Action Plan for the Town of Chatham Ponds

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Action Plan for the Town of Chatham Ponds

1. Introduction and Scope

This report summarizes the water quality and aquatic habitat conditions of the freshwater ponds of Chatham, and recommends measures for protection and restoration of this valuable resource. Twenty inland ponds are included in this report; the ponds range in size from 0.5 to 16.7 ha (1.2 – 41 acres) and are used for aesthetic enjoyment, recreational fishing, swimming, and boating.

In July 2003, Ecologic and Stearns & Wheler entered into an agreement with the Town to develop an action plan for protecting and restoring the nutrient-related water quality of a total of 17 freshwater ponds of Chatham. An additional three ponds, Minister's Pond, Fox Pond, and Cranberry (a flooded bog), were added to the original scope at the request of Dr. Robert Duncanson of the Town of Chatham Water Quality Laboratory during the site visit of July 15, 2003. The site visit was an opportunity to complete a visual assessment of habitat quality and land use in the ponds' watersheds. The location of the ponds within the Town of Chatham is illustrated in Figure 1.

We used existing data describing water quality and aquatic habitat conditions within the ponds, drawing on the characterization published in the Cape Cod Pond and Lake Atlas for eight of the ponds (Cape Cod Commission Water Resources Office, May 2003). These data were complemented by additional data available from the Town of Chatham Water Quality Laboratory including results of the 2001 and 2002 monitoring program. In addition, we reviewed the findings of the qualitative Pond Shoreline Survey Report (Horsley & Witten, February 2003) developed for several ponds in the Pleasant Bay Watershed. Stearns & Wheler provided a series of GIS land use maps.

This report defines potential options for protection and improvement of the freshwater ponds of Chatham and develops a set of specific recommendations. The recommendations reflect our assessment of effectiveness (both short-term and long-term), cost, permitting issues, and recreational impacts. The recommended actions include institutional, technical, and public education components. Some recommendations are town-wide, while others are directed to specific ponds. An overall implementation strategy is presented that defines priority actions and sequencing of recommendations.

2. Nutrients and Eutrophication

"Lakes seem, on the scale of years or human life spans, permanent features of the landscape, but they are geologically transitory, usually born of catastrophe and mature and die quietly and imperceptibly" (Hutchinson 1957). This often-cited quote from a classic limnology text provides excellent context for reviewing the current and future conditions of the ponds of Chatham. The ponds may be arrayed along a continuum from open, clear, water with little visible algal growth to extremely shallow, productive systems well on their way to becoming wetlands (Figure 2).

Eutrophication, the term for both the process and the effects of enrichment of surface water systems (including lakes, ponds, estuaries, and reservoirs), is a major water quality issue. As aquatic systems become increasingly enriched with plant nutrients, organic matter, and silt the

Data Source: MassGIS .5 Meter Color Orthophoto

1 inch equals 1,500 feet

File Location: D:\GIS Project Folder\Job#\Chatham\Freshwater Ponds.mxd

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Town of Chatham, MA

FRESHWATER PONDS

FIGURE 1

result is increased biomass of algae and plants, reduced water clarity, and ultimately, a reduction in volume. Aesthetic quality and habitat conditions are degraded; surface waters may lose suitability for recreational uses and water supply as eutrophication proceeds. The composition and abundance of the aquatic biota may be altered.

While eutrophication is a natural process, it can be greatly accelerated by human activities. There are numerous lakes and ponds included in state compendia of impaired waters; most are listed due to excessive nutrient inputs from nonpoint sources such as agricultural runoff and (less frequently) point sources.

Figure 2. Algal bloom in Perch Pond (left) and clear waters of White Pond (right).

3. Managing Eutrophication

Water resources managers focus on identifying and controlling the sources of nutrients, organic material, and silt to aquatic ecosystems in an effort to slow down the eutrophication process. Two important processes have been quantified for many aquatic systems: (1) the relationship between watershed activities and loading, and (2) the relationship between loading and resultant water quality conditions. For the first relationship, scientists, engineers, and planners have quantified nutrient runoff from various conditions of land use and population density. For the second, limnologists and oceanographers have determined the physical and hydrologic features such as depth and water residence time that contribute to assimilative capacity. These relationships form the basis for defining an acceptable loading to aquatic systems to meet water quality objectives.

Mathematical models of the relationships between external loading and water quality response have been developed to enable mangers to predict the effectiveness of control actions. These models vary greatly in complexity and sophistication. However, all of the models follow a systematic process as outlined below:

- Define existing water quality and habitat conditions and determine whether desired uses are being met.
- Identify pollutant(s) responsible for degraded water quality and/or habitat conditions.
- Define targets (defined as ambient concentrations of pollutant(s) that will support desired use).
- Quantify acceptable loads, specific to each water body, which will meet target conditions.
- Identify contributing point and nonpoint sources of pollution.
- Quantify transport and attenuation from source to water body.
- Develop a strategy for source reductions or other measures to meet targets.

Phosphorus is most often the limiting nutrient for primary productivity and algal biomass in inland lakes of the Northeast. This finding has focused lake restoration and management techniques on controlling the concentration of phosphorus and has led to significant improvements in many systems. However, Cooke et al. (1993) point out that many lakes are shallow, with extensive wetland and littoral zones and macrophyte communities. The complexity of nutrient flux and food web interactions at the sediment-water interface in highly productive shallow regions of lakes and ponds cannot be ignored. Nutrient cycling and biological interactions in shallow weedy sections of the ponds may contribute to maintaining elevated nutrient levels and undesirable plant growth long after external loading controls have been implemented. This is an important consideration for many of the kettle ponds of Chatham.

While phosphorus is the key to managing eutrophication of the inland ponds, nitrogen is the limiting nutrient for primary production for the coastal ecosystem. Nitrogen enrichment has resulted in degradation of estuarine and marine water quality and habitat conditions, and wastewater is a major source of nitrogen. Scientists and regulators from the federal EPA, state DEP, academic community, Cape Cod Commission, and municipalities used a systematic process to define the need for and extent of reductions in nitrogen loading (Massachusetts Department of Environmental Protection 2003 "The Massachusetts Estuaries Project Embayment Restoration and Guidance for Implementation Strategies"). Findings of this analysis are now being incorporated into land use and facilities decisions throughout Cape Cod.

4. Kettle Pond Ecosystems

The ponds of Cape Cod are kettle ponds, formed as depressions left behind by ice blocks as the glacial ice retreated between 14,000 and 17,000 years ago. According to Portnoy et al (2001), while the ponds of Cape Cod have a common glacial origin, their subsequent evolution differs based on the depth of the original ice block, landscape position relative to sea level, and the texture (particle size) of the soils in the ponds' watersheds. Cultural effects are also to be added to this list; the ponds of Cape Cod are influenced by the amount and type of development in the watershed, invasions of exotic species, application of lime to raise the naturally low pH of the waters, and fisheries management practices.

Unlike most lakes and ponds, kettle ponds do not have prominent tributary streams (inlets) and outlets (Figure 3). Groundwater seepage and direct precipitation, rather than surface water flows, are the source of water to the kettle ponds. The quality of the water in the ponds, therefore, is directly affected by the quality of the groundwater resource.

