
Potamogeton epihydrus (leafy pondweed)	S		
Potamogeton robbinsii (Robbins' pondweed)			S
Potentilla palustris (marsh cinquefoil)			E/S
Scirpus americanus (three square rush)	E		
Scirpus cyperinus (woolly grass)	E		
Scirpus validus (great bulrush)	E		
Sium suave (water parsnip)	E		
Typha latifolia (common cattail)	E	E	
Zizania aquatic (wild rice)		E	

E=emergent growth form; S=submergent growth form; E/S=emergent and submergent growth forms

After Cooke et al., 1986

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. 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, shoreline erosion during drawdown, loss of aesthetic appeal during drawdown, more frequent algal blooms after reflooding, reduction in water supply and impairment of recreational access during the drawdown (Nichols and Shaw 1983, Cooke et al. 1993). Inability to rapidly refill a drawn down lake is a standard concern in evaluating the efficacy of a drawdown. Winter drawdown can often avoid many of these negative side effects, but managers should be aware of the potential consequences of any management action (WDNR 1989).

Recolonization by resistant vegetation is sometimes a function of seed beds and sometimes the result of expansion of the shoreline vegetation fringe. *Najas* recolonized areas previously overgrown with *Myriophyllum* after the drawdown of Candlewood Lake in Connecticut (Siver et al. 1986), apparently from seeds that had been in those areas prior to milfoil dominance. Cattails and rushes are the most commonly expanding fringe species (Nichols and Shaw, WDNR 1989).

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.

Unintended effects within the littoral zone of a lake include loss of fish spawning areas and reduction of benthic invertebrate abundance and diversity. Few fish species spawn during winter in temperate climates (Scott and Crossman 1979), and spawning habitat improvement is more common than detrimental impacts (Cooke et al. 1993). Recolonization by invertebrates is usually rapid, although changes in species composition and diversity may occur and recolonization may be slow in large scale drawdowns (Cooke et al. 1993, WDNR 1989, VANR 1990).

Drawdown may affect water quality, particularly the parameters of clarity and dissolved oxygen concentration. Clarity will be a function of algal production and suspension of non-living particles. Algal production is most often related to phosphorus availability. By oxidizing exposed sediments, later release of phosphorus may be reduced through binding under oxic conditions, although post-drawdown algal blooms suggest that this mechanism may not be effective for all lakes. Some researchers have suggested that decomposition during drawdown makes nutrients more available for release, but there is little experimental evidence to support this mechanism (Cooke et al. 1993). It is likely that binding of iron and phosphorus influences phosphorus availability after drawdown, and the interplay between oxygen and levels of iron, sulfur and phosphorus is likely to vary among aquatic systems, resulting in variable nutrient availability.

Interaction between unexposed sediments and the lesser volume of water in the lake during drawdown can lead to depressed oxygen levels if oxygen demand exceeds aeration and sources of inflow are slight (Cooke et al. 1993, WDNR 1989). Compaction of sediment during drawdown varies with sediment type and dewatering potential, but any resulting compaction tends to last after refilling, reducing resuspension potential and post-drawdown turbidity (Kadlec 1962, Bay 1966, Cooke et al. 1993).

Recreational facilities and pursuits may be adversely impacted during a drawdown. Swimming areas will shrink and beach areas will enlarge during a drawdown. Boating may be restricted both by available lake area and by access to the lake. Again, winter drawdown will avoid most of these disadvantages, although lack of control over winter water levels can make ice conditions unsafe for fishing or skating.

Physical structures associated with the lake may be impacted by a drawdown. Outlet structures, docks and retaining walls may be subject to damage from freeze/thaw processes during overwinter drawdowns, if the water level is not lowered beyond all contact with the structure.

Downstream Considerations:
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.

Water Supply Considerations:
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 in Sturbridge, MA and Forge Pond in Westford, MA resulted in impairment of well water supplies, but there is little mention of impairment of well production in the reviewed literature.

Considerations for Hydraulically Connected Wetlands:
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. 1984). 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.

The naturally-occurring hydrologic regime is probably the single most important determinant for the establishment and maintenance of specific types of wetlands and wetland processes. Hydroperiod is the seasonal pattern of water levels in a wetland and is like a hydrologic signature of each wetland type. It is unique to each type of wetland and its constancy from year to year ensures reasonable stability for that wetland (Mitsch and Gosselink 1986).

