SINGLETARY LAKE
LAKE MANAGEMENT PLAN

May 1995

Prepared For:

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Introduction

Singletary Lake is a 330 acre, moderately deep, mesotrophic lake. Three unnamed tributaries and numerous storm drains, draining a watershed of more than 2290 acres, feed Singletary Lake. The watershed encompasses two municipalities, Millbury and Sutton, with the greatest portion of the watershed located in Sutton. The majority of flow enters via the south-bay tributary. Water leaving the lake discharges to several smaller ponds, and finally to the Blackstone River. The watershed is sparsely developed, except for the immediate shoreline and Sutton Center, that are highly developed. Undeveloped areas are primarily wooded and open land, with a portion of the watershed located in the Merrill Lake State Reservation.

Singletary Lake is used extensively for recreational purposes including swimming, boating and fishing. Public access is provided by a State boat ramp located in Millbury, and at a Town swimming beach in Sutton. The boat ramp is used extensively during the summer by recreational users and fishermen, and the lake hosts a number of bass tournaments. Historically, the lake has exhibited symptoms of eutrophication including:

- periodic algal blooms;
- reduced transparency; and
- infestations of nuisance exotic (non-native) aquatic vegetation species that have impaired recreational water uses and important aesthetic and wildlife habitat functions.

Because of the importance of Singletary Lake as a multiple use resource the Lake Singletary Watershed Association in cooperation with the Towns of Sutton and Millbury, has actively worked towards the management, restoration, and protection of the lake since 1982. The Division of Water Pollution Control (DWPC) in 1984-85 completed an intensive monitoring program of the lake and its tributaries similar in scope to a full-scale diagnostic study. This information was to be used to complete a full-scale diagnostic/feasibility study using funds provided by the Department of Environmental Management. As a result of state funding cutbacks, state funding to complete the data interpretation and develop a management plan was eliminated in 1988. Subsequently the Lake Singletary Watershed Association retained IEP, Inc. to complete the diagnostic portion of the study in 1989. A final diagnostic study report was issued in January 1991. Since that time, the Association has continued to work towards the completion of the feasibility study and development of a lake management plan. Recent in-lake management has focused largely on the control and eradication of infestations of Eurasian and variable watermilfoil, exotic, nuisance aquatic plants.

Matching funds were awarded to the Town of Sutton, to complete a lake management plan for Singletary Lake under the newly revamped state lakes funding program. The goal of this project is to draw together the wealth of existing information to serve as the basis for a comprehensive analysis of available management and restoration options, culminating in a recommended management program.

This report documents the findings of the Singletary Lake Management Project. Fugro identified the management needs for Singletary Lake, analyzed alternatives, and the developed a recommended management plan tailored specifically for Singletary Lake.

Identification of Management Needs

Historical Perspective

Singletary Lake has been the subject of investigations and varied management efforts. Water levels were historically managed by the Windle Mills, and by the Whittinsville Water Company for a 10 year period beginning in the early 1980's. About 3 years ago, water level control rights were assumed by the Town of Millbury. The lake served as a significant recreational resource since the early 1900's. While Singletary Lake was classified as mesoeutrophic, the Lake is exhibiting various problems commonly associated with the eutrophication process. Problems experienced at Singletary Lake include:

- Rooted plant growths have not changed significantly in composition over time. However, Eurasian watermilfoil (*Myriophyllum spicatum*), an invading nuisance species has become more prevalent.
- A second invasive, non-native species of rooted aquatic plant, variable watermilfoil (*Myriophyllum heterophyllum)*, was documented in a 1991 vegetation survey.
- Periodic low transparency, attributable to algae and possibly suspended sediments that adversely affect recreational utility.

Considering past investigations of Singletary Lake and its watershed, the causes and constraints associated with the above problems have been defined as follows:

- The persistence and expansion of Eurasian watermilfoil and variable watermilfoil within Singletary Lake are largely related to the aggressive growth characteristics of this plant; and possibly from re-introduction from non resident-boats or waterfowl. Resident boats may contribute the expansion of infestation by transporting plant fragments from colonized areas to previously uncolonized areas.
- Sediment enters from the watershed and is also generated organically within the lake. Sediment accumulations allow many rooted species, native and non-native, to expand coverage. There is enough nutrient-rich sediment in the lake now to support dense rooted plant growths without any future watershed inputs.
- Periodic algae blooms appear to be a consequence of nutrient inputs from the watershed, principally from stormwater runoff and septic system inputs.
- Eleven primary storm drains were identified during the Diagnostic Study that discharge directly to the lake. However, other drains probably exist.

- Of the estimated 151 dwellings located within 300 feet of the lake, 67% utilize septic tank/leachfield systems for wastewater disposal, 27% have cesspools, and 1% utilize an outhouse.
- 47% of the wastewater disposal systems were reported to have been in use for more than 20 years; 80% in use for more than 10 years.
- 50% of the property owners pumped out wastewater disposal systems less than once in 5 years.
- Historic monitoring data reveal phosphorus concentrations within the lake may vary greatly, ranging from <0.01 to 0.17 mg/l at the surface. There has been a limited amount of sampling completed since the 1984-85 diagnostic study. Typically this sampling has been limited to one sample collected during the summer or autumn of any given year. Again, this sampling data exhibits a substantial variability in phosphorus concentrations, ranging from <0.01 to 0.12 mg/l at the surface. Such limited one time sampling data must be interpreted in light of historic data. A single sample is only representative of the conditions on the date of sampling. There is inherent uncertainty and potential error associated with sample collection, laboratory analysis, and natural variability over time and space. Therefore, no single sample result should be given too much weight in the decision making process. A summary of available data is provided in Appendix A.

- Algal blooms have included bluegreen, diatoms, and green algae, with the bluegreens causing most of the blooms requiring treatment. Phosphorus limits algal growth. Other factors such as light may be important controls on algae in Singletary Lake as well. However, phosphorus is the factor with the greatest potential for control in this system, and could be made to limit algal growth.
- The largely undeveloped nature of the watershed minimizes the frequency and magnitude of current problems, but suggests a high potential for increased nutrient loading with future development. Therefore, it is appropriate that management goals focus on long-term protection as well as correction of current problems.

Management Goals

Setting a Numeric Load Reduction Target

In order to slow the process of eutrophication, it will be necessary to reduce the current loading of nutrients (phosphorus and nitrogen) to the lake, and minimize future increases in loading to the lake. Phosphorus is the logical target of management efforts.

By controlling phosphorus levels in the lake, we seek to shift conditions in the desired direction along the probability distribution for algal blooms, water clarity, or other dynamic lake features. Any reduction in inputs will reduce the frequency of such problems. However, some minimum reduction will be necessary to make a noticeable change, and an unrealistically (and possibly unachievably) large reduction would be necessary to achieve desirable conditions at all times. A phosphorus load reduction sufficient to maintain water clarity at 6.5 ft during an average year would produce greater water clarity during a dry year. Conversely, such reductions could produce longer periods of unacceptably low water clarity during a wet year. There is a range of loading which would be acceptable over the range of hydrologic conditions experienced in Singletary Lake. There will always be some probability of an algal bloom or other unwanted event. The goal of nutrient load reductions will be to minimize this risk at an acceptable cost.

Setting a phosphorus load reduction goal should be a function of choosing loading limits that provide acceptable lake conditions over the range of typical hydrologic conditions. In terms of actual management, it will be most economical to develop a plan that can be adjusted in response to hydrologic changes which signal loading changes. Use of a single load limit will result in either unnecessary expense under dry conditions or less than desirable lake conditions under wet weather hydrology. It is advisable to evaluate the ability of various load reductions to achieve desired lake conditions under the range of expected hydrologic conditions.

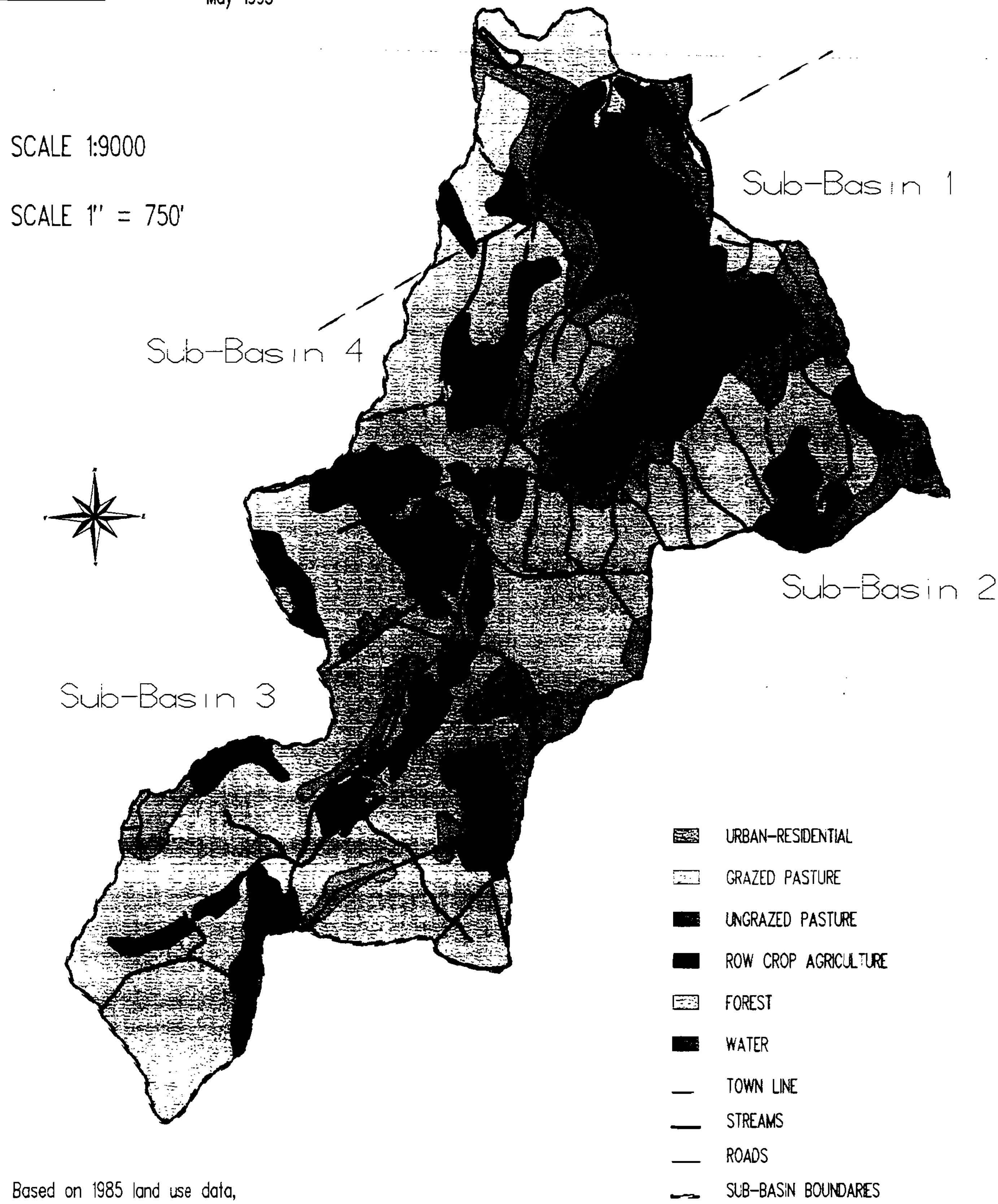
A minimum water clarity of 4 ft, measured as Secchi disk transparency (SDT), is the safety standard for contact recreation in waters of Massachusetts, and is an appropriate minimum acceptable level. Water clarity has typically exceed this limit in the past, with few reported transparencies below 6.5 feet. Therefore, a goal of 6.5 feet minimum transparency is an appropriate target for your management efforts.

For a given lake, the range of phosphorus loads over which water clarity problems appear and become severe (permissible and critical load limits) is dependent upon the unique hydrologic features of the lake (Vollenweider, 1975). Nutrient loading and trophic state modeling for Singletary Lake are provided in Appendix B. The permissible phosphorus load for Singletary Lake is estimated at 144 kg/yr (318 lbs/yr). The critical load, above which water clarity problems would be expected on a regular basis, is calculated to be 288 kg/yr (635 lbs/yr) for Singletary Lake. Based on knowledge gained from other Massachusetts lakes, these are reliable estimates of the range of loading over which water clarity deteriorates.

The average load to Singletary Lake (383 kg/yr or 844 lbs/yr) exceeds the critical and permissible loads. The range of estimated phosphorus loads (330 to 530 kg/yr or 727 to 1168 lbs/yr) exceeds the critical range for Singletary Lake (Table 1). Phosphorus load supports algae production in the lake, as measured by chlorophyll concentrations. Water clarity (secchi depth) is affected by the amount of algae in the lake, but also other factors such as suspended solids and natural water color. The range of water clarity observed in Singletary Lake over at least the last decade is understandable given the varied phosphorus loading. There have been "good" years and "bad" years; each linked to phosphorus loading, which has in turn been linked to the weather. Modeling results indicate that the 6.5 foot water clarity goal would not be met about 25% of the time under average conditions. This goal would not be met 13% of the time under dry conditions; and 31% of the time under wetter conditions (Table 1). For comparative purposes, the lake's response was predicted under both pristine (pre-development) and build-out scenarios

SINGLETARY LAKE BASIN LANDUSE

May 1995



Based on 1985 land use data,
field checked in 1988.

Figure 1

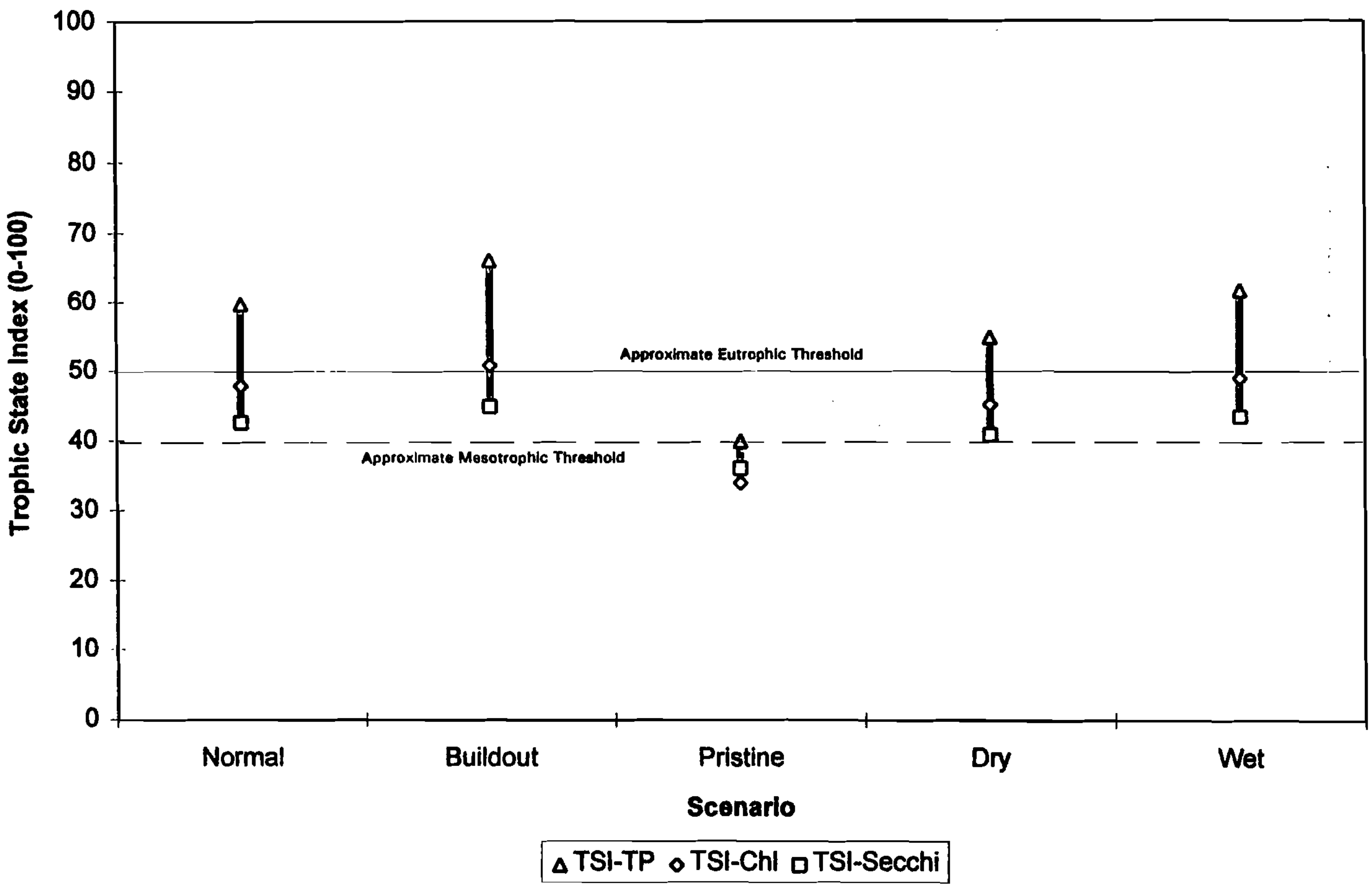
(Table 1). Under pristine conditions, before human influence in the watershed, average in-lake phosphorus concentrations would have been about one quarter of those observed today. Under pristine conditions the 6.5 foot goal would have been met 100% of the time. We also examined the impact of continued development in the watershed, where all developable land is developed in residential or urban land uses. Under this scenario, in-lake phosphorus concentrations are nearly double those observed under existing conditions, and the water clarity goal would not be met about 43% of the time. The nuisance criterion for chlorophyll concentrations that result in severe impairment of recreational water uses is 20 ppb (Carlson, 1977). This criterion would be exceed less than 3 percent of the time even under buildout conditions (Table 1). Figure 2 illustrates the trophic state indices for Singletary Lake under the varying scenarios examined. The trophic state index or TSI (Carlson, 1977) is calculated using three different parameters (total phosphorus, chlorophyll, and secchi disk). The graphic illustration exhibits the predicted TSI's as a range for each scenario. There is a disparity between the TSI predicted by phosphorus, and those predicted by chlorophyll and secchi disk. This may indicate that factors other than nutrients (e.g., suspended solids, light, micronutrients) have a measurable effect on chlorophyll (algae production) and water transparency. Under pristine conditions Singletary Lake would likely have been border-line mesotrophic (Figure 2). Further, it is apparent that the trophic condition during an extreme wet year would be similar to the condition that might be expected on a normal basis under buildout conditions in the watershed.

