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Durham Ponds Assessment and Plan

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Executive Summary

An assessment was prepared for Mill, Beards and Little Hale Ponds in Durham, New Hampshire. The ponds are all shallow impoundments and highly visible in the community but have experienced a proliferation of aquatic plants and algae in recent years. This effort included an evaluation of nutrient inputs and outputs as part of a nutrient budget and setting a target value for phosphorus and nitrogen that would result in much less algal growth and restore some of the historic recreation uses to the ponds. Limiting phosphorus and nitrogen loading to the ponds is critical to maintaining water quality over the long term however, there may be short term measures that could be implemented to improve the ponds for certain uses.

A five event monitoring program was conducted in the Durham ponds in 2013 to evaluate nutrient inputs and in-pond concentrations over the course of a growing season. Results of the program indicated that the ponds are nutrient rich with respect to both phosphorus and nitrogen, do not thermally stratify and support significant algae and aquatic plant growth. At times, the algae in the ponds are likely limited by nitrogen and at other times by phosphorus. Algae are also limited by the high flushing rates of the ponds.

A watershed and lake modeling effort was completed using LLRM. This effort concluded that the majority of the nutrients come from the watershed and a 60-75% reduction in nitrogen and phosphorus would improve water quality. Many of the activities currently underway as a part of the Oyster River Watershed Integrated Management Plan for Nitrogen (VHB 2014) will also reduce both nitrogen and phosphorus loading to the ponds. Dredging may help restore some of the historic uses of all three ponds by removing nutrient rich sediment and rooted aquatic plants and may mitigate some internal loading of phosphorus in Little Hale Pond but would generally be much more effective and last longer if preceded by or coupled with aggressive watershed nutrient reductions.

1.0 Introduction

Physical characteristics of the Durham ponds are presented in Table 1-1. Subwatersheds for the Durham ponds are presented in Figure 1-1. The watershed to pond area ratio is very high for all of the ponds. Lakes or ponds with watershed ratios greater than 10:1 often experience low water clarity, high phosphorus and obnoxious algal blooms when the watershed is highly developed or has high export of nutrients as is the case for each of these ponds. Furthermore, the amount of impervious cover (i.e., development) within a watershed is correlated with water quality. Poor water quality and significant changes in hydrology are typically experienced in watersheds where impervious cover is at or greater than 10% of the total area (CWP 2003). In areas where impervious cover is greater than 25% (CWP 2003) waters are typically of poor quality and may not support such uses as swimming, and drinking. While areas of the watersheds for these ponds are below the 10% threshold, some subwatershed areas are well above this threshold, particularly in the urban portions of Durham and the UNH college campus. These impervious areas are likely substantial contributors to the nutrient enrichment observed in the ponds. The flushing rate of each of these ponds is very high having important implications for phytoplankton growth and the appropriateness of many management opportunities.

The assessment and preliminary plan presented in this report characterizes the ponds, suggests aggressive watershed management and public education and considers the use of dredging to restore some of the historic uses of the ponds.

Table 1-1: Characteristics of Mill, Beards and Little Hale Ponds, Durham, NH.

Pond	Watershed (ha)	Pond (ha)	WS/Pond area	Flushing Rate
Mill	5124	3	1708	864
Beards	832	5.4	160	143
Little Hale	121	0.4	303	217

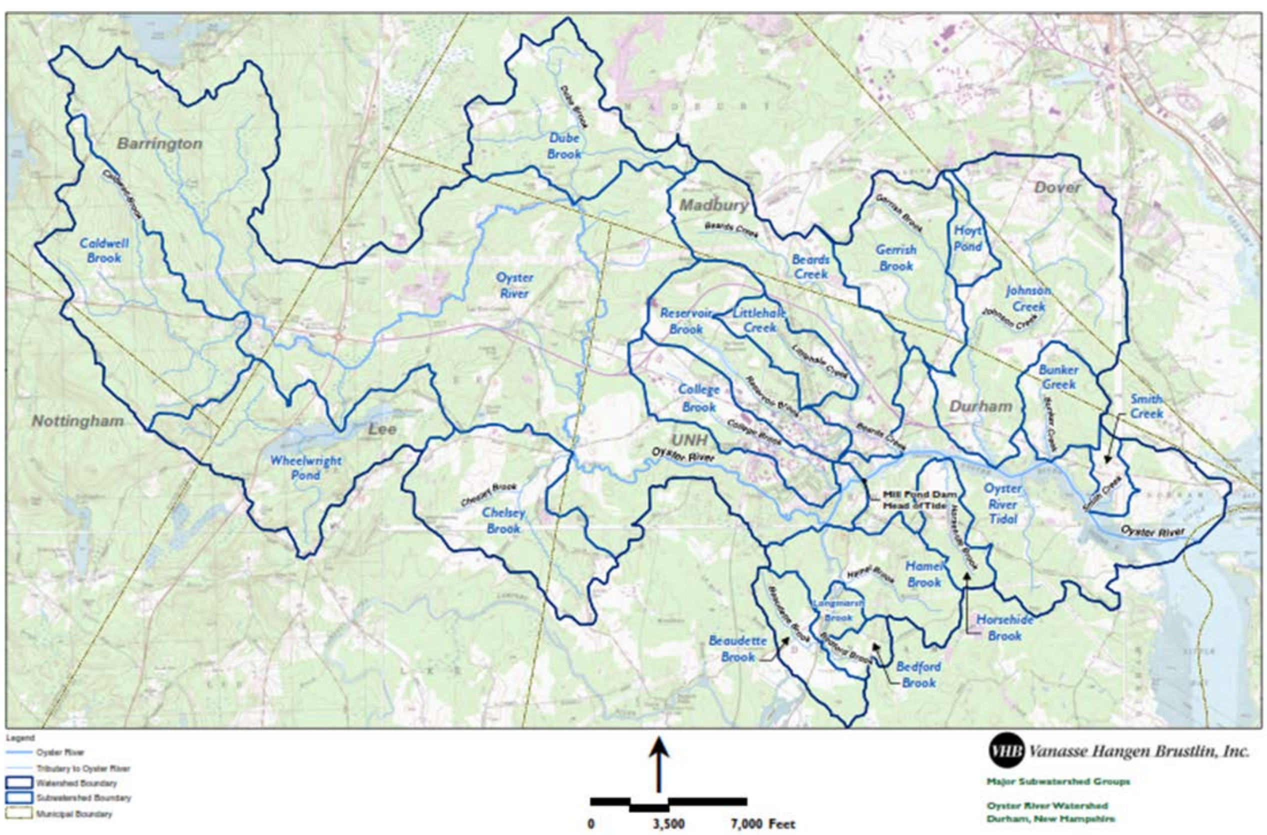


Figure 1-1: Durham ponds subwatersheds.

2.0 Water Quality and Ecology of the Ponds

Mill, Beards and Little Hale Ponds are all eutrophic (nutrient rich). The ponds have large stands of rooted submerged and emergent aquatic plants and experience frequent blooms of filamentous and planktonic phytoplankton. Each of them supports a limited number of warm water fish species. Fish populations are likely limited by small pond size and shallow water depth and high summer water temperatures. Fish passage is only provided at the Mill Pond dam**.**

Excessive plant growth is frequently observed in each of the Durham Ponds. Three growth forms are most troublesome:

- Free-floating microscopic cells, colonies or filaments, called phytoplankton that discolor the water and sometimes form green scum on the surface of the waterbody. These algae come from a variety of algal groups, including blue-greens, greens, diatoms and others, although the blue-greens (cyanobacteria) tend to be the most troublesome group due to high densities, taste and odor issues, and possible toxins. Cyanobacteria genera have been observed during summer algal blooms in the Durham Ponds.
- Mats of filamentous algae associated with sediments and weed beds, but often floating to the surface after a critical density is attained. These are most often green or blue-green algae. These are objectionable to most pond users and can have ecological consequences as well. Mats such as this were primarily observed in Little Hale Pond but are also present in both Beards and Mill Ponds.
- Macrophytes (vascular plants) are abundant in all of the ponds making shore fishing nearly impossible and access for paddlesports difficult. Swimming is virtually impossible in the main body of the ponds at present due to the difficulty accessing open water and shallow depths near shore. Many of these plants are non-native species.

Algae are fueled by nutrients (nitrogen and phosphorus) and reproduce mainly through cell division, although resting cysts are an important mechanism for surviving unfavorable periods. When growth conditions are ideal (warm, lighted, nutrient-rich), algae multiply rapidly and reach very high densities (blooms) in a matter of weeks. Fortunately, most of the time algal cells flush out of the Durham Ponds before they have a chance to reproduce to bloom concentrations. However, during low flow in mid-summer, blooms can and do form. The decay of algal cells following blooms can lead to oxygen depression in the deeper waters although that was not observed in the Durham Ponds in 2013.

Rooted aquatic plants typically increase in numbers in response to nutrient enrichment. Rooted plants typically respond to enrichment of the water column and sediments with nutrients while algae respond to nutrient concentrations in the water column. Sediment nutrient concentrations generally reflect past loading of nutrients to the ponds while water column concentrations reflect current and recent loading. Reduction in water column nutrients may not be sufficient to control rooted plants if nutrients are available in the sediments. Long-term control of aquatic plants may require both sediment and water column management. The monitoring program conducted in the Durham ponds was designed to evaluate nutrient inputs and in-pond concentrations over the course of a growing season. Five monitoring events were conducted. Four of the events included both in-pond and tributary monitoring. One event included only in-pond monitoring. The monitoring schedule is presented in Table 2-1 while the monitoring parameter list is presented in Table 2-2. Monitoring locations are shown in Figure 2-1. All monitoring data are presented in Appendix A.

Table 2-1: Durham ponds sampling schedule in 2013.

Sampling date	Season	Pond monitoring	Tributary monitoring
5/22/2013	Spring	x	
6/14/2013	Summer	x	x
8/1/2013	Summer	x	x
9/4/2013	Summer	x	x
10/10/2013	Fall	x	x

Table 2-2: Durham Ponds parameter list for 2013 monitoring.

Laboratory Parameter	Field (in situ) Parameters
Chlorophyll *a* (chlor *a)*	Temperature (T)
Dissolved color	Dissolved oxygen (DO)
Total phosphorus as P (TP)	pH
Soluble reactive phosphorus as P (SRP)	Secchi transparency
Non-purgeable organic carbon as C (NPOC)	Specific conductance (SC)
Total dissolved nitrogen as N (TDN)	
Nitrite plus nitrate as N (NO_2 + NO_3)	
Nitrite as N (NO_2)	
Ammonia as N (NH_4)	
Total nitrogen as N (N)	
Dissolved organic nitrogen as N (DON)	
Total inorganic nitrogen as N (TIN), calculated	
Total nitrogen/total phosphorus ratio (TN/TP), calculated	

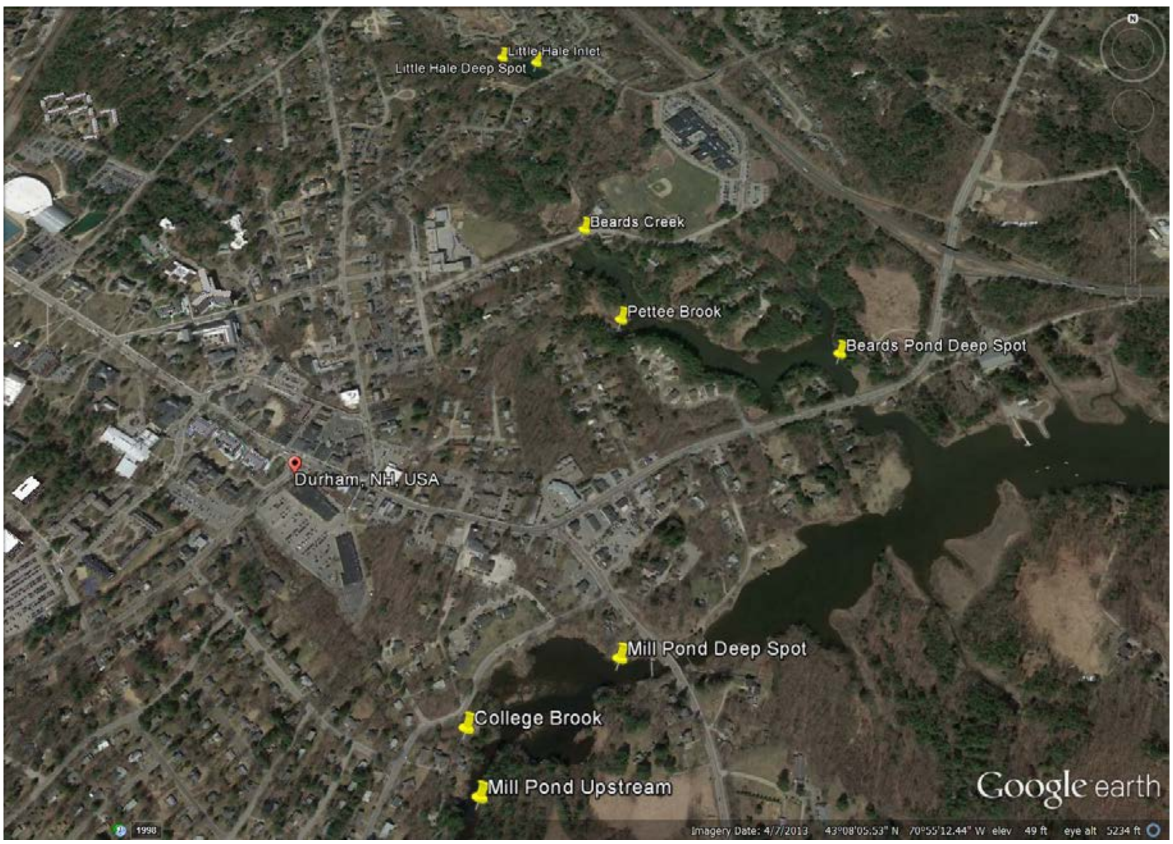


Figure 2-1: Monitoring locations in Durham ponds, 2013.

Mill Pond

Dissolved oxygen and temperature profile data collected for Mill Pond suggest that the pond does not routinely stratify and that generally pond water is mixed throughout the water column. This prevents the isolation of water at depth in the ponds and keeps oxygen present throughout the water column. Because of the shallow depth of Mill Pond, light penetrates to the bottom over most of the pond allowing photosynthetic production of oxygen at depth as well. This provides habitat for aquatic life at all depths and minimizes the potential release of phosphorus from the sediments that could occur under low oxygen conditions. Figures summarizing selected data for Mill Pond are presented in Figures 2-2 through 2-8.

Table 2-3 presents a summary of selected water quality parameters in Mill Pond and at Mill Pond tributary stations. Total phosphorus concentrations in Mill Pond are high, ranging from 0.046 to 0.074 mg/l. Typically in New England lakes, phosphorus concentrations in excess of 0.020 mg/l are sufficient to regularly fuel algal blooms. The presence of soluble reactive phosphorus (readily available for plant growth) in relatively high concentrations on all sampling dates further indicates that there is more phosphorus in Mill Pond than the existing algal and plant community can use. Observed concentrations in College Brook (0.041 to 0.198 mg/l) are substantially higher than those observed in the Oyster River upstream of Mill Pond (0.029-0.054 mg/l) particularly after rain. The June 14 event was preceded by 0.6 inches of rain in the previous 48 hours while the September 4 sampling event was preceded by nearly 2 inches of rain in the previous 48 hours During both of these events, TP concentrations in College Brook were three to four times higher than those observed upstream (Appendix A). Although flows are lower in College Brook than the Oyster River, reductions in phosphorus inputs to College Brook will be critical in the long term to reducing phosphorus concentrations in Mill Pond.

Similar to phosphorus, nitrogen concentrations in Mill Pond are high, however, the ratio of nitrogen to phosphorus observed in Mill Pond suggests that, at times, nitrogen as a plant nutrient is in shorter supply than phosphorus. At the concentrations currently observed, there is sufficient nitrogen and phosphorus to grow plants and algae in nuisance quantities. The management challenge is to reduce one or both of these nutrients to levels that will ultimately limit the amount of plant and algal growth that can occur in Mill Pond.