The hydrologic regime of a specific wetland system can be permanently altered by a variety of techniques including: (1) constructing or removing berms or other containment devices, (2) water supply augmentation by wells or surface water diversion, (3) diffusing streamflow through the use of mechanical "spreaders" or by physically altering (e.g., braiding) the existing streamflow, and (4) by diverting surface or groundwater flow from the wetland. Significant changes in hydroperiod can produce rapid changes in vegetative species zonation in non-forested wetlands (Brinson et al. 1981). Most drawdowns for lake management purposes constitute only a temporary influence on hydrologic regime, however, and will not necessarily have a detectable, widespread effect.

Duration and timing of the drawdown are important factors in limiting impacts to associated wetlands. The duration of the drawdown must be at least several weeks (and preferably longer), if previously submergent vegetation is to be impacted (EPA 1988). Drawdown of the water level in summer, if more than a week or two in duration, leads to desiccation and stress of wetland species in most cases. In contrast, a similar drawdown practiced during late fall or early winter is expected to have little impact on dormant emergent plants, but should have a destructive effect on exposed littoral zone submergents and their rootstocks.

The frequency of drawdown can be as important as its duration or timing. Annual summer lake drawdowns provide a level of disturbance that often leads to a wetland interface which, while productive, is devoid of all but the most hardy vegetation (aquatic grasses) and lacking in a smooth transition into the littoral zone (Burt 1988). In some cases, annual drawdowns are conducted specifically to prevent emergent wetland encroachment into the lake. The rationale is that if emergent wetlands encroachment into the lake. The rationale is that if emergent wetlands are permitted to extend further into the lake, their ensuing protected legal status would dictate lake management policy.

Management drawdowns to control nuisance submergent vegetation are usually recommended for alternate years (Cooke et al. 1993), although they may be practiced at a higher frequency initially. The "every other year" approach tends to prevent domination by resistant submergent plants. This level of disturbance should also promote a degree of rejuvenation and diversity of the emergent wetland community, and should increase the area of ecotonal overlap between the fringing marshlands and the open water.

Although drawdowns may prevent expansion of emergent vegetation, the absence of water level fluctuations alone probably does not promote intrusion of emergent wetland plants. While emergent wetland species may expand in conjunction with other factors (e.g., increased sedimentation, eutrophication), a stable water level would normally be more encouraging to the expansion of the submergent plant population. However, just as with the emergent vegetation, an expansion of submergents cannot take place without accompanying favorable light, substrate and nutrient conditions.

Most wetland plants are very well adapted for existence during conditions of fluctuating water level. In fact, a prolonged stable water level is known to lead towards dominance by single species in emergent wetland communities; nearly pure stands of common cattail or sedges/grasses are the most common manifestations of this phenomenon (Van der Valk and Davis 1980). Some water level fluctuation is required for elevated species diversity.

The nature of the wetland soils will influence wetland response to a drawdown. Generally the water table in a peat or muck soil is within one or two feet of the average ground surface (Bay 1966). The upper layer of a peat soil has been termed the active layer, the layer in which plant roots exist and the layer with the greatest water level fluctuation (Romanov 1968). The total porosity of the undecomposed raw peat moss horizon exceeds 95%, but the porosity of decomposed peat is only 83%. While this may not seem to be a major difference, lowering the water table in loose, porous, undecomposed peat removes 60 to 80% of the water in a given horizon, but an equal lowering in a decomposed peat removes only approximately 10% of the water (Bay 1966).

The loss of nutrients from wetland organic soils may have an adverse affect on wetland plant growth, especially after repeated annual or biannual drawdowns, but this potential impact is not well understood at this point and needs additional research. Where replacement of lost nutrients is possible, nutrient losses from exposed soils may not have any detectable effect on wetland communities.

Although often viewed as separate entities, wetlands and lakes really constitute a continuum of hydrologic resources, habitat values and recreational opportunities. The interaction between lake and wetland is complex, and any attempt at co-management must accommodate the subtleties of the relationship. The need for integrated watershed management is clear, but a set of goals with corresponding priorities is needed to reach decisions where conflicts occur (Wagner and Oglesby 1984).

