The Practical Guide to Lake Management in Massachusetts

A Companion to the Final Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management in Massachusetts

Commonwealth of Massachusetts
Executive Office of Environmental Affairs

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Prepared for the
Department of Environmental Protection
and
Department of Conservation and Recreation

Executive Office of Environmental Affairs,
Commonwealth of Massachusetts

By

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INTRODUCTION: ABOUT THIS MANUAL

This manual has been prepared as a companion guide to the Final Generic Environmental Impact Report (GEIR) on Eutrophication and Aquatic Plant Management in Massachusetts (Mattson et al. 2004). The GEIR is a larger document with more information, intended to satisfy the requirements for such a document under the Massachusetts Environmental Policy Act. This companion guide was developed to provide key information in a more concise and user-friendly format for Conservation Commissions, lake groups, and interested citizens. As this guide was developed from the GEIR, the efforts of all those involved in the preparation of the GEIR are acknowledged, especially Drs. Mark Mattson and Paul Godfrey, the primary authors of the original version of the GEIR, from which much of the information in this manual is taken.

The focus of this guide is on key aspects of each potential lake and watershed management technique that might be considered for the control of eutrophication and aquatic plants. It is intended to provide the reader with a general overview and enough information to evaluate whether or not a given technique is appropriate to the situation. It also indicates issues for each technique that must be considered in a more thorough feasibility assessment. For those involved with managing a lake, this manual provides information essential to understanding options and narrowing the choices, but is not always a substitute for competent advice from lake management experts. For Conservation Commissions, this guide highlights the salient issues that must be addressed if a management technique is to be applied properly under the Wetlands Protection Act and associated statutes. However, it cannot anticipate and address all possible situations that may arise or every factor that may go into a decision.

Lake and watershed management is a complex process that is interdisciplinary by nature and involves so many facets that it is difficult to know where to start in many cases. Compromises are almost always made between study and action, protection and conservation, restoration and maintenance, and expense and expedience. With limited time, funding and information, such compromises may indeed be necessary, although the regulatory framework within which management actions are permitted has minimum standards that set limits on management without appropriate justification. Iterative steps in the management of watersheds and lakes is often encouraged; small steps that move in the perceived correct direction cost less and have less potential to damage non-target organisms or features. However, some techniques are not effective unless applied at a larger scale, and ultimately the cost of management may be quite high. This guide cannot provide the solution to all potential problems or the answer to all possible questions, but it does provide a substantial amount of information intended to start interested groups in the right direction.

The organization of this manual is simple. Following this introduction is a section on lake and watershed features and processes, which is considered essential information for understanding management techniques and associated issues. Then there is a brief section on developing a lake and watershed management plan, distilled from the more lengthy discussion in the GEIR. The remainder of the manual is a compendium of management techniques aimed at controlling the input of nutrients or the accumulation of vascular plant and algal biomass. For each technique there are concise sections on how it works, what benefits it can provide, significant shortcomings or potentially undesirable impacts, factors that favor its use, information necessary to proper application, implementation guidance, permits that may be needed, and approximate costs. The information in this manual is abridged from the GEIR, and readers are encouraged to review relevant sections of the GEIR to gain additional insight on techniques of interest. Readers may also want to consult the references provided in this guide and in the more extensive ones in the GEIR, and should consider consulting relevant websites for updates and additional information. Two especially relevant websites are those of DEP’s Watershed Management Program (www.state.ma.us/dep/brp/wm/wmpubs.htm) and DAR’s Pesticides Program (www.state.ma.us/dfa/pesticides/water/aquatic/herbicides.htm).
ESSENTIAL BACKGROUND INFORMATION

The Origin and Nature of Lakes

The lakes in Massachusetts were created in two principal ways: by glacial activity approximately 12,000 years ago or by damming streams or small lake outlets, most of latter occurring during the early industrial age of the country for water power. In many respects, lakes are like people. They are born, grow older and die, with many possible conditions along the way. Through natural processes, lakes will become shallower and more eutrophic (nutrient-rich) and eventually fill in with sediment until they become wet meadows. The aging process is not identical for all lakes, however. Some lakes age quickly, others very slowly, and not all start out in the same condition. Many lakes that were formed by the glaciers no longer exist while others have changed little in 12,000 years. Yet lake aging is reversible. The rate of aging is determined by many factors including the depth of the lake, the nutrient richness of the surrounding watershed, the size of the watershed relative to the size of the lake, erosion rates, and human induced inputs of nutrients and other contaminants. Lakes are therefore highly variable in specific features, and goals for the management of each may vary as well.

Existing lakes can be subdivided into categories depending on their position along a continuum of fertility. Nutrient-poor lakes are termed oligotrophic, nutrient-rich lakes are eutrophic, and those in between are mesotrophic. Variations on this system are possible, and any system to boil the complexity of a lake into a single word will not be completely adequate to describe lakes. Lakes in one part of the Commonwealth may share many characteristics (depth, hydrology, fertility of surrounding soils) that cause them to be generally similar. Massachusetts can be divided into regions based on typical phosphorus levels in lakes (Figure 1).

Lakes that are created by damming streams may at first be eutrophic as nutrients in the previous stream's floodplain are released into the water column. Over a period of decades, the initial productivity tends to change until the impoundment takes on conditions governed more by the entire watershed, with depth and detention time as critical determinants of response to watershed inputs. Impoundments may never completely escape the legacy of their creation. They are commonly shallow and the pre-existing nutrient-rich bottom sediments may provide nutrients for abundant aquatic plant growth early in the life of the lake.

Human activity can unduly accelerate the process of lake aging or, in the case of introduced species or pollutants, force an unnatural response. Unnatural responses include the elimination of aquatic species as a result of acid deposition, algal blooms resulting from excessive nutrient enrichment, and the development of a dense monoculture of a non-native aquatic plant. However, it would be unrealistic to assume that managing cultural impacts on lakes can convert them all into infertile basins of clear water. Understanding the causes of individual lake characteristics (i.e., understanding the lake ecosystem) is a fundamental part of determining appropriate management strategies.

An ecosystem is a system of interrelated organisms and their physical-chemical environment. We need an operational unit that can be reasonably studied and will help explain all or most of the characteristics of the lake. The most useful definition of the lake ecosystem is the lake and its watershed because the watershed defines the terrestrial sources of the lake’s water (Figure 2). Most impacts on lakes can be related to characteristics of the watershed, although acid rain, mercury deposition and drought have demonstrated that not everything important to lakes occurs within the watershed. A lake is a web of interactions between hundreds of biological species, chemical compounds, hydrological processes and human actions, all in constant change. A tug on any part of the web ripples throughout the rest of the ecosystem. Ecology is the scientific study of these relationships and limnology is the study of freshwater ecology. Lake management involves the application of ecological principles and data to establish and maintain desirable conditions.
Figure 1. Regions of Massachusetts Based on Phosphorus Levels in Lakes (after Rohm et al. 1995)

Figure 2. The Hydrologic Cycle (Olem and Flock, 1990)
Key Features of Lakes

Water

Water is very abundant both on earth and in all living organisms. Water has properties that make life in lakes possible, particularly lakes in the northern parts of the world. Unlike most other compounds, water does not become increasingly denser as it becomes colder. Instead, water increases in density as it is cooled until it reaches 4°C (39°F). Upon further cooling to 0°C (32°F), it becomes lighter and floats on the surface until it has cooled sufficiently to freeze. If this were not true, lakes would freeze solid in our winters. Water also has a high specific heat and high latent heat of fusion; thus they are slow to thaw in spring and slow to cool in winter, thereby providing an extremely stable thermal environment for aquatic life. Water also vaporizes at temperatures common to our climate, producing water vapor and continuing the hydrological cycle of precipitation, runoff and infiltration, evaporation and transpiration. Water is one of the best solvents available and many compounds dissolve in it. These properties help to explain much of what we observe in lakes.

Hydraulic Residence

The average time required to completely renew a lake's water volume (lake volume divided by outflow rate) is called the hydraulic residence time. Hydraulic residence time is a function of the volume of water entering or leaving the lake relative to the volume of the lake (i.e., the water budget). The larger the lake volume and the smaller the inputs or outputs, the longer will be the residence time. Lake residence time may vary from a few hours or days to many years. Lake Superior, for example, has a residence time of 184 years. However, Massachusetts lakes typically have residence times of days to months. Our largest lake, Quabbin Reservoir, has a residence time of approximately three years. Mill Pond in West Newbury, MA with an area of 16 acres and mean depth of 4.1 feet has a residence time of 14 days, while Lake Massasoit (aka Watershops Pond, an impoundment of the Mill River) in Springfield has an average residence time of about a week. The flushing rate of a lake will determine how it responds to many inputs.

Mixing

The thermal structure of lakes also helps determine productivity and nutrient cycling. Lake thermal structure is determined by several factors. Lakes receive the vast majority of their heat at the surface from solar heating. Since warmer water floats, the water column must have an energy input to mix that heat deeper and in most lakes wind provides that energy. A lake that is completely protected from the wind will have a very warm but shallow layer at the surface with cold water below. A lake exposed to strong winds will have a cooler but thicker upper layer overlying the colder water. For many shallow Massachusetts lakes, the mixed layer may extend to the lake bottom. Deeper lakes may form a three-layered structure that throughout the summer consists of an upper warm layer (the epilimnion), a middle transition layer (the metalimnion, within which the point of greatest vertical change is called the thermocline), and a colder bottom layer (the hypolimnion).

A lake's thermal structure is not constant throughout the year. Beginning at ice out in early spring, all the lake's water, top to bottom, is close to the same temperature; the density difference is slight and water is easily mixed by spring winds. With warmer days, the difference between the surface and bottom waters increases until stratification occurs if lake depth is sufficient (Figure 3). Eventually, solar heating declines and the upper layer begins to cool and sink. Eventually in the fall, the lake has a similar temperature top to bottom. In winter, ice forms at the surface and a new, inverse stratification (cold over cool water) is created and persists until spring. The degree of stratification is important to the cycling of nutrients, variability in oxygen in deeper waters, movement of incoming water through the lake, and types of aquatic organisms that live in the lake (Figure 3).
Nutrients

Lakes may suffer from many impacts of human cultural development. Of primary concern for this review are nutrients. All plants need an appropriate balance of the essential major nutrients, particularly phosphorus, nitrogen, and carbon. They also need light. Assuming that light is readily available, plants take up nutrients in the proportion that their cells require. The nutrient that is in shortest supply relative to the plant’s needs will limit the growth of the plants. This is called the limiting nutrient concept. The ratios of plant needs to the concentration of nutrients in water suggest that phosphorus is the scarcest nutrient relative to plant demand for most freshwater systems. Some freshwater and most estuarine systems have nitrogen as the limiting nutrient, and trace elements can sometimes be limiting, but phosphorus is the logical target of management to control algae in lakes. Phosphorus is easier to control than many other nutrients, particularly carbon and nitrogen. The latter two have gaseous phases, so the atmosphere becomes a major source where both are quite abundant.

Lake managers typically compartmentalize all forms of phosphorus into three categories: dissolved, particulate and their sum, total phosphorus. Dissolved phosphorus is readily available for uptake by plants and, consequently, is usually found only in low concentrations during the growing season. At that time, most of the phosphorus will either be adsorbed to particles such as fine soil or clay or in living or dead plant or animal cells. However, the death and decay of an organism will begin the process of releasing the phosphorus in dissolved form where it can almost instantly be taken up by other organisms.
A map of typical total phosphorus levels for Massachusetts lakes provides a general expectation of phosphorus concentration for any lake under study (Figure 1). While this does not provide a quantitative breakdown of nutrient sources that can help pinpoint likely areas for nutrient control, it can provide a sense of the typical conditions for the region and suggest reasonable goals for nutrient management. A lake with much higher phosphorus levels than typical for that region may be a strong candidate for successful improvement by reducing cultural sources of phosphorus. Keeping phosphorus concentrations below the expected level for the corresponding area may require frequent management action.

Development of a nutrient budget (loading analysis) provides insight into the causes of lake eutrophication. Nutrient budgets depend on the determination of the amounts of a nutrient that are provided by sources such as natural surface runoff, non-point source pollution, leaking septic systems, atmospheric deposition, groundwater and wildlife. Nutrient budgets also determine the quantity of nutrients lost to the lake system by outflow and by deposition to the sediments. Quantifying nutrient loading requires assessment of the water budget and determination of the concentration of the nutrient in each source of water. Thus the quantity of nutrient provided by a tributary is the concentration times the volume of water per unit time (the flow). This is called the “load” for the nutrient and source being quantified. Just like a bank account, the input loads (deposits) minus the output mass (withdrawals) should equal the total change in the mass of nutrient in the lake. Knowing the relative inputs and costs of reducing them aids the development of a workable lake management strategy for controlling water quality and therefore preventing algal blooms. Nutrient budgets are less useful in the control of rooted aquatic plants.

Internal loading refers to nutrients recycled from the sediments. Internal loading may be a large source of phosphorus to the lake in certain circumstances. When lake sediments become anoxic as they would in a stratified eutrophic lake, phosphorus that is normally adsorbed to iron oxides under oxygenated conditions is released in dissolved form. This hypolimnietic phosphorus may be returned to upper water layers during turnover or even during stratification under unusual circumstances. Also, resuspended sediment (caused by wind or motorized watercraft) may release phosphorus back into the water column. Additional phosphorus may be “pumped” from shallow water sediments by aquatic macrophytes with roots in the sediment, particularly when the plants die at the end of the growing season. As might be expected, such internal phosphorus loading is often hard to estimate. The timing of this internal loading may make it more important than its magnitude suggests; internal cycling of nutrients may not be important in a yearly budget, but may be very important during the summer stratification period, which is also the growing season.

Nutrient budgets are commonly determined in two primary ways: by direct measurement or by estimation from various empirical relationships determined in past studies. Accurate determination of a nutrient budget by direct measurement is monitoring-intensive, requiring nearly constant measurement of water flow and frequent measurement of nutrient concentration in all or most incoming and outgoing components. One rainstorm may provide a large percentage of the nutrient input; if unmeasured or not measured with sufficient frequency at sufficient sites, the budget will be grossly in error. Groundwater samples may be difficult and/or expensive to collect. Flow rates are hard to determine precisely without expensive automated equipment, especially during storm events.

It is rarely possible to achieve or afford this level of monitoring. Consequently, nutrient budgets are often determined by loading estimates based on land uses and by models established from large databases. Detailed research on many watersheds has provided important loading factors or export coefficients to be expected from various types of land use, numbers of residents, sediment storage and other more easily measured factors. The quality of the nutrient budget will depend on the similarity between the study watershed and the calibrated watersheds in the literature. No method is likely to produce a very accurate estimate of the nutrient budget if monitoring frequency is low or if the watersheds are only moderately comparable. However, the credibility of the estimate can be
substantially increased if multiple methods are used and produce roughly comparable results. Agreement among multiple models, especially when calibrated for the study watershed with some real data specific to that system, can increase confidence in budget estimates. Key parts of a nutrient budget are shown in Figure 4. Generation of nutrient budgets is essential to many algal control efforts, but is less applicable to rooted plant control.

**Particulates**

Particulates may be either inorganic or organic, but lake managers typically define them as any object larger than 0.45 thousandths of a millimeter (0.45 micrometers). Larger particles will not stay suspended in water for long, but smaller particles may settle very slowly or not at all. Colloids are fine particles with almost the same density as water that remain suspended. Larger or heavier particles such as algae, bacteria, aquatic animals and silt will eventually settle to the bottom, although some of these may actively swim or possess flotation devices to counter the effects of gravity. These living particulates are addressed separately below.

Inorganic particles are relevant to aquatic plants and algae because they can contribute nutrients that have been adsorbed on the particles. In addition, they can accelerate the process of filling the lake to the point where a shallow, soft and nutrient-rich bottom is widely available for rooted aquatic plant growth. Most inorganic particulates will have originated from terrestrial sources, although wave action and human activity can stir up lake bottom sediments and redeposit them. Organic particles, sometimes referred to as detritus, are living or dead biota - plants, animals and bacteria. These eventually settle to the bottom where they decompose and release their nutrients.

**Bacteria**

Although never seen by most people, bacteria play a pivotal role in the life of lakes. They are the most abundant group of organisms in a lake and most of them are critical in converting any organic material to inorganic form. They may be free-floating in the water column, attached to a substrate or in the sediments. Many are aerobic, requiring oxygen for the conversion of organic material to inorganic forms and energy. Many others are anaerobic, using other chemical pathways to derive energy. One such group, the sulfate reducing bacteria, is instrumental in converting inorganic mercury to the highly toxic organic form, methyl mercury, as a byproduct of their growth. Some bacteria are photosynthetic.
(e.g., cyanobacteria, also called blue-green algae). Some bacteria create human health problems or have proven to be useful indicators of the likely presence of threats to human health. *Escherichia coli* is usually an innocuous bacterium found in our intestines, but its abundance in a lake indicates sewage, septic inputs or other fecal contaminants and the potential for the transfer of human bacterial and viral diseases.

**Algae**

Algae are mostly microscopic plants that may be free-floating (phytoplankton) or attached to a substrate (periphyton). They may be single-celled or have many cells. In a moderately rich lake, there could be nearly one hundred species of algae in a tablespoonful of lake water. In a eutrophic lake, there may be millions of cells in a gallon of water. Algae are divided into several major groups, principally based on the relative combination of photosynthetic pigments and characteristics of the cell wall, food storage form, and flagella, but each group has particular characteristics that often contribute to lake problems.

The blue-greens are evolutionary intermediates between heterotrophic bacteria and algae. They are considered to be bacteria (Cyanobacteria) with the photosynthetic pigment, chlorophyll. Blue-greens often form nuisance blooms, appearing like thick green paint on the lake’s surface and causing taste and odor problems in drinking water. Many blue-greens, particularly certain troublesome species, have the ability to “fix” nitrogen. While other algae must obtain their nutrients from dissolved inorganic (nitrate, nitrite, and ammonia) or organic nitrogen in the water, these blue-greens can use atmospheric nitrogen that is dissolved in the water. A shortage of inorganic and organic nitrogen can give nitrogen-fixing blue-greens a competitive edge, and they use other characteristics (flotation) to maintain it. Many of them have a gelatinous sheath that makes them undesirable to microscopic grazers. Three genera of blue-greens are so commonly associated with problems in lakes that lake managers have given them nicknames: Annie for *Anabaena*, Fannie for *Aphanizomenon* and Mike for *Microcystis*.

Conversely, diatoms are rarely problems in recreational lakes and usually form an important part of the food chain. They construct silica shells of many shapes with intricate markings. A hundred years ago, it was quite the fad to view slides of different diatom shells in elaborate displays. Electron microscopy has made the view even more spectacular. Despite their glass shells, these algae are easily eaten by small aquatic animals called zooplankton. Common planktonic diatoms include *Asterionella*, *Fragilaria*, *Tabellaria*, *Aulacoseira* and *Cyclotella*. Other chrysophytes (“golden” algae) live in shells that look like wine glasses or spiny coats with whipping flagella to move them about. Some of these non-diatom chrysophytes can cause taste and odor problems in drinking water reservoirs, but are rarely a problem in recreational lakes.

Green algae (Chlorophyta) are an incredibly diverse group ranging from single-celled to complex multicellular organisms that may be on the main evolutionary line to vascular plants. They are important constituents in the food chain, but some species can cause blooms in eutrophic lakes. They generally prefer a higher ratio of nitrogen to phosphorus than blue-green algae.

The dinoflagellates (Pyrrophyta) tend to be less abundant than the above groups but are interesting because some of the dinoflagellates cause harmful algal blooms in marine environments. Freshwater forms are not known to be toxic, but are often associated with high organic content waters. Cryptomonads, a related group of flagellates, are capable of photosynthesis but may prey upon bacteria. Because all are motile, they can often dramatically change their position in the water column to take advantage of local conditions. Often, they are found at the top of the thermocline where sinking organic material is slowed by the denser water but light is still sufficient. Euglenoids are another mostly flagellated group that share pigment composition with the green algae, but make use
of organic particles and dissolved compounds more like the dinoflagellates and cryptomonads. They can form surface scums that vary in color from green to red, and at high abundance are normally indicators of very poor water quality.

Most other algal groups are relatively rare in freshwater lakes and occur mainly in marine environments (i.e., red and brown algae). Each of the above groups has species with characteristics that may allow them to become very abundant and troublesome. Sometimes, knowing which species is in “bloom” can help understand the cause of the bloom. For example, certain blue-green algae often bloom when phosphorus is abundant and nitrate is low because they can fix nitrogen from dissolved air. They often prefer a period of calm water because they float and consequently shade out competing species. The concurrence of these conditions will usually result in blue-greens, but the absence of one element may shift the balance to another species or another algal group. The diatoms tend to prefer times of high mixing, cooler temperatures and higher silica availability - conditions found at spring and fall turnover. Many dinoflagellates seem to prefer conditions with above average organic material.

The dynamics of the thermal, light and nutrient regimes in lakes cause a fairly predictable pattern in the seasonal succession of algal species (Figure 5), but there may be surprises at any time. Typically, though, spring and fall turnover favor the diatoms which may become very abundant but usually do not cause severe impacts on human use, although some species cause taste and odor problems in drinking water reservoirs and can clog filters. After thermal stratification, green algae often become dominant for most of the summer when nitrogen is available, but they may be replaced by blue-green algae at higher temperatures, lower nitrogen concentrations, and high pH.

Because there are so many species of algae and identification requires considerable expertise, limnologists have developed surrogate measures of algal biomass. One of these is to measure the chlorophyll that all algae share, chlorophyll \(a\). Chlorophyll \(a\) can be measured very accurately and quite easily. Unfortunately, the correspondence between the amount of chlorophyll and the actual biomass of algae is somewhat variable. Not all algal species have equal amounts of chlorophyll per unit volume and the amount of chlorophyll in each species varies with the nutritional health of the cells. Nevertheless, chlorophyll has become a reliable and useful measure for lake management. A second, less closely related measure of algal biomass is Secchi disk transparency. It involves lowering a black and white disk into the water and recording how far down it remains visible (Figure 6). Visibility has been reasonably well related to chlorophyll and forms a part of lake assessment that almost anyone can accomplish.

**Aquatic Macrophytes**

As opposed to algae that are usually microscopic plants, these are large aquatic plants, easily visible to the naked eye. In shallow lakes with soft bottoms, the vast majority of lakes in Massachusetts, these are often the most abundant plants. Algae and macrophytes often compete for light, so it is unusual to find both as problems in any particular lake, although it does happen. Macrophytes may be rooted or free-floating, although most are rooted (Figure 7). They may also be submergent, emergent, or floating-leaved. There are many taxonomic groups but the above categories are often the most useful for understanding the causes of a macrophyte problem and determining an appropriate management strategy. In fact, within each category, many species may look very similar as their growth habit responds to common lake conditions. However, even though many macrophyte species appear similar, their propensity to cause problems in lakes varies. Effective management of macrophytes usually requires species identification. For example, a drawdown may reduce densities of fanwort (Cabomba caroliniana) but may increase densities of naiad (Najas flexilis) based on their overwintering strategies (vegetative vs seeds).
Figure 5. Seasonal Succession of Phytoplankton (Olem and Flock, 1990)
Diatoms tend to dominate in spring and fall, with greens and blue-greens dominant during summer, but many variations are possible.

Figure 6. Measurement of Secchi disk Transparency (Olem and Flock, 1990)
Figure 7. Typical Aquatic Plant Zones in Lakes and Ponds (From Kishbaugh et al., 1990)

Table 1. Introduced Species Known to Create Nuisance Conditions in Massachusetts

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<td>Brazilian elodea</td>
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<td>Hydrilla verticillata</td>
<td>Hydrilla</td>
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<tr>
<td>Lythrum salicaria</td>
<td>Purple loosestrife</td>
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<tr>
<td>Marsilea quadrifolia</td>
<td>Pepperwort</td>
</tr>
<tr>
<td>Myriophyllum aquaticum</td>
<td>Parrotfeather</td>
</tr>
<tr>
<td>Myriophyllum heterophyllum</td>
<td>Variable watermilfoil</td>
</tr>
<tr>
<td>Myriophyllum spicatum</td>
<td>Eurasian watermilfoil</td>
</tr>
<tr>
<td>Najas minor</td>
<td>Spiny naiad</td>
</tr>
<tr>
<td>Nelumbo sp.</td>
<td>Lotus</td>
</tr>
<tr>
<td>Nymphoides peltatum</td>
<td>Little floating heart</td>
</tr>
<tr>
<td>Phragmites sp.</td>
<td>Reed grass</td>
</tr>
<tr>
<td>Trapa natans</td>
<td>Water chestnut</td>
</tr>
</tbody>
</table>
Rooted aquatic plants typically grow from a root system embedded in the bottom sediment. Unlike algae, they derive most of their nutrients from the sediments just like terrestrial plants, but they may be able to absorb nutrients from the water column as well. Because they need light to grow, they cannot exist where the lake bottom is not exposed to sufficient light. The part of a lake where light reaches the bottom is called the photic zone. For many plants, nutrients in the sediments may be in excess and growth is limited by light, particularly during early growth when the plant is small and close to the bottom. Emergent plants solve the light problem by growing out of the water, but that limits them to fairly shallow depths. Free-floating plants also are not limited by light, except in cases of self-shading when growths are dense, but cannot use the sediments as a source of nutrients. Finally, floating-leaf plants have attempted to achieve the best of all worlds by having their roots in the sediment and leaves at the surface, but they still have depth limits.

** Introduced Plant Species **

A subset of aquatic macrophytes, these plants tend to have high nuisance potential. As a gateway for settlement of the country and as part of the modern trans-world travel network, Massachusetts is highly susceptible to introductions of non-native species. Recently introduced species, unlike the natural biota and even the non-native biota introduced more than a hundred years ago, have few or no enemies, and are often invasive pests that can totally dominate and eliminate native populations. They are easily introduced in a variety of unwitting ways, most notably through the aquarium and horticulture trades, with dispersal among lakes by boats. Waterfowl are also important vectors. In many situations where a non-native species has been introduced, a near monoculture of that species develops, reducing recreational utility and habitat value.

Introduced non-native species can displace a healthy and desirable aquatic community and produce economically and recreationally severe impacts even though no other change has occurred in the watershed. The introduction of a non-native and undesirable species can result from the actions of a single person who does not realize the eventual impact and may not be aware that he/she has introduced the non-native species.

Consider some examples. Introductions of Eurasian watermilfoil (*Myriophyllum spicatum*) in Lake Champlain (Vermont/New York), Lake George (New York), Okanagan Lake (British Columbia) and many lakes in Massachusetts and other states threaten otherwise healthy lakes. Within just a few years, a small patch of the introduced species can grow to fill the lake, top to bottom, within the photic zone. Another nuisance species, fanwort (*Cabomba caroliniana*), is a popular aquarium plant and may have been introduced from freshwater aquariums. Purple loosestrife, a beautiful non-native wetland plant, completely crowds out native species and creates stands so dense that wildlife habitat is degraded. It was introduced by horticulturists and gardeners. There are many non-native species of concern, not all as invasive as these examples. In most cases, they demand special attention. While an overabundance of native species and diminution of desired uses can be managed over time, introduced species generally require quick action if eradication is to be achieved. The environmental cost of delay is usually higher than the risk of immediate use of most control options. The quicker the response, the smaller the degree of intervention needed to protect the environment. It may be difficult to impossible to actually eradicate an invasive species, but the probability of achieving and maintaining control is maximized through early detection and rapid response.

The Massachusetts Department of Environmental Protection developed a database of non-native (i.e., introduced) aquatic plants based on surveys in 1993-94. The database does not represent a comprehensive listing of all lakes with non-native species, but is considered representative of conditions at the time. Of the 320 lakes surveyed, 64% had non-native species. The most commonly observed non-native species in these surveys were *Myriophyllum* (milfoil), *Cabomba* (fanwort) and *Lythrum* (loosestrife).
No non-native species were found in 115 of the surveyed lakes, although there is some debate as to how long a species must be present to be considered “native”. Variable milfoil (*Myriophyllum heterophyllum*) is not native to Massachusetts or New England, but remains a potential nuisance species. Likewise, some species of *Phragmites* are considered native but may still be invasive. Some species not found in the 320 surveyed lakes are known from other Massachusetts lakes now, most notably *Hydrilla* in one Cape Cod lake and *Myriophyllum aquaticum* in another Cape Cod lake. All of the species listed in Table 1 have been found in Massachusetts as of 2002, and the frequency of most has increased since the 1994 listing. DCR staff updated the earlier DEP survey for most of these lakes through 2003 (see Appendix VI of the GEIR).

**Native Plant Species**

In general, a healthy native plant community is considered desirable for a lake. Where the sediment is suitable and light penetrates, rooted plants will grow. The question is not whether or not rooted plants will be present in most lakes, but rather what types and at what density. A diverse assemblage of species indigenous to the area will in most cases not constitute a nuisance to people, and will provide valuable habitat. Invasive species, often defined as non-native or introduced forms, have a tendency to dominate the plant community as a consequence of competitive superiority and/or low loss rates to herbivores (plant eaters). In theory, a native assemblage will be more balanced. However, some native species can become “invasive”, expanding into areas either not previously colonized or at one time occupied by other native species. Such imbalances can lead to nuisance conditions, as with dense coverage by water lilies (*Nymphaea* or *Nuphar*) or watershield (*Brasenia*). Submergent growths of naiad (*Najas*) or coontail (*Ceratophyllum*) can become too dense, break free of the sediment, and become nuisances to boaters or swimmers. Native plant communities may therefore require management to remain in balance.

While the management of introduced species often focuses on eradication (which is itself a very difficult task), management of indigenous species with nuisance potential tends to favor control only to the extent necessary to restore balance. This may require ongoing maintenance, and it is generally true that rooted plant management is likely to require repetitive actions over a prolonged time period.

**Aquatic Animals**

Plants provide the habitat and food for many forms of animal life ranging from microscopic rotifers that filter tiny algae, to zooplankton that hunt larger algae, to insects, to fish and aquatic mammals that eat even larger plants or animals. A change in any part of this trophic web ripples throughout the system in subtle or even dramatic ways. As a very simplified example, consider the classic four level trophic system. Certain algal species may be preyed upon by zooplankton. Zooplankton are preyed upon by planktivorous fish species such as golden shiners (*Notemigonus crysoleucas*) that are then preyed upon by larger piscivorous species such as largemouth bass (*Micropterus salmoides*). Reducing the algal population by some other form of control may also reduce the zooplankton, the planktivorous fish and the piscivorous fish. Conversely, adding more piscivorous fish or increasing their ability to find their prey may reduce the planktivorous fish and reduce predation on zooplankton. The zooplankton can then increase in abundance and reduce algal biomass. Usually, the interrelationships are much more complicated, and it is generally difficult to predict the outcome. For example, increasing piscivorous fish may increase zooplankton predation on edible algae but give relatively inedible algae (e.g., blue-greens) an advantage. Loss of algae may promote macrophyte growth and provide shelter for planktivores, reducing piscivore impacts. Variability in biological response to management tends to be high.

Alterations, even temporary ones, may have serious effects on the biota. For example, one of the most critical periods in the life history of fish is during spawning. Some lake management practices may be relatively benign except when they coincide with the spawning period for fish that occur in the lake. Depending on the species, fish spawning generally occurs in spring or fall (Table 2). Care must be taken to evaluate possible impacts of the timing and magnitude of lake management actions.
Table 2. Spawning Conditions for Common Massachusetts Fish Species (after Everhart et al., 1975)

<table>
<thead>
<tr>
<th>Species</th>
<th>Spawning Time</th>
<th>Site</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow Perch <em>Perca flavescens</em></td>
<td>Early spring</td>
<td>Brush, aquatic plants</td>
<td>Deposited “rope” of eggs, usually on vegetation</td>
</tr>
<tr>
<td>White Perch <em>Morone americana</em></td>
<td>Late spring</td>
<td>Sand or gravel bottom</td>
<td>Egg scatterer</td>
</tr>
<tr>
<td>Bluegill <em>Lepomis macrochirus</em></td>
<td>Early summer</td>
<td>Littoral zone</td>
<td>Parental care; nest is a circular depression</td>
</tr>
<tr>
<td>Pumpkinseed <em>Lepomis gibbosus</em></td>
<td>Summer</td>
<td>Littoral zone</td>
<td>Parental care; nest is a circular depression</td>
</tr>
<tr>
<td>Largemouth Bass <em>Micropterus salmoides</em></td>
<td>Late spring</td>
<td>Littoral zone</td>
<td>Parental care; nest is a circular depression</td>
</tr>
<tr>
<td>Smallmouth Bass <em>Micropterus dolomieu</em></td>
<td>Spring, early summer</td>
<td>Gravel bottom</td>
<td>Nest builder</td>
</tr>
<tr>
<td>Brown Bullhead <em>Ameiurus nebulosa</em></td>
<td>Late spring</td>
<td>Littoral zone</td>
<td>Crevices or nests</td>
</tr>
<tr>
<td>Chain Pickerel <em>Esox niger</em></td>
<td>After ice out</td>
<td>Littoral zone</td>
<td>Eggs scattered among vegetation in shallow areas</td>
</tr>
<tr>
<td>Lake Trout <em>Salvelinus namaycush</em></td>
<td>Oct-Dec.</td>
<td>Sand or gravel bottom</td>
<td>Eggs scattered over gravel</td>
</tr>
<tr>
<td>Brook Trout <em>Salvelinus fontinalis</em></td>
<td>Sept.-Dec.</td>
<td>Gravel bottom of tributaries</td>
<td>Deposited in “redd” or nest</td>
</tr>
<tr>
<td>Brown Trout <em>Salmo trutta</em></td>
<td>Fall</td>
<td>Gravel bottom of tributaries</td>
<td>Deposited in “redd” or nest</td>
</tr>
<tr>
<td>River Herring <em>Alosa aestivalis</em> (Blueback)</td>
<td>Spring</td>
<td>Sand or gravel bottom</td>
<td>Egg scatterer</td>
</tr>
</tbody>
</table>

Note that some animals are also introduced, ranging from many fish species stocked for angling purposes to invertebrates that may represent major disruptions of energy flow in the aquatic food web. Angling is a major lake use, and a major role of the Department of Fish and Game is managing lake fisheries for the enjoyment of the angling public, but many of the fish in our lakes today are not native to the area. Both largemouth and smallmouth bass and both brown and rainbow trout are introduced species. Many baitfish species have been introduced as well, either intentionally to form a forage base for growing gamefish or accidentally as escapees from bait buckets. It was a common management practice in the late 1800s and first half of the 1900s to move fish from lake to lake, introducing a range of species to each lake and allowing “nature” to decide what would become abundant. It was also common to “reclaim” a lake (poison the existing fish and restock) when fishing was considered very poor over an extended period of years, usually as a consequence of overabundant panfish. Stocking is much more focused and tightly controlled these days, and is part of the overall management plan for many lakes and regions of the Commonwealth. Reclamation by poisoning is no longer practiced in Massachusetts.

Other possible introductions of greater concern include zebra mussels (*Dreissenia polymorpha*) and various non-native relatives. These bivalve molluscs (small freshwater clams) can out-compete all other molluscs, cover rocks, docks and other hard substrates, and filter the water to the extent that the open water food web may collapse. Zebra mussels have not been found in Massachusetts as of this writing, but are known from the region and pose a great threat to water supplies and recreational lakes, as well as to the overall ecology of lakes. Non-native zooplankton, crayfish, and other invertebrates threaten native biodiversity, but as of yet have not proven to disrupt overall lake ecology in Massachusetts. This is probably more a matter of lack of study than lack of impact.
LAKE MANAGEMENT PLANNING

The Lake Management Plan

Developing a lake management plan is a useful and necessary process to select and guide the implementation of complex management techniques. It may not be absolutely necessary in all cases, but is always appropriate for setting overall management goals and laying out the techniques that will be used to achieve those goals. Small projects, such as the installation of benthic barriers around a boat launch or swimming area, do not require a detailed lake management plan, but at a lakewide scale, such application would benefit from such a plan. In some cases it may not make sense for a town or state agency to develop a detailed plan for a system which they do not control unless cooperation of other towns, agencies or landowners is obtained. However, having the framework of a plan in place may facilitate that cooperation, and development of management plans by multiple towns in a watershed is encouraged.

The flow chart in Table 4 shows the process of developing and implementing a lake management plan and the parties that should be involved at each step. Like any sound construction, the foundation must be secure before the next level can be supported. That is, an error at the beginning will magnify throughout the entire process. When developing a lake and watershed management plan, it is very important to keep in mind that:

- **Not all plans need to have each of the components fully developed, and depending on the management issues, plans may not need to address some of the components at all.** Carefully consider resources and uses when prioritizing plan elements.
- **The size and detail of the plan should reflect the complexity of the lake and its management issues.** In general, a plan may range from a couple of pages for a small privately owned pond to several hundred pages for a large public lake with many uses and management issues.
- **The outline presented here provides a menu of options, but should not necessarily be adopted verbatim.** Elements and options are best evaluated in consultation with an experienced lake management professional.

As a general rule, having thorough data for these components will enable the production of a more valuable lake and watershed management plan and will increase the likelihood of successful protection and/or restoration of the water body. The other general rule is that the greater the potential impact or expense of a proposed management technique, the greater is the need for complete information. The common elements of lake management plans can be summarized as follows:

- **Problem Statement:** List issues/problems that should be addressed. Why is management action under consideration, and what previous reports, data, historic management actions and past recommendations support this need?
- **Management Goals:** Get public input by all stakeholders to provide a concise statement of goals, desired future uses and characteristics. Goals should be specific, measurable, and realistic/feasible.
- **Watershed and Lake Characteristics:** Include maps of watershed boundary, watercourses, drainage systems, geology, topography, soils, land use, any zoning, and pollutant sources. Provide maps of lake bathymetry and sediment types/depth. Collect data for hydrology and water quality and construct nutrient budgets. Model the system to the extent practical and necessary to predict results of management actions. Collect data for bacteria, algae, vascular plants, zooplankton, invertebrates, fish, reptiles, amphibians, birds and mammals, and check available maps and records for protected species.
- **Past In-Lake Management Techniques:** Review all physical, chemical and biological controls, and any other in-lake management techniques that have been implemented.
• **Existing Watershed Management Techniques:** Review all regulatory (e.g., zoning, resource protection bylaws, health statutes) and non-regulatory (i.e., educational, procedural and structural) management techniques that are in place and being used within the watershed.

• **In-Lake and Watershed Management Alternatives:** Evaluate options for feasibility, impacts, costs, and effectiveness to attain the goals.

• **Management Recommendations:** Include both short- and long-term management options for in-lake and watershed management, with time frames. Preventive and mitigative measures should be included. A description of the monitoring and evaluation process to be used for all proposed actions should be included, with pre- and post-management elements.

• **Plan Approval:** Present the plan at one or more well-publicized public meetings, and offer an opportunity for comment.

• **Implementation:** The five phases to implementation (funding, design, regulatory review, construction or application and follow up monitoring and evaluation) will be lake- and community-specific, but may involve considerable interaction with outside agencies and consultants.

The lake management plan represents the assimilation of all the previous steps into one understandable written document describing long-term goals for the lake and ways to achieve those goals, along with their ecological and financial consequences. If properly developed, it should be useful for a long time, modified as more is learned about the lake and progress is made.

Most plans focus on mitigating perceived problems, but protection will almost always be essential to maintain desirable qualities. Some lake users may perceive that a lake meets most of its intended uses and is unlikely to change, but lakes are dynamic systems prone to change even without human interference. A “hands off” approach can not be expected to preserve key qualities of the lake system, although knowing when not to take action can be as important as knowing what techniques to apply and when. It will be no less important for all of the lake management plan development steps to be followed for lakes to be protected than it is for lakes with serious problems.

All the steps of management planning can be difficult, but do not underestimate the importance of the early steps. The problem statement serves to clarify user perception of the problem and to distinguish between perception and reality. As stated earlier, individual lakes fall along a continuum of lake evolution from pristine, nearly sterile bowls of water to shallow, productive wetlands; all are natural states. Public perception also varies along a continuum with every individual preferring a slightly different view of a lake. Public perception may be in sharp conflict with the natural state of a lake and with a realistic expectation of what can be accomplished. The development of a problem statement is eventually a reconciliation of perception with reality. Reality in this case is determined by water quality monitoring and watershed evaluation, the latter being the tool to differentiate between human impacts and the natural state to the extent possible. At this early stage, it is imperative to involve as much of the community as possible in management planning. All subsequent steps will be easier if the chosen plan has broad community support created by participation in the plan’s development coupled with a realistic expectation of what can be accomplished.

With the previous steps in place, evaluation of possible management strategies becomes a focal point for the plan. A number of the diagnostic tools permit limited cost/benefit analysis. This review is principally focused on defining procedures acceptable in Massachusetts for the implementation of lake management controls. It recognizes that there are appropriate short-term strategies that are steps along the path of a long-term strategy. There may be short-term strategies that merely attempt to maximize human resource usage without significantly changing the natural state of a lake. Long-term strategies may have limited impact in the short-term but may eventually produce the closest approximation to a sustainable and healthy lake condition, maximize human resource use and may be more cost-effective. The appropriate choice will depend on community priorities, regulatory restrictions, specific characteristics of the lake, community resources and the effectiveness, adverse
impacts and costs of the available lake management techniques. This is admittedly a lot to consider all at once, but effective lake management is rarely a simple process.

As described, implementation appears to be the last step. It is actually part of a cycle of assessment and action, but does normally require the prior steps to be successful. However, for many previous implementation projects, it was almost the only step. The importance of completing the previous steps in arriving at an acceptable and successful implementation phase cannot be overemphasized. These steps can promote community support, develop funding and minimize the effort required to continue implementation in successive years.