Table 1. Predicted Nutrient Loading and Trophic Response For Various Scenarios

	Possible Scenario				
Parameter	**Normal**	**Wet**	**Dry**	**Pristine**	**Build-out**
P Load (kg/yr)	387	530	330	117	719
Avg. P Conc. (ppb)	47	54	34	12	73
Avg. Secchi Depth (m)	3.3	3.2	3.8	5.3	2.9
Avg. Chlorophyll (ppb)	5.8	6.4	4.4	1.4	7.8
% of time water clarity less than 6.5 feet	25	31	13	0	43
% of chlorophyll concentration greater than nuisance criteria (20 ppb)	1	2	0	0	3

A 62% reduction of the current average annual load would be required to achieve the permissible loading (144 kg/yr) for Singletary Lake. A 73% reduction would be required to achieve the same goal under wet conditions, and a 56% reduction under dry conditions. At the permissible loading level, the water clarity goal of 6.5 feet would be met about 99% of the time. The acceptable load to reduce the frequency of goal non-attainment to about 10% is 250 kg/yr. The current average load to Singletary Lake of 383 kg/yr would have to be reduced by 35% to achieve such a goal. To reduce the frequency of undesirable conditions to less than 5% would require a reduction in load to 193 kg/yr (or a 50 percent reduction).

Figure 2. Predicted Trophic State Index For Singletary Lake Under Varying Conditions



Temporal variability in the delivery of phosphorus and associated suspended solids to Singletary Lake limits the reliability of predicting water clarity from annual loads. However, it appears that measurable improvement could be made if the current average load was reduced by 35-50%. It may not be feasible to reduce loads to below the permissible threshold of 144 kg/yr. A minimum desirable load reduction of 35% and a maximum reduction of 50% is a reasonable goal for the evaluation of management alternatives. Management actions should either target a worst case scenario (50% reduction) or be flexible enough to allow adjustment to deal with changing ambient conditions. That is, provide a mechanism to provide greater reductions under higher load (wetter) conditions, and lesser reductions under dry conditions.

It is important to remember the erratic nature of phosphorus loading to Singletary Lake when formulating a management strategy. Since the lake responds to inputs on a weekly to monthly level, it is likely that success can be achieved with a management strategy that reduces pulsed or seasonal inputs associated with storm events during spring and summer, even if the total load reduction is less than the 35-50% desired reduction.

As mentioned previously, no significant reduction in phosphorus loading is necessary to achieve a water clarity in excess of the 4-foot safety standard. Under existing conditions, water clarity is expected to remain above the 6.5-foot criteria 75% of the time. A substantial reduction (35%) in load would be required increase the frequency of criteria attainment to 90%. Therefore, when considering management options, it will be important to closely examine the cost of load reduction relative to the perceived benefits.

Source elimination or reduction, where phosphorus inputs are eliminated or minimized at their source, is still highly desirable. In addition, protection mechanisms to minimize or prevent future increases in loads associated with development will be important to maintaining the quality of Singletary Lake. A flexible, low maintenance system would allow greater reductions during wet periods and the primary recreational season and lesser control (and associated expense) during dry periods and times of lesser lake use.

Vegetation Management Goals

The rooted plants of Singletary Lake and existing sediment accumulations are now largely self-perpetuating. However, the colonizable area of Singletary Lake is generally limited by the relatively steep basin slopes. Watershed management is critical to maintaining and improving water quality and clarity. However, no amount of watershed management is likely to reduce the distribution or density of plants; improved water clarity may actually result in increased plant coverage. Directed change in sediment and rooted plant features of Singletary Lake will require in-lake techniques. Just to what extent control should be exercised depends upon the intended uses of the lake. The following management goals relative to vegetation control and sediment accumulations have been identified for Singletary Lake:

- Eradicate or reduce populations of non-native, invasive species:
  Eradication or severe reduction in the density of non-native species (Eurasian Watermilfoil and Variable Watermilfoil) is viewed as an appropriate goal. But replacement by other species should be expected based on light and sediment features and is to some extent necessary to maintain habitat quality for fish and wildlife. Action to reduce the dominance of non-native species is encouraged with the assumption that other more desirable species will maintain beneficial plant coverage. Ideally, an aquatic vegetation control program for Singletary Lake should seek to replace dense assemblages of nuisance and/or non-native species with native species. Most native plant species are of greater habitat value but typically do not grow to the surface or as densely as Eurasian and variable watermilfoil.

- Enhance shoreline access:
  Increased shoreline access in areas currently impaired by dense vegetation growth seems like a desirable management objective, and could be accomplished with only minor changes in overall plant density. Water depths are adequate for most uses. Localized plant control for access and habitat improvement is an appropriate management objective.

- Control periodic nuisance algal blooms
  Periodic algae blooms have occurred historically at Singletary Lake, and have in some instances impaired recreational use of the lake during the period of the bloom. Such extreme *bloom* conditions are relatively infrequent. However, control options should such conditions occur should be evaluated as part of an overall lake management program.

Analysis of Management Alternatives

General Considerations

On the basis of past discussions and meetings with the Association, the management objectives for Singletary Lake include:

- Maintaining water clarity during the summer recreation season at a level suitable for contact recreation and aesthetic appeal;
- Prevent the spread of or eradicate nuisance non-native rooted plant species;
- Maintaining and improving the habitat of the lake for fish and other aquatic organisms;
- Preventing bacterial contamination of the lake that may impair recreational uses; and
- Minimizing the maintenance effort necessary to achieve these goals on a lasting basis.

The list of applicable lake and watershed management options is not really extensive (Table 2), but the combination of techniques and level of application creates an almost endless continuum of management strategies. Each lake and watershed system are to some extent unique, so a management plan is developed on a case by case basis using on or more of the techniques listed in Table 2. The techniques are divided into in-lake actions and watershed management options. The key is to select techniques that provide the desired level of control or protection within the constraints of economic, social and political limits.

Watershed Management Strategies

For purposes of evaluation, it is assumed that a reduction in phosphorus loading and protection against future increases in loading are the primary goals of watershed level management actions. Attendant reductions in nitrogen and sediment loading are considered desirable. However, by focusing on phosphorus it is believed that the desired level of water clarity can be achieved.

Applicability of Watershed Management Strategies

Nearly all the watershed level techniques in Table 2 have some applicability to Singletary Lake, but the degree of applicability and likely benefit varies.

<u>Agricultural Best Management Practices</u>

There are some areas of the watershed currently used for agricultural purposes. However, by comparison to the entire watershed, these represent a relatively small percentage of the nutrient loads to the lake. Best Management Practices (BMP's) for reducing pollutant discharge from agricultural activities could be applied, but would not provide a substantial reduction in the total nutrient load to the lake. There are no severe erosion problems known at this time.

<u>Behavior Modification/Changes in Land Use Practices</u>

The success of behavioral modifications can be difficult to evaluate, although such actions have a positive influence. The phosphate detergent ban in effect as the result of July 1993 passage of the Phosphate Bill (S910) is expected to yield less than a 8-14% reduction in phosphorus loading to Singletary Lake. Limitation of lawn fertilization, on the other hand, would produce a small effect on phosphorus loading by altering the quality of runoff from existing developed areas. Minimization of fertilizer use would become more important with future increases in watershed development. Likewise, street sweeping and catch basin cleaning also have a limited potential to substantially reduce nutrient loads to Singletary Lake.

Table 2. Lake Restoration and Management Options

Technique	Descriptive Notes	Applicability
A. Watershed Level	**Approaches applied to the drainage area of a water body.**	
1. Agricultural Best Management Practices	Application of techniques in forestry, animal, and crop science to minimize adverse impacts.	2
2. Bank and Slope Stabilization	Erosion control to reduce inputs of sediment and related substances.	3
3. Behavioral Modifications	Actions by individuals.	
♦ Use of Non-Phosphate Detergents	Elimination of a major waste water phosphorus source.	1
♦ Eliminate Garbage Grinders	Reduce load to treatment system.	1
♦ Limit Lawn Fertilization	Reduce potential for nutrient loading to lake.	2
♦ Limit Motorboat Activity	Reduce wave action, vertical mixing, and sediment resuspension.	2
♦ Eliminate Illegal Dumping	Reduce organic pollution, sediment loads and potentially toxic inputs to a water body.	1
4. Detention or Infiltration Basin Use and Maintenance	Lengthening of time of travel for pollutant flows and facilitation of natural purification processes.	2
5. Increased Street Sweeping and Catch Basin Cleaning	Removal of potential runoff pollutants from roads and drainage systems.	2
6. Maintenance and Upgrade of On-site Disposal Systems	Proper operation of localized systems and maximal treatment of wastewater to remove pollutants.	1
7. Provision of Sanitary Sewers	Community level collection and treatment of waste water to remove pollutants.	1
8. Stormwater or Wastewater Diversion	Routing of pollutant flows away from a target water body.	2
9. Zoning and Land Use Planning	Management of land to minimize deleterious impacts on water.	1
10. Treatment of Runoff or Stream Flows	Inactivation of nutrients or other treatments to chemically alter inflows.	2

Applicability: 1 = likely positive benefit; 2 = possible positive benefit; 3 = no anticipated benefit relative to management goals

Table 2. Lake Restoration and Management Options (continued)

Technique	Descriptive Notes	Applicability
B. In -Lake Level	**Actions performed within a water body.**	
1. Aeration and/or Destratification	Mechanical maintenance of oxygen levels and prevention of stagnation.	3
2. Biocidal Chemical Treatment (herbicides or algicides)	Addition of inhibitory substances intended to eliminate target species.	1
3. Biomanipulation or Habitat Management	Facilitation of biological interactions to alter ecosystem processes.	2
4. Bottom Sealing	Physical obstruction of rooted plant growths and/or sediment-water interaction.	3
5. Chemical Sediment Treatment	Addition of compounds that alter sediment features to limit plant growths or control chemical exchange reactions.	3
6. Dilution and/or Flushing	Increased flow to minimize retention of undesirable materials.	3
7. Dredging	Removal of sediments under wet or dry conditions.	3
8. Dye Addition	Introduction of suspended pigments to create light inhibition of plant growths.	3
9. Hydro-raking and Rotovation	Disturbance of sediments, often with removal of plants, to disrupt growth.	1
10. Hypolimnetic Withdrawal	Removal of oxygen-poor, nutrient-rich bottom waters.	3
11. Macrophyte Harvesting	Removal of plants by mechanical means.	2
12. Nutrient Inactivation	Chemical complexing and precipitation of undesirable dissolved substances.	3
13. Water Level Control	Flooding or drying of target areas to aid or eliminate target species.	1

Applicability: 1 = likely positive benefit; 2 = possible positive benefit; 3 = no anticipated benefit relative to management goals

Treatment and Diversion

Structural measures such as, detention and infiltration structures can reduce downstream transport of particulate material and associated phosphorus. Such structural measures can be used on a single site or used to treat runoff collected from a broader area. Treatment of runoff or tributary water using such structural measures prior to discharge into Singletary Lake provide a means of controlling loads that are not otherwise controllable by source reduction mechanisms. Diversion of phosphorus-laden runoff could eliminate significant loads, and land use planning could stem future load increases. However, this simply transfers the problem to some downstream system.

Wastewater Management

Improvements in wastewater handling would primarily affect nitrogen loads, especially in light of the detergent phosphate ban. However, the benefits of minimizing loads from septic systems through proper use and maintenance or the connection of residences to a municipal sewer treatment system are worthy of additional consideration.

Watershed Protection

A major concern with Singletary Lake is the potential degradation of the lake associated with future development. Approximately 66% of the watershed remains undeveloped. Although a portion of this land is probably undevelopable because of wetlands, conservation easements, or other land protection mechanisms, there remains a substantial potential for future development in the watershed. Unmitigated stormwater runoff from new development within the watershed may increase nutrient loading to the lake, and result in an acceleration of the eutrophication process. Watershed protection may be achieved by regulatory mechanisms (e.g., zoning and subdivision regulations) or land acquisition.

Many watershed protection mechanisms involve the formulation of guidelines, bylaws or regulations that govern land development and land use. As such there are certain social, economic, and political constraints to implementation. Town boards often operate with limited budgets and staff. This and the societal movements towards less regulation and control of personal property use, regulatory watershed management techniques are often difficult to implement. There is a growing movement towards providing incentives and voluntary programs that encourage buy-in and cooperation, rather than to implement strict rules and regulations.

While Sutton and Millbury have bylaws and subdivision regulations that govern development, there are few specific requirements or guidelines provided relative to water quality protection. Zoning lot sizes appear to be generally adequate within the watershed. The development of practical, stormwater treatment requirements or guidelines can provide an effective mechanism for guiding future development to minimize future impacts. Such guidelines can be formalized as regulations or simply implemented as a review tool by the town boards. However, such guidelines may be implemented more easily on an informal basis.

Stormwater guidelines Fugro developed for Framingham, Massachusetts are included in Appendix C. The guidelines would need to be tailored to the specific development scenarios and land use goals for Millbury and Sutton. Such guidelines could be applied only to the Singletary Lake watershed, or on a town-wide basis.

Outright land acquisition is rarely an affordable option. Other mechanisms available for protecting land from future development include land trusts, transfer of development rights (TDR), and other easements or restrictions. TDR transfers the development rights from one parcel of land to another. The seller of the rights benefits from the cash value of the development rights and a lower property assessment for tax purposes. The buyer of the rights benefits by being permitted by zoning guidelines to use these rights to increase development density on a receiving property. With careful planning, such transfers can protect a particularly sensitive resource by permitting more intensive development in the watershed of a less sensitive resource. All land or development right acquisition mechanisms should be driven by a careful assessment and identification of critical resource areas and their sensitivity to impact. In some cases, such assessments are performed as part of broader planning studies or the development of open space plans. The towns should seek out opportunities to evaluate resource protection via these mechanisms as town-wide master plans or open space plans are developed or updated. Regulatory boards may in some instances utilize easements or restrictions as part of mitigation of impacts for a given development project.

Public Education

The most important defined source of phosphorus (and nitrogen) is residential land and any associated on-site waste water disposal (septic) systems. It is advisable to start with input reduction at the sources, applying watershed techniques to minimize the pollutant loading to stream systems in the drainage area wherever possible. The kinds of source reduction activities that are needed are typically tied to Town bylaws (e.g., fertilizer use control, septic system inspection and pumping) or DPW functions (e.g., catch basin cleaning, street sweeping). Efforts should be made to promote sound environmental management throughout the watershed, but it should be recognized from the start that achieving watershed-wide management in this system presents substantial social, economic and political challenges.