From a lake management perspective, wetlands do not always act as good neighbors. Among their common, less desirable exports to lakes are organic material, color, turbidity, odors, easily resuspended particulates, nuisance insects, animal wastes, larger floating debris, and floating macrophytes (e.g., *Utricularia, Lemna*). Yet, it is undeniable that wetlands are critical to promoting a healthy lake flora and fauna and maintenance of desirable recreational and aesthetic qualities of most lakes. Furthermore, the Wetlands Protection Act establishes certain priorities and considerations without regard to potentially conflicting management goals. Management activities must therefore be structured around existing regulations.

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. Therefore; the depth, length, timing and frequency of the disturbance are critical elements in devising the most mutually beneficial program. This type of management is compatible with the idea of a multi-purpose lake, with various recreational and conservation zones (Jones 1988).

Extreme variations in wetland hydrology directly influence wildlife presence and production, and affect habitat quality through modification of the plant substrate, food abundance and variety, and physical elements that modify spatial relationships (Weller 1988). Common parameters of change are water depth, areal extent of flooding, and length of the hydroperiod. Additionally, rate of change is also critical and may be the primary cause of impact on some species. Drawdowns may cause an extreme variation in wetland hydrology, but the timing and duration of drawdown will be the primary determinants of its impact.

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APPENDIX D

TEMPLATE FOR DREDGING EVALUATION

TEMPLATE FOR DREDGING EVALUATION

Reasons For Dredging:

Increased depth/access
Removal of nutrient reserves
Control of aquatic vegetation
Alteration of bottom composition
Habitat enhancement
Reduction in oxygen demand
Other

Existing and Proposed Bathymetry:

Existing mean depth
Existing maximum depth
Proposed distribution of lake area over depth range (hypsograph)
Proposed mean depth
Proposed maximum depth
Proposed distribution of area over depth range

Volume Of Material To Be Removed:

In-situ volume to be removed
Distribution of volume over sediment types
Distribution of volume over lake area (key sectors)
Bulked volume (see below)
Dried volume (see below)

Physical Nature of Material To Be Removed:

Grain size distribution
Solids content
Organic content
Settling rate
Bulking factor
Drying factor
Residual turbidity

Chemical Nature of Material To Be Removed:

Metals levels
Organic contaminant levels
Nutrient levels
Oil and grease or TPH
Other contaminants

Nature of Underlying Material To Be Exposed:
Type of material
Comparison with overlying material

Protected Resource Areas:
Wetlands
Endangered species
Habitats of special concern
Species of special concern
Regulatory resource classifications

Dewatering Capacity of Sediments:
Dewatering potential
Dewatering timeframe
Methodological considerations

Flow Management:
System hydrology
Possible peak flows
Expected mean flows
Provisions for controlling water level
Methodological implications

Equipment Access:
Possible input and output points
Land slopes
Pipeline routing
Property issues

Relationship To Lake Uses:
Impact on existing uses during project
Impact on existing uses after project
Facilitation of additional uses

Potential Disposal Sites:
Possible containment sites
Soil conditions
Necessary site preparation
Volumetric capacity
Property issues
Long term disposal options

Dredging Methodologies:
Hydraulic options
Wet excavation
Dry excavation

Applicable Regulatory Processes:
General Federal or State review (NEPA or state equivalent)
Environmental impact reporting
Wetlands protection statutes
Dredging permits
Aquatic structures permits
Drawdown permits
Water diversion/use permits
Clean Water Act Section 401 (Water quality certification)
Clean Water Act Section 404 (US Army Corps of Engineers)
Fish and wildlife permits/notification
Dam safety/alteration permits
Waste disposal permits
Discharge permits

Removal Costs:
Engineering and permitting costs
Construction of containment area
Equipment purchases
Operational costs
Contract dredging costs
Ultimate disposal costs
Other costs
Total cost divided by volume to be removed

Uses Or Sale Of Dredged Material:
Possible uses
Possible sale
Target markets

Other Mitigating Factors:
Necessary watershed management
Ancillary project impacts
Economic setting
Political setting
Sociological setting

APPENDIX E

GLOSSARY OF AQUATIC TERMS

GENERAL AQUATIC GLOSSARY

Abiotic - Pertaining to any non-biological factor or influence, such as geological or meteorological characteristics.