Figure 3. Aerial photograph of Goose Pond illustrating hydrologic isolation of kettle ponds.

The lack of defined inlets and outlet for most ponds has some important implications for the cycling of nutrients and organic material. Nitrogen and phosphorus enter the ponds primarily as dissolved nutrients where they are incorporated into biomass. Water leaves the ponds through groundwater seepage and evaporation. Particulate biomass consequently remains in the ponds, and the nutrients continue to cycle through the food web. Ponds therefore become more productive over time; this natural phenomenon may be more important for kettle ponds where there is little opportunity for particulate material to leave the system. The Cape Cod Commission compiled dissolved oxygen (DO) measurements in the lower waters of 41 kettle ponds; data were from 1948 and 2001. Comparison of the data revealed that 76% of the measurements were lower in 2001 than 1948. These data provide strong evidence of an increasing level of productivity in the ponds over the intervening five decades (Cape Cod Commission, May 2003 p. 46).

5. Sources of Data and Information

5.1. Current Water Quality Conditions

Unfortunately, there are some data gaps that preclude completing an analysis for the inland ponds that is completely parallel to that outlined in Section 3 (managing eutrophication). Recent data are available to complete the first task, defining current water quality and habitat conditions. The Town of Chatham Water Quality Laboratory, under the direction of Dr. Robert Duncanson, has conducted a sampling program of 18 ponds during the summers of 2000, 2001 and 2002 and 2003. Trophic status indicators (nutrients, chlorophyll, Secchi disk transparency, and temperature/dissolved oxygen profiles) are measured along with pH, alkalinity, and color. Shoreline habitat was evaluated for five Chatham ponds within the Pleasant Bay Area of Critical Environmental Concern by Horsley and Witten Inc. (2003). A visual survey was conducted in July 2003 as part of this investigation. In addition, limited historical data are available for several of the larger ponds.

The Cape Cod Commission Water Resources Office published the Cape Cod Pond and Lake Atlas in May 2003; this document presents a summary and analysis of water quality status of eight of the Chatham ponds. The summaries provide an overview, indicating location, the nature of the shoreline, and predominant land uses. The fish community and stocking activities are described. Results of the late August 2001 snapshot sampling program are tabulated for 17 ponds; these results are interpreted with respect to whether ponds are considered impacted as indicated by concentrations of chlorophyll-*a*, phosphorus, and nitrogen.

The Town monitors several bathing beaches at the inland ponds for the presence and abundance of indicator bacteria. Finally, the Town of Chatham Water Quality Laboratory tracks water quality complaints from the public. The various data sources for each of the ponds are summarized in Table 1.

Table 1
Data Sources Used to Develop Chatham Ponds Action Plan

Pond	Historical Data (pre 1990)	Pleasant Bay ACEC Assessment	Chatham Water Quality Monitoring Program	Cape Cod Commission Atlas : description	Bathing beach bacteria testing	Visual Assessment July 2003
Black Pond-mid			x			x
Black Pond-west			x			
Black Pond-east			x	x		x
Blue Pond			x			
Emery Pond	x		x	x		x
Barclay Pond			x			x
Goose Pond	x		x	x	x	x
Lovers Lake	x	x	x	x		x

Pond	Historical Data (pre 1990)	Pleasant Bay ACEC Assessment	Chatham Water Quality Monitoring Program	Cape Cod Commission Atlas : description	Bathing beach bacteria testing	Visual Assessment July 2003
Mill Pond	x	x	x	x		x
Mary's Pond			x			x
Minister's Pond		x				x
Perch Pond			x			x
Pickerel Pond			x			x
Ryder Pond			x			x
Schoolhouse Pond	x		x	x	x	x
Stillwater Pond	x	x	x	x		x
Trout Pond			x			x
White Pond	x		x	x	x	x
Cranberry (flooded bog)						x
Fox Pond		x				x

5.2. Pollutants of Concern

The second task, identifying pollutants, is relatively straightforward. The scientific literature and other pond studies have highlighted the importance of phosphorus in regulating primary productivity of the inland ponds. Monitoring data confirm that concentrations of nitrogen in the Town's inland ponds exceed thresholds of saturation.

An additional water quality issue is mercury levels. The naturally acidic environment in the Cape Cod kettle ponds is correlated with elevated mercury concentration in fish tissue. According to the Cape Cod Commission, additional testing of fish for mercury content is recommended (Cape Cod Commission, Pond and Lake Atlas, May 2003 pg. 39).

5.3. Target Concentrations

Defining target concentrations to protect designated uses is the third task. Eutrophication, defined as enrichment of lakes and ponds with nutrients and the effects of this enrichment, is a continuum. Lakes and ponds progress from a nutrient-poor, clear water state (oligotrophic) through an intermediate state of higher biological productivity (mesotrophic) and eventually to a nutrient rich condition of very high biological productivity (eutrophic). Hypereutrophic lakes are turbid lakes, closest to the wetland status. However, lakes may exist in a trophic equilibrium for decades or centuries. When human activities accelerate the eutrophication process it is termed cultural eutrophication. Limnologists and lake mangers have developed guidelines to define the transition between trophic states based on phosphorus, water clarity, chlorophyll-a, and deep water dissolved oxygen concentrations (Table 2). However, assigning a lake or pond to one category still requires professional judgment considering the cumulative evidence of water quality conditions and the level of productivity.

Table 2
Trophic State and Indicator Parameters

	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
Average Total Phosphorus, upper waters (µg/l)	<10	10-35	35 -100	>100
Summer chlorophyll-a, upper waters (µg/l)	<2.5	2.5 - 8	8 - 25	>25
Peak chlorophyll-a (µg/l)	<8	8-25	25-75	>75
Average Secchi disk transparency, m	>6	6-3	3-1.5	<1.5
Minimum Secchi disk transparency, meters	>3	3-1.5	1.5-0.7	<0.7
Dissolved oxygen in lower waters (% saturation)	80 - 100	10-80	Less than 10	Zero

Source: Janus and Vollenweider 1981

As a refinement to these general categories, EPA is encouraging development of ecoregional criteria, designed to reflect site-specific conditions of watershed geology, land use, and hydrologic setting. These values are used to define thresholds for impacted and non-impacted conditions and thus target levels. Ecoregional criteria for Cape Cod ponds have been described in the Cape Cod Pond and Lake Atlas (Cape Cod Commission, May 2003); the ecoregional values (designated as subregion 84) are derived from a statistical evaluation of existing water quality conditions of "unimpacted" ponds for coastal New England, including Cape Cod. The 2001 PALS data were used to calculate thresholds for reference conditions using eight Cape Cod ponds. The eight ponds included a range of deep and shallow ponds; all were characterized with low nutrient and chlorophyll concentrations. Values for applicable ecoregional criteria are summarized in Table 3.

Table 3
Ecoregional Criteria

Parameter	Subecoregion 84 Reference Condition Threshold	Cape Cod Ponds based on 2001 PALS Data
Secchi depth	2 m	Not calculated
Chlorophyll-a	6 µg/l	1.7 µg/l
Total Nitrogen	0.41 mg/l	0.31 mg/l
Total Phosphorus	9 µg/l	10 µg/l

The status of the Chatham Ponds with respect to these criteria is summarized in Table 4, based on the late August 2001 snapshot sampling reported in the 2003 Atlas.