There is definite value in an education program that promotes management actions. Until desirable actions can be made mandatory and enforceable, some voluntary cooperation can be expected if watershed residents understand the relationship of their actions to water quality and are provided with information on how to minimize impacts. Education programs also help to develop the level of understanding that facilitates eventual enactment of legislation or bylaws that mandate the desired management actions.

Estimated Benefits of Applicable Watershed Management Techniques

Considering a current average load to Singletary Lake of 383 kg/yr and a desired load of 293 to 302 kg/yr, a load reduction of 35 to 48% is targeted. Lesser load reductions would be sufficient during dry years, when the phosphorus loads may be as low as 330 kg/yr under existing conditions. Greater reductions may be necessary during wet years, when phosphorus loads can be as high as 530 kg/yr.

Possible phosphorus load management actions were evaluated for achievable level of reduction for the source and/or the target area to which they would be applied, and for overall reduction of load to Singletary Lake. This analysis was based solely on the portion of the phosphorus load that could be eliminated by reasonable application of management techniques. For each source or target area, the impact on the represented portion of the phosphorus budget was calculated based on assumptions regarding management effectiveness and experience with each technique elsewhere. Reduction estimates are certainly subject to variation, and effort was made to predict the range of likely reduction in each case. Some estimates were derived by running the P8 Urban Catchment Model (IEP, 1990; Walker, 1990; Palmstrom and Walker, 1990).

Estimates of the achievable phosphorus reduction associated with each defined management action are presented in Table 3. Most available management approaches fall short of the desired level of reduction on an individual basis, and would need to be applied in combination to achieve the loading reduction goal. Techniques that have the greatest individual benefits include compliance with the existing phosphate detergent ban, wastewater management, and the treatment of direct stormwater discharges to the lake.

Source Reduction Strategies

Implementation of a fertilizer-use limitation, street sweeping, and catch basin cleaning could reduce the phosphorus load by 5%-7% overall at a cost of about $16,285 per kg of phosphorus reduced.

Wastewater management strategies aimed at improved use and maintenance of existing septic systems and repair or replacement of failing systems could provide a 7 - 14% reduction in the phosphorus loads to Singletary Lake. Annual administrative costs to implement a septic system maintenance program would be on the order of $10,000 - $15,000 with individual system owner costs of about $125 per system for pumping and inspection. The cost per kg of P reduced per year would be about $916. Replacement of failing systems would add considerably to the cost of the individual system owner. Sewering of the residences located within 300 feet of the lake or its

Table 3. Estimated Load Reduction Benefit of Various Watershed Management Alternatives

Management Option	Current Source Load (kg/yr)	Source Load Reduction (%)		Load Reduction Lake (%)		Estimated Cost per kg P reduced ($)a
		Min	Max	Min	Max	
Source Reduction Strategies						
Enforce phosphate detergent ban throughout watershed (affects septic system inputs)	39	100%	100%	10%	10%	$0
Enact bylaws to limit fertilization of lawns to "demonstrated need" cases	16.2	30%	50%	1%	2%	$2,058
Sweep streets an additional once per month (on average)	40.5	30%	40%	3%	4%	$13,169
Clean all catch basins twice more per year	5.67	50%	75%	1%	1%	$1,058
Require biennial inspection/pumping of septic systems w/ repair and replacement as indicated by inspection (assumes P-detergent ban benefits realized)	91	30%	60%	7%	14%	$916
Provide sanitary sewers with discharge outside watershed (assumes P-detergent ban benefits realized)	91	100%	100%	24%	24%	$10,989
Public Education program implemented for watershed residents	16.2	5%	25%	0%	1%	$2,963
Treatment Alternatives						
Retrofit of storm drains w/ direct discharge to lake w/ leaching catch basins (or similar structural treatment system)	40.5	30%	50%	3%	5%	$2,058
Limited impoundment and enhancement of wetland system in Putnam Pond for treatment of tributary inflows	55	6%	10%	1%	1%	$7,576
Alum treatment of storm flows in primary tributary	72	80%	90%	15%	17%	$599

a Costs figured as construction/implementation cost plus operational/administrative cost over 10 years tributaries could provide a 24% reduction in phosphorus load. The cost per kg of P load reduced is $11,000 per kg for sewering, assuming a $10,000,000 10 year implementation and operation cost.

Public Education

Ideally, a program of source control should be implemented on a watershed-wide basis. This is no small undertaking, however, particularly in light of the combination of techniques necessary to achieve the target reduction, the associated cost, and the need to involve two municipalities. Before any progress is likely, it is essential to educate the public with regard to what is at stake and how the resource can be preserved through both volunteer actions and community cooperation. Environmental management of the Singletary Lake watershed should therefore include a continuing education program for all residents of the watershed.

There are many actions that each watershed resident can take to minimize inputs of phosphorus and other pollutants to Singletary Lake, but a phosphorus-centered campaign should emphasize:

- Compliance with the phosphate detergent ban recently enacted for the Commonwealth; as much as half the phosphorus in waste water is from detergents.
- Minimization of the use of phosphate fertilizer, with testing of soils prior to application; residential runoff is suspected as the largest single source of phosphorus in this system.
- Proper disposal of yard waste and other phosphorus-containing materials; keep such materials away from wetlands and drainage systems.
- Having septic systems inspected for proper operation and maintained on about a two to three year cycle; properly functioning systems discharge little phosphorus, although nitrogen levels may be high.
- Minimizing runoff from property; percolation of storm water is preferable to piping or ditched transport, and can be promoted through maintenance of pervious surfaces wherever possible.

It would be useful in the early stages of this educational effort to send out a questionnaire that allows anonymous response to questions that define current practices with regard to the above factors. After educational materials have been distributed and a suitable time period has elapsed, follow-up questionnaires could be used to determine if volunteer actions are making any difference in management practices. Concurrent monitoring of tributaries could be used to determine any change in phosphorus loading. It may take several years to evaluate and detect changes, but documentation of impacts is critical to gauging success and adjusting the program as needed. This program should provide some improvement on its own and prepare residents for additional actions at the town level that require support. Such a program could be coupled with other environmental education programs, and should include components for school-aged children as well as adult residents.

It is difficult to estimate the load reduction benefits associated with changes in watershed resident land use behavior. However, the value of an education program is probably significant when one considers benefits associated with building consensus to implement other watershed management and protection alternatives. Costs for an educational program of the type described above would be largely a function of materials preparation and distribution. A budget of about $8,000-$12,000 should allow proper implementation over a three to five year period. Existing materials can be customized for use in a specific watershed as a valid and economical approach. Additional funds may be needed in subsequent years for reprints and updates.

Stormwater Treatment

Direct Stormwater Discharge Treatment

During the 1985 Diagnostic study, 11 primary storm drains were identified that directly discharge to the lake. Based upon information provided by the Association, it is likely that there are a number of other drains that also discharge untreated stormwater runoff directly to the lake. Direct discharges to the lake account for about 25% of the total load to the lake. Therefore, treatment of these discharges has the potential to provide a measurable reduction in the total load to the lake.

There are many structural alternatives available to treat stormwater runoff. However, many require a fairly large land area to achieve the desired level of treatment. There is little, if any, available land of suitable site to provide the necessary level of treatment. Leaching catchbasins, or other subsurface leaching or detention structures can reduce the need for large land areas for treatment. Leaching catchbasins or other similar structural treatment structures may provide a 30 - 50% removal of total phosphorus.

The use of leaching structures, such as leaching catchbasins, may be limited by the suitability of site conditions (soils, depth to water table, depth to bedrock) to properly infiltrate the runoff. These are similar constraints posed for septic systems. As some portions of the watershed near the lake have poor suitability for septic systems, it is likely that some areas may not provide suitable conditions for the use of leaching systems. A detailed survey of site conditions and specific identification of storm drains for treatment was beyond the scope of this project. However, it is likely that with additional information structural treatment systems could be designed to treat about 50% of the direct watershed runoff.

Structural treatment of watershed loads associated with direct stormwater discharges could provide an 3 - 5% reduction in phosphorus loads to the to the lake. The estimated range of costs assuming $15,000 per leaching catchbasin (assuming 15 basins) and associated maintenance over a 10 year period would be about $250,000. From a cost-benefit perspective, this alternative would cost about $2000 per kg of phosphorus removed. One cost advantage to this alternative is that basin retro-fitting could be spread over a number of years to accommodate fiscal constraints.

Tributary Inflow Treatment

Where input reductions are not workable or sufficient, the logical alternatives involve mitigation of unpreventable inputs, possibly through physical detention and attendant natural processes or through chemical treatment mechanisms.

A. Physical detention and sedimentation

The Association expressed an interest in the use of upstream ponds to remove pollutants. The dam has been breached on Putnam Pond. The remaining four ponds still impound water. However, the storage capacity of these ponds is not known. For the purposes of modeling a mean depth of 4 feet was assumed.

It is likely that the open water ponds, including Welsh, Schoolhouse, Adams, and Arnold Ponds, probably provide a modest level of pollutant removal in their current states. Considering our modeling results, these ponds collectively provide about 65% removal of the total phosphorus discharged to them. The dredging of one or more of these ponds to restore or enhance detention capacity lost through sedimentation would increase pollutant attenuation, but probably not sufficiently to justify the extreme cost associated with dredging. Putnam pond currently exists as a shallow marsh system with channelized flow in some areas, and a more diffuse flow in others.

Wetland systems have been documented to provide substantial pollutant removal, including the removal of nutrients. However, removal of dissolved nutrient fractions may only be seasonal, as nutrients are likely to be released upon death and decomposition of the plants. Sediment bound nutrients, however, are more likely to be removed via physical processes (e.g., sedimentation and filtration), and are less likely to be re-introduced into the water. In its existing condition, Putnam Pond provides a modest level of pollutant removal during small to mid-sized storms (about 4% removal). Based on our visual inspection, it would appear that the water could be impounded to a depth of about 1-2 feet. The wetland community could also be enhanced, and the flows modified by the strategic placement of berms to maximize contact with wetland vegetation. Modeling results indicate that simple re-establishment of the dam to impound about 5 feet of water in Putnam Pond does not appreciably change its pollutant removal capacity. In addition to the potential for water quality improvements, enhancements of Putnam Pond could also be combined with design features to improve wildlife habitat values.

Based on modeling results, only a marginal improvement in pollutant removal from that provided by existing conditions is provided by the modification of Putnam Pond. Modification of Putnam Pond will increase the phosphorus removal efficiency from the about 4% provided by existing conditions to 6%. The limited benefits provided are largely due to the fact that a substantial portion of the readily removable phosphorus is achieved in upstream ponds. The overall benefit to the lake would be about a 1% reduction in load, at a cost of $7,500 per kg of P removed. Such activities may involve a number of regulatory hurdles because they involve activities within or alteration of jurisdictional wetlands, and involve costly design. Given the relatively small benefit provided, and the potentially difficult regulatory requirements, modification to Putnam Pond is not recommended.

B. Alum treatment of tributary inflows

An alternative to physical in-stream treatment is the use of chemical treatment alternatives. Alum (aluminum sulfate) removes dissolved and particulate phosphorus. Phosphorus is either precipitated out as aluminum phosphate or binds with aluminum hydroxide floc formed when alum is combined with water, rendering the phosphorus unavailable to algae. When applied at proper doses, alum can remove 80 - 90% of the phosphorus. Where alkalinity is low, a buffered alum product is often used in combination with or in place of alum. Alum is commonly used in the treatment of drinking water to remove particulate material. It has also been used successfully in lakes to strip phosphorus from the water column or to prevent the release of nutrients from bottom sediments. More recently, alum has been successfully used to treat tributary and stormwater flows in Ohio, Florida, the upper midwest, and New Jersey. To our knowledge this technique has not yet been used in New England.

To treat in-stream flows a system is constructed that delivers alum at a dose appropriate to the in-stream flow. Such systems may be operated continually or on a seasonal basis. The system itself consists of a secure facility to house the system elements; a 3000 - 6000 gallon tank to hold a slurry of alum; a flow metering device; and system for mechanical mixing or aeration to maximize contact with the alum.

The advantages of this technique include that it provides high removal rates (80-90%) at a reasonable cost $600 per kg of P removed; allows flexibility of operation to address changes in load associated with variations in precipitation; and has minimal toxic risk. Aluminum is toxic to fish in its ionized state at fairly low concentrations (0.05 mg/l), however that chemical species is rare when pH is maintained between 6 and 8. The disadvantages of this technique are that phosphorus is inactivated within the aquatic system rather than prevented from entering; some build up of sediment and aluminum sludge may occur in the treatment settling area; requires the long-term addition of chemicals to the system; and downstream water chemistry and aquatic life could be adversely affected by improper dosing relative to ambient water chemistry.

This strategy could reduce the total load to Singletary Lake by as much as 15-17%, with a 10 year implementation cost of about $345,000. This cost includes an initial pilot treatment program followed by the design, permitting, and construction of a permanent facility. Monitoring costs for both the pilot program and long-term implementation are also included. Given some of the disadvantages of this alternative, and the long-term maintenance and operation costs, this alternative is not recommended at this time. If desired improvements are not accomplished through other source reduction or treatment alternatives, or if in-lake problems are worsened by increased loading in the future, it may be appropriate to revisit this alternative.

In-lake Management Strategies

Of the in-lake management measures listed in Table 1, dredging, rooted plant control techniques, and nutrient inactivation have the potential to reduce phosphorus loads to the lake. Extensive dredging would eliminate phosphorus reserves that may be involved with recycling in the lake. Rooted plant control techniques such as harvesting or drawdown would limit the plant biomass that can transfer phosphorus to the water column, especially upon decomposition in the autumn. Phosphorus inactivation, practiced in the past by alum addition, has the ability to bind and precipitate a major portion of the phosphorus load within the lake at the time of treatment and to reduce later release of phosphorus from the sediments. While these techniques may provide some level of nutrient control, only phosphorus inactivation has the potential to achieve the desired level of control, and tributary treatment is perceived as a more efficient and economical approach than in-lake treatment.

Because nutrient load reduction in the watershed is viewed as the preferred mechanism to prevent algae growth, the techniques addressed here will focus on control of rooted aquatic plants, which cannot be controlled by watershed management techniques. Table 4 provides a summary of the primary control alternatives for rooted aquatic plants. For completeness, however, a brief discussion is provided at the end of this section regarding in-lake strategies aimed at the control of algae growth.

Chemical Control

The use of herbicides to control aquatic plant growth has been in practice at Singletary Lake for a considerable period of time. Most recent efforts have largely focused on the control and eradication of exotic species of plants that have invaded the lake (Eurasian and variable watermilfoils). The currently employed chemical treatment program, using 2, 4-D, has reduced the spread of the exotic species, but has not eradicated the exotic plants. The areas targeted for treatment have ranged from several acres to as much as 20+ acres. Pre and post-treatment surveys are utilized to determine the anticipated areas for treatment each year. Herbicides have not been used for the broad scale control of rooted aquatic plants in the lake.

Continuation of the selective herbicide treatment program alone or in combination with other physical or mechanical techniques or with overwinter drawdown is recommended.

Table 4. In-Lake Alternatives for Controlling Rooted Aquatic Plants in Singletary Lake

	Herbicides	Harvesting	Hydroraking	Drawdown	Selective Dry Dredging
Cost Estimate (per acre)	\$350 - \$600	\$350-650	\$1,650-2,750	generally low cost, but specific to each lake	Very expensive (lake specific cost)
Advantages	♦ selective clearing of areas desired for recreational use ♦ targeting of nuisance species ♦ effective in control and eradication of some exotic plant species	♦ plant biomass and nutrient content removed ♦ selective clearing of areas desired for recreational use ♦ no chemicals, no water use conflicts, minimal controversy	♦ plant biomass removed or cleared in water depths up to 12 feet ♦ removes roots, rhizomes, and tubers ♦ removes associated sediment (hydroraking only) ♦ effective control for 1 to 3 years ♦ selective clearing of areas desired for recreational use	♦ especially effective on plants that propagate by roots, rhizomes, or tubers that are killed by exposure to drying and freezing conditions ♦ consolidations of organic sediments ♦ flood prevention ♦ effective control for 2 to 4 years	♦ plant biomass and sediments supporting of "weed beds" are removed ♦ water depths are increased ♦ effective long-term control
Limitations	♦ plant biomass and nutrient content not removed ♦ use of herbicides may be controversial or undesirable to lake users ♦ requires continued maintenance cost	♦ cutting depth limited to 5-7 feet ♦ no removal of roots, rhizomes, or tubers ♦ usually requires 1 to 3 cuttings per season ♦ requires disposal site ♦ recurring maintenance required	♦ creates short-term increase in turbidity ♦ required disposal site ♦ requires some recurring maintenance	♦ requires outlet structure with ability to drop lake water level ♦ no control of plants in deep water ♦ potential impacts to wetlands, fish, wildlife, and water supply wells ♦ interferes with winter uses of the lake	♦ high cost and complex permitting process ♦ potential impacts to wetlands, fish, wildlife, and water supply wells ♦ requires dewatering and disposal site

Physical Control

Physical control alternatives include the use of benthic weed barriers or manual pulling. Both strategies have been recommended previously for use at Singletary Lake in combination with selective herbicide treatments to contain and control exotic species. In particular, either the use of manual pulling or benthic barriers is appropriate for small areas, and particularly in areas of new infestation that are not effectively treatable with herbicides.