Chlorophyll *a* is the photosynthetic pigment found in all species of freshwater algae. Concentrations of chlorophyll *a* observed in Mill Pond are variable (Figure 2-4) and somewhat lower at times than what one would expect given the high nutrient concentrations. The high flushing rate of the pond likely plays a role in flushing algal cells out of the pond before they have the opportunity to reproduce to bloom concentrations especially during period of high flow and runoff. In addition, the dense macrophyte community in the pond likely competes with the algae for nutrients at times and encourages settling of solids and algal cells by reducing turbulence. Perhaps the worst set of conditions for the pond occurs during summer in hot, dry periods after moderate storms giving the algae plenty of nutrients from stormwater inputs coupled with sufficient time in the pond to reproduce and form nuisance bloom concentrations.

Table 2-3: 2013 mean (range) of selected water quality parameters in Mill Pond and tributaries.

	Total Phosphorus	Soluble Reactive Phosphorus	Total Nitrogen	Total Inorganic Nitrogen
Station	mg P/l	mg P/l	mg N/l	mg N/l
Mill Pond Deep	0.060 (0.046-0.074)	0.012 (0.007-0.016)	0.630 (0.580-0.690)	0.214 (0.163-0.265)
Mill Pond Upstream	0.039 (0.029-0.054)	0.011 (0.006-0.015)	0.600 (0.470-0.720)	0.149 (0.124-0.186)
College Brook	0.123 (0.041-0.198)	0.063 (0.004-0.103)	0.970 (0.610-1.540)	0.429 (0.191-0.965)

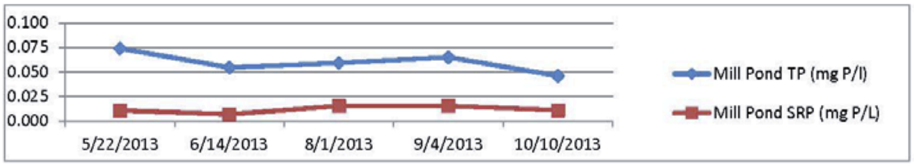


Figure 2-2: 2013 Mill Pond total phosphorus (TP) and soluble reactive phosphorus (SRP).

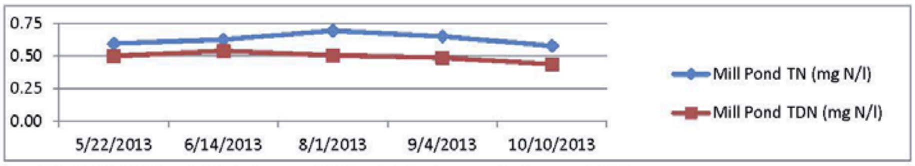


Figure 2-3: 2013 Mill Pond total nitrogen (TN) and total dissolved nitrogen (TDN).

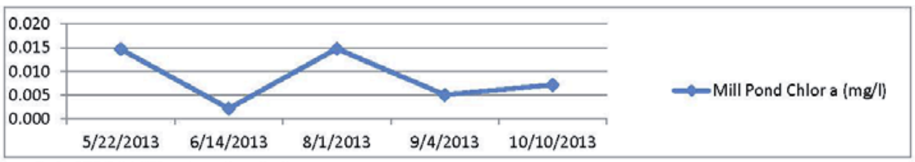


Figure 2-4: 2013 Mill Pond cholorphyll *a* .

Figure 2-5: 2013 Mill Pond Secchi transparency.

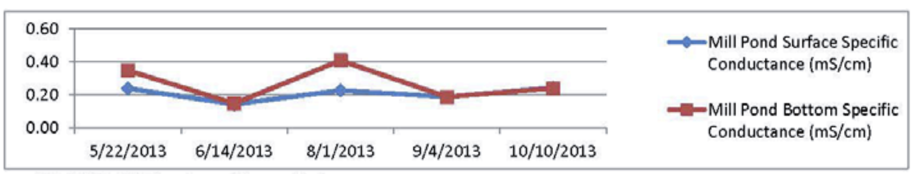


Figure 2-6: 2013 Mill Pond specific conductance.

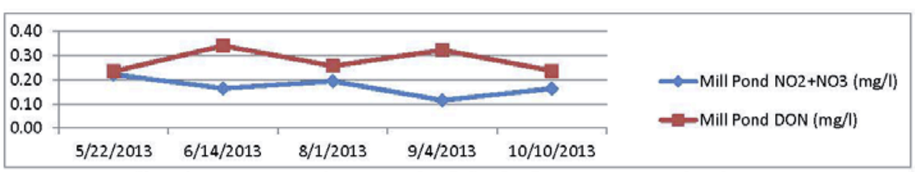


Figure 2-7: 2013 Mill Pond nitrite + nitrate (NO2+ NO3) and dissolved organic nitrogen (DON).

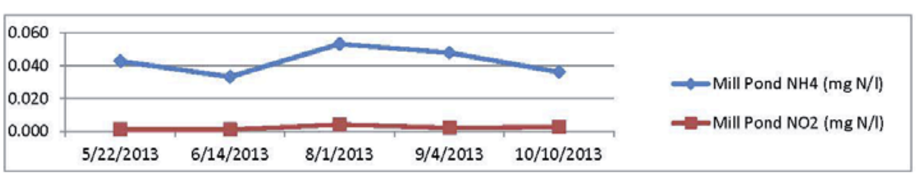


Figure 2-8: 2013 Mill Pond ammonium (NH4) and nitrite (NO2).

Beards Pond

Table 2-4 presents a summary of selected water quality parameters in Beards Pond and tributaries to Beards Pond. Figures 2-9 through 2-15 present 2013 water quality data for Beards Pond. Nutrient concentrations observed in Beards Pond are somewhat higher than those observed in Mill Pond, ranging from 0.054 to 0.085 mg/l for TP and 0.570-0.980 mg/l for TN. Similar to Mill Pond, the presence of soluble reactive phosphorus in relatively high concentrations on all sampling dates indicates that there is more phosphorus in Beards Pond than the existing algal and plant community can use. Observed concentrations in Pettee Brook are similar to those observed in the pond and substantially higher than those observed in Beards Creek.

In Beards Pond there is sufficient nitrogen and phosphorus to grow plants and algae in nuisance quantities. As in Mill Pond, the management challenge is to reduce one or both of these nutrients to levels that will ultimately limit the amount of plant and algal growth that can occur.

Concentrations of chlorophyll *a* observed in Beards Pond are quite variable (Figure 2-11), ranging from lower than might be expected given the nutrient concentrations to one very high value in August (0.040 mg/l). The flushing rate of Beards Pond is high (although lower than Mill Pond) and likely plays a role in flushing algal cells out of the pond before they have the opportunity to reproduce to bloom concentrations under moderate to high flow conditions. However, dry periods likely give the algal populations sufficient residence time in the pond to form nuisance blooms.

Table 2-4: 2013 mean (range) of selected water quality parameters in Beards Pond and tributaries.

	Total Phosphorus	Soluble Reactive Phosphorus	Total Nitrogen	Total Inorganic Nitrogen
Station	mg P/l	mg P/l	mg N/l	mg N/l
Beards Pond Deep	0.070 (0.054-0.085)	0.014 (0.006-0.035)	0.710 (0.570-0.980)	0.165 (0.068-0.226)
Pettee Brook	0.067 (0.060-0.086)	0.018 (0.004-0.037)	0.910 (0.770-1.170)	0.448 (0.207-0.757)
Beards Creek	0.038 (0.018-0.048)	0.009 (0.006-0.014)	0.600 (0.420-0.730)	0.231 (0.169-0.343)

Little Hale Pond

Table 2-5 presents a summary of selected water quality parameters in Little Hale Pond and its inlet. Figures 2-16 through 2-22 show selected 2013 water quality data for Little Hale Pond. Phosphorus concentrations observed in Little Hale are the highest of the three pond ranging from 0.057- 0.094 mg/l. Nitrogen concentrations are also high but not as high as those observed in Beards Pond and Mill Pond. As in the other two ponds, the presence of soluble reactive phosphorus in relatively high concentrations on all sampling dates indicates that there is more phosphorus in Little Hale Pond than the existing algae

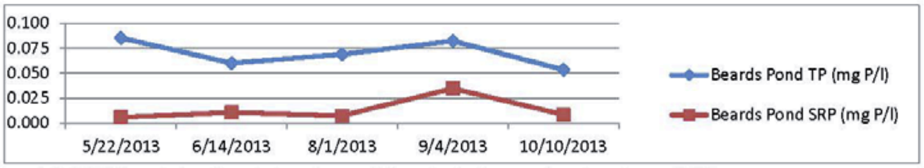


Figure 2-9: 2013 Beards Pond total phosphorus (TP) and soluble reactive phosphorus (SRP).

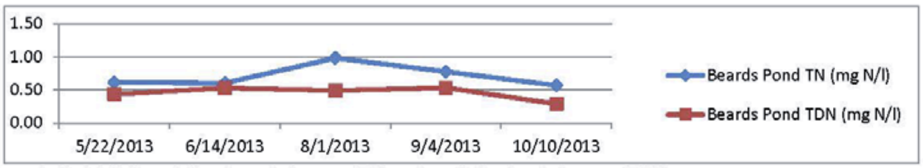


Figure 2-10: 2013 Beards Pond total nitrogen (TN) and total dissolved nitrogen (TDN).

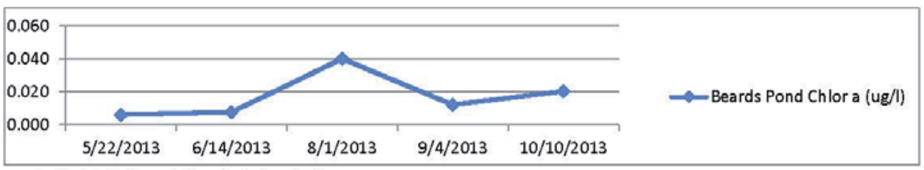


Figure 2-11: 2013 Beards Pond cholorphyll *a* .

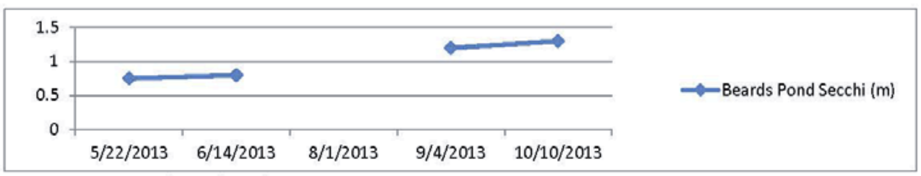


Figure 2-12: 2013 Beards Pond Secchi transparency.

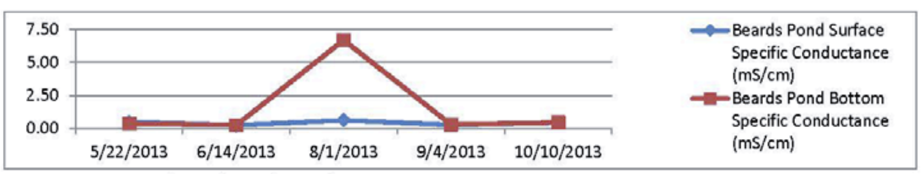


Figure 2-13: 2013 Beards Pond specific conductance.

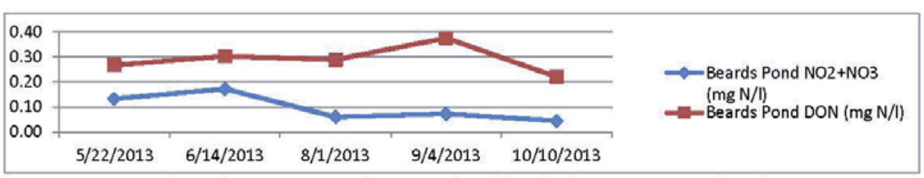


Figure 2-14: 2013 Beards Pond nitrite + nitrate (NO2+ NO3) and dissolved organic nitrogen (DON).

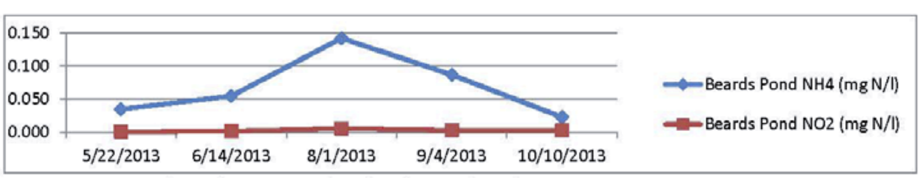


Figure 2-15: 2013 Beards Pond ammonium (NH4) and nitrite (NO2).

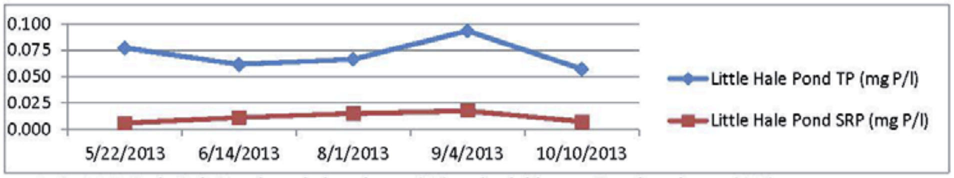


Figure 2-16: 2013 Little Hale Pond total phosphorus (TP) and soluble reactive phosphorus (SRP).

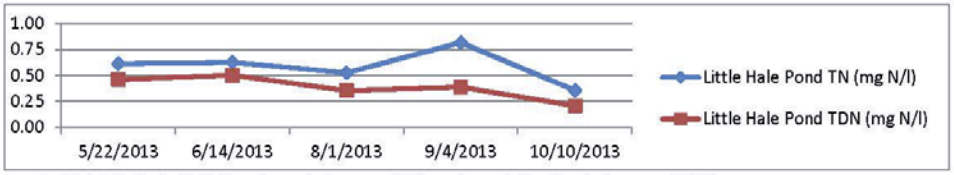


Figure 2-17: 2013 Little Hale Pond total nitrogen (TN) and total dissolved nitrogen (TDN).

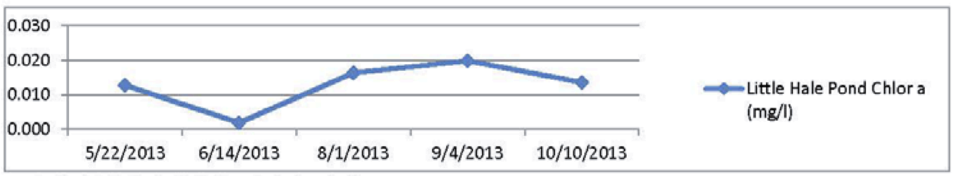


Figure 2-18: 2013 Little Hale Pond cholorphyll a.

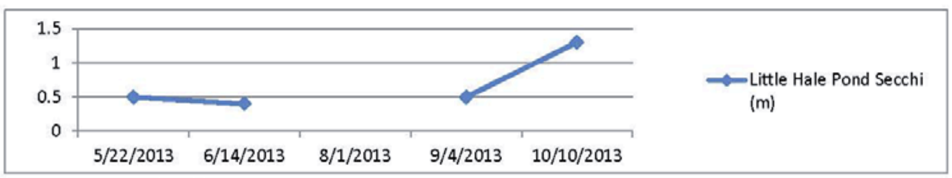


Figure 2-19: 2013 Little Hale Pond Secchi transparency.

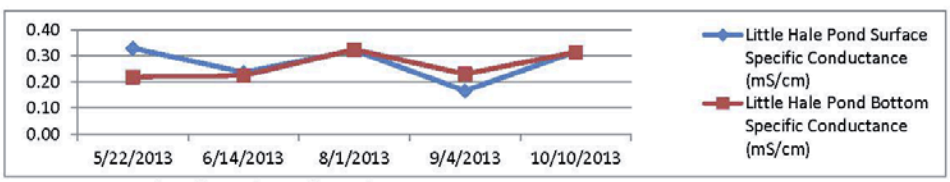


Figure 2-20: 2013 Little Hale Pond specific conductance.

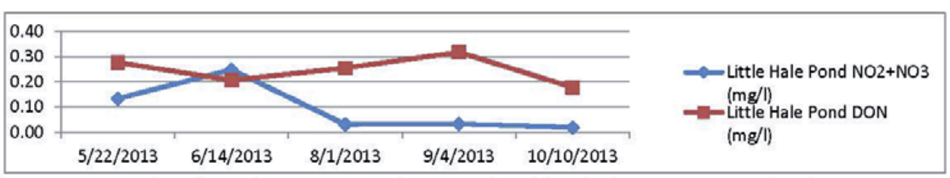


Figure 2-21: 2013 Little Hale Pond nitrite + nitrate (NO2+ NO3) and dissolved organic nitrogen (DON).