Acid precipitation - Atmospheric deposition (rain, snow, dryfall) of free or combined acidic ions, especially the nitrates, sulfates and oxides of nitrogen and sulfur fumes from industrial smoke stacks.

Adsorption - External attachment to particles, the process by which a molecule becomes attached to the surface of particle.

Algae - Aquatic single-celled, colonial, or multi-celled plants, containing chlorophyll and lacking roots, stems, and leaves.

Alkalinity - A reference to the carbonate and bicarbonate concentration in water. Its relative concentration is indicative of the nature of the rocks within a drainage basin. Lakes in sedimentary carbonate rocks are high in dissolved carbonates (hard-water lakes) whereas lakes in granite or igneous rocks are low in dissolved carbonate (soft-water lakes).

Ammonium - A form of nitrogen present in sewage and is also generated from the decomposition of organic nitrogen. It can also be formed when nitrites and nitrates are reduced. Ammonium is particularly important since it has high oxygen and chemical demands, is toxic to fish in un-ionized form and is an important aquatic plant nutrient because it is readily available.

Anadromous - An adjective used to describe types of fish which breed in freshwater rivers but spend most of their adult lives in the ocean. Before breeding, anadromous adult fish ascend the rivers from the sea.

Anoxic - Without oxygen.

Aphotic Zone - Dark zone, below the depth to which light penetrates. Generally equated with the zone in which most photosynthetic algae cannot survive, due to light deficiency.

Aquifer - Any geological formation that contains water, especially one that supplies wells and springs; can be a sand and gravel aquifer or a bedrock aquifer.

Artesian - The occurrence of groundwater under sufficient pressure to rise above the upper surface of the aquifer.

Assimilative Capacity - Ability to incorporate inputs into the system. With lakes, the ability to absorb nutrients or other potential pollutants without showing extremely averse effects.

Attenuation - The process whereby the magnitude of an event is reduced, as the reduction and spreading out of the impact of storm effects or the removal of certain contamination as water moves through soil.

Background Value - Value for a parameter that represents the conditions in a system prior to a given influence in space or time.

Bathymetry - The measurement of depths of water in oceans, seas, or lakes or the information derived from such measurements.

Benthic Deposits - Bottom accumulations which may contain bottom-dwelling organisms and/or contaminants in a lake, harbor, or stream bed.

Benthos - Bottom-dwelling organisms living on, within or attached to the sediment. The phytobenthos includes the aquatic macrophytes and bottom-dwelling algae. The zoobenthos (benthic fauna) includes a variety of invertebrate animals, particularly larval forms and mollusks.

Best Management Practices - (BMP's) State-of-the-art techniques and procedures used in an operation such as farming or waste disposal in order to minimize pollution or waste.

Biological Oxygen Demand - The BOD is an indirect measure of the organic content of water. Water high in organic content will consume more oxygen due to the decomposition activity of bacteria in the water than water low in organic content. It is routinely measured for wastewater effluents. Oxygen consumption is proportional to the organic matter in the sample.

Biota - Plant (flora) and animal (fauna) life.

Biotic - Pertaining to biological factors or influences, concerning biological activity.

Bloom - Excessively large standing crop of algae, usually visible to the naked eye.

Bulk Sediment Analysis - Analysis of soil material or surface deposits to determine the size and relative amounts of particles composing the material.

CFS - Cubic feet per second, a measure of flow.

Chlorophyll - Major light gathering pigment of all photosynthetic organisms imparting the characteristic color or green plants. Its relative measurement in natural waters is indicative of the concentration of algae in the water.

Chlorophyte - Green algae, algae of the division Chlorophyta.

Chrysophyte - Golden or yellow-green algae, algae of the division Chrysophyta.

Coliforms - Generally refers to bacterial species normally present in the large intestine (colon) and feces of all warm-blooded animals.

Color - Color is determined by visual comparison of a sample with known concentrations of colored solutions and is expressed in standard units of color. Certain waste discharges may turn water to colors which cannot be defined by this method; in such cases, the color is expressed qualitatively rather than numerically. Color in lake waters is related to solids, including algal cell concentration and dissolved substances.