This review, within the limits of available science and experience, attempts to describe management techniques that have been applied in Massachusetts and have a high probability of success under appropriate conditions. Lake management controls applied in accordance with this review have a reasonable chance of success, based on our present knowledge. Controls that are not covered by this review either have a seriously limited chance of success (often with major negative impacts) or represent a change in scientific knowledge and experience since this report was written. In the latter case, the burden of proof must fall on those proposing the strategy. However, regulatory agencies need to keep up with the science and recognize the value of experimentation in lake management. Few impacts to lakes are irreversible, and few targeted benefits can be achieved without at least temporary impact to some untargeted resources. Successful lake management requires balancing varied and sometimes competing interests.

Predicting the Outcome of Management

Knowing exactly how an aquatic system and all its inhabitants will respond is not usually possible; uncertainty is a fact of life, especially in lake management. The direction of anticipated change and the general magnitude of change can be predicted, however, at least for water quality and algae-related features of lakes. For management aimed at controlling nutrients to minimize algal blooms, many studies of watersheds have produced scientific literature statistically comparing nutrient inputs with average lake nutrient concentration, average chlorophyll concentration and Secchi disk transparency. Knowledge of any one of these parameters provides a rough estimate of all the others for relatively large, stratified north temperate lakes without dominant rooted plant growth. For other lakes, particularly lakes with abundant plant growth, these “empirical” models will not work as well and may not work at all, but we rely on them to make general predictions of lake response to nutrient controls.

Quite a few of these models have been developed; all are remarkably consistent and suggest that the general models are robust even though the confidence one can place in a specific prediction for a particular lake is limited. The details of the many available models and how to use them is beyond what this guide is intended to cover, but the ultimate goal is to understand how nutrient loading relates to lake attributes that affect lake uses.

Water clarity is often a key determinant of satisfaction with the appearance of a lake, and exhibits a strong curvilinear relationship with phosphorus (Figure 8). A change at low total phosphorus levels results in a much larger change in transparency than the same absolute change at a higher total phosphorus level. There is, however, considerable variation possible at any phosphorus level. The sources of variability can be very important to management decisions, and include the nature of the zooplankton community, the availability of phosphorus, and other sources of turbidity (such as suspended inorganic sediment). It is very difficult to predict exactly how a change in phosphorus loading will affect the clarity of an individual lake without considerable information on these other sources of variation in the relationship.

A variation on this approach is to use the empirical models to develop an index that can be related to perception of trophic state. One of the most widely used of these indices is Carlson’s Trophic State
Index (TSI). Knowing the total phosphorus, chlorophyll a, or transparency, one can calculate the TSI. The TSI scale ranges from 0 to 100 with each 10 units of increase representing a doubling in algal biomass. Unlike the measurements of nutrients or chlorophyll, the TSI has been related to problem perception (Figure 9). The primary value of the TSI will be in presenting comparative information to decision-makers in an easy to visualize, non-technical form.

Increasing levels of modeling sophistication are warranted when the choices to be made based on modeling results carry major costs. It is quite appropriate, however, to use simpler models to generate results for potential management scenarios for comparative purposes and to elucidate the level of management needed. It is extremely frustrating to conduct a program to reduce nutrient loading by 50%, only to find that no visible change in water clarity is gained because the system was out in the right hand portion of the graph in Figure 8 (high P, low clarity). It is very helpful to know the general order of magnitude of the loading reduction needed to meet program objectives before embarking on a load reduction campaign. Exact numerical predictions from models should not be believed in most cases, but the models do reliably indicate the direction and approximate degree of change to be expected.
Figure 8. Expected Range of Water Clarity with Changing Phosphorus Concentration.

Figure 9. Carlson’s Trophic State Index Related to Perceived Nuisance Conditions (Heiskary and Walker, 1987). Lengths of arrows indicate range over which a greater than 10 percent probability exists that users will perceive a problem.
Overview of Options

The GEIR and this Guide break up management options into two general categories: control of nutrients and control of aquatic plants. Control of nutrients is usually intended to reduce algal growth; it may prevent non-rooted vascular plant growth as well, but will not typically control rooted aquatic vegetation. Nutrient controls may occur in the watershed or in the lake, but if watershed controls are inadequate, in-lake controls will provide only temporary relief. Direct control of aquatic plants (vascular plants or algae) is often performed on a maintenance basis, but in some cases the community can be altered in more permanent ways.

One of the most effective ways to control algal populations is by limiting the nutrient supply to the lake, and thus limiting growth of algae. Phosphorus is the best nutrient to control, and the nutrient control options will deal primarily with phosphorus control. Even in cases where lakes are limited by nitrogen, phosphorus control is still the preferred method to control algae. In nutrient rich lakes, the growth of algae may be limited by light, and reduction in nutrient concentrations may not have a significant effect until the nutrient concentrations are lowered sufficiently to induce nutrient limitation.

One must identify the sources of nutrients before an effective control strategy can be determined. Once the relative importance of the sources of phosphorus is determined, one can examine the control techniques identified below for applicability and feasibility:

- Non-Point Source Management – control of diffuse nutrient sources from the watershed
- Point Source Management – control of point sources, usually piped discharges
- Hydraulic Controls – diversion, dilution, flushing, and hypolimnetic withdrawal strategies
- Phosphorus Inactivation – chemical binding of phosphorus to limit availability
- Artificial Circulation and Aeration – mixing and oxygen addition
- Dredging – removal of nutrient-laden sediments
- Bacterial Additives – encouraging uptake of nutrients by non-algal microbes
- Removal of Bottom Feeding Fish – elimination of major recyclers of nutrients

The needed or expected reduction in phosphorus loading should be modeled to predict the change in trophic status. In general, algal problems will be minimized at loadings less than Vollenweider’s (1968) permissible level, which is a calculated value dependent mainly on the depth and hydraulic residence time of the lake. Yet algal abundance in response to nutrient loading is a probability distribution, not a threshold function. Consequently, algal blooms may be expected at some reduced frequency, even at fairly low nutrient levels, and lakes will not respond identically to changes in loading. Acceptable results might be achieved at loadings higher than the permissible level, but unacceptable conditions can be expected where loading exceeds Vollenweider’s (1968) critical limit. Managers should be prepared to adjust strategies in response to resultant lake conditions; algal control through nutrient limitation is often an iterative process.

Additional ways to directly limit the density of algae may be needed on an interim or supplemental basis, and include the use of biocidal chemicals, dyes or biocontrol agents. Likewise, many aquatic vascular plants will not be controlled by nutrient reductions, and direct control techniques will be necessary. Direct rooted plant management options include physical, chemical and biological techniques as noted below:

- Drawdown - lowering of the water level to dry and freeze susceptible vegetation, with limited potential to control algal growth
- Harvesting - multiple methods of mechanical plant cutting, with or without removal, and algal collection
- Biological Control - biomanipulation, the practice of altering biological communities to control algae or macrophytes through biological interactions
- Benthic Barriers - placement of materials on the bottom of a lake to cover and impede the growth of macrophytes
- Herbicides and Algaecides - introduction of biocidal chemicals to directly kill vascular plants and/or algae
- Dyes and Covers - addition of coloring agents or sheet material to inhibit light penetration and reduce vascular plant and algae growths
- Dredging - removal of sediment and associated plants to inhibit growth
- Sonication – use of sound waves to disrupt and kill algal cells

In the case of nuisance species, especially introduced forms considered to be invasive, prevention is at least as important as management of existing infestations. Preventing the introduction of non-native plants is obviously the most desirable management option, but often this fails. One of the most active routes of introduction is the aquarium and landscaping trades; many of our greatest nuisance aquatic species can be traced to introductions by these commercial routes (Les, 2002). The need for laws and enforcement relating to such introductions remains great. This manual focuses on remediation for excessive macrophyte growths, and does not explicitly address approaches for prevention. However, as it is extremely difficult to truly eradicate introduced species, much greater emphasis is needed on controlling the undesirable spread of species by human actions.

A summary table of possible techniques for algae (and non-rooted vascular plant) control is presented in Table 4 and options for rooted plant control are summarized in Table 5, both adapted from Wagner (2001). All techniques have associated benefits and drawbacks, and those contemplating plant management should familiarize themselves with the following axioms for algae and vascular plant management:

**Axioms for the Control of Algae in Lakes**

1. **Where light and nutrients are sufficient and toxic substances are limited, algae will grow**
   - Phosphorus >0.01 mg/L and nitrogen >0.3 mg/L can support blooms
   - Phosphorus >0.05 mg/L and nitrogen >1.0 mg/L will usually support blooms
   - Very little light is necessary for some species of algae to bloom; normal daylight is adequate except at very high algal densities
   - Metals and some organic compounds are the primary toxicants for algae

2. **One factor will control the abundance of any given alga, but that factor can vary over time and among algae**
   - Some blue-greens can fix nitrogen, but require elements not needed by other algae
   - Succession of algae may be triggered by changing control factors
   - Control of the whole algal community by one factor occurs at extremes (e.g., low P or high Cu)

3. **Nutrient ratios are major determinants of the type of algae present**
   - N:P:Si ratio is most influential, but trace nutrients can have an effect as well
   - Blue-greens which can fix N thrive at low N:P ratios, while most greens prefer high N:P ratios
   - Diatoms require high Silica
   - Carbon can be important at very high N and P
   - Light can also be an important determinant of algal assemblage composition

4. **Productivity and biomass are related but separate concepts**
   - Productivity is a growth process
   - Biomass is the net result of growth and loss processes
   - High productivity leads to high biomass if loss processes are not adequate to maintain balance
5. **Diversity of algal adaptations may defeat controls other than maintaining low phosphorus**
- N fixation by blue-greens minimizes N limitation
- Buoyancy regulation allows vertical movement
- Auxiliary pigments assist in low or high light habitats
- Heterotrophy can sustain some algae
- Anti-grazing mechanisms can minimize zooplankton impacts
- Copper resistance by some algae limits control options with algaecides

6. **The most effective algal control is achieved through reduction of external and internal phosphorus loading**
- P can be made to limit productivity most reliably
- Essential to determine relative magnitude of sources of P
- May require multiple techniques and extended timeframe

7. **High grazing pressure yields the lowest algal biomass per unit of fertility**
- Large-bodied, herbivorous, zooplankton (*Daphnia*) at high biomass can limit algal biomass
- Algal adaptation can overcome grazing pressure if nutrients are sufficient

8. **Algaecides should only be used until growth processes can be controlled**
- Algaecides can provide short-term control and can prevent blooms if applied at the proper time
- Algaecides rarely provide long term control and can have adverse side effects

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**Axioms for the Control of Rooted Plants in Lakes**

1. **In lighted areas with suitable sediments, plants will grow**
- Light and substrate are critical factors
- A desire for no plants demands a maintenance program
- Management for a diverse native community is encouraged

2. **No amount of watershed management will control an existing infestation**
- Rooted aquatic plant growths are not controlled by clean water
- Increased water clarity may extend plant growth
- Watershed management complements in-lake management

3. **Understanding plant biology and ecology is essential to control**
- Native vs. non-native species differences exist
- Reproduction by seeds vs. vegetative propagation is important
- Monocotyledon vs. dicotyledon biology may affect results
- Light and nutrient needs vary substantially among plant groups

4. **There is no “One Size Fits All” solution to plant problems**
- Each situation is to some extent unique
- Adaptive strategies of plants require adaptive management
- Techniques can be applied in a wide range of levels and combinations

5. **It is unusual to successfully manage all plants in a lake with one technique**
- Variation in lake and plant features usually calls for multiple techniques
- Initial control and follow-up maintenance often require different approaches

6. **Prevention is far less expensive than restoration**
- Prevention costs are mainly associated with monitoring, regulation and small scale action
- Restoration costs typically involve expansive and repeated control efforts
- If restoration is achieved, additional prevention costs then apply
7. A regional focus is needed to protect the investment made in control
- Re-infestation from nearby lakes can reduce control longevity
- Control on a larger scale can be more efficient and economical
- Prevention measures are more effective on a regional scale

Table 3. Management Options for Control of Algae. (Adapted from Wagner 2001).

<table>
<thead>
<tr>
<th>OPTION</th>
<th>MODE OF ACTION</th>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
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<tbody>
<tr>
<td>WATERSHED CONTROLS 1) Management for nutrient input reduction</td>
<td>- Includes wide range of watershed and lake edge activities intended to eliminate nutrient sources or reduce delivery to lake&lt;br&gt;- Essential component of algal control strategy where internal recycling is not the dominant nutrient source, and desired even where internal recycling is important</td>
<td>- Acts against the original source of algal nutrition&lt;br&gt;- Creates sustainable limitation on algal growth&lt;br&gt;- May control delivery of other unwanted pollutants to lake&lt;br&gt;- Facilitates ecosystem management approach which considers more than just algal control</td>
<td>- May involve considerable lag time before improvement observed&lt;br&gt;- May not be sufficient to achieve goals without some form of in-lake management&lt;br&gt;- Reduction of overall system fertility may impact fisheries&lt;br&gt;- May cause shift in nutrient ratios which favor less desirable algae</td>
</tr>
<tr>
<td>1a) Point source controls</td>
<td>- More stringent discharge requirements&lt;br&gt;- May involve diversion&lt;br&gt;- May involve technological or operational adjustments&lt;br&gt;- May involve pollution prevention plans</td>
<td>- Often provides major input reduction&lt;br&gt;- Highly efficient approach in most cases&lt;br&gt;- Success easily monitored</td>
<td>- May be very expensive in terms of capital and operational costs&lt;br&gt;- May transfer problems to another watershed&lt;br&gt;- Variability in results may be high in some cases</td>
</tr>
<tr>
<td>1b) Non-point source controls</td>
<td>- Reduction of sources of nutrients&lt;br&gt;- May involve elimination of land uses or activities that release nutrients&lt;br&gt;- May involve alternative product use, as with no phosphate fertilizer</td>
<td>- Removes source&lt;br&gt;- Limited or no ongoing costs</td>
<td>- May require purchase of land or activity&lt;br&gt;- May be viewed as limitation of “quality of life”&lt;br&gt;- Usually requires education and gradual implementation</td>
</tr>
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| 1c) Non-point source pollutant trapping | - Capture of pollutants between source and lake  
- May involve drainage system alteration  
- Often involves wetland treatments (detention/infiltration)  
- May involve stormwater collection and treatment as with point sources | - Minimizes interference with land uses and activities  
- Allows diffuse and phased implementation throughout watershed  
- Highly flexible approach  
- Tends to address wide range of pollutant loads | - Does not address actual sources  
- May be expensive on necessary scale  
- May require substantial maintenance |
| **IN-LAKE PHYSICAL CONTROLS** | | | |
| 2) Circulation and destratification | - 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  
- May disrupt growth of blue-green algae  
- Counteraction of anoxia improves habitat for fish/invertebrates  
- May reduce internal loading of phosphorus | - May spread localized impacts  
- May lower oxygen levels in shallow water  
- May promote downstream impacts |
| 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 lake  
- Use of poorer quality water increases loads  
- Possible downstream impacts |
| 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 non-target resources  
- Possible impairment of water supply  
- Alteration of downstream flows and winter water level  
- May result in greater nutrient availability if flushing inadequate |
Table 3 - continued

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<thead>
<tr>
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</table>
| 5) Dredging | Sediment is physically removed by wet or dry excavation, with deposition in a containment area for dewatering | - Can control algae if internal recycling is main nutrient source  
- Increases water depth  
- Can reduce pollutant reserves  
- Can reduce sediment oxygen demand  
- Can improve spawning habitat for many fish species  
- Allows complete renovation of aquatic ecosystem | - Temporarily removes benthic invertebrates  
- May create turbidity  
- May eliminate fish community (complete dry dredging only)  
- Possible impacts from containment area discharge  
- Possible impacts from dredged material disposal  
- Interference with recreation or other uses during dredging |

5a) “Dry” excavation | Lake 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 | - Rarely truly a dry operation; tends to be messy  
- Eliminates most aquatic biota unless a portion left undrained  
- Eliminates lake use during dredging |

5b) “Wet” excavation | Lake 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, tends to be least cost dredging approach  
- May allow use of easily acquired equipment  
- May preserve aquatic biota | - Usually creates extreme turbidity  
- Normally requires intermediate containment area to dry sediments prior to hauling  
- May disrupt ecological function  
- Disrupts many uses |

5c) Hydraulic removal | Lake 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 lake 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 |
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<tbody>
<tr>
<td>6) Light-limiting dyes and surface covers</td>
<td>- Creates light limitation</td>
<td>- Creates light limit on algal growth without high turbidity or great depth</td>
<td>- May cause thermal stratification in shallow ponds</td>
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<td>- May achieve some control of rooted plants as well</td>
<td>- May facilitate anoxia at sediment interface with water</td>
</tr>
<tr>
<td>6.a) Dyes</td>
<td>- Water-soluble dye is mixed with lake water, thereby limiting light penetration and inhibiting algal growth</td>
<td>- Produces appealing color&lt;br&gt;- Creates illusion of greater depth</td>
<td>- May not control surface bloom-forming species&lt;br&gt;- May not control growth of shallow water algal mats&lt;br&gt;- Alters thermal regime</td>
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<td>- Dyes remain in solution until washed out of system.</td>
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<tr>
<td>6.b) Surface covers</td>
<td>- Opague sheet material applied to water surface</td>
<td>- Minimizes atmospheric and wildlife pollutant inputs</td>
<td>- Minimizes atmospheric gas exchange&lt;br&gt;- Limits recreational use</td>
</tr>
<tr>
<td>7) Mechanical removal</td>
<td>- Filtering of pumped water for water supply purposes&lt;br&gt;- Collection of floating scums or mats with booms, nets, or other devices&lt;br&gt;- Continuous or multiple applications per year usually needed</td>
<td>- Algae and associated nutrients can be removed from system&lt;br&gt;- Surface collection can be applied as needed&lt;br&gt;- May remove floating debris&lt;br&gt;- Collected algae dry to minimal volume</td>
<td>- Filtration requires high backwash and sludge handling capability for use with high algal densities&lt;br&gt;- Labor and/or capital intensive&lt;br&gt;- Variable collection efficiency&lt;br&gt;- Possible impacts on non-target aquatic life</td>
</tr>
<tr>
<td>8) Selective withdrawal</td>
<td>- Discharge of bottom water which may contain (or be susceptible to) low oxygen and higher nutrient levels&lt;br&gt;- May be pumped or utilize passive head differential</td>
<td>- Removes targeted water from lake efficiently&lt;br&gt;- Complements other techniques such as drawdown or aeration&lt;br&gt;- May prevent anoxia and phosphorus build up in bottom water&lt;br&gt;- May remove initial phase of algal blooms which start in deep water&lt;br&gt;- May create coldwater conditions downstream</td>
<td>- Possible downstream impacts of poor water quality&lt;br&gt;- May eliminate colder thermal layer that supports certain fish&lt;br&gt;- May promote mixing of remaining poor quality bottom water with surface waters&lt;br&gt;- May cause unintended drawdown if inflows do not match withdrawal</td>
</tr>
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<tr>
<td>9) Sonication</td>
<td>Sound waves disrupt algal cells</td>
<td>Supposedly affects only algae (new technique) - Applicable in localized areas</td>
<td>Uncertain effects on non-target organisms - May release cellular toxins or other undesirable contents into water column</td>
</tr>
<tr>
<td><strong>IN-LAKE CHEMICAL CONTROLS</strong></td>
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<tr>
<td>10) Hypolimnetic aeration or oxygenation</td>
<td>Addition of air or oxygen at varying depth provides oxic conditions - May maintain or break stratification - Can also withdraw water, oxygenate, then replace</td>
<td>Oxic conditions promote binding/sedimentation of phosphorus - Counteraction of anoxia improves habitat for fish/invertebrates - Build-up of dissolved iron, manganese, sulfide, ammonia and phosphorus reduced</td>
<td>May accidentally disrupt thermal layers important to fish community - Theoretically promotes supersaturation with gases harmful to fish - Biota may become dependent on continued aeration</td>
</tr>
<tr>
<td>11) Algaecides</td>
<td>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</td>
<td>Rapid elimination of algae from water column, normally with increased water clarity - May result in net movement of nutrients to bottom of lake</td>
<td>Possible toxicity to non-target species - Restrictions on water use for varying time after treatment - Increased oxygen demand and possible toxicity - Possible recycling of nutrients</td>
</tr>
<tr>
<td>11a) Forms of copper</td>
<td>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</td>
<td>Effective and rapid control of many algae species - Approved for use in most water supplies</td>
<td>Possible toxicity to aquatic fauna - Ineffective at colder temperatures - Accumulation of copper in system - Resistance by certain green and blue-green nuisance species - Rupturing of cells releases nutrients and toxins</td>
</tr>
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### Table 3 - continued

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| 11b) Synthetic organic herbicides | - Absorbed or membrane-active chemicals which disrupt metabolism  
- Causes structural deterioration | - Used where copper is ineffective  
- Limited toxicity to fish at recommended dosages  
- Rapid action | - Non-selective in treated area  
- Possible toxicity to aquatic fauna (varying degrees by dose and formulation)  
- Time delays on water use |
| 11c) Oxidants | - Disrupts most cellular functions, tends to attack membranes  
- Applied most often as a liquid. | - Potential selectivity against blue-greens  
- Moderate control of thick algal mats, used where copper alone is ineffective  
- Rapid action | - Older formulations tended to have high toxicity to some aquatic fauna  
- New formulations not well tested in the field yet |
| 12) 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 | - 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, mainly by aluminum at low or high pH  
- Possible release of phosphorus under anoxia (with Fe) or extreme pH (with Ca)  
- May cause fluctuations in water chemistry, especially pH, during treatment  
- Possible resuspension of floc in shallow areas  
- Adds to bottom sediment, but typically an insignificant amount |
| 13) Sediment oxidation | - Addition of oxidants, binders and pH adjusters to oxidize 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 |
### Table 3 - continued

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| 14) 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 |
| 15) 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 |
| IN-LAKE BIOLOGICAL CONTROLS | 16) 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 |
### Table 3 - continued

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<tbody>
<tr>
<td>16.a) Herbivorous fish (not permitted in MA)</td>
<td>Stocking of fish that eat algae</td>
<td>- Converts algae directly into potentially harvestable fish</td>
<td>- Typically requires introduction of non-native species</td>
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<td>- Grazing pressure can be adjusted through stocking rate</td>
<td>- Difficult to control over long term</td>
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<td>- Smaller algal forms may be benefited and bloom</td>
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<tr>
<td>16.b) Herbivorous zooplankton</td>
<td>Reduction in planktivorous fish to promote grazing pressure by zooplankton</td>
<td>- Converts algae indirectly into harvestable fish</td>
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<td>- May involve stocking piscivores or removing planktivores</td>
<td>- Zooplankton response to increasing algae can be rapid</td>
<td>- Highly variable response expected; temporal and spatial variability may be high</td>
</tr>
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<td>- May also involve stocking zooplankton or establishing refugia</td>
<td>- May be accomplished without introduction of non-native species</td>
<td>- Requires careful monitoring and management action on 1-5 yr basis</td>
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<td>- Generally compatible with most fishery management goals</td>
<td>- Larger or toxic algal forms may be benefited and bloom</td>
</tr>
<tr>
<td>17) Bottom-feeding fish removal</td>
<td>Removes fish that browse among bottom deposits, releasing nutrients to the</td>
<td>- Reduces turbidity and nutrient additions from this source</td>
<td>- Targeted fish species are difficult to eradicate or control</td>
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<td>water column by physical agitation and excretion</td>
<td>- May restructure fish community in more desirable manner</td>
<td>- Reduction in fish populations valued by some lake users (human/non-human)</td>
</tr>
<tr>
<td>18) Pathogens</td>
<td>Addition of inoculum to initiate attack on algal cells</td>
<td>- May create lakewide “epidemic” and reduction of algal biomass</td>
<td>- Largely experimental approach at this time</td>
</tr>
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<td>- May involve fungi, bacteria or viruses</td>
<td>- May provide sustained control through cycles</td>
<td>- May promote resistant nuisance forms</td>
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<td></td>
<td>- Can be highly specific to algal group or genera</td>
<td>- May cause high oxygen demand or release of toxins by lysed algal cells</td>
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<td>- Effects on non-target organisms uncertain</td>
</tr>
<tr>
<td>19) Competition and allelopathy</td>
<td>Plants may tie up sufficient nutrients to limit algal growth</td>
<td>- Harnesses power of natural biological interactions</td>
<td>- Some algal forms appear resistant</td>
</tr>
<tr>
<td></td>
<td>- Plants may create a light limitation on algal growth</td>
<td>- May provide responsive and prolonged control</td>
<td>- Use of plants may lead to problems with vascular plants</td>
</tr>
<tr>
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<td>- Chemical inhibition of algae may occur through substances released by other</td>
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<td>- Use of plant material may cause depression of oxygen levels</td>
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| 19a) Plantings for nutrient control | - Plant growths of sufficient density may limit algal access to nutrients  
- Plants can exude allelopathic substances which inhibit algal growth  
- Portable plant “pods”, floating islands, or other structures can be installed | - Productivity and associated habitat value can remain high without algal blooms  
- 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  
- 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 |
| 19b) 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, floating plants likely to be a recreational nuisance  
- Low surface mixing and atmospheric contact promote anoxia |
| 19c) 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 may bind phosphorus | - Materials and application are relatively inexpensive  
- Decline in algal abundance is more gradual than with algacides, 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 |
Table 4. Management Options for Control of Rooted Aquatic Plants. (Adapted from Wagner, 2001).

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<tbody>
<tr>
<td>PHYSICAL CONTROLS</td>
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<tr>
<td>1) Benthic barriers</td>
<td>- Mat of variable composition laid on bottom of target area, preventing growth</td>
<td>- Highly flexible control</td>
<td>- May cause anoxia at sediment-water interface</td>
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<td>- Can cover area for as little as several months or permanently</td>
<td>- Reduces turbidity from soft bottom sediments</td>
<td>- May limit benthic invertebrates</td>
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<tr>
<td></td>
<td>- Maintenance improves results</td>
<td>- Can cover undesirable substrate</td>
<td>- Non-selective interference with plants in target area</td>
</tr>
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<td></td>
<td>- Usually applied around docks, in boating lanes, and in swimming areas</td>
<td>- Can improve fish habitat by creating edge effects</td>
<td>- May inhibit spawning/feeding by some fish species</td>
</tr>
<tr>
<td>1.a) Porous or loose-weave synthetic materials</td>
<td>- Laid on bottom and usually anchored by weights or stakes</td>
<td>- Allows some escape of gases which may be generated underneath</td>
<td>- Allows some plant growth through pores</td>
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<td>- Removed and cleaned or flipped and repositioned at least once per year for maximum effect</td>
<td>- Panels may be flipped in place or removed for relatively easy cleaning or repositioning</td>
<td>- Gas may still build up underneath in some cases, lifting barrier from bottom</td>
</tr>
<tr>
<td>1.b) Non-porous or sheet synthetic materials</td>
<td>- Laid on bottom and anchored by many stakes, anchors or weights, or by layer of sand</td>
<td>- Prevents all plant growth until buried by sediment</td>
<td>- Gas build up may cause barrier to float upwards</td>
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<td>- Not typically removed, but may be swept or “blown” clean periodically</td>
<td>- Minimizes interaction of sediment and water column</td>
<td>- Strong anchoring makes removal difficult and can hinder maintenance</td>
</tr>
<tr>
<td>1.c) Improving sediment composition</td>
<td>- Sediments may be added on top of existing sediments or plants.</td>
<td>- Plant biomass can be buried</td>
<td>- Lake depth may decline</td>
</tr>
<tr>
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<td>- Use of sand or clay can limit plant growths and alter sediment-water interactions.</td>
<td>- Seed banks can be buried deeper</td>
<td>- Sediments may sink into or mix with underlying muck</td>
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<td>- Sediments can be applied from the surface or suction dredged from below muck layer (reverse layering technique)</td>
<td>- Sediment can be made less hospitable to plant growths</td>
<td>- Permitting for added sediment difficult</td>
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<td>- Nutrient release from sediments may be reduced</td>
<td>- Addition of sediment may cause initial turbidity increase</td>
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<td>- Surface sediment can be made more appealing to human users</td>
<td>- New sediment may contain nutrients or other contaminants</td>
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<td></td>
<td>- Reverse layering requires no addition or removal of sediment</td>
<td>- Generally too expensive for large scale application</td>
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</tr>
<tr>
<td>2) Dredging</td>
<td>- Sediment is physically removed by wet or dry excavation, with deposition in a</td>
<td>- Plant removal with some flexibility</td>
<td>- Temporarily removes benthic invertebrates</td>
</tr>
<tr>
<td></td>
<td>containment area for dewatering/disposal</td>
<td>- Increases water depth</td>
<td>- May create turbidity</td>
</tr>
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<td>- Dredging can be applied on a limited basis, but is most often a major</td>
<td>- Can reduce pollutant reserves</td>
<td>- May eliminate fish community (complete dry dredging only)</td>
</tr>
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<td>restructuring of a severely impacted system</td>
<td>- Can reduce sediment oxygen demand</td>
<td>- Possible impacts from containment area discharge</td>
</tr>
<tr>
<td></td>
<td>- Plants and seed beds are removed and regrowth can be limited by light and/or</td>
<td>- Can improve spawning habitat for many fish species</td>
<td>- Possible impacts from dredged material disposal</td>
</tr>
<tr>
<td></td>
<td>substrate limitation</td>
<td>- Allows complete renovation of aquatic ecosystem</td>
<td>- Interference with recreation or other uses during dredging</td>
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<td></td>
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<td>- May allow for growth of desirable species.</td>
<td>- Usually very expensive</td>
</tr>
<tr>
<td>2.a) “Dry” excavation</td>
<td>- Lake drained or lowered to maximum extent practical</td>
<td>- Tends to facilitate a very thorough effort</td>
<td>- Eliminates most aquatic biota unless a portion left undrained</td>
</tr>
<tr>
<td></td>
<td>- Target material dried to maximum extent possible</td>
<td>- May allow drying of sediments prior to removal</td>
<td>- Eliminates lake use during dredging</td>
</tr>
<tr>
<td></td>
<td>- Conventional excavation equipment used to remove sediments</td>
<td>- Allows use of less specialized equipment</td>
<td></td>
</tr>
<tr>
<td>2.b) “Wet” excavation</td>
<td>- Lake level may be lowered, but sediments not substantially</td>
<td>- Requires least preparation time or effort, tends to be least cost</td>
<td>- Usually creates extreme turbidity</td>
</tr>
<tr>
<td></td>
<td>dewatered</td>
<td>dredging approach</td>
<td>- Tends to result in sediment deposition in surrounding area</td>
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<td>- Draglines, bucket dredges, or long-reach backhoes used to</td>
<td>- May allow use of easily acquired equipment</td>
<td>- Normally requires intermediate containment area to dry sediments prior to hauling</td>
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<td>remove sediment</td>
<td>- May preserve most aquatic biota</td>
<td>- May cause severe disruption of ecological function</td>
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<td></td>
<td>- Impairs most lake uses during dredging</td>
</tr>
<tr>
<td>OPTION</td>
<td>MODE OF ACTION</td>
<td>ADVANTAGES</td>
<td>DISADVANTAGES</td>
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</tr>
<tr>
<td>2.c) Hydraulic (or pneumatic) removal</td>
<td>- Lake level not reduced</td>
<td>- Creates minimal turbidity and limits impact on biota</td>
<td>- Often leaves some sediment behind</td>
</tr>
<tr>
<td></td>
<td>- Suction or cutterhead dredges create slurry which is hydraulically pumped to containment area</td>
<td>- Can allow some lake uses during dredging</td>
<td>- Cannot handle extremely coarse or debris-laden materials</td>
</tr>
<tr>
<td></td>
<td>- Slurry is dewatered; sediment retained, water discharged</td>
<td>- Allows removal with limited access or shoreline disturbance</td>
<td>- Requires advanced and more expensive containment area</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Creates minimal turbidity and limits impact on biota</td>
<td>- Requires overflow discharge from containment area</td>
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<td>- Can allow some lake uses during dredging</td>
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<td></td>
<td>- Creates minimal turbidity and limits impact on biota</td>
<td></td>
</tr>
<tr>
<td>3) Dyes and surface covers</td>
<td>- Water-soluble dye is mixed with lake water, thereby limiting light penetration and inhibiting plant growth</td>
<td>- Light limit on plant growth without high turbidity or great depth</td>
<td>- May not control peripheral or shallow water rooted plants</td>
</tr>
<tr>
<td></td>
<td>- Dyes remain in solution until washed out of system.</td>
<td>- May achieve some control of algae as well</td>
<td>- May cause thermal stratification in shallow ponds</td>
</tr>
<tr>
<td></td>
<td>- Opaque sheet material applied to water surface</td>
<td>- May achieve some selectivity for species tolerant of low light</td>
<td>- May facilitate anoxia at sediment interface with water</td>
</tr>
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<td></td>
<td>- Light limit on plant growth without high turbidity or great depth</td>
<td>- Covers inhibit gas exchange with atmosphere and restrict recreation</td>
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<td>- May achieve some control of algae as well</td>
<td>- Cannot be used in water bodies with an active outlet</td>
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<td>- Cannot be used in water bodies with an active outlet</td>
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<tr>
<td>4) Mechanical removal (“harvesting”)</td>
<td>- Plants reduced by mechanical means, possibly with disturbance of soils</td>
<td>- Highly flexible control</td>
<td>- Possible impacts on aquatic fauna</td>
</tr>
<tr>
<td></td>
<td>- Collected plants may be placed on shore for composting or other disposal</td>
<td>- May remove other debris</td>
<td>- Non-selective removal of plants in treated area</td>
</tr>
<tr>
<td></td>
<td>- Wide range of techniques employed, from manual to highly mechanized</td>
<td>- Can balance habitat and recreational needs</td>
<td>- Possible spread of undesirable species by fragmentation</td>
</tr>
<tr>
<td></td>
<td>- Application once or twice per year usually needed</td>
<td></td>
<td>- Possible generation of turbidity</td>
</tr>
<tr>
<td>4.a) Hand pulling</td>
<td>- Plants uprooted by hand (“weeding”) and preferably removed</td>
<td>- Highly selective technique</td>
<td>- Labor intensive</td>
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<td></td>
<td></td>
<td></td>
<td>- Difficult to perform in dense stands</td>
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<td></td>
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<td>- Can cause fragmentation</td>
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</tbody>
</table>
### 4.b) Cutting (without collection)

- Plants cut in place above roots without being harvested
- Generally efficient and less expensive than complete harvesting
- Leaves root systems and part of plant for possible re-growth
- Leaves cut vegetation to decay or to re-root
- Not selective within applied area

### 4.c) Harvesting (with collection)

- Plants cut at depth of 2-10 ft and collected for removal from lake
- Allows plant removal on greater scale
- Limited depth of operation
- Usually leaves fragments which may re-root and spread infestation
- May impact lake fauna
- Limited selectivity within applied area
- More expensive than cutting

### 4.d) Rototilling

- Plants, root systems, and surrounding sediment disturbed with mechanical blades
- Can thoroughly disrupt entire plant
- Usually leaves fragments which may re-root and spread infestation
- May impact lake fauna
- Not selective within applied area
- Creates substantial turbidity
- More expensive than harvesting

### 4.e) Hydroraking

- Plants, root systems and surrounding sediment and debris disturbed with mechanical rake, part of material usually collected and removed from lake
- Can thoroughly disrupt entire plant
- Also allows removal of stumps or other obstructions
- Usually leaves fragments which may re-root and spread infestation
- May impact lake fauna
- Not selective within applied area
- Creates substantial turbidity
- More expensive than harvesting

### 5) Water level control

- Lowering or raising the water level to create an inhospitable environment for some or all aquatic plants
- Disrupts plant life cycle by dessication, freezing, or light limitation
- Requires only outlet control to affect large area
- Provides widespread control in increments of water depth
- Complements certain other techniques (dredging, flushing)
- Potential issues with water supply
- Potential issues with flooding
- Potential impacts to non-target flora and fauna
<table>
<thead>
<tr>
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</table>
| 5.a) Drawdown | - Lowering of water over winter period allows desiccation, freezing, and physical disruption of plants, roots and seed beds  
- Timing and duration of exposure and degree of dewatering are critical aspects  
- Variable species tolerance to drawdown; emergent species and seed-bearers are less affected  
- Most effective on annual to once/3 yr. basis | - Control with some flexibility  
- Opportunity for shoreline clean-up/structure repair  
- Flood control utility  
- Impacts vegetative propagation species with limited impact to seed producing populations | - Possible impacts on contiguous emergent wetlands  
- Possible effects on overwintering reptiles and amphibians  
- Possible impairment of well production  
- Reduction in potential water supply and fire fighting capacity  
- Alteration of downstream flows  
- Possible overwinter water level variation  
- Possible shoreline erosion and slumping  
- May result in greater nutrient availability for algae |
| 5.b) Flooding | - Higher water level in the spring can inhibit seed germination and plant growth  
- Higher flows which are normally associated with elevated water levels can flush seed and plant fragments from system | - Where water is available, this can be an inexpensive technique  
- Plant growth need not be eliminated, merely retarded or delayed  
- Timing of water level control can selectively favor certain desirable species | - Water for raising the level may not be available  
- Potential peripheral flooding  
- Possible downstream impacts  
- Many species may not be affected, and some may be benefitted  
- Algal nuisances may increase where nutrients are available |
| CHEMICAL CONTROLS 6) Herbicides | - Liquid or pelletized herbicides applied to target area or to plants directly  
- Contact or systemic poisons kill plants or limit growth  
- Typically requires application every 1-5 yrs | - Wide range of control is possible  
- May be able to selectively eliminate species  
- May achieve some algae control as well  
- May allow for more desirable plant growth | - Possible toxicity to non-target species  
- Possible downstream impacts  
- Restrictions of water use for varying time after treatment  
- Increased oxygen demand from decaying vegetation  
- Possible recycling of nutrients to allow other growths |
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| 6.a) Forms of copper | - Contact herbicide  
- Cellular toxicant, suspected membrane transport disruption  
- Applied as wide variety of liquid or granular formulations, often in conjunction with polymers or other herbicides | - Moderately effective control of some submersed plant species  
- More often an algal control agent | - Potentially toxic to aquatic fauna as a function of concentration, formulation, and ambient water chemistry  
- Ineffective at colder temperatures  
- Copper ion persistent; accumulates in sediments or moves downstream |
| 6.b) Forms of endothall  
(7-oxabicyclo [2.2.1] heptane-2,3-dicarboxylic acid) | - Contact herbicide with limited translocation potential  
- Membrane-active chemical which inhibits protein synthesis  
- Causes structural deterioration  
- Applied as liquid or granules | - Moderate control of some emersed plant species, moderately to highly effective control of floating and submersed species  
- Limited toxicity to fish at typical MA dosages  
- Rapid action | - Non-selective in treated area  
- Potentially toxic to aquatic fauna (varying degrees by formulation)  
- Time delays on use for water supply, agriculture and recreation |
| 6.c) Forms of diquat  
(6,7-dihydropyrido [1,2-2',1'-c] pyrazinediium dibromide) | - Contact herbicide  
- Absorbed by foliage but not roots  
- Strong oxidant; disrupts most cellular functions  
- Applied as a liquid, sometimes in conjunction with copper | - Moderate control of some emersed plant species, moderately to highly effective control of floating or submersed species  
- Limited toxicity to fish at recommended dosages, low toxicity at typical MA doses  
- Rapid action | - Non-selective in treated area  
- Potentially toxic to zooplankton at high application rates  
- Inactivated by suspended particles; ineffective in muddy waters |
| 6.d) Forms of glyphosate  
(N-[phosphonomethyl glycine) | - Contact herbicide  
- Absorbed through foliage, disrupts enzyme formation and function in uncertain manner  
- Applied as liquid spray | - Moderately to highly effective control of emergent and floating plant species  
- Can be used selectively, based on application to individual plants  
- Rapid action  
- Low toxicity to aquatic fauna at recommended dosages  
- No time delays for use of treated water | - Non-selective in treated area  
- Inactivation by suspended particles; ineffective in muddy waters  
- Not for use within 0.5 miles of potable surface water intakes |
Table 4 - continued

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>6.e) Forms of 2,4-D (2,4-dichlorophenoxyacetic acid)</td>
<td>Systemic herbicide - Readily absorbed and translocated throughout plant - Inhibits cell division in new tissue, stimulates growth in older tissue, resulting in gradual cell disruption - Applied as liquid or granules, frequently as part of more complex formulations, preferably during early growth phase of plants</td>
<td>Moderately to highly effective control of a variety of emergent, floating and submersed plant species - Can achieve some selectivity through application timing and concentration - Fairly fast action</td>
<td>Potential toxicity to aquatic fauna, depending upon formulation and ambient water chemistry - Time delays for use of treated water for agriculture and recreation - Not for use in potable water supplies</td>
</tr>
<tr>
<td>6.f) Forms of fluridone (1-methyl-3-phenyl-5-[-3-{trifluoromethyl}phenyl]-4[IH]-pyridinone)</td>
<td>Systemic herbicide - Inhibits carotenoid pigment synthesis and impacts photosynthesis - Best applied as liquid or granules during early growth phase of plants</td>
<td>Can be used selectively, based on concentration - Gradual deterioration of affected plants limits impact on oxygen level (BOD) - Effective against several difficult-to-control species - Low toxicity to aquatic fauna</td>
<td>Impacts on non-target plant species possible at higher doses - Extremely soluble and mixable; difficult to perform partial lake treatments - Requires extended contact time</td>
</tr>
<tr>
<td>6.g Forms of triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid)</td>
<td>Systemic herbicide, registration pending in MA at this time - Readily absorbed by foliage, translocated throughout plant - Disrupts enzyme systems specific to plants - Applied as liquid spray or subsurface injected liquid</td>
<td>Effectively controls many floating and submersed plant species - Can be used selectively, more effective against dicot plant species, including many nuisance species - Effective against several difficult-to-control species - Low toxicity to aquatic fauna - Fast action</td>
<td>Impacts on non-target plant species possible at higher doses - Restrictions on use of treated water for supply or recreation not yet certain for MA - Registration not complete in MA at time of table preparation</td>
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### Table 4 - continued

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<thead>
<tr>
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<tbody>
<tr>
<td><strong>BIOLOGICAL CONTROLS</strong></td>
<td>7) Biological introductions</td>
<td>- Fish, insects or pathogens which feed on or parasitize plants are added to system to affect control - The most commonly used organism is the grass carp, but the larvae of several insects have been used more recently, and viruses are being tested</td>
<td>- Provides potentially continuing control with one treatment - Harnesses biological interactions to produce desired conditions - May produce potentially useful fish biomass as an end product</td>
</tr>
<tr>
<td>7.a) Herbivorous fish</td>
<td>- Sterile juveniles stocked at density which allows control over multiple years - Growth of individuals offsets losses or may increase herbivorous pressure. Grass carp are illegal in Massachusetts.</td>
<td>- May greatly reduce plant biomass in single season - May provide multiple years of control from single stocking - Sterility intended to prevent population perpetuation and allow later adjustments</td>
<td>- May eliminate all plant biomass, or impact non-target species - Funnels energy into algae - Alters habitat - May escape upstream or downstream - Population control issues</td>
</tr>
<tr>
<td>7.b) Herbivorous insects</td>
<td>- Larvae or adults stocked at density intended to allow control with limited growth - Intended to selectively control target species - Milfoil weevil is best known, but still experimental</td>
<td>- Involves species native to region, or even targeted lake - Expected to have no negative effect on non-target species - May facilitate longer term control with limited management</td>
<td>- Population ecology suggests incomplete control likely - Oscillating cycle of control and re-growth - Predation by fish may complicate control - Other lake management actions may interfere with success</td>
</tr>
<tr>
<td>7.c) Fungal/bacterial/viral pathogens</td>
<td>- Inoculum used to seed lake or target plant patch - Growth of pathogen population expected to achieve control over target species</td>
<td>- May be highly species specific - May provide substantial control after minimal inoculation effort</td>
<td>- Effectiveness and longevity of control not well known - Infection ecology suggests incomplete control likely</td>
</tr>
<tr>
<td>7.d) Selective plantings</td>
<td>- Establishment of plant assemblage resistant to undesirable species - Plants introduced as seeds, cuttings or whole plants</td>
<td>- Can restore native assemblage - Can encourage assemblage most suitable to lake uses - Supplements targeted species removal effort</td>
<td>- Largely experimental - Nuisance species may eventually return assemblage - Introduced species may become nuisances</td>
</tr>
</tbody>
</table>
Below is a template for the presentation of each management technique

**NAME OF MANAGEMENT TECHNIQUE**

**How it Works**
Description of the technique, how it functions, and what one can expect from it.

**Benefits**
Explanation of desirable outcomes potentially accrued from the use of this technique. Note that listing does not guarantee that the potential benefit will be realized, and that the level of benefit may vary substantially among cases. Proper planning and implementation are required to gain listed benefits.