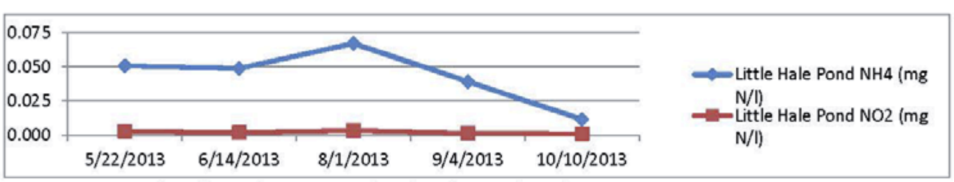


Figure 2-22: 2013 Little Hale Pond ammonium (NH4) and nitrite (NO2).

and plant communities can use. Observed inlet concentrations of phosphorus are lower than those observed in the pond suggesting that there may be some release of phosphorus from the sediments to the water column in Little Hale Pond. Conversations with a local resident suggested that a major development in the watershed immediately upstream of the pond coincided with an increase in plant and algal growth. Some of the load related to the development may now be slowly being released from the sediments. Because Little Hale Pond is in the watershed of Beards Pond, control of phosphorus in Little Hale will be beneficial to Beards as well as improving water quality in Little Hale

In Little Hale Pond there is sufficient nitrogen and phosphorus to grow plants and algae in nuisance quantities. The management challenge is to reduce one or both of these nutrients to levels that will ultimately limit the amount of plant and algal growth that can occur.

Table 2-5: 2013 mean (range) of selected water quality parameters in Little Hale Pond and its inlet.

	Total Phosphorus	Soluble Reactive Phosphorus	Total Nitrogen	Total Inorganic Nitrogen
Station	mg P/l	mg P/l	mg N/l	mg N/l
Little Hale Pond Deep	0.071 (0.057-0.094)	0.012 (0.006-0.018)	0.590 (0.360-0.820)	0.136 (0.031-0.297)
Inlet	0.039 (0.024-0.046)	0.011 (0.002-0.018)	0.610 (0.430-0.810)	0.321 (0.246-0.363)

Phosphorus is the primary limiting nutrient in most northern temperate lakes, hence algal growth is typically directly related to phosphorus concentrations. Nitrogen can also play a role in determining the type of algae present and the amount of algal growth in a water body since some cyanobacteria (blue-green algae) can fix nitrogen from the atmosphere. A nitrogen to phosphorus ratio of less than 10 generally suggests nitrogen limitation of algae growth while a ratio greater than 16 suggest phosphorus limitation. Between those numbers, either nitrogen or phosphorus availability may limit algal growth. An examination of water quality data collected during this study in 2013 shows a total nitrogen to total phosphorus ratios ranging from 6.2 to 14.3 (Table 2-6) These ratios suggests that algal growth in these ponds are limited by phosphorus at times and nitrogen at times, making control of both nitrogen and phosphorus important. It should be noted that concentrations of both phosphorus and nitrogen in all of the ponds are more than sufficient to grow algae and plants and in fact, light or flushing may be the limiting factor for algal growth currently. Because neither light nor flushing can be changed substantially, reduction of nutrients to the point where they limit plant and algal growth is still the most promising management strategy. However, because nutrient concentrations are currently so high, reductions in plant and algal growth may not be seen until substantial reductions in nutrient loading occur.

Table 2-6: Nitrogen to phosphorus ratios in the Durham ponds, 2013[1].

Pond	TN/TP (range)
Mill Pond	10.7 (8.0-12.5)
Beards Pond	10.3 (7.2-14.3)
Little Hale Pond	8.2 (6.2-10.1)

[1]TN/TP ratio over 16 suggests phosphorus limitation, ratio under 10 suggests nitrogen limitation

Since the Durham ponds are located immediately upstream of Great Bay, it is important to evaluate how they influence nutrient concentrations passing through the ponds. Typically, more nutrients are retained in ponds with dense macrophyte (aquatic plant) growth under low flow conditions than under high flow conditions (Saunders and Kalff 2001), at least while plants are actively growing. However, once aquatic plant biomass begins to die back in the mid to late summer, some of the nutrients incorporated in the plants are released back to the water column (Carpenter 1980, Carpenter and Lodge 1986, Farnsworth-Lee and Baker 2000). Sediment release of nutrients, primarily phosphorus, is another potential contributor to the observed nutrient concentrations in the ponds. Denitrification, the transformation of nitrate and nitrite in the water column to nitrogen gas by anaerobic bacteria represents a potential loss of nitrogen from the ponds. The nutrient flux through the ponds was estimated by subtracting the in-pond concentration of nutrients from the concentrations observed in the surface water inflows weighted by watershed area. This approximation does not take into account direct groundwater inflow to the ponds or atmospheric deposition however, these sources of water and nutrients are very small relative to the volume of water and mass of nutrients that enter the pond through surface water. Source and sink functions are presented in Table 2-7. The function of the ponds as sources or sinks for nutrients should be taken into account in any future management both for Great Bay and Little Hale Pond which is a source of water and nutrients to Great Bay via Beards Pond.

In general, the ponds themselves were larger sources of phosphorus later in the summer which is consistent with possible (not observed in this study) transient low dissolved oxygen concentrations at the sediment/water interface and low inflow from tributaries (this may have been a thinner layer than we could observe while measuring profiles). This may result in phosphorus releases from the sediment to the water column, particularly in Little Hale Pond. It is plausible that the growth and eventual dieback of dense stands of macrophytes in each of the Durham ponds results in storage and release of nitrogen from the macrophytes, resulting in the ponds being nitrogen sinks at times and sources at times. Additional sediment analysis for nutrients in the ponds would shed further light on the potential for sediment release.

Table 2-7: Pond function as a source[1] or sink[2] for nutrients[3].

Pond	TP	TN
Mill	source	sink at times, source at times
Beards	source	sink at times, source at times
Little Hale	large source	large sink at times, source at times

[1]source – more nutrients leave pond than come in.
[2]sink – more come into pond than leave pond.
[3] Source and sink calculated from monitoring data weighted by subwatershed area.

3.0 LLRM Model of Current Conditions

Current water, TP and TN loading was assessed using the LLRM methodology, which is a land use export/lake response model developed for use in New England and modified for New Hampshire lakes by incorporating New Hampshire land use TP and TN export coefficients when available.

The direct and indirect nonpoint sources of water, TP and TN to the Durham Ponds include:

- Atmospheric deposition (direct precipitation to the pond)s
- Surface water base flow (dry weather tributary flows, including any groundwater seepage into streams from groundwater)
- Stormwater runoff (runoff draining to tributaries or directly to the ponds)
- Waterfowl (direct input from resident and migrating birds)
- Direct groundwater seepage including septic system inputs from shorefront residences

Hydrologic Inputs and Water Loading

Calculating TP and TN loads to the Durham Ponds requires estimation of the sources of water to the ponds. The three primary sources of water are: 1) atmospheric direct precipitation; 2) runoff, which includes all overland flow to the tributaries and direct drainage to the lake; and 3) baseflow, which includes all precipitation that infiltrates and is then subsequently released to surface water in the tributaries or directly to the lake (i.e., groundwater). Baseflow is roughly analogous to dry weather flows in streams and direct groundwater discharge to the ponds. The annual water budget is broken down into its components in Table 3-1.

- Precipitation - Mean annual precipitation was assumed to be representative of a typical hydrologic period for the watershed. The annual precipitation value was derived from the USGS publication: Open File Report 96-395, “Mean Annual Precipitation and Evaporation - Plate 2”, (USGS 1996) and confirmed with precipitation data from weather station in Concord. For the Durham Ponds watersheds, 1.17 m (46.06 in) of annual precipitation was used.
- Runoff - For each land use category, annual runoff was calculated by multiplying mean annual precipitation by basin area and a land use specific runoff fraction. The runoff fraction represents the portion of rainfall converted to overland flow. This was compared to the standard water yield for this area.
- Baseflow - The baseflow calculation was calculated in a manner similar to runoff. However, a baseflow fraction was used in place of a runoff fraction for each land use. The baseflow fraction represents the portion of rainfall converted to baseflow.

The hydrologic budget was calibrated to a representative standard water yield for New England (Sopper and Lull, 1970; Higgins and Colonell 1971, verified by assessment of yield from various New England USGS flow gauging stations.

Table 3-1: Durham ponds annual water budget as estimated using LLRM.

WATER BUDGET	Mill	Beards	Little Hale
	m^3/yr	m^3/yr	m^3/yr
Atmospheric	44,928	42,120	13,221
Watershed Runoff	13,219,830	2,438,865	349,245
Watershed Baseflow	22,420,909	3,402,945	507,195
Total	35,685,667	5,883,930	869,661

3.1 Nutrient Inputs

Land Use Export

The Durham Ponds watershed boundaries were delineated using Geographic Information System (GIS). Land uses within the watershed were determined using GIS data (New Hampshire GRANIT 2013) and ground-truthing (when appropriate).

The TP and TN load for the watershed was calculated using export coefficients for each land use type. The watershed loading was adjusted based upon proximity to the ponds, soil type, presence of wetlands, and attenuation provided by Best Management Practices (BMPs) for water or nutrient export mitigation. The watershed load (baseflow and runoff) was combined with direct loads (atmospheric, septic system, and waterfowl) to calculate TP and TN loading. The generated load to the ponds was then input into a series of empirical models that provided predictions of in-pond TP and TN concentrations, chlorophyll *a* concentrations, algal bloom frequency and water clarity. Watershed land use is summarized in Table 3-2.

Atmospheric Deposition

Nutrient inputs from atmospheric deposition were estimated based on TP and TN coefficients for direct precipitation. The atmospheric load of 0.25 kg/ha/y includes both the mass of TP in rainfall and the mass in dryfall (Wetzel, 2001). The sum of these masses is carried by rainfall. The concentration calculated for use in the loading estimate 24 μg/L is roughly equivalent to the mean concentration (25 μg/L) observed in rainfall in Concord, NH (NH DES, 2008 Unpublished Data). The coefficient was then multiplied by the pond area (ha) in order to obtain an annual atmospheric deposition TP load. The coefficient used for atmospheric deposition of TN was 4.7 kg/ha/y (Wetzel 2001).

Waterfowl

Total phosphorus load from waterfowl was estimated using a TP and TN export coefficient and an estimate of annual mean waterfowl population. It was estimated that on average five waterfowl reside on the Mill Pond, seven on Beards Pond and two on Little Hale Pond. Waterfowl were assumed to be present for half of the year. The TP and TN export coefficients used for waterfowl were 0.56 kg/waterfowl/y and 0.95 kg/waterfowl/y, respectively. Waterfowl loadings of nutrients are very small relative to watershed loads.

Table 3-2: Land use categories by Durham pond subwatersheds.

	Area (Hectares)				
			Beards Pond		
	Mill Pond		Little Hale Pond		
Land Use	Oyster River	College Brook	Little Hale	Pettee Brook	Beards Creek
Urban 1 (Low Density Residential)	0.0	0.0	0.0	0.0	0.0
Urban 2 (Mid Density Residential/Commercial)	0.0	0.0	0.0	0.0	0.0
Urban 3 (Roads and rooftops)	37.0	44.0	5.0	34.0	12.0
Urban 4 (Industrial)	0.0	0.0	0.0	0.0	0.0
Urban 5 (Mowed Fields, Golf Course)	337.0	20.0	14.0	15.0	63.0
Agriculture 1 (Cover Crop)	207.0	3.0	0.0	0.0	19.0
Agriculture 2 (Row Crop)	43.0	0.0	0.0	0.0	0.0
Agriculture 3 (Grazing)	0.0	0.0	0.0	0.0	0.0
Agriculture 4 (UNH grass with manure)	16.0	21.0	0.0	2.0	2.0
Forest 1 (Deciduous)	0.0	0.0	0.0	0.0	0.0
Forest 2 (Non Deciduous)	0.0	0.0	0.0	0.0	0.0
Forest 3 (Mixed-mostly deciduous)	3964.0	65.0	87.0	168.0	299.0
Forest 4 (Wetland)	0.0	0.0	0.0	0.0	0.0
Open 1 (Wetland/Lake)	90.0	0.0	1.0	6.0	13.0
Open 2 (Meadow)	8.0	16.0	4.0	20.0	0.0
Urban 3 (Roads)-Mitigated	240.0	13.0	10.0	25.0	33.0
TOTAL	**4942.0**	**182.0**	**121.0**	**270.0**	**441.0**

Septic systems

TP export loading from residential septic systems was estimated within the 125 feet shoreline zone. The 125 feet zone is the minimum distance from lakes that new septic systems are allowed in New Hampshire with rapid groundwater movement through gravel soils. Most of Durham is currently served by municipal sewer including the entire Beards Creek/Little Hale subwatershed. There may be some residences that still utilize onsite septic systems in the Mill Pond subwatershed. It was assumed that as many as six (6) residences still had septic systems the potential to contribute directly to Mill Pond. Loading from other septic systems further away from the pond are accounted for in the land use coefficients used for the areal export analysis. The TP and TN load was calculated by multiplying a TP and TN export coefficient (based on literature values for wastewater TP and TN concentrations and expected water use), the number of dwellings, the mean number of people per dwelling, the number of days occupied per year, and an attenuation coefficient of 90% meaning that 10% of the phosphorus and nitrogen load from these systems reached Mill Pond, respectively. In Mill Pond, the TP and TN loading from shoreline septic systems is very low relative to watershed loads of these nutrients.

Internal Loading

Because the ponds do not stratify, internal loading was not expected be a major TP source to any of the ponds. However, the balance of nutrients to Little Hale Pond suggests that phosphorus is being released from the pond sediments. As a result, an internal load is only calculated for Little Hale based on typical phosphorus release rates of 6 $mg/m^2/day$. Additional sediment data may yield more accurate sediment release rates for Little Hale Pond. Although the internal load is small relative to the watershed load, it is likely that much of this load occurs in the mid-summer to early fall time period when watershed inputs are low. These internal loads may play an important role in the establishment and persistence of summer algal blooms in Little Hale Pond.

3.2 Phosphorus Loading Assessment Summary

The overall watershed of the Durham ponds consists of a mixture of rural, agricultural, residential and urban land uses. Because of their abundance and relatively high nutrient export coefficients, the developed areas of the watershed tend to yield a large portion of the nutrient load to the ponds. TP and TN loads were estimated based on runoff and groundwater land use export coefficients. The TP and TN loads were then attenuated as necessary to match tributary monitoring data. Loads from the watershed as well as direct sources were then used to predict in-pond concentrations of TP, TN, chl a, SDT, and algal bloom probability. The estimated load and in-pond predictions were then compared to in-pond concentrations. The attenuation factors were used as calibration tools to achieve a close agreement between predicted in-pond TP and TN and observed mean/median TP and TN. However, perfect agreement between modeled concentrations and monitoring data were not expected as monitoring data are limited to one season which may or may not have been representative of long term average conditions in the ponds.

The estimated existing TP and TN loads to each of the Durham Ponds by source are presented in Table 3-3.

Loading from the watershed was overwhelmingly the largest source of phosphorus and nitrogen to each of the ponds. Watershed management is the key to substantial improvements in the ponds and is discussed further in the management section of this report.

Table 3-3: Durham ponds modeled nutrient loading summary.