Use of either of these techniques is recommended on an as needed basis to contain and control new infestations of the exotic milfoils. These techniques may also prove useful to individual homeowners to improve shoreline access in those areas impaired by localized dense rooted aquatic plant growth. These techniques are not useful for non-rooted species, such as bladderwort, that can in some instances reach nuisance densities.

Mechanical Control

Two primary techniques are available for the control of rooted aquatic vegetation by mechanical means. These techniques include harvesting and hydro-raking.

Harvesting

Mechanical harvesting is a commonly used strategy to control nuisance aquatic plant growth. Mechanical harvesting is appropriately used for control of nuisance vegetation over large areas, where plant densities are high. In the case of Singletary Lake, the total area of vegetation coverage is limited, and plant densities are generally low to moderate, except in several localized areas. In addition, the presence of two exotic plants species Eurasian and Variable watermilfoil, reduces the desirability of mechanical harvesting for Singletary Lake. Milfoil reproduces aggressively from plant fragments. Therefore, use of harvesting in Singletary Lake would require extreme care, and special measures to prevent the spread of milfoil via fragmentation.

Harvesters have evolved substantially in their design since 1980, and generally offer greater capabilities, improved handling and control, and easier repair and maintenance. The typical base purchase cost for a harvester (7 foot cutting width, 5 foot cutting depth, and 400 cubic foot capacity hold) is approximately $70,000, and may run as much as $90,000 with various accessories and options. Harvesting efficiency varies greatly depending on the vegetation density, frequency of bottom obstructions, water depth, and travel distance to shoreline off-loading areas. Operating costs are likely to range from $100 to $200 per acre per year. As an alternative to harvester purchase and operation by Town personnel, harvesting services can be contracted. The cost for contract harvesting ranges from $350 to $650 per acre.

Given the relative cost of harvesting, moderate to low plant densities (except in localized areas), and potential for the spread of milfoil, mechanical harvesting is not recommended.

Hydro-raking

Hydro-raking is a variation on the harvesting technique that focus on the removal of root tissue instead of cutting the upper portions of aquatic plants. The hydro-rake is a barge-mounted machine resembling a floating backhoe, equipped with a york rake or bucket attachment on a hydraulic arm that can work in water depths up to twelve feet. The hydro-rake is used to excavate roots and other below ground plant tissues and the sediments associated with them. Hydro-raking is best applied in early spring before the development of new shoots and floating plant biomass.

Hydro-raking is a technique that enables removal efforts to be focused on selected areas that provide the greatest improvements for habitat or recreational use of Singletary Lake. Hydro-raking may provide control for longer periods of time than harvesting because it can remove or destroy roots and other tissues below ground level. It may be feasible to implement a two or three year cycle of removal efforts using hydro-raking periodically at a series of high priority locations. However, the expense and effort associated with hydro-raking will limit the area that can be managed with this technique, and other methods are likely to be necessary to substantially alter current vegetative cover or composition.

As with harvesting, disposal of plant biomass and associated sediments removed from the lake must be considered. Given greater depth operation and greater removal of sediments, hydro-raking is a slower process than more conventional harvesting. At a cost of $1,650 to $2,500 per acre, contract hydro-raking is only suitable for the control of vegetation within small areas, such as the swimming beach or boat docks. Use of hydro-raking in public recreation areas where weed growth impairs recreational uses may be appropriate. Individual homeowners might wish to consider use of hydro-raking in selected access or beach areas. Some cost savings may be realized by coupling individual homeowner's hydro-raking with municipal contracting for hydro-raking of public access or beach areas. In such situations, a minimum number of hours that must be contracted are usually set for the collective group or for individual areas.

Overwinter Drawdown

Drawdown is a technique for controlling aquatic plants by lowering the water level during winter and exposing them to the destructive effects of freezing and desiccation. Drawdown is generally accomplished by lowering a lake to some pre-determined level through a controlled outlet. Then the water level is held at that reduced elevation from December through February, after which water levels are restored to pre-drawdown levels. This technique has been used widely throughout the country as a low-cost means of controlling susceptible vegetation (Cooke et al., 1993). Results have been variable, depending upon the species of plants involved and the ability of the drawdown to dewater and freeze the sediments.

Potential adverse impacts associated with drawdown include impacts to adjacent and upgradient contiguous wetlands, shallow wells, recreational uses, non-target species, fisheries, and downstream resources. An analysis of the feasibility of overwinter drawdown for Singletary Lake is provided in Appendix D. The drawdown impact analysis examines the necessary level of drawdown and its potential effects on adjacent wetlands, non-target species, fisheries, and downstream resources.

Drawdown is only feasible if the outlet structure allows the water level to be manipulated below the normal water elevation. The current structure at Singletary Lake appears to have the capacity to reduce water levels by at least 5 feet, and perhaps by as much as 10 - 15 feet. The down gradient channel would appear to permit dewatering to a depth of 15-20 feet, with appropriate modifications to the outlet structure as necessary.

Tape grass was the dominant species, with moderate densities of Chara, Nitella, and Elodea, according to the vegetation survey completed by the State in 1985, and more recent visual inspections. The spread of Eurasian Watermilfoil and the recent introduction of a second nuisance exotic species Variable Watermilfoil (Myriophyllum heterophyllum) has been noted in recent years. In general, macrophyte growth in the lake is largely concentrated in coves and embayments, and probably limited to a depth of about 10 - 15 feet. Except for the nuisance exotic species the density and coverage of other aquatic plants do not severely impair recreational water uses of the lake. Therefore, rather than broad control of all macrophytes, the goal of drawdown in this case would be the control or eradication of the Eurasian and Variable Watermilfoils.

The nuisance exotic plant species observed in Singletary Lake (Eurasian watermilfoil and Variable watermilfoil) are susceptible to control by overwinter drawdown. Eradication or substantial reductions in the density and distribution of these nuisance species through drawdown would require exposing all areas currently colonized by these species to the effects of drawdown. Considering recent treatment reports completed by Aquatic Control Technology, it appears that the milfoil is largely contained within the 5 - 10 foot water depths. Other drawdown-susceptible plant species documented in Singletary Lake include bladderwort (*Utricularia* sp.) and waterweed (*Elodea canadensis*). Tapegrass (*Vallisneria*), and Chara, both previously documented in the lake, are generally resistant to drawdown, as are many of the common pondweeds (*Potamogeton* sp.) found in many New England lakes. Other more drawdown-tolerant species would be expected to colonize these areas over time. Some replacement species could produce nuisance conditions, but many are known to grow at lower densities and closer to the bottom.

Vegetation exposed by the drawdown will be dried and frozen, resulting in too little biomass to warrant any removal operation. Exposure of older organic deposits should cause sediments to shrink and compact. Drawdown is therefore a very attractive technique for the potential control of rooted aquatic plant growths in Singletary Lake.

To expose most of the colonized areas, a 10 to 15 foot drawdown would be necessary. However, members of the Association have reportedly observed milfoil at depths greater than 10-15 feet. This would expose approximately 119-153 acres of the lake bottom, and require the downstream discharge of about 3000-4000 acre-feet of water. Lesser drawdowns could provide control within the exposed areas. A 5-foot drawdown would expose about 75 acres of lake bottom, and would require the discharge of about 1770 acre-feet of water to achieve the desired drawdown water level. A 5-foot drawdown would likely expose a large portion, but not all of the areas currently infested with milfoil.

The primary disadvantage to drawdown at Singletary Lake is related to the shape of the lake basin, and the dramatic drawdown that would be required to expose areas currently colonized by vegetation. A large volume of water would need to be discharged within a fairly short time frame (ideally <2 months). This is compounded by the relatively small size of the watershed area, and hence runoff available for refill during the spring.

Assuming a 20 cfs discharge rate and average inflow rates, the time required to dewater to the desired elevation would be on the order of 84 - 186 days depending on the depth of drawdown. Under this scenario it would be difficult if not impossible to achieve a drawdown of 10-15 feet prior to ice cover on the lake. Under average inflow conditions, even a 5-foot drawdown would require about 84 days to accomplish dewatering. This would require beginning the dewatering process in September, to achieve the desired water level by the end of November under average conditions. Were conditions to be wetter than normal, dewatering to the desired water elevation would not be possible within a reasonable time frame. By increasing the rate of discharge, dewatering times could be reduced. The discharge rate of 20 cfs was selected based upon the maximum discharge recorded during the 1984-85 study of 17 cfs. Discharge rates measured during that study ranged from 0.09-17.0 cfs. If the outlet structure and downgradient channel permit, a discharge rate of 40 cfs would bring the dewatering time for a 10-foot drawdown into a reasonable range (about 70 days), and would permit a 5-foot drawdown to be achieved within about 45 days.

Refilling the lake from a 5-15 foot drawdown would require 86-190 days under average inflow conditions during the spring. If conditions were extremely dry, refill could take as long as 909 - 2010 days to restore water levels to pre-drawdown levels. The time required to refill, even under normal conditions, precludes the use of a 10-15 foot drawdown. Under average conditions, about 86 days would be required to refill the lake from a 5-foot drawdown. It is desirable to achieve complete refill prior to the spring spawning periods of resident fish species. This typically requires that water levels be restored by mid-April to avoid impacts to fisheries. Initiating the refill of the lake on February 1 would just meet the mid-April refill. Under extremely dry conditions, the refill time could be as long as 909 days.

Apart from the constraints posed by hydrologic conditions, no significant adverse environmental impacts are anticipate with a limited 5-foot drawdown (Appendix D). While most shoreline residences have deep bedrock or artesian wells, there are a number of residences that rely on shallow dug wells around the lake shoreline. Depending upon the depth of these wells and their proximity to the lake, even a limited drawdown may reduce water levels in the wells. Residents relying on shallow wells should be notified of the intention to drawdown, and the drawdown aborted if the drawdown results in the drying out of wells. Historically drawdowns of about 3 - 5 feet have been practiced at the lake for shoreline maintenance, and to our knowledge wells have not been adversely impacted.

Given the potential for adverse environmental impacts, a number of permits and approvals is required to implement overwinter drawdown. These may include, but are not limited, to Notice of Intent (Millbury and Sutton), Environmental Notification Form (ENF), Water Quality Certification (Section 401), and notification of the Division of Fisheries. A full Environmental Impact Report has been required by MEPA in response to some ENF's filed for overwinter drawdown. It should be noted that permitting costs may be high relative to the benefit gained from a limited drawdown.

A 5-foot drawdown is the maximum drawdown that is achievable to ensure a timely refill of the lake. With monitoring of conditions during drawdowns of successive depths, it may be possible to go beyond this 5-foot limit. Deeper drawdowns would require strict adherence to dewatering and refill schedules, and a willingness to abort the drawdown during years with below normal precipitation during the winter. During wet years, it may be necessary to abort drawdown due to the extended amount of time required to dewater the lake to the desired level. A program of successively greater drawdown over several years, beginning at 5 feet and incorporating monitoring and evaluation of potential impacts, is recommended. Because repetitive annual drawdowns can promote the colonization of drawdown resistant plant species, a staggered drawdown is recommended. After 3 consecutive years of drawdown, overwinter drawdowns should be staggered once over two to three years. During years when overwinter drawdown is not scheduled, the water levels may be temporarily reduced to facilitate shoreline maintenance without adverse impacts.

Selective Dredging

The most costly and complicated technique for controlling rooted aquatic vegetation is to excavate the sediments where plants grow in the lake basin. Dredging rejuvenates a lake ecosystem by removing sediments that have accumulated in the basin during the "aging" of the lake. To effectuate plant control by dredging it is necessary to dredge to a final depth sufficient to impose light limitation on the plants (typically greater than 10 feet), or until a substrate less hospitable to plant growth is encountered.

Dredging can be accomplished by one of two general techniques; dry dredging and hydraulic dredging. Dry dredging involves fully or partially draining the lake to allow conventional heavy track equipment to remove sediments and, therefore, would be planned in conjunction with a drawdown of Singletary Lake. The advantage of dry dredging is that selective areas can be deepened within the area of exposed sediment, and sediment containment and disposal are generally less complicated.

Hydraulic dredging, implemented previously in the northern basin of the lake, involves removal of sediments as a liquid slurry (typically only 10 - 30 percent solids) using a hydraulic dredge. The sediment-water slurry is then pumped to a containment area constructed on an adjacent upland area for dewatering. Hydraulic dredging is always costly and is often severely constrained by the availability of land for the construction of a containment area.

Water depths in Singletary Lake do not currently preclude or severely impair recreational water uses. Sediment accumulation and the associated loss of volume have been limited in Singletary Lake, except for the northern and southern cove areas. Sediment accumulations in these areas range from less than 0.5 feet to greater than 6 feet in these coves.

Although deepening the shallower parts of Singletary Lake holds some attraction, the technical and regulatory constraints presented by a major dredging do not favor such action. Certainly it is desirable to minimize the future input of sediment to the lake, and it may be necessary to clear channels to reduce flood hazards. However, no larger scale goals for sediment removal appear appropriate at this time.

Algae Control Options

The reduction of nutrient loads from the watershed is anticipated to reduce the severity and frequency of algal blooms. However, the need for control of algal growth on a periodic basis may be necessary, particularly during wet years. Of the thirteen in-lake management alternatives identified in Table 1, only eight have potential application for the control of algal growths. Applicable techniques include biocidal chemical treatment (e.g., algicides; copper sulfate), biomanipulation, dilution or flushing, dredging, dye addition, hypolimnetic withdrawal, and nutrient inactivation. Aeration/destratification can also in some instances reduce algae biomass. However the results tend to be less dependable.

Of the available techniques, dilution, flushing, and dyes are not suitable or beneficial given Singletary Lake's rapid flushing rate. Hypolimnetic withdrawal is not currently possible without the installation of a low level outlet structure. In addition, hypolimnetic withdrawal and nutrient inactivation (with alum) are both aimed at internal nutrient loads, which at Singletary Lake are small relative to external inputs.

Biomanipulation, while potentially effective, has less of a proven track record than other techniques, but may warrant further investigation in the future. Alteration of biological components of an aquatic system can often yield desired conditions on at least a temporary basis, but it is not a complete substitute for control of pollutant inputs.

The use of algicides (e.g., copper sulfate), on an as needed basis, represents the most cost effective technique for controlling algae in Singletary Lake. However, because copper has a tendency to accumulate within the system and is toxic to most organisms, minimization of treatment to the greatest extent possible is recommended. Copper compounds should be used cautiously and with the intent of preventing bloom formation instead of terminating an already present bloom. Proper implementation of this approach to algae control in Singletary Lake would involve biweekly monitoring in the lake for algal composition and abundance. Treatment should be triggered by increasing concentrations of potential bloom species.

Long-Term Monitoring Program

A long-term monitoring program is essential to track the success or limitations of watershed and in-lake management efforts. Lake and watershed management plans are not static documents, but rather evolving ones. Monitoring provides a mechanism to guide the management plan based on observed results. Basic water chemistry and nutrient concentrations should be monitored at one in-lake station on an annual basis during the summer. More frequent sampling (e.g., monthly during the summer) will provide a more complete data set for tracking changes. A single sample may capture an extreme or temporary condition that is not representative of typical conditions. The volunteer monitoring efforts provide an adequate basis for this monitoring program. The Association may wish to conduct more intensive monitoring on a periodic basis (e.g., once every three to five years). Such intensive sampling would involve sampling on multiple occasions at multiple locations (including tributaries) to augment a more limited monitoring program that is implemented on an annual basis. Measurements of water transparency using a secchi disk provide an extremely low cost mean to supplement chemical monitoring programs. Secchi disk measurements could be taken and recorded by Association members on a weekly basis during the summer.

With the implementation of overwinter drawdown, visual monitoring of lake conditions and close monitoring of precipitation against historic norms for the area will be necessary. In addition, annual vegetation surveys are recommended to guide drawdown as well as herbicide treatments. Regular secchi disk measurements conducted by Association volunteers will provide an indication of declining conditions that may warrant an algicide treatment. The need for algacide treatments should be confirmed by a microscopic examination of a sample for algae (including both identification and enumeration). Algicide treatments will be most effective if the treatment is performed before a bloom condition exists.