**Detriments**
Explanation of the undesirable impacts that could occur if this technique is used. Note that listing does not guarantee that such detriments will occur, as proper planning and implementation can eliminate many negative consequences. Some negative impacts may be unavoidable, however, and must be balanced with benefits if the technique is to be used.

**Information for Proper Application**
Listing of the data or analyses necessary to apply the technique in a way that maximizes benefit. Lack of such data may not negate the utility of the technique, but may compromise its value or shift the balance of benefits and detriments.

**Factors Favoring the Use of this Technique**
Brief explanation of conditions that suggest the technique would be appropriate and that the balance of benefits to detriments would be favorable. The list is generally written in a positive format; absence of the factor may indicate an unfavorable situation in some cases, while in others the lack of a favorable factor may have no negative consequences.

**Performance Guidelines**
Suggested limits, thresholds and factors that define appropriate use of the technique. This is an effort to define balance points for cost-benefit analysis and thresholds of acceptable risk, but is subjective. Any numerical values should not be construed to be regulatory standards or criteria unless so stated, but are offered for guidance purposes in planning management actions.

**Possible Permits**
Description of permits and approvals that may be necessary in Massachusetts to apply the technique. Listed permits may not be needed in all cases, as thresholds exist for many permits. However, potential applicants should investigate the need for any listed permit in each case.

**Impacts Specific to the Wetlands Protection Act**
Impacts, either beneficial or detrimental, on the eight specified interests of the WPA are listed and briefly explained.

**Cost Considerations**
Factors that affect costs and actual cost ranges or general rules from the literature or experience are provided. Recognize that cost can vary substantially among projects, even in what appear to be similar cases. Careful costing is recommended on a case by case basis, but estimates provided here will allow order of magnitude comparisons.
NON-POINT SOURCE CONTROLS: Source Management

How it Works
Source management consists of techniques that eliminate or reduce the potential for pollutants (in this case nutrients) to be released from a source. The most reliable way to do this is to eliminate the source, but this may not be practical in many cases. Alternatively, methods to reduce the release of a pollutant may be instituted. Most source control is achieved through laws, statewide or local bylaws or ordinances that restrict product contents or use or limit activities within a watershed. Where a feasible alternative product exists or targeted land uses do not already exist in the watershed, this can be a very successful approach. Where education reveals both an environmental and economic value by source elimination, success may also be achieved. For example, as established lawns require very little added phosphorus, homeowners should be able to save money and protect water quality while maintaining lawns. However, the cost of no-phosphorus fertilizer is not less than phosphorus-rich brands, and a cultural shift is needed to get people to put water quality ahead of their lawns or their pocketbooks. Additional methods of nutrient source control include erosion prevention, pet waste collection, management of wildlife, and water quality-based zoning. Phosphorus and nitrogen load reductions are highly variable, but tend not to exceed 33% and are often <10%. Use of source controls to prevent loading before it ever starts is the most beneficial use of this approach.

Benefits
- Prevention, elimination or reduction of sources clearly reduces the potential nutrient load
- Costs can be minimal and are spread over the population
- Pollutants other than nutrients can be controlled by the same actions

Detriments
- Source controls are the first line of defense, but will rarely be successful as the only line of defense.
- Compliance may be difficult to track or enforce
- Urbanized or agricultural watersheds may contain many sources that cannot be eliminated or even substantially reduced

Information for Proper Application
- Knowledge of the portion of the load comprised by the targeted source(s)
- Education and compliance programs
- Regulatory jurisdiction and limitations
- Means to measure success

Factors Favoring the Use of this Technique
- A substantial portion of the P and/or N load is associated with NPS pollution
- Studies have demonstrated the impact of identifiable sources
- Jurisdiction can be claimed over areas of NPS contribution
- Zoning or other restrictions on uses of land or products are properly justified and consistent with applicable state and local laws

Performance Guidelines
- Establish an effective public process for involvement of all relevant parties
- Collect the data necessary to support the control effort
- Focus on education before new regulation
- Enforce existing regulations equitably
- Monitor at a scale appropriate to the control effort; demonstrate improvement on or from small parcels before seeking to document any overall change in the lake. Seek funding to facilitate an incentive program

Possible Permits
- None likely

Impacts Specific to the Wetlands Protection Act
- All interests of the WPA are either benefited or unaffected by source controls.

Cost Considerations
- Variable but mostly low and internalized
- Assume $1-10/person for education or compliance effort

Non-Structural Source Controls include:
- Land Purchase for Conservation Purposes
- Conservation Easements - Purchase of development or other use rights for land
- Zoning
- Watershed Protection Districts
- Aquifer Protection Districts
- Wetlands Protection Statutes
- National Pollutant Discharge Elimination System (NPDES)
- Household Hazardous Waste Collection
- Fertilization Limitations
- Lawn Waste Control
- Vehicle Cleaning Regulations
- Agricultural Management Planning
- Other Ordinances and Regulations Governing Activities on the Land or Water
- Education
NON-POINT SOURCE CONTROLS: 
Pollutant Trapping by Maintained Inlet Devices

How it Works
Deep sump catch basins equipped with hooded outlets can be installed as part of a stormwater conveyance system. Deep sumps provide capacity for sediment accumulation and hooded outlets prevent discharge of floatables. Catch basins are usually installed as pre-treatment for other BMPs and are not generally considered adequate stormwater treatment as a sole system. Volume and outlet configuration are key features that maximize particle capture, but it is rare that the finer fraction of the sediment/nutrient load (which contains most nutrients) is removed by these devices. As a consequence, phosphorus removal is normally about 1-20% and nitrogen removal is similar.

A number of more advanced chamber designs are available. These self-contained units include an initial settling chamber for sediment removal, typically have hooded internal passages to trap oil and other floatables, and often incorporate some form of outlet pool to control exit velocity. Several rely on a vortex design to enhance sediment removal, while others rely on filtering mechanisms to augment the settling process. Such systems are most applicable as pre-treatment for other BMPs, but can trap much of the particulate nutrient load and are generally well suited as retrofits for relatively small areas in developed watersheds. Installing these devices as off-line systems may enhance nutrient removal, but their more common use as on-line pre-treatment devices can be very beneficial.

Such devices must be maintained, with periodic clean-out as determined by experience with filling rate. Typically they must be cleaned once per year, with twice per year (spring/fall) cleaning maximizing performance. Street sweeping is not essential to device performance, but is often integral to pavement management where inlet devices are used as significant pollutant controls.

Benefits
- Traps up to 80% of solids with associated pollutants
- Removal of coarse settleables and floatables maximizes discharge aesthetics
- Greatly extends performance of downstream controls such as detention or infiltration
- Installation below grade minimizes impacts on land use

Detriments
- Up to 90% of nutrients are dissolved or associated with the 20% smallest solids that are not removed by these traps
- Failure to maintain devices may result in no removal or clogging and flooding
- Generally inadequate as the sole control mechanism

Information for Proper Application
- Proper device size and attributes for expected load and cleaning frequency
- Monitoring to assess effectiveness and any need for adjustment

Factors Favoring the Use of this Technique
- A substantial portion of the P and/or N load is documented to be associated with coarse particulate NPS pollution.
- Studies have demonstrated the impact of identifiable storm water sources (e.g., piped runoff)
- Water associated with NPS inputs is important to lake hydrology
- Sizing and pollutant removal functions have been properly calculated
- Additional controls (e.g., detention, infiltration) are planned and can be enhanced by this approach

**Performance Guidelines**
- Collect the data necessary to demonstrate the problem and potential for improvement
- Design the system to meet demonstrated needs
- Develop a stormwater management plan in which inlet devices are one element; do not expect inlet devices to solve all stormwater problems
- Develop a maintenance plan
- Monitor at a scale appropriate to demonstrating results

**Possible Permits**
- None likely

**Impacts Specific to the Wetlands Protection Act**
All interests of the WPA are either benefited or unaffected.

**Cost Considerations**
Costs tend to range from a low of around $3000 for simple deep sump catch basins to a high of $30,000 for larger advanced basins with swirl concentrators, filters, multiple chambers, or other special controls. Catch basin cleaning tends to cost $30-100 per basin on a contract basis, depending on the number of basins cleaned. Purchase of street sweepers or catch basin cleaners can represent an expense in excess of $100,000 each, plus maintenance and operation costs.
NON-POINT SOURCE CONTROLS: Pollutant Trapping by Buffers and Swales

How it Works
Buffer strips are areas of grass or other dense vegetation that separate a waterway from an intensive land use. These vegetated strips allow overland flow to pass through vegetation that filters out some percentage of the particulates and decreases the velocity of the stormwater. Particulate settling and infiltration of water often occurs as the stormwater passes through the vegetation. Buffer strips need to be at least 25 ft wide before any appreciable benefit is derived, and superior removal requires a width >100 ft. This can create land use conflicts, but creative planting and use of buffer strips can be a low cost, low impact means to minimize inputs to the aquatic environment. Removal of phosphorus and nitrogen varies substantially (20-90%), with averages in the vicinity of 30% but greater removal achievable with proper design.

Swales are engineered ditches that provide detention and infiltration while transporting runoff to a planned discharge point. Use of dense vegetation and stone or wood check dams within the confines of a channel designed to handle substantial flows of runoff can slow water velocity, allow particulate nutrients to settle, and provide infiltration of a substantial fraction of the dissolved nutrient load. Less removal may occur during higher flows, but such flows do not often carry more of the total nutrient load than smaller storms in most watersheds as a consequence of the first flush phenomenon. Swales may be adequate for nutrient removal if large and long enough, but are more effective as pre-treatment devices before discharge to detention systems. Phosphorus removal is also highly variable (0-70%) with typical average removal at about 30%. Nitrogen removal averages about 25%.

Benefits
- Passively removes nutrients without long detention of flow
- Relatively simple to build and maintain
- Can blend aesthetically into the landscape
- May provide substantial habitat value as well as pollutant removal

Detriments
- Requires substantial land area
- Steep slopes will limit removal potential
- Maintenance may reduce effectiveness until vegetation re-grows

Information for Proper Application
- Climatic and drainage area data to provide estimate of maximum hydrologic loading
- Water quality data with separation of particulate and dissolved fractions, to allow estimation of needed width or length
- Ground slopes, soil types, and planned vegetative cover to allow removal estimation
- Monitoring to assess effectiveness and any need for adjustment

Factors Favoring the Use of this Technique
- A substantial portion of the P and/or N load is associated with NPS pollution
- Studies have demonstrated the impact of identifiable sources

Photographs on this page were provided by L. Gaherty of the BRPC.
- Water associated with NPS inputs is important to lake hydrology
- Sizing and pollutant removal functions have been properly calculated
- Land is available for placement of BMPs

**Performance Guidelines**
- Collect the data necessary to demonstrate the problem and potential for improvement
- Design buffers and swales to meet demonstrated needs; remember habitat and aesthetic functions as well as water quality benefits
- Use only native species in planting programs
- Seek funding to provide an incentive program
- Monitor at a scale appropriate to demonstrating results

**Possible Permits**
- None likely unless natural wetland resources are involved

**Impacts Specific to the Wetlands Protection Act**
All interests of the WPA are either benefited or unaffected, with the possible exception of groundwater quality protection if infiltration occurs in the buffer or swale.

**Cost Considerations**
Often very inexpensive to build and maintain, but maximum performance may require occasional cleaning and replanting. May cost as much as a few dollars per square foot of buffer (exclusive of any land purchase costs) and $25-50 per linear foot of swale with velocity barriers and infiltration capacity.
**NON-POINT SOURCE CONTROLS:**
**Pollutant Trapping by Detention**

**How it Works**
Detention ponds are basins that are designed to hold a portion of stormwater runoff for at least 12-24 hours and preferably longer. Pollutant removal is accomplished mainly through settling and biological uptake, although incorporation of infiltration capacity can add substantial adsorptive capacity as well. Design features are extremely varied and depend on pollutant removal goals, regional climate, and localized site conditions. Detention facilities can be large ponds with multiple forms of aquatic habitat or small “rain gardens”. Wet detention ponds are more effective than dry detention ponds as the latter have a greater risk of sediment re-suspension and generally do not provide adequate soluble pollutant removal. Dry detention ponds have less potential to support mosquitoes and provide greater detention capacity per unit cost. Although potentially very effective, the land requirement is typically large; the area should be at least 2% of the drainage area it serves, and preferably as much as 7% of that area.

Length to width ratio can be an important feature of detention systems, with a L:W ratio of 2:1 often applied. Outlet configuration can also make a big difference; graduated outlets that allow more water to exit as the water level rises are often needed to ensure flood protection, while filtration berms are used to hold back fine solids and hooded overflows are used to trap floatables. Addition of coagulants can enhance removal of dissolved nutrients and colloidal solids. Removal rates for phosphorus vary widely with design features and the nature of the load, with average values of 30-65% reported. Nitrogen removal tends to be somewhat lower, with averages in the 30-40% range.

**Benefits**
- Provides flood protection as well as water quality enhancement
- Generally passive removal with limited maintenance needs
- Can provide habitat value and blend aesthetically with landscape

**Detriments**
- Requires substantial land area
- Construction problems are common in areas of high ground water or abundant bedrock
- Wet ponds may become mosquito breeding areas

**Information for Proper Application**
- Climatic and drainage area data to provide estimate of variability in hydrologic loading
- Water quality data with separation of particulate, colloidal and dissolved fractions, to allow estimation of needed detention time and supplemental features (e.g., plantings, outlet features, polymer addition)
- Soil types, ground water depth and related data for construction planning
- Monitoring to assess effectiveness and any need for adjustment

**Factors Favoring the Use of this Technique**
- A substantial portion of the P and/or N load is associated with NPS pollution
- Studies have demonstrated the impact of identifiable sources
- Water associated with NPS inputs is important to lake hydrology
- Sizing and pollutant removal functions have been properly calculated
- Land is available for placement of the detention system
- Detention capacity is available to hold a substantial portion of the targeted runoff
- Detention and/or infiltration will not cause local flooding problems, wet basements, or structural damage

**Performance Guidelines**
- Collect the data necessary to demonstrate the problem and potential for improvement
- Design the system to meet demonstrated needs; consider flood prevention and water quality enhancement, providing appropriate capacity and rate of through-flow
- Develop a maintenance plan
- Monitor at locations appropriate to demonstrating results

**Possible Permits**
- NPDES permit from EPA under special circumstances
- WPA permit if natural wetland resources are involved

**Impacts Specific to the Wetlands Protection Act**
All interests of the WPA are either benefited or unaffected, with the possible exception of groundwater quality protection if infiltration occurs in the detention area.

**Cost Considerations**
Costs will vary with size, depth and special features, with typical values of $10-30 per cubic yard of capacity. On an areal basis, costs of $50,000-200,000 per acre could be expected, with an expected depth of at least 3 ft.

![Outlet structure for detaining a range of flows](image)

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![Detention Basin Design (after USEPA, 1999)](image)

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Management Techniques: Detention
NON-POINT SOURCE CONTROLS:
Pollutant Trapping by Infiltration

How it Works
Water quality response to runoff has been clearly linked to the portion of the watershed that is impervious. While natural surfaces such as clay soil, muck soils, and exposed rock are functionally impervious, human derived surfaces such as roads, parking lots, driveways and roofs are major sources of runoff in developing watersheds. Once imperviousness exceeds 10% of the watershed area, water quality problems are often observed, and at levels in excess of 25%, water quality impairment almost always occurs. Imperviousness can be minimized by narrowing roadways, limiting development footprints, and incorporating porous pavement wherever feasible. Removal rates vary, but average close to 50% for phosphorus and 60% for nitrogen when infiltration is facilitated.

Infiltration systems may include trenches, basins or dry wells, and involve the passage of water into the soil or through an artificial medium such as a constructed berm. Particles are filtered by the soil matrix and many soluble compounds are adsorbed to soil particles. Such systems require sufficient storage capacity to permit the gradual infiltration of runoff into suitable soils or through the constructed medium. Pre-treatment of the runoff removes larger particles before filtration, thereby aiding in the prevention of infiltration system failure due to clogging and sediment accumulation. Phosphorus removal is maximized by infiltration, but dissolved forms of nitrogen may be only minimally affected. Removal rates for phosphorus tend to be moderate to high, with averages of 60-70%. Despite limited effectiveness for dissolved nitrogen, total nitrogen removal rates are moderate, with averages near 50%. Variability is high, however, as a function of local conditions and design.

Site constraints such as shallow depth to groundwater or bedrock and poorly drained soils often limit the effective use of infiltration, so detailed knowledge of the site is essential when planning infiltration facilities. In sites with suitable conditions, off-line infiltration systems are generally preferred. One key to successful infiltration is providing adequate pre-infiltration settling time or other treatment to remove particles that could clog the interface at which infiltration occurs. Another key is having sufficient runoff detention capacity to allow delivery of runoff to the infiltration surface at a rate that maximizes performance. Both key factors can be met by combining adequate detention facilities with infiltration systems.

Benefits
- High removal based on multiple processes in soil or artificial media
- Removes many contaminants besides nutrients
- Can be used to minimize runoff and maximize ground water recharge
- Can include underground leaching to minimize surficial land use

Detriments
- Poor removal of dissolved nitrogen in most cases
- May contaminate ground water if pollutants (like dissolved N) are mobile
- Requires substantial land area; may interfere with surface uses if not subterranean
- May require substantial detention capacity or not work at all if soils
are not sufficiently permeable
- May raise localized groundwater table; possible issues for structures
- May clog if not adequately maintained; pretreatment of influent often necessary for optimal performance

Information for Proper Application
- Soil conditions and groundwater table elevation, to evaluate efficacy of infiltration and determine design criteria
- Drainage area and climatic data to estimate range of expected loading
- Water quality data for evaluating possible impacts on groundwater
- Monitoring to assess effectiveness and any need for adjustment

Factors Favoring the Use of this Technique
- A substantial portion of the P and/or N load is associated with NPS pollution
- Studies have demonstrated the impact of identifiable sources
- Sizing and pollutant removal functions have been properly calculated
- Land is available for placement of infiltration facilities
- Detention capacity is available to hold excess runoff until it can be infiltrated
- Infiltration will not cause local flooding problems, wet basements, or structural damage
- Infiltration will not cause groundwater quality deterioration

Performance Guidelines
- Collect the data necessary to demonstrate the problem and potential for improvement
- Design the system to meet demonstrated needs; provide trapping for solids that may clog system and appropriate storage capacity for expected infiltration rate
- Evaluate possible groundwater impacts; adhere to Massachusetts Stormwater Policy
- Develop a maintenance plan
- Monitor at locations appropriate to demonstrating results

Possible Permits
- Groundwater Discharge Permit from DEP

Impacts Specific to the Wetlands Protection Act
All interests of the WPA are either benefited or unaffected, with the possible exception of groundwater quality protection. The Massachusetts Stormwater Policy governs pre-treatment needs for infiltration scenarios and should be consulted.

Cost Considerations
Infiltration system costs vary with size and local site conditions. Simple leaching catch basins can be installed for $5000-10,000 each, while leaching trenches will tend to cost more (around $30,000 for a small system handling a few acres). Elaborate systems with back-up detention may cost considerably more. Leaching detention basins will cost about the same as a regular detention basin if the soils are suitable or could be up to twice as expensive if soil modification is needed. Maintenance needs may be substantial, including annual or semi-annual inspection and cleaning as warranted.
**NON-POINT SOURCE CONTROLS:**
*Pollutant Trapping by Constructed Wetlands*

**How it Works**
Detention systems tend to be created wetlands, but design features that combine open water and emergent wetlands tend to provide superior nutrient removal. These systems maximize pollutant removal through vegetative filtration, nutrient uptake, soil binding, bacterial decomposition, and enhanced settling. Much of the effectiveness of the treatment is related to microbial action; the plants are more the substrate than the active pollutant removers, but removal rates are higher in the presence of plants. Wetland systems are suitable for on-line or off-line treatment, but maintenance of adequate hydrology with off-line systems is necessary to support the complete wetland features that maximize effectiveness.

Constructed treatment wetlands can function effectively in cold environments, mainly as a function of subsurface flow and related microbial uptake, adsorption, and filtration processes. Presence of aerobic and anaerobic conditions in sequential portions of the system is essential to reduction in nitrogen through sequential oxidation and reduction of nitrogen forms to convert organic forms to nitrogen gas. There are many details of design that affect performance, with multi-chamber, high detention time systems with both surface and subsurface flow providing the highest nutrient removal rates. Decay of vegetation may raise nutrient export at times. Phosphorus removal is therefore highly variable, but averages 55-65%. Nitrogen removal is also highly variable, but averages close to 40%.

**Benefits**
- Combines features of emergent wetlands, ponds, and groundwater for maximum pollutant removal
- Can be installed in areas with high groundwater table
- May provide supplemental habitat value
- Relatively low maintenance needs

**Detriments**
- Some seasonal component to removal efficiency, although subsurface flow can offset this in many cases
- May have net release of nutrients during hydraulic washout after decay periods
- May act as breeding ground for mosquitoes

**Information for Proper Application**
- Soil conditions and groundwater table elevation, to evaluate efficacy of wetland maintenance and determine design criteria
- Drainage area and climatic data to estimate range of expected loading
- Water quality data for evaluating possible impacts on groundwater and special design needs for maximizing pollutant removal
- Monitoring to assess effectiveness and any need for adjustment

**Factors Favoring the Use of this Technique**
- A substantial portion of the P and/or N load is associated with NPS pollution
- Studies have demonstrated the impact of identifiable sources
- Sizing and pollutant removal functions have been properly calculated
- Land is available for placement of wetlands
- Detention capacity is available to hold a substantial portion of the targeted runoff

There are many types of wetlands, both natural and created. Successful design of wetlands for stormwater treatment benefits from a clear understanding of treatment goals and knowledge of wetland functions and processes.

![Constructed wetland](image)
- Detention and/or infiltration will not cause local flooding problems, wet basements, or structural damage
- Infiltration will not cause groundwater quality deterioration
- Maximum nitrogen removal is desired

**Performance Guidelines**
- Collect the data necessary to demonstrate the problem and potential for improvement
- Design the wetland to meet demonstrated needs; utilize multiple wetland processes; consider flood prevention and water quality enhancement, providing appropriate capacity and rate of through-flow
- Remember habitat and aesthetics in design, and use only native species in planting programs
- Develop a maintenance plan
- Monitor at locations appropriate to demonstrating results

**Possible Permits**
- Groundwater Discharge Permit from DEP

**Impacts Specific to the Wetlands Protection Act**
All interests of the WPA are either benefited or unaffected, with the possible exception of groundwater quality protection if infiltration occurs in the wetland.

**Cost Considerations**
Wetland creation can be very inexpensive if local site conditions favor wetness, but considerable design effort and careful construction are needed to maximize performance. Costs will be similar to those of detention basins ($50,000-200,000/acre), with potential additional planting costs. Multi-chamber designs that facilitate nitrification/denitrification will be most effective yet most expensive.
**NON-POINT SOURCE CONTROLS:**
Pollutant Trapping by Agricultural Best Management Practices

**How it Works**
The spatial and temporal features of planting, coupled with the actual crops chosen, can greatly affect the movement of nutrients off farm fields. Cover crops stabilize soils, and may be used as interim cover or as a supplemental crop in association with plants that grow up through the cover crop to form another layer above it. Interspersing of crops can create buffer zones such that potential nutrient losses facilitated by harvest of one crop are trapped by the other. The basic philosophy of the planting plan is to minimize bare soil and create buffer zones that have economic as well as ecological value.

The pattern of plowing on a farm can be a great aid to minimizing the movement of nutrients. Conservation tillage involves contouring, terracing, and related approaches that minimize the peak velocity attained by runoff and maximize infiltration of rainwater. Coupled with an effective planting plan, the quantity of runoff generated from the field can be greatly reduced; this translates into reduced nutrient loading to area waterways.

Livestock operations have the potential to contribute nutrient loads that overshadow most other sources, and represent a health hazard as well. Manures are of special concern as they are relatively high in nutrients and attempts to meet nitrogen requirements by application of manure may result in losses of phosphorus to surface waters. Handling manure in a manner that limits interaction with precipitation and incorporation into runoff is essential to protecting aquatic habitats. Manure application should be kept as far away as possible from streams and lakes and the application of manure should be avoided during winter months when frozen soils result in large losses in runoff. Covered feeding areas, manure collection systems, covered storage, and proper spreading on farm fields or disposal by other means are all necessities of best management for livestock facilities. Studies suggest alum and other chemical additives may reduce phosphorus leaching from manure. Conversion of manure to energy is a novel approach now being advanced.

Cranberry production is large in MA, and these operations are usually associated with lakes. While bogs use water to irrigate and most apply fertilizers and pesticides, the impact of these activities on downstream lakes is not certain. Current impacts on lakes from cranberry bogs tend to be linked to the fall harvest for wet-pick bogs and to periodic flushing (usually a post harvest through spring event) of all bogs. Water discharged from bogs, if not detained or otherwise treated, may carry large amounts of particulate nutrients into the receiving waters, often a lake or tributary to a lake. Dissolved phosphorus in anoxic winter discharges may be high. Nitrogen is usually in short supply in bogs, and concentrations of readily available nitrogen tend to be low. Microbial processes in lakes may recycle the bog inputs and eventually increase lake fertility. The key factor appears to be the volume of discharge relative to the volume of the lake, with larger relative volumes having greater potential impact.

Overall reduction in nutrient loading is difficult to predict, given the wide range of agricultural activities, local site conditions, and BMP options. Major reductions (>50%) have been realized from manure handling improvements, but substantial reductions from crop management practices also appear possible. Localized monitoring is essential to tracking progress.
Benefits
- Can minimize soil loss and associated economic cost
- Can minimize fertilizer costs
- May provide health benefits as well as nutrient loading reduction

Detriments
- Generally has unfavorable short-term cost-benefit balance from farmer’s perspective, unless supporting public funds are available
- Soil capacity for phosphorus from manure spreading is quickly exhausted, leading to a need for new and large disposal areas

Information for Proper Application
- Soil nutrient needs, to assess fertilizer needs or adsorptive capacity
- Farming plan, to ensure that BMPs have minimum impact on productivity
- Climatic information and local drainage pattern, to evaluate key sites/periods
- Ongoing monitoring to assess impacts and additional management needs

Factors Favoring the Use of this Technique
- A substantial portion of the P and/or N load is associated with NPS pollution
- Studies have demonstrated the impact of identifiable sources
- Sizing and pollutant removal functions have been properly calculated
- Land is available for placement of BMPs
- Cooperation of farmers
- Agricultural assistance funding is available

Performance Guidelines
- Collect the data necessary to demonstrate the problem and potential for improvement
- Seek involvement from farmers and farm agencies in selecting BMPs; develop a clear understanding of the agricultural operation before specifying BMPs
- Apply BMPs to meet demonstrated needs; focus on soil, nutrient and pesticide mobility
- Seek funding to provide an incentive program
- Develop a maintenance plan
- Monitor at locations appropriate to demonstrating results

Possible Permits
- None likely unless wetland resources are involved

Impacts Specific to the Wetlands Protection Act
All interests of the WPA are either benefited or unaffected.

Cost Considerations
Costs are highly variable in accordance with the type of farming, need for controls, and local site conditions. Manure handling and storage systems often cost on the order of $100,000 for a typical dairy herd or other livestock operation in MA. Procedural controls like conservation tillage or planting plans may carry minimal cost.
How it Works
Most on-site domestic sewage treatment consists of either the older cesspool (single chamber, open bottom pit type, no longer in construction) or the newer septic tank with leaching field or chamber (conventional septic systems). Most septic systems consist of a subsurface chambered tank where scum and settleable solids are removed from the liquid by gravity separation and a subsurface drain system where the clarified liquid effluent percolates into the soil. Regular inspection of the system is recommended, with pumping as experience dictates or according to calculations based on the number of people served and the size of the tank.

For conventional septic systems, the management techniques are detailed in Title 5 of the State Environmental Code 310 CMR 15.00 et. sec. For any new septic systems, the leach field must have a minimum setback of 50 feet from surface waters. To protect resources, additional restrictions on septic systems may be imposed by local ordinance.

Phosphorus is removed to a substantial degree in both the septic tank and the leachfield, owing to chemical reactions that tend to convert phosphorus into particulate forms. Even beyond the leaching field or chamber, soils adsorb phosphorus at high rates. Removal rates may be only 20-50% in the actual septic system, but removal rates >90% are expected through soil adsorption in most cases. Where the system is in fractured rock or compacted soil with fissures, high removal rates may not be realized. Likewise, where system failure results in breakout of septic effluent at the ground surface, or the soil capacity for phosphorus adsorption is exhausted, removal of phosphorus will be severely reduced. The phosphorus load to a lake from septic systems requires careful evaluation, however; do not assume high loading.

Even a properly sited, well-maintained, conventional septic system will release a substantial amount of nitrogen into the ground. Physical and chemical soil processes do little to reduce discharge concentrations, which may exceed 50 mg/L. Site limitations and the inability of conventional septic systems to capture more than about 10% of the nitrogen load has fostered a variety of alternative systems. Advanced on-site wastewater disposal systems may be applied in cases where a septic system fails and/or the site cannot accommodate a conventional system due to size or performance needs. There are many approved alternate technologies for septic systems in Massachusetts.

Many advanced systems are designed to remove nitrogen, with removal rates >50% and sometimes approaching 90%. Few advanced systems have a demonstrated ability to remove significantly more phosphorus than conventional systems, although some are being tested. Some systems are designed to enhance infiltration in low permeability sites, but all focus on achieving better overall effluent quality.

Tight tanks are an older alternative that eliminates the leaching function of on-site wastewater disposal and necessitate more frequent pump-out and hauling to an approved septage disposal site, usually a wastewater treatment facility operated by a municipality or regional authority.
The Practical Guide to Lake Management in Massachusetts

**Benefits**
- Properly designed, constructed and maintained septic systems minimize phosphorus input to lakes
- Advanced on-site wastewater disposal systems can minimize phosphorus and nitrogen inputs to lakes
- Tight tanks eliminate discharge to the groundwater or lake

**Detriments**
- Conventional septic systems provide minimal nitrogen removal
- Conventional septic systems do not function well where the groundwater table is high (<4-6 ft below leachfield elevation)
- On-site wastewater disposal systems depend upon soil adsorption of phosphorus for much of the removal function; leachfields are eventually exhausted, leading to inputs to lakes
- Maintenance is not required by state law or most local ordinances, and no individual effluent limitations are applied

**Information for Proper Application**
- Careful investigation that documents the importance of septic system inputs on lake conditions
- Local soil and groundwater conditions to allow proper siting and design
- Use levels (number of people, presence of dishwashers, garbage grinders, and other conveniences) to allow proper design
- Means to measure success

**Factors Favoring the Use of this Technique**
- A substantial portion of the P and/or N load is associated with septic systems
- Studies have demonstrated the impact of septic systems on the lake
- Sizing and pollutant removal functions have been properly calculated
- Required changes are properly justified and consistent with applicable state and local laws

**Performance Guidelines**
- Collect the data necessary to demonstrate the problem and potential for improvement
- Design systems or rehabilitation programs to meet demonstrated needs; match available designs to water quality goals
- Adhere to Title V regulations in the design and construction of septic systems
- Develop an inspection and maintenance plan
- Monitor at locations appropriate to demonstrating results

**Possible Permits**
- Title V compliance through DEP

**Impacts Specific to the Wetlands Protection Act**
All interests of the WPA are either benefited or unaffected by improved management of on-site wastewater disposal systems.

**Cost Considerations**
A conventional septic system will typically cost on the order of $10,000-15,000, with increased costs if local site conditions are problematic. Advanced systems tend to be more expensive, often in the range of $20,000-30,000 or even higher.
POINT SOURCE CONTROLS

How it Works
Point source pollution is defined as originating from a pipe or other distinct conveyance under federal regulations. Originally intended to deal with wastewater treatment discharges from industrial or municipal operations, the definition of a point source was extended in 1990 to include stormwater discharges where the delivery was an observable pipe, ditch, swale, curb cut, or other delivery device that could be construed as meeting the federal definition. Certain activities, such as concentrated animal feedlot operations (CAFOs), have also been classified as point sources in this manner. Point source discharges are governed by the National Pollutant Discharge Elimination System, or NPDES. Many states have been authorized to administer this program, but Massachusetts is still governed by the federal program and does not issue NPDES permits itself. The DEP is involved in NPDES issues, however, and provides considerable guidance on meeting federal requirements.

Although industry and other activities may have point source discharges of pollutants, most of the nutrient sources are from municipal WWTFs. The current thrust of WWTF permitting emphasizes meeting effluent concentrations that will protect lakes with reasonable dilution. Domestic wastewater enters a WWTF with P in excess of 3 mg/L and sometimes as high as 15 mg/L. N levels can exceed 40 mg/L, with values up to 70 mg/L not uncommon. Wastewater treatment in Massachusetts involves primary and secondary treatment and in some cases, tertiary treatment. Primary treatment involves the settling out of suspended solids in sedimentation tanks. Secondary treatment usually involves a biological component to oxidize and convert organic wastes, sometimes with chemical addition that reduces P levels. Resulting P concentrations can be as low as 0.3 mg/L, but are more often >1 mg/L and often as high as 3-4 mg/L. N levels of 10-15 mg/L are common, with concern directed toward the fraction of the N load that is present as toxic un-ionized ammonia. Well-functioning secondary treatment WWTFs tend to convert nearly all ammonia/ammonium to nitrate. However, nutrient levels from even the best secondary treatment facilities are well in excess of desirable levels in lakes.

Advanced waste treatment, or tertiary treatment, usually involves the removal of phosphorus and/or nitrogen. Phosphorus compounds are most often removed by coagulation with chemicals, sometimes with an additional filtering step. Dissolved air flotation (DAF) can also greatly reduce P concentrations, but is more commonly used in drinking water treatment than wastewater situations. Achievement of concentrations <0.5 mg/L is routinely possible through tertiary treatment, with targets set as low as 0.1 mg/L in some cases and current research aimed at achieving P concentrations of 0.01 to 0.02 mg/L. However, with a target lake P level of <0.02 mg/L and preferably <0.01 mg/L, WWTF inputs currently require substantial dilution to avoid eutrophication impacts on lakes.

There are many methods to remove nitrogen compounds, including ammonia stripping by air and nitrification-denitrification in biological reactors. Other advanced treatment methods that protect lakes include adsorption of residual organic and color compounds on activated carbon and the use of reverse osmosis and electrodialysis to remove dissolved solids. Wetland treatment has become popular for nutrient control as a polishing step in WWTFs, and some WWTFs are based mainly on biological activity as a mainstay of wastewater treatment.
Note that stormwater that is conveyed through any type of drainage system is defined by the EPA as a point source and subject to NPDES permits. The most salient provision of the NPDES program for stormwater is the requirement for a Stormwater Pollution Prevention Plan (SWPPP), which is a site- and activity-specific management guide for minimizing impacts on runoff from the site. The emphasis is on prevention of pollution, not treatment or remediation. The SWPPP includes provision for managing potential pollutants stored or used on site, limiting exposure of potentially polluting activities to precipitation and runoff, and measures for responding to spills, leaks, or other releases. Monitoring provisions are industry-specific and not overly stringent, but the whole process is a major step toward minimizing contamination of runoff and documenting that effort.

In some cases inflows to wastewater treatment plants are combined with urban stormwater flow. This is most often a result of underdesign of conveyance systems in the face of expanding user populations, with combined manholes for easy access to both sanitary and storm sewers being the primary point of mixing. This situation leads to excess hydraulic loading to the drainage system and/or WWTF during storms that may result in untreated or incompletely treated wastes being discharged to streams or lakes. Separating these Combined Sewer Systems (CSS) to avoid Combined Sewer Overflow (CSO) has been emphasized by the EPA and DEP for about two decades now, and substantial progress has been made.

One less well-known point source that has become a problem in Massachusetts is drinking water treated to comply with anti-corrosion provisions of the federal Safe Drinking Water Act of 1996. The most common chemical used to inhibit corrosion in distribution pipes is calcium phosphate, with concentrations of P in excess of 1 mg/L in many cases and sometimes as high as 5 mg/L, not much different than secondary treated sewage! Blowdown from boilers or hydrants, discharged directly to stormwater drainage systems, or leaks from water mains can provide a substantial input of P to downstream lakes. Use of potable water for make-up water in smaller ponds and swimming facilities can actually cause an algal bloom. Alternatives to calcium phosphate, such as a variety of silicates, are available but more expensive.

Management of point sources generally falls into the same categories as for non-point sources: source management and pollutant trapping. Source management includes bans on phosphorus in detergents and a variety of pretreatment requirements for businesses that might otherwise contribute excessive amounts of oils, metals or other contaminants of special concern. Pollutant trapping is a function of the treatment process, with tertiary treatment necessary to remove enough nutrients to protect lakes.

Source management for stormwater point sources is essential to improving discharge quality in nearly all cases. Nutrient removal from stormwater by treatment will depend on the BMPs applied, with removal rates typically in the 30-60% range. Source management for wastewater treatment facilities is only essential to the extent that it protects the treatment process, with improved treatment providing the greatest reduction in nutrient loading. Actual removal rates for phosphorus average 10% for primary, 20-40% for secondary, and 80-99% for tertiary. For nitrogen, removal rates average 510% for primary, 10-30% for secondary, and 50-90% for tertiary.
Benefits
- Control of centralized wastewater collection and treatment can result in a major reduction in loading
- Improved treatment can remove many contaminants as well as nutrients
- Stormwater management has great potential for reduced nutrient loading

Detriments
- Discharge of even the “cleanest” treated wastewater may still contain excessive concentrations of nutrients
- Centralized wastewater discharge localizes a potentially major impact and may affect hydrology of contributing watershed areas

Information for Proper Application
- An accurate nutrient budget that demonstrates the importance of the point source(s) in determining lake quality
- Water quality data for influent that supports treatment design
- Hydrologic data for receiving waters to evaluate dilution effects
- Source analysis for stormwater point sources, to allow minimization of impacts on runoff quality
- Ongoing monitoring to assess impacts and additional management needs

Factors Favoring the Use of this Technique
- A substantial portion of the P and/or N load is associated with point source pollution
- Studies have demonstrated the impact of identifiable discharges on the lake
- Water associated with point sources is important to lake hydrology
- Pollutant removal expected from source management or treatment upgrade has been properly calculated and is achievable
- Jurisdiction can be claimed over point sources

Performance Guidelines
- Collect the data necessary to demonstrate the problem and potential for improvement
- Meet all requirements of the NPDES program; seek to establish permit limits that meet water quality goals, but with recognition of other pollutant sources to the target lake
- Design the treatment system or upgrade to meet demonstrated needs; match treatment processes to water quality goals
- Monitor the effluent in accordance with NPDES requirements and at locations appropriate to demonstrating results

Possible Permits
- NPDES permit from EPA, with input from DEP

Impacts Specific to the Wetlands Protection Act
All interests of the WPA are either benefited or unaffected.