	Mill		Beards		Little Hale	
INPUTS	**TP (KG/YR)**	**TN (KG/YR)**	**TP (KG/YR)**	**TN (KG/YR)**	**TP (KG/YR)**	**TN (KG/YR)**
Atmospheric	1.0	18.0	0.9	16.9	0.3	5.3
Internal	0.0	0.0	0.0	0.0	2.7	0.0
Waterfowl	1.4	2.4	1.9	3.3	0.6	1.0
Septic System	1.1	2.2	0.0	0.0	0.0	0.0
Watershed Load	2,294.6	23,679.2	490.4	4,845.3	67.8	664.4
Total	2,298.1	23,701.8	493.3	4,865.6	71.3	670.6

3.3 Phosphorus Loading Assessment Limitations

While the analysis presented above provides a reasonable accounting of sources of TP loading to the Durham Ponds, there are several limitations to the analysis:

- Precipitation varies among years and hence hydrologic loading will vary. This may greatly influence TP and TN loads in any given year, given the importance of runoff to loading.
- Spatial analysis has innate limitations related to the resolution and timeliness of the underlying data. In places, local knowledge was used to ensure the land use distribution in the LLRM model was reasonably accurate, but data layers were not 100% verified on the ground. In addition, land uses were aggregated into classes which were then assigned export coefficients; variability in export within classes was not evaluated or expressed.
- TP and TN export coefficients as well as runoff/baseflow exports were representative but also had limitations as they were not calculated for the study water body, but rather are regional estimates.
- The TP and TN loading estimate from septic systems was limited by the assumptions associated with this calculation described above in the “Septic Systems” subsection.
- Water quality data for the Durham ponds are limited, restricting calibration of the model.

3.4 Lake Response to Current Phosphorus Loads

TP and TN load outputs from the LLRM Methodology were used to predict in-lake TP and TN concentrations using empirical models. The models include: Kirchner-Dillon (1975), Vollenweider (1975), Reckhow (1977), Larsen-Mercier (1976), and Jones-Bachmann (1976) for TP and three models presented by Bachman (1980) for TN. These empirical models estimate TP and TN from system features, such as depth and detention time of the waterbody. The load generated from the export portion of LLRM was used in these equations to predict in-lake TP and TN. The mean predicted TP and TN concentrations from these models was compared to measured (observed) values. Input factors in the export portion of the model, such as export coefficients and attenuation, were adjusted to yield an acceptable agreement between measured and average predicted TP and TN. Because these empirical models account for a degree of TP and TN loss to the lake sediments, the in-pond concentrations predicted by the empirical models are lower than those predicted by a straight mass-balance where the mass of TP and TN entering the pond is equal to the mass exiting the pond without any retention although retention is greatly reduced in ponds like the Durham Ponds with rapid flushing rates. Also, the empirical models are based on relationships derived from many other lakes and ponds. As such, they may not apply accurately to any one pond, but provide an approximation of predicted in-pond TP and TN concentrations and a reasonable estimate of the direction and magnitude of change that might be expected if loading is altered. These empirical modeling results and mean field data are presented in Table 3-4.

In general, predicted nutrient concentration match field data for the Durham Ponds. Because freshwater systems are most frequently limited by phosphorus, calibration focused on matching predicted phosphorus with field data. However, agreement between model predictions and field data is also good for nitrogen. In Little Hale Pond, the model somewhat over-predicts nitrogen levels. In all three ponds, the model substantially under-predicts chlorophyll *a* levels. Each of the ponds is rapidly flushed and it is likely that much of the time algal cells are washed out of the ponds before they can reproduce and form dense colonies. However as was seen in the measured data, during dry times, algal blooms can become established in the ponds. According to the models of the ponds, there are sufficient nutrients in the ponds to form algal blooms with chlorophyll *a* levels in excess of 0.010 mg/l more than 97% of the time. Were it not for the rapid flushing rate of the ponds, water quality would likely appear to be much worse.

Table 3-4: Predicted and measured water quality parameters in Durham ponds.

Water Quality Parameter	Mill Pond	Beards Pond	Little Hale Pond
Predicted TP (mg/l)	0.060	0.075	0.074
Measured TP (2013) (mg/l)	0.060	0.070	0.071
Predicted TN (mg/l)	0.640	0.770	0.724
Measured TN (2013) (mg/l)	0.630	0.710	0.590
Predicted Chlorophyll *a* (mg/l)	0.030	0.041	0.040
Measured Chlorophyll *a* (mg/l)	0.009	0.017	0.013
Predicted Probability of Algal Bloom > 0.010 mg/l	97.5%	99.5%	99.4%

The TP and TN loads estimated using the LLRM methodology translates to predicted mean in-pond TP concentrations ranging from 0.060 to 0.075 mg/L for the three Durham Ponds. These concentrations are sufficient to fuel substantial algal and plant growth in the ponds.

3.5 Reduction Needed

Current TP and TN loading and in-pond concentrations are more than sufficient to fuel algal blooms and encourage the growth of aquatic plants. In order to realize improvement in the appearance of the ponds, target reductions of both phosphorus and nitrogen were calculated. While improvement may be seen with lesser reduction and reductions beyond these may result in further improvement in the ponds, these levels were chosen to provide a readily apparent improvement in water quality that might be achievable with very aggressive watershed management. Estimates of nutrient reductions are presented in Table 3-5.

Table 3-5: Nutrient reductions needed to meet benchmark nutrient levels in Durham ponds.

Waterbody	P reduction required to reach 0.020 mg/L in ponds	N reduction required to reach 0.200 mg/L in ponds	Source
Mill Pond	66%	69%	LLRM modeling, this study
Beards Pond	73%	75%	LLRM modeling, this study
Little Hale Pond	73%	74%	LLRM modeling, this study
Great Bay	No target	30-50%	Great Bay Study(VHB 2014, in prep)[1]

[1]Target goals for Great Bay are based on comprehensive combined wastewater and non-point reductions required to avoid eutrophication of Great Bay.

These data, together with suggested management recommendations, provide a basis for the development of an action plan for the Durham Ponds discussed below

4.0 Potential Management Options

The following general TP and TN control plan provides recommendations for future best management practices (BMP) work and necessary water quality improvements. The recommendations are intended to provide potential watershed and pond management strategies that can improve water quality to meet target loads. Note that providing a comprehensive diagnostic/feasibility study is beyond the scope of this report, but we have attempted to narrow the range of management options in accordance with known loading issues, desired loading reductions and potential uses of the ponds.

The most applicable techniques for reducing loading of nutrients (and associated plant and algal growth) to the Durham Ponds are watershed management techniques aimed at reducing nutrient loading at the source. In-pond techniques such as dredging may help in re-establishing some uses of the ponds while watershed nutrient reductions are being implemented. A summary of typical nutrient management and in-pond options and their potential applicability to each of the Durham Ponds is presented in Table 4-1. Watershed options are discussed in Section 4-1 while in-pond options are discussed in Section 4-2. A summary of the pros, cons and applicability to the Durham ponds of many other in-pond options is presented in Appendix B.

The more watershed nutrient reduction that is accomplished prior to implementing in-pond techniques, the greater the longevity of the in-pond techniques. Further consideration of costs, regulatory constraints and environmental impacts is necessary before any of these strategies is implemented.

Table 4-1: Potential for improving water quality and support of designated uses in the Durham ponds.

Management Option	Mill	Beards	Little Hale
Watershed BMPs (N&P)	high	high	high
Dam Removal	medium	medium	medium
Plant Harvesting	medium	medium	low
Herbicides	medium	medium	medium
Dredging	high	medium	high
Aeration/oxygenation	low	low	low
Selective Withdrawal	low	medium	medium
Biomanipulation	low	low	low
Nutrient Inactivation	low	low	low
Limit waterfowl feeding	high	high	high
Public Education	high	high	high

4.1 Watershed Nutrient Management

The long-term successful implementation of management of the ponds will depend on reducing nutrient inputs from the watershed. It is anticipated that nutrient reductions associated with this plan will be conducted in phases. Watershed management BMPs are being proposed as a part of the nitrogen reduction strategy developed to benefit Great Bay. Most of the BMPs being considered for removal of nitrogen will also reduce phosphorus. The combination of nitrogen and phosphorus reductions will have direct benefits to the ponds. In addition to watershed management BMP's are non- structural BMP's geared towards source reduction. These include fertilizer limitations, zoning, land conservation, stream buffer protection, pet waste management and general public education. These critical elements are discussed further below.

Experience suggests that aggressive implementation of watershed BMPs may result in a maximum practical TP loading reduction of 60-70%. Greater reductions are possible, but consideration of costs, space requirements, and legal ramifications (e.g., land acquisitions, jurisdictional issues), limit attainment of such reductions. Most techniques applied in a practical manner do not yield >60% reductions in TP loads (Center of Watershed Protection, 2000). Better results may be possible with widespread application of low impact development techniques, as these reduce post-development volume of runoff as well as improve its quality, but there is not enough of a track record yet to generalize attainable results on a watershed basis. As presented in Table 3-5, reductions required to clearly improve water quality in the Durham ponds are on the order of 66-75% however, reductions on the order of 50% will likely have a positive effect on water quality in the ponds

There are a number of stormwater BMPs that could appropriately be implemented in the Durham Ponds watershed (Table 4-2). Stormwater BMPs fall into three main functional groups: 1) Recharge / Infiltration Practices, 2) Low Impact Development Practices, and 3) Extended Detention Practices. The table lists the practices, the pollutants typically removed and the degree of effectiveness for each type of BMP. Specific information on the BMPs is well summarized by the Center for Watershed Protection (2000).

The following sections describe general non-point nutrient (TP and TN) control methods that could be employed to control nutrient transport into the ponds. These management practices could provide reductions in current loading rates and should be considered along with other management options where it is appropriate to incorporate them into the existing landscape or future development and redevelopment proposals. As the ponds improve the implementation strategy should be re-evaluated using current data and modeling and the plan for further load reduction adapted accordingly.

Table 4-2: Best Management Practices selection matrix (adapted from ENSR 2005)

Key:
- Adverse Impact
- Moderate Mitigation
- Good Mitigation
- Minimal Mitigation
- Moderately Suited
- Well Suited
- Not Applicable

Management Practice	Ability to Mitigate: Runoff Volume (↑)	Peak Flow Rates (↑)	Bankfull Flow (↑)	Baseflow (↓)	Mod. Sed. Transport	Channel Morph. Changes [1]	In-Stream Temp. (↑)	Sediment conc. (↑)	Nutrient conc. (↑)	Metal Conc. (↑)	Hydrocarbon Conc. (↑)	Bacteria/Pathogens (↑)	Organic carbon Conc. (↑)	MTBE Conc. (↑)	Pesticide conc. (↑)	Deicer conc. (↑)	Applicability: New Development	Retrofit	Urban	Sub-Urban	Residential Sub-Division	Commercial	Industrial	Notes
Recharge / Infiltration Practices[2]																								
Infiltration Swale	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Moderate	Good	Moderate	Well Suited	Moderately Suited	Moderately Suited	Well Suited	Well Suited	Well Suited	Well Suited	Permeable site soils required. Pre-treatment recommended.
Infiltration Trench/Galley	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Moderate	Good	Moderate	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Permeable site soils required. Pre-treatment recommended.
Retention/Infiltration Basin	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Moderate	Good	Moderate	Well Suited	Moderately Suited	Moderately Suited	Well Suited	Well Suited	Well Suited	Well Suited	Permeable site soils required. Pre-treatment recommended.
Low Impact Development Practices																								
Bioretention	Good	Moderate	Moderate	Moderate	Moderate	Moderate	Good	Good	Good	Good	Good	Good	Good	Moderate	Good	Moderate	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	
Disconnecting Impervious Area	Good	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Minimal	Well Suited	Well Suited	Moderately Suited	Well Suited	Well Suited	Well Suited	Well Suited	
Flow Path Practices	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Well Suited	Not Applicable	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Includes increasing roughness, sheet flow, flow path length, and flattenting slopes.
Green Roof	Good	Good	Good	Minimal	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Well Suited	Moderately Suited	Well Suited	Well Suited	Moderately Suited	Well Suited	Well Suited	
Minimize Disturbance Area	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Well Suited	Not Applicable	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Used as a component of LID site design.
Minimize Site Imperviousness	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Well Suited	Not Applicable	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Includes imiting use of sidewalks, and reducing road/driveway length/width.
Porous Pavement	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	
Preserve Infiltratable Soils	Good	Moderate	Moderate	Good	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Well Suited	Not Applicable	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Used as a component of LID site design.
Preserve Natural Depression Areas	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Well Suited	Not Applicable	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Used as a component of LID site design.
Rain Barrels/Cisterns	Good	Moderate	Moderate	Moderate	Moderate	Moderate	Good	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	
Rain Garden	Good	Moderate	Moderate	Moderate	Moderate	Moderate	Good	Good	Good	Good	Good	Good	Good	Moderate	Good	Moderate	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	
Soil Amendment	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Well Suited	Well Suited	Moderately Suited	Well Suited	Well Suited	Moderately Suited	Moderately Suited	Used as a component of LID site design.
Vegetated Filter Strip	Good	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Minimal	Minimal	Minimal	Well Suited	Well Suited	Moderately Suited	Well Suited	Well Suited	Well Suited	Well Suited	
Vegetation Preservation	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Well Suited	Not Applicable	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Used as a component of LID site design.
Extended Detention Practices																								
Created Wetland/Biofilter Detention	Moderate	Good	Moderate	Minimal	Moderate	Moderate	Adverse	Moderate	Moderate	Moderate	Moderate	Minimal	Moderate	Moderate	Moderate	Moderate	Well Suited	Moderately Suited	Moderately Suited	Well Suited	Well Suited	Well Suited	Well Suited	
Extended Detention Pond	Minimal	Good	Moderate	Minimal	Moderate	Moderate	Adverse	Moderate	Moderate	Moderate	Good	Moderate	Moderate	Minimal	Moderate	Minimal	Well Suited	Moderately Suited	Moderately Suited	Well Suited	Well Suited	Well Suited	Well Suited	
Wet Detention	Minimal	Good	Moderate	Minimal	Moderate	Moderate	Adverse	Moderate	Moderate	Moderate	Good	Adverse	Moderate	Minimal	Moderate	Minimal	Well Suited	Moderately Suited	Moderately Suited	Well Suited	Well Suited	Well Suited	Well Suited	
Other Best Management Practices																								
Deep Sump Catch Basins	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal	Moderate	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Pre-treatment prior to infiltration BMPs
Sand/Organic Filter	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Minimal	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	
Swale	Moderate	Good	Moderate	Minimal	Moderate	Moderate	Minimal	Moderate	Moderate	Moderate	Good	Moderate	Moderate	Minimal	Moderate	Minimal	Well Suited	Moderately Suited	Moderately Suited	Well Suited	Well Suited	Well Suited	Well Suited	Dry swale with some infiltration.
Water Quality Inlet	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal	Moderate	Minimal	Minimal	Moderate	Minimal	Minimal	Minimal	Minimal	Minimal	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Well Suited	Includes proprietary hydrodynamic devices. Pre-treatment prior to exfiltration BMPs.

[1] *Impacts include channel enlargement/Incision/embededness, changes in pool/riffle structure, and reduced channel sinousity.*

[2] *Recharge and infiltration measures require permeable soils and pre-treatment is recommended. See specific BMP descriptions for more information.*

4.1.1 Land Development

As natural undisturbed land is developed, impervious areas and the potential for nutrient export are typically increased. Increased volume and rates of runoff from impervious roofs, driveways, and compacted soils causes greater potential for the transport of nutrients to surface water. If not properly managed, these increased flows can cause substantial erosion of land that previously had not conveyed water as well as along existing drainage channels. The sediment load from such erosion can be a major source of phosphorus as the available phosphorus is dissolved in the water and transported to surface water.

Specific sources of nutrients introduced with development include lawn and garden fertilizers, septic systems, and pet and livestock/fowl waste. Without proper erosion controls, a considerable mass of nutrients and sediment can be transported during construction activities.

4.1.1.1 Considerations for Management of Land Development

Proactive planning can preserve water quality. The watershed planning process is intended to give a direction and goal for planning and watershed management. Water quality impacts associated with development activities can be mitigated through zoning and planning ordinances and measures including:

- Removing the potential for development: If a land owner is willing, a conservation organization or the town can either remove the development rights from a property through a conservation easement, or through deeded ownership of the land. Land owners may donate conservation easements in exchange for tax deductions, or request financial compensation.
- General Ordinances
  - Local or regional bans on phosphorus in lawn fertilizer
- New Development / Construction Ordinances
  - Incorporate low impact development (LID) requirements
  - Minimize disturbed areas
  - Maintain natural buffers
  - Maximize setbacks from ponds and tributaries
  - Minimize impervious cover
  - Minimize construction footprint
  - Pervious pavers / pavement
  - Minimize soil compaction during construction
  - Provide drainage management for impervious areas (gravel & paved driveways, and roofs)
  - Dry wells
  - Infiltration trenches
  - Bioretention Systems (“rain gardens”)
  - Rain Barrels
- Enforcement of Ordinances

Any of the above provisions could be codified in the Durham Planning or Zoning regulations.