Table 4
Status of Chatham Ponds, based on Ecoregional Criteria

Pond	Impacted Criteria (Affected by Human Activities)		
	Chlor >1.7 µg/l	Total N > 0.31 mg/l	Total P > 10 µg/l
Barclay Pond	Impacted	Impacted	Impacted
Black Pond-east	Impacted	Impacted	Impacted
Black Pond- west	Impacted	Impacted	Impacted
Black Pond – mid	Impacted	Impacted	Impacted
Blue Pond	Impacted	Impacted	Impacted
Emery Pond	Impacted	Impacted	Impacted
Goose Pond	Impacted	At Risk	Unimpacted
Lovers Lake	Impacted	Impacted	Impacted
Mary's Pond	At Risk	Impacted	Impacted
Mill Pond	Impacted	Impacted	Impacted
Perch Pond	Impacted	Impacted	Impacted
Pickerel Pond	Impacted	Impacted	Impacted
Ryder's Pond	Impacted	Impacted	Impacted
Schoolhouse Pond	Impacted	At Risk	Impacted
Stillwater Pond	Impacted	Impacted	Impacted
Trout Pond	Impacted	Impacted	Impacted
White Pond	Impacted	Impacted	At Risk

Source: Chatham 2001 PALS Water Quality Snapshot Summary, Appended to Cape Cod Ponds and Lake Atlas, May 2003

5.4. Acceptable Loads to Meet Targets

Additional research and analysis are needed to calculate an acceptable external load of phosphorus to the ponds that would protect water quality conditions. The kettle ponds of Cape Cod present a unique challenge. Standard limnological models have been developed to quantify the relationship between external loading and in-lake concentration as a function of mean depth and water residence time. These standard models were developed based on empirical observations of a large number of lakes and ponds, with defined inlets and outlets. Because kettle ponds are fed by groundwater seepage, detailed research and monitoring are needed to quantify water residence time; these calculations have not been completed for the Chatham ponds.

5.5. Point and nonpoint sources of nutrients

Land use data are available for the Town, including the number and location of residences. Once the contributing area of groundwater flow into each pond is delineated, these data can be used to help quantify the potential contribution of septic effluent to the ponds. In general, the external sources of phosphorus to the Chatham Ponds include:

- groundwater influx (natural background)
- groundwater influenced by wastewater disposal (sewage plumes),
- runoff from surfaces such as roadways
- atmospheric deposition,
- shoreline erosion,
- swimmers,
- wildlife (gulls, waterfowl, deer etc).

In addition to the external sources, phosphorus cycles from the sediments, particularly in the deeper ponds subject to seasonal anoxia.

5.6. Transport and attenuation from source to ponds

Most of the sources listed above are direct inputs to the ponds: wildlife, swimmers, stormwater runoff, and shoreline erosion. One source, however, is the subject of investigation and debate. The extent to which phosphorus in septic effluent can reach surface waters is an issue of great importance to many communities. Research and monitoring indicates that subsurface phosphorus transport is influenced by depth to groundwater, soil texture, pH, geology, and groundwater quality, as well as by the nature of the on-site wastewater disposal systems (notably age, loading history, and maintenance).

In general, phosphorus is considered relatively immobile in the subsurface environment; environmental policy has focused largely on nitrogen transport. Phosphorus transport through groundwater to surface waters has been documented; for example, phosphorus associated with the sewage plume from the Massachusetts Military Reservation on Cape Cod is reaching Ashumet Pond (McCobb et al 2003). Phosphorus from septic systems may reach surface waters when intervening distances and travel times are short, when the groundwater environment is reducing (anoxic), or when sites for sorption of phosphorus onto aluminum and iron oxides are already saturated with phosphorus (Portnoy et al 2001). The Ashumet Pond investigation by USGS documented that phosphorus can desorb from subsurface soils exposed to uncontaminated groundwater with low pH (McCobb et al. 2003). This implies that phosphorus from on-site systems remains a reservoir in the soil that may be slowly mobilized and transported to the ponds along with groundwater.

Controlled experiments by Cogger et al (1988) examined the movement of nutrients and bacteria from septic systems installed in the sandy soils of a coastal barrier island. They reported that phosphorus was most likely to be mobile in wet, sandy soils, and that both loading rate and water table location affected phosphorus concentrations in the groundwater surrounding the leach field. Data from this investigation were also consistent with two processes for adsorption occurring: a fast reaction and a slow reaction.

The ponds of Chatham are situated in sandy soils, and the surrounding land areas have a variable depth to groundwater. Background pH is low, averaging 5.5 (McCobb et al. 2003). The sandy soils provide abundant iron and aluminum hydroxides for phosphorus adsorption. The reaction of soluble reactive phosphorus with sandy soil is described by two processes: a fast and reversible adsorption reaction on the surface of aluminum and iron oxides and a slow, diffusion-controlled process where the phosphorus either precipitates with aluminum or iron, or diffuses into micropores and becomes adsorbed to surfaces deep in the soil matrix (Shoumans and Breeuwsma 1997).

It appears that the soils of Chatham have capacity to bind phosphorus in groundwater based on the chemical composition. However, phosphorus removal is not permanent. Under certain conditions of groundwater chemistry, phosphorus adsorbed to the surface aluminum and iron hydroxides may desorb and move with the groundwater towards the kettle ponds. Groundwater pH on Cape Cod is within the range where this desorption reaction will occur. Phosphorus movement from subsurface soils would be exacerbated by conditions such as high organic loading that contribute to microbial activity and de-oxygenation of the groundwater resource.

Regulatory programs for septic systems existing in similar environments to the Cape Cod area show a variety of setback requirements, as summarized in Appendix A. In addition to setbacks, there is great interest in use of alternative technologies, some of which show excellent phosphorus removal capabilities. The Massachusetts Alternative Septic Systems Test Center and the Barnstable County Department of Health are presently investigating alternative technologies that would be applicable to the Town of Chatham. Results are not yet published, but commercially available technologies indicate effluent reductions in total phosphorus from 60-85% (*http://www.rucksystems.com/treatment/*) and close to 100% in soluble reactive phosphorus (SRP) (*http://www.lombardoassociates.com/phosrid.shtml*).

5.7. Strategy to meet targets

Given the nature of the kettle ponds and the sources of phosphorus to the Chatham Ponds, there are no easy answers to long-term water quality protection and improvement. Strategies fall into several categories: reducing the inputs of nutrients and sediment, altering internal cycling, increasing the output, and/or mitigating the symptoms of eutrophication. Management options for controlling algal growth typically differ from those to control the growth of aquatic plants and macroalgae (macrophytes). Feasible alternatives for protection and restoration of the Chatham Ponds are summarized in Appendix B.

6. Inventory of Chatham Ponds

The Chatham ponds exhibit a range of physical characteristics (Table 5).