Cost Considerations
Costs of source control tend to be nominal and internalized, as with substituting products or ingredients to avoid high nutrient content. Some source controls carry significant cost, as with moving possible contaminants into covered storage, but such action will limit liability on numerous fronts. Cost of treatment upgrade is usually substantial ($5-10 million) and carries significant operational costs as well ($100,000-$1 million/yr), in proportion to the volume of water treated.
HYDRAULIC CONTROLS: Dilution and Flushing

How it Works
Lake waters that have low concentrations of an essential nutrient are unlikely to exhibit algal blooms. While it is preferable to reduce nutrient loads to the lake, it is possible to lower (dilute) the concentration of nutrients within the lake by adding sufficient quantities of nutrient-poor water from some additional source. High amounts of additional water, whether low in nutrients or not, can also be used to flush algae out of smaller, linear impoundments faster than they can reproduce.

When water low in phosphorus is added to the inflow, the actual phosphorus load will increase, but the mean phosphorus concentration should decrease. Dilution or flushing washes out algal cells, but since the reproductive rate for algae is high (blooms form within days to a few weeks), only extremely high flushing rates will be effective without a significant dilution effect. A flushing rate of 10 to 15% of the lake volume per day is appropriate to minimize algal biomass build-up.

Outlet structures and downstream channels must be capable of handling the added discharge for this approach to be feasible. Qualitative downstream impacts must also be considered. Water used for dilution or flushing should be carefully monitored prior to use in the lake. Application of this technique is most often limited by the lack of an adequate supply of low nutrient water.

Benefits
- Reduces algal biomass without reducing nutrient loading
- May provide improved downstream habitat or recreational opportunity through elevated flows

Detriments
- Diverts water from other uses
- May cause flooding if downstream channel is incapable of handling enough flow
- Will not work with many isolated coves

Information for Proper Application
- Accurate hydrologic and nutrient budgets to allow evaluation of potential benefits
- Assessment of probable in-lake effects and an evaluation of downstream impacts
- Reliability of source water
- Routing information for new water source
- Monitoring program to track changes in detention time, nutrient levels and water clarity

Factors Favoring the Use of this Technique
- Actual reduction in nutrient inputs from identifiable sources is not practical, either for technical or jurisdictional reasons
- Water level fluctuation will not differ greatly from pre-treatment conditions
- Adequate water of a suitable quality is available for dilution or flushing
- Downstream problems with water quantity or quality will not be caused

Performance Guidelines
- Develop reliable hydrologic and nutrient budgets and evaluate probable outcomes of dilution or flushing
- Determine impacts of diverting water for use in dilution or flushing
Successful flushing requires a resultant detention time of less than about two weeks on a consistent basis during the growing season. This technique is primarily limited by reliability of water supply for this purpose.

Possible Permits
- WPA permit through local Conservation Commission/DEP
- Review by NHESP (further action if protected species are present)
- Chapter 91 Permit through DEP may be required for structural alterations in Great Ponds
- Dam Safety Permit may be required through DCR
- Rerouting of water in excess of 100,000 gpd may require a permit under the Water Management Act through DEP
- Possible 401 WQ permit through the DEP, but jurisdiction will depend upon which other permits are required and funding sources
- Possible NPDES permitting through EPA/DEP, depending on water quality of discharge.

Impacts Specific to the Wetlands Protection Act
- Protection of public and private water supply – Variable (depends on location of supply relative to discharge and detention time)
- Protection of groundwater supply – Neutral, unless there is a discharge to groundwater, in which case the impact could be beneficial or detrimental
- Flood control - Neutral (added flow must remain within tolerance limits for lake and downstream receiving waters)
- Storm damage prevention – Neutral (added flow must remain within tolerance limits for lake and downstream receiving waters)
- Prevention of pollution - Benefit in the lake (water quality enhancement) and possibly downstream
- Protection of land containing shellfish - Possible benefit through water quality enhancement in the lake and possible detriment with any downstream flow problems
- Protection of fisheries - Benefit (water quality enhancement), but possible detriment through reduced fertility and possible benefit or detriment downstream through flow changes
- Protection of wildlife habitat – Benefit (water quality enhancement), but possible detriment through reduced fertility and possible downstream benefit or detriment through flow changes

Cost Considerations
The cost of dilution and flushing varies mainly with the volume and availability of water. If a nearby upstream source of clean water could be diverted to a lake by gravity, or if a short canal can be constructed to provide a connection to a larger stream or river, the costs may be limited. Purchase of public water for this purpose will likely be very expensive. Expect $500-2500/acre/yr for application of these techniques, inclusive of permitting and monitoring, when a source of water is readily available. Costs may rise to $5,000-25,000/acre/yr if water is purchased, piped and/or pumped.
HYDRAULIC CONTROLS: Diversion

How it Works
Diversion is simply the re-routing of a discharge to avoid a sensitive resource, discharging instead to an alternative receiving water, typically downstream of the original discharge location or in another drainage basin. Diverting water from a lake may make sense if the associated nutrient load is undesirable and the loss of the hydrologic load will not have undue negative impacts. Ideally, diversion involves a small amount of water with a large amount of nutrients in it. Diversion is most often practiced in association with wastewater or stormwater discharges to lakes with adequate alternative water supplies. It suffers from the philosophical drawback of sending contaminated water elsewhere without addressing the source of nutrients, and may be difficult to permit, but it can be a very effective means of reducing nutrient inputs to a lake targeted for management.

Benefits
- Eliminates significant loads of nutrients
- Minimal long-term expense expected once gravity diversion complete

Detriments
- Removes a source of water to the lake
- Relocates impact elsewhere

Information for Proper Application
- Accurate hydrologic and nutrient budgets to allow evaluation of potential benefits
- Assessment of probable in-lake effects and an evaluation of downstream impacts
- Routing information for new discharge location
- Monitoring program to track changes in detention time, nutrient levels and water clarity in the target lake
- Monitoring program to assess impacts of new discharge location

Factors Favoring the Use of this Technique
- A substantial portion of the P and/or N load is associated with sources that can be diverted
- Studies have demonstrated the impact of the targeted discharge on the lake
- Water associated with sources to be diverted is not important to lake hydrology; water level fluctuation will not differ greatly from pre-treatment conditions
- Downstream problems with water quantity or quality will not be caused.

Performance Guidelines
- Develop reliable hydrologic and nutrient budgets and evaluate probable impacts of diversion on lake and any stream upstream of diversion
- Determine possible effects of diversion downstream of discharge
- Design diversion system and any necessary maintenance program; avoid flooding and erosion problems downstream of discharge
- Monitor quality of water in the lake and downstream of discharge

Possible Permits
- WPA permit through local Conservation Commission/DEP
- Review by NHESP (further action if protected species are present)
- Chapter 91 Permit through DEP may be required for structural alterations in Great Ponds
- Dam Safety Permit may be required through DCR
Management Techniques: Diversion

- Rerouting of water in excess of 100,000 gpd may require a permit under the Water Management Act through DEP
- 404 permit through the Corps of Engineers
- 401 WQ permit through the DEP
- NPDES permitting through EPA/DEP

**Impacts Specific to the Wetlands Protection Act**
- Protection of public and private water supply – Variable (depends on location of supply relative to discharge)
- Protection of groundwater supply – Neutral, unless there is a discharge to groundwater, in which case the impact could be detrimental
- Flood control – Most likely neutral (diverted flow must remain within tolerance limits for receiving waters)
- Storm damage prevention – Neutral (diverted flow must remain within tolerance limits for receiving waters)
- Prevention of pollution - Benefit in the lake (water quality enhancement), but possibly detrimental downstream (possible poor quality discharges)
- Protection of land containing shellfish - Possible benefit through water quality enhancement in the lake and possible detriment with any downstream water quality degradation
- Protection of fisheries - Benefit (water quality enhancement), but possible detriment through reduced fertility and possible detriment downstream with any water quality degradation
- Protection of wildlife habitat – Benefit (water quality enhancement), but possible detriment through reduced fertility

**Cost Considerations**
The cost of diversion varies greatly among cases, but is rarely inexpensive. The cost is primarily based on the required distance for transport and associated construction costs. If the water must be treated prior to discharge, that cost should also be included. Estimates for diversion of various wastewater discharges in Massachusetts have exceeded $5 million; these diversions were not implemented, in favor of improved treatment. Diverting storm drains may be a more economic approach if technical and permitting difficulties can be overcome.

Diversion of secondary treated sewage effluent from Dennisville Lake in NJ in about 1980 dramatically improved conditions within a decade.


**HYDRAULIC CONTROLS: Selective Withdrawal**

**How it Works**
For recreational lake management, the intent of selective withdrawal is usually to remove the poorest quality water from the lake, which is normally the water at the bottom of the lake unless an intense surface bloom of algae is underway. It is desirable to discharge water at a rate that prevents anoxia near the sediment-water interface, resulting in both improved lake conditions and an acceptable discharge quality. This can be accomplished in impoundments with small hypolimnia and/or large inflows. In most lake management cases, however, selective withdrawal will involve waters of poor quality and treatment may be necessary before discharge downstream.

Where phosphorus has accumulated in the hypolimnion through release from the sediments, selective discharge of hypolimnetic waters prior to fall turnover can reduce effective phosphorus loading. However, unless late summer inflows are substantial, this may result in a considerable drawdown of the lake level. Where a drawdown is planned, selective discharge may increase the benefit. Often an outlet structure must be retrofitted to facilitate selective withdrawal, but the one-time capital cost confers permanent control with minimal operation and maintenance costs.

Selective withdrawal for water supply means locating the intake at the depth where water quality is most advantageous for the intended use. It can be used in any system where vertical water density gradients are sufficiently stable, but is most often applied to more strongly stratified lakes. For potable water use of productive lakes, the choice is often between high algae concentrations in the epilimnion and high iron and/or manganese in the hypolimnion. Intakes located near the thermocline sometimes get both high algae and high metals. A choice of intake depths is preferred, allowing adjustment of intake depth in accordance with the best available water quality. For cooling water supply, cold hypolimnetic withdrawal is preferred, as long as it does not contain high levels of corrosive sulfides.

**Benefits**
- Removes poor quality water before it mixes with upper water layer; ideally prevents development of poor quality water
- Uses expected outflow in a more beneficial manner
- Can provide benefits for downstream coldwater fishery

**Detriments**
- May cause unintended drawdown
- May disrupt stratification
- May result in downstream discharge of poor quality water

**Information for Proper Application**
- Accurate hydrologic and nutrient budgets to allow evaluation of potential benefits and limitations
- Detailed knowledge of system morphometry and thermal structure to allow assessment of appropriate withdrawal depth
- Assessment of probable in-lake effects and downstream impacts
- Adequacy of inflow to keep the lake water budget in balance, in order to avoid an unintended water level decrease
- Drawdown plans, if hypolimnetic withdrawal is to be used in conjunction with this technique
- Outlet plans to facilitate design of withdrawal port
- Monitoring program to assess quality of discharged water, quality of water remaining in the lake, and stability of lake water level and stratification

Results for 17 lakes with 1 to 10 years of hypolimnetic withdrawal indicate that reduced epilimnetic phosphorus concentrations did result, presumably leading to lowered algal biomass. However, concerns over summer drawdown, disruption of stratification, and downstream water quality must all be addressed in a successful program.

In some large western reservoirs, hypolimnetic discharges constitute a major outflow and are responsible for maintenance of very productive downstream coldwater fisheries.
Factors Favoring the Use of this Technique
- A substantial portion of the P and/or N load is associated with sources that can be preferentially discharged
- Studies have demonstrated the impact of hypolimnetic load on the lake
- Water level fluctuation will not differ greatly from pre-treatment conditions
- Downstream problems with water quantity or quality will not be caused.
- Actual reduction in nutrient inputs from identifiable sources is not practical, either for technical or jurisdictional reasons

Performance Guidelines
- Develop reliable hydrologic and nutrient budgets and evaluate probable outcomes of selective withdrawal
- Determine possible effects on stratification and related habitat in the lake
- Determine possible downstream effects of increased flow and altered water quality
- Design withdrawal system and any necessary maintenance program
- Avoid lowered water level as a consequence of selective withdrawal (unless permitted as part of a drawdown)
- Avoid contravention of downstream water quality standards due to discharge
- Conduct selective withdrawal mainly during the summer and fall
- Monitor quality of in-lake and outgoing water

Possible Permits
- WPA permit through local Conservation Commission/DEP
- Review by NHESP (further action if protected species are present)
- Chapter 91 Permit through DEP may be required for Great Ponds
- Dam Safety Permit may be required through DCR
- Possible 404 permit through the Corps of Engineers
- Possible 401 WQ permit through the DEP
- Possible NPDES permitting through EPA/DEP

Impacts Specific to the Wetlands Protection Act
- Protection of public and private water supply – Variable (depends on location of supply relative to discharge or depth of intake)
- Protection of groundwater supply – Neutral, unless there is a discharge to groundwater, in which case the impact could be detrimental
- Flood control - Neutral (discharge must remain within tolerance limits for lake and downstream receiving waters)
- Storm damage prevention – Neutral (discharge must remain within tolerance limits for lake and downstream receiving waters)
- Prevention of pollution - Benefit in the lake (water quality enhancement), but possibly detrimental downstream (possible poor quality discharges)
- Protection of land containing shellfish - Possible benefit through water quality enhancement in the lake and possible detriment with any downstream water quality degradation

Selective withdrawal can be accomplished with a subsurface pipe. Head pressure derived from the difference between the water surface elevation and the discharge elevation forces water into the pipe at the inlet end (set in deeper water), even when the discharge elevation is higher than the inlet elevation.
- Protection of fisheries - Benefit (water quality enhancement), but possible detriment through reduced fertility and possible detriment downstream with any water quality degradation
- Protection of wildlife habitat – Benefit (water quality enhancement), but possible detriment through reduced fertility

**Cost Considerations**
Installation costs for withdrawal pipes typically range between $10,000 and $50,000, although higher costs are certainly possible if major outlet reconstruction is needed. Costs for treating the discharge could be substantial, but treatment has consisted mainly of aeration by passive means at limited capital and operational cost. A cost of <$100 per acre is suggested where structures are in place and no major downstream impacts are expected. The cost may rise to $1000-3000/acre where structural alterations and/or treatment of discharged water become necessary.
PHOSPHORUS INACTIVATION

How it Works
The release of phosphorus stored in lake sediments can be so extensive in some lakes and reservoirs that algal blooms persist even after incoming phosphorus has been significantly lowered. Phosphorus precipitation by chemical complexing removes phosphorus from the water column and can control algal abundance until the phosphorus supply is replenished. Inactivation of phosphorus in surficial lake sediments can greatly reduce the release of phosphorus from those sediments, minimizing the internal load. It is essentially an “anti-fertilizer” treatment. This technique is most effective after nutrient loading from the watershed is sufficiently reduced, as it acts only on existing phosphorus reserves, not new ones added post-treatment. In-lake treatments are used when studies indicate that the primary source of the phosphorus is internal (recycled from lake sediments). Such nutrient control generally does not reduce macrophyte abundance, but can control algal growths.

The three most common treatments for lakes employ salts of aluminum, iron, or calcium compounds. Nitrate treatments are very rare and are used to enhance phosphorus binding to natural iron oxides in sediments. For the aluminum, iron and calcium treatments, the typical compounds used include aluminum sulfate \((\text{Al}_2\text{(SO}_4\text{)_3})\times\text{H}_2\text{O}\), sodium aluminate \((\text{Na}_2\text{Al}_2\text{O}_4\times\text{H}_2\text{O})\), iron as ferric chloride \((\text{FeCl}_3)\) or ferric sulfate \((\text{Fe}_2\text{(SO}_4\text{)_3})\), and calcium as lime \((\text{Ca(OH)}_2)\) or calcium carbonate \((\text{CaCO}_3)\). Additional forms of aluminum are becoming more common.

Inactivators are applied to the surface or subsurface, in either solid or liquid form, normally from a boat or barge. These compounds dissolve and form hydroxides, \(\text{Al}^3\text{(OH)}_3\), \(\text{Fe(OH)}_3\), or in the case of calcium, carbonates such as calcite \((\text{CaCO}_3)\). These minerals form a floc that can remove particulates, including algae, from the water column within minutes to hours and precipitate reactive phosphates. Reactions continue at the surface-water interface, binding phosphorus that could otherwise be released from the sediment. Because aluminum and iron added as sulfates or chlorides dissolve to form acid anions along with the formation of the desired hydroxide precipitates, the pH will tend to decrease in low alkalinity waters unless basic salts such as sodium aluminate or lime are also added. Conversely, calcium is usually added as carbonates or hydroxides that tend to raise pH.

The various floc minerals behave very differently under high or low dissolved oxygen and they also differ in their response to changes in pH. Because of its ability to continue to bind phosphorus under the widest range of pH and oxygen levels, aluminum is usually the preferred phosphorus inactivator. Other binders are applied under specific conditions that favor their use, but not as commonly as aluminum.

Good candidate lakes for this procedure are those that have had external nutrient loads reduced to an acceptable level and have been shown, through a D/F study, to have a high internal phosphorus load (release from sediment). High natural alkalinity is also desirable to provide buffering capacity. Highly flushed impoundments are usually not good candidates because of an inability to limit phosphorus inputs. Treatment of lakes with low doses of alum may effectively remove phosphorus from the water column, but may be inadequate to provide long-term control of phosphorus release from lake sediments. High doses are needed to effectively bind phosphorus in the upper few inches of sediment and retard release.
Low doses of aluminum (1-5 mg/L) can be used to strip phosphorus out of the water column with limited effects on pH or other water quality variables, even in many poorly buffered waters. Mixing with aeration systems can increase treatment efficiency and lower the necessary dose. Aluminum doses in excess of 50 g/m² may be needed to thoroughly inactivate sediment phosphorus reserves and maximize treatment longevity. Areal doses (g/m²) convert to volumetric doses (g/m³ or mg/L) simply by dividing the areal dose by the water depth in meters. Doses around 10 mg/L are typically applied to stormwater discharges, and current efforts in stormwater management focus on capturing the floc in detention areas prior to discharge to the lake or stream.

Iron salts are very sensitive to dissolved oxygen levels. Under oxic conditions the ferric hydroxide floc is stable at normal pH conditions (pH>5). Under anoxic conditions, however, the iron in ferric hydroxide is reduced to soluble ferrous iron (Fe²⁺) and the floc dissolves, releasing the adsorbed phosphorus. Therefore, while iron acts as a natural binder in well-oxygenated systems, loss of oxygen in eutrophic lakes may disrupt this natural phosphorus inactivation process. Inactivation of phosphorus by iron will become very ineffective where anoxia is so strong that sulfate reduction occurs. In such cases, iron is preferentially bound by sulfides released as hydrogen sulfide, leaving little iron to bind with phosphorus. Consequently, iron is only used in well-aerated systems with naturally low iron levels, but may be the inactivator of choice as a supplement to an aeration system. Iron is generally not toxic at levels applied to lakes.

The stability of calcite is highly sensitive to pH, calcium, and carbonate concentrations. Consequently, treatment with calcium is effective only if pH is maintained at a relatively high level (8 or above). Such pH levels are found naturally only in the Berkshire region where elevating the pH by chemical addition to facilitate calcium effectiveness may have many adverse impacts on natural systems adjusted to lower pH. Calcium is more commonly used in alkaline lakes regions, such as Alberta, Canada, and has not been applied in Massachusetts or the northeastern USA except on a pilot basis.

Nitrate treatments such as Ca(NO₃)₂ neither precipitate nor inactivate phosphorus directly. Nitrates are injected directly into the surface sediments as a ‘sediment oxidation’ treatment, which in this case refers to maintaining a high redox (reduction-oxidation) potential and thus maintaining the stability of natural iron oxides in the sediments. That is, nitrate is broken up to yield oxygen before iron oxides, by preference of the active bacteria. Thus nitrates act indirectly to enhance and stabilize the ability of natural iron oxides to bind phosphorus in the sediments. In this manner, nitrate treatment is analogous to hypolimnetic aeration by providing an alternative source of oxygen. This approach is not commonly practiced anywhere and has never been tried in Massachusetts.

Benefits
- Rapid removal of available phosphorus from the water column
- Minimized internal loading of phosphorus
- Potential removal of a variety of other contaminants and algae

Detriments
- Potential for damage to aquatic life at depressed or elevated pH
- Limited longevity of effects if external loading is significant

Common application rates for stripping phosphorus from the water column range from 1 to 20 mg/L, while the range for inactivating surficial sediments is about 10 to 150 g/m². Without use of a buffer solution, dose is determined by the amount of inactivator that can be added without causing an undesirable pH level.

Floc formation during treatment should be visible, and a floc layer up to perhaps 3 inches deep will accumulate on the bottom afterward, but within a month this layer will have merged with the surficial sediments and adds minimal solid material to the lake.
Concentrations of reactive aluminum (Al\(^{3+}\)) are strongly influenced by pH. Aluminum is toxic to fish at levels of 100 to 200 ug/L at pH of < 6.0 and > 7.5, typically via gill membranes. The “safe” level of dissolved reactive aluminum is considered to be 50 ug/L, but these are not sharp thresholds.

Factors Favoring the Use of this Technique
- A substantial portion of the P load is associated with sediment sources within the lake
- Studies have demonstrated the impact of internal loading on the lake.
- External P load has been controlled to the maximum practical extent or is documented to be small; historic loading may have been much greater than current loading
- Inactivation of phosphorus in the water column is expected to provide interim relief from algal blooms and turbidity while a prolonged watershed management program is conducted to reduce external loading
- The lake is well buffered or buffering can be augmented to prevent major changes in pH during treatment
- Assays indicate no toxic effects during simulated treatment
- Where iron is to be used as an inactivator, oxygen is adequate at the bottom to maintain iron-phosphorus bonds
- Where calcium is to be used as an inactivator, normal background pH is high enough to maintain calcium-phosphorus bonds
- Where nitrate is to be used to alter redox potential and limit P release, nitrate can be effectively injected into the sediment without major release to the water column

Performance Guidelines
- Develop reliable phosphorus budget that demonstrates magnitude of internal loading
- Determine dose necessary to inactivate targeted phosphorus (water column or sediment)
- Determine chemicals to be used; consider oxygen regime and minimize shift in pH unless naturally outside range of 6.0 to 8.0 SU
- Secure appropriate access for equipment and chemicals; adhere to materials handling regulations in the transfer of chemicals to application equipment
- For larger lakes, treat non-contiguous sections of the lake on sequential days
- For higher doses of aluminum, split treatment to yield calculated in-lake aluminum level < 10 mg/L on any day
- In pH sensitive lakes with anoxic hypolimnia, consider injecting aluminum at or below the thermocline during stratification
- Monitor phosphorus, the inactivator compound, pH, alkalinity, water clarity, algae, zooplankton, benthic invertebrates and fish before, during and after treatment as appropriate to determine impacts to sensitive resources.
Possible Permits
- WPA permit through local Conservation Commission/DEP
- Review by NHESP (further action if protected species are present)
- Permit to Apply Chemicals from DEP
- Possible 401 WQ permit through the DEP

Impacts Specific to the Wetlands Protection Act
- Protection of public and private water supply – Benefit (water quality improvement)
- Protection of groundwater supply – Neutral (no significant interaction)
- Flood control - Neutral (no significant interaction)
- Storm damage prevention – Neutral (no significant interaction)
- Prevention of pollution - Benefit (water quality enhancement)
- Protection of land containing shellfish - Possible benefit through water quality enhancement in the lake and possible detriment by direct toxicity unless treatment is properly buffered
- Protection of fisheries - Possible benefit through water quality enhancement in the lake and possible detriment by direct toxicity unless treatment is properly buffered, plus possible detriment through reduced fertility
- Protection of wildlife habitat – Benefit (water quality enhancement), but possible detriment through reduced fertility

The most serious impact is the possibility for fish or invertebrate kills following treatment in low alkalinity lakes, but such impacts are preventable. Minimal adverse impacts are expected to either surface or groundwater supplies. Aluminum, iron and calcium are commonly added in water and wastewater treatment facilities with no significant adverse impacts (and generally a marked improvement in water quality).

Bioassays for fish impact prevention

Cost Considerations
Aluminum treatment costs typically range from $500-$1,000/acre, with the areal cost decreasing for larger treatments, unbuffered treatments, and lesser monitoring requirements. Higher cost may result from extreme controls and monitoring, as with the 2001 Ashumet Pond treatment. Costs for iron treatments are similar to those for alum treatment; the chemical is less expensive to purchase but higher doses are recommended. However, iron is best applied in conjunction with aeration systems, so total project cost is likely to be substantially higher. Calcium costs are slightly less expensive than alum, especially in hard water lakes where this technique is most likely to be applied. The cost is estimated at about $200/acre. Nitrate application to sediments is an expensive treatment, typically on the order of $5,000-10,000/acre.
ARTIFICIAL CIRCULATION

How it Works
Whole lake circulation is a technique for management of algae that tends to affect nutrient levels. The central process is the introduction of more oxygen, intended to limit internal recycling of phosphorus, thereby controlling algae. Other important processes may apply as well, however. Circulation strategies increase turbulence and minimize stratification. Whole lake artificial circulation is also referred to as destratification or whole lake aeration. Thermal stratification and features of lake morphometry such as coves create stagnant zones that may be subject to loss of oxygen, accumulation of sediment, or algal blooms. Artificial circulation minimizes stagnation and can eliminate thermal stratification or prevent its formation. Movement of air or water is normally used to create the desired circulation pattern in shallow (<20 ft) lakes, and this has been accomplished with surface aerators, bottom diffusers, and water pumps (Figure 10). Algae may simply be mixed more evenly in the available volume of water in many cases, but turbulence, changing light regime and altered water chemistry can cause shifts in algal types and reduce biomass.

Stratification is broken or prevented in deeper lakes through the injection of compressed air into lake water from a diffuser at the lake bottom (Figure 11a). The rising column of bubbles, if sufficiently powered, will produce lakewide mixing at a rate that eliminates temperature differences between top and bottom waters. The use of air as the mixing force also provides some oxygenation of the water, but the efficiency and magnitude of this transfer are generally low. In some instances, wind driven pumps have been used to move water. For air mixed systems, the general rule is that an air flow rate of 1.3 cubic feet per minute per acre of lake (9.2 m³/min/km²) will be needed to maintain a mixed system. However, there are many factors that could require different site specific air flow rates, and undersizing of systems is the greatest contributor to failure for this technique.

Algal blooms are sometimes controlled by destratification through one or more of the following processes:
- Introduction of dissolved oxygen to the lake bottom may inhibit phosphorus release from sediments, curtailing this internal nutrient source.
- In light-limited algal communities, mixing to the lake's bottom will increase the time a cell spends in darkness, leading to reduced photosynthesis and productivity.
- Rapid circulation and contact of water with the atmosphere, as well as the introduction of carbon dioxide-rich bottom water during the initial period of mixing, can increase the carbon dioxide content of water and lower pH, leading to a shift from blue-green algae to less noxious green algae.
- Turbulence can neutralize the advantageous buoyancy mechanisms of blue-green algae and cause a shift in algal composition to less objectionable forms such as diatoms.
- When zooplankton that consume algae are mixed throughout the water column, they are less vulnerable to visually feeding fish. If more zooplankters survive, their consumption of algal cells may also increase.

Artificial circulation can prevent winterkills of fish in eutrophic lakes that become anoxic during the winter. On a smaller scale, artificial circulation can be used to prevent ice formation around docks or other structures. The technique is also used to maintain acceptable water quality in drinking reservoirs.
as the oxic conditions created by the circulation reduce concentrations of nuisance substances such as hydrogen sulfide, ammonia, iron and manganese. For these types of problems artificial circulation has been very successful.

**Benefits**
- Increases mixing and decreases stagnation; may control algae by multiple means, and will at least spread out the algal biomass
- Increases oxygen levels and enhances habitat accordingly
- Increases die-off rate of bacteria

**Detriments**
- Mixing may distribute previously localized undesirable substances throughout the lake
- May resuspend sediment and increase turbidity if not carefully controlled
- May increase algal growth in some cases

**Information for Proper Application**
- An accurate nutrient budget with a detailed analysis of internal P sources
- Data related to each of the five possible control mechanisms (oxygenation/P inactivation, light limitation, pH/carbon source adjustment, buoyancy disruption, and enhanced grazing) should be analyzed and evaluated in terms of potential algal control. Specifically,
  a. Is there anaerobic release of phosphorus that can be mitigated by oxygenation of deep waters?
  b. Is the mixing zone deep enough to promote light limitation of algae?
  c. Is there a large amount of carbon dioxide in the bottom waters that could be mixed to the surface to favor the growth of non-blue-green algae?
  d. Is mixing predicted to counteract the buoyancy advantage of blue-greens over other algae?
  e. Will a dark, oxygenated refuge be created for zooplankton?
- Reliable estimate of the oxygen demand that must be met by the system
- Reliable estimate of the amount of air necessary to mix/destratify the lake
- Lake morphometry data that facilitates choice of aerator type and placement of aerators for maximum effectiveness
- Location and details of compressor and power source
- Monitoring to track oxygen and nutrient levels after implementation
- Monitoring to track water clarity and algal types and quantity

**Factors Favoring the Use of this Technique**
- A substantial portion of the P load is associated with anoxic sediment sources within the lake
- Studies have demonstrated the impact of internal loading on the lake
- External P load has been controlled to the maximum practical extent or is documented to be small; historic loading may have been much greater than current loading
- Hypolimnetic or sediment oxygen demand is high (>500 mg/m²/day)
- In addition to phosphorus management, control of other reduced compounds such as hydrogen sulfide, ammonia, manganese, and iron, is desired
- Adequate phosphorus inactivators are present for reaction upon addition of oxygen
- Shoreline space for a compressor or pump is available where access is sufficient, power is available, and noise impacts will be small
- The lake is bowl shaped, or at least not highly irregular in bathymetry (few separate basins and isolated coves)
- Long-term application of the technique is accepted
- Coldwater fishery habitat is limited or not a concern

Performance Guidelines
- Determine goals for circulation; if oxygenation is desired, oxygen demand must be determined; if destratification is desired, necessary mixing force must be determined
- Properly size equipment; avoid over- or underpowering
- Properly place equipment; avoid over- or underspacing
- Develop a maintenance plan for equipment
- Operate equipment in accordance with management goals to achieve temporal or spatial results as planned
- Monitor temperature and oxygen as indicators of mixing and aeration, and other water quality or biological variables as necessary to evaluate success

Possible Permits
- WPA permit through local Conservation Commission/DEP
- Review by NHESP (further action if protected species are present)
- Chapter 91 Permit through DEP may be required for Great Ponds

Impacts Specific to the Wetlands Protection Act
- Protection of public and private water supply – Benefit (water quality enhancement)
- Protection of groundwater supply – Neutral (no significant interaction)
- Flood control - Neutral (no significant interaction)
- Storm damage prevention – Neutral (no significant interaction)
- Prevention of pollution - Benefit (water quality enhancement)
- Protection of land containing shellfish - Benefit (water quality enhancement) with rare detriment by water quality variability induced by whole lake circulation
- Protection of fisheries - Benefit (water quality enhancement) with rare detriment by water quality variability and loss of coldwater habitat induced by whole lake circulation
- Protection of wildlife habitat – Benefit (water quality enhancement)

Adverse impacts to the eight interests of the Wetland Protection Act are not expected with the exception that in rare cases deleterious substances like hydrogen sulfide or ammonia may be circulated to the surface and cause temporary adverse impacts to fish and wildlife. In general, aeration is expected to improve habitat for fish and other organisms in lakes with anoxic hypolimnia, but artificial circulation can reduce or eliminate coldwater habitat for trout.

Cost Considerations
Costs include the initial purchase and installation of the pumps, pipes and diffusers as well as annual maintenance costs and annual electricity costs. Capital costs range from about $200 to $3,000/ac, while annual costs usually range from $50 to $800/ac. Actual costs depend on the amount of air required, which is related to lake area. The estimated range of cost for 20 years of application at a hypothetical 100-acre lake is $70,000 to $400,000.
Figure 10. Methods of Artificial Circulation and Aeration (from Wagner, 2001)
Figure 11. Destratifying (A) and Non-destratifying (B) Aeration

A. Destratifying aeration (provided by R. Geney of GES)

B. Non-destratifying (hypolimnetic) aeration (provided by R. Geney of GES)
HYPOLIMNETIC AERATION

How it Works

Hypolimnetic aeration is a technique for management of algae through control of nutrient levels. The central process is the introduction of more oxygen, intended to limit internal recycling of phosphorus, thereby controlling algae. Hypolimnetic aeration typically uses an air compressor as described for whole lake circulation, but in this case the upward plume is controlled to avoid mixing with the epilimnetic waters, and thus thermal stratification of the lake is maintained (Figure 10). The maintenance of stratification is often desirable as it maintains coldwater fish habitat and reduces transport of nutrients from the hypolimnion into the epilimnion where they may stimulate further algal blooms.

Aeration puts air into the aquatic system, increasing oxygen concentration by transfer from gas to liquid and generating a controlled mixing force. The oxygen transfer function is used to prevent hypolimnetic anoxia (Figure 11b). By keeping the hypolimnion from becoming anoxic during stratification, aeration should minimize the release of phosphorus, iron, manganese and sulfides from deep bottom sediments and decrease the build-up of undecomposed organic matter and oxygen-demanding compounds (e.g., ammonium). Hypolimnetic aeration can also increase the volume of water suitable for habitation by zooplankton and fish, especially coldwater forms. Pure oxygen can be used in place of air to maximize oxygen transfer at an increased cost.

A full lift hypolimnetic aeration approach moves hypolimnetic water to the surface, aerates it, and replaces it in the hypolimnion. Bringing the water to the surface can be accomplished with electric or wind-powered pumps, but is most often driven by pneumatic force (compressed air). Return flow to the hypolimnion is generally directed through a pipe to maintain separation of the newly aerated waters from the surrounding epilimnion. To provide adequate aeration, the hypolimnetic volume should be pumped and oxygenated at least once every 60 days.

Another hypolimnetic aeration system is the partial lift system, in which air is pumped into a submerged chamber in which exchange of oxygen is made with the deeper waters. The newly oxygenated waters are released back into the hypolimnion without destratification. A shoreline site for a housed compressor is needed, but the aeration unit itself is submerged and does not interfere with lake use or aesthetics.

An alternative approach involves a process called layer aeration. Water can be oxygenated by full or partial lift technology, but by combining water from different (but carefully chosen) temperature (and therefore density) regimes, stable oxygenated layers can be formed anywhere from the upper metalimnetic boundary down to the bottom of the lake. Each layer acts as a barrier to the passage of phosphorus, reduced metals and related contaminants from the layer below. Each layer is stable as a consequence of thermally mediated differences in density. The whole hypolimnion may be aerated, or any part thereof, to whatever oxygen level is deemed appropriate for the designated use. Maintenance of a highly oxidized layer for water supply will call for more oxygen than providing a refuge for zooplankton or fish.
The mechanism of phosphorus control exercised through hypolimnentic aeration is the maintenance of high oxygen and limitation of phosphorus release from sediments. Out of the processes listed for artificial circulation, the only other applicable mechanism for hypolimnentic aeration is provision of a zooplankton refuge, potentially increasing grazing potential. To successfully aerate a hypolimnion, the continuous oxygen demand of the sediments must be met, and experience dictates that the oxygen input needs to be about twice the measured oxygen demand. This demand may be reduced over time under aeration, but is unlikely to be eliminated.

Benefits
- Reduces release of phosphorus from the sediment and accumulation in the hypolimnion without eliminating stratification
- Reduces hypolimnentic accumulations of iron, manganese, ammonium and hydrogen sulfide
- Increases hypolimnentic oxygen levels and enhances habitat accordingly

Detriments
Theoretically possible to induce gas bubble disease in fish, but not a documented occurrence

Information for Proper Application
- Data requirements for this type of nutrient control include an accurate nutrient budget with a detailed analysis of internal sources of phosphorus
- The most critical information for designing an aeration system is the oxygen demand that must be met by the system; calculations and related interpretation for design purposes are best performed by experienced professionals
- Lake morphometry and stratification data are needed to facilitate choice of aerator features and placement of aerators for maximum effectiveness
- Location and details of compressor and power source are needed

Factors Favoring the Use of this Technique
- A substantial portion of the P load is associated with anoxic sediment sources within the lake
- Studies have demonstrated the impact of internal loading on the lake.
- External P load has been controlled to the maximum practical extent or is documented to be small; historic loading may have been much greater than current loading
- Hypolimnetic or sediment oxygen demand is high (>500 mg/m²/day)
- In addition to phosphorus management, control of other reduced compounds such as hydrogen sulfide, ammonia, manganese and iron, is desired
- Adequate phosphorus inactivators are present for reaction upon addition of oxygen
- Shoreline space for a compressor or pump is available where access is sufficient, power is available, and noise impacts will be small
- The lake is bowl shaped, or at least not highly irregular in bathymetry (few separate basins and isolated coves)
- Long-term application of the technique is accepted
- Coldwater fishery habitat is abundant or an important goal

Performance Guidelines
♦ Determine oxygen demand to be counteracted

Oligotrophic lakes typically have oxygen demands <250 mg/m²/day, while eutrophic lake values are >550 mg/m²/day; values of 2000 to 4000 mg/m²/day have been measured in hypereutrophic lakes.

Oxygen demand is normally calculated from actual data for the lake. For stratified lakes, the hypolimnentic oxygen demand (HOD, often a function of sediment oxygen demand, or SOD) can be calculated as the difference in oxygen levels at the time stratification formed and one or more points in time later during stratification. However, measurements obtained when the oxygen levels are <2 mg/L are deceiving, as oxygen consumption is not linear and will decline markedly as oxygen supply declines.
The Practical Guide to Lake Management in Massachusetts

- Properly size equipment; avoid over- or underpowering
- Properly place equipment; avoid over- or underspacing
- Develop a maintenance plan for equipment
- Operate equipment in accordance with management goals to achieve temporal or spatial results as planned
- Monitor temperature and oxygen as indicators of mixing and aeration, and other water quality or biological variables as necessary to evaluate success

Possible Permits
- WPA permit through local Conservation Commission/DEP
- Review by NHESP (further action if protected species are present)
- Chapter 91 Permit through DEP may be required for Great Ponds

Impacts Specific to the Wetlands Protection Act
- Protection of public and private water supply – Benefit (water quality enhancement)
- Protection of groundwater supply – Neutral (no significant interaction)
- Flood control - Neutral (no significant interaction)
- Storm damage prevention – Neutral (no significant interaction)
- Prevention of pollution - Benefit (water quality enhancement)
- Protection of land containing shellfish - Benefit (water quality enhancement)
- Protection of fisheries - Benefit (water quality enhancement)
- Protection of wildlife habitat – Benefit (water quality enhancement)

Cost Considerations
Costs can be standardized on a per kg oxygen basis as approximately $2.50/kg O₂ with operating costs of $0.072/kg O₂. Assuming a need to counteract an oxygen demand of 500 to 2000 mg/m²/day for 120 days per year, this suggests a capital cost of roughly $750 to $3,000/acre and an annual operational cost of $55 to $220/acre. Shape and depth of the lake will affect costs, with deep, single basin lakes requiring the simplest and least expensive systems.
DRAWDOWN

How it Works
Drawdown is a process whereby the water level is lowered by gravity, pumping or siphoning and held at that reduced level for some period of time, typically several months and usually over the winter. Drawdown can provide control of plant species that overwinter in a vegetative state, and oxidation of sediments may result in lower nutrient levels with adequate flushing. Drawdowns also provide flood control and allow access for nearshore clean ups and repairs to structures. The ability to control the water level in a lake is affected by area precipitation pattern, system hydrology, lake morphometry, and the outlet structure. The base elevation of the outlet or associated subsurface pipe(s) will usually set the maximum drawdown level, while the capacity of the outlet to pass water and the pattern of water inflow to the lake will determine if that base elevation can be achieved and maintained. In some cases, sedimentation of an outlet channel or other obstructions may control the maximum drawdown level.

Several factors affect the success of drawdown with respect to plant control. While drying of plants during drawdowns may provide some control, the additional impact of freezing is substantial, making drawdown a more effective strategy during late fall and winter. However, a mild winter or one with early and persistent snow may not provide the necessary level of drying and freezing. The presence of high levels of groundwater seepage into the lake may mitigate or negate destructive effects on target submergent species by keeping the area moist and unfrozen. The presence of extensive seed beds may result in rapid re-establishment of previously occurring plant species, some of which may be undesirable. Recolonization from nearby areas may be rapid, and the response of macrophyte species to drawdown is quite variable.

Aside from direct impact on target plants, drawdown can also indirectly and gradually affect the plant community by changing the substrate composition in the drawdown zone. If there is sufficient slope, finer sediments will be transported to deeper waters, leaving behind a coarser substrate. If there is a thick muck layer present in the drawdown zone, there is probably not adequate slope to allow its movement. However, where light sediment has accumulated over sand, gravel or rock, repetitive drawdowns can restore the coarse substrate and limit plant growths.

The actual conduct of a drawdown involves facilitating more outflow than inflow for several weeks or months. After the target water level is reached, outflow is roughly matched to inflow to maintain the drawdown for the desired period, usually at least a month and often up to 3 months, usually over the winter. At a time picked to allow refill before any undesirable spring impacts can occur, outflow is reduced (although it should not be eliminated) and “excess” inflow causes the water level to rise. In some cases, refill is commenced after an inch or two of ice forms, ripping up plants and bottom material. This “extreme disturbance” approach has been applied where sediments will not dewater sufficiently to provide the level of freezing and desiccation desired, but impacts have not been studied extensively.

Despite the apparent simplicity of the concept of drawdown, proper conduct of a drawdown to maximize effectiveness and minimize adverse side effects necessitates that many considerations be
addressed (Table 6). Expected response of target species (Table 7) is of particular importance when
plant control is the major goal.