4.1.2 Roads and Stormwater Management

There are many miles of road within the Durham Ponds watershed. Most of these roads are paved and many discharge runoff directly into streams that flow to the Durham Ponds.

4.1.2.1 Road Maintenance

To minimize sediment and nutrient transport from roadways into the Durham Ponds and tributaries, physical treatment practices should be employed and routine maintenance of the roads and drainage systems should be performed.

A primary mechanism for the transport of phosphorus from paved roads is sheet flow washing of sediments. Sand that is applied in winter to paved roads is a major source of sediment load to down gradient streams and ponds. Best management practices for minimizing the sediment and phosphorus load from paved roads are:

- Minimize use of sand and salt during the winter;
- Remove sand from the streets prior to spring rain and ground thaw;
- Routine monitoring of and removal of sediments in stormwater catch basins.

As runoff is channelized along roadside ditches, its potential to cause erosion and suspend sediment greatly increases. In order to minimize the sediment loads associated with drainage conveyance, it is important to understand the size and characteristics of the area draining to channel and properly engineer the channel and treatment practice for predicted storm volumes and peak rates.

Routine inspections of the drainage along roads are important for the identification of potential problems. Some problems with simple solutions such as a clogged culvert could cause major damage to a paved road.

4.1.2.2 Stormwater Management Practices

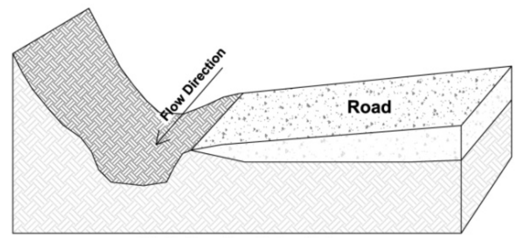
Paved and gravel roads are essentially impervious so during rain events water rapidly collects and flows to the nearest water conveyance channel or area where it can infiltrate to the ground. Road-side ditches have historically been built or were naturally created to rapidly drain stormwater to the nearest water body, but due to increased flooding, erosion, and contaminant transport associated with this practice, alternative techniques for managing road runoff are recommended. Minimizing the accumulation of channelized flow is the initial step toward controlling stormwater. This is accomplished by directing runoff to areas near the point of generation that are capable of naturally infiltration. As greater amounts of runoff accumulates, the complexity of capturing, slowing, and treating the stormwater increases along with the costs. The New Hampshire Stormwater Manual (NHDES, 2008) is a comprehensive resource for stormwater best management practices. As residential development, and road and driveway construction takes place in the Durham ponds watershed, it will be important that stormwater controls are implemented in accordance with this guidance document.

The following stormwater management practices are presented as examples of measures that could be employed in the Durham ponds watershed. These measures, as well as others that are listed in Table 4-2 and described in the NH Stormwater Manual should be considered for existing sites and those that are discovered or developed in the future.

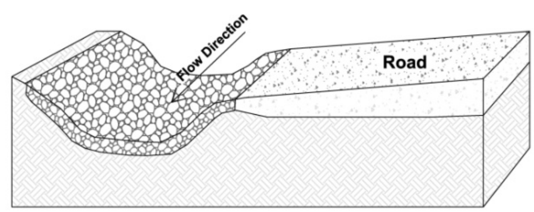
As a general rule, BMPs that encourage infiltration or stormwater detention would reduce channel erosion and reduce TP concentrations by settling and contact with the soil prior to entry to the lake. BMPs designed with vegetation will function to remove TN.

Swales

Swales convey stormwater along roadsides to prevent water from ponding on, or flowing over the road. In many cases, road-side swales are ditches that have been created by channelized stormwater eroding a path of least resistance. The sediment and nutrient load associated with this type of drainage is considerable, as is the potential damage to the road integrity and abutting property. Properly designed swales provide a channel that is capable of conveying expected storm flow rates without erosion. Factors that need to be considered in the design of a road-side swale include topographic slope, drainage area, expected storm flow, swale dimensions, outlet control, base material and vegetation.



High Erosion Potential
Narrow Roadside Ditch with Steep Side-Slope



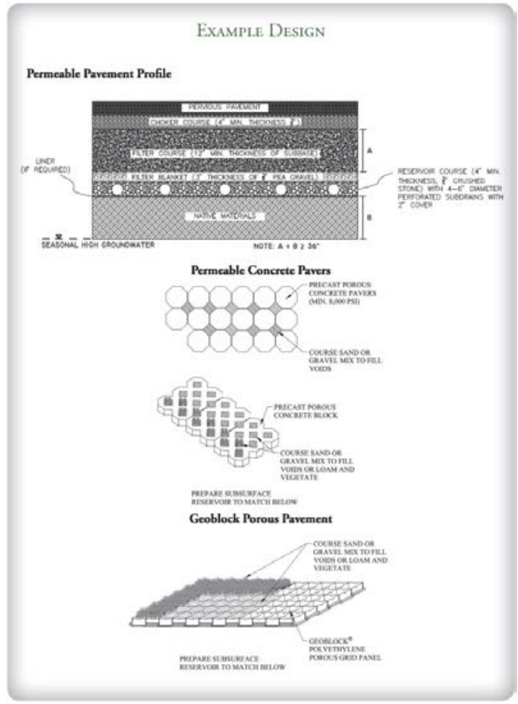
Low Erosion Potential
Riprap Reinforced Swale
Widened with Lowered Side-Slopes

The performance of swales can improved and their potential contribution to sediment and nutrient loading reduced by increasing their depth and width, reinforcing with appropriately sized riprap, installing check dams (riprap) and step pools, and reducing their slope (cross-section and profile). Where feasible, infiltration trenches should be considered in place of conveyance swales. Opportunities for swales to turn-out into areas with excess infiltration capacity should be assessed and utilized to convert channelized swale flow to sheet flow and infiltration.

Culvert Inlet and Outlet Scour Protection

To reduce sediment and nutrient loading associated with erosion at culvert inlets and outlets, loose sediments should be routinely removed, the inlet and outlet pools should be reinforced with appropriately sized riprap, and headwalls should be installed. Inlet and outlet culvert areas are subject to concentrated flow velocities so the potential for erosion at these locations is considerable. By installing an energy dissipation/settling pool at these locations where scour is likely due to high flow velocities, erosion can be mitigated. These pools are intended for use at the low point of swales and intermittent streams and stormwater drainage culverts, not perennial streams. The size of this type of pool is dependent upon the expected flow rates and the site conditions.

In some cases the installation of a deep-sump catch basin is appropriate for capturing runoff and reducing potential erosion associated with culvert designs. The area around the catch basin inlets should be reinforced with riprap to minimize sediment loading from the concentrated areas of flow immediately surrounding the basin.

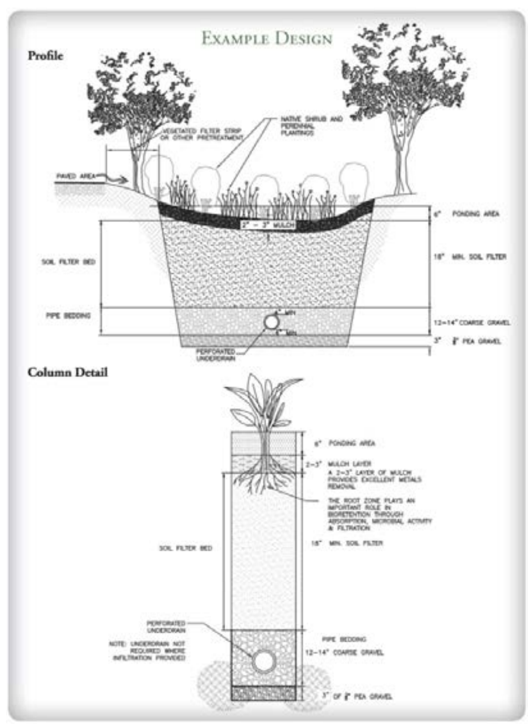


Drop Inlet Catch Basin

To reduce the potential for catch basins to be a source of sediment and nutrient loading it is important that sediments are routinely removed. The land cover immediately around catch basin inlets should be stable and sloped at grades that minimize the transport of sediments. In areas with high potential for sediment loads, the installation of a hydrodynamic separator should be considered. Catch basins with perforated bases should be considered for use as dry wells in areas with sufficient depth to groundwater and suitable soil permeability.

Pervious Pavement / Pavers

Properly designed and constructed pervious asphalt pavement and pervious concrete pavers result in no direct runoff from these areas. The installation of pervious pavement/pavers is ideal where land area for runoff treatment is insufficient and the ability to infiltrate runoff before it channelizes is limited. Factors that control the feasibility of this stormwater control option include the depth to groundwater, depth to bedrock, native soil permeability, topographic limitations, and expected traffic load. For optimal performance it is essential that pervious pavement / pavers are constructed in accordance with current design standards. Example design shown here is from the NH Stormwater Manual, 2008, Volume 2.



Bioretention System

Bioretention systems are shallow basins designed to infiltrate runoff thorough an engineered highly permeable soil material. Water treated with a bioretention system either infiltrates to the groundwater or discharges via an underdrain system. Bioretention systems are vegetated to assist with the uptake of pollutants and to blend in with landscape aesthetics. Typically these systems are designed with a treatment capacity of the 10-year 24-hour storm. Pretreatment to remove settleable solids is required, as is a means to bypass flows greater than the design storm. Design criteria are specified in the NH Stormwater Manual, 2008, Volume 2). Example design shown here is from the NH Stormwater Manual.

Total suspended solids and total phosphorus removal from properly designed and installed bioretention systems is reported to be approximately 90% and 65%, respectively (NH Stormwater Manual).

4.1.3 Shoreland Management

Shoreland activities can significantly contribute to sediment and nutrient loading to surface waters. To minimize the impact of shoreland development and associated near-pond and in-pond activities the following practices should be employed:

- Shoreland buffers should be maintained as specified in the NH Shoreland Water Quality Protection Act.
- Maintain a minimum of 50 foot buffer of natural vegetation along the shoreline;
  - No beach construction – filling along shoreline
  - Incorporate infiltration step designs on pathways to the water as specified in A Shoreland Homeowner's Guide to Stormwater Management (NHDES 2014).
- Lawn/Yard Maintenance;
  - No dumping of grass clippings in or near water
  - Minimal use of lawn fertilizer or no use of fertilizer
- Minimize impervious surfaces (roofs, driveways, etc…) and incorporate storm water controls to minimize runoff from impervious surfaces.
  - Rain Barrels
  - Dripline Trenches
  - Dry Wells
- Remove pet waste from shoreline areas;
- Minimize disturbance of lake sediments (avoid sediment churning from boat motors).

Many of the practices listed above are covered in detail in a recent publication entitled "Landscaping at the Water's Edge: An Ecological Approach" (UNH Cooperative Extension 2007).

4.1.4 Agriculture

Agriculture is currently a small but controllable source of nutrients to the Durham Ponds watershed. Nutrient loading from agricultural land can be managed through many methods including runoff controls and treatment, grazing area restrictions and setbacks, and manure application timing and buffers. Considerable information is available to assist with the management of nutrient loads from agricultural lands. The US Environmental Protection Agency has published a series of Nonpoint Source Management Fact Sheets (http://www.epa.gov/owow/nps/pubs.html#ag).

4.2 In-lake Techniques

There are numerous in-lake management options that could be considered for the Durham Ponds. These are discussed in much more detail in Appendix B. Those options that have particular relevance to the Durham Ponds are discussed in more detail here.

The factors that control the abundance of algae form the basis for attempts to manage and limit them. Light and nutrients are the primary needs for algae growth. Where algal densities, non-algal turbidity, or shading by rooted plants do not create a light limitation, the quantity of algae in a lake is usually directly related to the concentration of the essential plant nutrient in least supply. In many cases this element is phosphorus. Occasionally the limiting nutrient is nitrogen. In the Durham Ponds, the limiting nutrient fluctuates between nitrogen and phosphorus. Many of the watershed based nutrient control options discussed in Section 4.1 offer reductions in both nitrogen and phosphorus with the same practice or BMP. Appendix Table B-1 provides an outline of in-pond algal management techniques available for use at this time while Appendix Table B-2 provides information on relevant techniques for control of rooted aquatic plants. These tables present the range of options that could be applied. These techniques take advantage of algal ecology and supplement or counteract the forces involved in algal losses or growth, respectively.

Filamentous algal mats have a distinctive ecology and are difficult to control. Mats typically form at the sediment-water interface or in association with rooted plant beds, taking nutrition from decay processes in that zone and surviving at low light levels through high densities of photosynthetic pigments. As mat density increases, photosynthetic gases are often trapped, and the mat may float upward and expand. Grazing control of mats is negligible, settling is not a major force, and harvesting is not practical in most cases. Algaecides are often ineffective once a dense mat has formed, as contact between algae and algaecide is limited. Prevention of mat formation through sediment removal or treatment (phosphorus inactivation or early algaecide application) is preferable to dealing with extensive, well-formed mats.

Given the specific circumstances in the Durham Ponds many of the in-pond techniques listed in Appendix B warrant no further consideration at this time. Because the Durham ponds receive high nutrient loads from external sources, they are unlikely to respond acceptably to in-lake alternatives used alone without watershed control of nutrient loading. Details of the dredging option which may be most applicable to the Durham Ponds is provided in narrative form below.

4.2.1 Dredging

The elimination of substrate for plant growth can be controlled by removing layers of enriched sediment. This may produce lower in-pond nutrient concentrations and less rooted plant growth, assuming that there has been adequate diversion or treatment of incoming nutrient, organic and sediment loads from external sources and all nutrient rich sediment has been removed from the target areas.

Dredging the existing soft sediment in portions of the Durham Ponds should benefit some uses of the ponds by creating additional open water areas free of aquatic plants for recreation and fishing. Dredging is a very effective way to remove nutrient rich sediment as well as reserves of seeds, spores and other resting stages of plants. Dredging may also reduce internal loading which may be important for Little Hale Pond. Removal of all soft sediment down to inorganic substrate would essentially eliminate the ability for many species of plants to root and thrive and increase water depth, usually considered a benefit in most aquatic management programs.

Dredging may directly remove organisms from the ponds or have indirect impacts on organisms through changing substrate conditions and food resources. The change in bottom features will affect which organisms choose to dwell there after dredging; shifts in the composition of biological communities are to be expected. If water clarity is sufficient and not all soft sediment has been removed, growth of rooted aquatic plants may increase. Typically disturbed sites with nutrient rich sediment favor invasive species such as water milfoil. Potential sites for dredging in the three Durham ponds are presented in Figures 4-1 to 4-3.

Figure 4-1: Potential dredging locations in Mill Pond.

Figure 4-2: Potential dredging locations in Beards Pond

Figure 4-3: Potential dredging locations in Little Hale Pond.

Very preliminary cost estimates for dredging the Durham ponds are provided below (Table 4-3). The costs are not expected to be especially high relative to other dredging methods due to the ability to draw the ponds down and conduct much of the dredging in the dry. Cost estimates were adapted from Wagner (2004).

Without changes in the watershed load, or dredging to a depth where inorganic sediments are exposed, the lifespan of a dredging program for the ponds may be limited to 5-10 years. However, with watershed control of nutrients and sediments, and transforming the area to be dredged into one that is not favorable for aquatic plant growth, the lifespan can be greatly increased.

Table 4-3: Preliminary cost estimates for dredging in Durham ponds (adapted from Wagner 2004).