An annual budget of $1000 for routine monitoring, and $2000 for expanded monitoring every 3 to 5 years is reasonable for the implementation of a monitoring program that relies primarily on Association volunteers for sampling.

Recommended Management Program

Summary of Recommended Management Actions

Recommended management actions and objectives are summarized in Table 5. The anticipate quantitative benefit in terms of load reduction and estimated implementation costs are provided in Table 6. If all recommended actions are implemented the maximum likely load reduction associated with watershed management activities is about 30%. The anticipated range of load reduction is 21 - 30 percent of existing loads. While this falls short of the desired 35% minimum reduction, it is likely to be sufficient to provide an observable improvement in lake conditions. Additional actions, to achieve a greater reduction, were not deemed economically feasible, but could be added to the program if funding was available.

Implementation Schedule

An implementation schedule is provided in Figure 3. A five year program is envisioned, with public education occurring throughout the period. Algicide treatments would be used only as needed throughout the period. It is important to note that some recommendations require further more detailed data collection and design prior to implementation. The recommended schedule may be best used to examine the time scale for implementation relative to other elements of the management program. Available funding may be the greatest dictator of actual schedule.

Over the five year period, it may be necessary to refine the management program as new information becomes available, or as indicated by monitoring program results. At a minimum the management plan should be reviewed and revised as needed on five year intervals.

Potential Supplemental Funding Sources

There are currently two funding sources in Massachusetts applicable to the types of implementation actions recommended at Singletary Lake. These include the federally funded EPA 319 Nonpoint Source Program administered through the DEP, and a state funded Lake Management and Restoration Program administered by the Department of Environmental Management. Both programs operate on a 50 percent local match basis, typically providing small grants ($10,000 - $30,000) for qualifying projects. Funds are awarded on a competitive proposal basis, and proposals are typically requested only once per year.

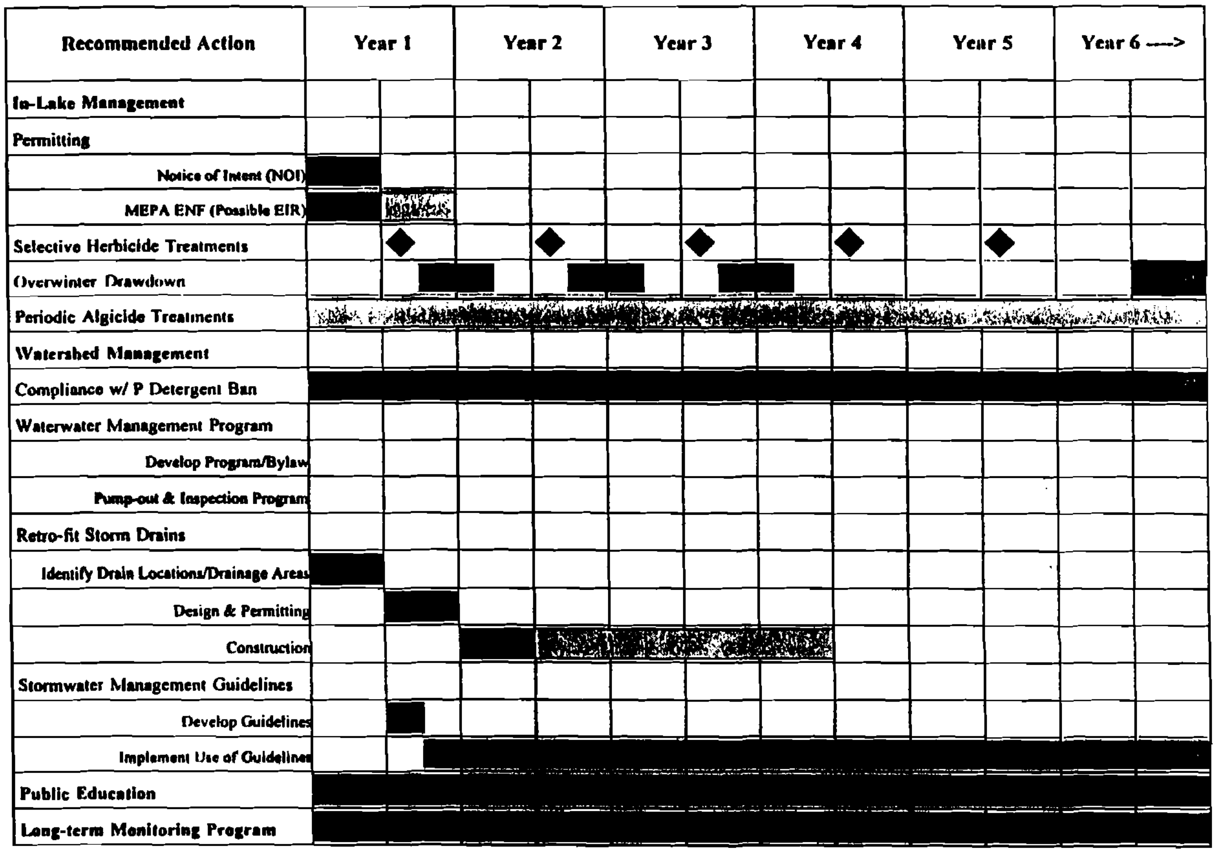
Table 5. Recommended Management Actions and Objectives

Recommended Action	Action Objective
Watershed Management Actions	
Compliance with Phosphate Detergent Ban	Reduce nutrient loads from Septic Systems
Implement a Wastewater Management Program	Reduce nutrient loads from Septic Systems
Retro-fit of Existing Storm Drains	Reduce nutrient and sediment loads associated with stormwater discharges
Develop Stormwater Management Guidelines	Minimize increases in loading associated with future development within the watershed
Public Education	Educate and inform watershed residents to minimize impacts to lake through modification of individual behavior and land use management; to build consensus for support of lake protection and management actions
In-Lake Management Actions	
Overwinter Drawdown	To provide a low cost means of controlling nuisance exotic plants and reduce the dependence on chemical alternatives for control
Selective Herbicide Treatments	To control nuisance exotic plant infestations
Periodic Algicide Treatments	To control periodic nuisance algae blooms
Long-Term Monitoring	To track the benefits of lake and watershed management activities; to guide lake and watershed management activities

Table 6. Recommended Management Options and Associated Implementation Costs

Management Option	Load Reduction Lake (%)	Cumulative Lake Load Reduction (%)	Implementation Cost ($k)	Annual Operation Cost ($k)
Watershed Management Actions				
Compliance w/ phosphate detergent ban	10	10	$0	$0
Wastewater management program	7-14	17-24	$10k	$28k
Retrofit of storm drains	3-5	20-29	$225-250k	$1k
Develop stormwater management guidelines to minimize loading from future development	***	***	$10-20k	$1
Public Education Program	1	21-30	$12k	$0
In-lake Management Actions				
Overwinter Drawdown	***	***	$5-25k	$0.5k
Herbicide Treatments (assuming annual treatments of 10 acres)	***	***	$0	$6k
Periodic Algicide Treatments (assuming 2 treatment in 5 years)	***	***	$0	$1.6k
Long-Term Monitoring Program	***	***	$0	$1.2k
Overall Program Totals		21-30%	$262-$317k	$39.3

Figure 3. Recommended Lake and Watershed Management Implementation Schedule



Both programs are highly competitive due to the large number of qualifying projects and limited funds available. Both funding programs emphasize action oriented projects (i.e., implementation instead of studies). Typically funds are not granted for securing environmental permits. The Singletary Lake project should be in a good position relative to the nature of projects sought under both programs. The education program could also be considered for funding under either program, but it is unlikely that hydro-raking, drawdown or algicide treatment would be eligible for funding. Watershed protection or management actions are given priority over in-lake approaches at this time.

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Appendix A
Summary of Historic Water Quality Data

Table B1. Summary of Singletary Lake Water Quality in 1984-85 (as average concentrations)

Parameter	Stations										
	1A	1B	1C	2	3	4	5	6	7	8	9
pH (s.u.)	6.2	5.8	5.8	5.8	5.5	6.4	6.1	6.1	5.4	5.4	5.8
Conductivity (µmhos/cm)	78	78	83	72	56	93	206	143	85	58	94
Alkalinity	14	9	9	11	7	10	15	20	13	6	11
Suspended Solids	4.3	1.5	4.5	4.5	6.2	3.9	4.4	6.8	4.1	17.6	3.1
Total Solids	85	52	54	59	62	64	153	124	54	121	66
Kjeldahl Nitrogen	0.67	0.68	0.69	0.79	0.69	0.70	0.96	0.76	0.88	0.69	0.58
Ammonia Nitrogen	0.05	0.06	0.09	0.06	0.03	0.06	0.06	0.14	0.10	0.05	0.15
Nitrate Nitrogen	0.04	0.08	0.28	0.06	0.14	0.10	0.15	0.64	0.12	0.13	2.1
Total Hardness	18	17	18	19	14	21	48	33	11	12	19
Chloride	10	10	10	8	2	14	37	32	4	2	7
Total Phosphorus	0.06	0.06	0.07	0.05	0.05	0.06	0.06	0.07	0.06	0.14	0.12
Total Coliform (#/100 ml)	24	—	—	152	362	692	520	1578	5487	381	310
Fecal Coliform? (#/100ml)	8	—	—	8	32	39	88	602	514	26	8

Note: All concentrations are mg/l unless indicated otherwise.

Table 2

Lake Singletary Water Quality Data Trends

By:	<—— MDWPC		——>	IEP	ACT	ACT	<—— LSWA/WWP		——>	ACT
Date:	1984/5			10/89	8/91	5/93	4/94-10/94			5/94
	low	high	ave				low	high	ave	
Secchi(m):	2.0	5.6	3.1	-	3.7	-	2.6	4.8	3.4	-
DO(mg/L):										
top	7.4	15.2	10.2	-	10.1	-	-	-	-	9.2
mid	6.8	13.3	9.7	-	9.8	-	-	-	-	9.2
bot	0.3	12.0	6.1	-	0.3	-	0.5	10.4	5.9	5.2
Temp(C):										
top	0.7	25.3	15.5	-	23.0	-	11.1	25.2	17.5	17.0
mid	1.6	24.0	14.8	-	22.1	-	-	-	-	15.5
bot	2.3	20.0	12.8	-	12.3	-	6.5	13.7	10.7	13.0
pH:										
top	5.1	7.5	6.2	7.2	6.7	6.99	-	-	-	6.81
mid	5.1	6.5	5.8	-	6.6	6.45	6.67	6.90	6.78	6.64
bot	4.7	6.9	5.8	6.6	6.5	6.39	-	-	-	6.40
Alk (mg/L):										
top	5	51	14	34	14	15	-	-	-	9.0
mid	8	10	9	-	14	14	7.5	16.3	9.7	9.0
bot	6	15	9	34	40	57	-	-	-	7.9
P (mg/L):										
top	0.01	0.17	0.06	<0.01	0.05	0.12	-	-	-	0.08
mid	0.03	0.16	0.06	-	0.19	0.03	-	-	0.008	0.23
bot	0.02	0.22	0.07	<0.01	0.09	0.13	-	-	-	0.09

Table 3

SINGLETARY POND

CHLOROPHYLL-A CONCENTRATIONS

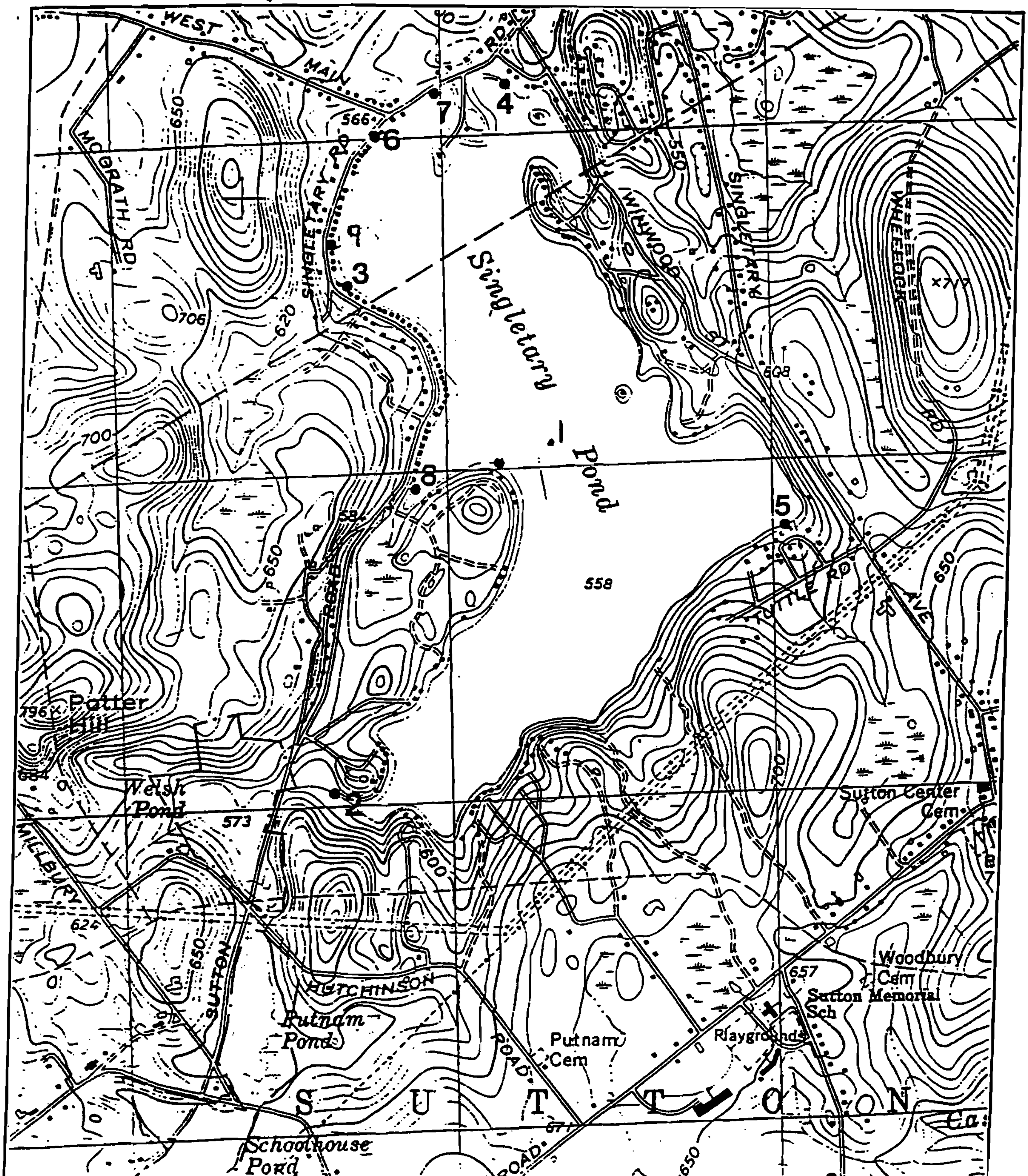
STATION 1

DATE	CONCENTRATION (mg/m^3)
11/06/84	5.06
12/12/84	3.6
1/24/85	4.8
2/26/85	-
3/19/85	-
4/02/85	6.9
4/16/85	4.4
4/29/85	5.5
5/13/85	3.9
5/29/85	3.7
6/11/85	1.3
6/24/85	9.2
7/09/85	4.1
7/22/85	3.8
8/06/85	4.3
8/21/85	16.3
9/03/85	2.1
10/09/85	11.04

Table 4

List of Sampling Stations

Station Number	Description
1	Mid-Lake Top
2	Main Inlet
3	NW Inlet
4	Outlet
5	SE Inlet
6	Storm Drain
7	Storm Drain
8	Wetland Inlet
9	Storm Drain
10	Welsh Pond



SCALE: 1"=1350' +/-

SAMPLING STATION LOCATIONS

MILLBURY & SUTTON, MASS

SINGLETARY LAKE FEASIBILITY STUDY

SINGLETARY LAKE ASSOCIATION

MARCH 1990 JOB No. SING-1

IEP inc.