Table 5
Summary of Physical Characteristics: Chatham Ponds

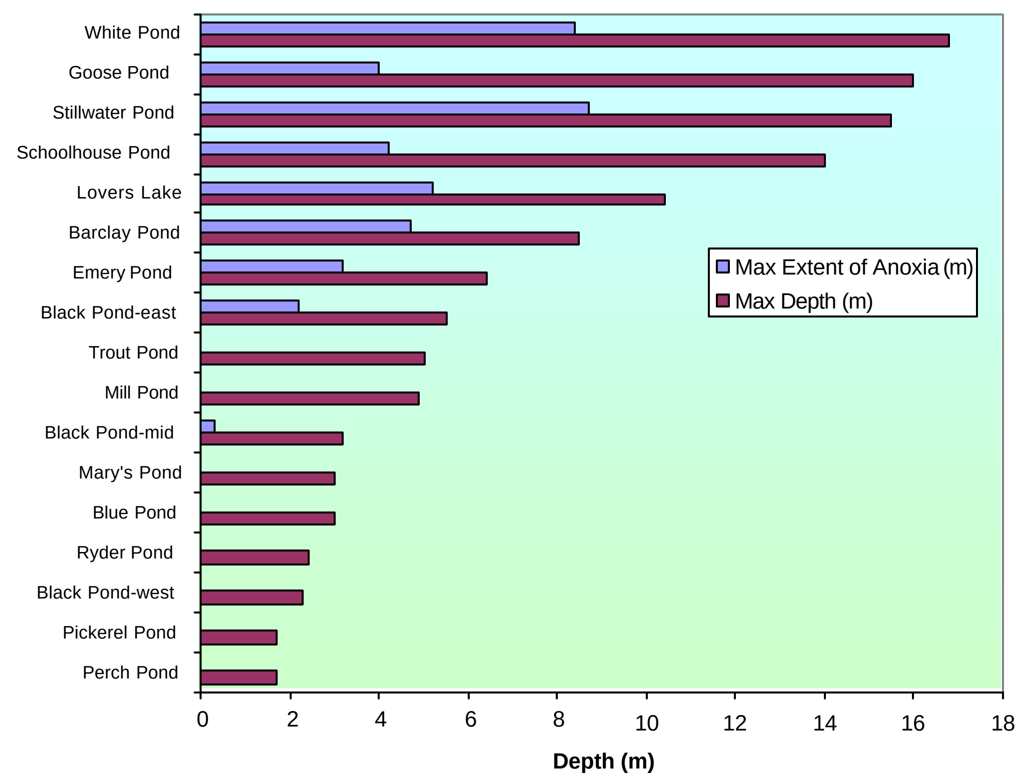
Pond	Max. Depth (m)	Surface Area (ha)	# of Res[1]	Public Beach	Surface Water Quality (2000 – 2002 Averages)				
					pH (standard units)	Alk. (mg/l)	Temp Diff.[2] (deg C)	Secchi (m)	Color
Black -mid	3.2	2	9		6.9	17.8	2.0	1.0	Green
Black -west	2.3	0.7	2		6.7	6.7	1.0	1.4	Brown
Black -east	5.5	2	12		6.4	5.7	7.0	2.2	Tea
Blue Pond	3	1.2	0		6.7	6.6	1.0	2.3	Green
Emery Pond	6.4	5.7	32		7.4	11.2	3.5	2.3	Clear
Barclay Pond	8.5	1.2	1		6.5	5.7	9.5	2.7	Tea
Goose Pond	16	16.7	8	Yes	6.6	2.6	4.0	5.5	Blue/G
Lovers Lake	10.4	15.2	38		8.7	19	7.0	1.5	Grn/Br
Mill Pond	4.9	9.5	22		6.6	11.3	1.5	1.6	Brown
Mary's Pond	3	1.7			6.3	5.0	0.7	B	Tea
Perch Pond	1.7	2.2	20		6.7	26.0	0.4	1.0	Tea
Pickerel Pond	1.7	0.5	16		5.8	1.7	0.2	B	Clear
Ryder Pond	2.4	2.3	11		6.2	2.3	0.3	B	Brown
Schoolhouse Pond	14	7.5	18	Yes	6.5	4.7	7.8	4.6	Green
Stillwater Pond	15.5	7.6	24		8.0	17.0	10.4	1.9	Green
Trout Pond	5	2	15		5.5	1.1	0.4	4.1	Clear
White Pond	16.8	16.3	50	Yes	9.1	9.1	8.5	3.6	Green

B=Bottom
[1] Number of residences with 300 ft of shoreline
[2] Maximum temperature difference (deg C) between surface and bottom samples

Ponds deeper than about 5 m exhibit some degree of thermal stratification during the summer. Bottom waters isolated from the atmosphere become depleted of oxygen as the microbial community decomposes organic material. Once the lower waters become anoxic (operationally defined as DO < 1 mg/l) phosphorus adsorbed to the lake bottom sediments become soluble and diffuses into the overlying water. As ponds become more productive, anoxia is measured higher in the water column. This relationship for the Chatham ponds is displayed in Figure 4. The axes are maximum depth of ponds, and maximum percent of the water column affected by anoxia (from the 2000 – 2002 data sets). Note that two ponds, Black Pond-mid and Stillwater Pond, plot outside of the general pattern. The extent of anoxia in these ponds is higher than the other ponds. Schoolhouse Pond, in contrast, has less anoxia, indicating higher water quality. The shallowest ponds (Perch, Pickerel, Black-west, Ryder, Blue, Mary's, Mill and Trout Ponds) do not develop oxygen depletion in the lower waters. Soluble phosphorus entering these ponds with the groundwater will become incorporated into the biota.

Ponds deep enough to stratify and productive enough to experience seasonal anoxia have elevated concentrations of phosphorus in the lower waters. In some lakes, wind-induced mixing and internal waves (seiches) may entrain the phosphorus-rich water into the upper sunlit layer where the nutrient can support algal growth (the photic zone) during the summer stratified period.

Figure 4
Maximum Depth and Extent of Anoxia



One measure of the probability of mixing between the upper and lower waters is the Osgood Index, named for the limnologist who developed an empirical relationship between lakes' surface area and depth, and the stability of the water column. Small, deep lakes are less likely to have wind-induced mixing of deep waters into the photic zone. Conversely, shallower lakes with larger surface area are more susceptible to wind mixing and phosphorus released from sediments may become entrained into the upper waters and available to support algal growth during the stratified period (Osgood 1988). Ponds with very low indices (less than approximately 4) are polymictic, exhibiting only ephemeral stratification. As the index increase, so does stability of the water column. Ponds with indices greater than about 20 are very stable; and would tend to mix later in the fall. Intermediate lakes would be susceptible to mixing of hypolimnetic waters during strong wind events; these ponds may destratify earlier in the fall when light and temperature conditions would support an algal bloom.

Several of the Chatham Ponds are somewhat susceptible to this internal phosphorus loading during summer as summarized in Table 6. However, all the Chatham kettle ponds mix throughout the water column in the fall, as the waters cool and the thermal gradient (and thus density differences) between the upper and lower layers breaks down. Phosphorus in the lower waters is distributed throughout the water column and is available for algal uptake given favorable conditions of light and temperature.