Combined Sewer - A sewer intended to serve as both a sanitary sewer and a storm sewer. It receives both sewage and surface runoff.

Composite Sample - A number of individual samples collected over time or space and composited into one representative sample.

Concentration - The quantity of a given constituent in a unit of volume or weight of water.

Conductivity - The measure of the total ionic concentration of water. Water with high total dissolved solids (TDS) level would have a high conductance. A conductivity meter tests the flow of electrons through the water which is heightened in the presence of electrolytes (TDS).

Confluence - Meeting point of two rivers or streams.

Conservative Substance - Non-interacting substance, undergoing no kinetic reaction; chlorides and sodium are approximate examples.

Cosmetic - Acting upon symptoms or given conditions without correcting the actual cause of the symptoms or conditions.

Cryptophyte - Algae of variable pigment concentrations, with various other unusual features. Algae of the division Cryptophyta, which if often placed under other taxonomic divisions.

Cyanophyte - Bluegreen algae, algae of the division Cyanophyta, actually a set of pigmented bacteria.

Decomposition - The metabolic breakdown of organic matter, releasing energy and simple organic and inorganic compounds which may be utilized by the decomposers themselves (the bacteria and fungi).

Deoxygenation - Depletion of oxygen in an area, used often to describe possible hypolimnetic conditions, process leading to anoxia.

Diatom - Specific type of chrysophyte, having a siliceous frustule (shell) and often elaborate ornamentation, commonly found in great variety in fresh or saltwaters. Often placed in its own division, the Bacillariophyta.

Dinoflagellate - Unicellular algae, usually motile, having pigments similar to diatoms and certain unique features. More commonly found in saltwater. Algae of the division Pyrrhophyta.

Discharge Measurement - The volume of water which passes a given location in a given time period, usually measured in cubic feet per second (cfs) or cubic meters per minute (m3/min).

Dissolved Oxygen (D.O.) - Refers to the uncombined oxygen in water which is available to aquatic life. Temperature affects the amount of oxygen which water can contain. Biological activity also controls the oxygen level. D.O. levels are generally highest during the afternoon and lowest just before sunrise.

Diurnal - Varying over the day, from day time to night.

Domestic Wastewater - Water and dissolved or particulate substances after use in any of a variety of household tasks, including sanitary systems and washing operations.

Drainage Basin - A geographical area or region which is so sloped and contoured that surface runoff from streams and other natural watercourses is carried away by a single drainage system by gravity to a common outlet. Also referred to as a watershed or drainage area. The definition can also be applied to subsurface flow in groundwater.

Dystrophic - Trophic state of a lake in which large quantities of nutrients may be present, but are generally unavailable (due to organic binding or other causes) for primary production. Often associated with acid bogs.

Ecosystem - A dynamic association or interaction between communities of living organisms and their physical environment. Boundaries are arbitrary and must be stated or implied.

Elutriate - Elutriate refers to the washings of a sample of material.

Epilimnion - Upper layer of stratified lake. Layer that is mixed by wind and has a higher average temperature than the hypolimnion. Roughly approximates the euphotic zone.

Erosion - The removal of soil from the land surface, typically by runoff water.

Euglenoid - Algae similar to green algae in pigment composition, but with certain unique features related to food storage and cell wall structure. Algae of the division Euglenophyta.

Eutrophic - High nutrient, high productivity trophic state generally associated with unbalanced ecological conditions and poor water quality.

Eutrophication - Process by which a body of water ages, most often passing from a low nutrient concentration, low productivity state to a high nutrient concentration, high productivity stage. Eutrophication is a long-term natural process, but it can be greatly accelerated by man's activities. Eutrophication as a result of man's activities is termed cultural eutrophication.

Fauna - A general term referring to all animals.

Fecal Coliform Bacteria - Bacteria of the coliform group that are present in the intestines or feces of warm-blooded animals. They are often used as indicators of the sanitary quality of the water. In the laboratory they are defined as all organisms which produce blue colonies within 24 hours when incubated at $44.5^{\circ}C \pm 0.2^{\circ}C$ on M-FC medium (nutrient medium for bacterial growth). Their concentrations are expressed as number of colonies per 100 ml of sample.