Table 5

Lake Singletary Water Analysis Data—LSWA/MassWWP

SAMPLE DATA	APR 94	MAY 94	JUN 94	JUL 94	AUG 94	SEP 94	OCT 94	AVE
DATE	4/30/94	6/04/94	6/26/94	7/20/94	8/28/94	10/01/94	11/4/94	
TIME	10:30	10:30	10:30	16:30	9:30	11:15	10:30	
SECCHI DEPTH (M)	2.60	3.05	4.25	4.80	3.00	3.00	3.25	3.42
3 X SECCHI (M)	7.80	9.15	12.75	14.40	9.00	9.00	9.75	
* 3 X SECCHI > BOTTOM			*	*			*	
SURF TEMP (°C)	11.1	15.8	20.2	25.2	20.8	15.5	13.9	17.5
BOTTOM DEPTH (M)	9.25	9.45	10.0	12.4	10.3	9.8	8.2	
BOTTOM TEMP (°C)	6.5	11.2	12.0	10.4	10.6	13.7	NO SAMP	10.7
SAMPLE DEPTH (M)	8.8	9.05	9.6	12.0	9.0	NO SAMP	7.8	
SAMPLE TEMP (°C)	6.5	11.8	19.8(?)	11.8	LOST	NO SAMP	13.3	10.9
DO #1	10.3	4.44	4.84	1.64	4.92	NO SAMP	9.24	
DO #2	10.4	4.24	5.88	0.52	LOST	NO SAMP	9.04	
AVE	10.4	4.34	5.36	1.08	4.92		9.14	5.9
INTEGRATED SAMPLE DATA								
DEPTH: SURFACE TO (M)	7.8	9.15	9(?)	10(?)	9.0	9.0	7.0	
TEMP (°C)	12.3	??	19.7	23.4	10.6(?)	14.5	13.1	16.6
pH	6.67	6.54	6.82	6.87	6.68	6.90	6.87	
DUPLICATE	NO DUP	6.46	6.76	6.87	6.66	6.90	6.92	
AVE	6.67	6.50	6.79	6.87	6.67	6.90	6.90	6.78
		pH LOW?					pH LOW?	
ALKALINITY	7.5	7.6	10.1	10.2	16.3	7.7	8.9	
DUPLICATE	NO DUP	7.8	9.6	10.1	16.3	7.8	8.3	
AVE	7.5	7.7	9.9	10.2	16.3	7.8	8.6	9.7

QC DATA	APR 94	MAY 94	JUN 94	JUL 94	AUG 94	SEP 94	OCT 94
	4/30/94	6/4/94	6/26/94	7/20/94	8/28/94	10/01/94	11/4/94
DO	7.12	7.68	5.84	8.16	9.36	NO SAMP	9.28
REPLICATE	7.00	7.72	6.00	8.20	9.60	NO SAMP	9.24
AVE	7.06	7.70	5.92	8.18	9.48		9.26
TARGET	7.24	7.59	6.04	8.40	9.88		
DIFFERENCE	-0.18	0.11	-0.12	-0.22	-0.40		
LOWER LIMIT	6.52	6.83	5.44	7.56	8.89		
UPPER LIMIT	7.96	8.35	6.64	9.24	10.87		
STATUS	OK	OK	OK	OK	OK		
pH	7.42	6.58	7.24	7.44	7.29	7.40	7.06
REPLICATE	7.40	6.61	7.34	7.41	7.32	7.42	7.17
AVE	7.41	6.60	7.29	7.43	7.31	7.41	7.12
TARGET	7.34	7.08	7.38	7.52	7.50		
DIFFERENCE	0.07	-0.48	-0.09	-0.09	-0.20		
LOWER LIMIT	7.04	6.78	7.08	7.32	7.20		
UPPER LIMIT	7.64	7.38	7.68	7.82	7.80		
STATUS	OK	LOW	OK	OK	OK		
ALKALINITY	8.8	3.8	7.5	9.9	12.2	8.6	11.6
REPLICATE	8.4	3.9	7.7	10.1	11.8	8.4	11.4
AVE	8.6	3.9	7.6	10.0	12.0	8.5	11.5
TARGET	9.13	4.1	8.45	10.5	12.35		
DIFFERENCE	-0.53	-0.25	-0.85	-0.50	-0.35		
LOWER LIMIT	6.13	1.1	5.45	7.5	9.35		
UPPER LIMIT	12.13	7.1	11.45	13.5	15.35		
STATUS	OK	OK	OK	OK	OK		

Appendix B
Trophic State Modeling

CNET LAKE AND RESERVOIR MODEL

Corps of Engineer Reservoir Model Network - P Limited Systems
CNET.WK1 VERSION 1.0 (FOR SEGMENTED OR MULTI-SCENARIO MASS BALANCE)

PROBLEM TITLE ————>		Singletary Lake						
SEGMENT LABELS————>		Whole Lake	Normal	Buildout	Pristine	Dry	Wet	
SEGMENT NUMBERS ———>		999	1	2	3	4	5	

MODEL INPUT TABLES

					SEGMENTS		
VARIABLE	**UNITS**	**999**	**1**	**2**	**3**	**4**	**5**
Segmented Model (1 = yes; 0 = no)	0						
Watershed Characteristics (User defined)							
Total Drainage Area	km2	9.36	9.36	9.36	9.36	9.36	9.36
Ungauged Drainage Area	km2	3.75	9.36	9.36	9.36	9.36	9.36
Ground Water Total P Conc.	ppb	10	0	0	0	0	0
Ground Water Ortho P Conc.	ppb	10	0	0	0	0	0
Segment/Reservoir Characteristics (User defined)							
Surface Area	km2	1.34	1.34	1.34	1.34	1.34	1.34
Mean Depth	m	7.6	7.6	7.6	7.6	7.6	7.6
Observed Phosphorus - Mean	ppb	47	47				
Observed Chl-a - Mean	ppb	5.8	5.8				
Observed Secchi - Mean	meters	3.34	3.34				
Non-Algal Turbidity (Calculated)	1/m	0.15	0.15	0.15	0.15	0.15	0.15
Global Parameters (User defined - Applicable to all segments)							
Precipitation	m/yr	1.21	1.21	1.21	1.21	1.21	1.21
Evaporation	m/yr	0.66	0.66	0.66	0.66	0.66	0.66
Infiltration	m/yr	0.4	0.4	0.63	0.63	0.63	0.63
Unit Runoff	m/yr	0.147	0.203	0.147	0.147	0.147	0.147
Atmospheric P Load	kg/km2-yr	30	30	30	30	30	30
Atmospheric Ortho P Load	kg/km2-yr	15	15	15	15	15	15

Land Use Export Coefficient P Load (User Defined)
Percent of Ungauged Drainage Area

		Whole Lake	**Normal**	**Buildout**	**Pristine**	**Dry**	**Wet**
Export Coeff.(kg/km2/yr)	**Landuse**	**999**	**1**	**2**	**3**	**4**	**4**
70	**Residential**	**26.0%**	15.5%	66.0%	0.0%	**15.5%**	**15.5%**
10	Forest/Open	59.6%	66.8%	19.0%	100.0%	66.8%	66.8%
100	Ag-Crop	0.0%	2.8%	0.0%	0.0%	2.8%	2.8%
80	Ag-Pasture	0.0%	1.4%	0.0%	0.0%	1.4%	1.4%
75	Urban	0.0%	0.0%	15.0%	0.0%	0.0%	0.0%
30	Pasture-Ungrazed	14.4%	13.5%	0.0%	0.0%	13.5%	13.5%
***	Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
0.7	Septic (cap.-yr)	248.2	248.2	372.3	0.0	248.2	248.2
	Upgradient Removal Factor	0.0	20.0%	20%	25%	25%	15%
	Soil Retention Factor (Septic)	0.25	0.25	0.25	0.25	0.25	0.25

CNET LAKE AND RESERVOIR MODEL

Individual Point or Tributary Source Data (User defined)

Point Source/Tributary	Flow hm3/yr	Total P ppb	Ortho P ppb	To Segment	Calc. Total P kg/yr	Calc. Ortho P kg/yr
Primary Tributary (Subbasin 3)	1.35	54	10	999	72.50	13.50
				1	0.00	0.00
				1	0.00	0.00
				2	0.00	0.00
				3	0.00	0.00
				1	0.00	0.00
				1	0.00	0.00
				999	0.00	0.00
				999	0.00	0.00
				999	0.00	0.00
				999	0.00	0.00
				999	0.00	0.00
				999	0.00	0.00
				999	0.00	0.00

Point Source/Tributary Characteristics (Calculated - no user input)

Flow	hm3/yr	1.35	0.00	0.00	0.00	0.00	0.00
Total P Conc	ppb	54	0	0	0	0	0
Ortho P Conc	ppb	10	0	0	0	0	0

Model Parameters

BATHTUB Total P Model Number	(1-8)	7	7	7	7	7	7
BATHTUB Total P Model Name		SETTLING	SETTLING	SETTLING	SETTLING	SETTLING	SETTLING
BATHTUB Chl-a Model Number	(2,4,5)	2	2	2	2	2	2
BATHTUB Chl-a Model Name		P L Q	P L Q	P L Q	P L Q	P L Q	P L Q
Beta = 1/S vs. C Slope	m2/mg	0.025	0.025	0.025	0.025	0.025	0.025
P Decay Calibration		1.34	1.33	1.33	1.33	1.33	1.33
Chlorophyll-a Calibration		0.287	0.287	0.287	0.287	0.287	0.287
Chla Temporal Coef. of Var.		0.62	0.62	0.62	0.62	0.62	0.62
Chla Nuisance Criterion	ppb	7.23	7.23	7.23	7.23	7.23	7.23

CNET LAKE AND RESERVOIR MODEL

MODEL OUTPUT FOR ——> Singletary Lake

VARIABLE	UNITS	SEGMENTS 999	1	2	3	4	5
Water Balance							
Direct Precipitation	hm3/yr	1.62	1.62	1.62	1.62	1.62	1.62
Ungauged	hm3/yr	0.55	1.90	1.38	1.38	1.38	1.38
Groundwater	hm3/yr	3.74	3.74	5.90	5.90	5.90	5.90
Point/Tributary Flow	hm3/yr	1.35	0.00	0.00	0.00	0.00	0.00
Upstream Segment	hm3/yr	0.00	0.00	0.00	0.00	0.00	0.00
Total Inflow	hm3/yr	7.26	7.26	8.89	8.89	8.89	8.89
Evaporation	hm3/yr	0.88	0.88	0.88	0.88	0.88	0.88
Outflow	hm3/yr	6.38	6.38	8.01	8.01	8.01	8.01
Available P Balance							
Precipitation Load	kg/yr	40	40	40	40	40	40
Ungauged Load	kg/yr	234	321	640	70	272	461
Groundwater	kg/yr	15	0	0	0	0	0
Point/Tributary Load	kg/yr	72	0	0	0	0	0
Upstream Segment	kg/yr	0	0	0	0	0	0
Internal Load	kg/yr	22	22	39	6	18	29
Total Load	kg/yr	383	383	719	117	330	530
Sedimentation	kg/yr	84	83	130	21	60	96
Outflow	kg/yr	299	300	588	95	270	433
Prediction Summary							
P Retention Coefficient	--	0.219	0.218	0.182	0.182	0.182	0.182
Mean Phosphorus	ppb	47	47	73	12	34	54
Mean Chlorophyll-a	ppb	5.8	5.8	7.8	1.4	4.4	6.4
Algal Nuisance Frequency	%	25	25	43	0	13	31
Mean Secchi Depth	meters	3.3	3.3	2.9	5.3	3.8	3.2
Carlson TSI P	--	60	60	66	40	55	62
Carlson TSI Chl-a	--	48	48	51	34	45	49
Carlson TSI Secchi	--	43	43	45	36	41	43
Critical Load (TP=20mg/m3)	kg/yr	288	288	288	288	288	288
Permissible Load (TP=10mg/m3)	kg/yr	144	144	144	144	144	144
Observed/Predicted Ratios							
Phosphorus - Mean		1.00	1.00	0.00	0.00	0.00	0.00
Chlorophyll-a - Mean		1.00	1.00	0.00	0.00	0.00	0.00
Secchi - Mean		1.00	1.00	0.00	0.00	0.00	0.00
Observed/Predicted T-Statistics							
Phosphorus - Mean		0.00	0.00	#NUM!	#NUM!	#NUM!	#NUM!
Chlorophyll-a - Mean		0.00	0.00	#NUM!	#NUM!	#NUM!	#NUM!
Secchi - Mean		0.00	0.00	#NUM!	#NUM!	#NUM!	#NUM!

Appendix C
Sample Stormwater Management Guidelines

STORMWATER MANAGEMENT GUIDELINES
FRAMINGHAM, MA

Overview

Development of land and the associated increase in impervious areas results in the increase of surface runoff and pollutant loads from the site. This runoff, often termed stormwater runoff or urban runoff, may if unmitigated result in flooding, damage of structures, and degradation of water and wetland resources. Nationally, nonpoint source pollution, including stormwater account for 76 and 65 percent of the degradation of lakes and rivers, respectively (EPA, 1989). A nationwide assessment of stormwater quality, referred to as the Nationwide Urban Runoff Program (NURP), was completed in 1983 documenting the presence of various pollutants in urban runoff (Athayde, 1983). There is also a growing recognition that in large part, the control of stormwater runoff and mitigation of its potential impacts falls in the hands of local regulatory bodies. However, local agencies and boards often have not had the resources or mechanisms in place to address all aspects of stormwater issues.

Design or performance specifications in zoning bylaws or subdivision regulations historically provided the regulatory mechanism for stormwater runoff control from developed sites. Traditionally, these regulations ensured proper site drainage, and flood control for downstream areas. These regulations primarily restricted peak flow velocities, and in some instance peak volumes, and are generically referred to as quantity control.

The regulatory and reviewing boards and departments within the Town of Framingham have recognized the need for comprehensive management of stormwater within the Town. To this end, Fugro-McClelland (East), Inc. was contracted to develop stormwater management guidelines for the town, which then could be incorporated into local regulations or bylaws by the Town personnel. Given the current level of development in some portions of the Town, many instances of inadequately mitigated stormwater runoff from historic development and roadways exist. However, the primary focus of this document is on stormwater guidance for new development.

The goals of any stormwater management program include:

1) Ensure adequate treatment is provided;
2) Ensure site practices which aim to minimize the generation of pollutants or transport of pollutants in stormwater; and
3) Ensure proper maintenance and use over the long-term.

As mentioned previously, the control of runoff velocity and/or volume has been a traditional requirement for development projects. Treatment to achieve water quality objectives is less common. The following section provides a brief summary of some of the alternative approaches to achieve water quality mitigation in stormwater runoff.

Alternative Treatment Requirements

Alternative treatment approaches generally fall into two categories. These are design specifications or performance requirements or standards. Depending upon the requirements, performance standards may be uniformly applied or be resource based.

1) Design Specifications

Design specifications place requirements on the site developer to design stormwater systems according to a set of fixed specifications. Design specifications often explicitly or implicitly specify a certain type of treatment device which would be uniformly required on all sites. Such an approach generally restricts innovation on the part of the developer, and does not consider varying site characteristics which may not be conducive to the required treatment practice. The use of such specifications does not consider the assimilative or carrying capacity of the receiving water resource.

An example of a design specification is to require 48 hour detention, or other specified detention time for runoff from sites over a given size. Generally speaking 24 or 48 hour detention times provide a fairly high level of particulate pollutant removal. The removal of dissolved or very fine particulate matter and its associated pollutants may vary considerably with such design specifications depending upon the specific design of the pond, and the presence or absence of aquatic vegetation. Another example of a design specification for water quality treatment is to require the treatment (traditionally through infiltration) of the first flush of runoff from the site.

3) Performance Requirements

Performance requirements or standards set an expected level of performance for the stormwater treatment systems, while allowing for flexibility in the actual types and sequences of treatment devices. An example of a performance standard is the use of treatment criteria such as requiring an 85% removal of total suspended solids for sensitive resources and 70% removal for non-sensitive as is advocated by the State of Rhode Island. This type of treatment level is based upon physical and hydraulic functions, and is reliably predicted by many stormwater runoff models. Indirectly, this approach addresses sensitivity of receiving resource to impacts by setting varying levels of treatment for varying resource sensitivity. It also uses an "Indicator Pollutant" concept, which provides greater certainty in predictions, and economically sound approach if monitoring is required.

Another performance based approach is to establish numeric discharge limits. Such limits must be developed in an understanding of technologically practical levels. Limits should also ideally be derived on a case by case basis in accordance with the load assimilative capacity of the receiving waterbody. However, sufficient information and expertise may not be available at the local level to determine the carrying capacity of the waterbody. This is not viewed as a practical alternative.

Recommended Stormwater Management Guidelines

The management of stormwater runoff from any site should address the following objectives:

1) Provide for effective site drainage

Stormwater should be handled within a site (or a watershed) in a manner that conducts surface runoff away from critical site features and conveys the runoff to a suitable outlet. This is accomplished by positive site grading and properly sized conveyance systems.