Table 6

Potential for Sediment Phosphorus to Enter Photic Zone during Summer

Pond	Mean Depth (m)	Surface Area (ha)	Anoxia	Maximum TP, lower waters * µg/l	Osgood Index	Probability of Entrainment during stratified period
Black -east	N/A	2	Yes	88	N/A	
Emery	3	5.7	Yes	246	12.6	Moderate
Barclay	N/A	1.2	Yes	89	N/A	
Lovers Lake	5	15.2	Yes	173	12.8	Moderate
Schoolhouse	7.7	7.5	Yes	56	28.2	Low
Stillwater	6	7.6	Yes	326	21.8	Low
Goose Pond	7.6	16.7	Yes	13	18.6	Low
White Pond	7	16.3	Yes	223	17.3	Low

*Based on 2000 – 2002 monitoring data, Town of Chatham Water Quality Laboratory

The water quality and aquatic habitat data collected during the 2001 – 2002 field investigations indicates that the Chatham Ponds are in various stages of eutrophication. While the data are somewhat limited, representing few sampling points, they do provide a basis for making an assessment of trophic state using the standard indicators described in Table 2. The final column in Table 7 represents a professional judgment of trophic state.

Table 7
Summary of Trophic State Parameters, Chatham Ponds

Pond	Surface Water Data, 2001 – 2002 (2000 data included where available [A])				Lower Water	
	Average TP (µg/l)	Average chlor (µg/l)	Max chlor (µg/l)	Range of Secchi Disk transparency (meters)	DO, % sat	Trophic State *
Black Pond-mid	44	12.6	19.0	0.8-1.29	20	E
Black Pond-west	22	20.4	32.0	1.9-2.3	80	E
Black Pond-east	28[A]	5.7[A]	7.1[A]	1.8-2.7	20	E
Blue Pond	17	2.3	2.4	1.9 - 2.9	100	M
Emery Pond	27[A]	6.7[A]	22.0[A]	0.5 - 4.5	0	E
Barclay Pond	17	3.3	3.3	2.4-3.0	0	M
Goose Pond	12[A]	1.8[A]	2.4[A]	4.4 - 8.1	40	M
Lovers Lake	37[A]	21.2[A]	47.0[A]	0.9 - 1.6	0	E
Mill Pond	28[A]	10.0[A]	14.1[A]	0.9 - 2.0	30	M/E
Mary's Pond	19	2.0	2.8	Bottom	80	M
Perch Pond	61	13.1	19.0	0.8 -1.3	20	E
Pickerel Pond	22	2.6	2.6	Bottom	100	M
Ryders Pond	27	4.3	5.7	Bottom	80	M/E
Schoolhouse	14[A]	2.9[A]	4.2[A]	~4	40	M
Stillwater Pond	29[A]	22.4[A]	47.0[A]	0.6 - 3.0	0	E
Trout Pond	15	2.0	2.5	3.6 - Bottom	0	M
White Pond	30[A]	3.5[A]	9.5[A]	2.8 - 4.6	30	M

[A] Includes 2000 data
E=eutrophic; M-mesotrophic
M/E signifies a pond that is on the border between mesotrophic and eutrophic conditions

Note that the concentrations of chlorophyll and phosphorus used to delineate trophic state are not the same as the concentrations used to define ecoregional reference lake conditions. The ecoregional criteria are, as described in Section 5 (target concentrations), based on water quality conditions measured in eight pristine Cape Cod ponds.

Based on this analysis, the Chatham Ponds may be grouped into categories describing current water quality and habitat conditions and use attainment. This grouping is presented in Table 8.

Table 8
Summary of Current Water Quality Conditions and Use Attainment

Depth Categories:	Water Quality and Aquatic Habitat Status, 2000 – 2002 Conditions		
	Meets Desired Uses	Meets Desired Uses, with Evidence of Degradation	Do Not Meet Desired Uses
Shallow (less than 3 m maximum depth)	Pickerel Pond Ryder Pond	Mill Pond	Perch (Newty) Pond Black Pond-west Cranberry *
Medium (3 – 8 m maximum depth)	Trout Pond Blue Pond Mary's Pond Minister's Pond	Fox Pond	Emery Pond Black Pond-mid Black Pond-east
Deep (greater than 8 m maximum depth)	Goose Pond Schoolhouse Pond Barclay's Pond	White Pond	Stillwater Pond Lover's Lake

* Cranberry (flooded bog) assessment was based on visual assessment from a single site visit.

7. Summary of Findings

Finding: Water quality conditions of the Chatham Ponds vary primarily as a function of depth.

- Shallow ponds tend to be most naturally productive, with emergent vegetation and macroalgae along the shoreline. Phytoplankton cells are abundant, limiting visibility and imparting a green tinge to the water.
- Deeper ponds are generally less productive, with lower concentrations of total phosphorus and chlorophyll -*a* and clearer water.
- Ponds deeper than 4-5 m exhibit seasonal anoxia (dissolved oxygen concentrations less than 1 mg/l in the lower waters) or hypoxia (dissolved oxygen concentrations less than 4 mg/l in the lower waters).
- Phosphorus enrichment of the lower waters is evident in many of the deeper ponds; the chance of this pool of nutrient mixing into the upper, sunlit waters and supporting algal growth during summer depends on the pond's depth and surface area.
- Phosphorus released to the lower waters is distributed throughout the water column during fall mixing. Because most of the kettle ponds lack defined outlets, much of this pool of phosphorus remains in the ponds and is available to support algal growth in the spring when light and temperature conditions are favorable.

Finding: The Chatham Ponds are in various stages of eutrophication; many are considered "impacted waters" based on regional criteria developed from limited measurements of water quality conditions in eight pristine Cape Cod ponds. However, designated uses are generally met.

- Summer chlorophyll-*a* concentration exceed thresholds for pristine waters (reference lake conditions), as defined by ecoregional data sets. This finding has been interpreted by the Cape Cod Commission to indicate that human activities have affected water quality and/or habitat conditions.
- The ponds are used for swimming, boating, recreational fishing and aesthetic enjoyment. While a few ponds exhibit visual degradation of water quality conditions, most are aesthetic assets and provide tremendous habitat for a diverse assemblage of aquatic biota.
- Monitoring for microbiological purity (using indicators of the potential presence of disease-causing organisms) indicates that the pond waters are safe for swimming.

Finding: Phosphorus is the limiting nutrient for primary production in the Chatham Ponds.

- Unlike the coastal embayments, phosphorus rather than nitrogen limits the production of algae and macrophytes in the inland ponds.
- The ratio of nitrogen to phosphorus is likely to influence the species composition of the algal community, particularly the importance of blue-green algae.
- The nitrogen: phosphorus ratio of the ponds is very high (ranging from 13 to 144). In general, higher values are associated with more oligotrophic conditions. The nitrogen/phosphorus ratio, on average, decreases from more than 100 on the oligotrophic side to less than 10 on the eutrophic side. This can be interpreted as a tendency for lakes to shift from phosphorus dependency to nitrogen dependency with increasing trophy (Janus and Vollenweider 1981). Generally, lakes are considered to be phosphorus limited when the N:P ratio is greater than 15, and nitrogen limited when the N:P ratio falls to 7 or below. N:P ratios measured during 2001 and 2002 are summarized in Table 9.