Pond Section	Mill Pond DS	Mill Pond US	Beards Pond	Little Hale Pond
Target Area dimensions (m)	75 x 75	40 x 40	40 x 400	30 x 80
Target Area (m2)	5625	1600	16000	2400
	Dredging 0.5M of Sediment			
Target Depth of Sediment to be Dredged (m)	0.5	0.5	0.5	0.5
Volume of Sediment to be Dredged (m3)	2813	800	8000	1200
Volume of Sediment to be Dredged (cy)	3679	1046	10464	1570
	Dredging 1M of Sediment			
Target Depth of Sediment to be Dredged (m)	1.0	1.0	1.0	1.0
Volume of Sediment to be Dredged (m3)	5625	1600	16000	2400
Volume of Sediment to be Dredged (cy)	7358	2093	20928	3139

	Dredging 0.5 M of Sediment			
Low Cost per CY	$5	$5	$5	$5
Low Dredging Cost	$18,394	$5,232	$52,320	$7,848
Medium Cost per CY	$15	$15	$15	$15
Medium Dredging Cost	$55,181	$15,696	$156,960	$23,544
High Cost per CY	$25	$25	$25	$25
High Dredging Cost	$91,969	$26,160	$261,600	$39,240
	Dredging 1 M of Sediment			
Low Cost per CY	$5	$5	$5	$5
Low Dredging Cost	$36,788	$10,464	$104,640	$15,696
Medium Cost per CY	$15	$15	$15	$15
Medium Dredging Cost	$110,363	$31,392	$313,920	$47,088
High Cost per CY	$25	$25	$25	$25
High Dredging Cost	$183,938	$52,320	$523,200	$78,480

At this point in time it may be advantageous to dredge portions of Mill Pond near the park and Little Hale Pond. Once Little Hale has been dredged and watershed loads have been controlled, dredging of portions of Beards Pond may be considered, however, the extent and cost of dredging Beards Pond may make that option impractical. Little Hale Pond on the other hand may have received a great deal of sediment and associated nutrients during the time when the watershed was developed.

These nutrient rich sediments may be an ongoing source of nutrients for both Little Hale and Beards pond. For Little Hale Pond the sediments may account for 5-10% of the loading on an annual basis but during portions of the growing season, particularly if it is dry, the sediments could be responsible for the majority of the phosphorus loading. Removal of these sediments may have a very beneficial impact on water quality and aquatic macrophyte growth.

4.3 Public Outreach and Education

The centerpiece of efforts to control nutrient loading to the Durham Ponds is public outreach and education. In addition to educating individual homeowners, businesses and public institutions on the implications of their actions on nutrient export to the ponds and the impact of nutrients on pond water quality, the secondary purpose to education and outreach is to educate decision makers at the town level so that nutrient management becomes part of the criteria evaluated as decisions are made on zoning, planning, public works, recreation and site development issues. In order to further public education, the following elements might be considered.

- **Current Program: Signage at the public park on Mill Pond and at the Mill Pond dam**.

- **Suggested Enhancements**
    - Build a kiosk to better present watershed and water quality information.
    - Stencil or put signs near storm drains in the watershed, particularly along Mill Pond, and above Little Hale Pond with a message that says: “Drains to pond and Great Bay, do not dump” or equivalent.”
    - Prepare and distribute flyers or information sheets on specific issues related to stormwater, fertilizer, shoreland protection and native plantings etc.
    - Present materials at local schools to engage young people.
    - Provide information related to successful BMP installation. This could range from a guided or self-tour of completed BMP projects to a seminar on landscaping that features a property that does an exceptionally good job at incorporating measures to reduce nutrient export to the ponds and is aesthetically pleasing.
    - Provide information and/or sponsor training courses for agricultural interests, developers or public works officials on BMPs for phosphorus reduction.

Durham is fortunate to have a great deal of public awareness of these issues at present due to the work of the town and the university but there is room for improvement as there are numerous instances of green lawns close to the ponds, inadequate shoreline buffers and old stormwater conveyance systems. Public education on water quality issues should be viewed as a continuous and ongoing process as the town moves forward.

4.4 Management Recommendations

Restoring historic uses of the ponds currently impaired by algal blooms and plant growth will require an extensive and comprehensive program of management strategies. Given that the Durham ponds continue to have large external nutrient loads, watershed non-point source control of nutrients should be the primary focus aimed at reducing nutrient loading at the source with emphasis on a blend of structural BMPs, planning and public education. In-pond techniques may help in re-establishing some uses of the ponds while watershed nutrient reductions are being implemented or may be viewed as a method for decreasing the time to recovery once watershed nutrient inputs have been controlled. In-pond techniques that could be considered include dredging. Implementation of a comprehensive program should provide lasting relief from algal blooms and excessive plant growth.

The more watershed nutrient reduction that is accomplished prior to implementing in-pond techniques, the greater the longevity of the in-pond techniques. Further consideration of these options will need to consider costs, public acceptance, permits and environmental impacts.

It may be advantageous to initially focus efforts on Mill Pond and Little Hale Pond. Watershed nutrient reduction should also occur in the Beards Pond watershed but it should be recognized that improvement of Little Hale is critical to realizing improvement in Beards Pond.

5.0 Potential Sources of Funding

Improvements and management techniques described in Section 5 above will require funding to install and complete. There are several primary sources of funding for nonpoint source projects in New Hampshire. These include, but are not limited to, Section 319 funding and several other programs detailed below. Alternative funding may be in the form of donated labor from the Durham Department of Public Works as well as the university, local volunteer groups and contractors from communities in the watershed. Brief descriptions of potential funding sources are provided below:

Section 319 Grant Funding: Funds for NH DES Watershed Assistance and Restoration Grants are appropriated through the U.S. Environmental Protection Agency under Section 319 of the Clean Water Act (CWA). Two thirds of the annual funds are available for restoration projects that address impaired waters and implement watershed based plans designed to achieve water quality standards. A project eligible for funds must plan or implement measures that prevent, control, or abate no-point source (NPS) pollution. These projects should: (1) restore or maintain the chemical, physical, and biological integrity of New Hampshire's waters; (2) be directed at encouraging, requiring, or achieving implementation of BMPs to address water quality impacts from land-use; (3) be feasible, practical and cost effective; and (4) provide an informational, educational, and/or technical transfer component. The project must include an appropriate method for verifying project success with respect to the project performance targets, with an emphasis on demonstrated environmental improvement. Nonprofit organizations registered with the N.H. Secretary of State and governmental subdivisions including municipalities, regional planning commissions, non-profit organizations, county conservation districts, state agencies, watershed associations, and water suppliers are eligible to receive these grants. More information on the NH DES Watershed Assistance and Restoration Grants can be found at: http://des.nh.gov/organization/divisions/water/wmb/was/categories/grants.htm

Conservation License Plate Program: To promote natural resource related programs throughout NH. Conservation Districts, Cooperative Extension, conservation commissions, schools, groups, and other non-profits can apply for funding. http://www.mooseplate.com

Land and Water Conservation Program: UNH Cooperative Extension helps New Hampshire communities and conservation groups with land and water conservation planning projects. Land & Water Conservation Program staff provide technical assistance, facilitation and guidance to communities interested in conserving their natural resources, prioritizing areas for protection, and working with local landowners to conserve land. Extension assistance is limited to project guidance and training, and does not include specific involvement in completing project tasks. http://extension.unh.edu/CommDev/CCAP.htm

Transportation Enhancement (TE) Program: The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) called for a ten percent designated share of all Surface Transportation Program funds to be used for Transportation Enhancement Activities. The intent of the program is to afford an opportunity to develop "livable communities" by selecting projects that preserve the historic culture of the transportation system and/or enhance the operation of the system for its users. The 1998 Transportation Equity Act for the 21st Century (TEA-21) continued the Transportation Enhancement Program and expanded the eligible use of funds. One of the categories of projects eligible for funding is "Environmental mitigation to address water pollution due to highway runoff or reduce vehicle-caused wildlife mortality while maintaining habitat connectivity."
http://www.nh.gov/dot/org/projectdevelopment/planning/documents/CitizensGuide-TransportationEnhancement.pdf

Agriculture Conservation Easement Program: The Agricultural Conservation Easement Program (ACEP) provides financial and technical assistance to help conserve agricultural lands and wetlands and their related benefits. Under the Agricultural Land Easements component, NRCS helps Indian tribes, state and local governments and non-governmental organizations protect working agricultural lands and limit non-agricultural uses of the land. Under the Wetlands Reserve Easements component, NRCS helps to restore, protect and enhance enrolled wetlands.
http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/easements/acep/?cid=stelprdb1242695

Forest Legacy Program: The Forest Legacy Program helps protect environmentally important private forestlands threatened with conversion to non-forest uses. The Secretary of Agriculture is responsible for the development and administration of the Forest Legacy Program. The US Forest Service in cooperation with States and other units of government is responsible for the implementation of the program. States have been granted the authority to establish criteria for their programs within the framework of the national program to help address specific needs and goals of their state.

To help maintain the integrity and traditional uses of private forest lands, the Forest Legacy Program promotes the use of conservation easements, legally binding agreements transferring a negotiated set of property rights from one party to another. Participation in the program is entirely voluntary.
http://www.nhdfl.org/land-conservation/forest-legacy-program.aspx

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Appendix A

2013 Durham Ponds Field and Laboratory Water Quality Data

Table A-1: Durham Ponds Field Data

Date	Station	Depth M	Temperature °C	Dissolved oxygen mg/l	pH	Secchi Transparency M	Specific Conductance mS/cm @ 25°C
5/22/2013	Mill Pond Deep	0.0	15.9	7.7	7.2	1.00	0.24
5/22/2013	Mill Pond Deep	0.5	15.6	7.9			0.24
5/22/2013	Mill Pond Deep	1.0	15.0	7.5			0.25
5/22/2013	Mill Pond Deep	1.5	14.6	7.1			0.29
5/22/2013	Mill Pond Deep	2.0	14.4	7.2			0.30
5/22/2013	Mill Pond Deep	2.5	14.2	5.8			0.35
6/14/2013	Mill Pond Deep	0.0	15.3	8.7	7	0.75	0.15
6/14/2013	Mill Pond Deep	0.5	15.3	8.4			0.15
6/14/2013	Mill Pond Deep	1.0	15.3	8.6			0.15
6/14/2013	Mill Pond Deep	1.5	15.3	8.6			0.15
6/14/2013	Mill Pond Deep	2.0	15.3	8.7			0.15
6/14/2013	Mill Pond Deep	2.5	15.3	8.7			0.15
8/1/2013	Mill Pond Deep	0.0	22.0	6.5	6.8	1.20	0.23
8/1/2013	Mill Pond Deep	0.5	21.4	5.6			0.24
8/1/2013	Mill Pond Deep	1.0	21.2	5.7			0.32
8/1/2013	Mill Pond Deep	1.5	20.8	3.7			0.38
8/1/2013	Mill Pond Deep	2.0	20.3	1.7			0.41
9/4/2013	Mill Pond Deep	0.0	20.6	6	6.6	0.75	0.19
9/4/2013	Mill Pond Deep	0.5	20.6	5.9			0.19
9/4/2013	Mill Pond Deep	1.0	20.6	5.8			0.19
9/4/2013	Mill Pond Deep	1.5	20.7	5.8			0.19
9/4/2013	Mill Pond Deep	2.0	20.6	5.9			0.19
9/4/2013	Mill Pond Deep	2.5	20.6	5.8			0.19
10/10/2013	Mill Pond Deep	0.0	13.3	7.1	6.8	0.75	0.24
10/10/2013	Mill Pond Deep	0.5	12.9	6.7			0.24
10/10/2013	Mill Pond Deep	1.0	12.8	6.4			0.24
10/10/2013	Mill Pond Deep	1.5	12.7	6.4			0.24
10/10/2013	Mill Pond Deep	2.0	12.6	6			0.25
10/10/2013	Mill Pond Deep	2.5	12.6	5.8			0.24
5/22/2013	Mill Pond Upper						
6/14/2013	Mill Pond Upper	0.0	15.3	8.9	7.0	0.75	0.13
8/1/2013	Mill Pond Upper	0.0	22.1	8.7	7		0.21
9/4/2013	Mill Pond Upper	0.0	20.2	7	6.7(est)		0.17
9/4/2013	Mill Pond Upper	0.5	20.2	6.8			0.17
9/4/2013	Mill Pond Upper	1.0	20.1	6.8			0.17
9/4/2013	Mill Pond Upper	1.5	20.1	6.9			0.17

Field Data

Date	Station	Depth M	Temperature °C	Dissolved oxygen mg/l	pH	Secchi Transparency M	Specific Conductance mS/cm @ 25°C
10/10/2013	Mill Pond Upper	0.0	12.8	7.6	6.8	1.00	0.20
10/10/2013	Mill Pond Upper	0.5	12.6	7.7			0.20
10/10/2013	Mill Pond Upper	1.0	12.4	7.7			0.20
10/10/2013	Mill Pond Upper	1.5	12.4	7.8			0.20
5/22/2013	Mill Pond College Brook						
6/14/2013	Mill Pond College Brook	0.0	14.3	9.1	7		0.33
8/1/2013	Mill Pond College Brook	0.0	21.5	7.2	6.6		0.39
9/4/2013	Mill Pond College Brook	0.0	18.6	7.4	6.7		0.85
10/10/2013	Mill Pond College Brook	0.0	12.3	9.1	6.8		0.42

Field Data

Date	Station	Depth M	Temperature °C	Dissolved oxygen mg/l	pH	Secchi Transparency M	Specific Conductance mS/cm @ 25°C
5/22/2013	Beards Pond Deep	0.0	17.1	8.6	7.2	0.75	0.51
5/22/2013	Beards Pond Deep	0.5	16.3	7.8			0.50
5/22/2013	Beards Pond Deep	1.0	15.7	8			0.42
5/22/2013	Beards Pond Deep	1.5	14.7	7.6			0.38
6/14/2013	Beards Pond Deep	0.0	17.4	7.9	7	0.80	0.25
6/14/2013	Beards Pond Deep	0.5	16.2	7.3			0.26
6/14/2013	Beards Pond Deep	1.0	15.9	6.9			0.27
6/14/2013	Beards Pond Deep	1.5	15.4	6.6			0.27
8/1/2013	Beards Pond Deep	0.0	23.0	3.6	7.5(est)		0.63
8/1/2013	Beards Pond Deep	0.5	21.9	1.6			0.70
8/1/2013	Beards Pond Deep	1.0	22.5	2.2			2.01
8/1/2013	Beards Pond Deep	1.5	23.5	12.1			6.69
9/4/2013	Beards Pond Deep	0.0	22.5	2.9	6.8	1.20	0.27
9/4/2013	Beards Pond Deep	0.5	22.0	2.7			0.28
9/4/2013	Beards Pond Deep	1.0	21.4	1.2			0.28
9/4/2013	Beards Pond Deep	1.5	21.2	0.1			0.31
10/10/2013	Beards Pond Deep	0.0	14.2	5.9	7.2	1.30	0.46
10/10/2013	Beards Pond Deep	0.5	13.7	5.8			0.45
10/10/2013	Beards Pond Deep	1.0	13.3	5.3			0.45
10/10/2013	Beards Pond Deep	1.5	13.1	4.9			0.45
5/22/2013	Beards Pond Pettee Brook						
6/14/2013	Beards Pond Pettee Brook	0.0	16.5	9.8	6.9		0.34
8/1/2013	Beards Pond Pettee Brook	0.0	21.3	8.6	7.3		0.50
9/4/2013	Beards Pond Pettee Brook	0.0	20.4	8.3	7.2		0.40
10/10/2013	Beards Pond Pettee Brook	0.0	12.2	9.9	7.2		0.78
5/22/2013	Beards Pond Beards Creek						
6/14/2013	Beards Pond Beards Creek	0.0	14.7	9.2	7		0.21
8/1/2013	Beards Pond Beards Creek	0.0	21.0	8.68	7.7		0.36
9/4/2013	Beards Pond Beards Creek	0.0	19.6	7.1	6.7		0.23
10/10/2013	Beards Pond Beards Creek	0.0	10.9	9.9	7.3		0.35