2) Provide for flood protection of the receiving watercourse

Stormwater runoff should be discharged from a site in a manner that does not overtax the capacity or the stability of the receiving watercourse. This may generally be accomplished by one or more of several methods:

a. Checking the downstream watercourse's capacity and stability conditions, and determining whether the peak discharge and velocities in the watercourse with the proposed site development are consistent with these existing conditions.

b. Providing temporary storage (detention) on-site, with release rates compatible with downstream capacity and stability.

c. Providing for infiltration of some or all of the excess runoff from development on-site, to minimize the increase of peak flows in the receiving watercourse (this option is limited to those sites with sufficient areas of suitable soils).

3) Provide for protection of the water quality of the receiving watercourse

This is accomplished through a number of measures, generally referred to as Best Management Practices (BMPs), aimed at preventing the generation and release of pollutants, limiting their transport, or removing them from the stormwater discharge (by some form of treatment). These measures include "housekeeping" practices such as pavement sweeping, erosion control practices, and "structural" practices, (e.g. wet ponds and infiltration systems).

Traditionally, storm drainage systems have consisted of roadside gutters or ditches, catch basins or other inlets, storm drain pipes, culverts, and channels, and "improved" natural waterways. These systems were chiefly designed to achieve Objective 1, effective site (or watershed) drainage. Framingham's ordinance section C.10 is an example of the type of criteria used to govern systems to meet this objective. The ordinance essentially implies, for example, that intensively developed areas should have stormwater systems capable of conveying the 50-year storm event through these areas.

While downstream flooding has always been a concern, it is only in the last 10 to 20 years that Objective 2 has come to be widely applied to individual developments. The rationale of this objective (controlling downstream flooding) can range from protecting downstream areas from major catastrophic events (e.g. the 100-year storm), to attempting to mimic predevelopment peak discharges for a full range of storms (for example, some jurisdictions now require multiple stage detention facilities that limit discharge rates from a site to predevelopment levels for the 2-year and 25-year storm events).

The application of Objective 3, stormwater quality control, is of relatively recent interest. The USEPA has focused on stormwater through the NPDES program and through nonpoint source pollution control programs, and states and municipalities are becoming involved in these programs. The criteria for meeting Objective 3 have not been standardized in practice as of this time.

Base on the above general discussion, and on our experience in working with the stormwater management programs of a number of community and state jurisdictions, we suggest the following criteria be applied to the development of stormwater management plans for any "major" site development in Framingham:

1. Objective I: Effective Site Drainage

a. Sites should be designed to provide positive site drainage, using accepted engineering practice as illustrated in Table 1.

b. Section C.12, "Building Grades", of the current Framingham ordinance should be retained.

c. Sites in FEMA-mapped flood zones should be designed for flood protection in accordance with FEMA guidelines (if such sites are to be developed at all). They should also be designed for compensating flood storage in accordance with state regulations.

Table 1

Recommended Minimum Gradients for Site Grading

Minimum Slope Gradients

Slope away from foundations:	
Pervious surfaces	5.0 % (*)
Impervious surfaces	1.0 % (a)
Slope to upper edge of a drainage swale	2.5 % (b)
Pervious surfaces:	2.0 %
Impervious surfaces:	
Concrete	1.0 % cross slope 0.5 % longitudinal slope
Bituminous	2.0 % cross slope 0.5 % longitudinal slope

(a) Minimum length, 10 feet or as limited by property lines.

(b) Can be used only where no steep adjacent slopes will contribute storm runoff.

Note: There are also maximum gradients allowable for safety considerations as well as slope stability and control of erosion. These are not shown.

d. Storm drainage conveyance systems should be designed to meet the following criteria (see Table 2):

- Piped systems should be sized to carry the runoff from a 10-year frequency storm (5-year frequency for recreation, conservation, open space, and agricultural districts).

- Areas that will either carry or be inundated by the excess flow in a 25-year frequency storm (single family residential districts) or 50 year storm (intensive use districts) should be designated on the design plans and sized for the associated flow or storage capacity. That is, the "10-year" pipe system may overflow, but we know where the excess water will be during the 25-year event (or 50-year event, as applicable). No area required for emergency access should be allowed to be ponded during this event.

- Culverts under major highways, and storm drainage systems serving critical structures, should be designed for an event equal or greater in magnitude than the 50-year storm (unless more conservative guidelines apply under state and federal agencies having jurisdiction).

- Detention storage facilities should be provided with outlet and spillway capacity to prevent overtopping during the 100-year flood event.

2. <u>Objective 2: Protection Against Downstream Flooding.</u>

a. If the area of a site is less than or equal to one percent of the watershed of the receiving watercourse, at the point of discharge, no analysis of detention requirements is necessary.

b. If a site discharges to an existing man-made drainage system, then the peak rate of discharge <u>from the site</u> to the system should be less than or equal to the pre-development peak rate (for the undeveloped site) for the 2-year and 25-year storm events.

c. If a site discharges to a natural watercourse, then the development should not result in the peak flow <u>in the watercourse</u> being greater than pre-development levels for the 2-year and 25-year storm.

d. Overtopping protection for the 100-year storm should be provided as indicated under Objective 1.

Table 2

Stormwater Management Design Criteria
Objective I: Effective Site Drainage

Land Use Zoning	Return Period (Years)	
	Piped Conveyance System	Dedicated Flow and Storage
Business, general, industrial, light industrial, apartments, garden apartments, single and two-family residential (R-1, G)	10	50
Single family residential R-2, R-3	10	25
Single family residential	10	25
Recreation, conservation, open spaces, agriculture	5	25
Major highways and structures	50	50
Detention storage overtopping protection	N/A	100

3. Objective 3: Stormwater Quality Control

Stormwater quality control requirements should be appropriate to the size of the proposed development. The following provides the definition of major, moderate, and minor level developments for the purposes of applying stormwater quality control requirements:

Major Category:	Site developments in excess of 20 acres in total area, with a total area of disturbance greater than 5 acres, and/or a post-development impervious area (including buildings pavement, roadways, etc.) greater than 3 acres.
Moderate Category:	Site developments greater than 10 acres but less than 20 acres in total area, with a total area of disturbance greater than 3 acres but less than 5 acres, and/or a post-development impervious area greater than 2 acres but less than 3 acres.
Minor Category:	Site developments less than 10 acres in total area, with a total area of disturbance less than 3 acres, and/or a post-development impervious area less than 2 acres.

a. Major developments should treat the "first flush" to achieve an 85% reduction in total suspended solids.

"First flush" is defined as the first one-half inch of runoff from the contributing drainage area of the developed site. For example a five acre site will contribute a "first-flush" volume of:

V = 5 acres x 0.5 inch x 1.0 ft/12 in.
= 0.21 acre-feet
= 9100 cubic feet

b. The first-flush volume should be diverted "off-line" to an appropriate stormwater BMP, or may be treated "in-line" in a multi-stage wet pond or extended detention basin.

c. In sensitive watersheds, an additional volume of runoff and/or additional levels and types of treatment may be required.

[WE RECOMMEND AND ARE WORKING ON SIMILAR BUT SLIGHTLY LESS RESTRICTIVE REQUIREMENTS FOR "MODERATE AND MINOR" LEVEL DEVELOPMENTS; SOME REFINEMENT TO CATEGORY DEFINITIONS IS LIKELY]

Method of Runoff Estimation:

Framingham's ordinance should be revised to designate the following guidance on use of runoff estimation methods:

1. USDA SCS reference should be to National Engineering Handbook, Section 4 - Hydrology, or SCS-TR-20 hydraulic model, or SCS-TR-55 Urban Hydrology for Small Watersheds (1986).

2. Rational Method reference should probably be to American Society of Civil Engineers Manual of Practices No. ____, 1992, or similar accepted reference.

3. Application of these methods should be in accordance with the limits specified in Table 3.

Table 3

Selection Criteria for Runoff Calculation Methods [1]

Output Requirements	Drainage Area	Appropriate Method
Peak discharge only	Up to 20 acres	1 4 5
	Up to 2000 acres	2 3 4 5
	Up to 5 square miles	2 3 4
	Up to 20 square miles	2 3 4
Peak discharge and runoff volume [2]	Up to 2000 acres	2 3 4 5
	Up to 20 square miles	2 3 4
Runoff hydrograph	Up to 20 square miles	2 3 4

1 Rational Method
2 SCS TR-20 Method
3 COE HEC-1 Method
4 SCS TR-55 Tabular Method
5 SCS TR-55 Graphical Method

APPENDIX D
Drawdown Impact Assessment

Background

Overwinter drawdown is a low cost and effective management tool for the long-term control of certain susceptible species of nuisance aquatic plants. Overwinter drawdown controls susceptible aquatic plants by dewatering a portion of the pond bottom over the winter, and subsequently exposing vascular plants to the combined effect of freezing and desiccation (drying). The effectiveness of drawdown to control plants hinges on the combined effect of freezing and drying. If freezing and dry conditions are not sustained for 4 - 6 weeks, the effectiveness of that years' drawdown may be reduced.

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 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.

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).

Lake and pond drawdown projects for aquatic plant control are subject to the jurisdiction of the Wetlands Protection Act, M.G.L. Chapter 131, Section 40, because lowering the water level in a lake or pond is an activity as defined in the Regulations (310 CMR 10.04) and is conducted in areas that are subject to review (310 CMR 10.02). Interim guidance for the evaluation of impacts associated with drawdown was issued by the Massachusetts Division of Wetlands and Waterways, Department of Environmental Protection (DEP) in September 1990. The following provides an analysis of the feasibility and potential impacts associated with the use of overwinter drawdown at Singletary Lake. This analysis addresses the primary issues outlined in the DEP guidance.

Control of Target Species

Macrophyte surveys of Singletary Lake completed by Aquatic Control Technology over the last number of years, documented an expansion of coverage by Eurasian Watermilfoil (*Myriophyllum spicatum*) and the introduction of a second exotic species Variable Watermilfoil (*Myriophyllum heterophyllum*). The watermilfoil infestations have expanded in colonizable substrates to a depth of 10 - 15 feet.

The susceptibility of the dominant nuisance species as well as other species observed in scattered locations to drawdown is summarized in Table D-1. Many of the species observed in Singletary Lake, and particularly the nuisance exotic Eurasian and Variable watermilfoils are susceptible to control by overwinter drawdown. Species that reproduce primarily by seeds, such as the pondweeds (*Potomogeton* spp.) are not typically controlled by drawdown, and may actually increase under post-drawdown conditions. These species tend to grow less densely, thus posing less of a nuisance to recreational uses, and tend to have higher value to wildlife. Therefore, the use of drawdown may provide control of nuisance plant species while increasing the relative abundance of less problematic species with greater habitat value.

Table D-1: Susceptibility of Macrophyte Species to Overwinter Drawdown

Species Observed	Relative Abundance	Mode of Reproduction	Drawdown Response: Decrease	Drawdown Response: No Change	Drawdown Response: Increase
Eurasian watermilfoil *Myriophyllum spicatum*	C	turions, fragments, seeds	♦		
Variable watermilfoil *Myriophyllum heterophyllum*	C	turions, fragments, seeds	♦		
White waterlily *Nymphaea odorata*	S	rhizomes, seeds	♦		
Watershield *Brasenia schreberi*	S	rhizomes, seeds	♦		
Chara *Chara* spp.	D	rhizomes, seeds	♦	♦	
Waterweed *Elodea* spp.	C	lateral buds, fragments, seeds	♦		
Pondweed *Potamogeton* spp.	S	rhizomes, seeds, winter buds		♦	♦
Bladderwort *Utricularia* spp.	C	turions	♦		
Tapegrass *Vallisneria americana*	D	rhizomes, tubers, seeds			♦

Relative Abundance: D = dominant; C = Common; S = Scattered/Sparse

Mode of Reproduction: From Hurley, 1990, Hellquist and Crow (various dates), Fernald (1950), and Godfrey and Wooten (1981)

Drawdown Response: From Cooke et al. (1993); Typical response to overwinter drawdown (expressed as a decrease, increase, or no change in plant density) as reported in the scientific literature. More than one response indicates reported variability of response. (* = no information available)

If implemented on an annual basis, the effectiveness of drawdown may diminish over time. This diminished effectiveness is associated with the replacement of drawdown-susceptible species by drawdown-tolerant species after repetitive drawdowns. A start up program that employs drawdown for two to three consecutive years, followed by a staggered program of drawdown every other year or two, minimizes the risk of developing a dominant plant community that is dominated by species resistant to drawdown.

Dam Structure and Outlet Channel

No inspection of the existing dam and outlet structure was completed. However, based upon available information, it is our understanding that the outlet structure is capable of a maximum drawdown of about 10-15 feet. Water leaves Singletary Lake flowing through an open channel into Singletary Brook, through Bierly and Mayo Ponds and finally to the Blackstone River.

Current interim guidance for drawdown requires that the structural integrity of the dam for drawdown be evaluated by a Registered Professional Engineer. This inspection should be completed prior to initiating the permitting process.

Area of Control

Aquatic vegetation occurs over about 153 acres of Singletary Lake. At present, water levels can be reduced by a maximum of 10-15 feet by via the existing outlet structure. The estimated bottom area exposed by a 5 foot drawdown would be about 75 acres or 50 percent of the current area of macrophyte growth. A 10-foot drawdown would expose about 119 acres, and a 15 foot drawdown, 153 acres.

Ideally, exposure of the full 153 acres of colonize area is desirable to ensure the maximum control of the exotic watermilfoil species. Less drawdowns of 5 - 10 feet would provide some benefit but would not prevent re-infestation of the exotic species from unexposed areas.

Hydrologic Analysis

The U.S. Geologic Survey (USGS) stream gauging station located on the Blackstone River provides the basis for the following hydrologic analysis. The published average, maximum, and minimum monthly stream flows at this gauge station for the period of record were used to estimate hydrologic inputs on a monthly basis to Singletary Lake. Estimates of monthly inflows were obtained by:

1. dividing the reported average, minimum, and maximum stream flows (expressed in cfs) by the drainage area of the gauge station to arrive at an areal water loading (expressed in cfs/square mile); and
2. multiplying that areal water loading rate by the watershed area of Singletary Lake (expressed in square miles) to arrive at an estimated inflow rate at Singletary Lake (expressed in cfs).

These calculations are illustrated in Table C-2. These estimates were then used to calculate dewatering and refill times, as well as to examine the time required to dewater after a re-flooding of the pond during the drawdown period.

The volume of the pond to be discharged for 5-, 10- and 15-foot drawdown scenarios are 1769, 2938, and 3910 acre-feet. For reference, the total volume of Singletary Lake is about 8250 acre-feet. A 5-, 10- , or 15-foot drawdown will reduce the total volume of the pond by 21, 36, or 47 percent, respectively.

Dewatering is typically accomplished between October and November. The maximum acceptable outflow rate was set at 125% of the observed maximum discharge rate of 17 cfs (IEP, 1991). Under average inflow conditions, the time required to dewater the pond while discharging at a rate of about 20 cfs (40 acre-feet/day) is 86 days for a 5-foot drawdown, ranging from 86-186 days for drawdowns of 5 - 15 feet. During a dry Fall, dewatering could be accomplished in as little as half the time projected for average conditions. If inflows approach the maximum observed inflow estimates, dewatering of the pond would not be possible at the assumed discharge rate. The likelihood of sustained inflows at or near the maximum observed during the period of record is unlikely. Drawdown would be slowed by sustaining such inflows for even a day or two, but compensation for such inflows could be made by increasing the rate of discharge or extending the dewatering time.

Refilling of the pond from a winter drawdown is typically initiated in February or March with the aim of reinstating normal water levels by April. Under average conditions, refill of Singletary Lake would be expected to occur within 89 - 190 days depending upon the depth of drawdown. Under extreme conditions of low inflow, refill could take as long as 909 - 2010 days (2.5 - 5.5 years) depending upon the depth of drawdown. The 5-foot drawdown could require as much as 909 days to refill under below normal inflow conditions. Under such circumstances it would not be possible to restore water levels within an acceptable time frame.