Table 9
Nitrogen:Phosphorus Ratios, Chatham Freshwater Ponds

Pond	N:P Ratio , 2001 Data	N:P Ratio , 2002 Data
Barclay Pond	51	65
Black Pond	42	44
Black Pond	33	52
Black Pond-Middle	64	70
Blue Pond	13	49
Emery Pond	63	44
Goose Pond	17	27
Lovers Lake	59	117
Marys Pond	53	35
Mill Pond	19	34
Perch Pond	26	54
Pickerel Pond	56	33
Ryders Pond	61	59
Schoolhouse Pond	17	15
Stillwater Pond	35	58
Trout Pond	17	25
White Pond	35	144

Finding: Phosphorus enters the Chatham Ponds from several sources; few (if any) of these sources are easily controlled.

- External sources of phosphorus include:
    - groundwater influx (natural background)
    - groundwater influenced by wastewater disposal (sewage plumes),
    - runoff from surfaces such as roadways
    - atmospheric deposition,
    - shoreline erosion,
    - swimmers,
    - wildlife (gulls, waterfowl, deer etc).
- Internal sources of phosphorus include:
    - Release from pond bottom sediments during anoxic conditions

Finding: Options for improving water quality and aquatic habitat conditions in the ponds are based on controlling inputs or altering the internal cycling of nutrients.

- Some inputs cannot be controlled by local action alone: atmospheric deposition, natural background phosphorus in groundwater, wildlife.
- Some inputs may be controlled using regulatory, structural, and/or educational means:
    - sewage plumes,
    - surface runoff,
    - shoreline erosion,
    - swimmers.
- Techniques to control internal phosphorus cycling:
    - Alum application to seal bottom sediments and prevent phosphorus release
    - Use aerators or mixers to keep water column oxygenated and accelerate the rate of decomposition of organic material
    - Drawdown ponds with outlet control structures
        - Winter drawdown to reduce macrophyte biomass

        - Permanent drawdown to accelerate transition of hypereutrophic pond to wet meadow
    - Selective dredging to deepen ponds, remove organic material, improve recreational
- Techniques to mitigate symptoms of eutrophication
    - Algaecide (e.g. copper sulfate)
    - Other herbicides
    - Biomanipulation
    - Weed harvesting
    - Benthic barriers

8. Recommendations

8.1. Public Education

- Forum to discuss pond ecology, range of conditions in Town ponds, and effective measure for improving water quality conditions.
- Education regarding the importance of remaining on trails and protecting riparian (shoreline) areas
- Education regarding application of fertilizers and pesticides

8.2. Land acquisition

- Town and Conservation Foundation to continue to pursue and acquire open space, incorporate resource-based priorities into decisions. Place high priority for acquisition of properties in riparian areas.

8.3. Bioengineering

- Revegetation of shoreline areas
- Trails through public lands planned, installed and maintained to reduce potential for erosion

8.4. Structural

- Wastewater collection
- Modification of systems for alum dosing
- Stormwater basins with water quality controls: operations and maintenance are critical.
- Pond level management (drawdown): Cranberry (flooded bog)
- Public toilet facilities for beach areas
- Improved stormwater management on parking lots adjacent to ponds

8.5. Inspection and Monitoring

- Inspection and maintenance of onsite systems
- Continued participation in PALS
- Modifications to monitoring program (Appendix C)

8.6. In-lake Measures

- Alum treatment to seal bottom sediments:
- Mixing
- Benthic barriers
- Mechanical or hand removal of weeds

Many of the recommendations apply to all the ponds and their surrounding watersheds. Specific observations and recommendations for the 20 ponds are summarized in Table 10.

Table 10
Summary of Major Findings and Recommendations for Chatham Ponds

Pond	Findings	Recommended Actions
Black Pond-mid	Undisturbed shoreline. Nutrient flow in from Emery	Education, protection
Black Pond-west	Algal blooms, macroalgae	Benthic barriers for recreation
Black Pond-east	Clear water, tannins. Some potential runoff from golf course.	Review fertilizer practices with golf course, to reduce potential loss to pond.
Blue Pond	High quality habitat, protected shoreline	Continued protection
Emery Pond	Algal blooms (wind-blown mats), emergents. Tannins in water Flow in from cranberry bog likely nutrient source	Public education re protecting shoreline vegetation, controls during construction. Hand pulling weeds, benthic barriers
Barclay Pond	Protected, high quality habitat	Continued protection
Goose Pond	Pristine appearance, clear water.	High priority for protection
Lovers Lake	Visible macroalgae, algal blooms	Nutrient inactivation Shoreline protection
Mill Pond	Very shallow, Lilies 60% cover, protected watershed. Abandoned cranberry bogs. No swimming areas	Protected by land ownership
Mary's Pond	Protected, high quality habitat	Continued protection
Perch Pond	No access. Filling in to wetland	Could provide public education regarding natural succession
Pickerel Pond	Lots of macroalgae	Stormwater management
Ryder’s Pond	Tannins. High quality aquatic habitat	Protection
Schoolhouse	Official beach.	Stormwater management in parking areas
Stillwater Pond	Visible macroalgae, algal blooms	Nutrient inactivation
Trout Pond	Algal bloom. Development, but little encroachment to shoreline	Stormwater management Septic inspection and maintenance
White Pond	High quality pond, clear water. Potential beach site. Some gulls, occasional elevated bacteria levels	Priority for protection.
Fox Pond (not monitored)	Emergents. Neighbors requested permission to apply herbicides. Formerly used aerator	Hand pulling emergents to improve access. Investigate use of solar or wind powered aerator
Cranberry Pond (not monitored)	Advanced eutrophication, aesthetically unappealing	Drawdown to accelerate transition to wetland
Minister’s Pond (not monitored)	Small kettle lake, protected. Tannins, some macroalgae	Education, protection

9. Priority Actions for the Town of Chatham

Actions recommended for 2003 – 2004

Convene a public educational forum to discuss current water quality and habitat conditions of the ponds of Chatham. Solicit public input on the desired future for the ponds (overall and for individual ponds). Major topics include:

- The eutrophication process
- The unique nature of the kettle ponds in nutrient cycling
- How have conditions changed in recent decades
- What can be done
- Why each pond requires different strategy (no action, protection, active intervention) based on physical characteristics, current conditions, and desired use
- What are the costs and benefits associated with alternatives
- How will overall wastewater and facilities decisions affect the ponds

Continue and expand the annual pond monitoring program to improve baseline data and gather data needed to apply for permits and funding for implementation of control measures. The recommended monitoring plan is included as Appendix C. Prepare an annual Chatham Pond Report Card to enhance public understanding of water quality conditions and contributing factors.

Estimate the potential build-out of pond watersheds (once delineations are complete). Use this analysis to refine the listing of ponds to be considered for wastewater collection and out-of basin disposal. Based on existing conditions, priority areas include the watersheds of Stillwater Pond, Lovers Lake, Emery Pond and White Pond (see Appendices A and B for specific recommendations)

Propose a local law requiring periodic inspection and pump out of individual on-site wastewater treatment systems. The frequency can be linked to distance to ponds, with more stringent requirements within a defined buffer zone.

Confer with engineering consultants, public health agencies, and MADEP to determine feasibility of requiring alum dosing to on-site wastewater disposal systems.

Review local erosion and sedimentation control laws and determine if they could be improved to prevent sediment loss to the ponds. If warranted, propose revisions for approval.