Benefits
- Kills vegetative portions of plants by drying, freezing, or physical disturbance
- Increases plant species richness in many cases
- Allows sediment oxidation and compaction, with potential reduction of sediment oxygen demand, sediment volume, and available nutrient content
- May reduce fine sediments in drawdown zone, creating coarser peripheral substrate and enhancing plant control and habitat for some organisms
- Provides protection from ice damage to shoreline and associated structures
- Facilitates access for shoreline clean-up, sediment removal, and structural maintenance
- Provides flood storage capacity
- Concentrates fish in a smaller volume, potentially allowing control of panfish and higher growth by gamefish

Detriments
- Will not kill seeds or other non-vegetative overwintering propagules, and may stimulate increased seed germination
- Nutrient release during exposed sediment oxidation may fuel increased algal production if not flushed from system before next growing season
- Will reduce available water for supplies, and may impair nearby shallow well production
- May strand and harm minimally mobile aquatic fauna (such as molluscs)
- Concentration of fish in smaller volume may harm some populations through predation or oxygen stress
- Fish may not be able to reach spawning areas during drawdown
- May expose and harm hibernating reptiles and amphibians
- May restrict access and cover for aquatic mammals and birds
- Limits human access where peripheral sediments are soft
- Although largely dormant in winter, hydrologically connected wetlands may experience some changes in species composition and relative abundance if dewatering occurs

The disadvantages of drawdown are linked to reduced areal coverage by water and lowered water volume and elevation. Water supply from the lake or wells may be impaired, and species that depend upon the exposed area may be harmed. Changes in exposed sediment features may affect water quality after refill. Downstream resources may be impacted as well. Repeated drawdown may result in the invasion of plants that are resistant to drawdowns, some of which may be nuisance species. Failure to refill the lake in time for spring spawning may affect fish populations. None of these impacts may be manifest, and various mitigative means may avoid or minimize them. However, it is difficult to predict the ecological impact to many non-target organisms, due largely to the lack of published information and site-specificity of many possible impacts.
Information for Proper Application
The listing of key considerations provided in Table 6 indicates the extensive data needs for proper implementation of this technique. Key needs include:
- Detailed hydrology and lake morphometry to allow estimates of drawdown and refill times under the range of potential conditions
- Knowledge of outlet features essential to releasing and holding water
- Maps of aquatic macrophytes and expected area of exposure
- Evaluation of sediment types and slopes in expected drawdown zone
- Biological surveys of populations perceived to be at risk from drawdown
- Assessment of downstream channel configuration and resources, to facilitate planning to minimize adverse impacts
- Local well depths or water supply intake elevations
- A carefully crafted monitoring program to track water levels and outflow, and to assess potential impacts, positive and negative

Factors Favoring the Use of this Technique
- The lake periphery is dominated by undesirable species that are susceptible to drying and freezing
- Drawdown can be achieved by gravity outflow via an existing outlet structure, or such a structure can be established for a reasonable cost
- Drawdown can reach a depth that impacts enough of the targeted plants to make a difference for recreational interests and habitat enhancement
- Areas to be exposed have sediments and slopes that promote dewatering
- Drawdown and refill can be accomplished within a few weeks under typical flow conditions and without causing downstream flows outside the natural range
- Drawdown can be timed to avoid key migration and spawning periods for non-target organisms
- Populations of molluscs or other nearshore-dwelling organisms of limited mobility are not significant
- The lake is not used for water supply and nearby wells are deep
- Flood storage capacity generated by drawdown prevents downstream flood impacts
- The downstream channel and associated resources will not be impacted by fluctuating flows expected during drawdown and refill periods
- Shoreline structures are prone to ice damage

Performance Guidelines
- Determine susceptibility of target plants to drawdown
- Evaluate potential risks to non-target flora and fauna
- Limit drawdown to 3 ft or contact the MDFG for assistance in evaluating impacts of greater drawdown
- Commence drawdown after the end of October unless there is a valid reason to begin earlier
- Achieve the target drawdown depth by the end of November, unless there is a valid reason to take more time; target a drawdown rate of <3 inches/day
- Achieve full lake status by the beginning of April, unless there is a valid reason for another target date for refill completion
- Keep outflow during drawdown below a discharge equivalent to 4 cfs per square mile of watershed; once the target water level is achieved, match outflow to inflow to the greatest extent possible, maintaining a stable water level
- Keep outflow during refill above a discharge equivalent to 0.5 cfs per square mile of watershed
- Conduct a monitoring program that includes water level, flow, water clarity, winter oxygen, the plant community, and representative sensitive faunal populations
- After target species are controlled, evaluate the potential to move to an every other or every third year drawdown schedule

Possible Permits
- WPA permit through local Conservation Commission/DEP
- Review by NHESP (further action if protected species are present)

Impacts Specific to the Wetlands Protection Act
- Protection of public and private water supply – Potential detriment (if adequate water for supply is not maintained), but can be neutral in some cases with proper management
- Protection of groundwater supply – Potential detriment (if lowered lake level lowers groundwater), but can be neutral (if adequate groundwater level is maintained or there is no significant interaction)
- Flood control – Benefit (flood storage potential increased)
- Storm damage prevention – Benefit (flood storage potential increased), but possible detriment as exposed areas may be subject to potentially damaging storm impacts
- Prevention of pollution – May provide benefit (water quality enhancement) or detriment (water quality deterioration), but impacts generally limited
- Protection of land containing shellfish – Detriment (shellfish potentially exposed), but impacts may be neutral in some cases, and shellfish habitat may be improved overall
- Protection of fisheries - Potential detriment by temporary habitat loss, potential benefit by habitat improvement (may have benefit and detriment to different species in same lake from same drawdown)
- Protection of wildlife habitat - Potential detriment by temporary habitat loss for completely aquatic species and impact on muskrat and beaver lodges, potential benefit by habitat improvement (may have benefit and detriment to different species in same lake from same drawdown)

Cost Considerations
Drawdown is a relatively inexpensive lake management technique, if the means to conduct a drawdown are present. Where an outlet structure facilitates drawdown, the cost may be as little as what is required to obtain permits, open and close the discharge structure, and monitor. If pumps are required to lower the water level, the drawdown will be more expensive. It is unusual to alter a dam for less than $100,000, but if the structure already supports water level control, costs of $3,000 to $10,000 per year would be a reasonable expectation for permitting and monitoring. Where protected species are present, permitting may be difficult and monitoring and mitigation costs can escalate.
Table 5. Key Considerations for Drawdown

Reasons for Drawdown
Access to structures for maintenance or construction – note that other permits may apply
Access to sediments for removal (dredging) – additional permits apply
Flood control – a major late winter benefit, but minimally available in spring with regulatory refill date
Prevention of ice damage to shoreline and structures – control of late winter water level needed
Sediment compaction – only if sediments dewater sufficiently
Rooted plant control – for species that rely on vegetative forms to overwinter
Fish reclamation – if the community is extremely out of balance and a management program exists

Necessary Drawdown Planning Information
Target level of drawdown – depth of water lost
Pond bathymetry – detailed contours for calculation exposed area
Area to be exposed – area of sediment at water depth < target depth, plus ice contact zone
Volume to remain – quantity of water available for habitat and supply during drawdown
Timing and frequency of drawdown – initiation/duration and whether annual or less frequent event
Outlet control features – method for controlling outflow
Climatological data – frequency of sub-freezing weather, precipitation and snow cover data
Normal range of outflow – maximum, minimum and average over expected time of drawdown
Outflow during drawdown and refill – provisions for downstream flow control (high and low)
Time to drawdown or refill – rate of water level change, number of days to achieve target level

In-Lake and Downstream Water Quality
Possible change in nutrient levels – any expected increases due to oxidation of sediments
Possible change in oxygen levels – any expected increase through oxidation or decrease under ice
Possible change in pH levels – any expected shift due to interactions with smaller volume
Other water quality issues – any expected changes as a function of drawdown

Water Supply
Use of lake water as a supply – dependence on water availability and impact of drawdown
Presence/dept of supply wells – potential for supply impairment
Alternative water supplies – options or supplying water to impacted parties
Emergency response system – ability to detect and address supply problems during drawdown
Downstream flow restrictions – maintenance of appropriate flows for downstream habitat and uses

Sediments
Particle size distribution (or general sediment type) – dewatering potential
Solids and organic content – dewatering potential, nutrient content
Potential for sloughing – potential for coarse sediment to be exposed in drawdown zone
Potential for shoreline erosion – threat of erosive impacts to bank resources
Potential for dewatering and compaction – possibility of sediment alteration and depth increase
Potential for odors – emissions from exposed area
Access and safety considerations – issues for use of lake during drawdown

Flood Control
Anticipated storage needs – ability to meet needs with target drawdown
Flood storage gained – volume available to hold incoming runoff
Effects on peak flows – dampening effect on downstream velocities and discharge
Table 5 (continued). Key Considerations for Drawdown

Protected Species
Presence of protected species – NHESP designated species may require special protection
Potential for impact – assessment of possible damage to protected populations
Possible mitigative measures – options for avoiding adverse impacts

In-lake Vegetation
Composition of plant community – details of species present and susceptibility to drawdown
Areal distribution of plants – mapping of plant locations relative to drawdown impact zone
Plant density – quantity of plants present
Seed-bearing vs. vegetative propagation – drawdown will only control vegetative propagators
Impacts to target and non-target species – analysis of which species will be impacted

Vegetation of Connected Wetlands
Composition of plant community – details of species present and susceptibility to drawdown
Areal distribution of plants – mapping of plant locations relative to drawdown impact zone
Plant density – quantity of plants present
Temporal dormancy of key species – potential for seasonal impacts
Anticipated impacts – analysis of likely effects of drawdown

Macroinvertebrates, Fish and Wildlife
Composition of fauna – types of animals present
Association with areas to be exposed – when and how drawdown zone is used on a regular basis
Breeding and feeding considerations – use of drawdown for breeding or food on intermittent basis
Expected effects on target and non-target species – analysis of likely faunal impacts

Downstream Resources
Erosion or flooding potential – susceptibility to impacts from varying flow
Possible habitat alterations – potential for impacts
Water quality impacts – potential for alteration
Direct biotic impacts – possible scour or low flow effects on biota
Recreational impacts – effects on downstream recreational uses
Supply impacts – effects on downstream supply uses

Access to the Pond
Alteration of normal accessibility – issues for seasonal use of pond by humans and wildlife
Possible mitigation measures – options for minimizing impacts

Associated Costs
Structural alteration to facilitate drawdown by gravity – expense for any needed changes to outlet
Pumping or alternative technology – operational expense for pumped or siphoned outflow
Monitoring program – cost of adequate tracking of drawdown and assessment of impacts

Other Mitigating Factors
Monitoring program elements – may be very lake specific and vary over years
Watershed management needs – additional actions beyond drawdown may be warranted
Ancillary project plans (dredging, shoreline stabilization) – additional actions may require separate planning and permitting
Table 6. Anticipated Response of Some Aquatic Plants to Winter Drawdown (After Cooke et al., 1993).

<table>
<thead>
<tr>
<th>Aquatic Plant</th>
<th>Change in Relative Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Increase</td>
</tr>
<tr>
<td>Acorus calamus (sweet flag)</td>
<td>E</td>
</tr>
<tr>
<td>Alternanthera philoxeroides</td>
<td>E</td>
</tr>
<tr>
<td>(alligator weed)</td>
<td></td>
</tr>
<tr>
<td>Asclepias incarnata (swamp milkweed)</td>
<td>S</td>
</tr>
<tr>
<td>Brasenia schreberi (watershield)</td>
<td>S</td>
</tr>
<tr>
<td>Cabomba caroliniana (fanwort)</td>
<td>S</td>
</tr>
<tr>
<td>Cephalanthus occidentalis</td>
<td>E</td>
</tr>
<tr>
<td>(buttonbush)</td>
<td></td>
</tr>
<tr>
<td>Ceratophyllum demersum (coontail)</td>
<td>S</td>
</tr>
<tr>
<td>Egeria densa (Brazilian Elodea)</td>
<td>S</td>
</tr>
<tr>
<td>Eichhornia crassipes (water hyacinth)</td>
<td>E/S</td>
</tr>
<tr>
<td>Eleocharis acicularis (needle spikerush)</td>
<td>S</td>
</tr>
<tr>
<td>Elodea canadensis (waterweed)</td>
<td>S</td>
</tr>
<tr>
<td>Glyceria borealis (mannagrass)</td>
<td>E</td>
</tr>
<tr>
<td>Hydrilla verticillata (hydrilla)</td>
<td>S</td>
</tr>
<tr>
<td>Leersia oryzoides (rice cutgrass)</td>
<td>E</td>
</tr>
<tr>
<td>Myrica gale (sweetgale)</td>
<td>E</td>
</tr>
<tr>
<td>Myriophyllum spp. (milfoil)</td>
<td>S</td>
</tr>
<tr>
<td>Najas flexilis (bushy pondweed)</td>
<td>S</td>
</tr>
<tr>
<td>Najas guadalupensis (southern naiad)</td>
<td>E/S</td>
</tr>
<tr>
<td>Nuphar spp. (yellow water lily)</td>
<td>E/S</td>
</tr>
<tr>
<td>Nymphaea odorata (water lily)</td>
<td>S</td>
</tr>
<tr>
<td>Polygonum amphibium (water smartweed)</td>
<td>E/S</td>
</tr>
<tr>
<td>Polygonum coccineum (smartweed)</td>
<td>E</td>
</tr>
<tr>
<td>Potamogeton epihydrus (leafy pondweed)</td>
<td>E</td>
</tr>
<tr>
<td>Potamogeton robbinsii (Robbins' pondweed)</td>
<td>S</td>
</tr>
<tr>
<td>Potentilla palustris (marsh cinquefoil)</td>
<td>E/S</td>
</tr>
<tr>
<td>Scirpus americanus (three square rush)</td>
<td>E</td>
</tr>
<tr>
<td>Scirpus cyperinus (wooly grass)</td>
<td>E</td>
</tr>
<tr>
<td>Scirpus validus (great bulrush)</td>
<td>E</td>
</tr>
<tr>
<td>Sium suave (water parsnip)</td>
<td>E</td>
</tr>
<tr>
<td>Typha latifolia (common cattail)</td>
<td>E</td>
</tr>
<tr>
<td>Zizania aquatic (wild rice)</td>
<td>E</td>
</tr>
</tbody>
</table>

E=emergent growth form; S=submergent growth form (includes rooted species with floating leaves); E/S=emergent and submergent forms.
CONVENTIONAL DRY DREDGING

How it Works
Dredging involves the removal of sediment. Conventional dry, conventional wet, and hydraulic/pneumatic dredging are each addressed separately here, as planning and impact considerations vary substantially. Dredging is perhaps best known for increasing depth, but dredging can be an effective lake management technique for the control of excessive algae and invasive growth of macrophytes. The management objectives of a sediment removal project are usually to deepen a shallow lake for boating and fishing, or to remove nutrient rich sediments that can cause algal blooms or support dense growths of rooted macrophytes.

Control of rooted aquatic vascular plants is achieved by either the removal of substrate hospitable for their growth or by deepening the area enough to create a light limitation on plant growth. The release of algae-stimulating nutrients from lake sediments can be controlled by removing layers of enriched materials. This can reduce internal loading and suppress algal production if internal sources are the dominant nutrient source. Even where incoming nutrient loads remain high, dredging can reduce benthic mat formation and related problems with filamentous green and blue-green algae, as these forms may initially depend on nutrient-rich substrates for nutrition. Dredging also removes the accumulated seed bed established by many vascular plants and the resting cysts deposited by a variety of algae. Dry, wet and hydraulic methods are illustrated in Figure 12.

Dry dredging involves partially or completely draining the lake and removing the exposed bottom sediments with a bulldozer or other conventional excavation equipment and trucking it away. Projects involving silts, sands, gravel and larger obstructions where water level can be controlled favor conventional, dry methodology. Although ponds rarely dry to the point where equipment can be used without some form of support (e.g., railroad tie mats or gravel placed to form a road), excavating under “dry” conditions allows very thorough sediment removal and a complete restructuring of the pond bottom. The term “dry” may be a misnomer in many cases, as organic sediments will not dewater sufficiently to be moved like upland soils. Dry dredging may resemble a large-scale excavation of pudding, and the more the material is handled, the more liquid it becomes.

Control of inflow to the lake is critical during dry excavation. For dry excavation, water can often be routed through the lake in a sequestered channel or pipe, limiting interaction with disturbed sediments. Water added from upstream or directly from precipitation will result in solids content rarely in excess of 50% and often as low as 30%. Consequently, some form of containment area is needed before material can be used productively in upland projects. Where there is an old gravel pit or similar area to be filled, one-step disposal is facilitated, but most projects involve temporary and permanent disposal steps.

A properly conducted dredging program removes accumulated sediment from a lake and effectively sets it back in time, to a point prior to significant sedimentation. Partial dredging projects are possible and may be appropriate depending upon management goals, but for maximum benefit it is far better to remove all “soft” sediment. Failed dredging projects are common, and failure can almost always be traced to insufficient consideration of the many factors that govern dredging success (Table 8).
Benefits
- Deepening of the lake for many purposes, including increased flood or water supply storage, improved recreational uses, enhanced pollutant trapping effectiveness, and dilution of nutrient loads
- Control of rooted plants if a depth (light) or substrate limitation is imposed
- Reduced algal mat formation by reduced nutrient supply and elimination of resting cysts
- Reduced planktonic algal abundance if internal loading is an important nutrient source and enough sediment is removed
- Removal of toxic substances or other unwanted materials accumulated in the sediment
- Reduced sediment-water interactions, with potential improvement in water quality
- Complete removal of soft sediments in any target area or even “overdredging” to removal of sand or gravel is facilitated by dry dredging

Detriments
- All possible impacts of drawdown, as the lake is lowered to facilitate dry dredging
- Loss of most biological components of the drained portion of the lake through physical disturbance
- Potential for downstream turbidity if throughflow is not controlled
- Peripheral land disruption for access by equipment
- Upland area must be provided for sediment disposal, with temporary alteration
- Contaminated sediments potentially subject to many restrictions on disposal

Information for Proper Application
Table 8 lists the many considerations applicable to a dredging project. Key factors include:
- Sediment quality, which will determine disposal options and cost
- Sediment quantity, which determines disposal volume needs and greatly affects cost
- Ability to control the lake level, which affects choice of dredging method
- Sensitive biological resources, which affects project goals and permitting
- Monitoring to track system recovery and overall project impacts

Factors Favoring the Use of this Technique
- There is a distinct need for increased depth in the lake
- Studies have demonstrated the impact of internal loading on the lake
- Studies have demonstrated the presence of contaminants that are impacting lake biota or uses
- Rooted plants and algal mats dependent on the soft sediments are impairing recreation and habitat value
- Habitat is degraded to the extent that a complete restructuring is desirable
- Partial drawdown or sequestering of the dredged area can be performed to limit impacts to aquatic species
- Sediments are “clean”, based on Massachusetts regulatory thresholds
- Suitable and sufficient containment and disposal areas are available close to the lake Performance Guidelines
- Address the many considerations for dredging provided in Table 8; pay particular attention to sediment quality and quantity and disposal arrangements
- Design the dredging project with local conditions in mind; address water level and flow control, appropriate equipment, access and staging areas, material dewatering and transport for disposal
- Excavate in accordance with all permits

Log MDC=0.79 logSD +0.25
where MDC= Maximum Depth of Colonization and SD= Secchi Depth, both in meters.
- Achieve a depth (light) or substrate (hard bottom) limitation if control of plant growth is a project goal; usually this involves removal of all soft sediment or achievement of a water depth in excess of 10 ft
- Remove sediment to expose a low nutrient layer if reduction of internal loading is a project goal; usually this involves removal of all soft sediment
- Restore or rehabilitate all access, temporary containment, and final disposal areas
- Monitor downstream flows and water quality during dry dredging
- Monitor recovery of lake biota and in-lake conditions relative to project goals (e.g., depth increase, plant control, water quality enhancement)

Possible Permits
- MEPA review
- WPA permit through local Conservation Commission/DEP
- Review by NHESP (further action if protected species are present)
- Chapter 91 permit through DEP may be required for Great Ponds
- 404 permit through the Corps of Engineers
- 401 WQ permit through the DEP
- Solid Waste permit for sediment disposal through DEP
- Possible Dam Safety permit through DCR

Impacts Specific to the Wetlands Protection Act
- Protection of public and private water supply – Benefit (water quality improvement); may also affect water quantity by uncapping springs and seepage areas. Short-term limitation on available water is possible during dredging
- Protection of groundwater supply – Generally neutral (no significant interaction), although uncapping of springs and seepage areas may increase interaction. Possible adverse impacts below containment area if contaminants leach
- Flood control – Generally neutral (no significant interaction), although greater depth could be an asset if drawdown is later practiced for flood control. Possible short-term benefit or detriment during dredging, depending upon flow controls applied
- Storm damage prevention – Generally neutral (no significant interaction), although greater depth could be an asset if drawdown is later practiced for damage control. Possible short-term benefit or detriment during dredging, depending upon flow controls applied
- Prevention of pollution – Expected benefit (water quality enhancement), although short-term detriment is possible if flows contact disturbed sediment
- Protection of land containing shellfish – Possible long-term benefit through water quality enhancement, but potential short-term detriment by direct removal and lack of water
- Protection of fisheries – Possible long-term benefit through water quality and physical habitat enhancement, but potential short-term detriment by habitat loss during dry dredging
- Protection of wildlife habitat – Expected long-term benefit (water quality enhancement, invasive plant control), but possible short-term detriment by habitat loss during dry dredging

Impacts to interests of the Wetlands Protection Act from a specific dredging project are highly dependent upon site-specific features and project design.

Cost Considerations
Because the cost varies depending on the volume of material removed, costs are usually expressed per cubic yard (cy) of material removed. Generally, the larger the project, the smaller the cost per cubic yard. The proper way to estimate dredging costs is to consider each element of the project, which may vary dramatically among projects. The total cost can be divided by the total yardage to get
a cost per cubic yard, but this may not be especially meaningful in estimating other dredging projects. With that caveat in mind, a typical range of costs for dry dredging projects in recent years is $8 to $25/cy, with $15/cy suggested as a rough estimator for considering the general magnitude of a project under initial consideration. It is important, however, to develop a more careful estimate during further project planning, and many smaller projects (<50,000 cy) have incurred costs in excess of $30/cy. Total cost can be reduced if the dredged material is clean enough to be sold as a soil amendment. Recovery of more than $1/cy is unusual, however. In some cases, contractors have wanted the material in the lake, or more likely the sand and gravel under the muck in the lake, and were willing to perform dry dredging at a much reduced cost. Income from excavation should not be assumed, however, unless a firm agreement is in hand. As part of a major overhaul of a lake, dredging is often accompanied by other management actions such as stormwater treatment, construction of recreational amenities or fish habitat enhancement. These associated improvements add to overall project cost but are not specifically part of the dredging project cost estimated here.

Dry dredging: excavation of dry lake bed (provided by C. Carranza of BEC)
Figure 12. Wet, Dry and Hydraulic Dredging Approaches (from Wagner, 2001).
### Table 7. Key Considerations for Dredging

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<td>Property issues</td>
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### Table 7 (continued).  Key Considerations for Dredging

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<td>Clean Water Act Section 404 (USACE wetlands)</td>
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<td>Dam safety/alteration permit (DCR)</td>
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<td>Waste disposal permit (DEP)</td>
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<tr>
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<td></td>
<td>Political setting</td>
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<td>Sociological setting</td>
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CONVENTIONAL WET DREDGING

How it Works
Dredging involves the removal of sediment. Conventional dry, conventional wet, and hydraulic/pneumatic dredging are each addressed separately here, as planning and impact considerations vary substantially. Dredging is perhaps best known for increasing depth, but dredging can be an effective lake management technique for the control of excessive algae and invasive growth of macrophytes. The management objectives of a sediment removal project are usually to deepen a shallow lake for boating and fishing, or to remove nutrient rich sediments that can cause algal blooms or support dense growths of rooted macrophytes.

Control of rooted aquatic vascular plants is achieved by either the removal of substrate hospitable for their growth or by deepening the area enough to create a light limitation on plant growth. The release of algae-stimulating nutrients from lake sediments can be controlled by removing layers of enriched materials. This can reduce internal loading and suppress algal production if internal sources are the dominant nutrient source. Even where incoming nutrient loads remain high, dredging can reduce benthic mat formation and related problems with filamentous green and blue-green algae, as these forms may initially depend on nutrient-rich substrates for nutrition. Dredging also removes the accumulated seed bed established by many vascular plants and the resting cysts deposited by a variety of algae. Dry, wet and hydraulic methods are illustrated in Figure 12.

Wet dredging may involve a partial drawdown, especially to avoid downstream flow of turbid water, but sediment will be excavated from areas overlain by water. Sediment will be very wet, often only 10 to 30% solids unless sand and gravel deposits are being removed. Clamshell dredges, draglines, and other specialized excavation equipment are used in what most people would consider a very messy operation. Excavated sediment must usually be deposited in a bermed area adjacent to the pond or into other water-holding structures until dewatering can occur. This approach is most often practiced when water level control is limited. Aside from small ponds, this technique is applicable to ocean harbors, and has been practiced in Boston and New Bedford.

Conventional wet dredging methods create considerable turbidity, and steps must be taken to prevent downstream mobilization of sediments and associated contaminants. For wet excavation projects, inflows must normally be routed around the lake, as each increment of inflow must be balanced by an equal amount of outflow, and the in-lake waters may be very turbid. It should be noted, however, that more recent bucket dredge designs greatly limit the release of turbid water and have been approved for use in potentially sensitive aquatic settings such as Boston Harbor.

A properly conducted dredging program removes accumulated sediment from a lake and effectively sets it back in time, to a point prior to significant sedimentation. Partial dredging projects are possible and may be appropriate depending upon management goals, but for maximum benefit it is far better to remove all “soft” sediment. Failed dredging projects are common, and failure can almost always be traced to insufficient consideration of the many factors that govern dredging success (Table 8).

Benefits
- Deepening of the lake for many purposes, including increased flood or water supply storage, improved recreation, enhanced pollutant trapping effectiveness and dilution of nutrient loads
- Control of rooted plants if a depth (light) or substrate limitation is imposed
- Reduced algal mat formation by reduced nutrient supply and elimination of resting cysts
- Reduced planktonic algal abundance if internal loading is an important nutrient source and enough sediment is removed
- Removal of toxic substances or other unwanted materials accumulated in the sediment
- Reduced sediment-water interactions, with potential improvement in water quality
Detriments
- All possible impacts of drawdown, if the lake is lowered to any appreciable extent
- Loss of many biological components of the lake through physical disturbance and high turbidity
- Potential for downstream turbidity if outflow is not controlled
- Peripheral land disruption for access by equipment
- Upland area must be provided for sediment disposal, with temporary alteration
- Contaminated sediments potentially subject to many restrictions on disposal
- Potentially incomplete dredging as a consequence of not being able to visually appraise underwater sediment conditions and high suspended solids levels that may form a thin muck layer upon settling

Information for Proper Application
Table 8 lists the many considerations applicable to a dredging project. Key factors include:
- Sediment quality, which will determine disposal options and cost
- Sediment quantity, which determines disposal volume needs and greatly affects cost
- Ability to control the lake level, which affects choice of dredging method
- Sensitive biological resources, which affects project goals and permitting
- Monitoring to track system recovery and overall project impacts

Factors Favoring the Use of this Technique
- There is a distinct need for increased depth in the lake, but water level cannot be lowered and controlled to facilitate dry dredging, or water level must be maintained for other uses
- Studies have demonstrated the impact of internal loading on the lake
- Studies have demonstrated the presence of contaminants that are impacting lake biota or uses
- Rooted plants and algal mats dependent on the soft sediments are impairing recreation and habitat value
- Habitat is degraded to the extent that a complete restructuring is desirable
- Sequestering of the dredged area can be performed to limit impacts to aquatic species
- Sediments are “clean”, based on Massachusetts regulatory thresholds
- Suitable and sufficient containment and disposal areas are available close to the lake

Performance Guidelines
- Address the many considerations for dredging provided in Table 8; pay particular attention to sediment quality and quantity and disposal arrangements
- Design the dredging project with local conditions in mind; address flow control, appropriate equipment, access and staging areas, material dewatering and transport for disposal
- Excavate in accordance with all permits
- Achieve a depth (light) or substrate (hard bottom) limitation if control of plant growth is a project goal; usually this involves removal of all soft sediment or achievement of a water depth in excess of 10 ft
- Remove sediment to expose a low nutrient layer if reduction of internal loading is a project goal; usually this involves removal of all soft sediment
- Restore or rehabilitate all access, temporary containment, and final disposal areas
- Monitor in-lake water quality during wet dredging
- Monitor downstream flows and water quality during wet dredging
- Monitor recovery of lake biota and in-lake conditions relative to project goals (e.g., depth increase, plant control, water quality enhancement)
Possible Permits
- MEPA review
- WPA permit through local Conservation Commission/DEP
- Review by NHESP (further action if protected species are present)
- Chapter 91 permit through DEP may be required for Great Ponds
- 404 permit through the Corps of Engineers
- 401 WQ permit through the DEP
- Solid Waste permit for sediment disposal through DEP
- Possible Dam Safety permit through DCR
- Possible NPDES permitting through EPA/DEP

Impacts Specific to the Wetlands Protection Act
- Protection of public and private water supply – Benefit (water quality improvement); may also affect water quantity by uncappping springs and seepage areas. Short-term limitation on available water is possible during dredging
- Protection of groundwater supply – Generally neutral (no significant interaction), although uncappping of springs and seepage areas may increase interaction. Possible adverse impacts below containment area if contaminants leach
- Flood control – Generally neutral (no significant interaction), although greater depth could be an asset if drawdown is later practiced for flood control. Possible short-term benefit or detriment during dredging, depending upon flow controls applied
- Storm damage prevention – Generally neutral (no significant interaction), although greater depth could be an asset if drawdown is later practiced for damage control. Possible short-term benefit or detriment during dredging, depending upon flow controls applied
- Prevention of pollution – Expected benefit (water quality enhancement), although short-term detriment is possible during unsequestered wet dredging due to turbidity generation
- Protection of land containing shellfish – Possible long-term benefit through water quality enhancement, but potential short-term detriment by direct removal or water quality impacts
- Protection of fisheries – Possible long-term benefit through water quality and physical habitat enhancement, but potential short-term detriment by water quality impairment during wet dredging
- Protection of wildlife habitat – Expected long-term benefit (water quality enhancement, invasive plant control), but possible short-term detriment by water quality impairment during wet dredging

Impacts to interests of the Wetlands Protection Act from a specific dredging project are highly dependent upon site-specific features and project design.

Cost Considerations
As cost depends on the volume of material removed, costs are usually expressed per cubic yard (cy) of material removed. Generally, the larger the project, the smaller is the cost per cubic yard. The proper way to estimate dredging costs is to consider each element of the project, which may vary dramatically among projects. The total cost can be divided by the total yardage to get a cost per cubic yard, but this may not be especially meaningful in estimating other dredging projects. With that caveat in mind, a typical range of costs for wet dredging projects in recent years is $15 to $25/cy, with $20/cy suggested as a rough estimator for considering the general magnitude of a project under initial consideration. It is important, however, to develop a more careful estimate during further project planning, as much higher costs are possible as a function of site-specific conditions. Resale of dredged material or allowing access to sand and gravel under muck deposits can reduce costs, but such income should not be assumed unless a firm agreement is in hand.
HYDRAULIC OR PNEUMATIC DREDGING

How it Works
Dredging involves the removal of sediment. Conventional dry, conventional wet, and hydraulic/pneumatic dredging are each addressed separately here, as planning and impact considerations vary substantially. Dredging is perhaps best known for increasing depth, but dredging can be an effective lake management technique for the control of excessive algae and invasive growth of macrophytes. The management objectives of a sediment removal project are usually to deepen a shallow lake for boating and fishing, or to remove nutrient rich sediments that can cause algal blooms or support dense growths of rooted macrophytes.

Control of rooted aquatic vascular plants is achieved by either the removal of substrate hospitable for their growth or by deepening the area enough to create a light limitation on plant growth. The release of algae-stimulating nutrients from lake sediments can be controlled by removing layers of enriched materials. This can reduce internal loading and suppress algal production if internal sources are the dominant nutrient source. Even where incoming nutrient loads remain high, dredging can reduce benthic mat formation and related problems with filamentous green and blue-green algae, as these forms may initially depend on nutrient-rich substrates for nutrition. Dredging also removes the accumulated seed bed established by many vascular plants and the resting cysts deposited by a variety of algae. Dry, wet and hydraulic methods are illustrated in Figure 12.

A more advanced form of wet dredging, hydraulic dredging usually involves a suction type of dredge that has a cutter head. Agitation combined with suction removes the sediments as a slurry containing approximately 15-20% solids by volume, although this may increase to as high as 30 to 40% in some cases or be as low as 5% with especially watery sediments in difficult areas. This slurry is typically pumped to a containment area in an upland setting where the excess water can be separated from the solids by settling (with or without augmentation). The supernatant water can be released back to the lake or some other waterway. The containment area for a hydraulic dredging project is usually a shallow diked area that is used as a settling basin. The clarified water may be treated with flocculation and coagulation techniques to further reduce the suspended solids in the return water.

Hydraulic dredging is normally favored for removal of large amounts of highly organic sediments with few rocks, stumps or other obstructions and where water level control is limited. This type of project does require a containment area to be available where removed sediments are separated from water, and may involve secondary removal of the dried sediment from the containment area for ultimate disposal elsewhere. Usually the containment area is not far from the lake, but a slurry can be pumped multiple miles along a suitable route with booster pumps.

Innovations in polymers and belt presses for sediment dewatering have reached the point where hydraulically dredged slurry can be treated as it leaves the lake to the extent necessary to load it directly onto trucks for transport to more remote sites. Solids content of the resultant material is still
too low for many uses without further drying or mixing with sand, but the need for a large containment area can be avoided with this technology. The cost of coagulation and mechanical dewatering may be at least partially offset by savings in containment area construction and ultimate material disposal. Likewise, pumping the slurry into geo-tubes (engineered filter bags) can also enhance dewatering in a limited space.

Pneumatic dredging, in which air pressure is used to pump sediments out of the lake at a higher solids content (50 to 70%) has not yet been performed in Massachusetts or surrounding states. This would seem to be a highly desirable approach, given containment area limitation in many cases and more rapid drying with higher solids content. However, few of these dredges are operating within North America, and there is little freshwater experience upon which to base a review. Considerations are much like those for hydraulic dredging.

A properly conducted dredging program removes accumulated sediment from a lake and effectively sets it back in time, to a point prior to significant sedimentation. Partial dredging projects are possible and may be appropriate depending upon management goals, but for maximum benefit it is far better to remove all “soft” sediment. Failed dredging projects are common, and failure can almost always be traced to insufficient consideration of the many factors that govern dredging success (Table 8).

Benefits
- Deepening of the lake for many purposes, including increased flood or water supply storage, improved recreational uses, enhanced pollutant trapping effectiveness, and dilution of nutrient loads
- Control of rooted plants if a depth (light) or substrate limitation is imposed
- Reduced algal mat formation by reduced nutrient supply and elimination of resting cysts
- Reduced planktonic algal abundance if internal loading is an important nutrient source and enough sediment is removed
- Removal of toxic substances or other unwanted materials accumulated in the sediment
- Reduced sediment-water interactions, with potential improvement in water quality
- Less disruption of biological components of the aquatic system and less impact on peripheral land than for conventional excavation approaches

Detriments
- Upland area must be provided for sediment disposal, with temporary alteration
- Contaminated sediments potentially subject to many restrictions on disposal
- Potentially incomplete dredging as a consequence of not being able to visually appraise underwater sediment conditions and high suspended solids levels that may form a thin muck layer upon settling
- Less effective than conventional excavation approaches where there are obstructions such as boulders, stumps or underwater structures
Information for Proper Application
Table 8 lists the many considerations applicable to a dredging project. Key factors include:
- Sediment quality, which will determine disposal options and cost
- Sediment quantity, which determines disposal volume needs and greatly affects cost
- Obstructions or other factors that limit access to soft sediments by the hydraulic dredge
- Containment area features and routing of the slurry to the containment area
- Discharge location and water quality for supernatant from the containment area
- Monitoring to track system recovery and overall project impacts

Factors Favoring the Use of this Technique
- There is a distinct need for increased depth in the lake
- Studies have demonstrated the impact of internal loading on the lake
- Studies have demonstrated the presence of contaminants that are impacting lake biota or uses
- Rooted plants and algal mats dependent on the soft sediments are impairing recreation and habitat value
- Significant biological resources remain and warrant protection during dredging
- Sediment is largely muck, and rocks, stumps and other obstructions are minimal
- Sediments are “clean”, based on Massachusetts regulatory thresholds
- Suitable and sufficient containment and disposal areas are available close to the lake

Performance Guidelines
- Address the many considerations for dredging provided in Table 8; pay particular attention to sediment quality and quantity and disposal arrangements
- Design the dredging project with local conditions in mind; address flow control, appropriate equipment, access and staging areas, material dewatering and transport for disposal
- Excavate in accordance with all permits
- Achieve a depth (light) or substrate (hard bottom) limitation if control of plant growth is a project goal; usually this involves removal of all soft sediment or achievement of a water depth in excess of 10 ft
- Remove sediment to expose a low nutrient layer if reduction of internal loading is a project goal; usually this involves removal of all soft sediment
- Restore or rehabilitate all access, temporary containment, and final disposal areas
- Monitor containment area discharge quality during hydraulic dredging
- Monitor downstream flows and water quality during hydraulic dredging
- Monitor recovery of lake biota and in-lake conditions relative to project goals (e.g., depth increase, plant control, water quality enhancement)

Possible Permits
- MEPA review
- WPA permit through local Conservation Commission/DEP
- Review by NHESP (further action if protected species are present)
- Chapter 91 permit through DEP may be required for Great Ponds
- 404 permit through the Corps of Engineers
- 401 WQ permit through the DEP
- Solid Waste permit for sediment disposal through DEP

All photos on this page provided by J. Walsh of BEC
- Possible NPDES permitting through EPA/DEP

**Impacts Specific to the Wetlands Protection Act**

- Protection of public and private water supply – Benefit (water quality improvement); may also affect water quantity by uncapping springs and seepage areas.
- Protection of groundwater supply – Generally neutral (no significant interaction), although uncapping of springs and seepage areas may increase interaction. Possible adverse impacts below containment area if contaminants leach
- Flood control – Generally neutral (no significant interaction), although greater depth could be an asset if drawdown is later practiced for flood control.
- Storm damage prevention – Generally neutral (no significant interaction), although greater depth could be an asset if drawdown is later practiced for damage control.
- Prevention of pollution – Expected benefit (water quality enhancement), although short-term detriment is possible during hydraulic dredging with containment area problems
- Protection of land containing shellfish – Possible long-term benefit through water quality enhancement, but potential short-term detriment by direct removal
- Protection of fisheries – Possible long-term benefit through water quality and physical habitat enhancement
- Protection of wildlife habitat – Expected long-term benefit (water quality enhancement, invasive plant control)

Impacts to interests of the Wetlands Protection Act from a specific dredging project are highly dependent upon site-specific features and project design.

**Cost Considerations**

Because the cost varies greatly with the volume of material removed, costs are usually expressed per cubic yard (cy) of material removed. Generally, the larger the project, the smaller is the cost per cubic yard. The proper way to estimate dredging costs is to consider each element of the project, which may vary dramatically among projects. The total cost can be divided by the total yardage to get a cost per cubic yard, but this may not be especially meaningful in estimating other dredging projects. With that caveat in mind, a typical range of costs for dry dredging projects in recent years is $7 to $20/cy, with $12/cy suggested as a rough estimator for considering the general magnitude of a project under initial consideration. It is important, however, to develop a more careful estimate during detailed project planning. Smaller dredging projects (<50,000 cy) applying hydraulic methods have incurred costs in excess of $30/cy.

For hydraulic dredging, cost factors of major importance include:

- Volume of material – Hydraulic dredging is often not economical at low volumes
- Distance to containment area – The need for booster pumps increases cost
- Size of containment area – The size of dredge and rate of pumping depend upon the available volume for containment and resultant detention time. Additionally, cost will escalate if dredging must cease periodically to allow containment area clean-out
- Obstructions and clogging agents – Efficient use of the cutterhead and pipeline will be impeded by rocks, stumps, structures and dense plant growths

Total cost can be reduced if the dredged material is clean enough to be sold as a soil amendment. Recovery of more than $1/cy is unusual, however. Income from resale should not be assumed, however, unless a firm agreement is in hand. Because hydraulic dredging is not suited to economic removal of coarse sand and gravel, no savings from access to such deposits is expected.
Below is a template for the presentation of each management technique

NAME OF MANAGEMENT TECHNIQUE

How it Works
Description of the technique, how it functions, and what one can expect from it.

Benefits
Explanation of desirable outcomes potentially accrued from the use of this technique. Note that listing does not guarantee that the potential benefit will be realized, and that the level of benefit may vary substantially among cases. Proper planning and implementation are required to gain listed benefits.

Detriments
Explanation of the undesirable impacts that could occur if this technique is used. Note that listing does not guarantee that such detriments will occur, as proper planning and implementation can eliminate many negative consequences. Some negative impacts may be unavoidable, however, and must be balanced with benefits if the technique is to be used.

Information for Proper Application
Listing of the data or analyses necessary to apply the technique in a way that maximizes benefit. Lack of such data may not negate the utility of the technique, but may compromise its value or shift the balance of benefits and detriments.

Factors Favoring the Use of this Technique
Brief explanation of conditions that suggest the technique would be appropriate and that the balance of benefits to detriments would be favorable. The list is generally written in a positive format; absence of the factor may indicate an unfavorable situation in some cases, while in others the lack of a favorable factor may have no negative consequences.