Fecal Streptococci Bacteria - Bacteria of the Streptococci group found in intestines of warm-blooded animals. Their presence in water is considered to verify fecal pollution. They are characterized as gram positive, coccoid bacteria which are capable of growth in brain-heart infusion broth. In the laboratory they are defined as all the organisms which produce red or pink colonies within 48 hours at $35^{\circ}C \pm 1.0^{\circ}C$ on KF medium (nutrient medium for bacterial growth). Their concentrations are expressed as number of colonies per 100 ml of sample.

Flora - general term referring to all plants.

Food Chain - A linear characterization of energy and chemical flow through organisms such that the biota can be separated into functional units with nutritional interdependence. Can be expanded to a more detailed characterization with multiple linkage, called a food web.

Grain Size Analysis - A soil or sediment sorting procedure which divides the particles into groups depending on size so that their relative amounts may be determined. Data from grain size analyses are useful in determining the origin of sediments and their behavior in suspension.

Groundwater - Water in the soil or underlying strata, subsurface water.

Hardness - A physical-chemical characteristic of water that is commonly recognized by the increased quantity of soap required to produce lather. It is attributable to the presence of alkaline substances (principally calcium and magnesium) and is expressed as equivalent calcium carbonate ($CaCO_3$).

Humus - Humic substances form much of the organic matter of sediments and water. They consist of amorphous brown or black colored organic complexes.

Hydraulic Detention Time - Lake water retention time, amount of time that a random water molecule spends in a water body; time that it takes for water to pass from an inlet to an outlet of a water body.

Hydraulic Dredging - Process of sediment removal using a floating dredge to draw mud or saturated sand through a pipe to be deposited elsewhere.

Hydrologic Cycle - The circuit of water movement from the atmosphere to the earth and return to the atmosphere through various stages or processes such as precipitation, interception, runoff, infiltration, percolation, storage, evaporation, and transpiration.

Hypolimnion - Lower layer of a stratified lake. Layer that is mainly without light, generally equated with the aphotic zone, and has a lower average temperature than the epilimnion.

Impervious - Not permitting penetration or percolation of water.

Intermittent - Non-continuous, generally referring to the occasional flow through a set drainage path. Flow of a discontinuous nature.

Kjeldahl Nitrogen - The total amount of organic nitrogen and ammonia in a sample, as determined by the Kjeldahl method, which involves digesting the sample with sulfuric acid, transforming the nitrogen into ammonia, and measuring it.

Leachate - Water and dissolved or particulate substances moving out of a specified area, usually a landfill, by a completely or partially subsurface route.

Leaching - Process whereby nutrients and other substances are removed from matter (usually soil or vegetation) by water. Most often this is a chemical replacement action, prompted by the qualities' of the water.

Lentic - Standing, having low net directional motion. Refers to lakes and impoundments.

Limiting Nutrient - That nutrient of which there is the least quantity, in relation to its importance to plants. The limiting nutrient will be the first essential compound to disappear from a productivity system, and will cause cessation of productivity at that time. The chemical form in which the nutrient occurs and the nutritional requirements of the plants involved are important here.

Limnology - The comprehensive study of lakes, encompassing physical, chemical and biological lake conditions.

Littoral Zone - Shallow zone occurring at the edge of aquatic ecosystems, extending from the shoreline outward to a point where rooted aquatic plants are no longer found.

Loading - Inputs into a receiving water that may exert a detrimental effect on some subsequent use of that water.

Lotic - Flowing, moving. Refers to streams or rivers.

Macrofauna - A general term which refers to animals which can be seen with the naked eye.

Macrophyte - Higher plant, macroscopic plant, plant of higher taxonomic position than algae, usually a vascular plant. Aquatic macrophytes are those macrophytes that live completely or partially in water. May also include algal mats under some definitions.

Mesotrophic - An intermediate trophic state, with variable but moderate nutrient concentrations and productivity.

MGD - Million gallons per day, a measure of flow.

Micrograms per Liter (ug/l) - A unit expressing the concentration of chemical constituents in solution as mass (micrograms) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter.

Nitrate - A form of nitrogen that is important since it is the end product in the aerobic decomposition of nitrogenous matter. Nitrogen in this form is stable and readily available to plants.