Convene technical committee (or select consultant) to initiate detailed planning and cost estimating, identify funding sources, secure non-local funding as available, and acquire permits for alum application to Stillwater Pond and/or Lovers Lake. With funding and permits, treat ponds in summer 2005.

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Appendix A. Summary of Regulatory Setbacks and Recommendations for Septic Systems in Coastal Areas

- Buzzards Bay Watershed Management Plan
    - Recommends 250 ft setback from surface waters and wetlands, (viral pollution)
    - Where this setback cannot be met, changes in system design and application rate are required to ensure removal of viruses.
- New Hampshire's Shoreland Protection Act [3.10 Leach Field And Septic Tank Setback (Added 1990, Amended 1992)]
    - "Where the naturally occurring receiving soil down-gradient of the leaching portions of a septic system is a porous sand and gravel material with a percolation rate faster than two (2) minutes per inch, the setback shall be at least 125 feet.
    - For naturally occurring receiving soils with restrictive layers within 18 inches of the surface, the setback shall be at least 100 feet; and
    - For naturally occurring receiving soils with any other characteristics the setback shall be at least 75 feet.."
- CAMA Handbook For Development In Coastal North Carolina: Section 3
    - Septic tanks and drainfields must be located at least 100 feet from waters classified as WS IV by the Environmental Management Commission.
    - No sewers, septic tank fields or other sources of pollution may be built within 500 feet of the edge of the Fresh Pond in the Nags Head/Kill Devil Hills Fresh Pond watershed. Between 500 feet and 1,200 feet from the pond, septic systems are limited to one system serving a single-family home with no more than four bedrooms (or an equivalent volume of sewage) on a tract of land at least 40,000 square feet in size.
- Rhode Island towns:
    - Burrillville: 200 ft from wetlands
    - Charlestown:
        - 100 feet from a freshwater or coastal wetland.
        - 200 feet from a ten-foot-wide flowing body of water.
        - 100 feet from flowing bodies of water less than 10 feet wide.
        - 100 feet from intermittent streams.
        - 100 feet from floodplains.
    - Foster: 200 ft from any pond, stream, spring or brook
    - Glocester: 150 ft from ponds, streams or springs
    - Jamestown: 150 ft from any freshwater
    - Narrangasett: Special use permits for septic systems within 150 ft. of coastal and freshwater wetlands.
    - New Shoreham:
        - 150 feet of vegetated buffer shall be maintained from any septic system to a freshwater wetland or coastal feature.
        - 200 feet of vegetated buffer shall be maintained from any septic system to Sands Pond, Peckham Pond and Fresh Pond.
    - Scituate: 150 ft from surface waters
    - South Kingstown requires special use permits for all septic systems located:
        - Within 50 feet of a bog, marsh, swamp or pond.
        - Within 200 feet of flowing bodies of water 10 feet or more in width.
        - Within 100 feet of flowing bodies of water less than10 feet in width.
        - Within 150 feet of floodplains.
        - Within 150 feet of other freshwater wetlands
    - Warren: 150 ft from any body of water, including wetlands
    - West Greenwich: 200 ft from edge of any pond or stream

Appendix B. Summary of Pond Management Alternatives

Category 1: Control Inputs

	1	2	3
Method	Reduce phosphorus from on-site wastewater disposal systems by centralized collection and disposal outside of watershed zone of influence	Reduce phosphorus from on-site wastewater disposal systems by modifications to require alum additions to septic tanks	Reduce phosphorus from on-site wastewater disposal systems by requiring frequent inspections and maintenance of systems
How does it Work?	Collection system and treatment/disposal	Physical modification to wastewater systems	Modification to local laws
Potential Benefits	Decreased loading of all wastewater contaminants, including pathogens	Decreased loading of phosphorus	Decreased loading of all wastewater contaminants, including pathogens
Potential Drawbacks	Could increase development pressure	More complex systems, more maintenance. More sludge	Public acceptance needs to be very high
Data gaps to make decision	Integrated with rest of wastewater decisions. Existing data do not define extent of problem	Existing data do not define extent of problem	Existing data do not define extent of problem
Costs (Relative)	High (likely to receive some public funds)	Moderate (may receive public funds for demonstration)	Low (borne by homeowners)
Permitting issues	Collection system will have environmental impact. Need to identify acceptable site for disposal to groundwater. Conservation Commission approval needed.	Dept. of Heath approvals, sludge disposal Conservation Commission approval needed.	Dept. of Health approvals Conservation Commission approval needed.
Longevity	High	Moderate	Moderate
Ponds that might be appropriate for this alternative	Highest number of on-site systems are in Lovers, White, Stillwater, Emery	Impaired ponds with >20 residences: Emery, Stillwater, Lovers. Non-impaired ponds, at least 15 residences: White, Schoolhouse. Consider Trout and Pickerel, based on water quality	all

Category 1 (continued): Control Inputs

	4	5	6
Method	Water quality inlets to stormwater infiltration basins	Public education and outreach	Discourage gulls by using scare techniques
How does it Work?	Stormwater collection and treatment prior to groundwater discharge	Educate public on importance of landscaping, erosion controls, beach sanitation	Reduces nutrient deposition from birds
Potential Benefits	Reduced loading	Reduced loading. Increase public awareness of ponds and their vulnerability	Reduced loading of nutrients and bacteria
Potential Drawbacks	Most systems designed to capture sediment. Higher maintenance	None	Disruptive
Data gaps to make decision	No estimate of the contribution of soluble P from stormwater	None	Estimate maximum number of gulls, use research reported in Portnoy (1990)
Costs (Relative)	Low	Low	Low
Permitting issues	Requires siting, Conservation Commission approval needed.	None	Needs approvals from Fish and Wildlife, MADEP. Conservation Commission approval needed.
Longevity	Moderate	Moderate (prevention of incremental source likely to be a small source)	Likely to be effective only while active measures are taken, although birds may move to other areas
Ponds that might be appropriate for this alternative	All, especially those with developed watersheds, Trout and Pickerel have evidence of sediment deposition from runoff	All	White

Category 2: Alter Internal Cycling of Nutrients

	1	2	3
Method	Alum application	Sediment oxidation	Circulation
How does it Work?	Alum hydrolyzes in water, forming a floc. As the floc settles it removes particulate material as well as any dissolved P. If applied properly, forms a barrier on sediment surface that will continue to trap P.	Procedure injects calcium nitrate into top 10" sediment to break down organics and promote denitrification.	Prevents stratification from developing. Keeps more oxygen in water column and thus available to break down organic material.
Potential Benefits	• Long history of use • Does not seem to affect other aquatic organisms • May create layer over sediments retarding future sediment P release • Long-term results • Readily available	If successful will greatly reduce internal P loading from sediments	Reduces surface algal blooms, improved habitat for aquatic biota, may retard sediment P release
Potential Drawbacks	Low pH ponds, need buffering (sodium aluminate). Potential for aluminum toxicity if pH declines. Loss of benthic organisms.	Optimal pH of sediments 7 – 7.5; would require liming. Considered an experimental technique.	Results likely to be subtle, requires energy source (electric, solar or wind). May increase algal production throughout water column.
Data gaps to make decision	Sediment testing to estimate optimal dose	Sediment testing to calculate dose	DO profiles over season, history
Costs (Relative)	Can be high, application rate estimated at $70 per 40-lbs.(40 lbs. treats 1ac-ft) *	Can be high, $8,000 – $12,000 per acre *	Variable, depending on power source. Solar-powered mixing devices may cost $25,000
Permitting issues	Requires permit, testing for optimal dose. MADEP cautious following Hamblin Pond fishkill. Conservation Commission approval needed.	Requires permit, testing for optimal dose. Conservation Commission approval needed.	Conservation Commission approval needed.
Longevity	Moderate (at least several years)	Moderate (at least several years)	Only effective when mixers working
Ponds that might be appropriate for this alternative	Deeper ponds with elevated TP in lower waters: Stillwater, Lovers.	Impaired ponds with DO depletion: Emery, Trout	Fox