Field Data

Date	Station	Depth M	Temperature °C	Dissolved oxygen mg/l	pH	Secchi Transparency M	Specific Conductance mS/cm @ 25°C
5/22/2013	Little Hale Pond Deep	0.0	16.2	8.1	7.2	0.50	0.33
5/22/2013	Little Hale Pond Deep	0.5	14.2	7.4			0.29
5/22/2013	Little Hale Pond Deep	1.0	13.0	7.5			0.22
5/22/2013	Little Hale Pond Deep	1.5	12.8	7.5			0.22
6/14/2013	Little Hale Pond Deep	0.0	15.4	8.6	7	0.40	0.24
6/14/2013	Little Hale Pond Deep	0.5	13.6	8.5			0.20
6/14/2013	Little Hale Pond Deep	1.0	13.1	8.8			0.20
6/14/2013	Little Hale Pond Deep	1.5	13.1	7.7			0.23
8/1/2013	Little Hale Pond Deep	0.0	24.1	10.3	8	1.3(bottom)	0.32
8/1/2013	Little Hale Pond Deep	0.5	22.2	7.8			0.32
8/1/2013	Little Hale Pond Deep	1.0	21.1	2.9			0.33
9/4/2013	Little Hale Pond Deep	0.0	20.6	5.5	6.8	0.50	0.17
9/4/2013	Little Hale Pond Deep	0.5	19.9	2.3			0.17
9/4/2013	Little Hale Pond Deep	1.0	19.5	0.1			0.23
10/10/2013	Little Hale Pond Deep	0.0	12.2	6.3	7.6	1.30	0.32
10/10/2013	Little Hale Pond Deep	0.5	11.7	5.2			0.32
10/10/2013	Little Hale Pond Deep	1.0	11.5	5.7			0.32
5/22/2013	Little Hale Pond Inlet						
6/14/2013	Little Hale Pond Inlet	0.0	13.0	10.4	7		0.21
8/1/2013	Little Hale Pond Inlet	0.0	23.8	10.7	8.4		0.23
9/4/2013	Little Hale Pond Inlet	0.0	18.0	7.5	7.2		0.30
10/10/2013	Little Hale Pond Inlet	0.0	10.8	10	7.3		0.33

Table A-2: Durham Ponds Laboratory Data

Laboratory Data

Date	Station	Sampling Depth M	Chlorophyll a mg/L	Dissolved color CPU	TP mg P/L	SRP mg P/L	NPOC (mg C/L)	TDN (mg N/L)	NO3+NO2 (mg N/L)	NO2 mg N/L	NH4 mg N/L	TN (mg N/L)	DON (mg N/L)	TIN (calc) (mg N/L)	TN/TP
5/22/2013	Mill Pond Deep	0-2.5	0.015	82.7	0.074	0.011	5.7	0.50	0.22	0.001	0.043	0.59	0.23	0.265	8.0
6/14/2013	Mill Pond Deep	0-2	0.002	145.1	0.055	0.007	9.2	0.54	0.16	0.001	0.033	0.63	0.34	0.198	11.5
8/1/2013	Mill Pond Deep	0-2	0.015	95.6	0.059	0.016	6.8	0.50	0.19	0.004	0.053	0.69	0.26	0.247	11.7
9/4/2013	Mill Pond Deep	0-2	0.005	110.6	0.065	0.016	8.6	0.49	0.12	0.002	0.048	0.65	0.32	0.163	10.0
10/10/2013	Mill Pond Deep	0-2	0.007	90.6	0.046	0.011	5.7	0.44	0.16	0.003	0.036	0.58	0.24	0.200	12.5
	Mill Pond Deep ave		0.009	104.9	0.060	0.012	7.2	0.49	0.17	0.002	0.043	0.63	0.28	0.214	10.7
5/22/2013	Mill Pond Upper														
6/14/2013	Mill Pond Upper	Surface Grab			0.040	0.012	9.3	0.52	0.16	0.003	0.025	0.66	0.34	0.186	16.6
8/1/2013	Mill Pond Upper	Surface Grab			0.033	0.015	7.3	0.44	0.11	0.002	0.018	0.47	0.31	0.127	14.1
9/4/2013	Mill Pond Upper	Surface Grab			0.054	0.013	7.6	0.42	0.09	0.001	0.033	0.72	0.29	0.124	13.4
10/10/2013	Mill Pond Upper	Surface Grab			0.029	0.006	5.8	0.41	0.14	0.001	0.017	0.55	0.26	0.158	18.7
	Mill Pond Upper ave				0.039	0.011	7.5	0.45	0.13	0.002	0.023	0.60	0.30	0.149	15.7
5/22/2013	Mill Pond College Brook														
6/14/2013	Mill Pond College Brook	Surface Grab			0.198	0.093	12.6	0.89	0.17	0.004	0.022	1.06	0.70	0.191	5.4
8/1/2013	Mill Pond College Brook	Surface Grab			0.041	0.004	6.8	0.63	0.25	0.002	0.028	0.68	0.35	0.283	16.8
9/4/2013	Mill Pond College Brook	Surface Grab			0.165	0.103	8.4	1.52	0.92	0.004	0.048	1.54	0.56	0.965	9.4
10/10/2013	Mill Pond College Brook	Surface Grab			0.088	0.050	4.7	0.43	0.26	0.001	0.021	0.61	0.16	0.277	7.0
	Mill Pond College Brook ave				0.123	0.063	8.1	0.87	0.40	0.003	0.030	0.97	0.44	0.429	9.6

Laboratory Data

Date	Station	Sampling Depth M	Chlorophyll a mg/L	Dissolved color CPU	TP mg P/L	SRP mg P/L	NPOC (mg C/L)	TDN (mg N/L)	NO3+NO2 (mg N/L)	NO2 mg N/L	NH4 mg N/L	TN (mg N/L)	DON (mg N/L)	TIN (calc) (mg N/L)	TN/TP
5/22/2013	Beards Pond Deep	0-1.5	0.006	85.4	0.085	0.006	5.3	0.43	0.13	0.001	0.035	0.61	0.27	0.167	7.2
6/14/2013	Beards Pond Deep	0-2	0.008	67.2	0.060	0.011	7.7	0.53	0.17	0.002	0.055	0.61	0.30	0.226	10.1
8/1/2013	Beards Pond Deep	0-1	0.040	46.0	0.069	0.008	6.8	0.49	0.06	0.006	0.142	0.98	0.29	0.203	14.3
9/4/2013	Beards Pond Deep	0-1	0.012	84.1	0.082	0.035	7.8	0.53	0.07	0.003	0.087	0.78	0.37	0.160	9.4
10/10/2013	Beards Pond Deep	0-1	0.020	42.5	0.054	0.009	4.6	0.29	0.04	0.003	0.023	0.57	0.22	0.068	10.6
	Beards Pond Deep ave		0.017	65.0	0.070	0.014	6.5	0.46	0.10	0.003	0.068	0.71	0.29	0.165	10.3
5/22/2013	Beards Pond Pettee Brook														
6/14/2013	Beards Pond Pettee Brook	Surface Grab			0.063	0.004	10.0	0.65	0.22	0.000	0.030	0.77	0.40	0.246	12.3
8/1/2013	Beards Pond Pettee Brook	Surface Grab			0.060	0.009	5.9	1.02	0.70	0.005	0.053	1.17	0.26	0.757	19.5
9/4/2013	Beards Pond Pettee Brook	Surface Grab			0.060	0.022	10.2	0.71	0.19	0.001	0.019	0.85	0.50	0.207	14.2
10/10/2013	Beards Pond Pettee Brook	Surface Grab			0.086	0.037	5.2	0.74	0.56	0.003	0.019	0.85	0.16	0.582	9.9
	Beards Pond Pettee Brook ave				0.067	0.018	7.8	0.78	0.42	0.002	0.030	0.91	0.33	0.448	14.0
5/22/2013	Beards Pond Beards Creek														
6/14/2013	Beards Pond Beards Creek	Surface Grab			0.048	0.006	6.7	0.52	0.22	0.004	0.023	0.73	0.28	0.240	15.2
8/1/2013	Beards Pond Beards Creek	Surface Grab			0.039	0.007	5.5	0.56	0.31	0.002	0.033	0.62	0.21	0.343	16.0
9/4/2013	Beards Pond Beards Creek	Surface Grab			0.047	0.014	7.5	0.47	0.14	0.002	0.026	0.62	0.30	0.169	13.1
10/10/2013	Beards Pond Beards Creek	Surface Grab			0.018	0.008	3.5	0.29	0.15	0.001	0.020	0.42	0.12	0.174	23.5
	Beards Pond Beards Creek ave				0.038	0.009	5.8	0.46	0.21	0.002	0.025	0.60	0.23	0.231	17.0

Laboratory Data

Date	Station	Sampling Depth M	Chlorophyll a mg/L	Dissolved color CPU	TP mg P/L	SRP mg P/L	NPOC (mg C/L)	TDN (mg N/L)	NO3+NO2 (mg N/L)	NO2 mg N/L	NH4 mg N/L	TN (mg N/L)	DON (mg/L)	TIN (calc) (mg N/L)	TN/TP
5/22/2013	Little Hale Pond Deep	0-1.5	0.013	57.5	0.078	0.006	7.1	0.46	0.13	0.003	0.051	0.61	0.28	0.184	7.9
6/14/2013	Little Hale Pond Deep	0-1.5	0.002	107.5	0.062	0.011	5.7	0.50	0.25	0.002	0.049	0.62	0.21	0.297	10.1
8/1/2013	Little Hale Pond Deep	0-1.2	0.016	56.1	0.067	0.015	5.9	0.35	0.03	0.004	0.067	0.53	0.25	0.098	7.9
9/4/2013	Little Hale Pond Deep	0-1.2	0.020	97.8	0.094	0.018	8.7	0.39	0.03	0.002	0.039	0.82	0.32	0.072	8.7
10/10/2013	Little Hale Pond Deep	0-1	0.014	40.6	0.057	0.007	4.1	0.21	0.02	0.001	0.012	0.36	0.18	0.031	6.2
	Little Hale Pond Deep ave		0.013	71.9	0.071	0.012	6.3	0.38	0.09	0.002	0.043	0.59	0.25	0.136	8.2
5/22/2013	Little Hale Pond Inlet														
6/14/2013	Little Hale Pond Inlet	Surface Grab			0.046	0.013	5.9	0.45	0.22	0.002	0.023	0.55	0.20	0.246	11.9
8/1/2013	Little Hale Pond Inlet	Surface Grab			0.044	0.002	4.5	0.59	0.29	0.003	0.049	0.81	0.25	0.335	18.3
9/4/2013	Little Hale Pond Inlet	Surface Grab			0.040	0.018	4.5	0.53	0.31	0.002	0.033	0.66	0.19	0.340	16.3
10/10/2013	Little Hale Pond Inlet	Surface Grab			0.024	0.010	3.2	0.37	0.34	0.000	0.024	0.43	0.00	0.363	17.8
	Little Hale Pond Inlet ave				0.039	0.011	4.5	0.48	0.29	0.002	0.032	0.61	0.16	0.321	16.1

Appendix B

Screening of In-pond Options for Management of Durham Ponds

Table B-1: Management options for the control of algae (modified for this report from Wagner 2004)

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICATION TO DURHAM PONDS
Physical Controls				
1) Hypolimnetic aeration or oxygenation	♦ Addition of air or oxygen at varying depth provides oxic conditions ♦ May maintain or break stratification ♦ Can also withdraw water, oxygenate, then replace	♦ Oxic conditions promote binding/sedimentation of phosphorus ♦ Counteraction of anoxia improves habitat for fish/invertebrates ♦ Build-up of dissolved iron, manganese, ammonia and phosphorus reduced	♦ May disrupt thermal layers important to fish community ♦ May promote super-saturation with gases harmful to fish	No. Widespread anoxia has not been observed in any of the Durham Ponds.
2) Circulation and de-stratification	♦ Use of water or air to keep water in motion ♦ Intended to prevent or break stratification ♦ Generally driven by mechanical or pneumatic force	♦ Reduces surface build-up of algal scums ♦ Promotes uniform appearance ♦ Counteraction of anoxia improves habitat for fish/invertebrates ♦ Can eliminate localized problems without obvious impact on whole lake	♦ May spread localized impacts ♦ May increase oxygen demand at greater depths ♦ May promote downstream impacts	No. The Durham Ponds do not stratify and also flush rapidly so there is little potential for additional mixing to help the situation.
3) Dilution and flushing	♦ Addition of water of better quality can dilute nutrients ♦ Addition of water of similar or poorer quality flushes system to minimize algal build-up ♦ May have continuous or periodic additions	♦ Dilution reduces nutrient concentrations without altering load ♦ Flushing minimizes detention; response to pollutants may be reduced	♦ Diverts water from other uses ♦ Flushing may wash desirable zooplankton from ponds ♦ Use of poorer quality water increases loads ♦ Possible downstream impacts	No. The ponds flush rapidly as it is. Any effect from addition of high quality water would be extremely short lived.
4) Light-limiting dyes and surface covers	♦ Creates light limitation	♦ Creates light limit on algal growth without high turbidity or great depth ♦ May achieve some control of rooted plants as well	♦ May cause thermal stratification in shallow ponds ♦ May facilitate anoxia at sediment interface with water	No. These options would be impractical given the high flushing rate of the ponds.
4.a) Dyes	♦ Water-soluble dye is mixed with lake water, thereby limiting light penetration and inhibiting algal growth ♦ Dyes remain in solution until washed out of system.	♦ Produces appealing color ♦ Creates illusion of greater depth	♦ May not control surface bloom-forming species ♦ May not control growth of shallow water algal mats	No. See above.
4.b) Surface covers	♦ Opaque sheet material applied to water surface	♦ Minimizes atmospheric and wildlife pollutant inputs	♦ Minimizes atmospheric gas exchange ♦ Limits recreational use	No. See above.

5) Mechanical removal	♦ Filtering of pumped water for water supply purposes ♦ Collection of floating scums or mats with booms, nets, or other devices ♦ Continuous or multiple applications per year usually needed	♦ Algae and associated nutrients can be removed from system ♦ Surface collection can apply on an "as needed" basis ♦ May remove floating debris ♦ Collected algae dry to minimal volume	♦ Filtration requires high backwash and sludge handling capability for use with high algal densities ♦ Labor intensive unless a mechanized system applied, in which case it is capital intensive ♦ Many algal forms not amenable to collection by net or boom ♦ Possible impacts on non-targeted aquatic life	No. This option would not significantly decrease nutrient levels in the ponds so would require ongoing operation.
6) Selective withdrawal	♦ Discharge of bottom water which may contain (or be susceptible to) low oxygen and higher nutrient levels ♦ Intake of water from low algae layer to maximize supply quality ♦ May be pumped or utilize passive head differential	♦ Removes targeted water from lake efficiently ♦ Complements other techniques such as drawdown or aeration ♦ May prevent anoxia and phosphorus build up in bottom water ♦ May remove initial phase of algal blooms which start in deep water ♦ May create coldwater conditions downstream	♦ Possible downstream impacts of poor water quality ♦ May eliminate colder thermal layer important to certain fish ♦ May promote mixing of some remaining poor quality bottom water with surface waters ♦ May cause unintended drawdown if inflows do not match withdrawal	May be helpful in Little Hale however nutrients removed from Little Hale will be transported downstream to Beards Pond. Not applicable to other ponds due to a lack of documented stratified conditions.
<u>Chemical controls</u>				
7) Algaecides	♦ Liquid or pelletized algaecides applied to target area ♦ Algae killed by direct toxicity or metabolic interference ♦ Typically requires application at least once/yr, often more frequently	♦ Rapid elimination of algae from water column , normally with increased water clarity ♦ May result in net movement of nutrients to bottom of lake	♦ Possible toxicity to non-target areas or species of plants/animals ♦ Restrictions on water use for varying time after treatment ♦ Increased oxygen demand and possible toxicity from decaying algae ♦ Possible recycling of nutrients, allowing other growths	No. This is considered a short-term measure that will not address loading of phosphorus and may increase internal cycling. Chemical application may also harm non-target plant and animals in the benthic zone as well as in the wetlands associated with the ponds.
7.a) Forms of copper	♦ Contact algaecide ♦ Cellular toxicant, suggested disruption of photosynthesis, nitrogen metabolism, and membrane transport ♦ Applied as wide variety of liquid or granular formulations, often in conjunction with chelators, polymers, surfactants or herbicides	♦ Effective and rapid control of many algae species ♦ Approved for use in most water supplies	♦ Toxic to aquatic fauna as a function of concentration, formulation, temperature, pH, and ambient water chemistry ♦ Ineffective at colder temperatures ♦ Copper ion persistent; accumulates in sediments or moves downstream ♦ Certain green and blue-green nuisance species are resistant to copper ♦ Lysing of cells releases cellular contents (including nutrients and toxins) into water column	No. Considered a short term measure. May be toxic to non-target organisms. May accumulate in sediments.