Performance Guidelines
Suggested limits, thresholds and factors that define appropriate use of the technique. This is an effort to define balance points for cost-benefit analysis and thresholds of acceptable risk, but is subjective. Any numerical values should not be construed to be regulatory standards or criteria unless so stated, but are offered for guidance purposes in planning management actions.

Possible Permits
Description of permits and approvals that may be necessary in Massachusetts to apply the technique. Listed permits may not be needed in all cases, as thresholds exist for many permits. However, potential applicants should investigate the need for any listed permit in each case.

Impacts Specific to the Wetlands Protection Act
Impacts, either beneficial or detrimental, on the eight specified interests of the WPA are listed and briefly explained.

Cost Considerations
Factors that affect costs and actual cost ranges or general rules from the literature or experience are provided. Recognize that cost can vary substantially among projects, even in what appear to be similar cases. Careful costing is recommended on a case by case basis, but estimates provided here will allow order of magnitude comparisons.
**NON-POINT SOURCE CONTROLS: Source Management**

**How it Works**

Source management consists of techniques that eliminate or reduce the potential for pollutants (in this case nutrients) to be released from a source. The most reliable way to do this is to eliminate the source, but this may not be practical in many cases. Alternatively, methods to reduce the release of a pollutant may be instituted. Most source control is achieved through laws, statewide or local bylaws or ordinances that restrict product contents or use or limit activities within a watershed. Where a feasible alternative product exists or targeted land uses do not already exist in the watershed, this can be a very successful approach. Where education reveals both an environmental and economic value by source elimination, success may also be achieved. For example, as established lawns require very little added phosphorus, homeowners should be able to save money and protect water quality while maintaining lawns. However, the cost of no-phosphorus fertilizer is not less than phosphorus-rich brands, and a cultural shift is needed to get people to put water quality ahead of their lawns or their pocketbooks. Additional methods of nutrient source control include erosion prevention, pet waste collection, management of wildlife, and water quality-based zoning. Phosphorus and nitrogen load reductions are highly variable, but tend not to exceed 33% and are often <10%. Use of source controls to prevent loading before it ever starts is the most beneficial use of this approach.

**Benefits**

- Prevention, elimination or reduction of sources clearly reduces the potential nutrient load
- Costs can be minimal and are spread over the population
- Pollutants other than nutrients can be controlled by the same actions

**Detriments**

- Source controls are the first line of defense, but will rarely be successful as the only line of defense.
- Compliance may be difficult to track or enforce
- Urbanized or agricultural watersheds may contain many sources that cannot be eliminated or even substantially reduced

**Information for Proper Application**

- Knowledge of the portion of the load comprised by the targeted source(s)
- Education and compliance programs
- Regulatory jurisdiction and limitations
- Means to measure success

**Factors Favoring the Use of this Technique**

- A substantial portion of the P and/or N load is associated with NPS pollution
- Studies have demonstrated the impact of identifiable sources
- Jurisdiction can be claimed over areas of NPS contribution
- Zoning or other restrictions on uses of land or products are properly justified and consistent with applicable state and local laws

**Performance Guidelines**

- Establish an effective public process for involvement of all relevant parties
- Collect the data necessary to support the control effort
- Focus on education before new regulation
- Enforce existing regulations equitably
- Monitor at a scale appropriate to the control effort; demonstrate improvement on or from small parcels before seeking to document any overall change in the lake. Seek funding to facilitate an incentive program

**Possible Permits**
- None likely

**Impacts Specific to the Wetlands Protection Act**
- All interests of the WPA are either benefited or unaffected by source controls.

**Cost Considerations**
- Variable but mostly low and internalized
- Assume $1-10/person for education or compliance effort

### Non-Structural Source Controls include:
- Land Purchase for Conservation Purposes
- Conservation Easements - Purchase of development or other use rights for land
- Zoning
- Watershed Protection Districts
- Aquifer Protection Districts
- Wetlands Protection Statutes
- National Pollutant Discharge Elimination System (NPDES)
- Household Hazardous Waste Collection
- Fertilization Limitations
- Lawn Waste Control
- Vehicle Cleaning Regulations
- Agricultural Management Planning
- Other Ordinances and Regulations Governing Activities on the Land or Water
- Education
How it Works
Deep sump catch basins equipped with hooded outlets can be installed as part of a stormwater conveyance system. Deep sumps provide capacity for sediment accumulation and hooded outlets prevent discharge of floatables. Catch basins are usually installed as pre-treatment for other BMPs and are not generally considered adequate stormwater treatment as a sole system. Volume and outlet configuration are key features that maximize particle capture, but it is rare that the finer fraction of the sediment/nutrient load (which contains most nutrients) is removed by these devices. As a consequence, phosphorus removal is normally about 1-20% and nitrogen removal is similar.

A number of more advanced chamber designs are available. These self-contained units include an initial settling chamber for sediment removal, typically have hooded internal passages to trap oil and other floatables, and often incorporate some form of outlet pool to control exit velocity. Several rely on a vortex design to enhance sediment removal, while others rely on filtering mechanisms to augment the settling process. Such systems are most applicable as pre-treatment for other BMPs, but can trap much of the particulate nutrient load and are generally well suited as retrofits for relatively small areas in developed watersheds. Installing these devices as off-line systems may enhance nutrient removal, but their more common use as on-line pre-treatment devices can be very beneficial.

Such devices must be maintained, with periodic clean-out as determined by experience with filling rate. Typically they must be cleaned once per year, with twice per year (spring/fall) cleaning maximizing performance. Street sweeping is not essential to device performance, but is often integral to pavement management where inlet devices are used as significant pollutant controls.

Benefits
- Traps up to 80% of solids with associated pollutants
- Removal of coarse settleables and floatables maximizes discharge aesthetics
- Greatly extends performance of downstream controls such as detention or infiltration
- Installation below grade minimizes impacts on land use

Detriments
- Up to 90% of nutrients are dissolved or associated with the 20% smallest solids that are not removed by these traps
- Failure to maintain devices may result in no removal or clogging and flooding
- Generally inadequate as the sole control mechanism

Information for Proper Application
- Proper device size and attributes for expected load and cleaning frequency
- Monitoring to assess effectiveness and any need for adjustment

Factors Favoring the Use of this Technique
- A substantial portion of the P and/or N load is documented to be associated with coarse particulate NPS pollution.
- Studies have demonstrated the impact of identifiable storm water sources (e.g., piped runoff)
- Water associated with NPS inputs is important to lake hydrology
- Sizing and pollutant removal functions have been properly calculated
- Additional controls (e.g., detention, infiltration) are planned and can be enhanced by this approach

**Performance Guidelines**
- Collect the data necessary to demonstrate the problem and potential for improvement
- Design the system to meet demonstrated needs
- Develop a stormwater management plan in which inlet devices are one element; do not expect inlet devices to solve all stormwater problems
- Develop a maintenance plan
- Monitor at a scale appropriate to demonstrating results

**Possible Permits**
- None likely

**Impacts Specific to the Wetlands Protection Act**
All interests of the WPA are either benefited or unaffected.

**Cost Considerations**
Costs tend to range from a low of around $3000 for simple deep sump catch basins to a high of $30,000 for larger advanced basins with swirl concentrators, filters, multiple chambers, or other special controls. Catch basin cleaning tends to cost $30-100 per basin on a contract basis, depending on the number of basins cleaned. Purchase of street sweepers or catch basin cleaners can represent an expense in excess of $100,000 each, plus maintenance and operation costs.
How it Works
Buffer strips are areas of grass or other dense vegetation that separate a waterway from an intensive land use. These vegetated strips allow overland flow to pass through vegetation that filters out some percentage of the particulates and decreases the velocity of the stormwater. Particulate settling and infiltration of water often occurs as the stormwater passes through the vegetation. Buffer strips need to be at least 25 ft wide before any appreciable benefit is derived, and superior removal requires a width >100 ft. This can create land use conflicts, but creative planting and use of buffer strips can be a low cost, low impact means to minimize inputs to the aquatic environment. Removal of phosphorus and nitrogen varies substantially (20-90%), with averages in the vicinity of 30% but greater removal achievable with proper design.

Swales are engineered ditches that provide detention and infiltration while transporting runoff to a planned discharge point. Use of dense vegetation and stone or wood check dams within the confines of a channel designed to handle substantial flows of runoff can slow water velocity, allow particulate nutrients to settle, and provide infiltration of a substantial fraction of the dissolved nutrient load. Less removal may occur during higher flows, but such flows do not often carry more of the total nutrient load than smaller storms in most watersheds as a consequence of the first flush phenomenon. Swales may be adequate for nutrient removal if large and long enough, but are more effective as pre-treatment devices before discharge to detention systems. Phosphorus removal is also highly variable (0-70%) with typical average removal at about 30%. Nitrogen removal averages about 25%.

Benefits
- Passively removes nutrients without long detention of flow
- Relatively simple to build and maintain
- Can blend aesthetically into the landscape
- May provide substantial habitat value as well as pollutant removal

Detriments
- Requires substantial land area
- Steep slopes will limit removal potential
- Maintenance may reduce effectiveness until vegetation re-grows

Information for Proper Application
- Climatic and drainage area data to provide estimate of maximum hydrologic loading
- Water quality data with separation of particulate and dissolved fractions, to allow estimation of needed width or length
- Ground slopes, soil types, and planned vegetative cover to allow removal estimation
- Monitoring to assess effectiveness and any need for adjustment

Factors Favoring the Use of this Technique
- A substantial portion of the P and/or N load is associated with NPS pollution
- Studies have demonstrated the impact of identifiable sources
- Water associated with NPS inputs is important to lake hydrology
- Sizing and pollutant removal functions have been properly calculated
- Land is available for placement of BMPs

**Performance Guidelines**
- Collect the data necessary to demonstrate the problem and potential for improvement
- Design buffers and swales to meet demonstrated needs; remember habitat and aesthetic functions as well as water quality benefits
- Use only native species in planting programs
- Seek funding to provide an incentive program
- Monitor at a scale appropriate to demonstrating results

**Possible Permits**
- None likely unless natural wetland resources are involved

**Impacts Specific to the Wetlands Protection Act**
All interests of the WPA are either benefited or unaffected, with the possible exception of groundwater quality protection if infiltration occurs in the buffer or swale.

**Cost Considerations**
Often very inexpensive to build and maintain, but maximum performance may require occasional cleaning and replanting. May cost as much as a few dollars per square foot of buffer (exclusive of any land purchase costs) and $25-50 per linear foot of swale with velocity barriers and infiltration capacity.
**NON-POINT SOURCE CONTROLS:**  
*Pollutant Trapping by Detention*

How it Works
Detention ponds are basins that are designed to hold a portion of stormwater runoff for at least 12-24 hours and preferably longer. Pollutant removal is accomplished mainly through settling and biological uptake, although incorporation of infiltration capacity can add substantial adsorptive capacity as well. Design features are extremely varied and depend on pollutant removal goals, regional climate, and localized site conditions. Detention facilities can be large ponds with multiple forms of aquatic habitat or small “rain gardens”. Wet detention ponds are more effective than dry detention ponds as the latter have a greater risk of sediment re-suspension and generally do not provide adequate soluble pollutant removal. Dry detention ponds have less potential to support mosquitoes and provide greater detention capacity per unit cost. Although potentially very effective, the land requirement is typically large; the area should be at least 2% of the drainage area it serves, and preferably as much as 7% of that area.

Length to width ratio can be an important feature of detention systems, with a L:W ratio of 2:1 often applied. Outlet configuration can also make a big difference; graduated outlets that allow more water to exit as the water level rises are often needed to ensure flood protection, while filtration berms are used to hold back fine solids and hooded overflows are used to trap floatables. Addition of coagulants can enhance removal of dissolved nutrients and colloidal solids. Removal rates for phosphorus vary widely with design features and the nature of the load, with average values of 30-65% reported. Nitrogen removal tends to be somewhat lower, with averages in the 30-40% range.

**Benefits**
- Provides flood protection as well as water quality enhancement
- Generally passive removal with limited maintenance needs
- Can provide habitat value and blend aesthetically with landscape

**Detriments**
- Requires substantial land area
- Construction problems are common in areas of high ground water or abundant bedrock
- Wet ponds may become mosquito breeding areas

**Information for Proper Application**
- Climatic and drainage area data to provide estimate of variability in hydrologic loading
- Water quality data with separation of particulate, colloidal and dissolved fractions, to allow estimation of needed detention time and supplemental features (e.g., plantings, outlet features, polymer addition)
- Soil types, ground water depth and related data for construction planning
- Monitoring to assess effectiveness and any need for adjustment

**Factors Favoring the Use of this Technique**
- A substantial portion of the P and/or N load is associated with NPS pollution
- Studies have demonstrated the impact of identifiable sources
- Water associated with NPS inputs is important to lake hydrology
- Sizing and pollutant removal functions have been properly calculated
- Land is available for placement of the detention system
- Detention capacity is available to hold a substantial portion of the targeted runoff
- Detention and/or infiltration will not cause local flooding problems, wet basements, or structural damage

**Performance Guidelines**
- Collect the data necessary to demonstrate the problem and potential for improvement
- Design the system to meet demonstrated needs; consider flood prevention and water quality enhancement, providing appropriate capacity and rate of through-flow
- Develop a maintenance plan
- Monitor at locations appropriate to demonstrating results

**Possible Permits**
- NPDES permit from EPA under special circumstances
- WPA permit if natural wetland resources are involved

**Impacts Specific to the Wetlands Protection Act**
All interests of the WPA are either benefited or unaffected, with the possible exception of groundwater quality protection if infiltration occurs in the detention area.

**Cost Considerations**
Costs will vary with size, depth and special features, with typical values of $10-30 per cubic yard of capacity. On an areal basis, costs of $50,000-200,000 per acre could be expected, with an expected depth of at least 3 ft.

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Outlet structure for detaining a range of flows

Detention Basin Design (after USEPA, 1999)
NON-POINT SOURCE CONTROLS:
Pollutant Trapping by Infiltration

How it Works
Water quality response to runoff has been clearly linked to the portion of the watershed that is impervious. While natural surfaces such as clay soil, muck soils, and exposed rock are functionally impervious, human derived surfaces such as roads, parking lots, driveways and roofs are major sources of runoff in developing watersheds. Once imperviousness exceeds 10% of the watershed area, water quality problems are often observed, and at levels in excess of 25%, water quality impairment almost always occurs. Imperviousness can be minimized by narrowing roadways, limiting development footprints, and incorporating porous pavement wherever feasible. Removal rates vary, but average close to 50% for phosphorus and 60% for nitrogen when infiltration is facilitated.

Infiltration systems may include trenches, basins or dry wells, and involve the passage of water into the soil or through an artificial medium such as a constructed berm. Particles are filtered by the soil matrix and many soluble compounds are adsorbed to soil particles. Such systems require sufficient storage capacity to permit the gradual infiltration of runoff into suitable soils or through the constructed medium. Pretreatment of the runoff removes larger particles before filtration, thereby aiding in the prevention of infiltration system failure due to clogging and sediment accumulation. Phosphorus removal is maximized by infiltration, but dissolved forms of nitrogen may be only minimally affected. Removal rates for phosphorus tend to be moderate to high, with averages of 60-70%. Despite limited effectiveness for dissolved nitrogen, total nitrogen removal rates are moderate, with averages near 50%. Variability is high, however, as a function of local conditions and design.

Site constraints such as shallow depth to groundwater or bedrock and poorly drained soils often limit the effective use of infiltration, so detailed knowledge of the site is essential when planning infiltration facilities. In sites with suitable conditions, off-line infiltration systems are generally preferred. One key to successful infiltration is providing adequate pre-infiltration settling time or other treatment to remove particles that could clog the interface at which infiltration occurs. Another key is having sufficient runoff detention capacity to allow delivery of runoff to the infiltration surface at a rate that maximizes performance. Both key factors can be met by combining adequate detention facilities with infiltration systems.

Benefits
- High removal based on multiple processes in soil or artificial media
- Removes many contaminants besides nutrients
- Can be used to minimize runoff and maximize ground water recharge
- Can include underground leaching to minimize surficial land use

Detriments
- Poor removal of dissolved nitrogen in most cases
- May contaminate ground water if pollutants (like dissolved N) are mobile
- Requires substantial land area; may interfere with surface uses if not subterranean
- May require substantial detention capacity or not work at all if soils
are not sufficiently permeable
- May raise localized groundwater table; possible issues for structures
- May clog if not adequately maintained; pretreatment of influent often necessary for optimal performance

Information for Proper Application
- Soil conditions and groundwater table elevation, to evaluate efficacy of infiltration and determine design criteria
- Drainage area and climatic data to estimate range of expected loading
- Water quality data for evaluating possible impacts on groundwater
- Monitoring to assess effectiveness and any need for adjustment

Factors Favoring the Use of this Technique
- A substantial portion of the P and/or N load is associated with NPS pollution
- Studies have demonstrated the impact of identifiable sources
- Sizing and pollutant removal functions have been properly calculated
- Land is available for placement of infiltration facilities
- Detention capacity is available to hold excess runoff until it can be infiltrated
- Infiltration will not cause local flooding problems, wet basements, or structural damage
- Infiltration will not cause groundwater quality deterioration

Performance Guidelines
- Collect the data necessary to demonstrate the problem and potential for improvement
- Design the system to meet demonstrated needs; provide trapping for solids that may clog system and appropriate storage capacity for expected infiltration rate
- Evaluate possible groundwater impacts; adhere to Massachusetts Stormwater Policy
- Develop a maintenance plan
- Monitor at locations appropriate to demonstrating results

Possible Permits
- Groundwater Discharge Permit from DEP

Impacts Specific to the Wetlands Protection Act
All interests of the WPA are either benefited or unaffected, with the possible exception of groundwater quality protection. The Massachusetts Stormwater Policy governs pre-treatment needs for infiltration scenarios and should be consulted.

Cost Considerations
Infiltration system costs vary with size and local site conditions. Simple leaching catch basins can be installed for $5000-10,000 each, while leaching trenches will tend to cost more (around $30,000 for a small system handling a few acres). Elaborate systems with back-up detention may cost considerably more. Leaching detention basins will cost about the same as a regular detention basin if the soils are suitable or could be up to twice as expensive if soil modification is needed. Maintenance needs may be substantial, including annual or semi-annual inspection and cleaning as warranted.
How it Works
Detention systems tend to be created wetlands, but design features that combine open water and emergent wetlands tend to provide superior nutrient removal. These systems maximize pollutant removal through vegetative filtration, nutrient uptake, soil binding, bacterial decomposition, and enhanced settling. Much of the effectiveness of the treatment is related to microbial action; the plants are more the substrate than the active pollutant removers, but removal rates are higher in the presence of plants. Wetland systems are suitable for on-line or off-line treatment, but maintenance of adequate hydrology with off-line systems is necessary to support the complete wetland features that maximize effectiveness.

Constructed treatment wetlands can function effectively in cold environments, mainly as a function of subsurface flow and related microbial uptake, adsorption, and filtration processes. Presence of aerobic and anaerobic conditions in sequential portions of the system is essential to reduction in nitrogen through sequential oxidation and reduction of nitrogen forms to convert organic forms to nitrogen gas. There are many details of design that affect performance, with multi-chamber, high detention time systems with both surface and subsurface flow providing the highest nutrient removal rates. Decay of vegetation may raise nutrient export at times. Phosphorus removal is therefore highly variable, but averages 55-65%. Nitrogen removal is also highly variable, but averages close to 40%.

Benefits
- Combines features of emergent wetlands, ponds, and groundwater for maximum pollutant removal
- Can be installed in areas with high groundwater table
- May provide supplemental habitat value
- Relatively low maintenance needs

Detriments
- Some seasonal component to removal efficiency, although subsurface flow can offset this in many cases
- May have net release of nutrients during hydraulic washout after decay periods
- May act as breeding ground for mosquitoes

Information for Proper Application
- Soil conditions and groundwater table elevation, to evaluate efficacy of wetland maintenance and determine design criteria
- Drainage area and climatic data to estimate range of expected loading
- Water quality data for evaluating possible impacts on groundwater and special design needs for maximizing pollutant removal
- Monitoring to assess effectiveness and any need for adjustment

Factors Favoring the Use of this Technique
- A substantial portion of the P and/or N load is associated with NPS pollution
- Studies have demonstrated the impact of identifiable sources
- Sizing and pollutant removal functions have been properly calculated
- Land is available for placement of wetlands
- Detention capacity is available to hold a substantial portion of the targeted runoff
- Detention and/or infiltration will not cause local flooding problems, wet basements, or structural damage
- Infiltration will not cause groundwater quality deterioration
- Maximum nitrogen removal is desired

Performance Guidelines
- Collect the data necessary to demonstrate the problem and potential for improvement
- Design the wetland to meet demonstrated needs; utilize multiple wetland processes; consider flood prevention and water quality enhancement, providing appropriate capacity and rate of through-flow
- Remember habitat and aesthetics in design, and use only native species in planting programs
- Develop a maintenance plan
- Monitor at locations appropriate to demonstrating results

Possible Permits
- Groundwater Discharge Permit from DEP

Impacts Specific to the Wetlands Protection Act
All interests of the WPA are either benefited or unaffected, with the possible exception of groundwater quality protection if infiltration occurs in the wetland.

Cost Considerations
Wetland creation can be very inexpensive if local site conditions favor wetness, but considerable design effort and careful construction are needed to maximize performance. Costs will be similar to those of detention basins ($50,000-200,000/acre), with potential additional planting costs. Multi-chamber designs that facilitate nitrification/denitrification will be most effective yet most expensive.
The Practical Guide to Lake Management in Massachusetts

NON-POINT SOURCE CONTROLS:
Pollutant Trapping by Agricultural Best Management Practices

How it Works
The spatial and temporal features of planting, coupled with the actual crops chosen, can greatly affect the movement of nutrients off farm fields. Cover crops stabilize soils, and may be used as interim cover or as a supplemental crop in association with plants that grow up through the cover crop to form another layer above it. Interspersing of crops can create buffer zones such that potential nutrient losses facilitated by harvest of one crop are trapped by the other. The basic philosophy of the planting plan is to minimize bare soil and create buffer zones that have economic as well as ecological value.

The pattern of plowing on a farm can be a great aid to minimizing the movement of nutrients. Conservation tillage involves contouring, terracing, and related approaches that minimize the peak velocity attained by runoff and maximize infiltration of rainwater. Coupled with an effective planting plan, the quantity of runoff generated from the field can be greatly reduced; this translates into reduced nutrient loading to area waterways.

Livestock operations have the potential to contribute nutrient loads that overshadow most other sources, and represent a health hazard as well. Manures are of special concern as they are relatively high in nutrients and attempts to meet nitrogen requirements by application of manure may result in losses of phosphorus to surface waters. Handling manure in a manner that limits interaction with precipitation and incorporation into runoff is essential to protecting aquatic habitats. Manure application should be kept as far away as possible from streams and lakes and the application of manure should be avoided during winter months when frozen soils result in large losses in runoff. Covered feeding areas, manure collection systems, covered storage, and proper spreading on farm fields or disposal by other means are all necessities of best management for livestock facilities. Studies suggest alum and other chemical additives may reduce phosphorus leaching from manure. Conversion of manure to energy is a novel approach now being advanced.

Cranberry production is large in MA, and these operations are usually associated with lakes. While bogs use water to irrigate and most apply fertilizers and pesticides, the impact of these activities on downstream lakes is not certain. Current impacts on lakes from cranberry bogs tend to be linked to the fall harvest for wet-pick bogs and to periodic flushing (usually a post harvest through spring event) of all bogs. Water discharged from bogs, if not detained or otherwise treated, may carry large amounts of particulate nutrients into the receiving waters, often a lake or tributary to a lake. Dissolved phosphorus in anoxic winter discharges may be high. Nitrogen is usually in short supply in bogs, and concentrations of readily available nitrogen tend to be low. Microbial processes in lakes may recycle the bog inputs and eventually increase lake fertility. The key factor appears to be the volume of discharge relative to the volume of the lake, with larger relative volumes having greater potential impact.

Overall reduction in nutrient loading is difficult to predict, given the wide range of agricultural activities, local site conditions, and BMP options. Major reductions (>50%) have been realized from manure handling improvements, but substantial reductions from crop management practices also appear possible. Localized monitoring is essential to tracking progress.
The Practical Guide to Lake Management in Massachusetts

Benefits
- Can minimize soil loss and associated economic cost
- Can minimize fertilizer costs
- May provide health benefits as well as nutrient loading reduction

Detriments
- Generally has unfavorable short-term cost-benefit balance from farmer’s perspective, unless supporting public funds are available
- Soil capacity for phosphorus from manure spreading is quickly exhausted, leading to a need for new and large disposal areas

Information for Proper Application
- Soil nutrient needs, to assess fertilizer needs or adsorptive capacity
- Farming plan, to ensure that BMPs have minimum impact on productivity
- Climatic information and local drainage pattern, to evaluate key sites/periods
- Ongoing monitoring to assess impacts and additional management needs

Factors Favoring the Use of this Technique
- A substantial portion of the P and/or N load is associated with NPS pollution
- Studies have demonstrated the impact of identifiable sources
- Sizing and pollutant removal functions have been properly calculated
- Land is available for placement of BMPs
- Cooperation of farmers
- Agricultural assistance funding is available

Performance Guidelines
- Collect the data necessary to demonstrate the problem and potential for improvement
- Seek involvement from farmers and farm agencies in selecting BMPs; develop a clear understanding of the agricultural operation before specifying BMPs
- Apply BMPs to meet demonstrated needs; focus on soil, nutrient and pesticide mobility
- Seek funding to provide an incentive program
- Develop a maintenance plan
- Monitor at locations appropriate to demonstrating results

Possible Permits
- None likely unless wetland resources are involved

Impacts Specific to the Wetlands Protection Act
All interests of the WPA are either benefited or unaffected.

Cost Considerations
Costs are highly variable in accordance with the type of farming, need for controls, and local site conditions. Manure handling and storage systems often cost on the order of $100,000 for a typical dairy heard or other livestock operation in MA. Procedural controls like conservation tillage or planting plans may carry minimal cost.
NON-POINT SOURCE CONTROLS: Pollutant Trapping by Managing Septic Systems

How it Works
Most on-site domestic sewage treatment consists of either the older cesspool (single chamber, open bottom pit type, no longer in construction) or the newer septic tank with leaching field or chamber (conventional septic systems). Most septic systems consist of a subsurface chambered tank where scum and settleable solids are removed from the liquid by gravity separation and a subsurface drain system where the clarified liquid effluent percolates into the soil. Regular inspection of the system is recommended, with pumping as experience dictates or according to calculations based on the number of people served and the size of the tank.

For conventional septic systems, the management techniques are detailed in Title 5 of the State Environmental Code 310 CMR 15.00 et. sec. For any new septic systems, the leach field must have a minimum setback of 50 feet from surface waters. To protect resources, additional restrictions on septic systems may be imposed by local ordinance.

Phosphorus is removed to a substantial degree in both the septic tank and the leachfield, owing to chemical reactions that tend to convert phosphorus into particulate forms. Even beyond the leaching field or chamber, soils adsorb phosphorus at high rates. Removal rates may be only 20-50% in the actual septic system, but removal rates >90% are expected through soil adsorption in most cases. Where the system is in fractured rock or compacted soil with fissures, high removal rates may not be realized. Likewise, where system failure results in breakout of septic effluent at the ground surface, or the soil capacity for phosphorus adsorption is exhausted, removal of phosphorus will be severely reduced. The phosphorus load to a lake from septic systems requires careful evaluation, however; do not assume high loading.

Even a properly sited, well-maintained, conventional septic system will release a substantial amount of nitrogen into the ground. Physical and chemical soil processes do little to reduce discharge concentrations, which may exceed 50 mg/L. Site limitations and the inability of conventional septic systems to capture more than about 10% of the nitrogen load has fostered a variety of alternative systems. Advanced on-site wastewater disposal systems may be applied in cases where a septic system fails and/or the site cannot accommodate a conventional system due to size or performance needs. There are many approved alternate technologies for septic systems in Massachusetts.

Many advanced systems are designed to remove nitrogen, with removal rates >50% and sometimes approaching 90%. Few advanced systems have a demonstrated ability to remove significantly more phosphorus than conventional systems, although some are being tested. Some systems are designed to enhance infiltration in low permeability sites, but all focus on achieving better overall effluent quality.

Tight tanks are an older alternative that eliminates the leaching function of on-site wastewater disposal and necessitate more frequent pump-out and hauling to an approved septage disposal site, usually a wastewater treatment facility operated by a municipality or regional authority.
The Practical Guide to Lake Management in Massachusetts

Benefits
- Properly designed, constructed and maintained septic systems minimize phosphorus input to lakes
- Advanced on-site wastewater disposal systems can minimize phosphorus and nitrogen inputs to lakes
- Tight tanks eliminate discharge to the groundwater or lake

Detriments
- Conventional septic systems provide minimal nitrogen removal
- Conventional septic systems do not function well where the groundwater table is high (<4-6 ft below leachfield elevation)
- On-site wastewater disposal systems depend upon soil adsorption of phosphorus for much of the removal function; leachfields are eventually exhausted, leading to inputs to lakes
- Maintenance is not required by state law or most local ordinances, and no individual effluent limitations are applied

Information for Proper Application
- Careful investigation that documents the importance of septic system inputs on lake conditions
- Local soil and groundwater conditions to allow proper siting and design
- Use levels (number of people, presence of dishwashers, garbage grinders, and other conveniences) to allow proper design
- Means to measure success

Factors Favoring the Use of this Technique
- A substantial portion of the P and/or N load is associated with septic systems
- Studies have demonstrated the impact of septic systems on the lake
- Sizing and pollutant removal functions have been properly calculated
- Required changes are properly justified and consistent with applicable state and local laws

Performance Guidelines
- Collect the data necessary to demonstrate the problem and potential for improvement
- Design systems or rehabilitation programs to meet demonstrated needs; match available designs to water quality goals
- Adhere to Title V regulations in the design and construction of septic systems
- Develop an inspection and maintenance plan
- Monitor at locations appropriate to demonstrating results

Possible Permits
- Title V compliance through DEP

Impacts Specific to the Wetlands Protection Act
All interests of the WPA are either benefited or unaffected by improved management of on-site wastewater disposal systems.

Cost Considerations
A conventional septic system will typically cost on the order of $10,000-15,000, with increased costs if local site conditions are problematic. Advanced systems tend to be more expensive, often in the range of $20,000-30,000 or even higher.

Detailed D/F studies (those involving direct measurement of in-seepage quality) indicate limited impacts from septic systems on most lakes (range of 0-25% of total P load, with a mean of 6-8%). Septic systems should be managed for long-term successful operation, but it should not be assumed that they are major sources of phosphorus without supporting data.

Conventional septic systems are potentially large contributors of nitrogen, as little nitrogen is removed by the system or the soil into which effluent is discharged. Advanced designs can provide greater removal at increased cost.
POINT SOURCE CONTROLS

How it Works

Point source pollution is defined as originating from a pipe or other distinct conveyance under federal regulations. Originally intended to deal with wastewater treatment discharges from industrial or municipal operations, the definition of a point source was extended in 1990 to include stormwater discharges where the delivery was an observable pipe, ditch, swale, curb cut, or other delivery device that could be construed as meeting the federal definition. Certain activities, such as concentrated animal feedlot operations (CAFOs), have also been classified as point sources in this manner. Point source discharges are governed by the National Pollutant Discharge Elimination System, or NPDES. Many states have been authorized to administer this program, but Massachusetts is still governed by the federal program and does not issue NPDES permits itself. The DEP is involved in NPDES issues, however, and provides considerable guidance on meeting federal requirements.

Although industry and other activities may have point source discharges of pollutants, most of the nutrient sources are from municipal WWTFs. The current thrust of WWTF permitting emphasizes meeting effluent concentrations that will protect lakes with reasonable dilution. Domestic wastewater enters a WWTF with P in excess of 3 mg/L and sometimes as high as 15 mg/L. N levels can exceed 40 mg/L, with values up to 70 mg/L not uncommon. Wastewater treatment in Massachusetts involves primary and secondary treatment and in some cases, tertiary treatment. Primary treatment involves the settling out of suspended solids in sedimentation tanks. Secondary treatment usually involves a biological component to oxidize and convert organic wastes, sometimes with chemical addition that reduces P levels. Resulting P concentrations can be as low as 0.3 mg/L, but are more often >1 mg/L and often as high as 3-4 mg/L. N levels of 10-15 mg/L are common, with concern directed toward the fraction of the N load that is present as toxic un-ionized ammonia. Well-functioning secondary treatment WWTFs tend to convert nearly all ammonia/ammonium to nitrate. However, nutrient levels from even the best secondary treatment facilities are well in excess of desirable levels in lakes.

Advanced waste treatment, or tertiary treatment, usually involves the removal of phosphorus and/or nitrogen. Phosphorus compounds are most often removed by coagulation with chemicals, sometimes with an additional filtering step. Dissolved air flotation (DAF) can also greatly reduce P concentrations, but is more commonly used in drinking water treatment than wastewater situations. Achievement of concentrations <0.5 mg/L is routinely possible through tertiary treatment, with targets set as low as 0.1 mg/L in some cases and current research aimed at achieving P concentrations of 0.01 to 0.02 mg/L. However, with a target lake P level of <0.02 mg/L and preferably <0.01 mg/L, WWTF inputs currently require substantial dilution to avoid eutrophication impacts on lakes.

There are many methods to remove nitrogen compounds, including ammonia stripping by air and nitrification-denitrification in biological reactors. Other advanced treatment methods that protect lakes include adsorption of residual organic and color compounds on activated carbon and the use of reverse osmosis and electrodialysis to remove dissolved solids. Wetland treatment has become popular for nutrient control as a polishing step in WWTFs, and some WWTFs are based mainly on biological activity as a mainstay of wastewater treatment.
Note that stormwater that is conveyed through any type of drainage system is defined by the EPA as a point source and subject to NPDES permits. The most salient provision of the NPDES program for stormwater is the requirement for a Stormwater Pollution Prevention Plan (SWPPP), which is a site- and activity-specific management guide for minimizing impacts on runoff from the site. The emphasis is on prevention of pollution, not treatment or remediation. The SWPPP includes provision for managing potential pollutants stored or used on site, limiting exposure of potentially polluting activities to precipitation and runoff, and measures for responding to spills, leaks, or other releases. Monitoring provisions are industry-specific and not overly stringent, but the whole process is a major step toward minimizing contamination of runoff and documenting that effort.

In some cases inflows to wastewater treatment plants are combined with urban stormwater flow. This is most often a result of underdesign of conveyance systems in the face of expanding user populations, with combined manholes for easy access to both sanitary and storm sewers being the primary point of mixing. This situation leads to excess hydraulic loading to the drainage system and/or WWTF during storms that may result in untreated or incompletely treated wastes being discharged to streams or lakes. Separating these Combined Sewer Systems (CSS) to avoid Combined Sewer Overflow (CSO) has been emphasized by the EPA and DEP for about two decades now, and substantial progress has been made.

One less well-known point source that has become a problem in Massachusetts is drinking water treated to comply with anti-corrosion provisions of the federal Safe Drinking Water Act of 1996. The most common chemical used to inhibit corrosion in distribution pipes is calcium phosphate, with concentrations of P in excess of 1 mg/L in many cases and sometimes as high as 5 mg/L, not much different than secondary treated sewage! Blowdown from boilers or hydrants, discharged directly to stormwater drainage systems, or leaks from water mains can provide a substantial input of P to downstream lakes. Use of potable water for make-up water in smaller ponds and swimming facilities can actually cause an algal bloom. Alternatives to calcium phosphate, such as a variety of silicates, are available but more expensive.

Management of point sources generally falls into the same categories as for non-point sources: source management and pollutant trapping. Source management includes bans on phosphorus in detergents and a variety of pretreatment requirements for businesses that might otherwise contribute excessive amounts of oils, metals or other contaminants of special concern. Pollutant trapping is a function of the treatment process, with tertiary treatment necessary to remove enough nutrients to protect lakes.

Source management for stormwater point sources is essential to improving discharge quality in nearly all cases. Nutrient removal from stormwater by treatment will depend on the BMPs applied, with removal rates typically in the 30-60% range. Source management for wastewater treatment facilities is only essential to the extent that it protects the treatment process, with improved treatment providing the greatest reduction in nutrient loading. Actual removal rates for phosphorus average 10% for primary, 20-40% for secondary, and 80-99% for tertiary. For nitrogen, removal rates average 510% for primary, 10-30% for secondary, and 50-90% for tertiary.
Benefits
- Control of centralized wastewater collection and treatment can result in a major reduction in loading
- Improved treatment can remove many contaminants as well as nutrients
- Stormwater management has great potential for reduced nutrient loading

Detriments
- Discharge of even the “cleanest” treated wastewater may still contain excessive concentrations of nutrients
- Centralized wastewater discharge localizes a potentially major impact and may affect hydrology of contributing watershed areas

Information for Proper Application
- An accurate nutrient budget that demonstrates the importance of the point source(s) in determining lake quality
- Water quality data for influent that supports treatment design
- Hydrologic data for receiving waters to evaluate dilution effects
- Source analysis for stormwater point sources, to allow minimization of impacts on runoff quality
- Ongoing monitoring to assess impacts and additional management needs

Factors Favoring the Use of this Technique
- A substantial portion of the P and/or N load is associated with point source pollution
- Studies have demonstrated the impact of identifiable discharges on the lake
- Water associated with point sources is important to lake hydrology
- Pollutant removal expected from source management or treatment upgrade has been properly calculated and is achievable
- Jurisdiction can be claimed over point sources

Performance Guidelines
- Collect the data necessary to demonstrate the problem and potential for improvement
- Meet all requirements of the NPDES program; seek to establish permit limits that meet water quality goals, but with recognition of other pollutant sources to the target lake
- Design the treatment system or upgrade to meet demonstrated needs; match treatment processes to water quality goals
- Monitor the effluent in accordance with NPDES requirements and at locations appropriate to demonstrating results

Possible Permits
- NPDES permit from EPA, with input from DEP

Impacts Specific to the Wetlands Protection Act
All interests of the WPA are either benefited or unaffected.

Cost Considerations
Costs of source control tend to be nominal and internalized, as with substituting products or ingredients to avoid high nutrient content. Some source controls carry significant cost, as with moving possible contaminants into covered storage, but such action will limit liability on numerous fronts. Cost of treatment upgrade is usually substantial ($5-10 million) and carries significant operational costs as well ($100,000-$1 million/yr), in proportion to the volume of water treated.
HYDRAULIC CONTROLS: Dilution and Flushing

How it Works
Lake waters that have low concentrations of an essential nutrient are unlikely to exhibit algal blooms. While it is preferable to reduce nutrient loads to the lake, it is possible to lower (dilute) the concentration of nutrients within the lake by adding sufficient quantities of nutrient-poor water from some additional source. High amounts of additional water, whether low in nutrients or not, can also be used to flush algae out of smaller, linear impoundments faster than they can reproduce.

When water low in phosphorus is added to the inflow, the actual phosphorus load will increase, but the mean phosphorus concentration should decrease. Dilution or flushing washes out algal cells, but since the reproductive rate for algae is high (blooms form within days to a few weeks), only extremely high flushing rates will be effective without a significant dilution effect. A flushing rate of 10 to 15% of the lake volume per day is appropriate to minimize algal biomass build-up.

Outlet structures and downstream channels must be capable of handling the added discharge for this approach to be feasible. Qualitative downstream impacts must also be considered. Water used for dilution or flushing should be carefully monitored prior to use in the lake. Application of this technique is most often limited by the lack of an adequate supply of low nutrient water.

Benefits
- Reduces algal biomass without reducing nutrient loading
- May provide improved downstream habitat or recreational opportunity through elevated flows

Detriments
- Diverts water from other uses
- May cause flooding if downstream channel is incapable of handling enough flow
- Will not work with many isolated coves

Information for Proper Application
- Accurate hydrologic and nutrient budgets to allow evaluation of potential benefits
- Assessment of probable in-lake effects and an evaluation of downstream impacts
- Reliability of source water
- Routing information for new water source
- Monitoring program to track changes in detention time, nutrient levels and water clarity

Factors Favoring the Use of this Technique
- Actual reduction in nutrient inputs from identifiable sources is not practical, either for technical or jurisdictional reasons
- Water level fluctuation will not differ greatly from pre-treatment conditions
- Adequate water of a suitable quality is available for dilution or flushing
- Downstream problems with water quantity or quality will not be caused

Performance Guidelines
- Develop reliable hydrologic and nutrient budgets and evaluate probable outcomes of dilution or flushing
- Determine impacts of diverting water for use in dilution or flushing
Successful flushing requires a resultant detention time of less than about two weeks on a consistent basis during the growing season. This technique is primarily limited by reliability of water supply for this purpose.

Possible Permits
- WPA permit through local Conservation Commission/DEP
- Review by NHESP (further action if protected species are present)
- Chapter 91 Permit through DEP may be required for structural alterations in Great Ponds
- Dam Safety Permit may be required through DCR
- Rerouting of water in excess of 100,000 gpd may require a permit under the Water Management Act through DEP
- Possible 401 WQ permit through the DEP, but jurisdiction will depend upon which other permits are required and funding sources
- Possible NPDES permitting through EPA/DEP, depending on water quality of discharge.