* Source for cost estimates: Holdren et al. 2001

Category 2 (continued): Alter Internal Cycling of Nutrients

	4	5
Method	Dredging	Drawdown
How does it Work?	Sediment is physically removed, also removing accumulated nutrients and organic material	Lowering water level will dry sediments and allow sediments to oxidize and compact.
Potential Benefits	Reduced internal nutrient supply, increases water depth, can reduce sediment oxygen demand	May alter nutrient availability. Opportunity for shoreline cleanup.
Potential Drawbacks	Expensive if disposal site not nearby. Temporary turbidity, removes macroinvertebrates, temporarily interferes with recreation. Might reduce ponds' natural capacity for denitrification and thus allow more soluble nitrogen to make its way to coastal embayments.	Possible impacts on contiguous wetlands, may change habitat for amphibians. Ponds with water level controls may be managed for herring. Temporary loss of waterfowl habitat. Potential to create highly unappealing aesthetic conditions for neighbors.
Data gaps to make decision	Quality of sediments (affects disposal options and costs), detailed bathymetry to estimate volumes and costs.	Water level control needed, therefore not feasible for most ponds
Costs (Relative)	$15,000 - $50,000/acre *	<$100/acre if structures adequate*
Permitting issues	Requires permit for dredging and disposal Conservation Commission approval needed.	Permit required, complexity depends on impacts on wetland and other ponds. Conservation Commission approval needed.
Longevity	Moderate to long	Moderate to long
Ponds that might be appropriate for this alternative	Lovers, Stillwater, Emery	Cranberry

* Source for cost estimates: Holdren et al. 2001

Category 3: Mitigate the Symptoms of Eutrophication

	1	2	3
Method	Mechanical removal of weeds	Hand pulling weeds	Benthic barriers
How does it Work?	Removes rooted aquatic plants from targeted areas using various mechanical means	Removes rooted aquatic plants from targeted areas	Mat of variable composition laid on bottom of target areas, used in swimming areas or around docks
Potential Benefits	Highly flexible	Highly flexible	Prevents plant growth, reduces turbidity from soft sediments
Potential Drawbacks	Creates turbidity, may spread some plants by fragmentation	Labor intensive	Require maintenance
Data gaps to make decision	Useful for areas where recreational access is limited by weeds	Useful for areas where recreational access is limited by weeds	Useful for areas where recreational access is limited by weeds
Costs (Relative)	Hydroraking or rotavation $2000/acre*	$100/acre*	$20,000 /acre (only small areas typically treated)*
Permitting issues	Turbidity, avoidance of critical habitat areas and spawning/early life stages of fish community Conservation Commission approval needed.	Minimal Conservation Commission approval needed.	Minimal, need to avoid critical habitat Conservation Commission approval needed.
Longevity	Usually needs to be repeated once or twice a year	Usually needs to be repeated once or twice a year	Need to be replaced every 1 – 2 years
Ponds that might be appropriate for this alternative	Trout, Pickerel, Emery, Stillwater (cove areas); Fox	Areas where homeowners access diminishing (e.g. Ministers, Emery, Fox, Stillwater, Lovers, Trout, Pickerel)	Areas where homeowner access diminishing (e.g. Ministers, Emery, Fox, Stillwater, Lovers, Trout, Pickerel)

* Source for cost estimates: Holdren et al. 2001

Category 3 (continued): Mitigate the Symptoms of Eutrophication

	1	2	3
Method	Chemical control of algae (several copper-based and organic compounds approved for this use)	Chemical control of macrophytes	Mechanical harvesting of macrophytes
How does it Work?	Algaecides: kill algae by direct toxicity or by metabolic interference	Various modes of uptake to plant and biochemical pathways disrupted, ultimately results in plant senescence and death	Plants cut in place, depth of 2 – 10 ft roots not harvested. Cuttings collected and removed from pond
Potential Benefits	Rapidly eliminates algae from water column	Reduces density of macrophytes in treated areas	Improved recreational access
Potential Drawbacks	May be toxic to non-target organisms, nutrients from decaying algae may recycle, oxygen demand created to decompose killed cells, may restrict water uses	May be toxic to non-target organisms, nutrients from decaying plants may recycle, oxygen demand created, may restrict water uses	Non selective in harvested area, may disrupt habitat, may remove native insects that help control plants
Data gaps to make decision	Water pH, alkalinity, background concentrations of metals; sediment quality (AVS and TOC)	Detailed species inventories needed to select most appropriate chemicals	Species abundance, access points for equipment, disposal sites
Costs (Relative)	Depends on compound, Chelated copper compounds range $150 – 300/acre per application*	Depends on compound. Range per acre: $200 (Diquat) to $1000 (Fluoridone, three applications)*	For moderately dense, submersed vegetation: assume $200 – 600/acre*
Permitting issues	Requires permit and approvals from environmental and public health agencies, including Conservation Commission.	Requires permit and approvals from environmental and public health agencies, including. Conservation Commission	Minor, need to develop plan for harvesting and upland disposal sites. Conservation Commission approval needed.
Longevity	Short-term (weeks to months)	Annual	Short-term (weeks)
Ponds that might be appropriate for this alternative	None recommended	None recommended	None recommended

* Source for cost estimates: Holdren et al. 2001

Appendix C. Recommended Water Quality Monitoring Program

The existing water quality monitoring program provides an excellent foundation for tracking baseline water quality conditions. We recommend certain modifications, as outlined below.

Program element	Current Program	Recommended Program	Rationale
Parameters measured	Secchi disk transparency, total P, total N, chlorophyll-*a*, phaeophytin, total alkalinity, field parameters (profile DO, pH, temperature at deepest point); Bacteria sampling at public beaches to assess suitability for water contact recreation.	Same, consider if there is a cost savings associated with dropping total N (although data consistency may be important to SMAST program)	Data indicate that ponds are P limited (N:P ratio is high)
Ponds monitored by Town	17 ponds	Add Fox Delete Perch	(Fox) Provide guidance to homeowners regarding potential benefits of mixing. (Perch) Problematic access, natural progression to wetland well underway
Frequency	Variable	At least monthly (May – October) for all ponds. Biweekly profile and water quality sampling recommended for Stillwater and Lovers (to support alum assessment), and other deep ponds (Goose, White, Schoolhouse, Barclays).	Increased frequency will support more robust averages and better comparisons to ecoregional criteria.
Matrix	Water column	Water column, add limited sediment testing in ponds considered for alum treatment to quantify labile phosphorus.	Need to evaluate sediment phosphorus flux