7.b) Forms of endothall (7-oxabicyclo [2.2.1] heptane-2,3-dicarboxylic acid)	♦ Contact algaecide ♦ Membrane-active chemical which inhibits protein synthesis ♦ Causes structural deterioration ♦ Applied as liquid or granules, usually as hydrothol formulation for algae control	♦ Moderate control of thick algal mats, used where copper is ineffective ♦ Limited toxicity to fish at recommended dosages ♦ Rapid action	♦ Non-selective in treated area ♦ Toxic to aquatic fauna (varying degrees by formulation) ♦ Time delays on use for water supply, agriculture and recreation ♦ Safety hazards for applicators	No. See above.
7.c) Forms of diquat (6,7-dihydropyrido [1,2-2',1'-c] pyrazinediium dibromide)	♦ Contact algaecide ♦ Absorbed directly by cells ♦ Strong oxidant; disrupts most cellular functions ♦ Applied as a liquid, sometimes in conjunction with copper	♦ Moderate control of thick algal mats, used where copper alone is ineffective ♦ Limited toxicity to fish at recommended dosages ♦ Rapid action	♦ Non-selective in treated area ♦ Toxic to zooplankton at recommended dosage ♦ Inactivated by suspended particles; ineffective in muddy waters ♦ Time delays on use for water supply, agriculture and recreation	No. See above.
8) Phosphorus inactivation	♦ Typically salts of aluminum, iron or calcium are added to the lake, as liquid or powder ♦ Phosphorus in the treated water column is complexed and settled to the bottom of the lake ♦ Phosphorus in upper sediment layer is complexed, reducing release from sediment ♦ Permanence of binding varies by binder in relation to redox potential and pH ♦ Potential for use on inlet streams as well	♦ Can provide rapid, major decrease in phosphorus concentration in water column ♦ Can minimize release of phosphorus from sediment ♦ May remove other nutrients and contaminants as well as phosphorus ♦ Flexible with regard to depth of application and speed of improvement	♦ Possible toxicity to fish and invertebrates, especially by aluminum at low pH ♦ Possible release of phosphorus under anoxia or extreme pH ♦ May cause fluctuations in water chemistry, especially pH, during treatment ♦ Possible resuspension of floc in shallow areas with extreme turbulence ♦ Adds to bottom sediment, but typically an insignificant amount	Not likely, sediment release of phosphorus has not been documented as a major source in the ponds with the possible exception of Little Hale. Additional study would have to be conducted on the accumulation of sediments and the nutrient flux of sediments in Little Hale before this could be recommended.
9) Sediment oxidation	♦ Addition of oxidants, binders and pH adjustors oxidizes sediment ♦ Binding of phosphorus is enhanced ♦ Denitrification is stimulated	♦ Can reduce phosphorus supply to algae ♦ Can alter N:P ratios in water column ♦ May decrease sediment oxygen demand	♦ Possible impacts on benthic biota ♦ Longevity of effects not well known ♦ Possible source of nitrogen for blue-green algae	No. Anoxic conditions have not been observed in the water column of the ponds. The oxic state of surficial sediments is variable.

10) Settling agents	♦ Closely aligned with phosphorus inactivation, but can be used to reduce algae directly too ♦ Lime, alum or polymers applied, usually as a liquid or slurry ♦ Creates a floc with algae and other suspended particles ♦ Floc settles to bottom of lake ♦ Re-application typically necessary at least once/yr	♦ Removes algae and increases water clarity without lysing most cells ♦ Reduces nutrient recycling if floc sufficient ♦ Removes non-algal particles as well as algae ♦ May reduce dissolved phosphorus levels at the same time	♦ Possible impacts on aquatic fauna ♦ Possible fluctuations in water chemistry during treatment ♦ Resuspension of floc possible in shallow, well-mixed waters ♦ Promotes increased sediment accumulation	No. Flushing rate is very high in the ponds so this would be a very short term measure.
11) Selective nutrient addition	♦ Ratio of nutrients changed by additions of selected nutrients ♦ Addition of non-limiting nutrients can change composition of algal community ♦ Processes such as settling and grazing can then reduce algal biomass (productivity can actually increase, but standing crop can decline)	♦ Can reduce algal levels where control of limiting nutrient not feasible ♦ Can promote non-nuisance forms of algae ♦ Can improve productivity of system without increased standing crop of algae	♦ May result in greater algal abundance through uncertain biological response ♦ May require frequent application to maintain desired ratios ♦ Possible downstream effects	No. This option is contrary to ongoing watershed management initiatives for Great Bay.
12) Management for nutrient input reduction	♦ Includes wide range of watershed and lake edge activities intended to eliminate nutrient sources or reduce delivery to lake ♦ Can involve adding doses alum and alum into tributaries ♦ Essential component of algal control strategy where internal recycling is not the dominant nutrient source, and desired even where internal recycling is important	♦ Acts against the original source of algal nutrition ♦ Decreased effective loading of nutrients to lake ♦ Generally most cost effective over long term ♦ Facilitates ecosystem management approach which considers more than just algal control	♦ May involve considerable lag time before improvement observed?? ♦ May not be sufficient to achieve goals without some form of in-lake management ♦ Reduction of overall system fertility may impact fisheries ♦ May cause shift in nutrient ratios which favor less desirable species ♦ May cost more in the short term, as source management is generally more involved than one or a few treatments of symptoms of eutrophication	Option is essential to changing the trophic status of the ponds. Efforts underway as a part of the Great bay nitrogen initiative will benefit ponds as well. See Management Options for further discussion.
<u>**Biological Controls**</u>				
13) Enhanced grazing	♦ Manipulation of biological components of system to achieve grazing control over algae ♦ Typically involves alteration of fish community to promote growth of large herbivorous zooplankton, or stocking with phytophagous fish	♦ May increase water clarity by changes in algal biomass or cell size distribution without reduction of nutrient levels ♦ Can convert unwanted biomass into desirable form (fish) ♦ Harnesses natural processes to produce desired conditions	♦ May involve introduction of exotic species ♦ Effects may not be controllable or lasting ♦ May foster shifts in algal composition to even less desirable forms	No. Modification of aquatic ecosystem in Duham Mill Pond would be impractical given connection to the rest of the Oyster River. Little Hale and Beards have similar connections to each other. Introduction of non-native fish may not be permittable. Flushing of all 3 ponds is too high to encourage growth of zooplankton population prior to be washed out of the ponds.

13.a) Herbivorous fish	♦ Stocking of fish which eat algae	♦ Converts algae directly into potentially harvestable fish ♦ Grazing pressure can be adjusted through stocking rate	♦ Typically requires introduction of non-native species ♦ Difficult to control over long term ♦ Smaller algal forms may be benefited and bloom	No. See above.
13.b) Herbivorous zooplankton	♦ Reduction in planktivorous fish to promote grazing pressure by zooplankton ♦ May involve stocking piscivores or removing planktivores ♦ May also involve stocking zooplankton or establishing refugia	♦ Converts algae indirectly into harvestable fish ♦ Zooplankton community response to increasing algae can be rapid ♦ May be accomplished without introduction of non-native species ♦ Generally compatible with most fishery management goals	♦ Highly variable response expected; temporal and spatial variability may be problematic ♦ Requires careful monitoring and management action on 1-5 yr basis ♦ May involve non-native species introduction(s) ♦ Larger or toxic algal forms may be benefited and bloom	No. See above.
14) Bottom-feeding fish removal	♦ Removes fish which browse among bottom deposits, releasing nutrients to the water column by physical agitation and excretion	♦ Reduces turbidity and nutrient additions from this source ♦ May restructure fish community in more desirable manner	♦ Targeted fish species are difficult to eradicate or control ♦ Reduction in fish populations valued by some lake users (human and non-human)	No. Modification of aquatic ecosystem in the Durham Ponds is undesirable given the fact that they are connected to other water bodies.
15) Fungal/bacterial/viral pathogens	♦ Addition of inoculum to initiate attack on algal cells	♦ May create lakewide “epidemic” and reduction of algal biomass ♦ May provide sustained control for several years ♦ Can be highly specific to algal group or genera	♦ Largely experimental approach at this time ♦ Considerable uncertainty of results ♦ May promote resistant forms with high nuisance potential ♦ May cause high oxygen demand or release of toxins by lysed algal cells ♦ Effects on non-target organisms uncertain	No. Flushing rate in the ponds is too high for this to be effective and technique is unproven.
16) Competition and allelopathy	♦ Plants may tie up sufficient nutrients to limit algal growth ♦ Plants may create a light limitation on algal growth ♦ Chemical inhibition of algae may occur through substances released by other organisms	♦ Harnesses power of natural biological interactions ♦ May provide responsive and prolonged control	♦ Some algal forms appear resistant ♦ Use of plants may lead to problems with vascular plants ♦ Use of plant material may cause depression of oxygen levels	No. Modification of aquatic ecosystem in the Durham Ponds is undesirable given the fact that they are connected to other water bodies. There are already dense beds of vascular plants in the ponds. Addition of more is likely undesirable.

16.a) Plantings for nutrient control	♦ Plant growths of sufficient density may limit algal access to nutrients ♦ Plants can exude allelopathic substances which inhibit algal growth	♦ Productivity and associated habitat value can remain high without algal blooms ♦ Portable plant "pods" , floating islands, or other structures can be managed to limit interference with recreation and provide habitat ♦ Wetland cells in or adjacent to the lake can minimize nutrient inputs	♦ Vascular plants may achieve nuisance densities ♦ There will be a water depth limitation on rooted plants but not algae ♦ Vascular plant senescence may release nutrients and cause algal blooms ♦ The switch from algae to vascular plant domination of a lake may cause unexpected or undesirable changes in lake ecology, especially energy flow	No. Modification of aquatic ecosystem in the Durham Ponds is undesirable given the fact that they are connected to other water bodies. There are already dense beds of vascular plants in the ponds. Addition of more is likely undesirable.
16.b) Plantings for light control	♦ Plant species with floating leaves can shade out many algal growths at elevated densities	♦ Vascular plants can be more easily harvested than most algae ♦ Many floating species provide valuable waterfowl food	♦ At the necessary density, the floating plants will be a recreational nuisance ♦ Low surface mixing and atmospheric contact will promote anoxia near the sediment	No. Modification of aquatic ecosystem in the Durham Ponds is undesirable given the fact that they are connected to other water bodies. There are already dense beds of vascular plants in the ponds. Addition of more is likely undesirable.
16.c) Addition of barley straw	♦ Input of barely straw can set off a series of chemical reactions which limit algal growth ♦ Release of allelopathic chemicals can kill algae ♦ Release of humic substances can bind phosphorus	♦ Materials and application are relatively inexpensive ♦ Decline in algal abundance is more gradual than with algaecides, limiting oxygen demand and the release of cell contents	♦ Success appears linked to uncertain and potentially uncontrollable water chemistry factors ♦ Depression of oxygen levels may result ♦ Water chemistry may be altered in other ways unsuitable for non-target organisms ♦ Some forms of algae may be resistant and could benefit from the treatment	Likely not. Flushing rate of ponds is too high to see a long term effect. Perhaps possible in Little Hale Pond during summer.

Table B-2: Management options for the control of rooted aquatic plants (modified for this project from Wagner 2004)

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES	APPLICATION TO DURHAM PONDS
<u>Physical Controls</u>				
1) Dredging	♦ Sediment is physically removed by wet or dry excavation, with deposition in a containment area for dewatering ♦ Dredging can be applied on a limited basis, but is most often a major restructuring of a severely impacted system ♦ Nutrient reserves are removed and algal growth can be limited by nutrient availability	♦ Can control macrophytes if dredged to inorganic substrate or to depth below photic zone. ♦ Increases water depth ♦ Can reduce pollutant reserves ♦ Can reduce sediment oxygen demand ♦ Can improve spawning habitat for many fish species	♦ Temporarily removes benthic invertebrates ♦ May create turbidity ♦ Possible impacts from containment area discharge ♦ Possible impacts from dredged material disposal ♦ Interference with recreation or other uses during dredging	Option under consideration. See Management Options for discussion.

1.a) "Dry" excavation	♦ Pond drained or lowered to maximum extent practical ♦ Target material dried to maximum extent possible ♦ Conventional excavation equipment used to remove sediments	♦ Tends to facilitate a very thorough effort ♦ May allow drying of sediments prior to removal ♦ Allows use of less specialized equipment	♦ Eliminates most aquatic biota unless a portion left un-drained ♦ Eliminates pond use during dredging	Likely feasible for Mill Pond and Little Hale. Possibly feasible for Beards
1.b) "Wet" excavation	♦ Pond level may be lowered, but sediments not substantially exposed ♦ Draglines, bucket dredges, or long-reach backhoes used to remove sediment	♦ Requires least preparation time or effort. ♦ May allow use of easily acquired equipment ♦ May preserve aquatic biota	♦ Usually creates extreme turbidity ♦ Tends to result in sediment deposition in surrounding area ♦ Normally requires intermediate containment area to dry sediments prior to hauling ♦ May cause severe disruption of ecological function ♦ Usually eliminates most pond uses during dredging	No. Because ponds can be drawn down and accessed easily dry excavation will likely be cheaper and easier.
1.c) Hydraulic removal	♦ Pond level not reduced ♦ Suction or cutterhead dredges create slurry which is hydraulically pumped to containment area ♦ Slurry is dewatered; sediment retained, water discharged	♦ Creates minimal turbidity and impact on biota ♦ Can allow some pond uses during dredging ♦ Allows removal with limited access or shoreline disturbance	♦ Often leaves some sediment behind ♦ Cannot handle coarse or debris-laden materials ♦ Requires sophisticated and more expensive containment area ♦ Requires overflow discharge from containment area	No. Because ponds can be drawn down and accessed easily dry excavation will likely be cheaper and easier.
2) Herbicides	• Liquid or pelletized herbicides applied to target area • Plants killed by direct toxicity or metabolic interference • Typically requires application at least once/yr, often more frequently	♦ Rapid elimination of aquatic plants ♦ May result in movement of nutrients to bottom of lake or release to water column	♦ Possible toxicity to non-target areas or species of plants/animals ♦ Restrictions on water use for varying time after treatment ♦ Increased oxygen demand and possible toxicity from decaying plants ♦ Possible recycling of nutrients, allowing other growths	No. This is considered a short-term measure that will not address loading of phosphorus and may increase internal cycling. Chemical application may also harm non-target plant and animals in the benthic zone and downstream as well as in the wetlands associated with the ponds.
3) Plant Harvesting	• Plants are mechanically harvested and removed from the ponds either through hydro-raking or cutting	♦ Removes plants and sometimes roots ♦ Removes some nutrients with plant biomass	♦ Short term measure ♦ Benefit stops when cutting stops ♦ May encourage fast growing invasive species ♦ Large capital and O&M expense ♦ Can cause short term turbidity spikes ♦ May fragment plants encouraging regrowth or transport downstream	No. This is considered a short-term measure akin to mowing a lawn. Access and water depth would make this very difficult to accomplish. Water bodies are not big enough to support purchase of dedicated harvesting equipment.

4) Drawdown	♦ Lowering of water over autumn period allows oxidation, desiccation and compaction of sediments ♦ Duration of exposure and degree of dewatering of exposed areas are important ♦ Algae are affected mainly by reduction in available nutrients.	♦ May reduce available nutrients or nutrient ratios, affecting algal biomass and composition ♦ Opportunity for shoreline clean-up/structure repair ♦ Flood control utility ♦ May provide rooted plant control as well	♦ Possible impacts on contiguous emergent wetlands ♦ Possible effects on overwintering reptiles or amphibians ♦ Reduction in potential water supply and firefighting capacity ♦ Alteration of downstream flows ♦ Possible overwinter water level variation ♦ May result in greater nutrient availability if flushing inadequate	Possibly. Each of the ponds can be drawn down however, winters may not be cold enough to eliminate macrophytes resulting in thicker colonies of invasive species. Due to flushing rate and supply of nutrients from watershed, this option is likely to have little impact on algal growth.
5) Dam Removal	♦ Removing dams would eliminate ponds ♦ Stream habitat would result	♦ Would eliminate pond water quality problems ♦ Would remove barriers ♦ Would create stream habitat	♦ May result in sediment mobility downstream ♦ Would eliminate pond uses	Possibly. However, this option cannot be evaluated in the context of pond management as it will eliminate the ponds.