Impacts Specific to the Wetlands Protection Act
- Protection of public and private water supply – Variable (depends on location of supply relative to discharge and detention time)
- Protection of groundwater supply – Neutral, unless there is a discharge to groundwater, in which case the impact could be beneficial or detrimental
- Flood control - Neutral (added flow must remain within tolerance limits for lake and downstream receiving waters)
- Storm damage prevention – Neutral (added flow must remain within tolerance limits for lake and downstream receiving waters)
- Prevention of pollution - Benefit in the lake (water quality enhancement) and possibly downstream
- Protection of land containing shellfish - Possible benefit through water quality enhancement in the lake and possible detriment with any downstream flow problems
- Protection of fisheries - Benefit (water quality enhancement), but possible detriment through reduced fertility and possible benefit or detriment downstream through flow changes
- Protection of wildlife habitat – Benefit (water quality enhancement), but possible detriment through reduced fertility and possible downstream benefit or detriment through flow changes

Cost Considerations
The cost of dilution and flushing varies mainly with the volume and availability of water. If a nearby upstream source of clean water could be diverted to a lake by gravity, or if a short canal can be constructed to provide a connection to a larger stream or river, the costs may be limited. Purchase of public water for this purpose will likely be very expensive. Expect $500-2500/acre/yr for application of these techniques, inclusive of permitting and monitoring, when a source of water is readily available. Costs may rise to $5,000-25,000/acre/yr if water is purchased, piped and/or pumped.
HYDRAULIC CONTROLS: Diversion

How it Works
Diversion is simply the re-routing of a discharge to avoid a sensitive resource, discharging instead to an alternative receiving water, typically downstream of the original discharge location or in another drainage basin. Diverting water from a lake may make sense if the associated nutrient load is undesirable and the loss of the hydrologic load will not have undue negative impacts. Ideally, diversion involves a small amount of water with a large amount of nutrients in it. Diversion is most often practiced in association with wastewater or stormwater discharges to lakes with adequate alternative water supplies. It suffers from the philosophical drawback of sending contaminated water elsewhere without addressing the source of nutrients, and may be difficult to permit, but it can be a very effective means of reducing nutrient inputs to a lake targeted for management.

Benefits
- Eliminates significant loads of nutrients
- Minimal long-term expense expected once gravity diversion complete

Detriments
- Removes a source of water to the lake
- Relocates impact elsewhere

Information for Proper Application
- Accurate hydrologic and nutrient budgets to allow evaluation of potential benefits
- Assessment of probable in-lake effects and an evaluation of downstream impacts
- Routing information for new discharge location
- Monitoring program to track changes in detention time, nutrient levels and water clarity in the target lake
- Monitoring program to assess impacts of new discharge location

Factors Favoring the Use of this Technique
- A substantial portion of the P and/or N load is associated with sources that can be diverted
- Studies have demonstrated the impact of the targeted discharge on the lake
- Water associated with sources to be diverted is not important to lake hydrology; water level fluctuation will not differ greatly from pre-treatment conditions
- Downstream problems with water quantity or quality will not be caused.

Performance Guidelines
- Develop reliable hydrologic and nutrient budgets and evaluate probable impacts of diversion on lake and any stream upstream of diversion
- Determine possible effects of diversion downstream of discharge
- Design diversion system and any necessary maintenance program; avoid flooding and erosion problems downstream of discharge
- Monitor quality of water in the lake and downstream of discharge

Possible Permits
- WPA permit through local Conservation Commission/DEP
- Review by NHESP (further action if protected species are present)
- Chapter 91 Permit through DEP may be required for structural alterations in Great Ponds
- Dam Safety Permit may be required through DCR
Management Techniques: Diversion

- Rerouting of water in excess of 100,000 gpd may require a permit under the Water Management Act through DEP
- 404 permit through the Corps of Engineers
- 401 WQ permit through the DEP
- NPDES permitting through EPA/DEP

Impacts Specific to the Wetlands Protection Act
- Protection of public and private water supply – Variable (depends on location of supply relative to discharge)
- Protection of groundwater supply – Neutral, unless there is a discharge to groundwater, in which case the impact could be detrimental
- Flood control – Most likely neutral (diverted flow must remain within tolerance limits for receiving waters)
- Storm damage prevention – Neutral (diverted flow must remain within tolerance limits for receiving waters)
- Prevention of pollution - Benefit in the lake (water quality enhancement), but possibly detrimental downstream (possible poor quality discharges)
- Protection of land containing shellfish - Possible benefit through water quality enhancement in the lake and possible detriment with any downstream water quality degradation
- Protection of fisheries - Benefit (water quality enhancement), but possible detriment through reduced fertility and possible detriment downstream with any water quality degradation
- Protection of wildlife habitat – Benefit (water quality enhancement), but possible detriment through reduced fertility

Cost Considerations
The cost of diversion varies greatly among cases, but is rarely inexpensive. The cost is primarily based on the required distance for transport and associated construction costs. If the water must be treated prior to discharge, that cost should also be included. Estimates for diversion of various wastewater discharges in Massachusetts have exceeded $5 million; these diversions were not implemented, in favor of improved treatment. Diverting storm drains may be a more economic approach if technical and permitting difficulties can be overcome.

Diversion of secondary treated sewage effluent from Dennisville Lake in NJ in about 1980 dramatically improved conditions within a decade
HYDRAULIC CONTROLS: Selective Withdrawal

How it Works
For recreational lake management, the intent of selective withdrawal is usually to remove the poorest quality water from the lake, which is normally the water at the bottom of the lake unless an intense surface bloom of algae is underway. It is desirable to discharge water at a rate that prevents anoxia near the sediment-water interface, resulting in both improved lake conditions and an acceptable discharge quality. This can be accomplished in impoundments with small hypolimnia and/or large inflows. In most lake management cases, however, selective withdrawal will involve waters of poor quality and treatment may be necessary before discharge downstream.

Where phosphorus has accumulated in the hypolimnion through release from the sediments, selective discharge of hypolimnetic waters prior to fall turnover can reduce effective phosphorus loading. However, unless late summer inflows are substantial, this may result in a considerable drawdown of the lake level. Where a drawdown is planned, selective discharge may increase the benefit. Often an outlet structure must be retrofitted to facilitate selective withdrawal, but the one-time capital cost confers permanent control with minimal operation and maintenance costs.

Selective withdrawal for water supply means locating the intake at the depth where water quality is most advantageous for the intended use. It can be used in any system where vertical water density gradients are sufficiently stable, but is most often applied to more strongly stratified lakes. For potable water use of productive lakes, the choice is often between high algae concentrations in the epilimnion and high iron and/or manganese in the hypolimnion. Intakes located near the thermocline sometimes get both high algae and high metals. A choice of intake depths is preferred, allowing adjustment of intake depth in accordance with the best available water quality. For cooling water supply, cold hypolimnetic withdrawal is preferred, as long as it does not contain high levels of corrosive sulfides.

Benefits
- Removes poor quality water before it mixes with upper water layer; ideally prevents development of poor quality water
- Uses expected outflow in a more beneficial manner
- Can provide benefits for downstream coldwater fishery

Detriments
- May cause unintended drawdown
- May disrupt stratification
- May result in downstream discharge of poor quality water

Information for Proper Application
- Accurate hydrologic and nutrient budgets to allow evaluation of potential benefits and limitations
- Detailed knowledge of system morphometry and thermal structure to allow assessment of appropriate withdrawal depth
- Assessment of probable in-lake effects and downstream impacts
- Adequacy of inflow to keep the lake water budget in balance, in order to avoid an unintended water level decrease
- Drawdown plans, if hypolimnetic withdrawal is to be used in conjunction with this technique
- Outlet plans to facilitate design of withdrawal port
- Monitoring program to assess quality of discharged water, quality of water remaining in the lake, and stability of lake water level and stratification

Results for 17 lakes with 1 to 10 years of hypolimnetic withdrawal indicate that reduced epilimnetic phosphorus concentrations did result, presumably leading to lowered algal biomass. However, concerns over summer drawdown, disruption of stratification, and downstream water quality must all be addressed in a successful program.

In some large western reservoirs, hypolimnetic discharges constitute a major outflow and are responsible for maintenance of very productive downstream coldwater fisheries.
Factors Favoring the Use of this Technique
- A substantial portion of the P and/or N load is associated with sources that can be preferentially discharged
- Studies have demonstrated the impact of hypolimnetic load on the lake
- Water level fluctuation will not differ greatly from pre-treatment conditions
- Downstream problems with water quantity or quality will not be caused.
- Actual reduction in nutrient inputs from identifiable sources is not practical, either for technical or jurisdictional reasons

Performance Guidelines
- Develop reliable hydrologic and nutrient budgets and evaluate probable outcomes of selective withdrawal
- Determine possible effects on stratification and related habitat in the lake
- Determine possible downstream effects of increased flow and altered water quality
- Design withdrawal system and any necessary maintenance program
- Avoid lowered water level as a consequence of selective withdrawal (unless permitted as part of a drawdown)
- Avoid contravention of downstream water quality standards due to discharge
- Conduct selective withdrawal mainly during the summer and fall
- Monitor quality of in-lake and outgoing water

Possible Permits
- WPA permit through local Conservation Commission/DEP
- Review by NHESP (further action if protected species are present)
- Chapter 91 Permit through DEP may be required for Great Ponds
- Dam Safety Permit may be required through DCR
- Possible 404 permit through the Corps of Engineers
- Possible 401 WQ permit through the DEP
- Possible NPDES permitting through EPA/DEP

Impacts Specific to the Wetlands Protection Act
- Protection of public and private water supply – Variable (depends on location of supply relative to discharge or depth of intake)
- Protection of groundwater supply – Neutral, unless there is a discharge to groundwater, in which case the impact could be detrimental
- Flood control - Neutral (discharge must remain within tolerance limits for lake and downstream receiving waters)
- Storm damage prevention – Neutral (discharge must remain within tolerance limits for lake and downstream receiving waters)
- Prevention of pollution - Benefit in the lake (water quality enhancement), but possibly detrimental downstream (possible poor quality discharges)
- Protection of land containing shellfish - Possible benefit through water quality enhancement in the lake and possible detriment with any downstream water quality degradation

Selective withdrawal can be accomplished with a subsurface pipe. Head pressure derived from the difference between the water surface elevation and the discharge elevation forces water into the pipe at the inlet end (set in deeper water), even when the discharge elevation is higher than the inlet elevation.
- Protection of fisheries - Benefit (water quality enhancement), but possible detriment through reduced fertility and possible detriment downstream with any water quality degradation
- Protection of wildlife habitat – Benefit (water quality enhancement), but possible detriment through reduced fertility

**Cost Considerations**
Installation costs for withdrawal pipes typically range between $10,000 and $50,000, although higher costs are certainly possible if major outlet reconstruction is needed. Costs for treating the discharge could be substantial, but treatment has consisted mainly of aeration by passive means at limited capital and operational cost. A cost of <$100 per acre is suggested where structures are in place and no major downstream impacts are expected. The cost may rise to $1000-3000/acre where structural alterations and/or treatment of discharged water become necessary.
PHOSPHORUS INACTIVATION

How it Works
The release of phosphorus stored in lake sediments can be so extensive in some lakes and reservoirs that algal blooms persist even after incoming phosphorus has been significantly lowered. Phosphorus precipitation by chemical complexing removes phosphorus from the water column and can control algal abundance until the phosphorus supply is replenished. Inactivation of phosphorus in surficial lake sediments can greatly reduce the release of phosphorus from those sediments, minimizing the internal load. It is essentially an “anti-fertilizer” treatment. This technique is most effective after nutrient loading from the watershed is sufficiently reduced, as it acts only on existing phosphorus reserves, not new ones added post-treatment. In-lake treatments are used when studies indicate that the primary source of the phosphorus is internal (recycled from lake sediments). Such nutrient control generally does not reduce macrophyte abundance, but can control algal growths.

The three most common treatments for lakes employ salts of aluminum, iron, or calcium compounds. Nitrate treatments are very rare and are used to enhance phosphorus binding to natural iron oxides in sediments. For the aluminum, iron and calcium treatments, the typical compounds used include aluminum sulfate (Al₂(SO₄)₃ xH₂O), sodium aluminate (Na₂Al₂O₄ xH₂O), iron as ferric chloride (FeCl₃) or ferric sulfate (Fe₂(SO₄)₃), and calcium as lime (Ca(OH)₂) or calcium carbonate (CaCO₃). Additional forms of aluminum are becoming more common.

Inactivators are applied to the surface or subsurface, in either solid or liquid form, normally from a boat or barge. These compounds dissolve and form hydroxides, Al(OH)₃, Fe(OH)₃, or in the case of calcium, carbonates such as calcite (CaCO₃). These minerals form a floc that can remove particulates, including algae, from the water column within minutes to hours and precipitate reactive phosphates. Reactions continue at the surface-water interface, binding phosphorus that could otherwise be released from the sediment. Because aluminum and iron added as sulfates or chlorides dissolve to form acid anions along with the formation of the desired hydroxide precipitates, the pH will tend to decrease in low alkalinity waters unless basic salts such as sodium aluminate or lime are also added. Conversely, calcium is usually added as carbonates or hydroxides that tend to raise pH.

The various floc minerals behave very differently under high or low dissolved oxygen and they also differ in their response to changes in pH. Because of its ability to continue to bind phosphorus under the widest range of pH and oxygen levels, aluminum is usually the preferred phosphorus inactivator. Other binders are applied under specific conditions that favor their use, but not as commonly as aluminum.

Good candidate lakes for this procedure are those that have had external nutrient loads reduced to an acceptable level and have been shown, through a D/F study, to have a high internal phosphorus load (release from sediment). High natural alkalinity is also desirable to provide buffering capacity. Highly flushed impoundments are usually not good candidates because of an inability to limit phosphorus inputs. Treatment of lakes with low doses of alum may effectively remove phosphorus from the water column, but may be inadequate to provide long-term control of phosphorus release from lake sediments. High doses are needed to effectively bind phosphorus in the upper few inches of sediment and retard release.
Low doses of aluminum (1-5 mg/L) can be used to strip phosphorus out of the water column with limited effects on pH or other water quality variables, even in many poorly buffered waters. Mixing with aeration systems can increase treatment efficiency and lower the necessary dose. Aluminum doses in excess of 50 g/m² may be needed to thoroughly inactivate sediment phosphorus reserves and maximize treatment longevity. Areal doses (g/m²) convert to volumetric doses (g/m³ or mg/L) simply by dividing the areal dose by the water depth in meters. Doses around 10 mg/L are typically applied to stormwater discharges, and current efforts in stormwater management focus on capturing the floc in detention areas prior to discharge to the lake or stream.

Iron salts are very sensitive to dissolved oxygen levels. Under oxic conditions the ferric hydroxide floc is stable at normal pH conditions (pH>5). Under anoxic conditions, however, the iron in ferric hydroxide is reduced to soluble ferrous iron (Fe²⁺) and the floc dissolves, releasing the adsorbed phosphorus. Therefore, while iron acts as a natural binder in well-oxygenated systems, loss of oxygen in eutrophic lakes may disrupt this natural phosphorus inactivation process. Inactivation of phosphorus by iron will become very ineffective where anoxia is so strong that sulfate reduction occurs. In such cases, iron is preferentially bound by sulfides released as hydrogen sulfide, leaving little iron to bind with phosphorus. Consequently, iron is only used in well-aerated systems with naturally low iron levels, but may be the inactivator of choice as a supplement to an aeration system. Iron is generally not toxic at levels applied to lakes.

The stability of calcite is highly sensitive to pH, calcium, and carbonate concentrations. Consequently, treatment with calcium is effective only if pH is maintained at a relatively high level (8 or above). Such pH levels are found naturally only in the Berkshire region where elevating the pH by chemical addition to facilitate calcium effectiveness may have many adverse impacts on natural systems adjusted to lower pH. Calcium is more commonly used in alkaline lakes regions, such as Alberta, Canada, and has not been applied in Massachusetts or the northeastern USA except on a pilot basis.

Nitrate treatments such as Ca(NO₃)₂ neither precipitate nor inactivate phosphorus directly. Nitrates are injected directly into the surface sediments as a ‘sediment oxidation’ treatment, which in this case refers to maintaining a high redox (reduction-oxidation) potential and thus maintaining the stability of natural iron oxides in the sediments. That is, nitrate is broken up to yield oxygen before iron oxides, by preference of the active bacteria. Thus nitrates act indirectly to enhance and stabilize the ability of natural iron oxides to bind phosphorus in the sediments. In this manner, nitrate treatment is analogous to hypolimnetic aeration by providing an alternative source of oxygen. This approach is not commonly practiced anywhere and has never been tried in Massachusetts.

### Benefits
- Rapid removal of available phosphorus from the water column
- Minimized internal loading of phosphorus
- Potential removal of a variety of other contaminants and algae

### Detriments
- Potential for damage to aquatic life at depressed or elevated pH
- Limited longevity of effects if external loading is significant

**Benefits**
- Common application rates for stripping phosphorus from the water column range from 1 to 20 mg/L, while the range for inactivating surficial sediments is about 10 to 150 g/m². Without use of a buffer solution, dose is determined by the amount of inactivator that can be added without causing an undesirable pH level.

**Detriments**
- Floc formation during treatment should be visible, and a floc layer up to perhaps 3 inches deep will accumulate on the bottom afterward, but within a month this layer will have merged with the surficial sediments and adds minimal solid material to the lake.
Concentrations of reactive aluminum ($\text{AL}^{3+}$) are strongly influenced by pH. Aluminum is toxic to fish at levels of 100 to 200 ug/L at pH of < 6.0 and > 7.5, typically via gill membranes. The “safe” level of dissolved reactive aluminum is considered to be 50 ug/L, but these are not sharp thresholds.

Toxicity can be avoided by properly buffering inactivator additions, treating repeatedly at a lower dose, treating parts of the lake sequentially, or by injecting the inactivator into the bottom waters during stratification.

Information for Proper Application
- An accurate nutrient budget that includes a detailed analysis of internal sources of phosphorus
- Sediment testing for available sediment phosphorus
- Recent information on pH and alkalinity at all depths to properly predict potential changes in pH and to minimize impacts
- Knowledge of lake oxygen regime and biotic components is helpful in planning treatments
- An accurate depth map of the lake is required to properly evaluate dosing
- In addition to jar tests to establish doses and ratios of chemicals, toxicity tests with a sensitive fish species may be desirable
- Monitoring of pH, alkalinity and any biotic reactions is appropriate during treatment, with follow-up monitoring if any deviations from the expected range are detected
- Estimates of effectiveness should be made for lake recovery in terms of total phosphorus levels and Secchi disk transparency.
- For deep lakes, hypolimnetic dissolved phosphorus concentration should decrease dramatically and should be checked.

Factors Favoring the Use of this Technique
- A substantial portion of the P load is associated with sediment sources within the lake
- Studies have demonstrated the impact of internal loading on the lake.
- External P load has been controlled to the maximum practical extent or is documented to be small; historic loading may have been much greater than current loading
- Inactivation of phosphorus in the water column is expected to provide interim relief from algal blooms and turbidity while a prolonged watershed management program is conducted to reduce external loading
- The lake is well buffered or buffering can be augmented to prevent major changes in pH during treatment
- Assays indicate no toxic effects during simulated treatment
- Where iron is to be used as an inactivator, oxygen is adequate at the bottom to maintain iron-phosphorus bonds
- Where calcium is to be used as an inactivator, normal background pH is high enough to maintain calcium-phosphorus bonds
- Where nitrate is to be used to alter redox potential and limit P release, nitrate can be effectively injected into the sediment without major release to the water column

Performance Guidelines
- Develop reliable phosphorus budget that demonstrates magnitude of internal loading
- Determine dose necessary to inactivate targeted phosphorus (water column or sediment)
- Determine chemicals to be used; consider oxygen regime and minimize shift in pH unless naturally outside range of 6.0 to 8.0 SU
- Secure appropriate access for equipment and chemicals; adhere to materials handling regulations in the transfer of chemicals to application equipment
- For larger lakes, treat non-contiguous sections of the lake on sequential days
- For higher doses of aluminum, split treatment to yield calculated in-lake aluminum level < 10 mg/L on any day
- In pH sensitive lakes with anoxic hypolimnia, consider injecting aluminum at or below the thermocline during stratification
- Monitor phosphorus, the inactivator compound, pH, alkalinity, water clarity, algae, zooplankton, benthic invertebrates and fish before, during and after treatment as appropriate to determine impacts to sensitive resources.
Possible Permits
- WPA permit through local Conservation Commission/DEP
- Review by NHESP (further action if protected species are present)
- Permit to Apply Chemicals from DEP
- Possible 401 WQ permit through the DEP

Impacts Specific to the Wetlands Protection Act
- Protection of public and private water supply – Benefit (water quality improvement)
- Protection of groundwater supply – Neutral (no significant interaction)
- Flood control - Neutral (no significant interaction)
- Storm damage prevention – Neutral (no significant interaction)
- Prevention of pollution - Benefit (water quality enhancement)
- Protection of land containing shellfish - Possible benefit through water quality enhancement in the lake and possible detriment by direct toxicity unless treatment is properly buffered
- Protection of fisheries - Possible benefit through water quality enhancement in the lake and possible detriment by direct toxicity unless treatment is properly buffered, plus possible detriment through reduced fertility
- Protection of wildlife habitat – Benefit (water quality enhancement), but possible detriment through reduced fertility

The most serious impact is the possibility for fish or invertebrate kills following treatment in low alkalinity lakes, but such impacts are preventable. Minimal adverse impacts are expected to either surface or groundwater supplies. Aluminum, iron and calcium are commonly added in water and wastewater treatment facilities with no significant adverse impacts (and generally a marked improvement in water quality).

Cost Considerations
Aluminum treatment costs typically range from $500-$1,000/acre, with the areal cost decreasing for larger treatments, unbuffered treatments, and lesser monitoring requirements. Higher cost may result from extreme controls and monitoring, as with the 2001 Ashumet Pond treatment. Costs for iron treatments are similar to those for alum treatment; the chemical is less expensive to purchase but higher doses are recommended. However, iron is best applied in conjunction with aeration systems, so total project cost is likely to be substantially higher. Calcium costs are slightly less expensive than alum, especially in hard water lakes where this technique is most likely to be applied. The cost is estimated at about $200/acre. Nitrate application to sediments is an expensive treatment, typically on the order of $5,000-10,000/acre.
How it Works
Whole lake circulation is a technique for management of algae that tends to affect nutrient levels. The central process is the introduction of more oxygen, intended to limit internal recycling of phosphorus, thereby controlling algae. Other important processes may apply as well, however. Circulation strategies increase turbulence and minimize stratification. Whole lake artificial circulation is also referred to as destratification or whole lake aeration. Thermal stratification and features of lake morphometry such as coves create stagnant zones that may be subject to loss of oxygen, accumulation of sediment, or algal blooms. Artificial circulation minimizes stagnation and can eliminate thermal stratification or prevent its formation. Movement of air or water is normally used to create the desired circulation pattern in shallow (<20 ft) lakes, and this has been accomplished with surface aerators, bottom diffusers, and water pumps (Figure 10). Algae may simply be mixed more evenly in the available volume of water in many cases, but turbulence, changing light regime and altered water chemistry can cause shifts in algal types and reduce biomass.

Stratification is broken or prevented in deeper lakes through the injection of compressed air into lake water from a diffuser at the lake bottom (Figure 11a). The rising column of bubbles, if sufficiently powered, will produce lakewide mixing at a rate that eliminates temperature differences between top and bottom waters. The use of air as the mixing force also provides some oxygenation of the water, but the efficiency and magnitude of this transfer are generally low. In some instances, wind driven pumps have been used to move water. For air mixed systems, the general rule is that an air flow rate of 1.3 cubic feet per minute per acre of lake (9.2 m$^3$/min/km$^2$) will be needed to maintain a mixed system. However, there are many factors that could require different site specific air flow rates, and undersizing of systems is the greatest contributor to failure for this technique.

Algal blooms are sometimes controlled by destratification through one or more of the following processes:
- Introduction of dissolved oxygen to the lake bottom may inhibit phosphorus release from sediments, curtailing this internal nutrient source.
- In light-limited algal communities, mixing to the lake's bottom will increase the time a cell spends in darkness, leading to reduced photosynthesis and productivity.
- Rapid circulation and contact of water with the atmosphere, as well as the introduction of carbon dioxide-rich bottom water during the initial period of mixing, can increase the carbon dioxide content of water and lower pH, leading to a shift from blue-green algae to less noxious green algae.
- Turbulence can neutralize the advantageous buoyancy mechanisms of blue-green algae and cause a shift in algal composition to less objectionable forms such as diatoms.
- When zooplankton that consume algae are mixed throughout the water column, they are less vulnerable to visually feeding fish. If more zooplankters survive, their consumption of algal cells may also increase.

Artificial circulation can prevent winterkills of fish in eutrophic lakes that become anoxic during the winter. On a smaller scale, artificial circulation can be used to prevent ice formation around docks or other structures. The technique is also used to maintain acceptable water quality in drinking reservoirs.
as the oxic conditions created by the circulation reduce concentrations of nuisance substances such as hydrogen sulfide, ammonia, iron and manganese. For these types of problems artificial circulation has been very successful.

**Benefits**
- Increases mixing and decreases stagnation; may control algae by multiple means, and will at least spread out the algal biomass
- Increases oxygen levels and enhances habitat accordingly
- Increases die-off rate of bacteria

**Detriments**
- Mixing may distribute previously localized undesirable substances throughout the lake
- May resuspend sediment and increase turbidity if not carefully controlled
- May increase algal growth in some cases

**Information for Proper Application**
- An accurate nutrient budget with a detailed analysis of internal P sources
- Data related to each of the five possible control mechanisms (oxygenation/P inactivation, light limitation, pH/carbon source adjustment, buoyancy disruption, and enhanced grazing) should be analyzed and evaluated in terms of potential algal control. Specifically,
  a. Is there anaerobic release of phosphorus that can be mitigated by oxygenation of deep waters?
  b. Is the mixing zone deep enough to promote light limitation of algae?
  c. Is there a large amount of carbon dioxide in the bottom waters that could be mixed to the surface to favor the growth of non-blue-green algae?
  d. Is mixing predicted to counteract the buoyancy advantage of blue-greens over other algae?
  e. Will a dark, oxygenated refuge be created for zooplankton?
- Reliable estimate of the oxygen demand that must be met by the system
- Reliable estimate of the amount of air necessary to mix/destratify the lake
- Lake morphometry data that facilitates choice of aerator type and placement of aerators for maximum effectiveness
- Location and details of compressor and power source
- Monitoring to track oxygen and nutrient levels after implementation
- Monitoring to track water clarity and algal types and quantity

**Factors Favoring the Use of this Technique**
- A substantial portion of the P load is associated with anoxic sediment sources within the lake
- Studies have demonstrated the impact of internal loading on the lake
- External P load has been controlled to the maximum practical extent or is documented to be small; historic loading may have been much greater than current loading
- Hypolimnetic or sediment oxygen demand is high (>500 mg/m²/day)
- In addition to phosphorus management, control of other reduced compounds such as hydrogen sulfide, ammonia, manganese and iron, is desired
- Adequate phosphorus inactivators are present for reaction upon addition of oxygen
- Shoreline space for a compressor or pump is available where access is sufficient, power is available, and noise impacts will be small
- The lake is bowl shaped, or at least not highly irregular in bathymetry (few separate basins and isolated coves)
- Long-term application of the technique is accepted
- Coldwater fishery habitat is limited or not a concern

**Performance Guidelines**
- Determine goals for circulation; if oxygenation is desired, oxygen demand must be determined; if destratification is desired, necessary mixing force must be determined
- Properly size equipment; avoid over- or underpowering
- Properly place equipment; avoid over- or underspacing
- Develop a maintenance plan for equipment
- Operate equipment in accordance with management goals to achieve temporal or spatial results as planned
- Monitor temperature and oxygen as indicators of mixing and aeration, and other water quality or biological variables as necessary to evaluate success

**Possible Permits**
- WPA permit through local Conservation Commission/DEP
- Review by NHESP (further action if protected species are present)
- Chapter 91 Permit through DEP may be required for Great Ponds

**Impacts Specific to the Wetlands Protection Act**
- Protection of public and private water supply – Benefit (water quality enhancement)
- Protection of groundwater supply – Neutral (no significant interaction)
- Flood control - Neutral (no significant interaction)
- Storm damage prevention – Neutral (no significant interaction)
- Prevention of pollution - Benefit (water quality enhancement)
- Protection of land containing shellfish - Benefit (water quality enhancement) with rare detriment by water quality variability induced by whole lake circulation
- Protection of fisheries - Benefit (water quality enhancement) with rare detriment by water quality variability and loss of coldwater habitat induced by whole lake circulation
- Protection of wildlife habitat – Benefit (water quality enhancement)

Adverse impacts to the eight interests of the Wetland Protection Act are not expected with the exception that in rare cases deleterious substances like hydrogen sulfide or ammonia may be circulated to the surface and cause temporary adverse impacts to fish and wildlife. In general, aeration is expected to improve habitat for fish and other organisms in lakes with anoxic hypolimnia, but artificial circulation can reduce or eliminate coldwater habitat for trout.

**Cost Considerations**
Costs include the initial purchase and installation of the pumps, pipes and diffusers as well as annual maintenance costs and annual electricity costs. Capital costs range from about $200 to $3,000/ac, while annual costs usually range from $50 to $800/ac. Actual costs depend on the amount of air required, which is related to lake area. The estimated range of cost for 20 years of application at a hypothetical 100-acre lake is $70,000 to $400,000.
Figure 10. Methods of Artificial Circulation and Aeration (from Wagner, 2001)
Figure 11. Destratifying (A) and Non-destratifying (B) Aeration
HYPOLIMNETIC AERATION

How it Works
Hypolimnetic aeration is a technique for management of algae through control of nutrient levels. The central process is the introduction of more oxygen, intended to limit internal recycling of phosphorus, thereby controlling algae. Hypolimnetic aeration typically uses an air compressor as described for whole lake circulation, but in this case the upward plume is controlled to avoid mixing with the epilimnetic waters, and thus thermal stratification of the lake is maintained (Figure 10). The maintenance of stratification is often desirable as it maintains coldwater fish habitat and reduces transport of nutrients from the hypolimnion into the epilimnion where they may stimulate further algal blooms.

Aeration puts air into the aquatic system, increasing oxygen concentration by transfer from gas to liquid and generating a controlled mixing force. The oxygen transfer function is used to prevent hypolimnetic anoxia (Figure 11b). By keeping the hypolimnion from becoming anoxic during stratification, aeration should minimize the release of phosphorus, iron, manganese and sulfides from deep bottom sediments and decrease the build-up of undecomposed organic matter and oxygen-demanding compounds (e.g., ammonium). Hypolimnetic aeration can also increase the volume of water suitable for habitation by zooplankton and fish, especially coldwater forms. Pure oxygen can be used in place of air to maximize oxygen transfer at an increased cost.

A full lift hypolimnetic aeration approach moves hypolimnetic water to the surface, aerates it, and replaces it in the hypolimnion. Bringing the water to the surface can be accomplished with electric or wind-powered pumps, but is most often driven by pneumatic force (compressed air). Return flow to the hypolimnion is generally directed through a pipe to maintain separation of the newly aerated waters from the surrounding epilimnion. To provide adequate aeration, the hypolimnetic volume should be pumped and oxygenated at least once every 60 days.

Another hypolimnetic aeration system is the partial lift system, in which air is pumped into a submerged chamber in which exchange of oxygen is made with the deeper waters. The newly oxygenated waters are released back into the hypolimnion without destratification. A shoreline site for a housed compressor is needed, but the aeration unit itself is submerged and does not interfere with lake use or aesthetics.

An alternative approach involves a process called layer aeration. Water can be oxygenated by full or partial lift technology, but by combining water from different (but carefully chosen) temperature (and therefore density) regimes, stable oxygenated layers can be formed anywhere from the upper metalimnetic boundary down to the bottom of the lake. Each layer acts as a barrier to the passage of phosphorus, reduced metals and related contaminants from the layer below. Each layer is stable as a consequence of thermally mediated differences in density. The whole hypolimnion may be aerated, or any part thereof, to whatever oxygen level is deemed appropriate for the designated use. Maintenance of a highly oxidized layer for water supply will call for more oxygen than providing a refuge for zooplankton or fish.
The mechanism of phosphorus control exercised through hypolimnetic aeration is the maintenance of high oxygen and limitation of phosphorus release from sediments. Out of the processes listed for artificial circulation, the only other applicable mechanism for hypolimnetic aeration is provision of a zooplankton refuge, potentially increasing grazing potential. To successfully aerate a hypolimnion, the continuous oxygen demand of the sediments must be met, and experience dictates that the oxygen input needs to be about twice the measured oxygen demand. This demand may be reduced over time under aeration, but is unlikely to be eliminated.

**Benefits**
- Reduces release of phosphorus from the sediment and accumulation in the hypolimnion without eliminating stratification
- Reduces hypolimnetic accumulations of iron, manganese, ammonium and hydrogen sulfide
- Increases hypolimnetic oxygen levels and enhances habitat accordingly

**Detriments**
Theoretically possible to induce gas bubble disease in fish, but not a documented occurrence

**Information for Proper Application**
- Data requirements for this type of nutrient control include an accurate nutrient budget with a detailed analysis of internal sources of phosphorus
- The most critical information for designing an aeration system is the oxygen demand that must be met by the system; calculations and related interpretation for design purposes are best performed by experienced professionals
- Lake morphometry and stratification data are needed to facilitate choice of aerator features and placement of aerators for maximum effectiveness
- Location and details of compressor and power source are needed

**Factors Favoring the Use of this Technique**
- A substantial portion of the P load is associated with anoxic sediment sources within the lake
- Studies have demonstrated the impact of internal loading on the lake.
- External P load has been controlled to the maximum practical extent or is documented to be small; historic loading may have been much greater than current loading
- Hypolimnetic or sediment oxygen demand is high (>500 mg/m$^2$/day)
- In addition to phosphorus management, control of other reduced compounds such as hydrogen sulfide, ammonia, manganese and iron, is desired
- Adequate phosphorus inactivators are present for reaction upon addition of oxygen
- Shoreline space for a compressor or pump is available where access is sufficient, power is available, and noise impacts will be small
- The lake is bowl shaped, or at least not highly irregular in bathymetry (few separate basins and isolated coves)
- Long-term application of the technique is accepted
- Coldwater fishery habitat is abundant or an important goal

**Performance Guidelines**
- Determine oxygen demand to be counteracted

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**Oligotrophic lakes**
- Typically have oxygen demands <250 mg/m$^2$/day, while
eutrophic lake values are >550 mg/m$^2$/day; values of 2000 to 4000 mg/m$^2$/day have been measured in hypereutrophic lakes.

**Oxygen demand**
- Normally calculated from actual data for the lake.
- For stratified lakes, the hypolimnetic oxygen demand (HOD, often a function of sediment oxygen demand, or SOD) can be calculated as the difference in oxygen levels at the time stratification formed and one or more points in time later during stratification. However, measurements obtained when the oxygen levels are <2 mg/L are deceiving, as oxygen consumption is not linear and will decline markedly as oxygen supply declines.
- Properly size equipment; avoid over- or underpowering
- Properly place equipment; avoid over- or underspacing
- Develop a maintenance plan for equipment
- Operate equipment in accordance with management goals to achieve temporal or spatial results as planned
- Monitor temperature and oxygen as indicators of mixing and aeration, and other water quality or biological variables as necessary to evaluate success

Possible Permits
- WPA permit through local Conservation Commission/DEP
- Review by NHESP (further action if protected species are present)
- Chapter 91 Permit through DEP may be required for Great Ponds

Impacts Specific to the Wetlands Protection Act
- Protection of public and private water supply – Benefit (water quality enhancement)
- Protection of groundwater supply – Neutral (no significant interaction).
- Flood control - Neutral (no significant interaction)
- Storm damage prevention – Neutral (no significant interaction)
- Prevention of pollution - Benefit (water quality enhancement)
- Protection of land containing shellfish - Benefit (water quality enhancement)
- Protection of fisheries - Benefit (water quality enhancement)
- Protection of wildlife habitat – Benefit (water quality enhancement)

Cost Considerations
Costs can be standardized on a per kg oxygen basis as approximately $2.50/kg O₂ with operating costs of $0.072/ kg O₂. Assuming a need to counteract an oxygen demand of 500 to 2000 mg/m²/day for 120 days per year, this suggests a capital cost of roughly $750 to $3,000/acre and an annual operational cost of $55 to $220/acre. Shape and depth of the lake will affect costs, with deep, single basin lakes requiring the simplest and least expensive systems.
**DRAWDOWN**

*How it Works*

Drawdown is a process whereby the water level is lowered by gravity, pumping or siphoning and held at that reduced level for some period of time, typically several months and usually over the winter. Drawdown can provide control of plant species that overwinter in a vegetative state, and oxidation of sediments may result in lower nutrient levels with adequate flushing. Drawdowns also provide flood control and allow access for nearshore clean ups and repairs to structures. The ability to control the water level in a lake is affected by area precipitation pattern, system hydrology, lake morphometry, and the outlet structure. The base elevation of the outlet or associated subsurface pipe(s) will usually set the maximum drawdown level, while the capacity of the outlet to pass water and the pattern of water inflow to the lake will determine if that base elevation can be achieved and maintained. In some cases, sedimentation of an outlet channel or other obstructions may control the maximum drawdown level.

Several factors affect the success of drawdown with respect to plant control. While drying of plants during drawdowns may provide some control, the additional impact of freezing is substantial, making drawdown a more effective strategy during late fall and winter. However, a mild winter or one with early and persistent snow may not provide the necessary level of drying and freezing. The presence of high levels of groundwater seepage into the lake may mitigate or negate destructive effects on target submergent species by keeping the area moist and unfrozen. The presence of extensive seed beds may result in rapid re-establishment of previously occurring plant species, some of which may be undesirable. Recolonization from nearby areas may be rapid, and the response of macrophyte species to drawdown is quite variable.

Aside from direct impact on target plants, drawdown can also indirectly and gradually affect the plant community by changing the substrate composition in the drawdown zone. If there is sufficient slope, finer sediments will be transported to deeper waters, leaving behind a coarser substrate. If there is a thick muck layer present in the drawdown zone, there is probably not adequate slope to allow its movement. However, where light sediment has accumulated over sand, gravel or rock, repetitive drawdowns can restore the coarse substrate and limit plant growths.

The actual conduct of a drawdown involves facilitating more outflow than inflow for several weeks or months. After the target water level is reached, outflow is roughly matched to inflow to maintain the drawdown for the desired period, usually at least a month and often up to 3 months, usually over the winter. At a time picked to allow refill before any undesirable spring impacts can occur, outflow is reduced (although it should not be eliminated) and “excess” inflow causes the water level to rise. In some cases, refill is commenced after an inch or two of ice forms, ripping up plants and bottom material. This “extreme disturbance” approach has been applied where sediments will not dewater sufficiently to provide the level of freezing and desiccation desired, but impacts have not been studied extensively.

Despite the apparent simplicity of the concept of drawdown, proper conduct of a drawdown to maximize effectiveness and minimize adverse side effects necessitates that many considerations be...
addressed (Table 6). Expected response of target species (Table 7) is of particular importance when plant control is the major goal.

**Benefits**
- Kills vegetative portions of plants by drying, freezing, or physical disturbance
- Increases plant species richness in many cases
- Allows sediment oxidation and compaction, with potential reduction of sediment oxygen demand, sediment volume, and available nutrient content
- May reduce fine sediments in drawdown zone, creating coarser peripheral substrate and enhancing plant control and habitat for some organisms
- Provides protection from ice damage to shoreline and associated structures
- Facilitates access for shoreline clean-up, sediment removal, and structural maintenance
- Provides flood storage capacity
- Concentrates fish in a smaller volume, potentially allowing control of panfish and higher growth by gamefish

**Detriments**
- Will not kill seeds or other non-vegetative overwintering propagules, and may stimulate increased seed germination
- Nutrient release during exposed sediment oxidation may fuel increased algal production if not flushed from system before next growing season
- Will reduce available water for supplies, and may impair nearby shallow well production
- May strand and harm minimally mobile aquatic fauna (such as molluscs)
- Concentration of fish in smaller volume may harm some populations through predation or oxygen stress
- Fish may not be able to reach spawning areas during drawdown
- May expose and harm hibernating reptiles and amphibians
- May restrict access and cover for aquatic mammals and birds
- Limits human access where peripheral sediments are soft
- Although largely dormant in winter, hydrologically connected wetlands may experience some changes in species composition and relative abundance if dewatering occurs

The disadvantages of drawdown are linked to reduced areal coverage by water and lowered water volume and elevation. Water supply from the lake or wells may be impaired, and species that depend upon the exposed area may be harmed. Changes in exposed sediment features may affect water quality after refill. Downstream resources may be impacted as well. Repeated drawdown may result in the invasion of plants that are resistant to drawdowns, some of which may be nuisance species. Failure to refill the lake in time for spring spawning may affect fish populations. None of these impacts may be manifest, and various mitigative means may avoid or minimize them. However, it is difficult to predict the ecological impact to many non-target organisms, due largely to the lack of published information and site-specificity of many possible impacts.
**Information for Proper Application**

The listing of key considerations provided in Table 6 indicates the extensive data needs for proper implementation of this technique. Key needs include:

- Detailed hydrology and lake morphometry to allow estimates of drawdown and refill times under the range of potential conditions
- Knowledge of outlet features essential to releasing and holding water
- Maps of aquatic macrophytes and expected area of exposure
- Evaluation of sediment types and slopes in expected drawdown zone
- Biological surveys of populations perceived to be at risk from drawdown
- Assessment of downstream channel configuration and resources, to facilitate planning to minimize adverse impacts
- Local well depths or water supply intake elevations
- A carefully crafted monitoring program to track water levels and outflow, and to assess potential impacts, positive and negative

**Factors Favoring the Use of this Technique**

- The lake periphery is dominated by undesirable species that are susceptible to drying and freezing
- Drawdown can be achieved by gravity outflow via an existing outlet structure, or such a structure can be established for a reasonable cost
- Drawdown can reach a depth that impacts enough of the targeted plants to make a difference for recreational interests and habitat enhancement
- Areas to be exposed have sediments and slopes that promote dewatering
- Drawdown and refill can be accomplished within a few weeks under typical flow conditions and without causing downstream flows outside the natural range
- Drawdown can be timed to avoid key migration and spawning periods for non-target organisms
- Populations of molluscs or other nearshore-dwelling organisms of limited mobility are not significant
- The lake is not used for water supply and nearby wells are deep
- Flood storage capacity generated by drawdown prevents downstream flood impacts
- The downstream channel and associated resources will not be impacted by fluctuating flows expected during drawdown and refill periods
- Shoreline structures are prone to ice damage

**Performance Guidelines**

- Determine susceptibility of target plants to drawdown
- Evaluate potential risks to non-target flora and fauna
- Limit drawdown to 3 ft or contact the MDFG for assistance in evaluating impacts of greater drawdown
- Commence drawdown after the end of October unless there is a valid reason to begin earlier
- Achieve the target drawdown depth by the end of November, unless there is a valid reason to take more time; target a drawdown rate of <3 inches/day
- Achieve full lake status by the beginning of April, unless there is a valid reason for another target date for refill completion
- Keep outflow during drawdown below a discharge equivalent to 4 cfs per square mile of watershed; once the target water level is achieved, match outflow to inflow to the greatest extent possible, maintaining a stable water level.
- Keep outflow during refill above a discharge equivalent to 0.5 cfs per square mile of watershed.
- Conduct a monitoring program that includes water level, flow, water clarity, winter oxygen, the plant community, and representative sensitive faunal populations.
- After target species are controlled, evaluate the potential to move to an every other or every third year drawdown schedule.