Nitrite - A form of nitrogen that is the oxidation product of ammonia. It has a fairly low oxygen demand and is rapidly converted to nitrate. The presence of nitrite nitrogen usually indicates that active decomposition is taking place (i.e., fresh contamination).

Nitrogen - A macronutrient which occurs in the forms of organic nitrogen, ammonia nitrogen, nitrite nitrogen and nitrate nitrogen. Form of nitrogen is related to a successive decomposition reaction, each dependent on the preceding one, and the progress and decomposition can be determined in terms of the relative amounts of these four forms of nitrogen.

Nitrogen-fixation - The process by which certain bacteria and bluegreen algae make organic nitrogen compounds (initially $NH4^+$) from elemental nitrogen (N_2) taken from the atmosphere or dissolved in the water.

Non-point Source - A diffuse source of loading, possibly localized but not distinctly definable in terms of location. Includes runoff from all land types.

Nutrients - Are compounds which act as fertilizers for aquatic organisms. Small amounts are necessary to the ecological balance of a waterbody, but excessive amounts can upset the balance by causing excessive growths of algae and other aquatic plants. Sewage discharged to a waterbody usually contains large amounts of carbon, nitrogen, and phosphorus. The concentration of carbonaceous matter is reflected in the B.O.D. test. Additional tests are run to determine the concentrations of nitrogen and phosphorus. Storm water runoff often contributes substantial nutrient loadings to receiving waters.

Oligotrophic - Low nutrient concentration, low productivity trophic state, often associated with very good water quality, but not necessarily the most desirable stage, since often only minimal aquatic life can be supported.

Organic - Containing a substantial percentage of carbon derived from previously living organisms; of a living organism.

Overturn - The vertical mixing of layers of water in the spring and fall caused by seasonal changes in temperature in temperature climate zones.

Oxygen Deficit - A situation in lakes where respiratory demands for oxygen become greater than its production via photosynthesis or its input from the drainage basins, leading to a decline in oxygen content.

Periphyton - Attached forms of plants and animals, growing on a substrate.

pH - A hydrogen concentration scale from 0 (acidic) to 14 (basic) used to characterize water solutions. Pure water is neutral at pH 7.0.

Phosphorus - A macronutrient which appears in waterbodies in combined forms known as ortho- and poly-phosphates and organic phosphorus. Phosphorus may enter a waterbody in agricultural runoff where fertilizers are used. Storm water runoff from highly urbanized areas, septic system leachate, and lake bottom sediments also contribute phosphorus. A critical plant nutrient which is often targeted for control in eutrophication prevention plans.

Photic Zone - Illuminated zone, surface to depth beyond which light no longer penetrates. Generally equated with the zone in which photosynthetic algae can survive and grow, due to adequate light supply.

Photosynthesis - Process by which primary producers make organic molecules (generally glucose) from inorganic ingredients, using light as an energy source. Oxygen is evolved by the process as a byproduct.

Phytoplankton - Algae suspended, floating or moving only slightly under their own power in the water column. Often the dominant algae form in standing waters.

Plankton - The community of suspended, floating, or weakly swimming organisms that live in the open water of lakes and rivers.

Point Source - A specific source of loading, accurately definable in terms of location. Includes effluents or channeled discharges that enter natural waters at a specific point.

Pollution - Undesirable alteration of the physical, chemical or biological properties of water, addition of any substance into water by human activity that adversely affects its quality. Prevalent examples are thermal, heavy metal and nutrient pollution.

Potable - Useable for drinking purposes, fit for human consumption.

Primary Productivity (Production) - Conversion of inorganic matter to organic matter to organic matter by photosynthesizing organisms. The creation of biomass by plants.

Riffle Zone - Stretch of a stream or river along which morphological and flow conditions are such that rough motion of the water surface results. Usually a shallow rocky area with rapid flow and little sediment accumulation.

Riparian - Of, or related to, or bordering a watercourse.

Runoff - Water and its various dissolved substances or particulates that flows at or near the surface of land in an unchanneled path toward channeled and usually recognized waterways (such as a stream or river).

Secchi Disk Transparency - An approximate evaluation of the transparency of water to light. It is the point at which a black and white disk lowered into the water is no longer visible.