The effectiveness of drawdown relies on continuous freezing and dry conditions in the sediment for a 4 to 6 week period of time. In the instance where inflows exceed the maximum desirable outflow rates during the drawdown period, the pond bottom may become re-flooded. Because the effectiveness is diminished by wet conditions, dewatering after flooding is important. Several scenarios of re-flooding and subsequent dewatering were examined, including inflows at the maximum estimated rate observed during December and January sustained for 24 hours, 48

Table D-2. Overwinter Drawdown Hydrologic Evaluation

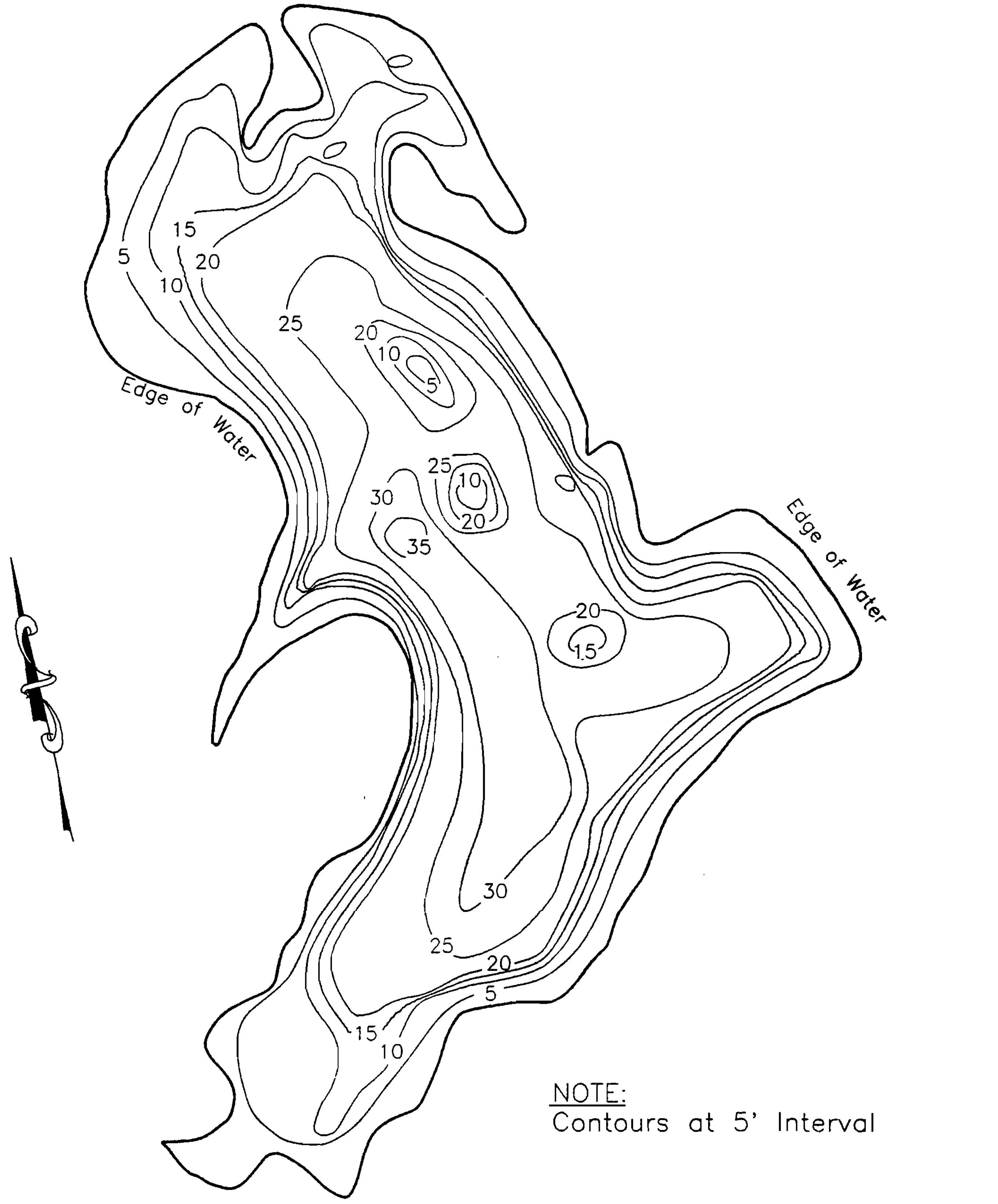
"DESK-TOP" HYDROLOGIC BUDGET -- Singletary Lake

INPUT PARAMETERS	Units	Average Annual	Drawdown Period (Oct - Nov)			Refill Period (Feb - Mar)		
			Min	Max	Mean	Min	Max	Mean
Watershed Area	sq.mi	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Lake Surface Area	acres	330.0	330.0	330.0	330.0	330.0	330.0	330.0
Lake Volume	ac-ft	8228.3	8228.3	8228.3	8228.3	8228.3	8228.3	8228.3
Lake Volume	hm3	10.15	10.15	10.15	10.15	10.15	10.15	10.15
Precipitation	in	47.6	4.4	4.4	4.4	3.7	3.7	3.7
Evaporation Rate	in/yr	26.0	2.0	3.4	2.2	1.4	4.3	2.8
Unit Runoff Rate	cfs/sq.mi	1.8	0.1	5.1	1.2	0.5	5.6	3.1
Time-weighted Measured Outflow (1984-85)	cfs	3.4	0.0	9.2	4.6	0.9	13.1	7.0
Precipitation -> Lake	ac-ft/d	3.6	0.3	0.3	0.3	0.3	0.3	0.3
Runoff -> Watershed	ac-ft/d	12.9	0.7	36.5	8.6	3.4	39.9	22.0
Total Hydrologic Input	ac-ft/d	16.5	1.1	36.8	9.0	3.7	40.2	22.3
Evaporation	ac-ft/d	2.0	0.2	0.3	0.2	0.1	0.3	0.2
Total Outflow	ac-ft/d	14.5	0.9	36.5	8.8	3.5	39.8	22.1
Total Surface Outflow	hm3/yr	6.5	0.4	16.5	4.0	1.6	17.9	9.9
Flushing Rate	times/yr	0.6	0.0	1.6	0.4	0.2	1.8	1.0
Retention Time	years	1.6	24.6	0.6	2.6	6.4	0.6	1.0
Retention Time	days	566.6	8979.1	225.1	935.6	2320.8	206.4	372.9

Table D-2. Overwinter Drawdown Hydrologic Evaluation

Drawdown Hydrologic Analysis

Parameter	Units	5-foot	10-foot	15-foot	20-foot
Drawdown Depth	ft	5	10.0	15.0	20.0
Drawdown Volume	ac-ft	1769.0	2938.0	3910.0	6042.0
Dewatering Time (max outflow = 20 cfs)					
Min Inflow	days	49.3	81.9	109.0	168.4
Max Inflow	days	207.4	344.4	458.3	708.2
Mean Inflow	days	84.2	139.9	186.1	287.6
Dewatering Rate (max outflow = 20 cfs)					
Min Inflow	ft/day	0.10	0.12	0.14	0.12
Max Inflow	ft/day	0.02	0.03	0.03	0.03
Mean Inflow	ft/day	0.06	0.07	0.08	0.07
Refill Time (minimum outflow of .9 cfs)					
Min Inflow	days	909.3	1510.2	2009.8	3105.6
Max Inflow	days	46.0	76.4	101.7	157.1
Mean Inflow	days	86.0	142.9	190.2	293.8
Refill Rate (minimum outflow of .9 cfs)					
Min Inflow	ft/day	0.01	0.01	0.01	0.01
Max Inflow	ft/day	0.11	0.13	0.15	0.13
Mean Inflow	ft/day	0.06	0.07	0.08	0.07



Client: Singletary Lake Association	**Bathymetric Map**	Figure 1	FUGRO
Project: Singletary Lake Diagnostic Study	Millbury / Sutton, MA	1" = 941'±	
	December 1994	Job No.16-16-8111	

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hours, and 7 days. Under these conditions, 1 - 6 days would be required to dewater the flooded volume while maintaining the maximum desirable discharge rate. Such extreme conditions, sustained for more than 48-hours are unlikely, and the re-flooding that could occur with sustained flows for 24 or 48 hours would be easily removed within 5 days, thus minimizing any disruption to the drawdown.

Water levels should be checked periodically, and outflow discharge rates adjusted to maintain the desired depth of drawdown. Regional precipitation or USGS gauge records should also be tracked on a regular basis during the drawdown period to signal possible extreme conditions, such as a particularly dry winter, that would prompt an early refill to assure adequate water levels by the late spring. A maximum 5-foot drawdown is recommended based upon this hydrologic analysis. Greater drawdown depths may be possible when climate conditions are favorable. However, an increases in drawdown should be accomplished by increasing drawdown water depths by one foot each year with close monitoring.

Water Quality

Long-term benefits in water quality are expected as a result of implementing the overwinter drawdown. The decomposition of aquatic plants under water increases the rate of oxygen depletion and recycling of nutrients in ponds and lakes. In addition, macrophytes may also "pump" nutrients from the sediments into the water column during the growing season. Reduction of plant biomass by drawdown would reduce these impacts, although it is not clear that either are particularly important in the pond's nutrient budget. No short-term or long-term water quality impacts to downstream water resources are expected. Because drawdown takes place during the fall and winter, after fall circulation, the water discharge from the pond is expected to be well oxygenated, and without excess nutrient concentrations. Therefore, while the volume of discharge may increase during the dewatering period (about 84 days for a 5 -foot drawdown), the quality of the discharge should not be substantially different that the normal discharge from the pond.

A modified approach to drawdown that involves increasing water level after ice formation to rip out growths by floating the frozen sediments to the surface. While effective for plant control, this modified approach moves sediment around in the lake, and may cause temporary problems with turbidity. Outflow restrictions would be required if this modified approach was taken to avoid discharge of sediment laden waters to downstream areas. The advantage of this approach is that the period of drawdown can be lessened. Therefore, while not recommended as a first approach, this modified approach might be considered if overwinter drawdown impacts to the adjacent wells proved to be unworkable at the 5 drawdown depth.

Private Water Supplies

While most shoreline residences have deep bedrock or artesian wells, there are a number of residences that rely on shallow dug wells around the lake shoreline. Depending upon the depth of these wells and their proximity to the lake, even a limited drawdown may reduce water levels in the wells. Residents relying on shallow wells should be notified of the intention to drawdown, and the drawdown aborted if the drawdown results in the drying out of wells. Historically drawdowns of about 3 - 5 feet have been practiced at the lake for shoreline maintenance, and to our knowledge wells have not been adversely impacted.

Fisheries

No recent fish surveys have been completed by the Division of Fisheries and Wildlife on Singletary Lake. However, a typical assemblage of warmwater fish species would be expected base don a 1978 fisheries survey completed by the Division of Fisheries and Wildlife. The typical spawning period for many warmwater species (e.g., bluegill, pumpkinseed, perch, bass) is April to June. Bluegill and pumpkinseed are also known to spawn throughout the summer season in some instances. Rainbow and brown trout have been stocked in the lake previously, but are not expected to establish reproducing populations based on the lake conditions. Anticipated refill by April should minimize or eliminate any potential adverse affects to fish spawning.

Reducing the pond volume, and thus increasing the density of fish within the remaining volume, can in some instances result in oxygen depletion and subsequent fish kills. Such impacts are mitigated by maintaining a sufficient volume of water, and also by the magnitude and frequency of inflows that will renew oxygen depleted waters. At normal through-flow (1 - 5 cfs) for Singletary Lake, water replacement should be adequate to maintain a dissolved oxygen concentration greater than 5 mg/l, under almost any drawdown depth. Once drawn down, however, the pond cannot be refilled quickly in response to low flows, creating a risk of fish kill. A drawdown of 15-feet would reduce the pond volume by 47% and could limit the volume available for the overwintering of fish. A drawdown of such depths is not recommended. A drawdown of 10-feet would reduce the pond volume by about 36%, but would generally retain sufficient volume for the overwintering of fish, given the magnitude of inflows associate with the pond's watershed. Adverse impacts to fish associated with a 5- or 10-foot drawdown are not anticipated.

Physical improvement of fish spawning areas is a desirable benefit of drawdown (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. 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).

Wetlands and Wildlife

A vegetative community is absent in the areas actively maintained as swimming beaches, and residential waterfront areas. There are limited areas of natural wetland bordering the lake, as much of the shoreline is developed.

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.

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. Adverse impacts to the bordering wetland communities associated with drawdown are not anticipated.

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). 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. Since emergent shoreline vegetation tends to be favored by drawdowns, populations of furbearers are expected to benefit (WDNR 1989).

Rare Species

The pond and adjacent wetland areas are not listed as estimated habitat for rare or threatened species (based on 1993 habitat maps).

Recreational Water Uses

The implementation of overwinter drawdown is not expected to interfere with winter recreational uses of the pond. Loss of areas may be somewhat of a nuisance. Sufficient area will remain for skating if such activities are permitted. Drawdown, if accomplished before ice cover, is not expected to affect normal ice conditions on the pond. However, as under normal conditions, caution should be used to ensure that safe ice exists. Warm weather and/or large runoff or snow melt conditions may compromise ice safety. Refill to normal water level is expected before April. Therefore, adverse impacts to spring and summer recreational uses are not anticipated.

Alternatives Analysis

A part of a comprehensive lake and watershed management project, alternatives for both in-lake and watershed management were examined. The analysis of in-lake management options for the control of rooted aquatic vegetation that occurs over nearly 50% of the lake surface area included:

- mechanical harvesting;
- hydro-raking;
- herbicides;

- overwinter drawdown; and
- selective dredging.

The primary goal of vegetation management for Singletary Lake is the control of nuisance, exotic infestations of Eurasian and Variable watermilfoil, rather than the broader objective of reducing the overall coverage and density of all aquatic vegetation. Of the techniques evaluated, harvesting was not recommended given the relatively high cost, and the potential for harvesting to spread watermilfoil. Selective dredging was not considered economically feasible for the benefit gained. Herbicides have been used historically, and are recommended for the continued control of milfoil. Drawdown used in conjunction with continued herbicide treatments is intended to facilitate the control and possible eradication of milfoil, and to reduce the dependence on herbicides for control of these plants.

In addition to in-lake management activities aimed at controlling rooted aquatic vegetation, various watershed management activities have been recommended to control nutrient loads that stimulate algae growth in the pond.

Recommended Program

On the basis of the above analysis, the use of a 5-foot overwinter drawdown for the control of rooted aquatic vegetation appears feasible, and without significant adverse impacts when undertaken in a carefully controlled and monitored setting. The following program is recommended to optimize control and minimize potential impacts:

1. **Schedule**: Implement a graduated drawdown program beginning with a 5-foot drawdown during the first year; increasing the extent to a maximum of 10 feet contingent upon satisfactory results of monitoring of adjacent wells, and refill times.

2. **Frequency**: Implement overwinter drawdown annually for the first two to three years, and every other year or every two years thereafter. The frequency may be modified based upon the results of vegetation surveys. However, in no case should drawdown be implemented for more than three consecutive years.

3. **Dewatering**: Dewatering should commence on or about September 1 at rate of 1 inch per day to provide sufficient time for dewatering prior to the formation of ice cover. This rate of elevation drop is approximately equivalent to a discharge rate of 20 cfs or about 15.5 cfs above normal inflows for the period (about 11.5 cfs greater than the observed average annual outflow rate, and 3 cfs above observed maximum outflow rates).

4. **Water Level Maintenance**: The pond level should be maintained at the desired drawdown level from late October through mid February. If high inflows occur during the drawdown

period that result in an increase in the water elevation, the drawdown levels should be restored as soon as possible.

5. **Refill**: Refilling the pond should typically begin on or about February 1. In no case should refill be initiated any later than February 15. A minimum outflow of 0.5 cfs should be maintained during the refill period. Refill to normal pool elevation should occur within 14 to 90 days under most circumstances. Initiating refill prior to ice-out will disrupt ice cover, and may pose a risk to any docks or other structures present along the shoreline. However, this may be a necessary risk to ensure refill by mid-April.

6. **Monitoring and Inspections**: The following program of inspections and monitoring should be conducted in conjunction with the implementation of drawdown. This monitoring and inspection program is designed to guide the drawdown program implementation as well as to provide an early detection mechanism for potential impacts to the adjacent municipal wells.

   - Well Monitoring - During the period of drawdown residents should periodically monitoring water levels in their wells, or check water flows to ensure than sufficient water is available in the well. If adverse impacts are noted, the drawdown should be halted and refill initiated until measures can be taken (e.g., installing deeper well points).

   - Vegetation Surveys - Annual vegetation surveys should be completed to document the areal coverage and species distribution of aquatic plants. Plant surveys should be conducted in mid to late summer to assess conditions under maximum plant coverage.

   - Pond Water Level - The water level of the pond should be measured at a fixed location on a daily basis during dewatering and refill, and weekly during the period of drawdown. Supplemental water level measurements should be made following significant rain events (greater than 0.5 inches) or snow melt periods to adjust outflow rates to maintain drawdown water levels during the drawdown period.

   - Outlet Channel Inspection - During the dewatering period, the downstream channel should be inspected for evidence of scouring or flooding and the discharge rate reduced as necessary to prevent such conditions. The outlet channel must be kept clear of obstructions.