**Possible Permits**
- WPA permit through local Conservation Commission/DEP
- Review by NHESP (further action if protected species are present)

**Impacts Specific to the Wetlands Protection Act**
- Protection of public and private water supply – Potential detriment (if adequate water for supply is not maintained), but can be neutral in some cases with proper management.
- Protection of groundwater supply – Potential detriment (if lowered lake level lowers groundwater), but can be neutral (if adequate groundwater level is maintained or there is no significant interaction).
- Flood control – Benefit (flood storage potential increased).
- Storm damage prevention – Benefit (flood storage potential increased), but possible detriment if exposed areas may be subject to potentially damaging storm impacts.
- Prevention of pollution – May provide benefit (water quality enhancement) or detriment (water quality deterioration), but impacts generally limited.
- Protection of land containing shellfish – Detriment (shellfish potentially exposed), but impacts may be neutral in some cases, and shellfish habitat may be improved overall.
- Protection of fisheries - Potential detriment by temporary habitat loss, potential benefit by habitat improvement (may have benefit and detriment to different species in same lake from same drawdown).
- Protection of wildlife habitat - Potential detriment by temporary habitat loss for completely aquatic species and impact on muskrat and beaver lodges, potential benefit by habitat improvement (may have benefit and detriment to different species in same lake from same drawdown).

**Cost Considerations**
Drawdown is a relatively inexpensive lake management technique, if the means to conduct a drawdown are present. Where an outlet structure facilitates drawdown, the cost may be as little as what is required to obtain permits, open and close the discharge structure, and monitor. If pumps are required to lower the water level, the drawdown will be more expensive. It is unusual to alter a dam for less than $100,000, but if the structure already supports water level control, costs of $3,000 to $10,000 per year would be a reasonable expectation for permitting and monitoring. Where protected species are present, permitting may be difficult and monitoring and mitigation costs can escalate.
Table 5. Key Considerations for Drawdown

**Reasons for Drawdown**
- Access to structures for maintenance or construction – note that other permits may apply
- Access to sediments for removal (dredging) – additional permits apply
- Flood control – a major late winter benefit, but minimally available in spring with regulatory refill date
- Prevention of ice damage to shoreline and structures – control of late winter water level needed
- Sediment compaction – only if sediments dewater sufficiently
- Rooted plant control – for species that rely on vegetative forms to overwinter
- Fish reclamation – if the community is extremely out of balance and a management program exists

**Necessary Drawdown Planning Information**
- Target level of drawdown – depth of water lost
- Pond bathymetry – detailed contours for calculation exposed area
- Area to be exposed – area of sediment at water depth < target depth, plus ice contact zone
- Volume to remain – quantity of water available for habitat and supply during drawdown
- Timing and frequency of drawdown – initiation/duration and whether annual or less frequent event
- Outlet control features – method for controlling outflow
- Climatological data – frequency of sub-freezing weather, precipitation and snow cover data
- Normal range of outflow – maximum, minimum and average over expected time of drawdown
- Outflow during drawdown and refill – provisions for downstream flow control (high and low)
- Time to drawdown or refill – rate of water level change, number of days to achieve target level

**In-Lake and Downstream Water Quality**
- Possible change in nutrient levels – any expected increases due to oxidation of sediments
- Possible change in oxygen levels – any expected increase through oxidation or decrease under ice
- Possible change in pH levels – any expected shift due to interactions with smaller volume
- Other water quality issues – any expected changes as a function of drawdown

**Water Supply**
- Use of lake water as a supply – dependence on water availability and impact of drawdown
- Presence/depths of supply wells – potential for supply impairment
- Alternative water supplies – options or supplying water to impacted parties
- Emergency response system – ability to detect and address supply problems during drawdown
- Downstream flow restrictions – maintenance of appropriate flows for downstream habitat and uses

**Sediments**
- Particle size distribution (or general sediment type) – dewatering potential
- Solids and organic content – dewatering potential, nutrient content
- Potential for sloughing – potential for coarse sediment to be exposed in drawdown zone
- Potential for shoreline erosion – threat of erosive impacts to bank resources
- Potential for dewatering and compaction – possibility of sediment alteration and depth increase
- Potential for odors – emissions from exposed area
- Access and safety considerations – issues for use of lake during drawdown

**Flood Control**
- Anticipated storage needs – ability to meet needs with target drawdown
- Flood storage gained – volume available to hold incoming runoff
- Effects on peak flows – dampening effect on downstream velocities and discharge
Table 5 (continued). Key Considerations for Drawdown

Protected Species
Presence of protected species – NHESP designated species may require special protection
Potential for impact – assessment of possible damage to protected populations
Possible mitigative measures – options for avoiding adverse impacts

In-lake Vegetation
Composition of plant community – details of species present and susceptibility to drawdown
Areal distribution of plants – mapping of plant locations relative to drawdown impact zone
Plant density – quantity of plants present
Seed-bearing vs. vegetative propagation – drawdown will only control vegetative propagators
Impacts to target and non-target species – analysis of which species will be impacted

Vegetation of Connected Wetlands
Composition of plant community – details of species present and susceptibility to drawdown
Areal distribution of plants – mapping of plant locations relative to drawdown impact zone
Plant density – quantity of plants present
Temporal dormancy of key species – potential for seasonal impacts
Anticipated impacts – analysis of likely effects of drawdown

Macronvertebrates, Fish and Wildlife
Composition of fauna – types of animals present
Association with areas to be exposed – when and how drawdown zone is used on a regular basis
Breeding and feeding considerations – use of drawdown for breeding or food on intermittent basis
Expected effects on target and non-target species – analysis of likely faunal impacts

Downstream Resources
Erosion or flooding potential – susceptibility to impacts from varying flow
Possible habitat alterations – potential for impacts
Water quality impacts – potential for alteration
Direct biotic impacts – possible scour or low flow effects on biota
Recreational impacts – effects on downstream recreational uses
Supply impacts – effects on downstream supply uses

Access to the Pond
Alteration of normal accessibility – issues for seasonal use of pond by humans and wildlife
Possible mitigation measures – options for minimizing impacts

Associated Costs
Structural alteration to facilitate drawdown by gravity – expense for any needed changes to outlet
Pumping or alternative technology – operational expense for pumped or siphoned outflow
Monitoring program – cost of adequate tracking of drawdown and assessment of impacts

Other Mitigating Factors
Monitoring program elements – may be very lake specific and vary over years
Watershed management needs – additional actions beyond drawdown may be warranted
Ancillary project plans (dredging, shoreline stabilization) – additional actions may require separate planning and permitting
Table 6. Anticipated Response of Some Aquatic Plants to Winter Drawdown (After Cooke et al., 1993).

<table>
<thead>
<tr>
<th>Plant Name</th>
<th>Change in Relative Abundance</th>
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<tr>
<td></td>
<td>Increase</td>
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<tr>
<td>Acorus calamus (sweet flag)</td>
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<tr>
<td>Alternanthera philoxeroides (alligator weed)</td>
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<tr>
<td>Asclepias incarnata (swamp milkweed)</td>
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<td>Brasenia schreberi (watershield)</td>
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<td>Cabomba caroliniana (fanwort)</td>
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<tr>
<td>Cephalanthus occidentalis (buttonbush)</td>
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<tr>
<td>Ceratophyllum demersum (coontail)</td>
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</tr>
<tr>
<td>Egeria densa (Brazilian Elodea)</td>
<td>E</td>
</tr>
<tr>
<td>Eichhornia crassipes (water hyacinth)</td>
<td>S</td>
</tr>
<tr>
<td>Eleocharis acicularis (needle spikerush)</td>
<td>S</td>
</tr>
<tr>
<td>Elodea canadensis (waterweed)</td>
<td>S</td>
</tr>
<tr>
<td>Glycercia borealis (mannagrass)</td>
<td>E</td>
</tr>
<tr>
<td>Hydrilla verticillata (hydrilla)</td>
<td>S</td>
</tr>
<tr>
<td>Leersia oryzoides (rice cutgrass)</td>
<td>E</td>
</tr>
<tr>
<td>Myrica gale (sweetgale)</td>
<td>E</td>
</tr>
<tr>
<td>Myriophyllum spp. (milfoil)</td>
<td>S</td>
</tr>
<tr>
<td>Najas flexilis (bushy pondweed)</td>
<td>S</td>
</tr>
<tr>
<td>Najas guadalupensis (southern naiad)</td>
<td>S</td>
</tr>
<tr>
<td>Nuphar spp. (yellow water lily)</td>
<td>E/S</td>
</tr>
<tr>
<td>Nymphaea odorata (water lily)</td>
<td>S</td>
</tr>
<tr>
<td>Polygonum amphibium (water smartweed)</td>
<td>E/S</td>
</tr>
<tr>
<td>Polygonum coccineum (smartweed)</td>
<td>E</td>
</tr>
<tr>
<td>Potamogeton epihydrus (leafy pondweed)</td>
<td>S</td>
</tr>
<tr>
<td>Potamogeton robbinsii (Robbins' pondweed)</td>
<td>S</td>
</tr>
<tr>
<td>Potentilla palustris (marsh cinquefoil)</td>
<td>E/S</td>
</tr>
<tr>
<td>Scirpus americanus (three square rush)</td>
<td>E</td>
</tr>
<tr>
<td>Scirpus cyperinus (wooly grass)</td>
<td>E</td>
</tr>
<tr>
<td>Scirpus validus (great bulrush)</td>
<td>E</td>
</tr>
<tr>
<td>Sium suave (water parsnip)</td>
<td>E</td>
</tr>
<tr>
<td>Typha latifolia (common cattail)</td>
<td>E</td>
</tr>
<tr>
<td>Zizania aquatic (wild rice)</td>
<td>E</td>
</tr>
</tbody>
</table>

E=emergent growth form; S=submergent growth form (includes rooted species with floating leaves); E/S=emergent and submergent forms
CONVENTIONAL DRY DREDGING

How it Works
Dredging involves the removal of sediment. Conventional dry, conventional wet, and hydraulic/pneumatic dredging are each addressed separately here, as planning and impact considerations vary substantially. Dredging is perhaps best known for increasing depth, but dredging can be an effective lake management technique for the control of excessive algae and invasive growth of macrophytes. The management objectives of a sediment removal project are usually to deepen a shallow lake for boating and fishing, or to remove nutrient rich sediments that can cause algal blooms or support dense growths of rooted macrophytes.

Control of rooted aquatic vascular plants is achieved by either the removal of substrate hospitable for their growth or by deepening the area enough to create a light limitation on plant growth. The release of algae-stimulating nutrients from lake sediments can be controlled by removing layers of enriched materials. This can reduce internal loading and suppress algal production if internal sources are the dominant nutrient source. Even where incoming nutrient loads remain high, dredging can reduce benthic mat formation and related problems with filamentous green and blue-green algae, as these forms may initially depend on nutrient-rich substrates for nutrition. Dredging also removes the accumulated seed bed established by many vascular plants and the resting cysts deposited by a variety of algae. Dry, wet and hydraulic methods are illustrated in Figure 12.

Dry dredging involves partially or completely draining the lake and removing the exposed bottom sediments with a bulldozer or other conventional excavation equipment and trucking it away. Projects involving silts, sands, gravel and larger obstructions where water level can be controlled favor conventional, dry methodology. Although ponds rarely dry to the point where equipment can be used without some form of support (e.g., railroad tie mats or gravel placed to form a road), excavating under “dry” conditions allows very thorough sediment removal and a complete restructuring of the pond bottom. The term “dry” may be a misnomer in many cases, as organic sediments will not dewater sufficiently to be moved like upland soils. Dry dredging may resemble a large-scale excavation of pudding, and the more the material is handled, the more liquid it becomes.

Control of inflow to the lake is critical during dry excavation. For dry excavation, water can often be routed through the lake in a sequestered channel or pipe, limiting interaction with disturbed sediments. Water added from upstream or directly from precipitation will result in solids content rarely in excess of 50% and often as low as 30%. Consequently, some form of containment area is needed before material can be used productively in upland projects. Where there is an old gravel pit or similar area to be filled, one-step disposal is facilitated, but most projects involve temporary and permanent disposal steps.

A properly conducted dredging program removes accumulated sediment from a lake and effectively sets it back in time, to a point prior to significant sedimentation. Partial dredging projects are possible and may be appropriate depending upon management goals, but for maximum benefit it is far better to remove all “soft” sediment. Failed dredging projects are common, and failure can almost always be traced to insufficient consideration of the many factors that govern dredging success (Table 8).
**Benefits**
- Deepening of the lake for many purposes, including increased flood or water supply storage, improved recreational uses, enhanced pollutant trapping effectiveness, and dilution of nutrient loads
- Control of rooted plants if a depth (light) or substrate limitation is imposed
- Reduced algal mat formation by reduced nutrient supply and elimination of resting cysts
- Reduced planktonic algal abundance if internal loading is an important nutrient source and enough sediment is removed
- Removal of toxic substances or other unwanted materials accumulated in the sediment
- Reduced sediment-water interactions, with potential improvement in water quality
- Complete removal of soft sediments in any target area or even “overdredging” to removal of sand or gravel is facilitated by dry dredging

**Detriments**
- All possible impacts of drawdown, as the lake is lowered to facilitate dry dredging
- Loss of most biological components of the drained portion of the lake through physical disturbance
- Potential for downstream turbidity if throughflow is not controlled
- Peripheral land disruption for access by equipment
- Upland area must be provided for sediment disposal, with temporary alteration
- Contaminated sediments potentially subject to many restrictions on disposal

**Information for Proper Application**
Table 8 lists the many considerations applicable to a dredging project. Key factors include:
- Sediment quality, which will determine disposal options and cost
- Sediment quantity, which determines disposal volume needs and greatly affects cost
- Ability to control the lake level, which affects choice of dredging method
- Sensitive biological resources, which affects project goals and permitting
- Monitoring to track system recovery and overall project impacts

**Factors Favoring the Use of this Technique**
- There is a distinct need for increased depth in the lake
- Studies have demonstrated the impact of internal loading on the lake
- Studies have demonstrated the presence of contaminants that are impacting lake biota or uses
- Rooted plants and algal mats dependent on the soft sediments are impairing recreation and habitat value
- Habitat is degraded to the extent that a complete restructuring is desirable
- Partial drawdown or sequestering of the dredged area can be performed to limit impacts to aquatic species
- Sediments are “clean”, based on Massachusetts regulatory thresholds
- Suitable and sufficient containment and disposal areas are available close to the lake Performance Guidelines
- Address the many considerations for dredging provided in Table 8; pay particular attention to sediment quality and quantity and disposal arrangements
- Design the dredging project with local conditions in mind; address water level and flow control, appropriate equipment, access and staging areas, material dewatering and transport for disposal
- Excavate in accordance with all permits
- Achieve a depth (light) or substrate (hard bottom) limitation if control of plant growth is a project goal; usually this involves removal of all soft sediment or achievement of a water depth in excess of 10 ft
- Remove sediment to expose a low nutrient layer if reduction of internal loading is a project goal; usually this involves removal of all soft sediment
- Restore or rehabilitate all access, temporary containment, and final disposal areas
- Monitor downstream flows and water quality during dry dredging
- Monitor recovery of lake biota and in-lake conditions relative to project goals (e.g., depth increase, plant control, water quality enhancement)

Possible Permits
- MEPA review
- WPA permit through local Conservation Commission/DEP
- Review by NHESP (further action if protected species are present)
- Chapter 91 permit through DEP may be required for Great Ponds
- 404 permit through the Corps of Engineers
- 401 WQ permit through the DEP
- Solid Waste permit for sediment disposal through DEP
- Possible Dam Safety permit through DCR

Impacts Specific to the Wetlands Protection Act
- Protection of public and private water supply – Benefit (water quality improvement); may also affect water quantity by uncapping springs and seepage areas. Short-term limitation on available water is possible during dredging
- Protection of groundwater supply – Generally neutral (no significant interaction), although uncapping of springs and seepage areas may increase interaction. Possible adverse impacts below containment area if contaminants leach
- Flood control – Generally neutral (no significant interaction), although greater depth could be an asset if drawdown is later practiced for flood control. Possible short-term benefit or detriment during dredging, depending upon flow controls applied
- Storm damage prevention – Generally neutral (no significant interaction), although greater depth could be an asset if drawdown is later practiced for damage control. Possible short-term benefit or detriment during dredging, depending upon flow controls applied
- Prevention of pollution – Expected benefit (water quality enhancement), although short-term detriment is possible if flows contact disturbed sediment
- Protection of land containing shellfish – Possible long-term benefit through water quality enhancement, but potential short-term detriment by direct removal and lack of water
- Protection of fisheries - Possible long-term benefit through water quality and physical habitat enhancement, but potential short-term detriment by habitat loss during dry dredging
- Protection of wildlife habitat – Expected long-term benefit (water quality enhancement, invasive plant control), but possible short-term detriment by habitat loss during dry dredging

Impacts to interests of the Wetlands Protection Act from a specific dredging project are highly dependent upon site-specific features and project design.

Cost Considerations
Because the cost varies depending on the volume of material removed, costs are usually expressed per cubic yard (cy) of material removed. Generally, the larger the project, the smaller the cost per cubic yard. The proper way to estimate dredging costs is to consider each element of the project, which may vary dramatically among projects. The total cost can be divided by the total yardage to get
a cost per cubic yard, but this may not be especially meaningful in estimating other dredging projects. With that caveat in mind, a typical range of costs for dry dredging projects in recent years is $8 to $25/cy, with $15/cy suggested as a rough estimator for considering the general magnitude of a project under initial consideration. It is important, however, to develop a more careful estimate during further project planning, and many smaller projects (<50,000 cy) have incurred costs in excess of $30/cy. Total cost can be reduced if the dredged material is clean enough to be sold as a soil amendment. Recovery of more than $1/cy is unusual, however. In some cases, contractors have wanted the material in the lake, or more likely the sand and gravel under the muck in the lake, and were willing to perform dry dredging at a much reduced cost. Income from excavation should not be assumed, however, unless a firm agreement is in hand. As part of a major overhaul of a lake, dredging is often accompanied by other management actions such as stormwater treatment, construction of recreational amenities or fish habitat enhancement. These associated improvements add to overall project cost but are not specifically part of the dredging project cost estimated here.

*Dry dredging: excavation of dry lake bed (provided by C. Carranza of BEC)*
Figure 12. Wet, Dry and Hydraulic Dredging Approaches (from Wagner, 2001).
### Table 7. Key Considerations for Dredging

<table>
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<th><strong>Reasons For Dredging:</strong></th>
<th><strong>Existing and Proposed Bathymetry:</strong></th>
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<tr>
<td>Increased depth/access</td>
<td>Existing mean depth</td>
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<tr>
<td>Removal of nutrient reserves</td>
<td>Existing maximum depth</td>
</tr>
<tr>
<td>Control of aquatic vegetation</td>
<td>Proposed distribution of lake area over depth range</td>
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<tr>
<td>Alteration of bottom composition</td>
<td>Proposed mean depth</td>
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<td>Habitat enhancement</td>
<td>Proposed maximum depth</td>
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<tr>
<td>Reduction in oxygen demand</td>
<td>Proposed distribution of area over depth range</td>
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<table>
<thead>
<tr>
<th><strong>Volume Of Material To Be Removed:</strong></th>
<th><strong>Physical Nature of Material To Be Removed:</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>In-situ volume to be removed</td>
<td>Grain size distribution</td>
</tr>
<tr>
<td>Distribution of volume among sediment types</td>
<td>Solids and organic content</td>
</tr>
<tr>
<td>Distribution of volume over lake area (key sectors)</td>
<td>Settling rate</td>
</tr>
<tr>
<td>Bulked volume (see below)</td>
<td>Bulking factor</td>
</tr>
<tr>
<td>Dried volume (see below)</td>
<td>Drying factor</td>
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<td></td>
<td>Residual turbidity</td>
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<table>
<thead>
<tr>
<th><strong>Nature of Underlying Material To Be Exposed:</strong></th>
<th><strong>Chemical Nature of Material To Be Removed:</strong></th>
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<tbody>
<tr>
<td>Type of material</td>
<td>Metals levels</td>
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<tr>
<td>Comparison with overlying material</td>
<td>Petroleum hydrocarbon levels</td>
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<td>Nutrient levels</td>
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<td>Pesticides levels</td>
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<td>PCB levels</td>
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<tr>
<td></td>
<td>Other organic contaminant levels</td>
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<td>Other contaminants of concern (site-specific)</td>
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</table>

<table>
<thead>
<tr>
<th><strong>Dewatering Capacity of Sediments:</strong></th>
<th><strong>Flow Management:</strong></th>
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<tbody>
<tr>
<td>Dewatering potential</td>
<td>System hydrology</td>
</tr>
<tr>
<td>Dewatering timeframe</td>
<td>Possible peak flows</td>
</tr>
<tr>
<td>Methodological considerations</td>
<td>Expected mean flows</td>
</tr>
<tr>
<td></td>
<td>Provisions for controlling water level</td>
</tr>
<tr>
<td></td>
<td>Methodological implications</td>
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<table>
<thead>
<tr>
<th><strong>Protected Resource Areas:</strong></th>
<th><strong>Relationship To Lake Uses:</strong></th>
</tr>
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<tbody>
<tr>
<td>Wetlands</td>
<td>Impact on existing uses during project</td>
</tr>
<tr>
<td>Endangered species</td>
<td>Impact on existing uses after project</td>
</tr>
<tr>
<td>Habitats of special concern</td>
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</tr>
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<td>Species of special concern</td>
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<td>Regulatory resource classifications</td>
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<thead>
<tr>
<th><strong>Equipment Access:</strong></th>
<th><strong>Dredging Methodologies:</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Possible input and output points</td>
<td>Hydraulic (or pneumatic) options</td>
</tr>
<tr>
<td>Land slopes</td>
<td>Wet excavation</td>
</tr>
<tr>
<td>Pipeline routing</td>
<td>Dry excavation</td>
</tr>
<tr>
<td>Property issues</td>
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<thead>
<tr>
<th><strong>Potential Disposal Sites:</strong></th>
<th><strong>Dredging Methodologies:</strong></th>
</tr>
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<tr>
<td>Possible containment sites</td>
<td>Hydraulic (or pneumatic) options</td>
</tr>
<tr>
<td>Soil conditions</td>
<td>Wet excavation</td>
</tr>
<tr>
<td>Necessary site preparation</td>
<td>Dry excavation</td>
</tr>
<tr>
<td>Volumetric capacity</td>
<td></td>
</tr>
<tr>
<td>Property issues</td>
<td></td>
</tr>
<tr>
<td>Long term disposal options</td>
<td></td>
</tr>
</tbody>
</table>
## Key Considerations for Dredging

### Applicable Regulatory Processes:
- MEPA review (Environmental Notification Form)
- Environmental impact reporting (EIR if needed)
- Wetlands Protection Act (Order of Conditions)
- Dredging permits (Chapter 91)
- Aquatic structures permits (Chapter 91)
- Drawdown notification (to DFWELE)
- Water Management Act (diversion/use permits)
- Clean Water Act Section 401 (WQ certification)
- Clean Water Act Section 404 (USACE wetlands)
- Dam safety/alteration permit (DCR)
- Waste disposal permit (DEP)
- Discharge permits (NPDES, USEPA/DEP)

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

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

### Other Mitigating Factors:
- Necessary watershed management
- Ancillary project impacts
- Economic setting
- Political setting
- Sociological setting
CONVENTIONAL WET DREDGING

How it Works
Dredging involves the removal of sediment. Conventional dry, conventional wet, and hydraulic/pneumatic dredging are each addressed separately here, as planning and impact considerations vary substantially. Dredging is perhaps best known for increasing depth, but dredging can be an effective lake management technique for the control of excessive algae and invasive growth of macrophytes. The management objectives of a sediment removal project are usually to deepen a shallow lake for boating and fishing, or to remove nutrient rich sediments that can cause algal blooms or support dense growths of rooted macrophytes.

Control of rooted aquatic vascular plants is achieved by either the removal of substrate hospitable for their growth or by deepening the area enough to create a light limitation on plant growth. The release of algae-stimulating nutrients from lake sediments can be controlled by removing layers of enriched materials. This can reduce internal loading and suppress algal production if internal sources are the dominant nutrient source. Even where incoming nutrient loads remain high, dredging can reduce benthic mat formation and related problems with filamentous green and blue-green algae, as these forms may initially depend on nutrient-rich substrates for nutrition. Dredging also removes the accumulated seed bed established by many vascular plants and the resting cysts deposited by a variety of algae. Dry, wet and hydraulic methods are illustrated in Figure 12.

Wet dredging may involve a partial drawdown, especially to avoid downstream flow of turbid water, but sediment will be excavated from areas overlain by water. Sediment will be very wet, often only 10 to 30% solids unless sand and gravel deposits are being removed. Clamshell dredges, draglines, and other specialized excavation equipment are used in what most people would consider a very messy operation. Excavated sediment must usually be deposited in a bermed area adjacent to the pond or into other water-holding structures until dewatering can occur. This approach is most often practiced when water level control is limited. Aside from small ponds, this technique is applicable to ocean harbors, and has been practiced in Boston and New Bedford.

Conventional wet dredging methods create considerable turbidity, and steps must be taken to prevent downstream mobilization of sediments and associated contaminants. For wet excavation projects, inflows must normally be routed around the lake, as each increment of inflow must be balanced by an equal amount of outflow, and the in-lake waters may be very turbid. It should be noted, however, that more recent bucket dredge designs greatly limit the release of turbid water and have been approved for use in potentially sensitive aquatic settings such as Boston Harbor.

A properly conducted dredging program removes accumulated sediment from a lake and effectively sets it back in time, to a point prior to significant sedimentation. Partial dredging projects are possible and may be appropriate depending upon management goals, but for maximum benefit it is far better to remove all “soft” sediment. Failed dredging projects are common, and failure can almost always be traced to insufficient consideration of the many factors that govern dredging success (Table 8).

Benefits
- Deepening of the lake for many purposes, including increased flood or water supply storage, improved recreation, enhanced pollutant trapping effectiveness and dilution of nutrient loads
- Control of rooted plants if a depth (light) or substrate limitation is imposed
- Reduced algal mat formation by reduced nutrient supply and elimination of resting cysts
- Reduced planktonic algal abundance if internal loading is an important nutrient source and enough sediment is removed
- Removal of toxic substances or other unwanted materials accumulated in the sediment
- Reduced sediment-water interactions, with potential improvement in water quality
Detriments
- All possible impacts of drawdown, if the lake is lowered to any appreciable extent
- Loss of many biological components of the lake through physical disturbance and high turbidity
- Potential for downstream turbidity if outflow is not controlled
- Peripheral land disruption for access by equipment
- Upland area must be provided for sediment disposal, with temporary alteration
- Contaminated sediments potentially subject to many restrictions on disposal
- Potentially incomplete dredging as a consequence of not being able to visually appraise underwater sediment conditions and high suspended solids levels that may form a thin muck layer upon settling

Information for Proper Application
Table 8 lists the many considerations applicable to a dredging project. Key factors include:
- Sediment quality, which will determine disposal options and cost
- Sediment quantity, which determines disposal volume needs and greatly affects cost
- Ability to control the lake level, which affects choice of dredging method
- Sensitive biological resources, which affects project goals and permitting
- Monitoring to track system recovery and overall project impacts

Factors Favoring the Use of this Technique
- There is a distinct need for increased depth in the lake, but water level cannot be lowered and controlled to facilitate dry dredging, or water level must be maintained for other uses
- Studies have demonstrated the impact of internal loading on the lake
- Studies have demonstrated the presence of contaminants that are impacting lake biota or uses
- Rooted plants and algal mats dependent on the soft sediments are impairing recreation and habitat value
- Habitat is degraded to the extent that a complete restructuring is desirable
- Sequestering of the dredged area can be performed to limit impacts to aquatic species
- Sediments are “clean”, based on Massachusetts regulatory thresholds
- Suitable and sufficient containment and disposal areas are available close to the lake

Performance Guidelines
- Address the many considerations for dredging provided in Table 8; pay particular attention to sediment quality and quantity and disposal arrangements
- Design the dredging project with local conditions in mind; address flow control, appropriate equipment, access and staging areas, material dewatering and transport for disposal
- Excavate in accordance with all permits
- Achieve a depth (light) or substrate (hard bottom) limitation if control of plant growth is a project goal; usually this involves removal of all soft sediment or achievement of a water depth in excess of 10 ft
- Remove sediment to expose a low nutrient layer if reduction of internal loading is a project goal; usually this involves removal of all soft sediment
- Restore or rehabilitate all access, temporary containment, and final disposal areas
- Monitor in-lake water quality during wet dredging
- Monitor downstream flows and water quality during wet dredging
- Monitor recovery of lake biota and in-lake conditions relative to project goals (e.g., depth increase, plant control, water quality enhancement)
Possible Permits
- MEPA review
- WPA permit through local Conservation Commission/DEP
- Review by NHESP (further action if protected species are present)
- Chapter 91 permit through DEP may be required for Great Ponds
- 404 permit through the Corps of Engineers
- 401 WQ permit through the DEP
- Solid Waste permit for sediment disposal through DEP
- Possible Dam Safety permit through DCR
- Possible NPDES permitting through EPA/DEP

Impacts Specific to the Wetlands Protection Act
- Protection of public and private water supply – Benefit (water quality improvement); may also affect water quantity by uncapping springs and seepage areas. Short-term limitation on available water is possible during dredging
- Protection of groundwater supply – Generally neutral (no significant interaction), although uncapping of springs and seepage areas may increase interaction. Possible adverse impacts below containment area if contaminants leach
- Flood control – Generally neutral (no significant interaction), although greater depth could be an asset if drawdown is later practiced for flood control. Possible short-term benefit or detriment during dredging, depending upon flow controls applied
- Storm damage prevention – Generally neutral (no significant interaction), although greater depth could be an asset if drawdown is later practiced for damage control. Possible short-term benefit or detriment during dredging, depending upon flow controls applied
- Prevention of pollution – Expected benefit (water quality enhancement), although short-term detriment is possible during unsequestered wet dredging due to turbidity generation
- Protection of land containing shellfish – Possible long-term benefit through water quality enhancement, but potential short-term detriment by direct removal or water quality impacts
- Protection of fisheries – Possible long-term benefit through water quality and physical habitat enhancement, but potential short-term detriment by water quality impairment during wet dredging
- Protection of wildlife habitat – Expected long-term benefit (water quality enhancement, invasive plant control), but possible short-term detriment by water quality impairment during wet dredging

Impacts to interests of the Wetlands Protection Act from a specific dredging project are highly dependent upon site-specific features and project design.

Cost Considerations
As cost depends on the volume of material removed, costs are usually expressed per cubic yard (cy) of material removed. Generally, the larger the project, the smaller is the cost per cubic yard. The proper way to estimate dredging costs is to consider each element of the project, which may vary dramatically among projects. The total cost can be divided by the total yardage to get a cost per cubic yard, but this may not be especially meaningful in estimating other dredging projects. With that caveat in mind, a typical range of costs for wet dredging projects in recent years is $15 to $25/cy, with $20/cy suggested as a rough estimator for considering the general magnitude of a project under initial consideration. It is important, however, to develop a more careful estimate during further project planning, as much higher costs are possible as a function of site-specific conditions. Resale of dredged material or allowing access to sand and gravel under muck deposits can reduce costs, but such income should not be assumed unless a firm agreement is in hand.
HYDRAULIC OR PNEUMATIC DREDGING

How it Works
Dredging involves the removal of sediment. Conventional dry, conventional wet, and hydraulic/pneumatic dredging are each addressed separately here, as planning and impact considerations vary substantially. Dredging is perhaps best known for increasing depth, but dredging can be an effective lake management technique for the control of excessive algae and invasive growth of macrophytes. The management objectives of a sediment removal project are usually to deepen a shallow lake for boating and fishing, or to remove nutrient rich sediments that can cause algal blooms or support dense growths of rooted macrophytes.

Control of rooted aquatic vascular plants is achieved by either the removal of substrate hospitable for their growth or by deepening the area enough to create a light limitation on plant growth. The release of algae-stimulating nutrients from lake sediments can be controlled by removing layers of enriched materials. This can reduce internal loading and suppress algal production if internal sources are the dominant nutrient source. Even where incoming nutrient loads remain high, dredging can reduce benthic mat formation and related problems with filamentous green and blue-green algae, as these forms may initially depend on nutrient-rich substrates for nutrition. Dredging also removes the accumulated seed bed established by many vascular plants and the resting cysts deposited by a variety of algae. Dry, wet and hydraulic methods are illustrated in Figure 12.

A more advanced form of wet dredging, hydraulic dredging usually involves a suction type of dredge that has a cutter head. Agitation combined with suction removes the sediments as a slurry containing approximately 15-20% solids by volume, although this may increase to as high as 30 to 40% in some cases or be as low as 5% with especially watery sediments in difficult areas. This slurry is typically pumped to a containment area in an upland setting where the excess water can be separated from the solids by settling (with or without augmentation). The supernatant water can be released back to the lake or some other waterway. The containment area for a hydraulic dredging project is usually a shallow diked area that is used as a settling basin. The clarified water may be treated with flocculation and coagulation techniques to further reduce the suspended solids in the return water.

Hydraulic dredging is normally favored for removal of large amounts of highly organic sediments with few rocks, stumps or other obstructions and where water level control is limited. This type of project does require a containment area to be available where removed sediments are separated from water, and may involve secondary removal of the dried sediment from the containment area for ultimate disposal elsewhere. Usually the containment area is not far from the lake, but a slurry can be pumped multiple miles along a suitable route with booster pumps.

Innovations in polymers and belt presses for sediment dewatering have reached the point where hydraulically dredged slurry can be treated as it leaves the lake to the extent necessary to load it directly onto trucks for transport to more remote sites. Solids content of the resultant material is still
too low for many uses without further drying or mixing with sand, but the need for a large containment area can be avoided with this technology. The cost of coagulation and mechanical dewatering may be at least partially offset by savings in containment area construction and ultimate material disposal. Likewise, pumping the slurry into geo-tubes (engineered filter bags) can also enhance dewatering in a limited space.

Pneumatic dredging, in which air pressure is used to pump sediments out of the lake at a higher solids content (50 to 70%) has not yet been performed in Massachusetts or surrounding states. This would seem to be a highly desirable approach, given containment area limitation in many cases and more rapid drying with higher solids content. However, few of these dredges are operating within North America, and there is little freshwater experience upon which to base a review. Considerations are much like those for hydraulic dredging.

A properly conducted dredging program removes accumulated sediment from a lake and effectively sets it back in time, to a point prior to significant sedimentation. Partial dredging projects are possible and may be appropriate depending upon management goals, but for maximum benefit it is far better to remove all “soft” sediment. Failed dredging projects are common, and failure can almost always be traced to insufficient consideration of the many factors that govern dredging success (Table 8).

Benefits
- Deepening of the lake for many purposes, including increased flood or water supply storage, improved recreational uses, enhanced pollutant trapping effectiveness, and dilution of nutrient loads
- Control of rooted plants if a depth (light) or substrate limitation is imposed
- Reduced algal mat formation by reduced nutrient supply and elimination of resting cysts
- Reduced planktonic algal abundance if internal loading is an important nutrient source and enough sediment is removed
- Removal of toxic substances or other unwanted materials accumulated in the sediment
- Reduced sediment-water interactions, with potential improvement in water quality
- Less disruption of biological components of the aquatic system and less impact on peripheral land than for conventional excavation approaches

Detriments
- Upland area must be provided for sediment disposal, with temporary alteration
- Contaminated sediments potentially subject to many restrictions on disposal
- Potentially incomplete dredging as a consequence of not being able to visually appraise underwater sediment conditions and high suspended solids levels that may form a thin muck layer upon settling
- Less effective than conventional excavation approaches where there are obstructions such as boulders, stumps or underwater structures
Information for Proper Application

Table 8 lists the many considerations applicable to a dredging project. Key factors include:
- Sediment quality, which will determine disposal options and cost
- Sediment quantity, which determines disposal volume needs and greatly affects cost
- Obstructions or other factors that limit access to soft sediments by the hydraulic dredge
- Containment area features and routing of the slurry to the containment area
- Discharge location and water quality for supernatant from the containment area
- Monitoring to track system recovery and overall project impacts

Factors Favoring the Use of this Technique

- There is a distinct need for increased depth in the lake
- Studies have demonstrated the impact of internal loading on the lake
- Studies have demonstrated the presence of contaminants that are impacting lake biota or uses
- Rooted plants and algal mats dependent on the soft sediments are impairing recreation and habitat value
- Significant biological resources remain and warrant protection during dredging
- Sediment is largely muck, and rocks, stumps and other obstructions are minimal
- Sediments are “clean”, based on Massachusetts regulatory thresholds
- Suitable and sufficient containment and disposal areas are available close to the lake

Performance Guidelines

- Address the many considerations for dredging provided in Table 8; pay particular attention to sediment quality and quantity and disposal arrangements
- Design the dredging project with local conditions in mind; address flow control, appropriate equipment, access and staging areas, material dewatering and transport for disposal
- Excavate in accordance with all permits
- Achieve a depth (light) or substrate (hard bottom) limitation if control of plant growth is a project goal; usually this involves removal of all soft sediment or achievement of a water depth in excess of 10 ft
- Remove sediment to expose a low nutrient layer if reduction of internal loading is a project goal; usually this involves removal of all soft sediment
- Restore or rehabilitate all access, temporary containment, and final disposal areas
- Monitor containment area discharge quality during hydraulic dredging
- Monitor downstream flows and water quality during hydraulic dredging
- Monitor recovery of lake biota and in-lake conditions relative to project goals (e.g., depth increase, plant control, water quality enhancement)

Possible Permits

- MEPA review
- WPA permit through local Conservation Commission/DEP
- Review by NHESP (further action if protected species are present)
- Chapter 91 permit through DEP may be required for Great Ponds
- 404 permit through the Corps of Engineers
- 401 WQ permit through the DEP
- Solid Waste permit for sediment disposal through DEP

All photos on this page provided by J. Walsh of BEC
Impacts Specific to the Wetlands Protection Act
- Protection of public and private water supply – Benefit (water quality improvement); may also affect water quantity by uncapping springs and seepage areas.
- Protection of groundwater supply – Generally neutral (no significant interaction), although uncapping of springs and seepage areas may increase interaction. Possible adverse impacts below containment area if contaminants leach
- Flood control – Generally neutral (no significant interaction), although greater depth could be an asset if drawdown is later practiced for flood control.
- Storm damage prevention – Generally neutral (no significant interaction), although greater depth could be an asset if drawdown is later practiced for damage control.
- Prevention of pollution – Expected benefit (water quality enhancement), although short-term detriment is possible during hydraulic dredging with containment area problems
- Protection of land containing shellfish – Possible long-term benefit through water quality enhancement, but potential short-term detriment by direct removal
- Protection of fisheries - Possible long-term benefit through water quality and physical habitat enhancement
- Protection of wildlife habitat – Expected long-term benefit (water quality enhancement, invasive plant control)

Impacts to interests of the Wetlands Protection Act from a specific dredging project are highly dependent upon site-specific features and project design.

Cost Considerations
Because the cost varies greatly with the volume of material removed, costs are usually expressed per cubic yard (cy) of material removed. Generally, the larger the project, the smaller is the cost per cubic yard. The proper way to estimate dredging costs is to consider each element of the project, which may vary dramatically among projects. The total cost can be divided by the total yardage to get a cost per cubic yard, but this may not be especially meaningful in estimating other dredging projects. With that caveat in mind, a typical range of costs for dry dredging projects in recent years is $7 to $20/cy, with $12/cy suggested as a rough estimator for considering the general magnitude of a project under initial consideration. It is important, however, to develop a more careful estimate during detailed project planning. Smaller dredging projects (<50,000 cy) applying hydraulic methods have incurred costs in excess of $30/cy.

For hydraulic dredging, cost factors of major importance include:
- Volume of material – Hydraulic dredging is often not economical at low volumes
- Distance to containment area – The need for booster pumps increases cost
- Size of containment area – The size of dredge and rate of pumping depend upon the available volume for containment and resultant detention time. Additionally, cost will escalate if dredging must cease periodically to allow containment area clean-out
- Obstructions and clogging agents – Efficient use of the cutterhead and pipeline will be impeded by rocks, stumps, structures and dense plant growths

Total cost can be reduced if the dredged material is clean enough to be sold as a soil amendment. Recovery of more than $1/cy is unusual, however. Income from resale should not be assumed, however, unless a firm agreement is in hand. Because hydraulic dredging is not suited to economic removal of coarse sand and gravel, no savings from access to such deposits is expected.