Secondary Productivity - The growth and reproduction (creation of biomass) by herbivorous (plant-eating) organisms. The second level of the trophic system.

Sedimentation - The process of settling and deposition of suspended matter carried by water, sewage, or other liquids, by gravity. It is usually accomplished by reducing the velocity of the liquid below the point at which it can transport the suspended material.

Sewage (Wastewater) - The water borne, human and animal wastes from residences, industrial/commercial establishments or other places, together with such ground or surface water as may be present.

Specific Conductance - Yields a measure of a water sample's capacity to convey an electric current. It is dependent on temperature and the concentration of ionized substances in the water. Distilled water exhibits specific conductance of 0.5 to 2.0 micromhos per centimeter, while natural waters show values from 50 to 500 micromhos per centimeter. In typical New England lakes, Specific Conductance usually ranges from 100-300 micromhos per cm. The specific conductance yields a generalized measure of the inorganic dissolved load of the water.

Stagnant - Motionless, having minimal circulation or flow.

Standing Crop - Current quantity of organisms, biomass on hand. The amount of live organic matter in a given area at any point in time.

Storm Sewer - A pipe or ditch which carries storm water and surface water, street wash and other wash waters or drainage, but excludes sewage and industrial wastes.

Stratification - Process whereby a lake becomes separated into two relatively distinct layers as the result of temperature and density differences. Further differentiation of the layers usually occurs as the result of chemical and biological processes. In most lakes, seasonal changes in temperature will reverse this process after some time, resulting in the mixing of the two layers.

Substrate - The base of material on which an organism lives, such as cobble, gravel, sand, muck, etc.

Succession - The natural process by which land and vegetation patterns change, proceeding in a direction determined by the forces acting on the system.

Surface Water - Refers to lakes, bays, sounds, ponds, reservoirs, springs, rivers, streams, creeks, estuaries, marshes, inlets, canals, oceans and all other natural or artificial, inland or coastal, fresh or salt, public or private waters at ground level.

Suspended Solids - Those which can be removed by passing the water through a filter. The remaining solids are called dissolved solids. Suspended solids loadings are generally high in stream systems which are actively eroding a watershed. Excessive storm water runoff often results in high suspended solids loads to lakes. Many other pollutants such as phosphorus are often associated with suspended solids loadings.

Taxon (Taxa) - Any hierarchical division of a recognized classification system, such as a genus or species.

Taxonomy - The division of biology concerned with the classification and naming of organisms. The classification of organisms is based upon a hierarchical scheme beginning with Kingdom and progressing to the Species level or even lower.

Tertiary Productivity - The growth and reproduction (creation of biomass) by organisms that eat herbivorous (plant-eating) organisms. The third level of the trophic system.

Thermocline - Boundary level between the epilimnion and hypolimnion of a stratified lake, variable in thickness, and generally approximating the maximum depth of light penetration and mixing by wind.

Total Coliform Bacteria - A particular group of bacteria that is used as an indicator of possible sewage pollution. They are characterized as aerobic or facultative anaerobic, gramnegative, nonspore-forming, rod-shaped bacteria which ferment lactose with gas formation within 48 hours at 35°C. In the laboratory these bacteria are defined as the organisms which produce colonies within 24 hours when incubated at 35°C± 1.0°C on M-Endo medium (nutrient medium for bacterial growth). Their concentrations are expressed as number of colonies per 100 ml of sample.

Trophic Level - The position in the food chain determined by the number of energy transfer steps to that level; 1 = producer; 2 = herbivore; 3, 4, 5 = carnivore.

Trophic State - The stage or condition of an aquatic system, characterized by biological, chemical and physical parameters.

Turbidity - The measure of the clarity of a water sample. It is expressed in Nephalometric Turbidity Units which are related to the scattering and absorption of light by the water sample.

Volatile Solids - That portion of a sample which can be burned off, consisting of organic matter, including oils and grease.

Water Quality - A term used to describe the chemical, physical, and biological characteristics of water, usually with respect to its suitability for a particular purpose or use.

Watershed - Drainage basin, the area from which an aquatic system receives water.

Zooplankton - Microscopic animals suspended in the water; protozoa, rotifers, cladocerans, copepods and other small invertebrates.